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SURFACE RUNOFF ESTIMATION OF AMRAVATI RIVER BASIN USING INTEGRATED SCS-CN, RS AND GIS TECHNIQUES

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Abstract:

A river basin is a hydrological unit surrounded by natural ridges that allow the runoff to drain in a well-defined drainage pattern of streams flowing within the boundaries of the watersheds due to rainfall. Rainfall and runoff are the substantial hydrologic component in the water resources assessment. Various methods are available to estimate runoff from rainfall; still, the Soil Conservation Service Curve Number (SCS-CN) method remains the most popular and often used method as runoff curve number (CN) is an essential factor of the SCS-CN method and depends upon land use/land cover (LULC), soil type, and antecedent soil moisture (AMC) data. Also, various parameters, such as Hydrological Soil Characteristics (HSG), precipitation (P), Potential Maximum Retention (PMR), and Antecedent Moisture Condition (AMC) are the mandatory inputs to the SCS-CN model. In the results, the daily runoff from the Amravati River basin for an average of 31 years, i.e., 1990 to 2021, has been used. As a result, the average annual surface runoff calculated for the Amravati River basin is 223 mm. The total average volume of runoff is 1.77 X 10^8 m^3/year or 1.77 X 10^{11} Liters/year or 6.25 thousand Million Cubic Feet (TMC), representing 35.68 % of the total average annual rainfall.

Key Words: *Rainfall, Runoff, RS & GIS Technology, SCS-CN Method, Curve Number*

Introduction:

Water is used in many spheres of our environment that assist human beings direct or indirectly. The most essential scopes of water for human beings are drinking, agriculture and energy production. All land of the earth's surface is a part of a watershed or river basin constituted by the water that flows over it and via it (Sarkar et al., 2020; Haque et al., 2020; Pandey et al., 2012). A river basin is a hydrological unit surrounded by natural ridgelines that allow the runoff to drain in a well- defined drainage pattern of streams flowing within the edges of the watersheds due to rainfall (Altaf et al., 2013; Ormsbee et al., 2020; Bhat et al., 2019). Rainfall is basically necessitated to meet various requirements, including agriculture, hydropower, industries, climate, and environmental systems, and is the primary source of runoff (Meraj et al., 2021). The water supplies for reloading groundwater in the watershed are critical for rainfall and runoff (Sateeshkumar et al., 2017). Management of water resources affects a system strategy that includes all hydrological components and the ties, relationships, interactions, consequences, and conditional relation between these components (Al-Ghobari and Dewidar, 2021).

Runoff is a significant hydrologic constituent in the water resources assessment (Ibrahim et al., 2021). Most water resource applications rely on runoff as a necessity hydrologic variable (Shadeed and Almasri, 2010). Runoff is the flow of precipitated water by a channel in the catchment area after all surface and subsurface losses have been met.

River basin features such as length, width, area, shape, drainage design, soil type, vegetation cover, land usage, and hydrological conditions affect the rainfall-runoff procedure substantially (Caletka et al., 2020). Rainfall characteristics like intensity, duration, and distributions are the main components for the occurrent and runoff assess. Water flow happens when soil is infiltrated with high-capacity, and excess water from precipitation, snowmelt, or other water sources flows over the land called surface run-off. This is the most vital hydrologic cycle (Satheesh kumar et al., 2017). The relationship between the quantity of precipitation and the significant runoff is generally dependent on soil Infiltration. The rainfall-runoff relationship is exceptionally complex, influenced by various storm and drainage characteristics (Verma et al., 2020a, 2020b; Lian et al., 2020).

Various methods are available for finding out the runoff, such as the rational method, the Green-Ampt method, and the SCS-CN method (Jaafar et al., 2019). Spatio-temporal rainfall unevenness assessment Tropical rainfall measurement mission (TRMM) Multi-satellite precipitation data (TMPA) can be analyzed. (Singh et al., 2011). One of the most usual computing methods for the amount of surface runoff in catchments for a given rainfall event is the SCS-CN method. This method expects the use of a basic empirical formula and tables and curves that are readily accessible. A high number of curves mean high runoff and low (urban areas) infiltration, while a low number of curves mean low runoff and high (dry soil) infiltration (Shadeed and Almasri, 2010). The Soil Conservation Service-Curve Number (SCS-CN) method developed by the National Resources Conservation Service (NRSC), United States Department of Agriculture (USDA) in 1969, is a simple, predictable and stable conceptual method for estimation of direct runoff depth based on storm rainfall depth. Numeric catchment characteristics are the foundation of runoff determination in this method. The process aims to determine the precise runoff curve number (CN) that defines the runoff potential. A combination of land-use type, soil group, and Antecedent Soil Moisture Condition (AMC) is used to estimate the runoff curve number. Soil type is divided into four Hydrologic Soil Groups (HSG): soil types of Group A, Group B, Group C, and Group D. Soil type under the “Group A" hydrologic soil group has a high infiltration rate. In contrast, soils with a low infiltration rate come under the “Group D" hydrologic soil group.

Remote sensing and GIS techniques are good for the planning, developing, and dealing of natural resources and water resources in worldwide research. Remote sensing satellite imagery provides a synoptical view and broad area coverage of any river basin. The GIS environment helps incorporating various thematic data sets in one platform and executes spatial analysis for decision making. Due to the synergism between the two techniques, RS and GIS play a fundamental role in hydrological applications; a hydrologist can prepare a combined use (Balkhair and Rahman, 2021). An efficient tool in analysing parameters such as land use, land cover, soil, topographical and hydrological conditions is the GIS, designed to restore, manipulate, recover and view spatial and non-spatial data. With the GIS framework, remote sensing allows quickly capturing, evaluating, and interpreting multi-disciplinary data on a wide scale and is very helpful for planning watersheds. It takes a lot of time and effort to estimate the runoff capacity from un-gauged watersheds using traditional methods. For inaccessible terrain, traditional runoff calculation methods are not simple and are not economical for a large number of small watersheds (Singh et al., 2014; Farooq et al., 2021a; Pandey et al., 2013). The geospatial system has developed into an essential hydrologic modelling method since it is highly constructive to generate model parameters in a spatially distributed manner (Singh and Pandey, 2014: Farooq et al., 2021b; Bera and Singh, 2021).

In the Amravati River basin, calculating surface runoff is very significant. Every year, the Amravati River basin experiences a drought-like position due to low average annual rainfall and excessive runoff. The basin contains many land use/land cover classes, with agriculture being the most substantial land-use class in the study region. Fallow land and open shrubland are the essential land-use types for surface runoff. While measuring runoff potential, the hydrologic soil group also has significant utility, representing the soil character, category, and capability infiltration.

Study area:

Amravati River is an important tributary of Tapi River system, flowing through Maharashtra States. It originates from fringes of Sahyadri range, 650 m above mean sea level west of Deccan plateau in Dhule District, Maharashtra. It flows 57.73 kms eastwards and joins Tapi River at Shendvade in Dhule District, Maharashtra. The study basin extends between Latitudes 21° 09' 44'' to 21° 24' 42'' N and Longitudes 74° 12' 55'' to 74° 44' 06'' E. spanning an area of 795 sq. km (Fig. 1).

Material and methods:

Daily observed meteorological data collect from IMD, Pune for the period 1990–2021 were used for the present study. The SOI topographical maps of 1:50000 scale acquired from Survey of India, Dehradun, were used to rectify satellite imagery, base map formulation, and feature validation of the study area. The Landsat-8 ETM (30 m) (Enhanced Multispectral Scanner) satellite imagery was used to prepare various thematic maps of the study area. The soil texture map of the study area was obtained from the National Bureau of Soil Survey and Land-use Planning. The Land-use/Land cover is one of the important variables for runoff estimation. Land use map prepared by using Landsat-8 satellite imagery using ERDAS Imagine 2015 and Arc GIS 10.5 software. On-screen digitization procedure applied for land use map formulation through visual interpretation of satellite imagery on a 1:50000 scale. The LULC classes depicted in the study area are agricultural land, built-up area, forest, wastelands, and water bodies. For the assessment of the rainfall water as surface runoff, Soil texture is essential for hydrologic soil group determination; a hence required thematic layer of soil type obtained from the National Bureau of Soil Survey and Land Use Planning (NBSS and LUP). Hydrological Soil Group (HSG) maps of the study area are developed using Arc GIS 10.5 software based on soil texture. According to the soil's minimum infiltration rate, the HSG is explicit as four groups; Group A, B, C, and D. The overlay operation is executed using the land use map and hydrologic soil group map to describe land use and soil group for each polygon and find out every land-use class area under the same soil group for specified CN values. The CN of each unique land use-soil group is attributed within the basin boundary based on the standard SCS curve number method. The SCS-CN technique explaining the water balance equation can be enounced below (Soulis and Valiantzas, 2012).

$$Q = \frac{(P - Ia)^2}{P - Ia + S}$$

Where; Q is the runoff depth (to get volume, multiply by the basin area). P is the rainfall depth. Ia is the initial abstraction. S is the basin storage. All units of depth are in mm.

The amount of rainfall that falls before runoff is started can be conceived as initial abstraction and this is generally assumed to be 0.2S. Eq. is generally composed as (Ling et al., 2020):

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

For the Indian condition, the CN is related to S with

$$S = \frac{1000 - 10}{CN}$$

The CN (a dimensionless number ranging from 0 to 100) is determined from a table based on land-use/land cover (LU/LC), hydrological soil group (HSG).

Result and discussion:

In the present study, the SCS-CN method was used for surface runoff estimation of the Amravati River basin. The runoff generation method is majorly complex, nonlinear, dynamic in character, and impacted by numerous interconnected physical factors. Therefore, accurate runoff assessment is accomplished for worthful management and development of water resources. In the Amravati River basin, drought-like positions prevail every year due to low average annual rainfall and high runoff. The basin comprises different land use/ land cover classes, and present research exposes that agriculture is the dominant land use class in the study region. The fallow land plays a critical role in the surface runoff among the other land-use types. The hydrologic soil group also has substantial functionality while assessing the runoff potential, constituting the soil character, category, and capability infiltration. In the present study, the hydrologic soil group types of groups A, B, C, and D were set up concerning soil map, geospatial data, and other secondary data. The result exposes that the C type of hydrological soil group is mainly covered throughout the Amravati River basin area. By overlay analysis of LULC and HSG in the GIS environment, the CN values were allotted according to USDA SCS, and the AMC values are AMC I, AMC II, and AMC III.

Land use:

Land use is a significant indicator of surface runoff. Forests, water bodies, agricultural land are poor sources of surface runoff, built-up land, barren land are good sources. Five major land use types Forests 127.2 km^2, Water bodies 31.8 km^2, Agricultural land 572.4 km^2, Barren land 7.95 km^2 and Built-Up Land 55.65 km^2 are identified in the Amravati basin. Barren land having extent is located in southern and western parts of the basin. Forests are concentrated in southern and western parts; small patches occur in the southeast. Agricultural land is widely scattered, its major concentration is in the southwest, west, central, northeast and eastern part of the basin. Built- up land mainly comprises Dondaicha town and some villages. Water bodies include Amravati River and Reservoirs.

Hydrologic soil group:

Soils have been categorized into four different hydrologic soil classes: A, B, C, and D groups, based on infiltration rate, texture, intensity, drainage order, and water transmission capacity. Based on the hydrological soil group, the maximum area of the Amravati River basin is characterized under group C of hydrological soil that is nearly 41.31%. Group B hydrological soil is 23.14%, group A hydrological soil observed as 22.39%, group D hydrological soil followed as 13.16%, The Amravati River basin is predominantly dominated by the Group C type of soil class. The HSG classification and characteristics given in Table 1.

Table 1 USDA-SCS Soil classification.

Hydrologic Soil Group	Type of Soil	Runoff potential	Infiltration Rate mm/h	Remarks
Group A	Deep black soil	Low	More than 7.5	High rate of water transmission
Group B	medium black soil	Moderate	3.8 to 7.5	Moderate rate of water transmission
Group C	shallow black soil	Moderate	1.3 to 3.8	Moderate rate of water transmission
Group D	red sandy soil	High	Less than 1.3	Moderate rate of water transmission

Curve number:

The Curve Number (CN) is calculated grounded on the hydrological soil group, land-use class, hydrological situation, and precedent moisture state (AMC), a dimensionless number run-off index. A hydrologic soil category of Group A, B, C, and D is assigned to each soil type, depending on its infiltration characteristics. The CN values can vary between 1 and 100. The higher CN values commend a higher run-off. The Union Overlay analysis performed with soil, land use map, and hydrological soil group map prepared a new polygon attribute table using Arc GIS 10.5. The result obtained from this HSG- polygon attribute table is used to compute the study area's total area-weighted curve number. The maximum curve number assigns 99 for river/water bodies, whereas the minimum curve number gives 25 for dense forest. Spatial distribution of SCS CN values shows in Fig. ()

Rainfall:

The average annual rainfall is not uniform in this region. Therefore, the rainfall data from the year 1990 to 2021 has been used in the present study (Fig No. 1). The average annual rainfall from the year 1990 to 2021 was observed as 625 mm/year. Therefore, the volume of the yearly average rainfall of the study region is found as 4.96 X 10^8 m^3/year or 4.96 X 10^{11} liter/year or 17.52 TMC. Such can be calculated as catchment area size in m2, multiplied by average annual rainfall in mm, equal to total rainwater falling on a catchment area in an average year in liters.

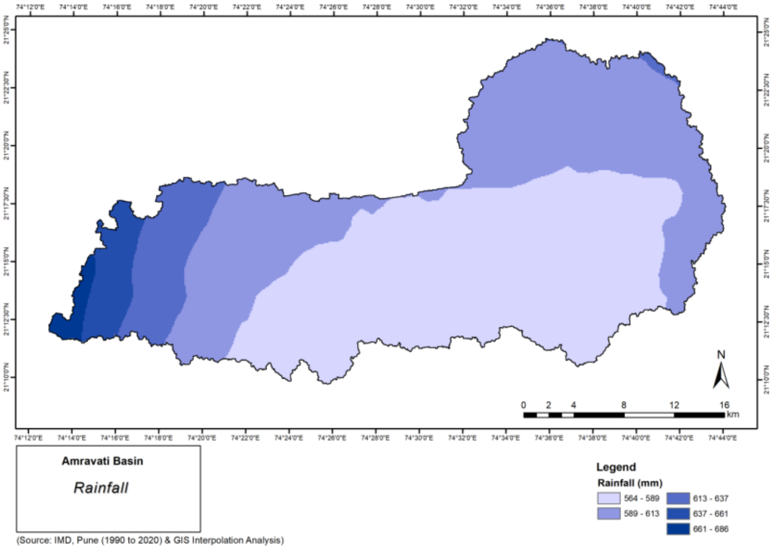

Fig. No. 1

Runoff calculation:

Available daily rainfall data from the year 1990 to 2021 has been evaluated in this study. The SCS-CN method was used in this study for runoff estimation. The average annual runoff from 1990 to 2021 was observed as 223 mm/year. The average annual runoff depth volume is observed as 1.77 X 10^8 m^3/year or 1.77 X 10^{11} Liters/year or 6.25 TMC (thousand Million Cubic Feet), which is 35.68% of the total yearly average rainfall of the study region. In the study area calculated spatial distribution of Runoff (Fig. No.2). Very high runoff zone (More than 300 mm) observed at the western side of the basin, high runoff zone (250 – 300 mm) observed at the western and southern divide of the basin. Moderate runoff zone (200 – 250 mm) is dominant zone in the Amravati River basin, while low runoff zone (150 – 200 mm) situated at the central part of the basin. Very low runoff zone (125 – 150 mm) is observed at patchy manner in central part of the basin.

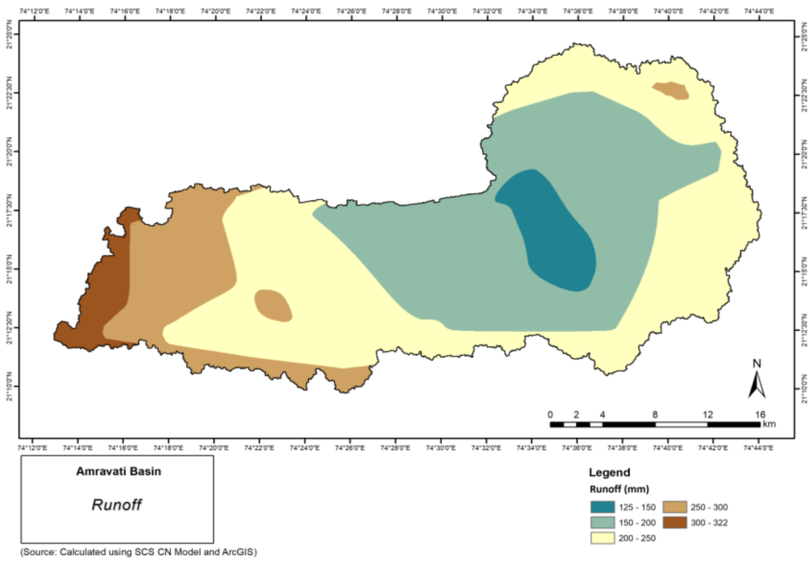

Fig. No. 2

Table 2 Spatial distribution of Runoff Zones

Runoff Zones	Runoff (mm)	Area (sq.km)	Area (%)
Very Low	125 - 150	93.413	11.75
Low	150 - 200	166.155	20.90
Moderate	200 - 250	291.368	36.65
High	250 - 300	170.528	21.45
Very High	300 - 322	73.538	9.25
	Total	795.000	100.00

Existing recharge structures and proposed new recharge sites:

Recharge structures can be projected based on the topography, geology, geomorphology, LULC, slope, aspect, soil type, etc., in any Amravati River basin. For site excerption of recharge structures, it is necessity to regard all the above parameters, lay over them in the GIS environment, and attribute weightage to each feature class and overlay analysis to describe appropriate sites for these structures. In the current study, overlay analysis has been performed using Arc GIS 10.5 software to choose new recharge sites based on available data and the recent result of estimated runoff (Fig. No. 3). There are many types of water recharge structures available, but in this study propose earthen bunds, nala bunds, check and stop dams for runoff perspective. Earthen bunds are in general proposed to prevent soil erosion at ridgetops and retard the velocity of the water. So, the location of this structure can be considered as 1st order stream local depression on pediments and wastelands areas. The material used for construction these structures can be loose boulders and clay. Nala bunds are the structures to recharge the weathered zones, store the water in a contract depression. The appropriate site of this structure can be conceived narrow, shallow, nallah bounded by agricultural land from both sides with open dug wells pose in them, on sallow buried pediments and single croplands. The material used for construction such facilities can be the earthen structure that may have gates. Check dams are normally advised to reduce the run-off velocity and check the siltation. So, the emplacement of this structure can be believed as topographic depressions where sufficient space for backwater storage enough drainage catchment necessitated on pediments, wastelands, and valley areas. The material used for constructing these structures can be earthen brick structures. Stop dams are the constructions to store the rainwater. Rock floor is exposed in nallah and has ample storage capacity. Desirable site of this structure can be conceived as pediments/valleys where primary and secondary porosity is least, and wasteland, rocky/barren outcrops areas. The material used for construction these facilities can be concrete materials.

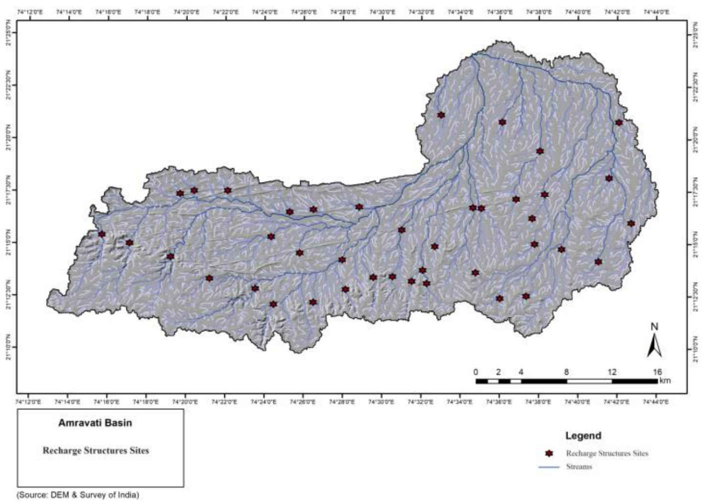

Fig. No. 3

Conclusion:

The present study points that the SCS-CN method incorporated with GIS techniques is good for runoff estimate. This method can also be used in watershed management efficaciously. Fluctuation in runoff potential is ascertained in the incurred result with different land use/land cover and changing soil conditions in the study area. Mostly the Amravati River basin points a high curve number of more than 50, which means moderate runoff in the Amravati River basin. The average annual runoff from 1990 to 2021 was observed as 223 mm/year, the total average annual runoff depth estimated as 1.77285 X 10^8 m^3/year or 1.77285 X 10^{11} Liters/year. Available daily rainfall data from the year 1990 to 2021 has been evaluated in this study. The average annual rainfall was observed as 625 mm/ year. Land use of the study area is classified into five major classes: built-up, agricultural land, forest, wasteland, and river/water bodies. The land use map shows that agriculture is the dominant land use class in the Amravati River basin. The study area's soil is classified into four hydrological soil groups A, B, C, and D, with a minimum infiltration rate. The soil map points that most of the study area is covered by group C of the hydrological soil group. Finally, the Soil Conversations Service – Curve Number (SCS-CN) technique has been successfully demonstrated better, necessitating less time and capability to handle big data sets and a more liberal environmental region to determine potential artificial recharge structure sites.

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