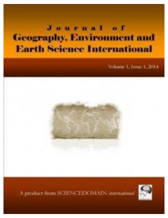

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Surface Runoff Estimation Using SCS-CN Method in Siddheswari River Basin, Eastern India

Hemanta Sutradhar[1*]

[1]Department of Geography, Visva-Bharati University, Bolpur (Santiniketan), India.

Author's contribution

The sole author designed, analyzed, interpreted and prepared the manuscript.

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ABSTRACT

The Soil Conservation Service-Curve Number (SCS-CN) method is one of indirect methods of runoff estimation developed by National Resources Conservation Service (NRSC), United States Department of Agriculture (USDA). The main objectives of the present study are to estimate surface runoff, runoff coefficient of the Siddheswari river basin using SCS-CN method and to predict hydrological scenario of the basin based on the surface runoff conditions with the aid of Remote Sensing (RS) and Geographical Information System (GIS).The result shows that the very high annual runoff found in the middle and lower catchment and high runoff concentrated in southern portion of the catchment mainly because of lack of vegetation and uncovered surface but the low runoff concentrated in the middle-northern tip of the basin due dense vegetation cover.

Keywords: Service-Curve Number (SCS-CN); Remote Sensing (RS); Geographical Information System (GIS); runoff.

1. INTRODUCTION

Rainfall (precipitation), the major components of hydrological cycle and the principle source of runoff [1]. The occurrence as well as quantity of runoff are dependent on the characteristics of rainfall events like intensity, duration and distribution and watershed characteristics like

**Corresponding author: E-mail: hemantasutradhar5@gmail.com;*

size, shape, slope, drainage pattern, geology, soil, geomorphology, climatic condition and land use/land cover [2,3] and controlling the hydrological cycle and soil erosion [4]. Soil erosion by running water i.e. through surface runoff has been recognized as one of the severe hazard as it reduces soil productivity by removing the fertile topsoil [5] in this concern estimation of runoff is necessary so that proper prediction of runoff related hazard as well as benefits would be possible for watershed management. To estimate surface runoff depth the Soil Conservation Service-Curve Number (SCS-CN) method developed by National Resources Conservation Service (NRSC), United States Department of Agriculture (USDA) [6,7,1] and described in the Soil Conservation Services (SCS) National Engineering handbook Sect. 4: Hydrology (NEH-4) [8]. The first version of the handbook was published in 1954. Subsequent revision followed in 1956, 1964, 1965, 1971, 1972, 1985 and 1993 [9]. Among several indirect methods of runoff estimation (Manning's equation, Talbot's method, Rational method, Creager's equation etc.) SCS-CN methods is considered as a well-accepted methods because of its simplicity; Predictability and stable conceptual methodologies; required inputs are generally available; relates runoff to soil type, land use/land cover and management practices for estimation of runoff depth [10,11,1] although like other methods this method is not free from some limitations viz. possible sudden jumps in the computed runoff due to using three AMC levels permitting unreasonable sudden jumps in CN, lack of clear guidance on how to vary antecedent moisture conditions, and no explicit dependency between the initial abstraction and the antecedent moisture [12]; the SCS-CN method was not applicable at sub-daily time resolution [13]; the runoff calculated from the SCS method was much more sensitive to the CN chosen than to rainfall depths, intensity [14]. SCS-CN method is highly sensitive to changes in values of its single parameter, CN and it is ambiguous considering the effect of antecedent moisture conditions [15, 16, 17, 14] but despite having some afore mention limitations this methods considered as an effective method of runoff estimation. Actually SCS-CN method estimates the runoff generating from the rainfall or the excess amount of rainfall in the form of runoff and mainly based on the water balance calculation [18]. The main objectives of the present study are to estimate surface runoff, runoff coefficient of the Siddheswari river basin using SCS-CN method and to predict hydrological scenario of the basin based on the surface runoff conditions with the aid of Remote Sensing (RS) and Geographical Information System (GIS).

2. REGIONAL SETTNGS OF STUDY AREA

A major right bank non-perennial tributaries of Mayurakshi (Matihara, Tepra, Bhamri, Kushkarni, Kuya), river Siddheswari (about 872.54 Sq.km area) out falling into its master stream

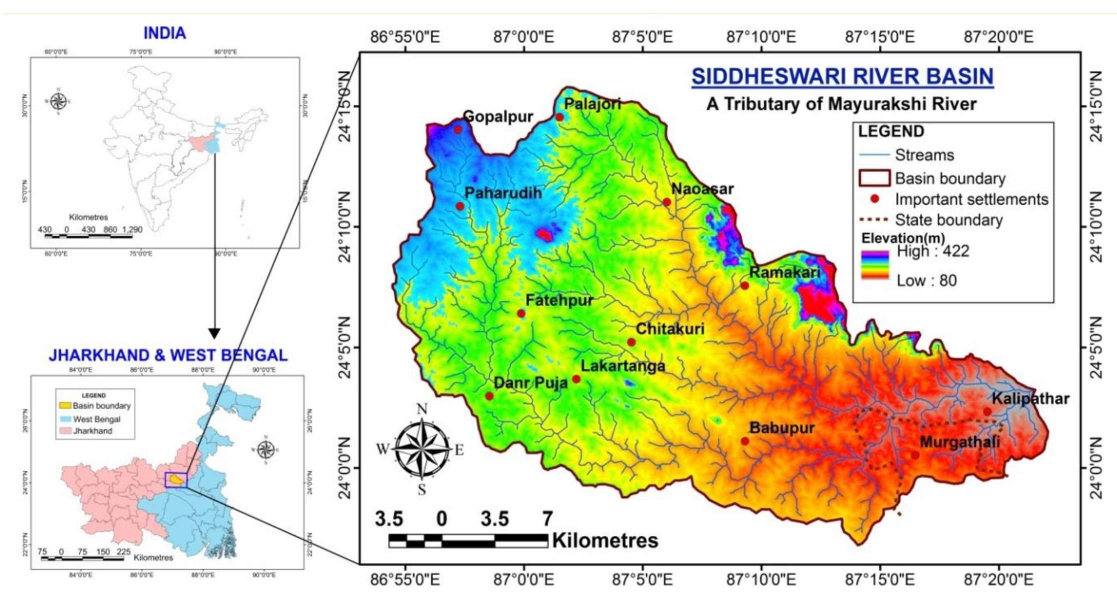

Fig. 1. Reference map of Siddheswari river basin

Mayurakshi at 98.4 Km (8 km downstream of Massanjore dam) from the source of Mayurakshi river [19,20,21]. The length of its main stream is 81.35 Km having 394 streams (319 first (334.20 Km length), 62 second (197.11 Km length), 9 third (63.11 Km length), 3 fourth (67.33 Km length), and 1 fifth (34.50 Km length) order streams. The Siddheswari river basin (Fig. 1) covering the parts of Jamtara, Deoghar, Dumka districts of Jharkhand and little portion of Birbhum district of West Bengal lies between $23^{0}57'00''$ to N $24^{0}16'00''$ N latitudes and $86^{0}55'00''$ E to $87^{0}22'00''$ E longitudes. The Siddheswari river flowing through Chhotonagpur fringe covering with more than 75% of the river basin is occupied by the Laterite and Lateritic formation, 18% is covered with unclassified Granite gneiss with enclaves of metamorphic and the remaining portion (7%) is covered with Sandstone, shale, Siltstone, Augean gneiss and Migmatite formation [22].

3. METHODOLOGY

3.1 Data Bases and Sources

The base map of the study area has been prepared from Survey of India (SOI) topographical maps (sheets no.72 P/1, 72 P/4, 72 P/8, 73 I/13, 73 M/1, 73 M/5) on 1:50,000 scale and updated using LANDSAT 8 OLI imagery (path/row 139/43). The drainage network map for the study area prepared from manual digitized of scanned SOI toposheets that have been used as stream link layer. LANDSAT 8 OLI imagery also used to prepare land use land cover (LULC) mapping based on visual interpretation using SOI toposheets; Soil texture map has been prepared using State Agriculture Management and Extension Training Institute (SAMETI, Jharkhand) provided district wise soil texture map series on 1:250,000 scale. Available last 5 years (2013-2017) Rainfall data has been collected from Indian metrological department. Finally, all data has been registered into Universal Transverse Mercator (UTM) projection northern zone 45 datum WGS 84 (except LANDSAT 8 OLI satellite imagery and Shuttle Radar Topography Mission Digital Elevation Model (SRTM DEM v3, 1-arc sec) data as these are already georeferenced). For thematic analysis Arc GIS (v. 10.5) and ERDAS Imagine (v. 9.2) softwares has been used. MS Office Excel 2010 has been used for necessary calculation.

3.2 Surface Run off Estimation Methodology

To estimate runoff soil texture map has been grouping into Hydrological soil group (HSG) maintaining the guidelines of USDA National Engineering Handbook (NEH) and prepare the Hydrological soil group map consists with group B, C and D [23]. After that to assign Curve Number (CN) the HSG and LULC map layer has been intersected in GIS environment using Arc GIS (v. 10.5) software and CN values are assign based on Antecedent moisture condition II (AMC II) condition (Soil characteristics are Average condition, Initial abstraction=0.1S, Five day antecedent rainfall are 13–28 mm and 36–53 mm for Dormant and Growing seasons respectively) [24, 6] using the SCS-CN table [25, 26, 27, 24] and converted into the Antecedent moisture condition III (AMC III) as it is considered the suitable condition for Indian situation using following [24] formula-

CN=CNIII for AMC-III:

$$\frac{CN_{II}}{0.427+(0.00573*CN_{II})} \tag{1}$$

Where, CN_{II} = Curve Number for AMC II condition

After that, the potential maximum retention (S) in mm has been calculated using the following formula [24]-

$$S=\frac{25400}{CN}-254 \tag{2}$$

Where, CN = Curve Number.

The runoff has been calculated using runoff equation following formula [24]-

$$P_{e}=\frac{(P-Ia)^{2}}{(P-Ia)+S} \tag{3}$$

Where, P_e = Surface runoff (mm)
P = Rainfall (mm)
Ia = Initial abstraction (mm)
S = Potential Retention (mm)

And finally the Runoff Coefficient is calculated using following equation [24]-

$$RC = \frac{P_e}{P} \quad (4)$$

Where,

Pe = Surface runoff (mm)
P = Rainfall (mm)

In the present study Rainfall, CN, Ia, HSG, LULC has been assign for each point of the covered study area using Arc GIS software and S, P_e, RC has been calculated for each point and finally presented in the map.

4. RESULTS AND DISCUSSION

4.1 Land Use/Land Covers (LULC)

The entire river basin has been classified into five broad LULC (Fig. 2) categories namely fallow land, built up areas, agricultural land, natural vegetation and water bodies using a supervised image classification method. Classified image shows that the largest portion occupied by agricultural land and least portion is covered with water bodies; fallow lands are mainly concentrated in the north-western portion of the basin, dense forest cover existing largely in the middle-northern tip of the catchment area. As agricultural land, natural vegetation and Fallow Land are the major LULC classes (Table 1) of the Siddheswari river basin these three LULC classes playing the main guiding role for a runoff in this region.

4.2 Soil Texture (T)

The region covered with six soil textural classes (Fig. 3): Coarse loamy (Ustrothents), Fine loamy (Paleustalfs), Fine (Paleustalfs), Fine-loamy (Haplustepts), Loamy (Ustorthents) and Loamy-skeletal (Ustorthents) (Table 2). Fine loamy (Paleustalfs) textural classes dominate in the present study area (34.15 %) whereas Loamy-skeletal (Ustorthents) texture is found very little portion (1.42 %). Coarse texture indicating low runoff and high infiltration whereas fine texture exhibits high runoff due to low infiltration capacity as runoff occurs only when the rate of rainfall on a surface exceeds the rate at which water can infiltrate the soil [28,29,11]. Studies by Brakensiek DL and Rawls WJ [30]; Maestre FT and Cortina J [31]; Roth CH [32] suggested that the runoff generation is related to the infiltration capacity of soil.

Table 1. Land use land cover class

Land use land cover Classes	Area in Sq.Km	Area in%
Fallow Land	55.43	6.35
Built up areas	5.84	0.67
Agriculture	714.31	81.86
Natural Vegetation	95.37	10.93
Water bodies	1.61	0.18
Total	872.55	100.00

4.3 Hydrological Soil Group (HSG)

The Hydrological soil grouping has been done maintaining the guidelines of National Engineering Handbook (NEH) of USDA [23] based on the soil texture map. It is mainly done for curve number (CN) calculation as the CN is the outcome of combine map of Land use land cover (LULC), Hydrological Soil Groups (HSG) and Antecedent moisture condition (AMC). The entire basin is occupied with three HSG (Fig. 4) viz. C, B and D higher to lower areal extent respectively (Table 3).

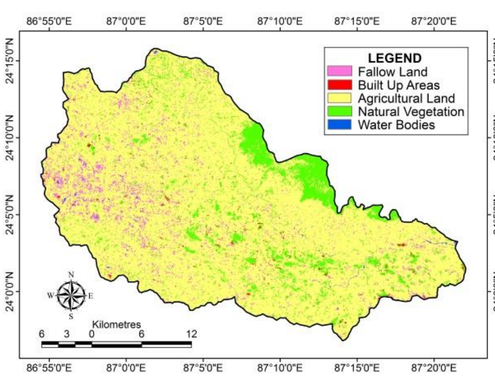

Fig. 2. Land use and land cover map

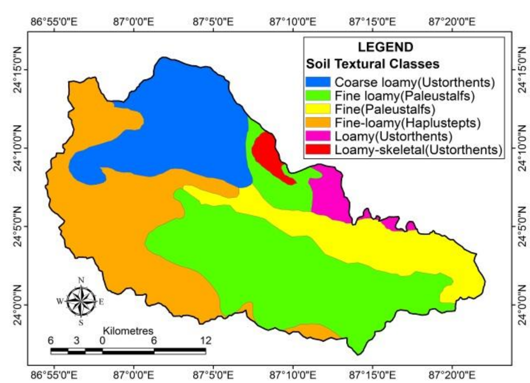

Fig. 3. Soil Texture map

Table 2. Soil textural classes and their spatial coverage

Textural Classes	Area (sq.km)	% of total area
Fine loamy (Paleustalfs)	297.95	34.15
Coarse loamy (Ustorthents)	173.06	19.83
Fine-loamy (Haplustepts)	241.69	27.70
Fine (Paleustalfs)	122.24	14.01
Loamy-skeletal (Ustorthents)	12.42	1.42
Loamy (Ustorthents)	25.17	2.88
Total	872.55	100

Table 3. Hydrological soil groups and their spatial coverage

Hydrological soil groups	Area in Sq.Km	Area in%
B	173.05	19.83
C	661.88	75.86
D	37.58	4.31
Total	872.55	**100.00**

4.4 Curve Number (CN)

CN has been generated using the integration result of HSG, LULC and AMC III as AMC III is considered as the suitable condition for Indian situation. The 60.95 to 98.69 the lower CN values mainly found in the Natural vegetation covered area with HSG D but the higher CN values are mainly existing in the agricultural land with the HSG C and the moderate CN values are found in the areas covering with agricultural land, fallow land with the association of HSG B and C (Fig. 5). A high curve number means high runoff and low infiltration; whereas a low curve number means little runoff and high infiltration or it can be stated that more abundant the precipitation, the higher will be the CN [33,34].

4.5 Rainfall (R)

Rainfall is one of the positively related factors of runoff generation, i.e. higher the rainfall naturally higher will be a runoff but as the surface conditions viz. LULC, soil texture etc. directly and indirectly modified the runoff, the higher rainfall not merely mean higher runoff conditions. The average annual rainfall (R) map (Fig. 6) exhibiting higher rainfall in the lower portion of the basin and relatively higher rainfall in the upper portion of the river basin and the middle and lower region shows moderate rainfall throughout the year. The average rainfall varies from 1083.70 mm to 1394.17 mm.

4.6 Surface Retention(S)

Surface retention value of the basin varies between 3.37 mm to 162.73 mm the S value ranges between 8.180000001-14.81 mm covers the highest area of the basin while the S value ranges between 78.54000001-162.73 mm covers the least area (Fig. 7).

4.7 Runoff (P_e)

Runoff estimation has been done for three seasons: pre-monsoon, monsoon and post-monsoon season as well as yearly basis and for mapping runoff each season and annual estimated runoff values are categories into five sub-categories viz. very low, low, moderate, high and very high runoff values (Fig. 11). For pre-monsoon (Fig. 8) very high runoff found in the

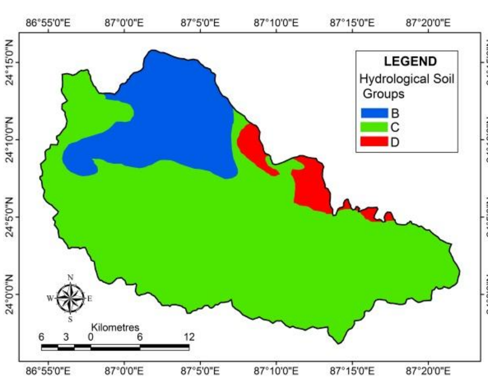

Fig. 4. Hydrological soil group map

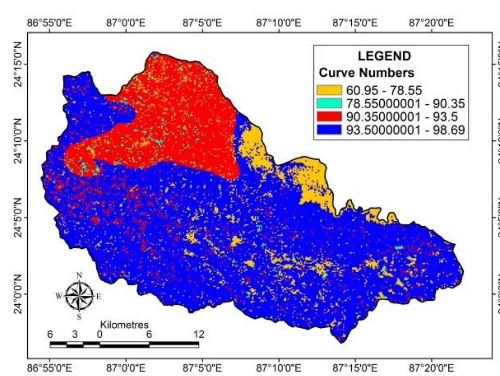

Fig. 5. Curve Number map

southern portion of the basin whereas for monsoon very high runoff values concentrated northern portion but in case of post-monsoon (Fig. 10) very high runoff values are unevenly distributed and covering very minimum area in comparison with pre-monsoon and monsoon season (Fig. 9). Annual runoff map showing the very high runoff in the middle and lower catchment and high runoff concentrated in southern portion of the catchment mainly because of lack of vegetation and uncovered surface but the low runoff concentrated in the middle-northern tip of the basin due dense vegetation cover.

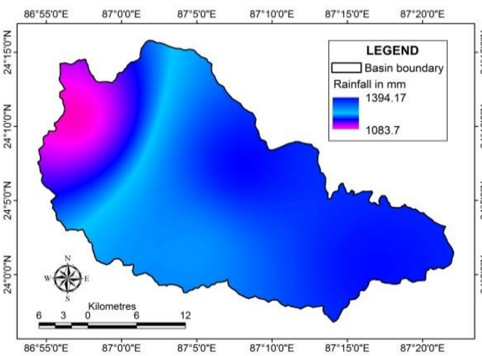

Fig. 6. Average annual rainfall map

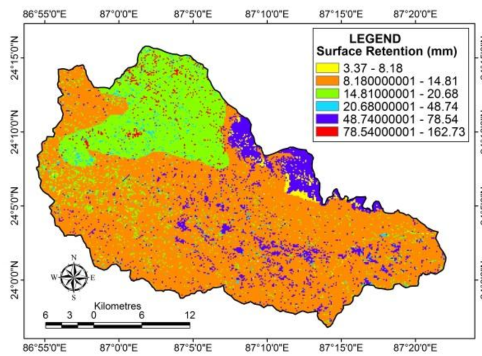

Fig. 7. Surface retention map

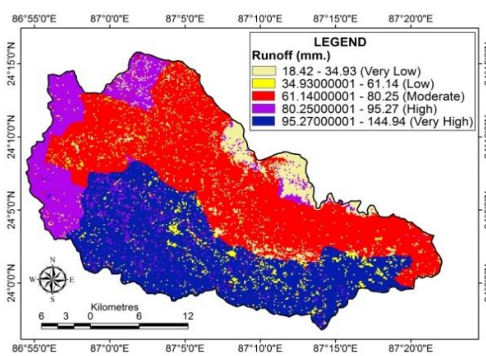

Fig. 8. Pre-monsoon runoff map

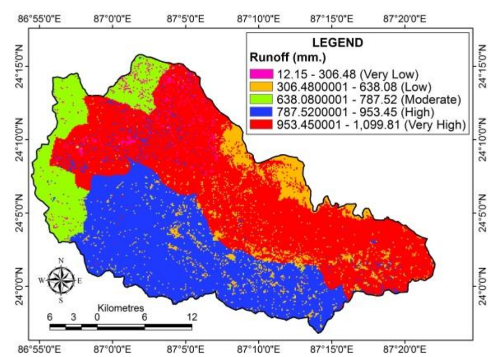

Fig. 9. Monsoon runoff map

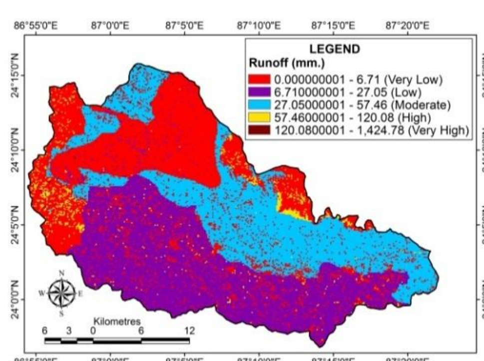

Fig. 10. Post-monsoon runoff map

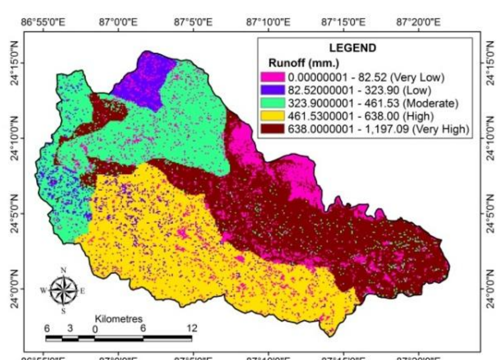

Fig. 11. Annual runoff map

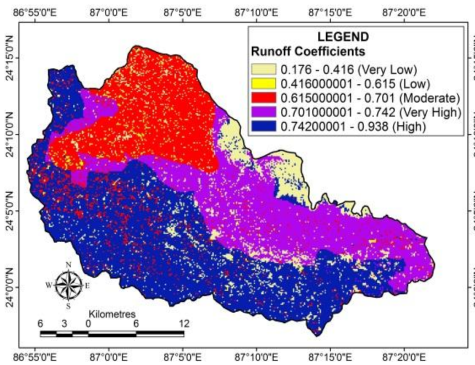

Fig. 12. Pre-monsoon runoff coefficient map

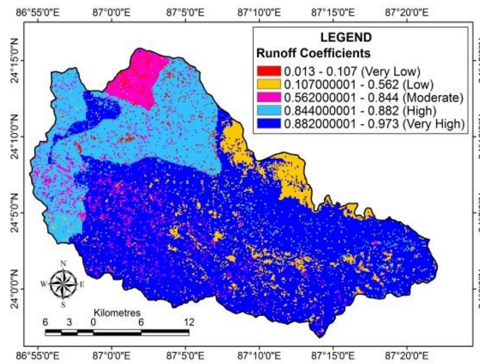

Fig. 13. Monsoon runoff coefficient map

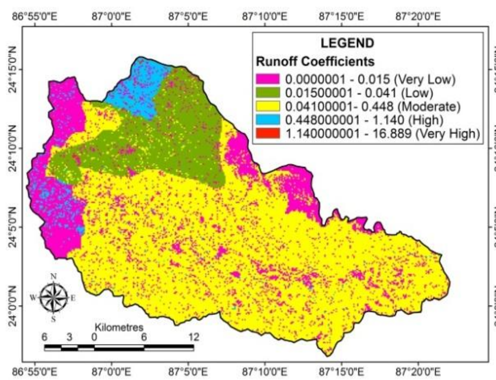

Fig. 14. Post-monsoon runoff coefficient map

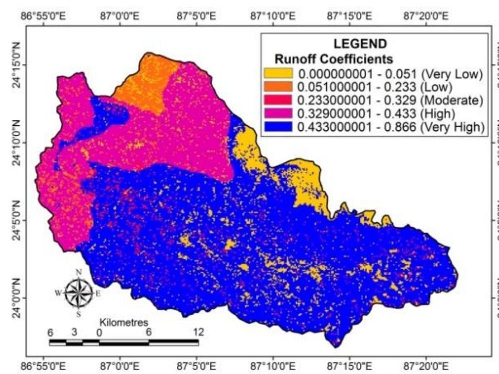

Fig. 15. Annual runoff coefficient map

4.8 Runoff Coefficient (RC)

Runoff coefficient is the ratio of the peak rate of direct runoff to the average intensity of rainfall in a storm [25]. Runoff Coefficient has been calculated for three seasonal basis: Pre-Monsoon (Fig. 12), Monsoon (Fig. 13) and Post-Monsoon (Fig. 14) and finally for yearly (Fig. 15) basis. The runoff coefficient (RC) is relating the amount of runoff to the amount of precipitation received. RC value is larger for areas with low infiltration and high runoff (pavement, steep gradient), and lower for permeable, well vegetated areas (forest, flat land). In monsoon and pre-monsoon season high to very high RC values are found more or less the same spatial location indicating flash flooding areas during storms as water moves fast over land on its way to a river channel or a valley floor but for post-monsoon the reverse condition shows i.e. moderate to low RC indicating no risk of flash flooding during storm events.

5. CONCLUSION

In the present study SCS-CN methods is used with the aid of RS and GIS for surface runoff and runoff coefficient estimation and to predict hydrological scenario of the basin based on the surface runoff conditions and result shows higher runoff and runoff coefficient values are found in the middle and southern portion of the watershed while very low runoff found mainly in the dense vegetation covered, highly permeable areas located middle-northern edge of the basin. So in conclusion it can be stated that the very high runoff, as well as runoff coefficient areas, demand necessary management practices mainly soil and water management practices for betterment of the overall condition of watershed.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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