Rainfall- Runoff Modeling of Kodar Watershed Using SCS-CN Method

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ABSTRACT: *Runoff is one of the major hydrological parameter, which can be measured precisely. It plays a vital role in the planning of ground water recharging and storage structure, flood estimation, soil erosion and reservoir sedimentation monitoring and estimation. In order to calculate runoff Soil Conservation Services Curve Number method is one of prominent method for the estimating the runoff, which depends upon the infiltration capacity of the soil based on hydrological soil group, land use land cover type including the antecedent moisture content(AMC) of the soil. The method is based on the remote sensing and GIS technique. A Digital Elevation Model of 12.5 meter Revolution has been used in the study, which is downloaded from Alaska European Satellite Agency , LULC data of the study area has been taken through NRSC, Hyderabad and Soil data, which is further classified into hydrological soil group has been taken from NBSS&LUP Nagpur, which is of 1:250000 scale. The thematic layer of the above input parameter has been generated on GIS platform. In present study an attempt is made to compute the surface runoff of Kodar watershed of Mahanadi basin located in Mahasamund district of Chhattisgarh. DEM is used for performing the delineation of the watershed, LULC and soil data is clipped as per the delineated watershed. Hydrological data such as the rain gauge station location and daily rainfall data are used for the simulating the model, which is taken from CGWRD state data center. Thiessen polygon is generated in the ArcGIS which shows the influence of the rain gauge station over the study area. Weighted rainfall and weighted CN values are computed in Microsoft Excel and ArcGIS. One of the influencing factor for CN calculation is AMC and is taken as per the previous 5 days rainfall data for the dormant and growing season, CN values, potential maximum runoff and initial abstraction is computed respectively. Runoff is being simulated corresponding to the rainfall data and above parameters. The estimated amount of average annual runoff is 31% of average Annual rainfall for the study area.*

Keywords: DEM, LULC, GIS, CN, AMC.

Introduction: Rainfall-runoff relationship is a complex phenomenon and is influenced by topographical, hydro metrological factor and their characteristics. There are several approaches to estimate the runoff. SCS-CN method developed by National Resources Conservation Service (NRCS), United States Department of Agriculture (USDA) in 1969, is simple conceptual method for estimation of direct runoff depth based on rainfall depth[8]. In the present study SCS-CN method is used for estimating the runoff depth in the Kodar watershed of Chhattisgarh State. The objective of this study is to estimate the quantity of surface runoff from the study area using GIS based SCS-CN method.

Study Area: Kodar watershed cover the area of Mahasamund district, of Chhattisgarh state, which is located in between latitude of 21°01'00"N to 21°14'30"N and longitude of 82º10'30"E to 82º23'30"E. Kodar watershed have catchment area of 326.45sqkm and average annual rainfall is 1066.8 mm. The main river that flows across the Kodar watershed is Kodar River, which is a tributary of Mahanadi River.

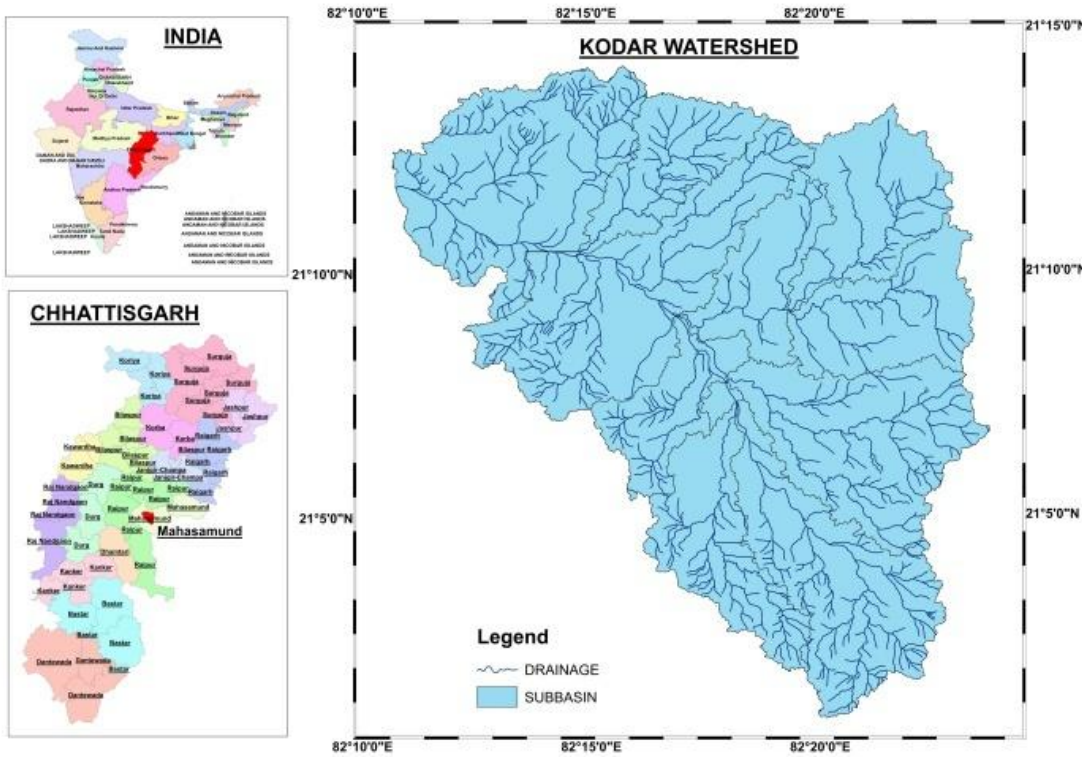


Figure-1 Location Map Kodar Watershed

SCS-CN Method

(A) The first concept is that the ratio of actual amount of runoff to maximum potential runoff is equal to the ratio of actual infiltration to the potential maximum retention. This proportionality concept is expressed as

$$\frac{(P - I_a - Q)}{S} = \frac{Q}{(P - I_a)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where P = precipitation in millimeters ($P \geq Q$); Q = runoff in millimeters;
S = potential maximum retention in millimeters;
I_a = Initial Abstraction

(B) The second concept is that the amount of initial abstraction is some fraction of the potential maximum retention and thus expressed as:

$$Ia = \lambda S \text{ (for indian condition } \lambda = 0.2\text{)} \ldots\ldots\ldots(2)$$

$$\text{Where } S = \frac{25400}{CN} - 254 \qquad \ldots\ldots(3)$$

Solving equation (1) and using equation (2) we have

$$Q = \frac{(P - I_a)^2}{(P - I_a + S)} \qquad \ldots\ldots\ldots\ldots(4)$$

For Indian condition I_a= 0.2S, thus equation (4) becomes:

$$Q = \frac{(P - 0.2S)^2}{(P - 0.8S)} \qquad \ldots\ldots\ldots\ldots(5)$$

Equation (5) is the rainfall – runoff relation used in the estimation of runoff from the storm rainfall[8].

Hydrologic Soil Group (HSG)

Soils are classified by the natural resource conservation service in four hydrologic soil group based on the soils group are A, B, C and D. details of this classification can be found in „urban hydrology for small watersheds" published by the engineering division of the natural resource conservation service, USDA, TR-55The hydrologic soil groups of the study area have been identified corresponding to the standard HSGs and their textural classes as[6]-

Group A - These soils have low runoff potential and high infiltration rates even when thoroughly wetted they consist of chiefly of deep, well to excessively drained sands or gravels and have a high rate of water transmission (> 0.30 in/hr.) e.g. soil having texture of Sand , loamy sand or sandy loam[7].

Group B - These soils have moderate infiltration rates when thoroughly wetted and consist chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission (0.15-0.30 in/hr.) e.g. soil having texture of Silty loam or loam, gravelly loam soils[7].

Group C - These soils 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 texture. These soils have a low rate of water transmission (0.05-0.15 in/hr.) e.g. soil having texture of Silt loam or loam, gravelly loam soils[7].

Group D - These soils have high runoff potential. They have very low infiltration rates when thoroughly wetted and consist chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a clay pan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very low rate of water transmission (0-0.05 in/hr.) e.g. soil having texture of Rocky outcrops, clayey soils[7].

Antecedent Moisture Condition (AMC)

AMC indicates the moisture content of soil at the beginning of the rainfall event. The AMC is an attempt to account for the variation in curve number in an area under consideration from time to time. Three levels of AMC were documented by SCS AMC_I, AMC_{II} & AMC_{III}. The limits of these three AMC classes are based on rainfall magnitude of previous five days and season (dormant season and growing season). AMC for determination of curve number is given in Table 1[1]-

Table 1: AMC for determination of CN value[8]

AMC	Total Rain in Previous 5 days	
	Dormant Season	Growing Season
I	Less than 13 mm	Less than 36 mm
II	13 to 28 mm	36 to 53 mm
III	More than 28 mm	More than 53 mm

.

Methodology

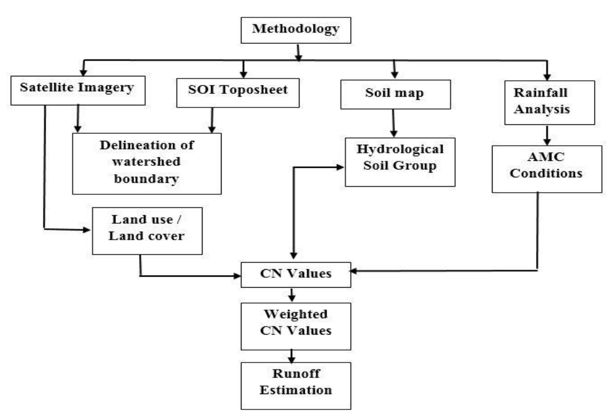


Figure- 2 Methodology for Rainfall Runoff Modeling (Vinithra,2013)

The methodology adopted in assessing the runoff potential of the study area is explained in the following steps-

a) Delineation of watershed boundary with the help of Digital Elevation Model which is downloaded from the Alaska satellite Facilities European space agency, then soil map and land use land cover map which is obtained from National Bureau of Soil Survey and Land use Planning Nagpur and National Remote Sensing Center Hyderabad is clipped from the watershed boundary in GIS platform.

b) Classification of Land use and Land cover information of the study area using the satellite imageries and Survey of India topographic sheet in GIS platform.Land use and Land cover map of the study area is shown in Figure- 3

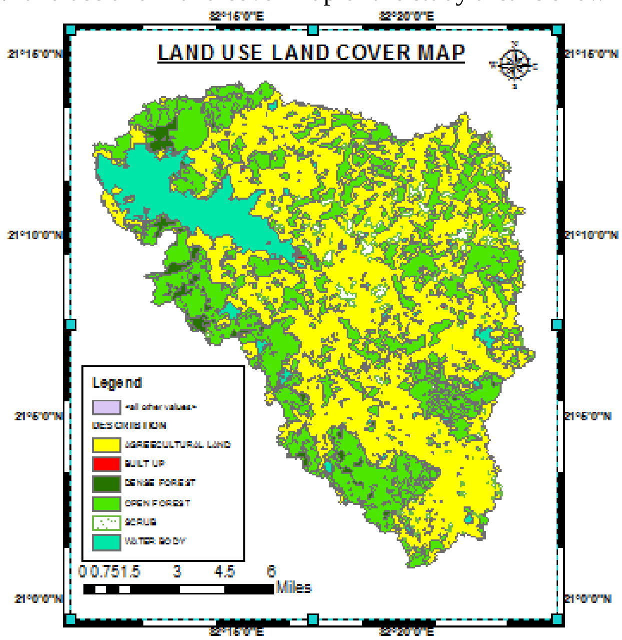


Figure- 3:- Land use and Land cover map

c) Soil properties of the study area obtained is used for making appropriate hydrological soil classification A, B, C and D from the field data and various literatures as shown in Figure- 4

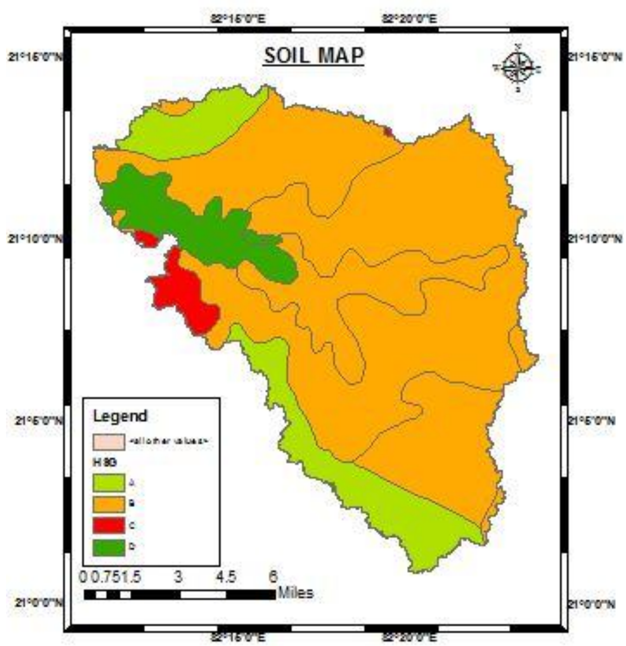


Figure- 4 Soil Map with HSG classification

d) Thiessen polygons are prepared for each identified rain gauge station which is obtained from State Data Centre, Water Resources Department Chhattisgarh Raipur. For each area weighted CN_{II}, CN_{I} and CN_{III} were determined. CN_{II} for AMC_{II} is given in Table 2.

Table 3: Curve Number for various Landuse corresponding to HSG

S.No.	Landuse	Hydrological Soil Group			
		A	B	C	D
1	2	3	4	5	6
1	Agricultural Land	59	69	76	79
2	Build up	77	86	91	93
3	Deciduous forest	26	40	58	61
4	Other wasteland	33	47	64	67
5	Degraded forest	28	44	60	64
6	Scrubland	28	44	60	64
7	Water bodies	100	100	100	100

CN_I for AMC $_I$ is calculated as:

$$CN_I = \frac{CN_{II}}{(2.281 - 0.01281\, CN_{II})} \quad \text{...(6)}$$

CN_{II} for AMC $_{III}$ is calculated as:

$$CN_{III} = \frac{CN_{II}}{(0.427 - 0.00573\, CN_{II})} \quad \text{..(7)}$$

e) Weighted area Composite Curve Number for various conditions of land use and hydrologic soil conditions are computed as follows:

$$CCN = \frac{(CN_1 \times A_1 + CN_2 \times A_2 \;+ \text{....................} CN_n \times A_n)}{A} \quad \text{.....(8)}$$

Where A_1, A_2, A_3,…., A_n represent areas of polygon having CN values CN_1, CN_2, CN_3,..........….,CN_n respectively and A is the total area. The composite curve number are as follows: AMC $_I$ = 63.68; AMC $_{II}$ = 82.15; AMC $_{III}$ = 90.35.

f) Using equation (5) with rainfall data, corresponding runoff series is derived[8].

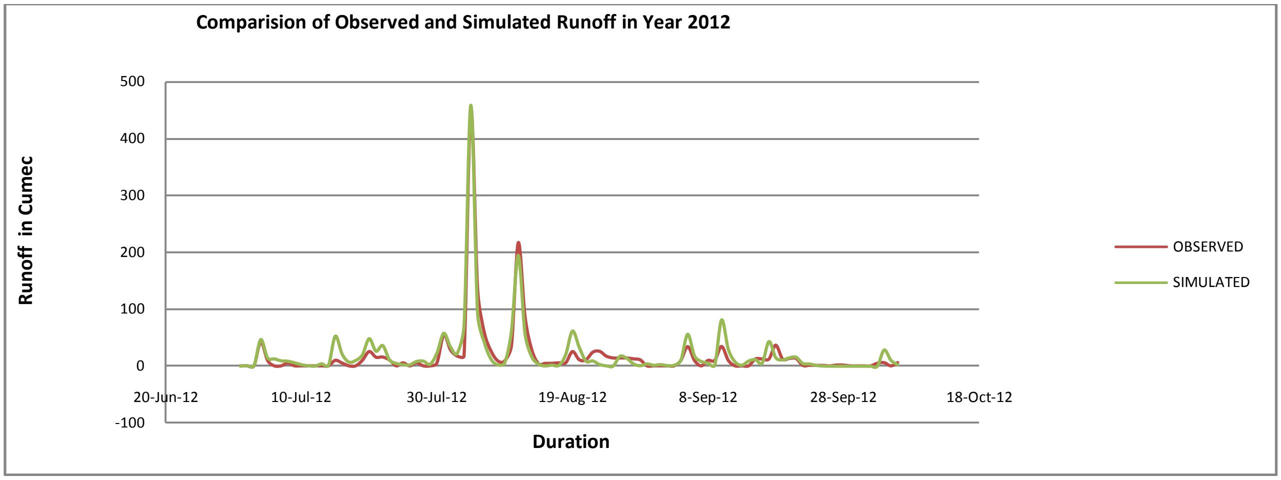
Result and Discussion: In the GIS based SCS-CN model, the CN and daily rainfall values were used as inputs to compute daily runoff. For weightage curve numbers, the runoff estimated for different AMC conditions. The individual composite curve number was computed for all study area for AMC_{II} condition. Using equation (5) the daily runoff depth were computed. The sample of daily rainfall runoff computation is shown in Table 3. From the daily runoff, monthly and annual values can be derived. The runoff depths are computed for each rainfall event for the years 1994-2016 and average annual runoff obtained from rainfall data of 23 year is 31% of the average annual rainfall. Rainfall events whose intensity is less than 0.2S, the runoff depth is taken as zero. Daily Runoff data of the year 2012 is compared with observed data which are follows approximately same trends hence this method is very good for the of Runoff.

This method is very suitable for the study area because we consider each parameter which will affect the runoff in this method and get actual runoff potential in the watershed area because other methods are based on certain assumptions.

Most of the hydraulic structure is failed during floods due to imprecise calculation of Runoff. Our expectation from hydraulic structure is not fulfilled and there is a huge economic loss due to improper planning of the structure .Here with the help of this method Runoff depth and volume is calculated which plays a vital role in planning and selection of suitable site for the construction of reservoirs, diversion, ponds, percolation tank, dug wells, gully plug, check dams etc. for deciding storage ground water recharging structures capacity. Also peak runoff of the years is useful for the design of waterway over the check dam and waste weir so that our structures will remains safe against the maximum flow, outflanking and overturning serve their purpose during the life span.

Table 3: Computed Rainfall Runoff table Curve Number for various Landuse corresponding to HSG

Year	Annual Rainfall in MM	Annual Runoff in MM	Percentage of Runoff	Peak Runoff of the year in Cumec
1994	1418.7	505.15	0.36	220.82
1995	903.5	277.51	0.31	187.34
1996	614.9	114.39	0.19	53.77
1997	875.9	202.79	0.23	82.17
1998	684.4	121.9	0.18	44.64
1999	728.4	153.02	0.21	147.44
2000	539.8	77.69	0.14	52.42
2001	639.2	86.76	0.14	36.86
2002	640.2	193.86	0.30	226.23
2003	1282.8	472.15	0.37	229.61
2004	951.2	364.61	0.38	410.12
2005	1133.6	341.95	0.30	343.91
2006	1046.8	446.11	0.43	329.71
2007	1386.5	582.08	0.42	469.37
2008	785	233.43	0.30	285.41
2009	911.9	354.93	0.39	223.53
2010	1096.7	421.43	0.38	235.02
2011	1441.1	491.93	0.34	384.83
2012	**1156.9**	**504.65**	**0.44**	**452.12**
2013	1440.6	582.1	0.4	216.09
2014	1248.4	394.09	0.32	392.61
2015	863.4	362.3	0.42	182.61
2016	936.3	219.41	0.23	101.11



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Reference

1. Ahmad, I., Verma, V. and Verma, M.K., 2015. Application of curve number method for estimation of runoff potential in GIS environment. In 2nd International Conference on Geological and Civil Engineering, IPCBEE (Vol. 80, pp. 16-20).
2. Johnson, L.E., 2016. Geographic information systems in water resources engineering. CRC Press.
3. Nagarajan, N. and Poongothai, S., 2011. Spatial mapping of runoff from a watershed using SCS-CN method with remote sensing and GIS. Journal of Hydrologic Engineering, 17(11), pp.1268-1277.
4. Patel, J., Singh, N.P., Prakash, I. and Mehmood, K., 2017. Surface Runoff Estimation Using SCS-CN method-A Case Study on Bhadar Watershed, Gujarat, India. Imperial Journal of Interdisciplinary Research, 3(5).
5. Seth, S.M., Bhism, K., Thomas, T. and Jaiswal, R.K., 1997. Rainfall-Runoff Modelling for Water Availability Study in Ken River Basin Using SCS-CN Model and Remote Sensing Approach (Vol. 98). Technical Reports, NationalInstitute of Hydrology, Roorkee, No. CS/AR-12/97.
6. Vinithra, R., and Yeshodha, L., 2013.Rainfall- Runoff Modelling Using SCS-CN Method: A Case Study of Krishnagiri District, Tamilnadu, International Journal of Science and Research (IJSR) ISSN (Online): 2319-7064
7. Soil Conservation Service (1986), Urban Hydrology for Small Watersheds. Technical Release 55, United States Department of Agriculture (USDA).
8. Subramanya, K., 2013. Engineering Hydrology. McGraw-Hill Education (India) Private Limited. New Delhi.
9. Suresh R., 2016. Soil and Water Conservation Engineering . Standard Publishers Distributers-Delhi.