International Journal of Multidisciplinary Research and Development
Online ISSN: 2349-4182, Print ISSN: 2349-5979; Impact Factor: RJIF 5.72
Received: 12-07-2020; Accepted: 27-07-2020; Published: 13-08-2020
www.allsubjectjournal.com
Volume 7; Issue 8; 2020; Page No. 172-177

Geospatial technique for runoff estimation based on SCS-CN method in Sudha river basin of Indrayani River

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Abstract
Hydrology plays a vital role in protection and management of water above and below the ground surface. Rainfall runoff is important component contributing significantly to the hydrological cycle. In India, the availability of accurate information on runoff is scarcely available at few selected sites. Therefore, estimation of runoff is needed for water resource planning, environmental impact analysis and for effective management of a watershed.
In this present study, integration of remote sensing data of Sudha watershed area of Indrayani Sub-basin and application of the SCS CN model in a GIS environment has helped us to provide a powerful tool for estimation of runoff at the selected site. RS and GIS were effectively used to manage spatial and non-spatial data base that represent the hydrologic characteristics of a watershed. The land use and land cover map, soil map, rainfall data were collected from different sources and processes. The Soil Conservation Service Curve Number (SCS – CN) method were used to estimate runoff. It is simple, predictable and stable conceptual method. It combines the watershed parameters and climatic factor in one entity called the curve number P. The present study were successfully demonstrated an integrated remote sensing and GIS technique to suggest the suitable zone for future artificial recharge structures in the Sudha River sub watershed in Indrayani river basin.

Keywords: Hydrology, structures, management, structures

1. Introduction

A watershed is an area which drains all collected water to a common point. Each watershed has its own characteristics like shape, size, slope, geomorphology, drainage pattern, vegetation, soil type, climatic condition and land use. Watershed management involves proper use of land and water resources of a watershed for sustainable use of natural resources as well as optimum agricultural production.

Runoff is an important hydrologic variable in water resources applications (Tailor and Shrimali, 2016) [13]. Its occurrence depends on rainfall duration, intensity and its distribution. There are numerous methods available to estimate the runoff. In this study, Soil Conservation Service Curve Number (SCS-CN) method is used to estimate the runoff of the basin. The method was developed by US Department of Agriculture in which CN is estimated using land use, soil type, and Antecedent Soil Moisture Condition (AMC). The Sudha river watershed of Indrayani basin of Pune district is considered in this study. Assessing the runoff in the catchment in terms of the quantity is necessary for sustainable water management. The purpose of this study is to quantify the surface runoff volume of the Sudha river basin.

2. Research Methods

In this study, Soil Conservation Service Curve Number (SCS-CN) method is used to estimate the runoff of the basin. The method was developed by US Department of Agriculture in which CN is estimated using land use, soil type, and Antecedent Soil Moisture Condition (AMC).

2.1. Description of the Study area

The study was carried out in Sudha River watershed of Indrayani sub-basin, which is located in Maval Taluka of Pune District (Maharashtra). The study area lies between latitude 18046’30” N and 18049’30” N and Longitude 73040’30” E and 73046’30” E. It is about 120 km from Mumbai and 35 km from Pune. The highest altitude in this area is 855m above sea level. The study area includes Talegaon Dabhade city and surrounding rural area. The macro-watershed has an area of about 102 Sq.Km. Total population of study area as per 2011 census is 70,655. The average annual rainfall is 1296 mm (1980- 2013). Fig. 1 shows the location of Sudha river watershed area in the administrative map of Pune.

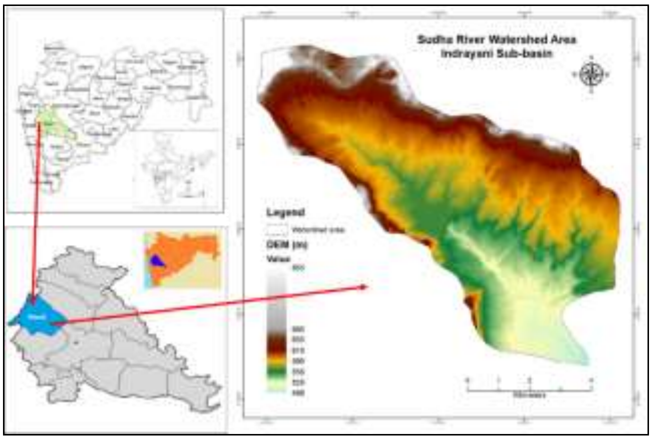

Fig 1: Sudha river watershed location in Pune

The Sudha river flows from leeward side of the Bhandara hill range, which has an average altitude of 680 m from the mean sea level. The source of Sudha river flow is from upper regions of Bhandara hill range. Jadhavwadi Dam is constructed on the western side of the basin. River flows from Jamborde, Sudvadi, Sudumbare, Yelvadi villages to meet into Indrayani River.

The catchment area is 5,573 Ha and dominant soil types are Bhabar soil, Medium black soil, Shallow black soil (Fig. 2) as classified by the National Bureau of Soil Survey and Land use Planning, (N.B.S.S. & L.U.P.) Delhi, Regional Centre. The catchment with presence of medium black soil is suitable for leguminous crops like cotton, turn and citrus fruits, wheat, jowar, millets, linseed, castor, tobacco, sugarcane, safflower, vegetables, etc. whereas shallow black soil areas are suitable for cultivation of jowar, rice, wheat, gram and cotton. The region with Bhabar soil is not much suitable for agricultural purpose due to highly porous nature of the soil.

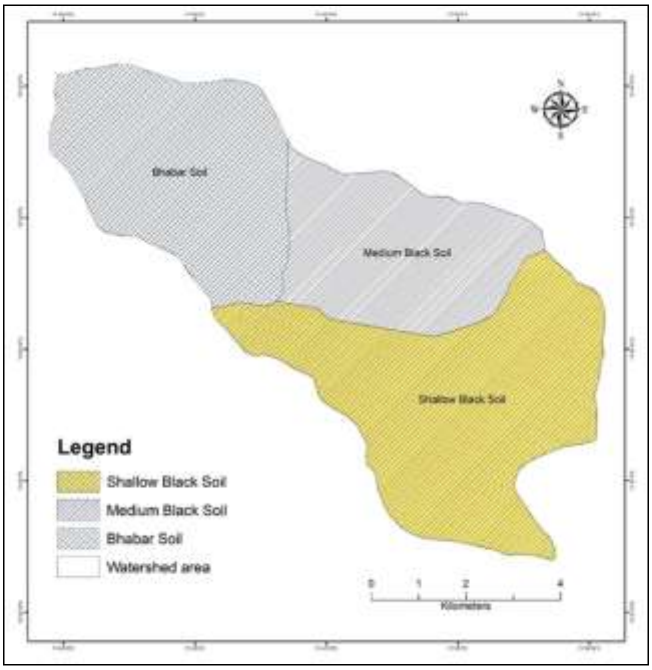

Fig 2: Soil Classification map of Sudha watershed

The climate of the Pune city and the surrounding area is mainly dry and warm. It has low-latitude semi-arid hot climate. Pune experiences three distinct seasons: summer, monsoon and winter. Typical summer months are from March to May, with maximum average temperatures ranging from 30°C to 35°C. The city receives an annual rainfall of 722 mm, mainly between June and September as a result of the southwest monsoon.

2.2. Model development and data collection

The surface runoff volume was computed using curve number method developed by the United States Department of Agriculture (USDA, 1986). The method depends on many factors including soil types, land use and cover and the antecedent soil moisture condition (Viji, Prasanna, & Ilangovan, 2015) [17]. The major steps used to determine the runoff volume is summarized in Fig. 3. The curve number method assumes that

$$Q = \frac{(P - 0.3S)^2}{(P + 0.7S)}$$

Equation 1: Runoff calculation

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

Equation 2: Potential maximum retention

Where, Q = the runoff volume (mm); P = Average daily precipitation (mm); S = potential maximum retention after runoff begins (mm) and is correlated to the soil and cover situations of catchment as given in Eq. (2) (NRCS, 2004).

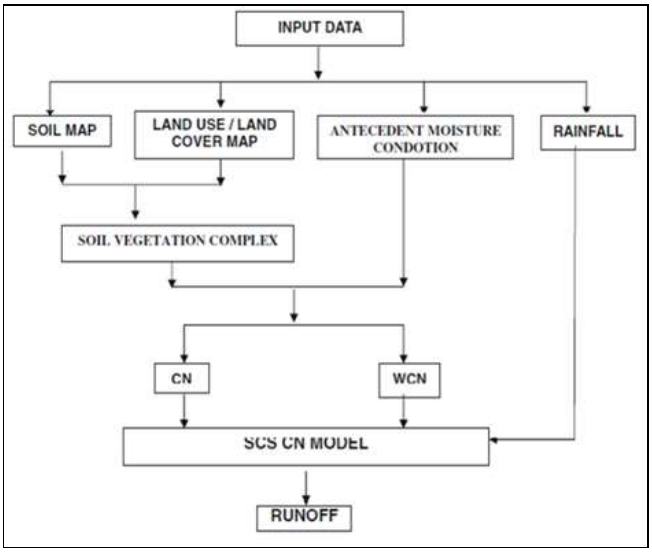

Fig 3: Flow chart for estimating runoff using SCS CN model

The curve number (CN) was computed on the basis of the hydrological soil group and land cover of the study area. High values of CN implies higher potential generation of runoff and has a range of 0–100 (NRCS, 2004).

2.2.1. Digital elevation model for catchment delineation

Catchment boundary was delineated using the Digital Elevation Model (DEM) within the MapInfo software. The topography was extracted from the DEM and was described in terms of slope and elevation.

2.2.2. Classification of land use and land cover

The land use and land cover of the study area was extracted from Landsat 8 imagery using supervised classification technique of image classification. The land use/cover of the study area was classified into five classes and includes water, vegetation, barren land, agriculture and settlement.

2.2.3. Hydrologic Soil Groups (HSG)

The soil type present in the study area is classified into four main classes as enlisted in the National Engineering Handbook (NEH) developed by USDA (Table 1). The digitized polygon of soil map is then classified into the Hydrologic Soil Groups (Group A-D).

Table 1: Details of Hydrological Soil Groups

Hydrologic Soil Group	*Type of Soil*	*Runoff potential*	*Final infiltration rate mm/hr*	*Distribution (%)*	*Remarks*
Group A	Deep, well drained sands and gravels	Low	>7.5	4.73	High rate of water transmission
Group B	Moderately deep, well drained with moderately fine to coarse textures	Moderate	3.8-7.5	25.54	Moderate rate of water transmission
Group C	Clay loams, shallow sandy loam, soils with moderately fine to fine textures	Moderate	1.3-3.8	52.04	Moderate rate of water transmission
Group D	Clay soils that swell significantly when wet, heavy plastic and soils with a permanent high-water table	High	<1.3	18.69	Moderate rate of water transmission

Source: NEH, USDA

2.2.4. Antecedent Moisture Condition (AMC)

AMC indicates the moisture content of soil at the beginning of the rainfall event. The AMC is an attempt to account for the variation in curve number in an area under consideration from time to time. Three levels of AMC were documented by SCS AMC I, AMC II & AMC III. The limits of these three AMC classes are based on rainfall magnitude of previous five days and season (dormant season and growing season).

Table 2: AMC classes

AMC Class	*Description of soil condition*	*Total five-day antecedent rainfall (mm)*	
		Dormant season	**Growing season**
I	Soils are dry but not to the wilting point; satisfactory cultivation has taken place.	<12.7 mm	<35.56 mm
II	Average conditions.	12.7 – 27.94 mm	35.56 – 53.34 mm
III	Heavy rainfall or light rainfall and low temperatures have occurred within last 5 days; Saturated soils.	>27.94 mm	53.34 mm

2.2.5. Curve Number

The USDA curve number modified for Indian conditions was used for the determination of the curve number for individual sub watersheds based on the hydrological soil groups and land use classes of respective areas and are expressed as weighted CN (AMCII) values (Table 3).

The CN was assigned considering soil map, hydrological soil groups and land use land cover. Each identified rain gauge station were utilized for Theissen polygon. For each Theissen cell, area weighted CN (AMC II) and also CN (AMC I) and CN (AMC III) were determined.

CN for AMC I is calculated as:

$$CN_I = CN_{II}/(2.281 - 0.01281CN_{II})$$

CN for AMC III is calculated as:

$$CN_{III} = CN_{II}/(0.427 + 0.00573CN_{II})$$

SCS runoff CN for hydrologic soil cover complex under AMC II condition for the study area is given in Table 3. Area weighted composite curve number for various conditions of land use and hydrologic soil conditions are computed as follows:

$$CN = (CN_1 \times A_1) + (CN_2 \times A_2) + \cdots \dots \dots + (CN_n \times A_n)/A$$

Equation 3: Area weighted Curve Number

Where A1, A2, A3, An represent area of polygon having CN values CN1, CN2, CN3, CNn respectively and A is the total area.

Table 3: Runoff Curve Numbers for (AMC II) for the Indian Conditions

S No.	*Landuse*	*Treatment/practice*	*Hydrologic condition*	*Curve numbers for Hydrologic soil group*			
				A	**B**	**C**	**D**
1	Cultivated	Straight row	…..	76	86	90	93
		Contoured	Poor	70	79	84	88
			Good	65	75	82	86
		Contoured and terraced	Poor	66	74	80	82
			Good	62	71	77	81
		Bunded	Poor	67	75	81	83
			Good	59	69	769	79
		Paddy (rice)	…..	95	95	5	95
2	Orchards	With under stony cover	…..	39	53	67	71
		Without under stony cover	…..	41	55	69	73
3	Forest	Dense	…..	26	40	58	61
		Open		28	44	60	64
		Shrubs		33	47	64	67
4	Pasture	……	Poor	68	79	86	89
			Fair	49	69	79	84
			Good	39	61	74	80
5	Wasted Land	…..	……	71	80	85	88
6	Hard Surface	……	…...	77	86	91	93

Source: Tripathi, 1999

3. Results and Discussion

3.1. Catchment Delineation

Assessment of the topography and elevation is necessary for understanding the morphological and hydrological development of the catchment. The DEM with stream network and sub-watersheds is presented in Fig 4 and Fig 5 respectively.

The Northern part of the study area has a hilly terrain and the central towards South Eastern part is plain area. The elevation values vary between 498 to 855 m. The minimum slope is between 0 and 2 degree and the highest is 89 degree. Result from Fig. 4 shows that the areas of the low elevation (498 m) might be affected by flood during heavy rainfall periods.

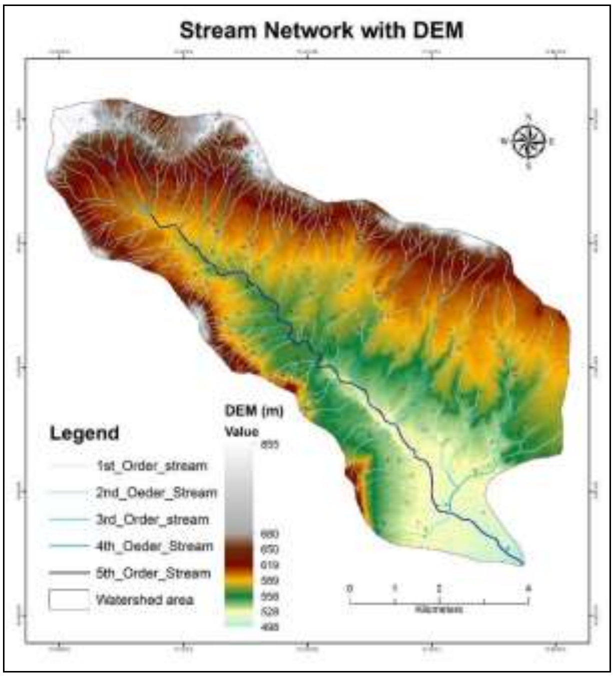

Fig 4: Stream Network with DEM

The elevation and slope may govern the stability of the catchment and control the quantity and distribution patterns from precipitation as well as downstream water supply in the catchment. The Sudha basin is dominated by higher slope of above 20 degree and thus prone to erosion.

Fig 4 shows that water in catchment flows from the areas of high elevation (855 m) to the areas of low elevation (498 m). The South Eastern part of the catchment may have risk of flooding because of low elevation (498 m).

Based on drainage pattern, the study area was divided into 13 sub watersheds (Fig. 5) having an area of 55.73 Sq kms.

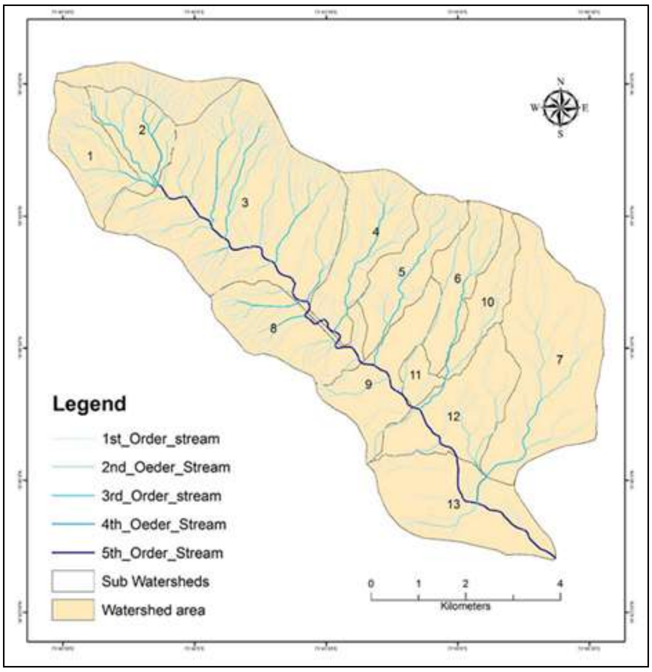

Fig 5: Sub-watershed of Sudha basin

3.2. Catchment runoff volume

3.2.1. Land use and Land cover classification

Fig. 6 shows land use land cover classification of the study basin. The classification shows that Vegetation, Open/Barren Land and Water bodies together occupy 37.37% of the total area whereas Settlement and agricultural land occupy 62.62% area. These percentages suggest that the impact of human activities or human interference on natural or physical features are comparatively high.

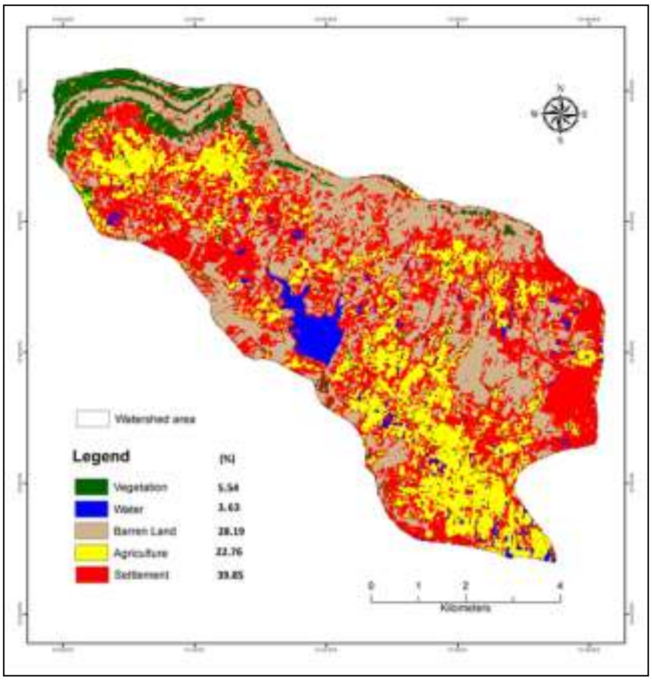

Fig 6: Land use land cover classification of the study basin

The results of classification suggest that area under Water bodies accounts 3.63%, area under Agriculture is 22.76%, Vegetation is 5.54 %, Settlements is 39.85 % and Open/Barren Land is 28.19 % of the total area and thus the total area is divided in above five major components or classes (Table 4).

Table 4: Land use Land cover classification details

S No.	*Class / Land Cover Type*	*Percentage (%)*	*Sq.Km*
1	Agriculture	22.76	12.68
2	Vegetation	5.54	3.08
3	Settlements	39.85	22.20
4	Barren Lands	28.19	15.70
5	Water	3.63	2.02

3.2.2. Catchment hydrological soil groups classification

Distribution of surface soil types, according to Land use/Land cover classification of the study basin is depicted in table below. These are derived as per NEH, USDA (Table 5).

Table 5: Hydrological soil groups classification

S No.	*Classes*	*Percentage*	*Area (Sq.Km)*	*A*	*B*	*D*
1	Agriculture	22.77	12.68	62	74	86
2	Vegetation	5.54	3.09	49	69	84
3	Settlements	39.86	22.20	76	86	93
4	Barren Lands	28.19	15.71	71	80	88
5	Water	3.64	2.03	59	69	79

3.2.3. CN value for sub-watershed

According to National Engineering Handbook, Curve Number (CN) in each sub-watershed can be found from given soil type distributions, land uses, and AMC types. Considering the spatial variations of CN values in different areas in the sub-basin, weighted method was used to obtain the averaged CN-mean value in the sub-basin. This CN-mean is Curve Number in AMC Type II for the condition of every year the flood occurs, or the rainfall runoff induced by heavy storms.

Based on SCS Curve Number in NEH (National Engineering Handbook part-630), CN for different land uses and soil types is determined. The hydrologic condition was defined by the percentage of ground cover area. The modulated CN value for each sub-watershed is shown in Table 6 and 7.

The land use and soil type of the catchment were computed to find the weighted CN values with the standard table. For calculating surface runoff volume, antecedent soil moisture II (AMCII) was considered.

Table 6: Sudha river Sub-Watershed CN value in AMC II conditions

Sub Watershed	*Area Sq.km (Ai)*	*CN*	*CN (AMC II)*
Sub - Watershed 1	2.78	66	3.42
Sub - Watershed 2	2.16	67	2.70
Sub - Watershed 3	13.06	77	18.75
Sub - Watershed 4	3.78	75	5.29
Sub - Watershed 5	2.97	59	3.27
Sub - Watershed 6	2.59	59	2.85
Sub - Watershed 7	8.03	93	13.92
Sub - Watershed 8	3.67	89	6.09
Sub - Watershed 9	3.16	95	5.60
Sub - Watershed 10	1.82	80	2.71
Sub - Watershed 11	0.64	95	1.13
Sub - Watershed 12	3.95	89	6.56
Sub - Watershed 13	5.02	84	7.86

3.2.4. Runoff Calculation

Runoff volume has been estimated based on SCS - CN Model. The curve number of the sub-watersheds, its area, potential retention (S) and AMC condition is used to estimate the runoff volume of the study basin (Table 7).

Table 7: Surface retention and Runoff Calculation

Sub Watershed	*Sq.km (Ai)*	*CN*	*CN (AMC II)*	*Surface Retention (S)*	*Q (mm)*
Sub - Watershed 1	2.78	66	3.42	130.85	572.94
Sub - Watershed 2	2.16	67	2.70	125.10	578.70
Sub - Watershed 3	13.06	77	18.75	75.87	630.80
Sub - Watershed 4	3.78	75	5.29	84.67	621.11
Sub - Watershed 5	2.97	59	3.27	176.51	529.38
Sub - Watershed 6	2.59	59	2.85	176.51	529.38
Sub - Watershed 7	8.03	93	13.92	19.12	697.64
Sub - Watershed 8	3.67	89	6.09	31.39	682.51
Sub - Watershed 9	3.16	95	5.60	13.37	704.87
Sub - Watershed 10	1.82	80	2.71	63.50	644.71
Sub - Watershed 11	0.64	95	1.13	13.37	704.87
Sub - Watershed 12	3.95	89	6.56	31.39	682.51
Sub - Watershed 13	5.02	84	7.86	48.38	662.20

The weighted CN value of sub watershed 1 to 13 is calculated as 3.42, 2.70, 18.75, 5.29, 3.27, 2.85, 13.92, 6.09, 5.60, 2.71, 1.13, 6.56 and 7.86 respectively. The runoff value for sub watershed 1 to 13 to be 572.94, 578.70, 630.80, 621.11, 529.38, 529.38, 697.64, 682.51, 704.87, 644.71, 704.87, 682.51 and 662.20 respectively.

Conclusion

Assessing the quantity of surface runoff generated in a catchment is very important for decision making as well as sustainability of present resources. The purpose of the study was to determine surface runoff volume. Findings from the study conclude that Sudha river watershed has high potential run off volume. The spatial distribution of CN value varies from 49 to 95 and are in correspondence with dense forest, barren land and water. This suggests that the region has moderately permeable soil condition. Another highest CN value 95 corresponds to the built-up land. The higher CN value has a high runoff whereas lower CN value has a low runoff. Due to the high infiltration capacity of the dense forest, the runoff is low and in the hard surface of the built-up land the runoff is high. The estimated runoff showed that the watershed had a good surface runoff potential. Hence, the surface water can be recharged into the ground by constructing suitable artificial ground water recharge structures.

A high amount of rain water is lost as runoff from the basin. Integrated watershed management and rain water harvesting could be a promising option to stabilize the water deficit and to improve crop productivity in the basin. Flood risk zone of the catchment was found to be at the south eastern part of the catchment. The flooding could be mitigated if advanced and suitable farming interventions are practised in the upper areas of the catchment.

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