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Preparation of curve number map of mand catchment, Chhattisgarh in ARCGIS 10.5

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Abstract
The study is carried out with a purpose to apply various techniques and tools in ArcGIS 10.5 for the delineation of Mand catchment, thirteen sub-watersheds and developing methods in order to calculate the weighted curve number for the all the thirteen sub-watersheds of Mand catchment in ArcGIS 10.5. Multiple layers like Hydrologic soil group layer, DEM and Land Use Land Cover layer was combined and CN map was prepared. In particular, SCS-CN (Soil Conservation Curve Number) is a method through which the estimation of the direct runoff can be achieved with the curve numbers determined. This method comprises numerous important properties of the watershed such as Hydrological Soil Groups and land use/ land cover, antecedent moisture content (AMC) which will use as an input for various hydrological model.

Keywords: SRTM-DEM, GIS, Sub-watershed delineation, LULC, HSG, Weighted curve number, CN Map

1. Introduction
A curve number (CN), an index developed by the Soil Conservation Service (SCS) now called the Natural Resource Conservation Service (NRCS), is used to estimate the amount of rainfall that infiltrates into the soil and the amount of surface runoff generated with the rainfall (Chin, 2000; Durrans, 2003) [3, 4]. The traditional method of delineating a watershed area from the topographic map is time consuming and is inaccurate. This traditional method has been replaced by the automatic extraction from a Digital Elevation Model (DEM). The DEM data can be used to derive geomorphic and topographic characteristics such as terrain slope, elevation, aspect, contour line, hill-shade, view shade, drainage, stream order and drainage density. The CN for a drainage basin is estimated using a combination of land use, soil, and antecedent soil moisture condition (AMC). There are four hydrologic soil groups: A, B, C and D. Group A have high infiltration rates and group D have low infiltration rates. The Soil Conservation Service Curve Number (SCS-CN) method is widely used for predicting direct runoff volume for a given rainfall event. This method was originally developed by the US Department of Agriculture, Soil Conservation Service and documented in detail in the National Engineering Handbook. Due to its simplicity, it soon became one of the most popular techniques among the engineers and the practitioners, mainly for small catchment hydrology. The main reasons for its success is that it accounts for many of the factors affecting runoff generation including soil type, land use and treatment, surface condition, and antecedent moisture condition, incorporating them in a single CN parameter. Furthermore, it is the only methodology that features readily grasped and has reasonably well documented environmental inputs and it is a well-established method, widely accepted for use in all the countries. This Curve Number plays an important role in any hydrological modelling such as the rainfall-runoff model for calculating runoff volume and peak discharges. As CN is considered very significant single parameter, in this study it is estimated in the environment of GIS to save time and for more accuracy in the results.

2. Location of Study Area
The study area is Mand catchment of Mahanadi basin which is the part of Chhattisgarh. The Mand catchment lies between the North attitudes of 21°42'15.525"N and 23°4'19.746"N and east longitudes of 82°50'54.503"E and 83°36'1.295"E (Fig 1). The Mand River originates from the northern part of the Mainpat plateau village Bargidih of District Sarguja of Chhattisgarh state. It then reaches the Chandrapur which is in the eastern part of Janjgir-Champa and joins the Mahanadi River. At first it flows through north-south and east-west and then north-south and south-east. The total contributing area is 5332.07 sq.km thus it contributes only 7.35% of Mahanadi basin in Chhattisgarh State. Mand River is a Mahanadi tributary, which joins Mahanadi River 28 km before the Orissa border and before the river reaches Hirakud dam. The Koirja nalla, Gopal nalla, Chhindai nalla and Kurket River are the principal tributaries. Its flow field is full of forest cover, trees, agricultural land, water bodies and natural boundary. The river rises in Surguja district of Chhattisgarh at an elevation of about 686 m and the river's total length is 241 km.
Mand catchment covers parts of Sarguja, Korba, Janjgir-Champa, Jashpur and Raigarh districts in which major part is of Raigarh district. Soils are mainly red sandy soil, red and yellow soils and red gravelly soils. The geology of the area has Barakar formation, Kamthi formation, Raigarh formation, Deccan trap and Chhotanagpur Gniessic rocks majorly. The region is enriched with three distinct seasons of subtropical monsoon climate, i.e. summer, monsoon and winter. The Southwest Monsoon starts in June and lasts until mid-September. The winter season runs from October to February. Summer season runs from March till mid-June. Rainfall is the area's major source of groundwater recharge and receives maximum rainfall (85 percent) during the southwestern monsoon season. The average annual rainfall

(2019) is 1382.12 mm. The normal maximum temperature is 42.5 °C during the month of May and 8.2 °C is the minimum during the month of January.

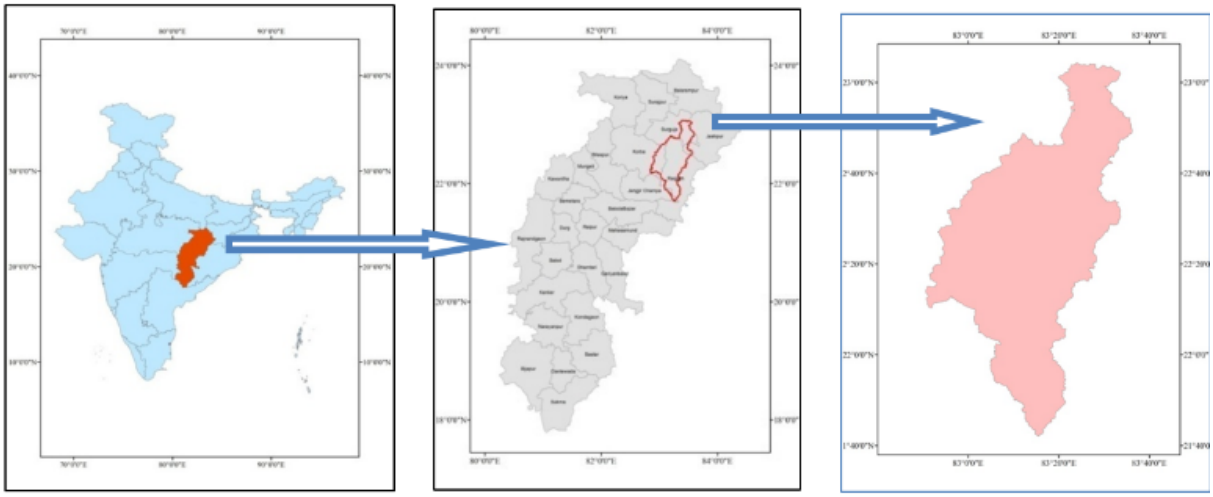

Fig 1: Location of the study area (Mand catchment)

3. Materials and Methods

The topography information is required for the delineation of the Mand catchment and for the preparation of drainage map. A digital elevation model (DEM) created from the data from the Shuttle Radar Topography Mission (SRTM) has been used in this analysis. The DEM was downloaded from the website of the United States Geological Survey (USGS), which was in the format of Tagged Information File Format (TIFF), with ground resolution of 30 m. Then, the developed DEM was processed to delineate the Mand Catchment and thirteen sub-watersheds (Fig. 3), using the Arc-Hydro extension tool of ArcGIS 10.5. Hydrological assessment based on SRTM DEM at catchment scale is more applied and more accurate compared to other available conventional techniques (Singh *et al*. 2014) [10]. In order to perform geometric correction, the DEM was re-projected to Universal Transverse Mercator (UTM) co-ordinate system with Datum WGS 1984 (Zone-44) with spatial resolution of 30 m. DEM of Mand catchment is shown in Fig. 2. The data collected for the study are soil map, sentinel-2 satellite data and SRTM-DEM of the Mand cathment. These collected data were then used for pre-processing in ArcGIS 10.5, in order to extract the Curve Number of the study area. The land use and Hydrological Soil Group map (HSG) were generated to calculate the Curve Number.

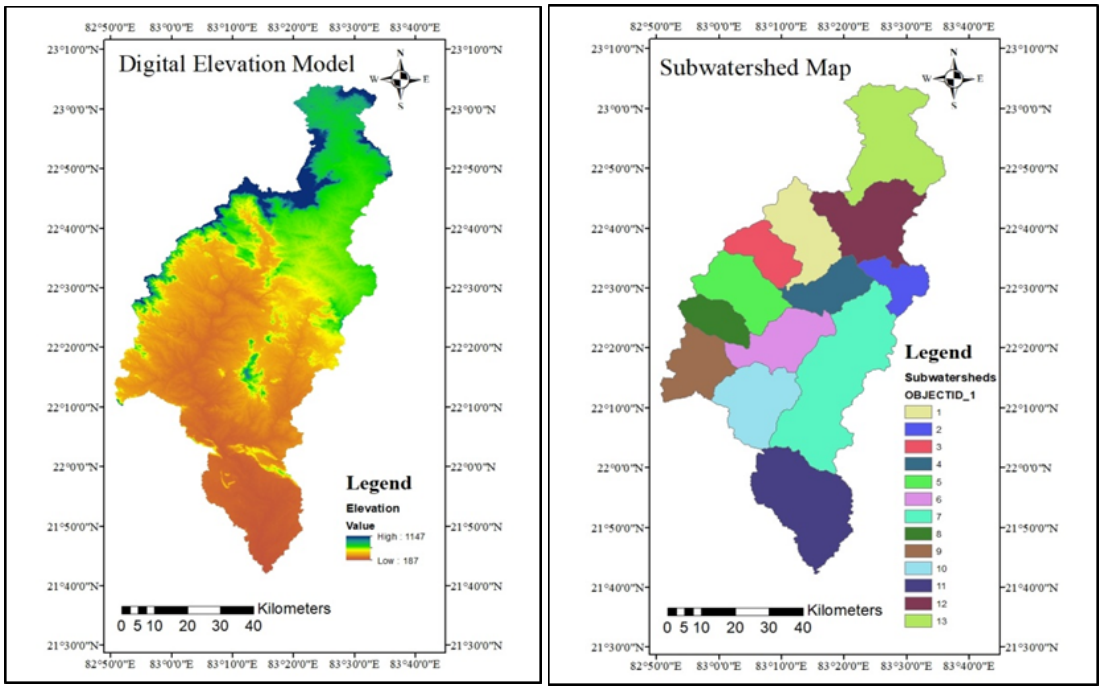

Fig 2: DEM Map

Fig 3: Sub-watershed Map

3.1 Land Use/ Land Cover (LULC) map preparation

Land use means different uses that are carried out on the land. Land cover applies to natural vegetation, bodies of water, rocks/soil, artificial cover and others that arise from transformations. Cloud-free sentinel-2 imagery was downloaded from the earthexplorer.usgs.gov website in the month of November 2019. The classification was carried out using supervised classification methods with a maximum likelihood algorithm. Supervised classification is preferred to other classification systems, as it shows a clearer and more diverse classification option.

3.2 Antecedent Soil Moisture Condition (AMC)

Antecedent Moisture Condition (AMC) refers to the water content present in the soil at a given time. Three precedent soil-moisture conditions were established by SCS and classified as I, II, III according to soil characteristics and rainfall limits for dormant and growing seasons. Classification of a prior condition of moisture is shown in Table 1. Average condition (AMC-II) is obtained in this analysis and AMC-II is used to assess the CN value for the Mand Catchment.

Table 1: Classification of Antecedent Moisture Conditions (AMC)

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

3.3 Hydrologic Soil Group Condition (HSG)

The classification of the hydrological soil groups is shown in Table 2. CN values were determined from the hydrological soil group and the previous watershed moisture conditions.

Table 2: USDA-SCS Soil Classification

S. No.	HSG	Soil Textures	Runoff Potential	Minimum Rate of Infiltration (mm/hr)	Water Transmission
A	Deep, well-drained Soils	Sand, Loamy sand or sandy Loam	Low	7.62- 11.43	High rate (0.30 in/hr)
B	Moderately Deep, well-drained with moderately fine to coarse textures	Silt loam or loam	Moderate	3.81- 7.62	Moderate rate (0.15-0.30 in/hr)
C	Moderately Fine to Fine Textures	Sandy Clay Loam	Moderate	1.27- 3.81	Low rate (0.05-0.15 in/hr)
D	Soil which	Clay loam,	High	0 - 1.27	Very Low rate
	Swell significantly when wet, Heavy plastic and soil with the permanent high water table	Silty clay loam, sandy clay, silt clay, clay			(0-0.05 in/hr)

(***Source:*** Engineering Hydrology, K. Subramanya, 2008)

3.4 Curve Number Estimation

Based on land cover, HSG and AMC, the CN (a dimensionless number ranging from 0 to 100) are determined from a table (Table 3). With the use of union tool, the land use map (Fig. 4) is superimposed on the hydrological soil group map (Fig. 5), polygon of each land use- soil group is obtained and finally, the area of each polygon is calculated and the curve number is assigned to each individual polygon based on the standard SCS curve number. The curve number for each area-weighting drainage basin determined from polygons of the land-use-soil group within the limits of the drainage basin. The Weighted CN equation is given below:

$$CNw = \frac{\sum(CNi * Ai)}{A}$$

Where,
CNw = weighted curve number.
CNi = curve number from 1 to any no.
Ai = area with curve number CNi

4. Results and Discussion

4.1 Delineation of the Mand catchment from DEM

The extraction of the drainage network of the study area was carried out from the DEM. Archydro tools in ArcGIS software, version 10.5 was used to extract drainage channels. The delineation of the catchment is followed by running the following functions: fill, flow accumulation, Flow direction, Stream definition, Stream Segmentation, Catchment Grid Delineation, Catchment Polygon, Drainage line, Adjoint Catchment processing and Drainage point. Mand river catchment was divided into 13 sub-watersheds. Total area of the catchment is 5332.07 sq.km. With perimeter of 589.73 km. Sub-watershed 7 has the maximum area of 943.68 sq.km. Whereas sub-watershed 2 has the minimum area of 179.56 sq.km.

Table 3: Curve Numbers for LULC types and different hydrologic soil groups compiled after SCS (1986) and Tailor & Shrimali (2016)

Land use and Land cover	Hydrologic Soil Group			
	A	B	C	D
Agricultural Land	72	81	88	91
Shallow water body	97	97	97	97
Deep water body	100	100	100	100
Dense forest	26	40	58	61
Open forest	28	44	60	64
Fallow land	77	86	91	94
Barren land	68	79	86	89
Scrubland	33	47	64	67
Settlement	77	86	91	93

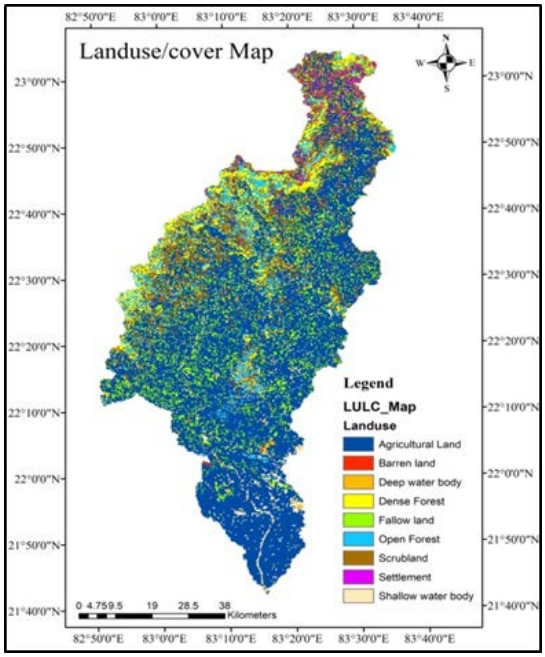

Fig 4: LULC Map

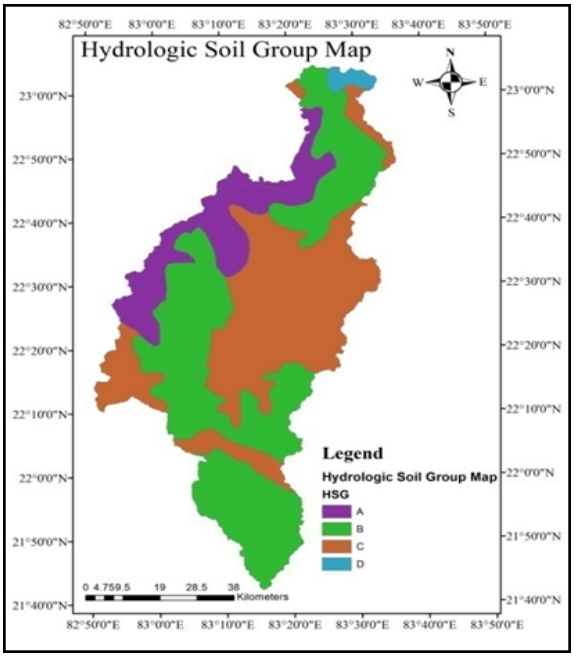

Fig 5: Hydrologic Soil Group Map

4.2 Curve Number Map Preparation

The Curve Number parameter is dimensionless and varies from 0 (maximum infiltration) to 100 (zero infiltration). The CN map has been obtained from the intersection of the soil hydrological group and land use. A curve number is assigned accordingly, based on standard SCS curve number. Curve number grid map for the Mand catchment is shown in Fig.6. The weighted curve number for each sub-watershed (Table 4) is calculated from area-weighing land use-soil group polygons within the sub-watershed.

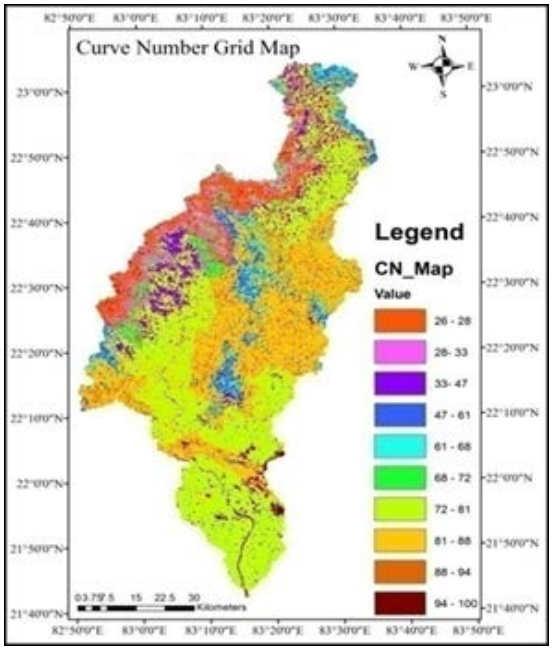

Fig 6: Curve Number Grid Map

Table 4: Weighted curve number for each sub-watershed

Sub-watersheds	1	2	3	4	5	6	7	8	9	10	11	12	13
Weighted Curve Number	66	81	66	73	67	73	73	66	67	73	72	67	70

5. Conclusions

The present study demonstrates the importance of GIS techniques and remote sensing and their utility for the research work. SRTM DEM was processed to delineate the Mand river catchment and drainage network and thirteen sub-watersheds using the Arc-Hydro extension tool of ArcGIS 10.5. This paper is also dealing with a reliable method for computing the CN values in the environment of GIS. The values of CN of the Mand catchment lies between 100 and 26. The results showed that a CN of 100 means surface water. The high curve numbers (100-77) corresponding to settlement and water bodies which indicates high runoff and low infiltration; while low curve numbers (72-26) corresponding to the forested area and agricultural land means low runoff and high infiltration rate.

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