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Geography

ESTIMATION OF RUNOFF USING SCS-CN AND GIS METHOD: A CASE STUDY OF HYDERABAD CITY

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ABSTRACT For effective management of the limited water resources and to prevent flash floods in metropolitan areas caused by an increasing impervious surface area, it is very important to estimate the runoff in a flooding areas. In this study, runoff estimates for Hyderabad city were calculated using the Geographic Information System (GIS) and the Soil Conservation Service Curve Number (SCS-CN) approach for two distinct time periods 1987 to 1991 and 2017 to 2021. Through the combination of remote sensing and GIS, land use details were acquired and analysed the runoff aspects.

KEYWORDS : Surface Runoff, Rainfall, Land Use, Land Cover

INTRODUCTION:

Being a finite resource, water is a precious gift from nature to humanity that must be managed carefully. The loss of biodiversity, air pollution, greenhouse gas emissions, the urban heat island effect and storm water runoff are only few of the harmful environmental effects of land use changes brought by urbanization. Widespread hardscape alters the hydrological response. Urbanization induce surface runoff of precipitation. During land development, impermeable surfaces such as parking lots, walkways, and roadways are built, these surfaces (made of materials like asphalt and concrete), together with rooftops, transport contaminated runoff to storm drains during rain and that impacts the groundwater recharge. As a result, the water table falls, and flooding takes place as there is more water on the surface. Planning and managing water resources depend on accurate runoff estimation, which throws a challenge to hydrologists, hydrological engineers and planners. The SCS-CN method is one of the most popular and widely adopted approach to study runoff estimates.

Geographical information system and SCS-CN method has been used by many scholars to estimate runoff, some of them are Rawls et al. attempted to Evaluate the methods for determining urban runoff curve numbers in 1981. Patil et al in the year 2008 studied the Development of a GIS Interface for Estimation of Runoff from Watersheds. Amutha R & P. Porchelvan in the year 2009 provided an intricate analysis of the Estimation of surface runoff in Malatter Sub-watershed using SCS-CN method. Ramakrishnan D et al conducted a case study in 2009 on SCS-CN and GIS based approach for identifying potential water harvesting sites in the Kali watershed, Mahi River Basin, India. Rao K et al attempted an Integrated Study of Geospatial Information Technologies for Surface Runoff Estimation in an Agricultural Watershed in India in the year 2010. Geena G.B. & P.N. Ballukraya in 2011 conducted a case study to Estimate runoff for Red hills watershed using SCS method and GIS. S. K. Mishra et al worked on Estimations of design runoff curve numbers for Narmada watershed (India) in 2013. A case study was done by Thakuriah Gitika & Saikia Ranjan in 2014 for Estimation of Surface Runoff using NRCS Curve number procedure in Buriganga Watershed, Assam, India. H.J.Ningaraju et al in the year 2016 conducted a case study in Kharadya mill watershed, India for Estimation of Runoff Using SCS-CN and GIS method in ungauged watershed. Siddi Raju R et al Estimated the Rainfall-Runoff using SCS-CN Method with RS and GIS Techniques for Mandavi Basin in YSR Kadapa District of Andhra Pradesh in 2018.

STUDY AREA

The Municipal Corporation of Hyderabad is located on the northern latitude of 17.366°N and eastern longitude of 78.476°E with a total geographical area of 178.18 sq. km. In 2007 the Municipal Corporation of Hyderabad was expanded and reorganised in to Greater Hyderabad Municipal Corporation (GHMC) with a total area of 650 Sq. Km. In the present analysis, the municipal corporation of Hyderabad (MCH) has been considered as the study area both in 1991 and 2021(Fig.1). The average height of the city is 540 mts above mean sea level. According to 2011 census, the total population of the city is 6,809,970 with a density of population 18172 persons per sq. km. Hyderabad is one of the cities of India with greater population growth and has potential to become the cyber capital of India. Yet the city's most pressing problems are shortage of water, ground water depletion, contamination of water bodies due to industrial effluents and sewage water, loss of green cover, housing congestion, air and noise pollution, illegal occupation of lakes and other water bodies, submergence due to rainwater etc. Hence the study area has become environmentally more vulnerable city. To understand and address these issues, studies on LULC and surface runoff are very much needed and helpful. Hence an attempt is made here with the following objectives.

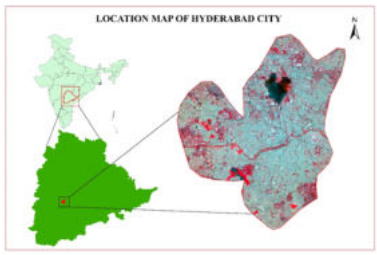

Fig-1

Objectives:

To analyse LULC of Hyderabad metropolitan city for the years 1991 and 2021.

To estimate surface runoff for the years 1987 to 1991 and 2017 to 2021.

DATA:

Land use land cover delineated from the Landsat images in arc GIS by using two cloud-free photos which were collected from LANDSAT 8-9 OLI/TIRS in 2021 and LANDSAT 4-5 TM in 1991, Soil type map has been downloaded from FAO-World soil data, Daily rain fall data downloaded from the website of Water Resource Information System for two time periods i.e., 1987 to 1991 and 2017 to 2021.

METHODOLOGY:

In this study, land use and land cover of the Municipal Corporation of Hyderabad were analysed using Remote sensing and GIS methodologies. Arc GIS was used for supervised classification. ArcGIS 10.4.1 software is utilized for data mapping and analysis. Hydrologic soil group curve number which was developed by the United States Department of Agriculture (USDA) in part 630 National engineering handbook was taken for type of soil present in study area. The SCS-CN method which was developed by the Soil Conservation Service - Curve Number (SCS-CN) method developed by National Resources Conservation Service (NRSC). United States Department of Agriculture (USDA) is simple predictable and stable conceptual method for estimation of direct depth, based on storm rainfall depth. Using LULC map and soil map, SCS-CN method was applied to study the runoff estimation. SCS-CN method developed by USDA used in many of the previous runoff studies worldwide.

RESULTS AND DISCUSSION:

Satellite data were used to interpret the study area's land use and land

cover categories. Table 1 displays the land cover and land use in the research area for the years 1991 and 2021. Primarily, it consists of Settlements (51.69% in 1991 and 74.03% in 2021), Barren Land (32.92% in 1991 and 15.75% in 2021), Vegetation (11.7% in 1991 and 7.42% in 2021) and Waterbodies (3.6% in 1991 and 2.79% in 2021). The study area is predominantly covered by the impervious surface area, where most of the direct surface runoff occurs.

Table 1: LAND USE LAND COVER OF HYDERABAD CITY

CLASS	1991		2021	
	AREA IN Sq.Km	AREA IN %	AREA IN Sq.Km	AREA IN %
Waterbodies	6.54	3.6	4.97	2.79
Vegetation	20.86	11.7	13.22	7.42
Barren land	58.66	32.92	28.06	15.75
Settlements	92.11	51.69	131.91	74.03
Total	178.18	100	178.18	100

SCS Curve Number Method

The most commonly used empirical method is the Soil Conservation Service Curve Number (SCS-CN) method to estimate the direct runoff from a watershed (USDA, 1972). The estimation of run-off using GIS based SCS-CN method is used here to study surface runoff in Hyderabad metropolitan city. The SCSCN method explaining the water balance equation can be expressed as below

$P = Q + F + Ia$ ..... (1)
$Q / P - Ia = F/S$ ..... (2)
$Q = (P - Ia)2 / (P - Ia) + S$ ..... (3)
where, P = Total precipitation (mm),
Q = Actual runoff (mm),
F = cumulative infiltration (mm),

Ia = Initial abstraction (mm) which represents all losses before the runoff begins and is given by empirical equation
$Ia = 0.2\,S$ ..... (4) Substituting in equation 3
$Q = (P - 0.2S)2 / (P + 0.8S)$ ..... (5)

Where S = potential maximum retention (mm) after the runoff begins in the watershed and is given by empirical equation
$S = 25400/CN - 254$ ..... (6)

Where CN is the curve number estimated using antecedent moisture condition (AMC) and hydrological soil group (HSG). The CN is a relative measure of retention of water by given soil vegetation complex and taken on valves from 0 to 100. HSG is expressed in terms of four groups (A, B, C and D), according to the soil after prolonged wetting (Table 2).

Table 2: HYDROLOGIC SOIL GROUPS FOR SOIL TECTURE

HSG	Soil textures
A	Sand, loamy sand, or sandy loam
B	Silt loam or loam
C	Sandy clay loam
D	Clay loam, silty clay loam, sandy clay, silty clay, or clay

Source: Part 630 National engineering handbook developed by the United States Department of Agriculture.

According to the data which was provided by FAO World soil data there is only one type of soil that is Clay in the study area (Fig. 2). Based on the hydrological soil group table, the study area consists of 'D' type of hydrologic soil group (HSG). The analysed values of HSG with Curve Number of the study area are also presented in Table 3 & 4.

Table 3: HYDROLOGIC SOIL GROUP CURVE NUMBER FOR 1991

Land cover type	Condition	CN
Woods-grass combination	Good	79
Crop residue cover	Good	90
Commercial and business Industrial	-	95

Table 5: CURVE NUMBER OF HYDROLOGIC SOIL GROUP

LULC	Soil	HSG	CN For 1991	CN For 2021	CN=∑ CN*Area/Total Area	
					1987 1991	2017-2021
Vegetation	Clay	D	79	86	87.99	91.51
Barren land		D	90	94		
Settlements		D	95	95		

Table 4: HYDROLOGIC SOIL GROUP CURVE NUMBER FOR 2021

Land cover type	Condition	CN
Woods-grass combination	Poor	86
Bare Soil	-	94
Commercial and business Industrial	-	95

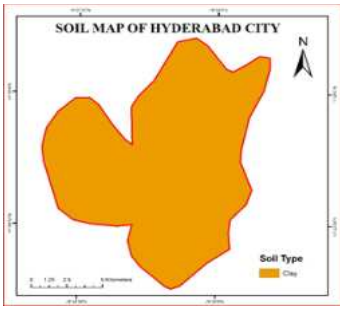

Fig-2

Based on the curve number provided by USDA for each type of land cover average curve number has been calculated for the types of land cover in study area by using the formula which is shown in table 5

ANTECEDENT MOISTURE CONDITION

The water content of the soil at a specific moment is referred to as the antecedent moisture condition. Runoff was significantly influenced by the antecedent soil moisture state, and an increase in value indicated an increase in runoff. In accordance with soil conditions and rainfall constraints for the dormant and growth seasons, the Soil Conservation Service (SCS) produced three antecedent soil moisture conditions, or AMC 1 (Dry), AMC 2 (Average), and AMC 3 (Wet). These conditions are displayed in Table 6.

Table 6: ANTECEDENT MOISTURE CONDITION

Formula	1987-1991	2017-2021
CN II =∑ CN*Area/Total Area	87.99	91.51
CNI=4.2*CNII/10-(0.058*CNII)	75.47	81.9
CNIII=23*CNII/10+(0.13*CNII)	94.39	96.12
Average	85.95	89.84

The daily rainfall data from 1987 to 1991 and 2017 to 2021 (collected from the Water Resource Information System website) were used to estimate the runoff of the study region for two distinct time periods, and the weighted curve number of Hyderabad city was computed. The monthly and annual runoff values are derived from the daily runoff results. Hyderabad's yearly rainfall and runoff for the years 1987 to 1991 and 2017 to 2021 are displayed in Table 7&8. Data indicates that the mean annual rainfall of Hyderabad city between 1987 and 1991 was 886.95 mm, while between 2017 and 2021 it is 948.06 mm.

Table 7: RUNOFF OF HYDERABAD CITY FROM 1987 TO 1991

Year	Actual Rainfall in mm	CN	S = (25400/CN)-254	Ia = 0.2s	Q = (P – 0.2S)2 / (P + 0.8S)	Runoff in percentage
1987	962.1	85.95	41.52	8.3	914.01	95
1988	836.86				789.02	94.38
1989	812.74				764.96	94.12
1990	995.74				947.59	95.16
1991	827.35				779.53	94.22
Average	886.95				839.022	94.57

The annual rainfall of Hyderabad city in the year 1987 is 962.1 mm and runoff is 914.01, which is 95% of total annual rainfall; in 1988, there is total rainfall of 836.86 and runoff is 94.38% of total annual rainfall, which is 789.02 mm; and in 1989, the annual rainfall is 812.74 mm and the runoff is 764.96 mm, which is 94.12% of total rainfall; in 1990, the annual rainfall is 995.74 mm, and the runoff is 947.59 mm, which is 95.16% of total rainfall; and in 1991, the annual rainfall is 827.35 mm,

with the runoff being 779.53 mm, which is 94.22% of total rainfall. The runoff for the five years from 1987 to 1991 is roughly equal.

Table 8: RUNOFF OF HYDERABAD CITY FEOM 2017 TO 2021

Year	Actual Rainfall in mm	CN	S = (25400/ CN)-254	Ia = 0.2S	Q = (P – 0.2S)2 / (P + 0.8S)	Runoff in percent
2017	942.79	89.84	28.72	5.74	909.18	96.43
2018	683.95				650.66	95.13
2019	843.21				809.7	96
2020	1331.82				1297.97	97.38
2021	938.55				904.95	96.42
Average	948.06				914.49	96.27

The annual rainfall of Hyderabad city in the year 2017 was 942.79 mm, and runoff was 909.18 mm, which is 96.43% of total annual rainfall. In 2018, there was total rainfall of 683.95 mm, and runoff was 95.13% of total annual rainfall, which was 650.66 mm. In 2019, 843.21 mm was the annual rainfall and 809.7 mm is the runoff, which is 96% of total rainfall; in 2020, there will be 1331.82mm of annual rainfall, and the runoff will be 1297.97 mm, which is 97.38% of annual rainfall; in 2021, the annual rainfall will be 938.55 mm, and the runoff will be 904.95 mm, which is 96.42% of total rainfall. The runoff of these five years from 2017 to 2021 is also approximately the same, only with a small difference. The average annual runoff of Hyderabad city from 1987 to 1991 was 839.022 mm, which is 94.57% of total annual rainfall, and for 2017 to 2021, it was 948.06 mm, which is 96.42% of annual rainfall. There was a 1.85% (approximately 2%) increase in annual runoff from 1987 to 2021.

CONCLUSION:

The aim of this study is to find the impact of increase in impervious area on runoff between 1991 and 2021. The results of this analysis show that the average annual runoff percentage between 1987 and 1991 was 94.57% and between 2017 and 2021 was 96.27%. There has been a nearly 2% increase in annual runoff in the span of 30 years, with an increase of 22.34% of impervious surface. It also concluded that the SCS-CN number approach combined with GIS can be used for the effective and efficient plan of land use.

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