Runoff Estimation of Indravati River Watershed of Chhattisgarh using Geospatial Technology

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Abstract : In present scenario, scarcity of water due to increased population and water demand is a major problem in countries like India. A proper management of water allocation is needed to overcome the situation. To manage and enhance water resources development activities in particularly undeveloped remote area like Bastar region of Chhattisgarh, it is essential to estimate runoff potential. In this study estimation of the runoff through raster based modelling in ArcGIS has been done. Several thematic layers have been generated according to Soil Conservation Services and Curve Number (SCS-CN) method and estimation of the runoff potential has been calculated. The runoff potential has been calculated on the basis of daily rainfall data from year 2006 to 2016. The net annual runoff potential, total rainfall and area wise land use land cover pattern has been estimated. The average annual runoff (2006-2016) in the study area is 37423.68 mm which is 53.24% of total rainfall. The study is useful in proper implementation of national watershed development plan in the study area.

***IndexTerms* – Runoff, ArcGIS, Hydroloical soil group, Antecedent moisture condition.**

I. INTRODUCTION

In view of the great importance attached to the monsoon phenomenon in India, it is necessary to estimate runoff potential of basin or sub-basin for sustainable development of watershed area. In the water resources studies, the main important variable is runoff and the calculation of the runoff of ungauged river basins is very complex and time consuming but necessary. The present system of water resources needs to be modified for harnessing and proper water allocation management of the water yielded from different size of the watersheds as surface and subsurface runoff, which can be possible by mathematical modelling to understand the hydrological processes of the particular watershed.

The one of simplest method for runoff estimation is Soil Conservation Services and Curve Number (SCS–CN). Based on SCS-CN technique, several models are being referred by researchers that are described in Mishra et al. (2002) [1], Oudin et al. (2005) [2], Satheesh kumar [3]. The hydrological and meteorological data are being used as input for mathematical models, developed for watershed hydrology analysis but the availability of temporal and spatial data is the main constraint hindering the implementation of these models especially in developing countries like India. Availability of such data needs to be maintained and used properly as a tool for the development of the country [4]. The advanced techniques such as remote sensing and Geographic Information System (GIS) for the collection, storing and analysing the data with respect to spatial and temporal distribution are being introduced worldwide. The several techniques used by different hydrologists according to Viji *et al.* [5] for runoff modelling are Frevert and Singh (2002) [6], GUPTA *et al.* (2004) [7], Mahboubeh *et al.* (2012) [8], Ruslin (2011) [9], Sharma *et al.* (2008) [10].

With the development of continuous hydrologic simulation models, CN was related directly to soil water content or estimated using rainfall and potential evapotranspiration (PET) to derive an index [11]. Various sources of temporal variability, such as the effect of spatio-temporal rainfall intensity variability, the effect of antecedent rainfall, etc., are used to make CN to be considered as a random variable with bounds of distribution of AMC-I and AMC-III [12]. The hydrological conditions such as land use, land cover and soil characteristics are affecting the curve number. A rainfall runoff model can be really helpful to estimate very complex hydrological phenomenon like potential runoff of any river basin [13]. The AMC is a function of the total rainfall of previous 5 days and the infiltration capacity of soil of the watershed. It is divided into three classes, AMC-I (dry), AMC-II (normal), and AMC-III (wet). The AMC-II grade is considered as the reference condition for CN values, chosen by the National Engineering Handbook tables (SCS, 1971a) [14].

II. METHODOLOGY AND DATA USED

2.1 Study Area

The area taken for study is the watershed of Indravati river, which is a tributary of Godavari River. The river flows for 535 km and has a drainage area of 41,665 sq. km which includes area of Orissa, Maharashtra and Chhattisgarh. The largest part of the watershed area, covering only Chhattisgarh, is 27760.199 sq. km in which the study has been done. It lies between 18’45’7”N to 19’26’51.202”N and 80’ 41’7”E to 81’11’E as shown in Fig. 1.

Indravati river flows across the southern side of the district Bastar and known as “The life line” of the district, which is known as one of the greenest districts in India. Indravati has numerous tributaries, the largest being the Pamer Chinta. Topographically the study area have undulating forest plateau, of about 2000 feet height, and some disconnected chains of hills. About 51% of the total geographic area of the Bastar district is covered by forests and receives more than normal rainfall of 1600 mm with 60-70 rainy days having a tropical climatic condition. The extensive mass of hills known as Abujhmar, is situated to the west and southwest of Narayanpur at the southern side of Indravati river watershed. Abujhmar still remains the terra incognita of the state of Chhattisgarh which needs many developments, hydrological development being one of them. The altitude of Abujhmar region ranges from 2000 to 3160 feet above mean sea level.

Indravati receives large amount of water, resulting in its being the only river navigation available in the state. The water available can be used for many developments and needs proper water allocation management. In this context the study has been done to determine potential runoff getting in the Indravati river.

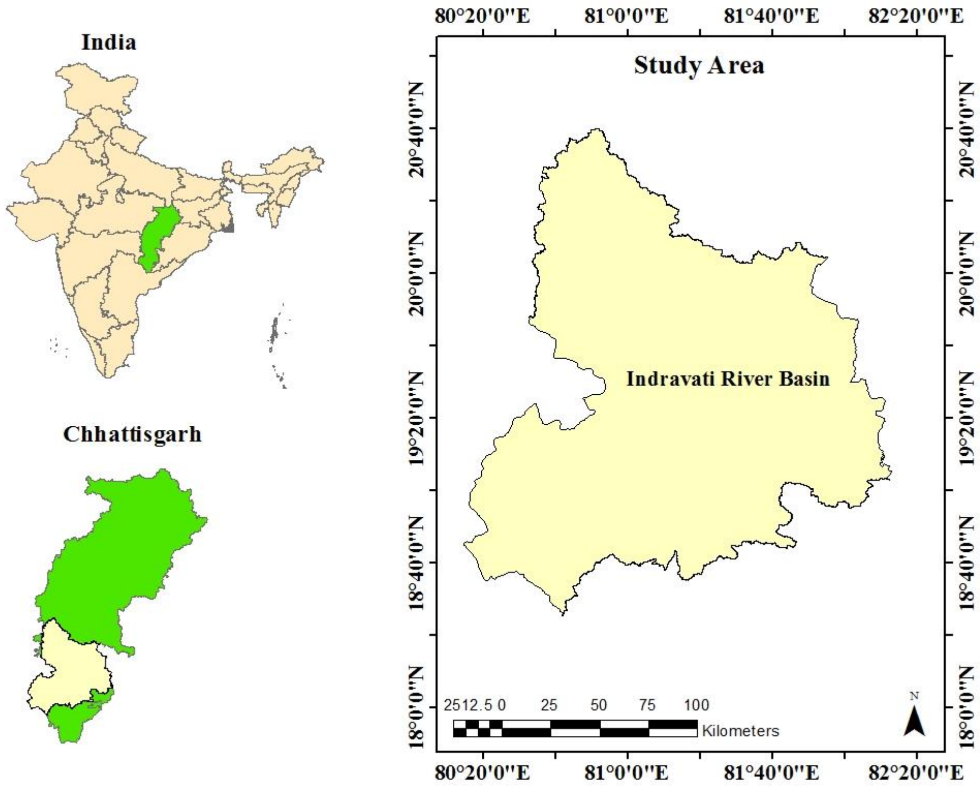

Fig. 1 Study Area

2.2 Data Required

Remote Sensing data used in this study i.e. Digital Elevation Model (DEM), soil, Land Use Land Cover (LULC), taken from different sources has been listed in Table 1.

Table 1 Data Sources

S.N.	Data	Sources
1.	CARTO SAT-1 Digital Elevation Model (CARTODEM-3 R1)	Indian Earth Observation, National Remote Sensing http://bhuvan.nrsc.gov.in/data/download/index.php
2.	Digital Soil Map Of The World- ESRI Shape file	Food and Agricultural organization united Nations http://www.fao.org/geonetwork/srv/en/metadata.show?id=14116
3.	Land cover map 5min_2012_tif file	Spatial data analytics & location platform ESRI http://www.esri.com/metadata/esriprof80.dtd

Here DEM is used to generate the watershed. Soil and LULC map, shown in Fig. 3 and 4 respectively are used to classify different hydrological soil group and antecedent moisture conditions to assign curve number for each LULC class for further calculation to determine the potential runoff of Indravati river watershed.

2.3 Rainfall Data

The study area cover 24 rain gauge stations, which shown in Fig. 2. The 10 years rainfall data (2006 to 2016) taken from National Informatics Centre (NIC), Chhattisgarh has been used in this study.

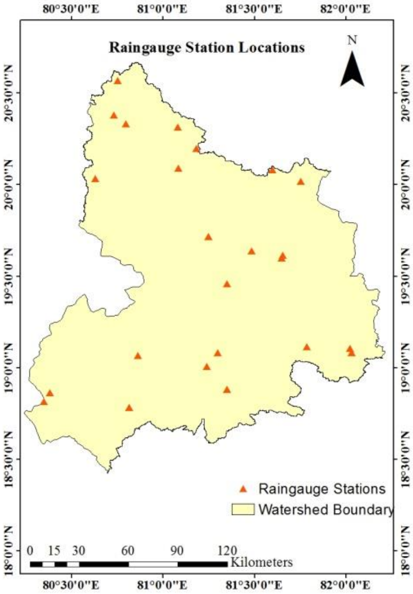

Fig. 2 Raingauge Station

2.4 Hydrological Soil Group (HSG)

As per National Engineering Handbook (NEH) [16] developed by USDA, soils are classified in four groups A, B, C and D based upon the infiltration, permeability and other characteristics. The distributed HSG of the study area is shown in Fig. 3.

Group A: Soils in this group have low runoff potential and high infiltration rate when thoroughly wet. Water is transmitted freely through the soil.

Group B: Soils in this group have moderately low runoff potential and moderate infiltration rate when thoroughly wet. Water transmission through the soil is moderate.

Group C: Soils in this group have moderately high runoff potential and low infiltration rate, when thoroughly wet. Water transmission is somewhat restricted through the soil.

Group D: Soils in this group have high runoff potential and low very low infiltration rate, when thoroughly wet. Water transmission is restricted through the soil.

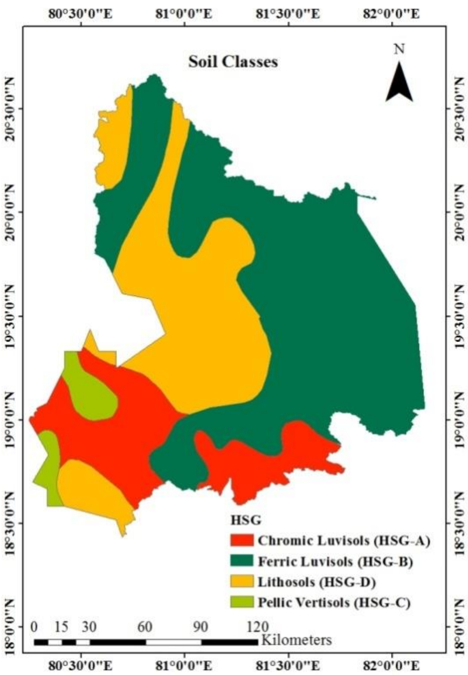

Fig. 3 Soil Classes

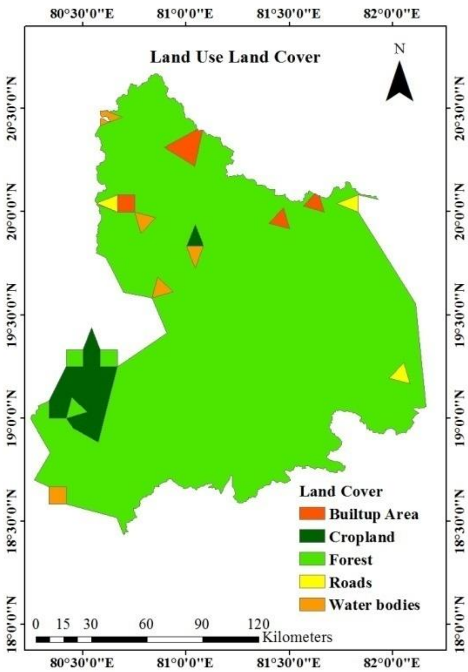

Fig. 4 Land Use Land Cover

2.5 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 as AMC-I, AMC-II & AMC-III. The limits of these three AMC classes are based on rainfall magnitude of previous five days and season as shown in Table 2.

Table 2 Antecedent Moisture Condition (AMC) for Determining the Value of CN

AMC TYPE	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

Souces: National Engineering Handbook [16]

2.6 SCS-CN Method

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 [17], refer to equation (2.1).

$$\frac{Q}{(P - I_a)} = \frac{F}{S} \quad (2.1)$$

Where, P = total precipitation, I_a = initial abstraction, F = cumulative infiltration excluding I_a, Q = direct surface runoff.

The second concept is that the amount of initial abstraction is some fraction of the potential maximum retention [17], refer to (2.2).

$$I_a = \lambda S \quad (2.2)$$

$$S = \frac{25400}{CN} - 254 \quad (2.3)$$

Where, CN denotes the curve number at different AMC conditions. CN at AMC-I and AMC-III condition can be calculated using already fixed CN at AMC-II condition, refer (2.4) and (2.5).

a) CN for AMC I is calculated as

$$CN_I = \frac{CN_{II}}{(2.281 - 0.01281\ CN_{II})} \quad (2.4)$$

b) CN for AMC III is calculated as

$$CN_{III} = \frac{CN_{II}}{(0.427 + 0.00573\ CN_{II})} \quad (2.5)$$

For this study CN at AMC-II condition i.e. average of CN at AMC-I and AMC-III condition, has been taken for calculation and listed in Table 3.

Table 3 Curve Number for HSG under AMC-II Conditions

Land Use	Hydrological Soil Goup			
	A	**B**	**C**	**D**
Agricultural land	95	95	95	95
Water bodies	100	100	100	100
Forest	26	40	58	61
Build Up	-	92	-	95
Wasteland	-	98	-	-

Souces: National Engineering Handbook [16]

By combining (1), (2) and (3), runoff can be calculated in mm, refer to (2.6) and (2.7).

$$Q = \frac{(P - I_a)^2}{P - I_a + S} \qquad \text{For } P > \lambda S \qquad (2.6)$$

$$Q = 0 \qquad \text{For } P < \lambda S \qquad (2.7)$$

A flow chart, representing overall methodology applied for the study is shown in Fig. 5.

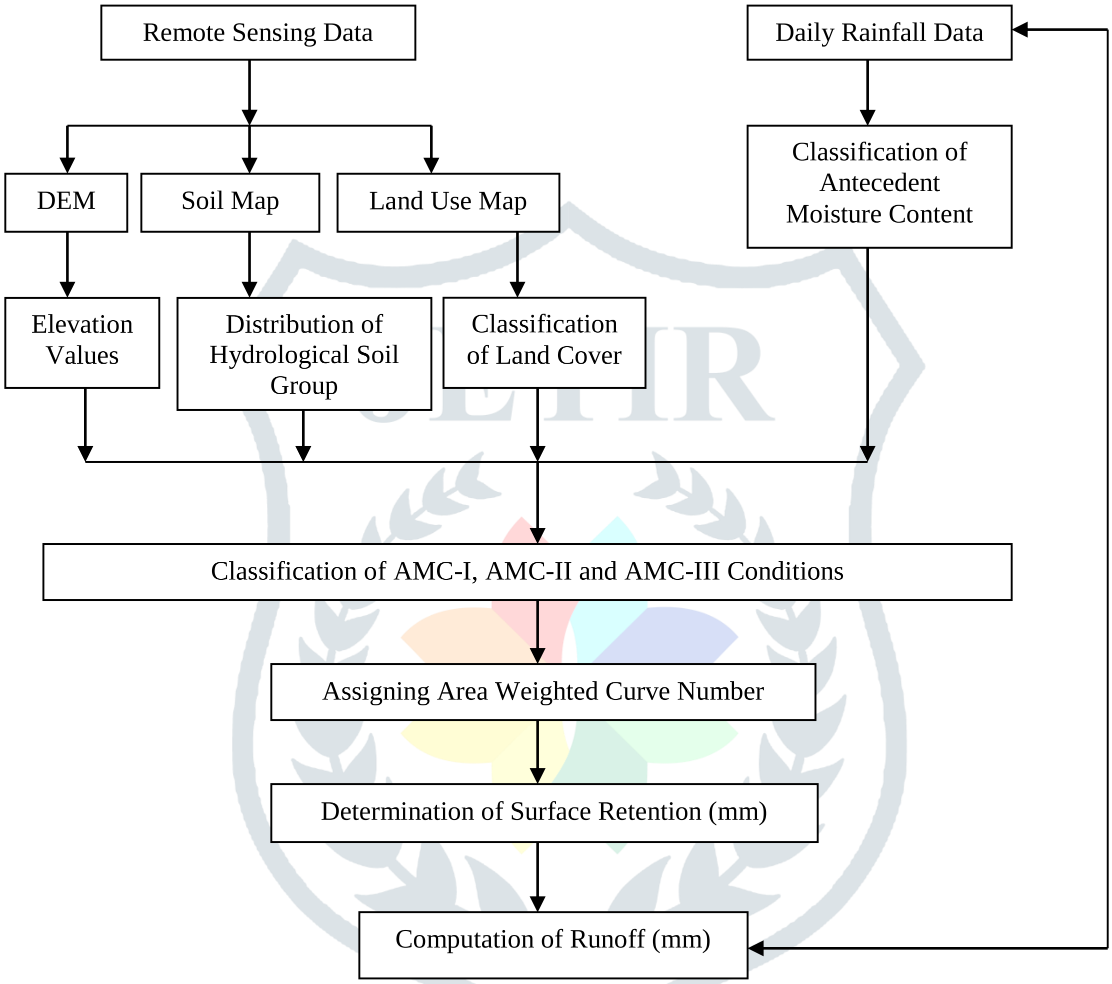

Fig. 5 Methodology

III. Result and Conclusions

The average curve number (CN-II) of the study area ranges between 40 to 60, resulting in the average annual runoff (2006-2016) of about 37423.68 mm i.e. 53.24% of the total rainfall. Result shows that a good amount of water yield is available in indravati river which can be used for irrigation as well as other hydrological development in Bastar district. An integrated approach, remote sensing and ESRI based GIS technique in conjunction with field data can be successfully used in estimation of potential runoff. The result of this study can be used in agricultural water management, soil and water conservation, as well as in mitigation of natural hazards such as drought and flood. This SCS model can be used in future assessment of climate change and land use land cover impact assessment with respect to runoff -rainfall modelling in water resources. The study is definitely useful for proper implementation of national watershed development plan in the study area. Also result of this study can be used in PKSY (Pradhan Mantri Krishi Sinchai Yojna) & distinct irrigation plan.

IV. Acknowledgment

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REFERENCES

[1] Mishra, S.K., Jain, M.K. and Singh, V.P., 2004. Evaluation of the SCS-CN-based model incorporating antecedent moisture. Water resources management, 18(6), pp.567-589.Ali, A. 2001.Macroeconomic variables as common pervasive risk factors and the empirical content of the Arbitrage Pricing Theory. Journal of Empirical finance, 5(3): 221–240.

[2] Oudin, L., Hervieu, F., Michel, C., Perrin, C., Andréassian, V., Anctil, F. and Loumagne, C., 2005. Which potential evapotranspiration input for a lumped rainfall–runoff model?: Part 2—Towards a simple and efficient potential evapotranspiration model for rainfall–runoff modelling. Journal of hydrology, 303(1-4), pp.290-306.

[3] Satheeshkumar, S., Venkateswaran, S. and Kannan, R., 2017. Rainfall–runoff estimation using SCS–CN and GIS approach in the Pappiredipatti watershed of the Vaniyar sub basin, South India. Modeling Earth Systems and Environment, 3(1), p.24

[4] Kangsabanik, S. and Murmu, S., 2017, May. Rainfall-runoff modelling of Ajay river catchment using SWAT model. In IOP Conference Series: Earth and Environmental Science (Vol. 67, No. 1, p. 012033). IOP Publishing.

[5] Viji, R., Prasanna, P.R. and Ilangovan, R., 2015. Modified SCS-CN and Green-Ampt methods in surface runoff modelling for the kundahpallam watershed, nilgiris, western ghats, india. Aquatic Procedia, 4, pp.677-684.

[6] Singh, V.P. and Frevert, D.K. eds., 2002. Mathematical models of large watershed hydrology. Water Resources Publication.

[7] Wagener, T., Wheater, H. and Gupta, H.V., 2004. Rainfall-runoff modelling in gauged and ungauged catchments. World Scientific.

[8] Ebrahimian, M., Nuruddin, A.A.B., Soom, M.A.B.M., Sood, A.M. and Neng, L.J., 2012. Runoff Estimation in Steep Slope Watershed with Standard and Slope-Adjusted Curve Number Methods. Polish Journal of Environmental Studies, 21(5).

[9] Anwar, M.R., 2011. The Rainfall-Runoff Model Using The Watershed Physical Characteristic Approach. International Journal of Civil & Environmental Engineering, 11(6).

[10] Wheater, H., Sorooshian, S. and Sharma, K.D. eds., 2007. Hydrological modelling in arid and semi-arid areas. Cambridge University Press.

[11] Williams, J.R., Kannan, N., Wang, X., Santhi, C. and Arnold, J.G., 2011. Evolution of the SCS runoff curve number method and its application to continuous runoff simulation. Journal of Hydrologic Engineering, 17(11), pp.1221-1229.

[12] Soulis, K.X. and Valiantzas, J.D., 2012. SCS-CN parameter determination using rainfall-runoff data in heterogeneous watersheds–the two-CN system approach. Hydrology and Earth System Sciences, 16(3), pp.1001-1015.

[13] Vinithra, R. and Yeshodha, L., 2016. Rainfall–runoff modelling using SCS–CN method: a case study of Krishnagiri District, Tamilnadu. Int J Sci Res, 5(3), pp.2319-7064.

[14] Wang, J.J., Ding, J.L., Zhang, Z. and Chen, W.Q., 2017, February. Improved Algorithm of SCS-CN Model Parameters in Typical Inland River Basin in Central Asia. In IOP Conference Series: Earth and Environmental Science (Vol. 57, No. 1, p. 012051). IOP Publishing.

[15] FAO Soil Units 1974 ,Extract from “Legend of the Soil Map of the World”,1974,UNESCO,Paris.

[16] Hydrologic Soils Groups 2007, National Engineering Handbook, National Resources Conservation Services, USDA.

[17] Subramanya, K., 2013. Engineering Hydrology, 4e. Tata McGraw-Hill Education.