ISSN: 0974-5823 Vol. 7 No. 1 January, 2022

International Journal of Mechanical Engineering

Runoff estimation from Kshipra river basin using SCS-CN method

Parikshit Joshi[1,*] and Dr. Jayesh Juremalani[2]

[1]*Research Scholar , Dept. of Civil Engineering, PIET, Parul University, Vadodara, Gujarat-391760, India.*

[2] *Associate Professor, Dept. of Civil Engineering, PIET, Parul University, Vadodara, Gujarat-391760, India.*

Abstract: The goal of this study is to find watersheds with high flood potential based on their features for surface runoff generation. A land use map was created by combining Landsat 7 ETM+ image bands 2, 3, and 4 (30m) with PAN band 8 (15m) for classification. For the construction of the land use map, the supervised maximum likelihood classification approach was used. Kshipra river basin geographical coverage is 5661.24 km^2. Agriculture (87.0 %), forest (1.18 %), wasteland (4.78 %), built-up (4.87 %), and water bodies (1.28 %) were the major land use categories classified on the 10 November 2017 Landsat 7 ETM+ image. The hydrological soil groups generated in the GIS environment have identified two soil groups that exist in the study area, namely group C and group D. Using DEM and stream network, the Kshipra river catchment has been divided into 22 watersheds. For each sub-watershed, the SCS-CN model was used to estimate run-off. According to the flood potential analysis, sub-watershed no. 19 has the greatest flood potential, while sub-watershed no. 7 has the least. Forty years rainfall data from 1980-2020 has been used for run-off calculation for 22 sub- basin. The relationship was fitted through 2nd order polynomial between rainfall and runoff for all 22 sub-basin and a high correlation was observed ($R^2 = 0.99$). The flood potential analysis in the Kshipra river basin tributary demonstrates that the SCS-CN method can be used to predict run-off in poorly gauged watersheds utilising hydrological parameters acquired from remote sensing and GIS data.

Keywords: Remote sensing, GIS, Landsat 7 ETM+, Runoff, SCS-CN technique.

1. Introduction

The draining or flowing off of precipitation from a catchment area through a surface channel is referred to as runoff. As a result, it represents the catchment's output in a given unit of time. The climatic, geomorphological, topographical, and landuse aspects of a catchment or watershed all influence surface runoff generation. The importance of topographical factors and soil types with land use as a hydrological soil group has been emphasized above. A watershed's flood potential is increased by a mix of features that favor runoff formation and concentration. Because they lack comprehensive records of runoff generation during a rainfall event to understand the hydrological response, most watersheds in India have been poorly gauged or un-gauged. In flood-prone catchments, each watershed's peak flood flow or flood potential must be calculated. There are several ways for estimating discharge in the literature, including the Rational method, the Soil Conservation Service- Curve Number (SCS-CN) method, Cook's method, and the Unit hydrograph method. The SCS-CN approach, on the other hand, is critical for predicting direct runoff or discharge from an ungauged watershed's rainfall excess.

Sindhu et al. (2013) used the SCS-CN approach to estimate surface runoff in the Nallur Amanikere Watershed. They discovered differences in runoff potential with varied land uses/covers and soil conditions.

Sharma et al. (2016) used the SCS-CN approach in conjunction with remote sensing and GIS data to estimate runoff from a tributary of the lower Tapi basin. A 30m raster grid size digital elevation model (DEM) was created from a field survey utilising a 3m accuracy Global Positioning System (GPS) and Survey of India topographical maps at a scale of 1:50,000 with a 10m contour interval. This aided in the creation of a hydrological soil map, and a land use map was created by combining Landsat 7 ETM+ image bands 2, 3, and 4 (30m) with PAN band 8 (15m) for classification. The results of a common event in 2010 were validated using stream gauge data, which showed high agreement with the model.

Aherwar and Aherwar (2018) have developed SCS-CN model to study the hydrological behavior of the Kshipra river. The models were evaluated on the basis of coefficient of determination (R^2), coefficient of correlation (r), Nash-Sutcliffe Efficiency and Root Mean Square Error. The estimated or simulated values were compared with the observed data which showed good consistency. The SCS-CN model showed Nash-Sutcliffe efficiency is 72%, coefficient of determination R2 values 0.616, coefficient of correlation is 0.78 and Root Mean Square Error is 83.09 which were satisfactorily close to the observed values. The study of the model indicates that the SCS-CN model is suitable for the hydrological study of the Kshipra river basin of Madhya Pradesh in India.

2. Study Area

The Kshipra, also known as the Kprshia or Avanti nadi, is a river in Madhya Pradesh state of central India. The river rises in the North of Dhar district, and flows north across the Malwa Plateau to join the Chambal River at the MP-Rajasthan boundary in Mandsaur district (Figure 1). Its nominal source is on the KokriBardi hill, 20km south-east of Indore near the small village of Ujeni. The holy city of Ujjain is situated on its east bank. Every 12 years, the Sinhastha fair (Kumbh Mela) takes place on the city's elaborate riverside ghats. The river navigates through four districts namely Dewas, Indore, Ujjain, and Ratlam. The majority of the Kshipra basin area falls in Indore and Ujjain districts however small part come under Ratlam and Dewas districts. The Kshipra River is located at an average altitude of 553 metres above Mean Sea Level. Length of Kshipra river is 195 km and basin covers a geographical area of 5661.24 km^2 (Figure 2). The watershed consists of Kshipra dam as a major surface water reservoir which is located in the study area. The research area lower left and upper right corners are located at 22.5'N 75'E and 24'N 76.5'E, respectively. The average annual rainfall in the study area is 731 mm.

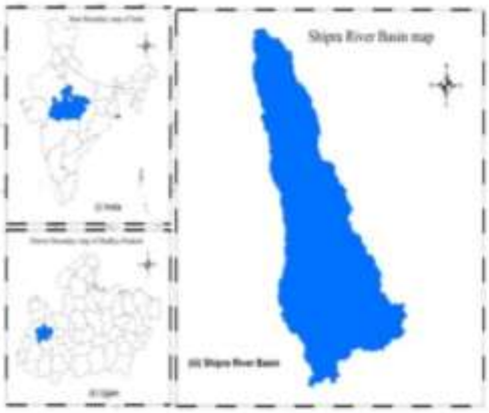

Figure 1. Study area

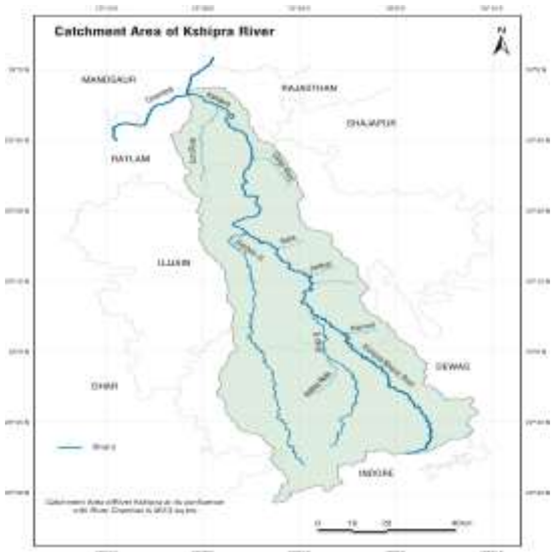

Figure 2. Catchment area

3. Methodology

Subwatershed delineation, land use map and hydrological soil group map production, CN calculation, and run-off estimation are the five processes in the research approach used to estimate surface run-off using the SCS-CN method. Figure 3 depicts the methodology flow chart.

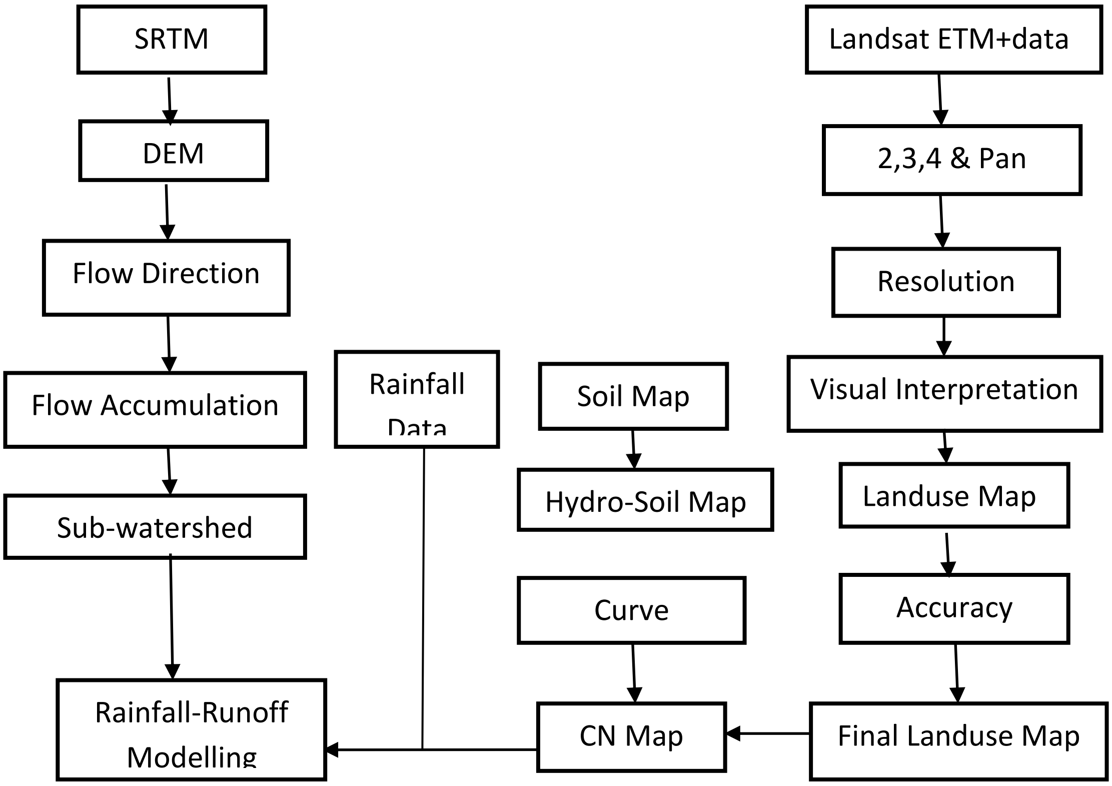

Figure 3. Flow chart of methodology

3.1 Watershed delineation

Using the ARC GIS hydrological model, 22 watersheds for the Kshipra river basin were delineated using a DEM with 30m raster cell size and 0.5m vertical precision (Figure 4). The steps are: I creating a depressionless DEM; (ii) calculating flow direction using the 3x3 cell neighbourhood algorithm; (iii) calculating flow accumulation and identifying cells with a given area; and (iv) delineation of watershed outlet points leading to sub-watershed delineation for a given threshold area. DEM was used to get watershed metrics such as flow length, river length, watershed outlet point, watershed area, river length, and river slope (Figure 5).

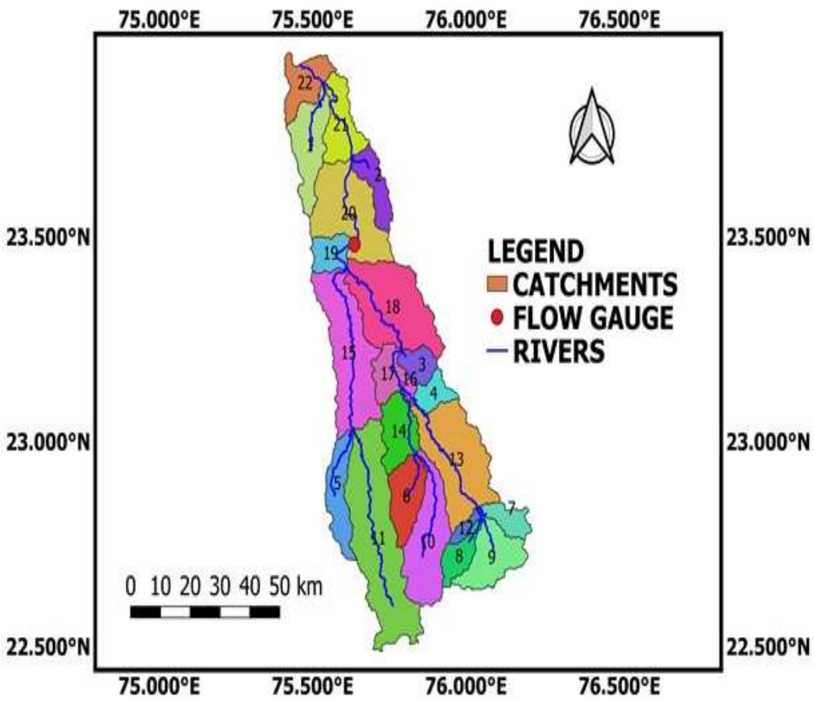

Figure 4 :Kshipra river sub-basins

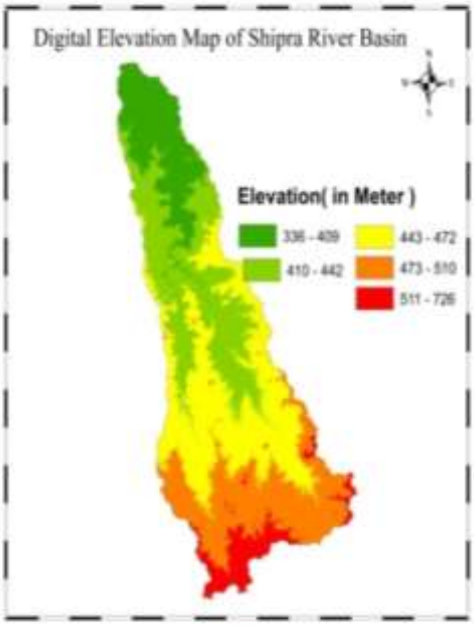

Figure 5: Digital Elevation Model (DEM)

3.2 Generating landuse map

Image analysis of satellite data was used to create the land use map of the Kshipra watershed. The image of Landsat 7 ETM+ (10 November 2017) bands 2, 3, 4 with a spatial resolution of 30 metres and PAN with a ground resolution of 15 metres was analysed.

The land use map was created using the Gaussian maximum likelihood approach of supervised classification with a field sample after image geometric rectification. Built-up land, farmland, forest, water bodies, and other land use categories are included in the study region, as illustrated in figure 6, and their data are given in table 1. Land use description as an input for the runoff generation process using the SCS-CN approach. Using SCS (1985) land use descriptions, hydrological soil types, and AMC conditions, the CN can be estimated empirically

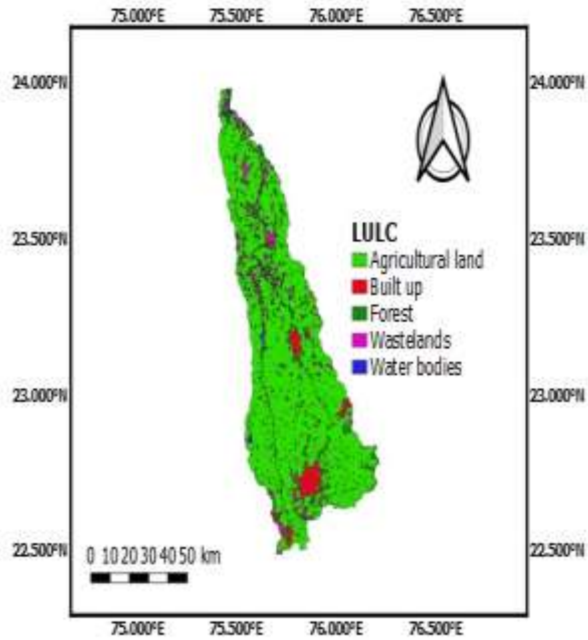

Figure 6: Land use map

3.3 Generating hydrological soil group map

To create hydrological soil group map, soil maps of study area were collected from Bhuvan, ISRO. Area of interest has been extracted from theses maps. On analysis, it was found that there are two types of soil in study area, namely group C and D. Class C belongs to Sandy clay loam of which very few patches were seen and most of the soil belongs to Class D which denotes Clay loam, silty clay loam, sandy clay, silty clay or clay.(Figure 7)

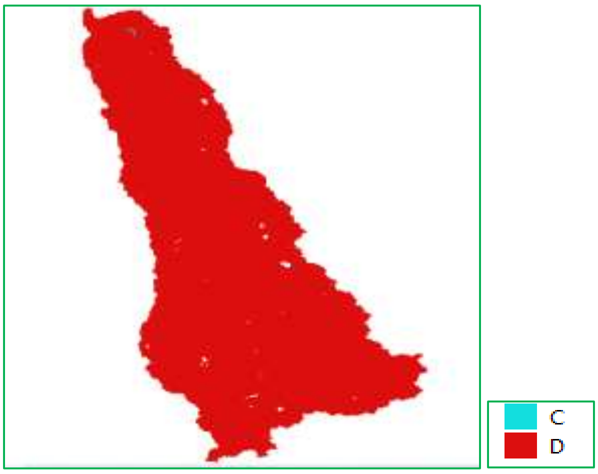

Figure 7 Hydrological soil group map

3.4 Generating CN map

The CN value was used to calculate the maximum possible soil retention. The value of CN is 100 for impervious surfaces and between 0< CN≤100 for other surfaces. Land use, hydrological soil group, hydrological condition, and AMC all influence the maximal possible storage of CN (Ponce and Hawkins, 1996). The CN map of 22 sub-watersheds was created using the Arc CN module of ArcGIS programme. Under a vector environment in GIS, the hydrologic soil group field from the soil map and the land use field from the land use map were selected for intersection. Following the intersection, a new map (land-soil map) was created with new polygons representing the united soil hydrologic group and land use.

3.5 Run-off estimation

The SCS-CN method implies that surface runoff will occur once initial losses are met. Using the SCS CN approach, Equation 1 can be utilized to explain the water balance. The main hypothesis of this method is that the ratio of direct runoff to rainfall depth minus initial losses (P- Ia) equals cumulative infiltration, as illustrated in equation 2 (Mishra and Singh, 2003).

$$P = Q + F + Ia \ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (1)$$

$$Q / (P-I_a) = F / S \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where P is total precipitation in millimetres, Ia denotes initial abstraction in millimetres, F denotes cumulative infiltration in millimetres, and Q denotes direct runoff in millimetres. S is the soil's maximum possible retention or storage capacity (mm). As stated in equation 3, the initial abstraction (mm) is considered to represent an abstraction fraction (typically 0.2) of the probable maximum retention according to USDA-SCS (1985) recommendations.

$$I_a = \lambda .S \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (3)$$

The direct storm runoff Q (mm) can be related to the effective rainfall and actual retention through the water balance equation 4 (Yu, 1998). Equation 4 is valid only

When $P \geq \lambda$ S and generally $I_a = 0.2S$, hence equation 4 can be written as;

$$Q_p = (P-I_a)^2 /(P-Ia+S)$$

$$= (P-0.2S)^2 /(P+0.8S) \ldots\ldots\ldots (4)$$

If effective rainfall $P \leq \lambda$ S, then direct storm runoff Q (mm) is taken as zero.

In practice, the potential maximum retention S (mm) of the soil is determined using the CN given in equation 5.

$$S = (254400/CN) – 254 \ldots\ldots\ldots\ldots.. (5)$$

The term CN is calculated using a table that takes into account land use, hydrological soil group, and antecedent moisture content (AMC). Based on landuse, hydrological soil group, and AMC, the hydrological soil group is divided into four classes: A, B, C, and D. Based on soil infiltration rate, the hydrological soil group is divided into four classes: A, B, C, and D. According to the rainfall limits for sowing and growing season, AMC is divided into three classes: I, II, and III.

4. Results and discussion

Land use, soil type, hydrological soil group, and CN all influence direct storm runoff. For supervised categorization of five land use classifications, Landsat 7 ETM+ data from 10 November 2017 was used. For categorization, a Landsat 7 ETM+ band 2, 3, 4 of 30m cell size was combined with a PAN band of 15m spatial resolution. The land use distribution within the Kshipra catchment reveals that it is largely an agriculture catchment, with agriculture accounting for 87.90 percent of the study area and the remaining land falling into other groups (Table 1).

Table 1: Area of LULC Classes

LULCTYPE	AREA (Km^2)	%
Agricultural Land	4845.905	87.90
Built up Area	268.2812	4.87
Forest	64.9044	1.18
Waste Lands	263.538	4.78
Water Bodies	70.3252	1.28
Total	**5512.954**	**100**

Table 2: Estimation of runoff for each watershed

Sub-Basin Id	Area (km^2)	Weighted CN	Rainfall (mm)	Runoff (mm)
1	263.00	74.04	217.86	213.71
2	138.58	73.68	251.28	247.05
3	96.07	73.87	216.34	212.15
4	89.80	73.38	229.10	224.80
5	201.87	73.14	268.47	264.11
6	211.39	73.19	267.02	262.68
7	97.92	71.61	191.47	186.79
8	110.94	73.11	208.43	204.08
9	255.14	72.82	202.16	197.75
10	403.27	73.26	218.77	214.45
11	806.96	73.60	286.83	282.57
12	40.40	73.11	208.43	204.08
13	538.15	72.96	280.24	275.84
14	203.37	73.14	226.56	222.22
15	547.81	73.80	219.51	215.31
16	21.56	74.03	205.62	201.47
17	126.89	73.25	229.14	224.81
18	541.17	73.95	195.80	191.64
19	112.37	74.47	291.75	287.67
20	467.24	74.43	258.24	254.16
21	213.91	74.23	214.76	210.65
22	173.44	74.38	229.60	225.52

The percentage flood contribution for each sub-watershed was estimated using the volume and surface runoff values presented in table 2.

Sub-watershed no. 19 has a high potential for flooding, while sub-watershed no. 7 has a low chance for flooding. Flooding potential is determined by CN, which is determined by the land use and soil parameters of the watershed, as shown in the results. After losses from evaporation, absorption, transpiration, and surface storage, a coefficient must be estimated that decreases total rainfall to runoff potential. It is reasonable to conclude that the higher the CN value, the greater the runoff generation.

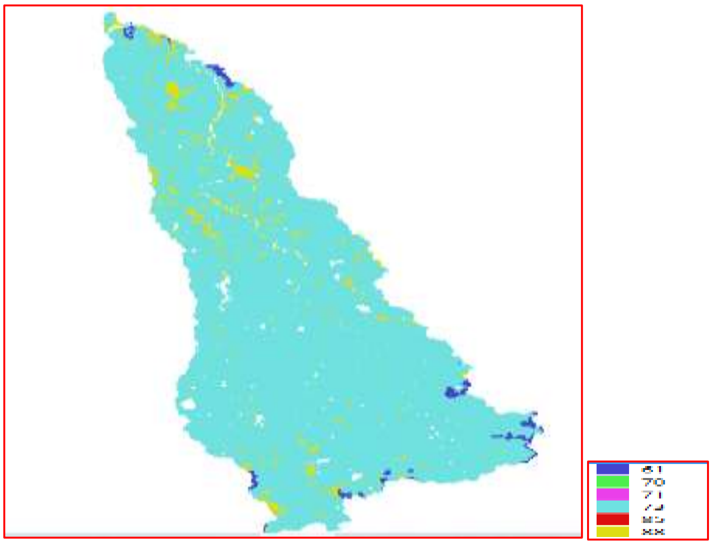

Figure 8: Curve number map

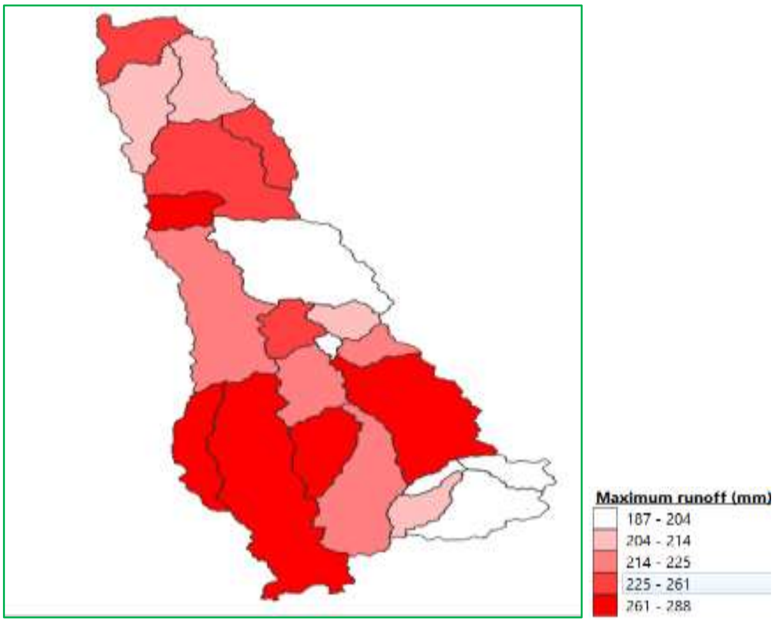

Figure 10 Maximum runoff depth

Forty years rainfall data from 1980-2020 has been used for run-off calculation for 22 sub- basin. Runoff depth value calculated for each grids from the equation. Figure 10 depicts the distribution of runoff depth. The relationship was fitted through 2nd order polynomial between rainfall and runoff for all 22 sub-basin and a high correlation was observed (R^2=0.99). Rainfall v/s Runoff plot shows good fit as shown below in figure 11. It reveals that CN Method hold good for hydrological analysis of Kshipra river basin.

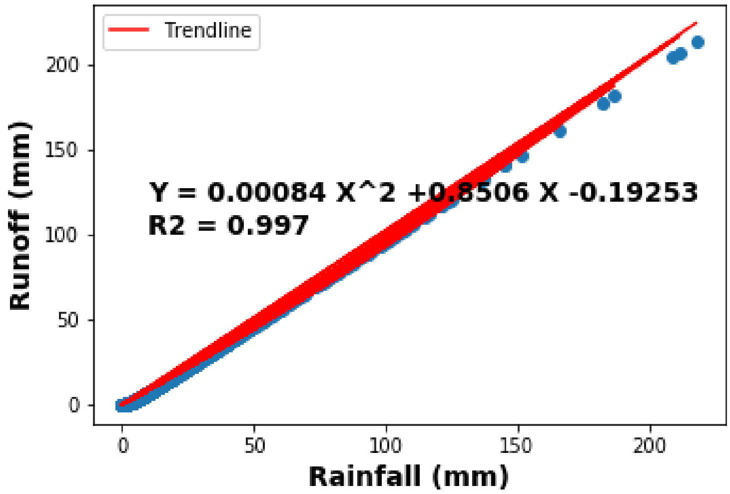

Figure 11: Rainfall v/s Runoff relationship

5. Conclusions

When traditional runoff estimation approaches fail, remote sensing and GIS data come in handy for estimating surface runoff. Both methods were used to generate model input for determining physical characteristics of the watershed, such as land use, hydrological soil group, and CN number. The classification of land use was done using a Gaussian maximum likelihood classifier, which has strong field acceptability. It has been used with the SCS-CN approach for watershed identification and flood potential estimation in the Kshipra basin. For rainfall runoff modelling, this analysis yields satisfactory results. It will be beneficial for flood forecasts, each watershed's flood contribution, and flood discharge measurements. The method could be useful for estimating runoff in ungauged catchments.

References

1. Aherwar, P., and Aherwar H, (2018). Rainfall runoff simulation by using SCS-CN model in Kshipra river basin of Madhya Pradesh, India. *The Pharma Innovation Journal* ; 7(12): 385-390.
2. Balvanshi, A. and H.L. Tiwari (2014). A comprehensive review of runoff estimation by the curve number method. International Journal of Innovative Research in Science, Engineering and Technology, Vol.3 (11), pp17480-17485.
3. Behzad, A., R.S. Mohsmmsd and E. Moghimi (2012). Estimating flood potential emphasizing on geomorphologic characteristics in Tarikn basin using the SCS method. European Journal of Experimental Biology, Vol. 2 (5), pp 1928-1935.
4. Katimon, A., M. Zulkifli and M. Yunos (2003). Flood potential estimation of two small vegetated watershed. Journal Kejuruteraan Awam, vol 15 (1), pp 1-15.
5. Mishra, S.K. and V.P. Singh (2003). Soil conservation service curve number methodology. Volume 43. Kluwer Academic Publishers, Dordrecht, The Netherlands.
6. Ponce, V.M. and R.H. Hawkins (1996). Runoff curve number: Has it reached maturity? Journal of Hydrologic Engineering, 1(1): 11-19.
7. SCS (1985). National engineering handbook, Section 4: Hydrology, Soil Conservation Service, USDA, Washington, DC.
8. Sharma, K.D. and S. Singh (1992). Runoff estimation using Landsat Thematic Mapper data and the SCS model. Hydrological Sciences 37 (1/2): 39-52.
9. Sharma, S.B., Singh, A.K., and Rajawat, A.S. (2016). Runoff estimation from a tributary of lower Tapi basin using SCS-CN method integrated with remote sensing and GIS data. Journal of Geomatics, 10 (1):29-35.
10. Sindhu D, B.L. Shivakumar, A.S. Ravikumar (2013). Estimation of surface runoff in Nallur Amanikere watershed using SCS-CN method. International Journal of Research in Engineering and Technology (2) pp 404- 409
11. Singh, A.K. and A.K. Sharma (2009). GIS and a remote sensing based approach for urban flood-plain mapping for the Tapi catchment, India. In IAHS Publ. 331, 389- 394. Yu, B. (1998). Theoretical justification of SCS method for runoff estimation. ASCE Journal of Irrigation and Drainage Engineering, 124: 306-310.
12. Zhan, X. and M.L. Huang (2004). ArcCN-Runoff: An ArcGIS tool for generation curve number and runoff maps. Environmental Modelling and Software 19: 875- 879.