Rainfall-Runoff Modeling Using NRCS-CN method and GIS approach

Rekha Verma*
Research Scholar
Jamia Millia Islamia,
New Delhi
rkhvrm87@gmail.com

Azhar Hussian
Associate Professor
Jamia Millia Islamia,
New Delhi
azhar_jmi@hotmail.com

Mohammed Sharif
Professor
Jamia Millia Islamia,
New Delhi
msharif@jmi.ac.in

Abstract: Rainfall-Runoff modeling is a hydrological modeling which is extremely important for water resources planning, development, and management. In this paper, Natural Resource Conservation Service-Curve Number (NRCS-CN) method along with Geographical Information System (GIS) approach was used to evaluate the runoff resulting from the rainfall of four stations, namely, Bilodra, Kathlal, Navavas and Rellawada of Sabarmati River basin. The rainfall data were taken for 10 years (2005-2014). The curve number which is the function of land use, soil and antecedent moisture condition (AMC) was generated in GIS platform. The CN value generated for AMC- I, II and III were 57.29, 75.39 and 87.77 respectively. Using NRCS-CN method, runoff depth was calculated for all the four stations. The runoff depth calculated with respect to the rainfall for Bilodra, Kathlal, Navavas and Rellawada shows a good correlation of 0.96. The computed runoff was compared with the observed runoff which depicted a good correlation of 0.73, 0.70, 0.76 and 0.65 for the four stations. This method results in speedy and precise estimation of runoff from a watershed.

Keywords: *Rainfall-Runoff modelling, NRCS-CN, GIS, Antecedent soil moisture condition (AMC), Curve Number (CN).*

1. INTRODUCTION

Water resources development act as a salient factor in attaining multibranched economic and social development of a country. As the population of India is 16% of the World's population, there exist a great pressure on the use of water to cater the demand of this country. As per the latest estimates of Central Water Commission, Indian river systems cluster up to 1800 km^2 accounting 4% of the World's total annual flows. Over the last few decades, there has been a substantial progress in the development and management of water resources. This has also led to the exploitation of the water resources resulting in the misuse of surface water and exploitation of the groundwater. This develops a need of proper and efficient water resource planning as a pre-requisite for any development activity.

Rainfall events generates runoff, and this runoff is dependent on the characteristics of the rainfall i.e., duration and intensity of rainfall. Along with this, the basin characteristics like length, soil type, slope, land use and shape of the basin, also have a notable impact on the amount of rainfall. Rainfall-Runoff modeling is a hydrological modeling tool which determines the amount of runoff that leaves the basin/catchment from the rainfall received by the basin. Several methods are available for rainfall-runoff modeling like deterministic model and stochastic models. An empirical relationship was provided by Soil Conservation Services and Curve Number (SCS-CN) method for computing runoff as a function of land use and soil type. SCS-CN is the simplest method for rainfall-runoff modeling. Rainfall runoff relationship can be envisaged by the factors like initial abstraction, actual retention, and direct runoff.

SCS-CN method was developed in 1954 by the U.S Department of Agriculture and was documented in National Engineering handbook (NEH-4) section 4 published by the Soil Conservation Service in 1956 (USDA, 1985 and TR-55, 1986). SCS-CN method converts the rainfall into surface runoff by making use of curve number, derived on the basis of the basin characteristics. SCS-CN method is known as NRCS-CN (National Resource Conservation Service-Curve Number) method. Curve number is an index developed by the NRCS and depends upon the land use, soil type and antecedent soil moisture condition (AMC). The curve number range between 0 to 100. Higher CN values represent higher runoff potential and vice-versa. Many research have been done to estimate the curve number by using Geographic Information System (GIS). Ara et al., (2018) used modified SCS-CN method to estimate runoff considering parameters like vegetation cover, slope, watershed area. Gajbhiye et al., (2017) generated the curve number of Kanhaiya nala watershed by making use of GIS platform and also considered the effect of slope. Kumar et al., (2017) estimated the surface runoff of a catchment using SCS-CN method. Viji et al., (2015) calculated runoff in Kundahpalam watershed considering curve number aa the prime factor for AMC. Ahmad et al., (2015) divulged that GIS based SCS-CN method are capable to be used efficiently to calculate runoff from the watershed having similar geo-hydrological characteristics. Garg et al., (2013) determined the runoff potential in geo-spatial environment by modifying NRCS-CN method for slope. Nayak et al., (2012) showed that a good correlation exists between the estimated and observed runoff depth using CN and GIS. Gajbhiye et al., (2012) determined the runoff depth using NRCS-CN method with GIS and the effect of slope on runoff generation. Pandy et al., (2002) identified the land use/land cover as an important parameter in SCS-CN. Sharma et al., (2001) deliberated the hydrologic response of a watershed to the changes in land use pattern using GIS and remote sensing. Gangodagamage et al., (2001) applied GIS and remote sensing technique for hydrological modelling.

The objective of this study is to estimate the runoff from the study area using NRCS-CN method with GIS environment and remote sensing. The estimated runoff was compared with the observed runoff in the watershed to ascertain the use of NRCS-CN method for the calculation of runoff.

2. STUDY AREA AND SOURCE OF DATA

Sabarmati River is a major river of India which flows in the west. The Sabarmati river basin extends over the states of Rajasthan and Gujarat over an area of 21,674 Sq. km with maximum length and width of 300 km and 150 km respectively. It lies between 70°58’ to 73°51’ east and 22°15’ to 24°47’ north. The basin has been divided into 2 sub-basins-Sabarmati Upper Sub-Basin covering about 64.58% of the total area and Lower sub basin covering 35.42% of the total geographical area of the basin. Four stations of Sabarmati river basin were considered for the study, namely, Rellawada, Kathlal, Bilodra, and Navavas. The location of the study area is shown in Fig.1. The data required for the modelling were Digital Elevation Model, Land Use, soil map and meteorological data. The source of the data acquired in this study is shown in Table-I.

3. METHODOLOGY

The methodology adopted in this study is shown in the Fig.2. To determine the direct runoff, SCS-SN method was used. The steps are explained below-

Generation of Curve Number

The watershed was delineated from SRTM DEM using ArcGIS with ArcHydro tool as an extension tool. The land use map for the delineated watershed was extracted from the LULC decadal map. The land cover was reclassified into four categories- water bodies, medium residential, forest and agricultural as shown in the Fig.3. The dominate class of land use all over the watershed is agricultural land sheathing79.94% of the entire basin area.

The soil map for the watershed was extricated from FAO soil portal. The soil data was classified into four hydrologic soil group i.e., A, B, C ana D based on their properties (Table-II).

Most of the area of the watershed has loamy soil which falls in HSG B category as shown in Fig.4.

The land use and soil map are intersected together. After intersection, a new map with new polygon representing the merged land use and soil hydrologic group was created. A CN grid was generated for the entire watershed in which each polygon was assigned an appropriate CN value using HEC-GeoHMS tool in ArcGIS. Natural Resource Conservation Service (NRCS) developed an index known as Curve Number (CN), to represent the anticipated quantity of storm water runoff from a watershed. The CN value range from 0 to 100. These curve number were obtained from SCS TR55 (1986) (USDA, 1985 and TR-55, 1986). The weighted curve number was calculated by use of area-weighting from the land use-soil group of each polygon within the basin area using Eq.1. The curve number thus obtained is for AMC–II.

$$CNw = \sum_{i=1}^{n} \frac{(CNi * Ai)}{A} \qquad (1)$$

Where CNw = Weighted Curve Number

CNi = Curve number from 1 to any number ‘n’

Ai = Area having Curve number CNi

A = Total basin area.

Antecedent Soil Moisture Condition (AMC)

AMC is an indicative of the moisture/water content available in the soil at the onset of the rainfall event. In order to determine the curve number variation in a watershed, AMC is an important factor to be considered. Three antecedent soil moisture condition namely, AMC I, AMC II and AMC III were documented by SCS. This AMC classification is based on the magnitude of the rainfall of five days prior to the rainfall event for dormant season and growing season as shown in the Table-III.

To convert the CN values of the watershed from AMC-II to AMC-I and AMC-III, the following conversion formulas are used (SCS,1972)-

$$CN(I) = \frac{CN(II)}{2.281 - 0.0128\, CN(II)} \qquad (2)$$

$$CN(III) = \frac{CN(II)}{0.427 + 0.00573\, CN(II)} \qquad (3)$$

Calculation of Surface Runoff

To estimate the direct runoff resulting from the rainfall from the watershed, USDA Soil Conservation Service developed a method known as Soil Conservation Service-Curve Number (SCS-CN) in 1954. The NRCS-CN method formerly known as SCS-CN method is formed on the basis of water balance equation and consists of two fundamental hypotheses. The first hypotheses relate to the ratio of the quantity of direct surface runoff to the maximum possible quantity of runoff is equal to the ratio of the amount of infiltration to the potential maximum surface retention. The second hypotheses relate to the proportion of initial abstraction to the maximum potential surface retention [12,13,14].

$$P = Ia + F + Q \tag{4}$$

$$\frac{Q}{P-Ia} = \frac{F}{S} \tag{5}$$

$$Ia = \lambda S \tag{6}$$

Where P = Precipitation (mm), F = Cumulative Infiltration excluding Ia, S = Potential maximum surface retention (mm), Ia = Initial abstraction (mm), Q = Direct surface runoff (mm), and λ= Initial abstraction ratio taken as 0.2. By combining Eq.4 and 5, an expression for Q is given:

$$Q = \frac{(P-Ia)^2}{(P+S-Ia)} \tag{7}$$

By substituting *Ia = 0.2S* in Eq.7, the expression for Q can be written as-

$$Q = \frac{(P - 0.2S)2}{(P + 0.8S)} \tag{8}$$

This Eq.8 is valid for P > Ia, otherwise Q = 0. Potential maximum retention (S) can be calculated by using the expression-

$$S = \frac{25400}{CN} - 254 \tag{9}$$

where, CN = Curve Number.

4. RESULTS AND DISCUSSION

The watershed was delineated using SRTM DEM. The land use and soil maps were processed using GIS platform to generate CN grid. The resulted CN grid is shown in the Fig.5.

The weighted curve number was worked out for AMC-II condition and CN value for AMC-I and AMC-III were calculated using equation (2) and (3) as shown in Table-IV. The curve number for AMC-I, AMC-II and AMC-III comes out to be 57.29, 75.39 and 87.77 respectively.

Runoff Depths

The daily rainfall values and the generated CN value was used as input data in NRCS-CN model to work out the corresponding runoff depths. The runoff depths for all the selected stations were estimated using Eq.8 for a period of 10 years (2005 – 2014). The runoff depth for the rainfall events whose intensity were less than initial abstraction (0.2S) were considered zero. The annual rainfall and the estimated annual runoff for Rellawada, Bilodra, Kathlal and Navavas stations is shown in the Table-V.

The graphical representation of rainfall and the corresponding calculated runoff for the four stations for 10 years is shown in Fig.6.

The scatter plot showing the correlation between rainfall and the estimated runoff using NRCS-CN method for all the four stations is shown in Fig.7. There exists a good correlation between the rainfall and the calculated runoff.

The calculated runoff depth was compared with the observed runoff depth. The scatter plot showing the correlation between the estimated runoff and observed runoff for all the four stations is shown in Fig.8. The result shows a good correlation between the simulated and the observed runoff. The coefficient of determination value comes out to be 0.65, 0.73, 0.7 and 0.76 for Rellawada, Bilodra, Kathlal and Navavas station respectively. Remote sensing and GIS with application of NRCS-CN model proves to be a powerful tool in estimation of runoff. NRCS-CN method based on GIS environment will help the researchers in the preservation of water resources in the watersheds. This method facilitates speedy and more precise estimation of runoff from a watershed.

5. CONCLUSION

The runoff depth for Bilodra, Kathlal, Navavas and Rellawada were calculated using NRCS-CN method. The estimated runoff was compared with the observed runoff which depicted a good correlation having the value of coefficient of determination as 0.73, 0.70, 0.76 and 0.65 respectively. GIS emerges as an efficient tool in the devising of most of the input parameters necessary for NRCS-CN method. It may be culminated that the rainfall intensity, land use pattern, soil type, AMC to be considered as prime factors in estimating surface runoff. NRCS-CN method with GIS and remote sensing can be successfully and efficiently used for land use planning and water resource management.

6. DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from SWDC, Gandhinagar, India. Restrictions apply to the availability of these data, which were used under license for this study. Data are available at https://swhydrology.gujarat.gov.in/ with the permission of SWDC, Gandhinagar.

REFERENCES

Ahmad, I., Verma, V., & Verma, M. K. (2015, January). Application of curve number method for estimation of runoff potential in GIS environment. In *2nd international conference on geological and civil engineering* (Vol. 80, No. 4, pp. 16-20).

Ara, Z., & Zakwan, M. (2018). Estimating runoff using SCS curve number method. *Int J Emerg Technol Adv Eng*, *8*, 195-200.

Gajbhiye, S., & Mishra, S. K. (2012, March). Application of NRSC-SCS curve number model in runoff estimation using RS & GIS. In *IEEE-International conference on advances in engineering, science and management (ICAESM-2012)* (pp. 346-352). IEEE.

Gangodagamage, C., & Agrarwal, S. P. (2001). Hydrological modeling using remote sensing and GIS. In *22nd Asian Conference on Remote Sensing* (Vol. 5).

Garg, V., Nikam, B. R., Thakur, P. K., & Aggarwal, S. P. (2013). Assessment of the effect of slope on runoff potential of a watershed using NRCS-CN method. *International Journal of Hydrology Science and Technology*, *3*(2), 141-159.

Meshram, S. G., Sharma, S. K., & Tignath, S. (2017). Application of remote sensing and geographical information system for generation of runoff curve number. *Applied Water Science*, *7*(4), 1773-1779.

Nayak, T., Verma, M. K., & Bindu, S. H. (2012). SCS curve number method in Narmada basin. *International Journal of Geomatics and Geosciences*, *3*(1), 219-228.

Pandey, A., & Sahu, A. K. (2002). Generation of CN using RS and GIS. *http//www. gisdevelopment. net*.

Satheesh kumar, S., Venkateswaran, S., & 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), 24.

Sharma, T., Kiran, P. S., Singh, T. P., Trivedi, A. V., & Navalgund, R. R. (2001). Hydrologic response of a watershed to land use changes: a remote sensing and GIS approach. *International Journal of Remote Sensing*, *22*(11), 2095-2108.

Subramanya, K. (2013). *Engineering Hydrology, 4e*. Tata McGraw-Hill Education.

USDA, S. (1985). Hydrology, National Engineering Handbook, Section 4. *US Department of Agriculture, Washington, DC, USA*.

USDA, S. (1986). Urban hydrology for small watersheds. *Technical release*, *55*, 2-6.

Viji, R., Rajesh Prasanna, P., & Ilangovan, R. (2015). Gis based SCS-CN method for estimating runoff in Kundahpalam watershed, Nilgries District, Tamilnadu. *Earth Sciences Research Journal*, *19*(1), 59-64.