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Computation of Runoff by SCS-CN Method from Micro- watersheds of Urmodi Basin in Maharashtra State Using RS and GIS

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Abstract: Flood is a natural or manmade phenomenon and timely and accurate forecasting of flood is very important however, forecasting of flood is a difficult task due to influence of rainfall-runoff process which depends on various factors. Estimation of surface runoff in a watershed is based on the rate of received precipitation and discharge at the outlet. In this study runoff from micro-watersheds of Urmodi basin in Maharashtra state was computed by Soil Conservation Service-Curve Number (SCS-CN) method using RS and GIS techniques. Various thematic maps such as soil map, land use/land cover, stream order, slope *etc*. were prepared using remote sensing and GIS. Daily rainfall data was used for determination of runoff. Antecedent moisture conditions for different CNs were determined with the help of combined land use land cover and hydrologic soil group map in (ArcGIS) GIS environment. Results showed that the highest runoff for Bharatgaon and Nagthane micro-watersheds was 46.20 mm and 54 mm respectively. Total runoff depth for the year 2014 was computed as 215.05 mm for Bharatgaon micro-watershed and 277.68 mm for Nagthane micro-watershed. Different soil and water conservation measures and water harvesting structures were recommended to control soil erosion and to harness the surface runoff.

Keywords*: GIS, Remote Sensing, Runoff, SCS-CN method.*

Introduction

In recent years, the global climate is changing with accelerated rate causing extreme weather events like drought and flood more frequently. This can have significant impact on agriculture, natural resources, overall ecosystem and livelihood. Rainfall-runoff are the important components contributing significantly to the hydrological cycle. In surface hydrology, rainfall-runoff processes play a vital role. The runoff estimation is one of the most important phenomena in hydrologic design of soil water conservation structures. It is also an important aspect in engineering planning, environmental impact assessment, flood forecasting and water balance calculations (Balvanshi and Tiwari 2014). Now-a-days applications of Remote Sensing (RS) and Geographic Information Systems (GIS) techniques are increasingly used for planning, development, and management of natural resources at regional, national and international level. For an aggregated study of runoff modeling, remote sensing and GIS have gained significance in the determination of the runoff volume of watershed. RS and GIS are the efficient tools for managing natural disasters, design and construction of water conservation structure and flood forecasting / regulation. GIS is widely used for the preparation of most of the input data required by the Soil Conservation Service-Curve Number (SCS) curve number method (Sunder *et al*. 2010).The statistical analysis indicates that the SCS CN method can be applied to predict runoff depths of ungauged watershed (Buthkar and Regulwar 2015).

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Materials and Methods

Study area

Urmodi is the tributary of Krishna river, and its catchment lies in Satara district of Maharashtra. The Bharatgaon micro-watershed of this catchment lies between 17°35'54" N to 17°37'3" N latitude and 74°1'33" E to 74°2'13" E longitude. The Bharatgaon micro-watershed has an area of 123 ha. Nagthane micro watershed with total area of 264 ha, located between 17°33'22" N to 17°33'55" N latitude and 74°0'43" E to 74°2'25" E longitude. Government of Maharashtra has coded Urmodi catchment as watershed KR-14. Average daily temperature in this zone is about 27 ºC and May is the hottest month. Annual rainfall in the basin is of the order of 1250-1800 mm. The soil texture in the watershed varies from clay to clay loam. Climate of the study area is tropical with three distinct seasons. The location map of the study area is shown in (Fig. 1).

Data collection

Toposheets of study area were obtained from GIS unit cell, Commissionorate of Agriculture, Pune. The cloud free digital satellite data of the study area were obtained from the *Indian Remote Sensing Satellite* (IRS-1D LISS- III) digital data (Row no-147, Path no-48) to prepare land use/land cover (LU/LC) maps of the watershed. A 30m×30m resolution DEM was downloaded from BHUVAN website for the study area. The Soil map on 1:50,000 scale and soil characteristics data were obtained from the Maharashtra Remote Sensing Applications Centre (MRSAC), Nagpur. The daily rainfall data of study area for year 2014 were collected from Hydrology User Group, Nashik.

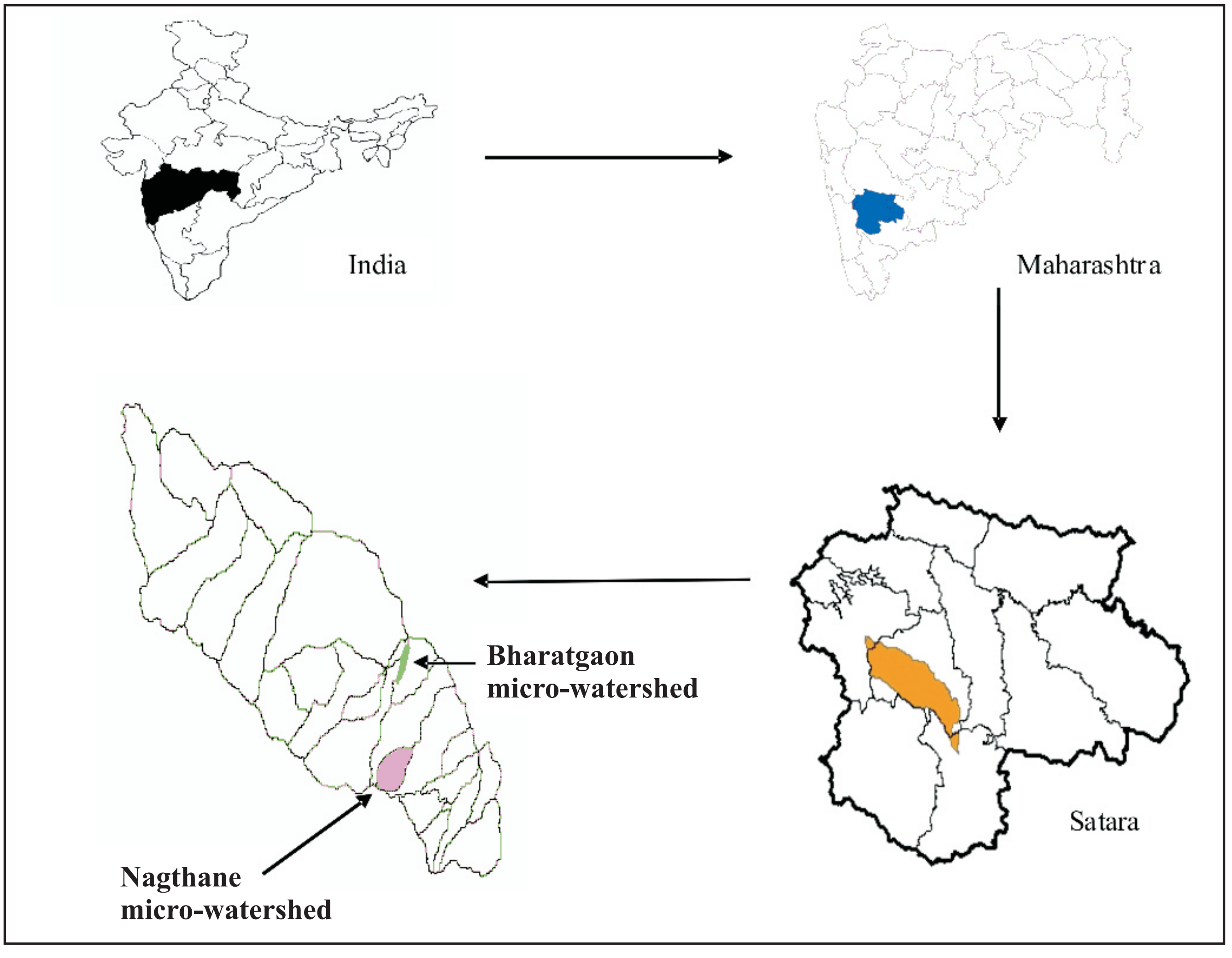

Fig. 1. Location map of study area

Table 1. Rainfall limits for estimating antecedent moisture conditions

AMC	Total Rain in Preceding 5 days(mm) Dormant Season	Growing Season
I	<13	< 36
II	13 to 28	36 to 53
III	> 28	> 53

Methodology

In this study, various data such as satellite images, digital elevation model (DEM), soil map and rainfall data were used for estimation of surface runoff. Land use/land cover map for the month of November was prepared using LISS III data. Slope map of the study area was derived from DEM using ERDAS imagine software. The hydrological soil group (HSG) map (1:50,000 scale) was generated with the help of soil texture map. The runoff estimates for different combinations of soil group, land use classes and Antecedent Moisture Condition (AMC) classes were estimated by adopting the procedure of 'SCS-CN method'. The Soil Conservation Service (Soil Conservation Service 1985) for conditions prevailing in the United States originally developed the curve number method. Since then, it has been adapted to conditions in other parts of the world. Runoff depth was computed using following equation (Nayak *et al.* 2012).

$$Q = \frac{(P - 0.3S)^2}{P + 0.7S} \quad \dots (1)$$

Where,

Q = Runoff, mm

P = Rainfall, mm

S = Potential maximum retention (ability of a watershed to abstract and retain storm precipitation), mm.

The potential maximum retention (S) and watershed characteristics are related through an intermediate parameter, called curve number (CN). It is an index that represents the combination of hydrological soil group, land use pattern, and antecedent moisture conditions and is expressed as (Muthu and Santhi 2015).

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

CN has a range of $100 \geqslant CN \geqslant 0$. A $CN = 100$ represents a condition of zero potential retention and $CN = 0$ represents an infinitely abstracting catchment with $S = \infty$.

Antecedent Moisture Condition

Antecedent Moisture Condition (AMC) is defined as the wetness index of soil. It refers to the moisture content present in the soil at the beginning of the rainfall runoff event under consideration (Khaddor and Alaoui 2014). AMC is determined on the basis of five days antecedent rainfall amounts (Table 1).

Estimation of CN:

For a watershed that consists of several soil types and land uses, a composite CN is calculated as (Nasiri and Alipur 2014)

$$CN_{composite} = \frac{\Sigma(Ai \times CNi)}{\Sigma Ai} \quad \dots (3)$$

Where,

$CN_{composite}$ = the composite CN used for runoff volume computations

i = an index of watersheds sub-divisions of uniform land use and soil type

CNi = Curve number for sub-division i and

Ai = the drainage area of subdivision i

CN for AMC I am calculated as:

$$CN_I = \frac{CN_{II}}{_{II}} \quad \dots (4)$$

CN for AMC-III is calculated as:

$$CN_{III} = \frac{CN_{II}}{_{II}} \quad \dots (5)$$

Table 2. Curve number values for different land use categories and HSGs (Khaddor and Alaoui 2014)

Land Use	Hydrologic Soil Group			
	A	B	C	D
Build Up	76	86	90	93
Agriculture Land	49	69	79	84
Tree cover	41	55	69	73
Forest	26	40	58	61
Wasteland	71	80	85	88
Water bodies	100	100	100	100

Results and discussion

Land use land cover map

The LU/LC in the Bharatgaon micro-watershed area was classified into three classes: (i) Agriculture (ii) Forest and (iii) Wasteland (Fig. 2). Similarly the LU/LC in Nagthane micro-watershed was classified into four classes (Fig. 3). Land use/ land cover pattern of Bharatgaon micro-watershed revealed that majority of watershed land comes under agriculture class (105.92 ha), 86 per cent of the total area of watershed. Next dominant class is forest (10.92 ha) which covers about 8.50 per cent of total area followed by wasteland (6.37 ha) which is about 5.50 per cent of total area). The Nagthane micro-watershed showed similar kind of LU/LC pattern. The agricultural class covers 230 ha of the total area which is about 80.98 per cent of the total area. Wasteland area covers about 11.26 per cent of area. Forest and build up land covers 14 ha and 8 ha respectively which is about 5.30 per cent and 2.81 per cent of the total area respectively.

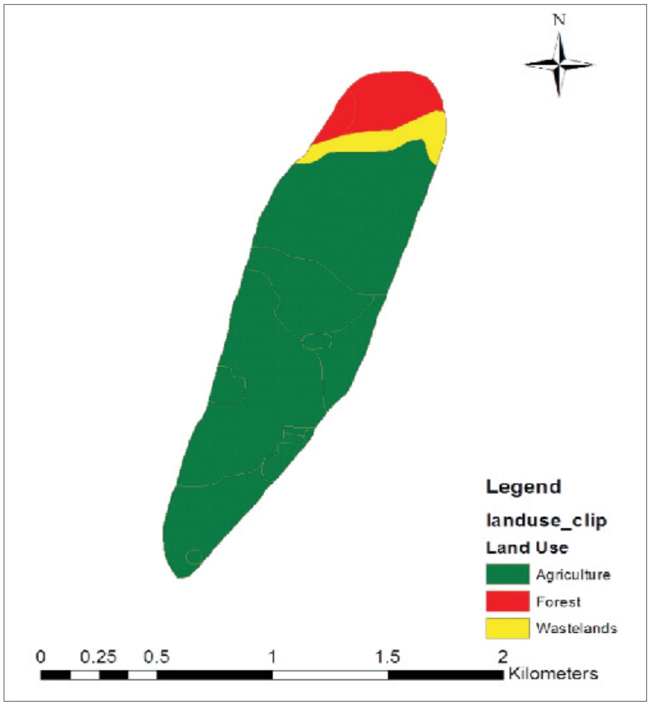

Fig. 2. Land use land cover map of Bharatgaon micro-watershed

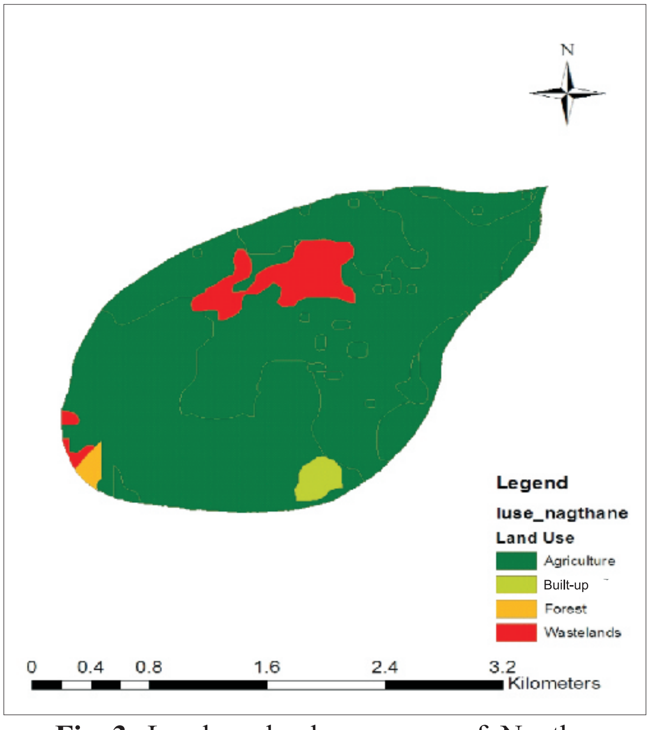

Fig. 3. Land use land cover map of Nagthane micro-watershed

Digital Elevation Model (DEM)

Digital Elevation model (DEM) is a simple, regularly spaced grid of elevation points. DEM of the study area was downloaded from web portal of National Remote Sensing centre and it was used to generate the slope map of micro watersheds (Fig. 4).

Drainage network map

Drainage network map of the study area was prepared by using DEM (Fig. 4 & 5). In Nagthane micro-watershed, the first order stream covers total length of 9 km which is 55.38 per cent of the total drainage length. The second order stream has total length of 5 km which is 30.76 per cent of the total length, the third order stream has total length of 2.25 km (13.84%). Bharatgaon area is mostly drained by the first order streams having maximum drainage length of 2.74 km, which covers about 57.56 per cent of total length of drainage. Second order has 2.02 km length. It is 42.43 per cent of total length of drainage.

Runoff estimation by SCS-CN method

In SCS-CN method, the CN values used were CN_I=64.54, CN_{II}=80.68 and CN_{III}=91.68 for AMC-I, AMC-II and AMC-III respectively as inputs to compute daily runoff. The individual composite curve number was computed for study area for AMC II condition. Then using equation (4) and (5) CN_I and CN_{III} were computed. The results of runoff computation for Bharatgaon micro-watershed using SCS curve number method are shown in table 3. Total 14 runoff events were observed where moderate runoff was recorded in the watershed. The watershed soil belongs to HSG, C and D which have texture as clay, clay loam, gravelly clay loam and gravely clay. The specific maximum retention for the 1st event was observed to be 23.05 mm for a curve number of 91.68 which showed the AMC III condition and yielded the runoff of 3.59 mm. The highest runoff of the season occurred during the 2nd event showed the AMC-III condition which was accounted to be 46.20 mm (Table 3 and Fig. 6). The 3rd, 7th, 11th, 12th, 13th and

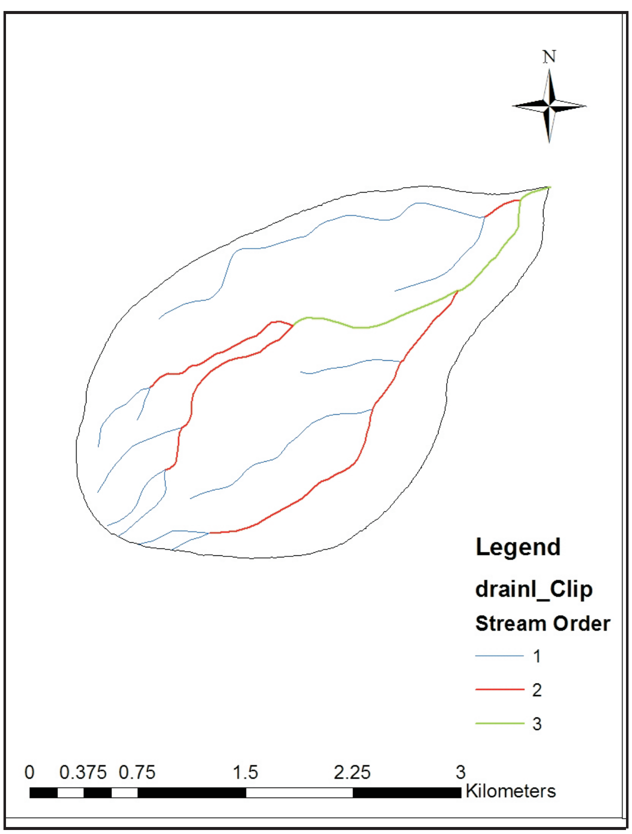

Fig. 4. Stream order map of Nagthane micro watershed

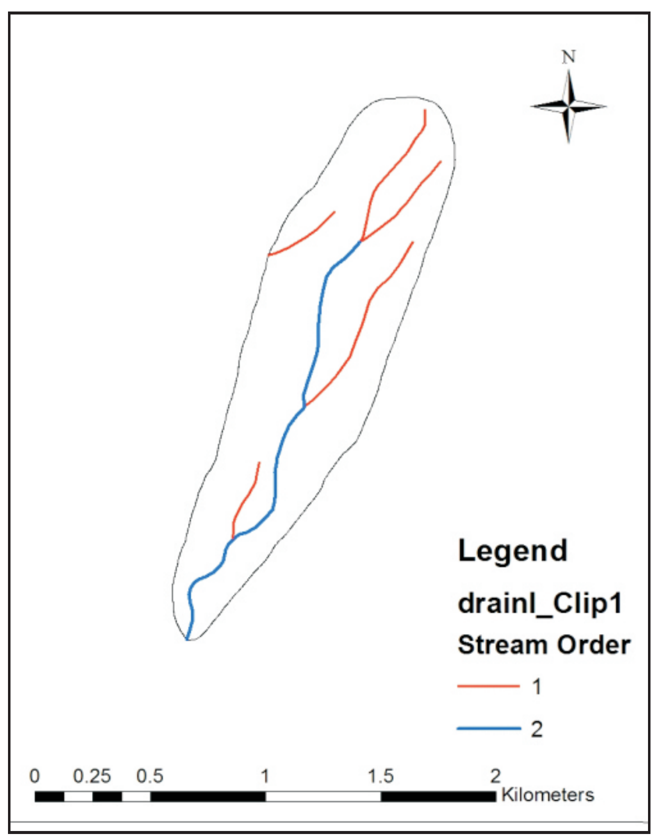

Fig. 5. Stream order map of Bharatgaon micro watershed

14th rainfall events showed the AMC-I condition and yielded runoff of 6.95, 7.52, 5.39, 8.76, 5.72 and 8.86, respectively. Similarly the lowest selected rainfall event occurred on 14th event which yielded runoff of 8.76 mm. The total annual rainfall of the area was 713.50 mm with the runoff of about 215.05 mm for the year 2014. Similarly for the Nagthane micro-watershed 14 runoff events were observed.. The curve number for different AMC conditions were CN_I= 72.43, CN_{II}= 85.70, CN_{III}= 93.63 (Table 4).

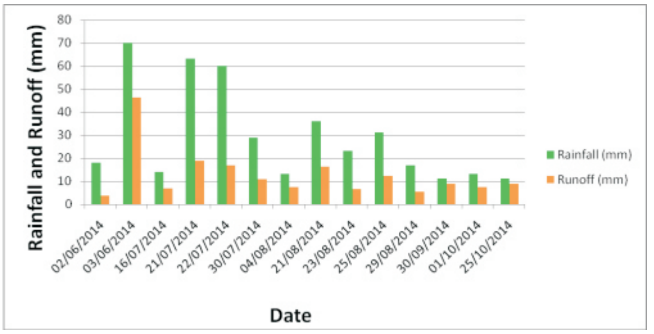

Fig. 6. Daily rainfall and runoff in Bharatgaon micro-watershed

Table 3. Daily rainfall and runoff values for Bharatgaon micro watershed

Sr. no	Date	Rainfall (mm)	Specific Retention	CN	AMC	Runoff (mm)
1	2/06/2014	18	23.05	91.68	III	3.59
2	3/06/2014	70	23.05	91.68	III	46.20
3	16/07/2014	14	139.55	64.54	I	6.95
4	21/07/2014	63	60.82	80.68	II	18.97
5	22/07/2014	60	60.82	80.68	II	16.99
6	30/07/2014	29	23.05	91.68	III	10.80
7	4/08/2014	13	139.55	64.54	I	7.52
8	21/08/2014	36	23.05	91.68	III	16.22
9	23/08/2014	23	23.05	91.68	III	6.61
10	25/08/2014	31	23.05	91.68	III	12.30
11	29/08/2014	17	139.55	64.54	I	5.39
12	30/09/2014	11	139.55	64.54	I	8.76
13	1/10/2014	13	139.55	64.54	I	7.52
14	25/10/2014	11	139.55	64.54	I	8.76

Table 4. Daily runoff values for Nagthane micro-watershed

Sr. no	Date	Rainfall (mm)	Specific Retention	CN	AMC	Runoff (mm)
1	2/06/2014	22	17.28	93.63	III	8.29
2	3/06/2014	73	17.28	93.63	III	54.0
3	21/07/2014	70	17.28	93.63	III	51.17
4	22/07/2014	63	17.28	93.63	III	44.51
5	23/07/2014	40	17.28	93.63	III	23.26
6	30/07/2014	29	17.28	93.63	III	13.80
7	21/08/2014	40	17.28	93.63	III	23.26
8	25/08/2014	33	17.28	93.63	III	17.15
9	19/09/2014	10	96.68	72.43	I	4.64
10	30/09/2014	11	96.68	72.43	I	4.12
11	1/10/2014	13	96.68	72.43	I	3.17
12	25/10/2014	15	96.68	72.43	I	2.37
13	14/11/2014	30	17.28	93.63	III	14.62
14	15/11/2014	53	42.30	85.70	II	19.63

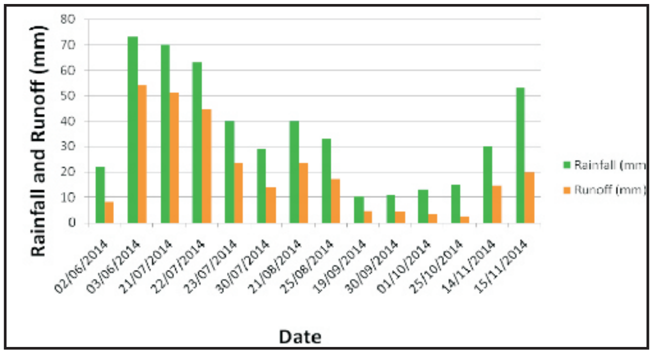

Fig. 7. Daily rainfall and runoff in Nagthane micro-watershed

The highest rainfall occurred during 2nd event which was about 73 mm and generated runoff of 54 mm. The maximum retention for 2nd event was 17.28 mm and the CN was 93.63 which represent AMC-III condition. The lowest rainfall occurred during 9th event yielded 4.64 mm runoff with maximum retention of 96.68 mm which represents AMC-I condition (Table 4 & Fig. 7). The total rainfall in the micro watershed was 860 mm which generated about total runoff of 277.68 mm.

Conservation and water harvesting planning for micro watersheds

Soil and water conservation measures for micro-watersheds were recommended based on climatic, soil (depth and texture) and topographical characteristics of micro-watershed (Srivastava *et al.*, 2010). Earlier Bharatgaon and Nagthane micro-watersheds were untreated *i.e.* no soil and water conservation measures. Different agronomical measures such as contour farming, strip cropping were suggested in Bharatgaon and Nagthane micro-watershed to conserve the soil and water. Water harvesting structures such as check dam, percolation pond and farm pond were suggested based on runoff coefficient, slope map, rainfall and stream order map.

Length and height of proposed check dams, height of impounded water and water spread area behind the structures were measured at two locations in micro watersheds. Actual storage capacities of two structures (check dams) were determined. Design specifications of proposed check dams are given in table 5.

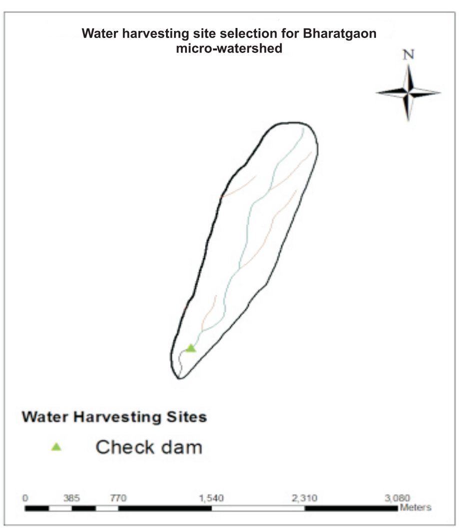

Fig. 8. Water harvesting site selection for Bharatgaon micro-watershed

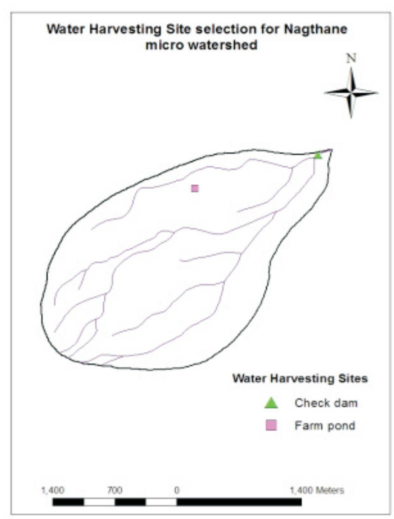

Fig. 9. Water harvesting site selection for Nagthane micro-watershed

Table 5. Design specifications of proposed check dams

Sr.No.	Structure	Length (m)	Height (m)	Average height of impounded water(m)	Water spread area (m^2)	Storage capacity (m^3)
1.	Check Dam	21.5	2.5	2.27	1935	4392.45
2.	Check Dam	17	2.1	1.82	1530	2784.6

Benefits on implementation of conservation measures and water harvesting structures

Recommended soil and water conservation measures are expected to reduce the slope length, protect the land from degradation and help to control the soil erosion from the watershed. Water harvesting structures will provide water storage for supplementary irrigation, help in moderating the floods in downstream areas and improve *in-situ* moisture conservation for increased biomass production. Besides, groundwater recharge is likely to improve due to adoption of different water harvesting structures and conservation measures in micro watersheds of Urmodi basin.

Conclusions

The integration of remote sensing data and the SCS CN model in a GIS environment provides a powerful tool for assessment of runoff for recommending suitable soil and water conservation measures in a watershed.

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