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ESTIMATION OF SURFACE RUNOFF USING SCS-CN AND GEO-INFORMATICS IN MORNI SUB WATERSHED, HARYANA

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Abstract: The development of watershed aims at productive utilization of all the available natural resources in the entire area extending from ridge line to stream outlet. Remote sensing and GIS techniques are being increasingly used for planning, management and development of watersheds. Estimation of surface water runoff is critical to the management of sub-watersheds. In the present study, Soil Conservation Services–Curve Number (SCS-CN) method has been applied for estimation of surface water runoff for Morni Sub-watershed in Shivalik hills of Himalaya. Various parameters such as land use/land cover (LU/LC), soil texture, rainfall, geology and hydrological soil group (HSG) were used to compute runoff using this equation. Curve Number (CN) selection is related to soil type, soil infiltration capability and land use/land cover (LU/LC). The areas of different land use/land cover and soil combinations were obtained and accordingly different CN values were assigned as per NRSC Hydrological Soil Group (HSG) classification. Thus weighted CN for whole sub watershed was calculated and found to be 59.78. Based upon 5-days (13-17 June, 2015) antecedent rainfall period, the CN for Antecedent Moisture Condition (AMC-III) was determined by using a conversion factor as suggested by Suresh, 1997 (Soil and Water Conservation Engineering).Using this CN value, Potential Maximum Soil Retention (S) was calculated as 71.64 mm In order to account for water losses occurring due to plant interceptions, infiltration and surface storage which occur prior to runoff, Initial abstraction 'Ia' was calculated as 0.2 times of potential storage. The calculated value of S in combination with six years (2008-2013) annual rainfall (P) data was further used to estimate soil runoff from SCS equation. Result showed that the surface runoff volume (Q) is directly proportional to the annual rainfall (P). Coefficient of determination was found to be 0.90 for the study area which reveals a very linear relationship between rainfall and runoff. Six year (2008-2013) average annual rainfall of 720.68 mm produces a discharge runoff of 641.94 mm. It was concluded that a large amount of total rainfall i.e. about 89% goes untapped and waste as a surface runoff in Morni sub watershed.

Key words: Surface runoff, Watershed, Geo-informatics, SCS-CN

1. INTRODUCTION

A watershed is the area covering all the land that contributes runoff water to a common point. It is a natural physiographic or ecological unit composed of interrelated parts and functions. In some watersheds the aim may be to harvest maximum total quantity of water throughout the year for irrigation and drinking purpose. In Haryana, the availability of accurate information on runoff is scarcely available at most of the sites. However, quickening of watershed management programmed for conservation and development of natural resources management has necessitated the runoff information.

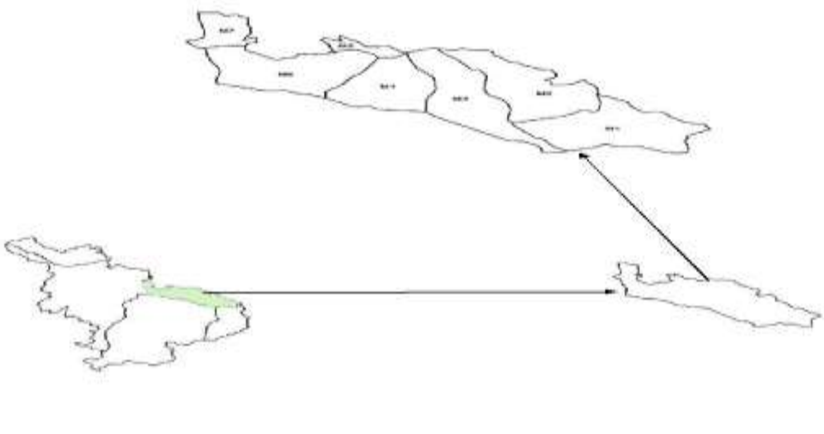

Fig. 1.1 Study Area

Advances in computational power and growing availability of spatial data have made it possible to accurately predict the runoff. The possibility of rapidly combining data of different types in a Geographical Information System (GIS) has led to significant increase in its use in hydrological applications. GIS and remote sensing are presently being used for solving environmental problems like degradation of land by water logging, soil erosion, deforestation, changes in ecological parameters and many more. An estimation of surface runoff is essential for reducing sediments and consequent hazards because runoff is the driving force behind soil erosion. Although many hydrologic models are available for the estimation of runoff, most physically based models are limited because of their large number of input parameters and complicated calibration requirements (Wu et al., 1993; Kothyari and Jain, 1997).Jasrotia et al; 2002 used a mathematical model to estimate rainfall, runoff in conjunction with remote sensing data and GIS using SCS CN method and runoff potential map. Amutha et al; 2009 showed that estimation of runoff by SCS-CN method integrated with GIS can be used in watershed management effectively. Somashekar et al.;2011 estimated surface runoff of Hesaraghatta watershed. The SCS-CN model is a simple, empirical model with clearly stated assumptions and few data requirements. Therefore, it has been widely used for water resource management, storm water modeling and runoff estimation for single rainfall events in small agricultural or urban watersheds (Greene and Cruise, 1995; Tsihrintzis and Hamid, 1997; Lewis et al., 2000; Chandrmohan and Durbude, 2001; He, 2003; Mishra et al., 2006; Sahu et al., 2010a). In the present study SCS-CN method was used to calculate runoff discharge of Morni sub watershed using ARCGIS 10 and ERDAS IMAGINE 2011 software and appropriate input data.

2. STUDY AREA

The present study was carried out for Morni sub watershed in Panchkula district (Fig. 1.1), Haryana. It is located at latitude 30°40'17"- 30°46'10"N and longitude 77°00'01"-77°09'52"E covering an area of about 6551.40 ha. The study area is divided in 7 micro watersheds named as M1, M2, M3, M4, M5, M6 and M7. The climate of Morni sub watershed is having, hot summers, cool winters and good monsoon rainfall. It has great variation in temperature (-1 °C to 43 °C). The average annual rainfall for six year (2008-2013) was found to be 720.68 mm, out of which 80% of annual rainfall is received in June to September months and also receives some rainfall in winter months due to western disturbances. Despite heavy rains in the area, water retention is very low because of steep slope which develops high surface runoff. Generally, the slope of the district is from north east to south west and most of the seasonal streams flow down and while spreading gravels/pebbles on its way. Research area is characterized by an undulating landscape and mountain ranges covered with vast forests. The relief of the area ranges from the lowest of 448.15 m to the highest elevation of 1453.43 m. Morni hills constitutes the highest point of Panchkula as well as of Haryana. The sub watershed consisted of sandstones/conglomerate, red stones, purple shale, grey to greenish sandstone with clay intercalations & purple shale, Quartzite, stromatolite, limestone and dolomite formation constituents. Also Valley fill shallow, Piedmont Alluvial Moderate and Structural Hill (Less, moderate and highly dissected) were observed in the study area. Various minor faults/fractures were also observed in the AOI.

3. MATERIALS AND METHODOLOGY

Survey of India (SOI) Toposheet No. 53B/13, 53B/14 and 53F/02 on 1:50,000 scale were used to delineate the study area. Very high resolution data from WORLDVIEW-2 satellite with 8 band multispectral capabilities of April 11, 2012, June 11, 2012 and June 12, 2012 on 1:2500 scale were used for digitization of land use/land cover map. Satellite data which is available in raster form needs to be geo-referenced to a map coordinate system so as to generate special information to be used subsequently in GIS environment. The process of geo-referencing spatial coordinate system WGS 1984 UTM zone 43N was assigned to raster image for the transformation of raster image to input coordinate system. All required images were rectified and then subjected to mosaicing and image enhancement. A DEM, Digital Elevation Model, is a raster file that depicts elevation in dark and light pixels; dark pixels denoting low areas of elevation, and light pixels denoting high areas of elevation. From the processed imagery DEM was extracted by specifying cell size of 2x2 m in x, y coordinates of LPS Project Manager toolbar. World view -2 Black and white data was used to derive DEM. Next step is to generate contours from extracted DEM. After mosaicing the extracted DEM using ERDAS EMAGINE 10.1, contours were generated in ARCMAP 10 with a given interval of 5 m. Table 3.1 shows the source of all required data to carry out this research.

Table-3.1 Data Used and Source of Data

S. no	Data Used	Source
1	Worldview-2 multispectral 8 band satellite data	HARSAC, Hisar
2	Worldview-2 stereoscopic image (black and white)	HARSAC, Hisar
3	Soil texture and Geology map	HARSAC, Hisar
4	Rainfall data	www.imd.gov.in

3.1 Land Use/Land Cover Classification

On screen digitization was done on WORLDVIEW-2 satellite data imagery on 1:2500 scale. The False Color Composite (FCC) (Blue, Green and Near IR1 band) of study area was prepared for preparation of land use/land cover maps. Land use/land cover was categorized in to different classes of built up area/settlement, agricultural land, wasteland, water bodies and forest. These areas were further sub-divided. Also on screen visual interpretation technique (Table 3.2) was used for the preparation of land use/land cover map which was based on the standard visual interpretation elements such as shape, size, colour, tone, texture and pattern.

Table-3.2 Land Use/Land Cover Class Interpretation Key

Land use/land cover classification	**Tone**	**Size**	**Shape**	**Texture**	**Association**
Built-up area/settlements	Whitish	Varying	Definite	Coarse	Streets
Agricultural land ➢ Terrace cultivation ➢ Old agricultural plantation	 Greenish Dark red	Varying	 Definite Regular	 Fine to medium Coarse with mottling	 Foothill/Rocky slope Agricultural land
Scrub (Wasteland)	Brown/Dull red	Varying	Irregular	Coarse	River/Rocky area
Water bodies ➢ River course ➢ Natural Pond	 Dark blue Light blue	Varying	 Irregular Irregular	Smooth	Built up area/agricultural land/scrub/forest
Forest ➢ Open forest ➢ Scrub Forest	 Red Dull red/Brown	Varying	Irregular	 Coarse with dark mottling Coarse with dark mottling	Outskirt of agricultural land

3.2 The Curve Number Method

The SCS Runoff Curve Number method is developed by the United States Department of Agriculture (USDA) Soil Conservation Service (SCS) and is a method of estimating rainfall excess from rainfall (Hjelmfelt, 1991). The method is described in detail in National Engineering Handbook (2004). This method is used widely and is accepted in numerous hydrologic studies. The SCS method originally was developed for agricultural watersheds in the mid-western United States; however it has been used throughout the world far beyond its original developers would have imagined.

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

where

- Q is runoff [L]
- P is rainfall [L]
- S is the potential maximum soil moisture retention after runoff begins [L]
- Ia is the initial abstraction ([L]; in), or the amount of water before runoff, such as infiltration, or rainfall interception by vegetation; and Ia = 0.2S.

Curve number is the governing factor, which predominantly affect the runoff amount which flows over the land after satisfying all losses. Although curve number itself has no physical meaning but also plays an important role in hydrological response.

The runoff curve number, CN, is then related

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

Curve number selection is related to soil type, soil infiltration capability, land use. To account for different soils' ability to infiltrate, NRCS has divided soils into four hydrologic soil groups (HSGs). They are defined as given in table 3.3.

Table-3.3 Hydrological Soil Group Classification

Soil group	Description	Minimum Infiltration
A	Soils in this group have a low runoff potential (high-infiltration rates) even when thoroughly wetted. They consist of deep, well to excessively well-drained sands or gravels. These soils have a high rate of water transmission.	7.62 - 11.43
B	Soils in this group have moderate infiltration rates when thoroughly wetted and consists chiefly of moderately deep to deep, well-drained to moderately well-drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.	3.81 - 7.62
C	Soils have slow infiltration rates when thoroughly wetted and consist chiefly of soils with a layer that impedes the downward movement of water, or soils with moderately fine-to fine texture. These soils have a slow rate of water transmission.	1.27 - 3.81
D	Soils have a high runoff potential (very slow infiltration rates) when thoroughly wetted. These soils consist chiefly of clay soils with high swelling potential, soils with a permanent high-water table, soils with a clay layer near the surface, and shallow soils over nearly impervious material. These soils have a very slow rate of water transmission.	0 - 1.27

(Source: Mc. Cuen, 1982)

According to LU/LC of the study area, curve number values were assigned as per their defined hydrologic soil groups. Table 3.4 shows the curve number values with respect to the hydrologic soil groups essential for SCS method.

Table-3.4 Curve Number Values With Respect to the Hydrologic Soil Groups

S. no.	Land use	Hydrologic Soil Group			
		A	B	C	D
1	Agricultural land without conservation (kharif)	72	81	88	91
2	Double crop	62	71	88	91
3	Agriculture plantation	45	53	67	72
4	Land with scrub	36	60	73	79
5	Land without scrub	45	66	77	83
6	Forest (degraded)	45	66	77	83
7	Forest plantation	25	55	70	77
8	Grass land/pasture	39	61	74	80
9	Settlement	57	72	81	86
10	Road/railway line	98	98	98	98
11	River/stream	97	97	97	97
12	Tanks without water	96	96	96	96
13	Tanks with water	100	100	100	100

(Source: Chow et al., 1988)

3.3 Antecedent Moisture Condition

After assigning a large variation of Curve number values in different land use land cover of sub watershed, weighted CN was calculated and CN value for AMC-III was obtained from table 3.6. Table 3.5 shows the Antecedent Moisture Conditions (AMC) classification based upon five days antecedent rainfall period.

Table-3.5 Classification of Antecedent Moisture Conditions (AMC)

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

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Table-3.6 Curve Numbers for AMC-I and AMC-III

S. No.	CN for AMC-II	Corresponding CN for	
		AMC-I	AMC-III
1	10	0.40	2.22
2	20	0.45	1.85
3	30	0.50	1.67
4	40	0.55	1.50
5	50	0.62	1.40
6	60	0.67	1.30
7	70	0.73	1.21
8	80	0.79	1.14
9	90	0.87	1.07
10	100	1.00	1.00

3.4 Co-efficient of Determination of SCS-CN Method

The coefficient of determination, denoted R2, is a number that indicates how well data fit a statistical model – sometimes simply a line or curve. It is a statistic used in the context of statistical models whose main purpose is either the prediction of future outcomes or the testing of hypotheses, on the basis of other related information. It provides a measure of how well observed outcomes are replicated by the model, as the proportion of total variation of outcomes explained by the model.

4. RESULTS

Various thematic layers were prepared such as Land use/land cover, Digital elevation model, soil texture map, geology map, Hydrologic soil group, annual rainfall data and Curve number map using primary and secondary available satellite data and sources.

4.1 Land Use/Land Cover

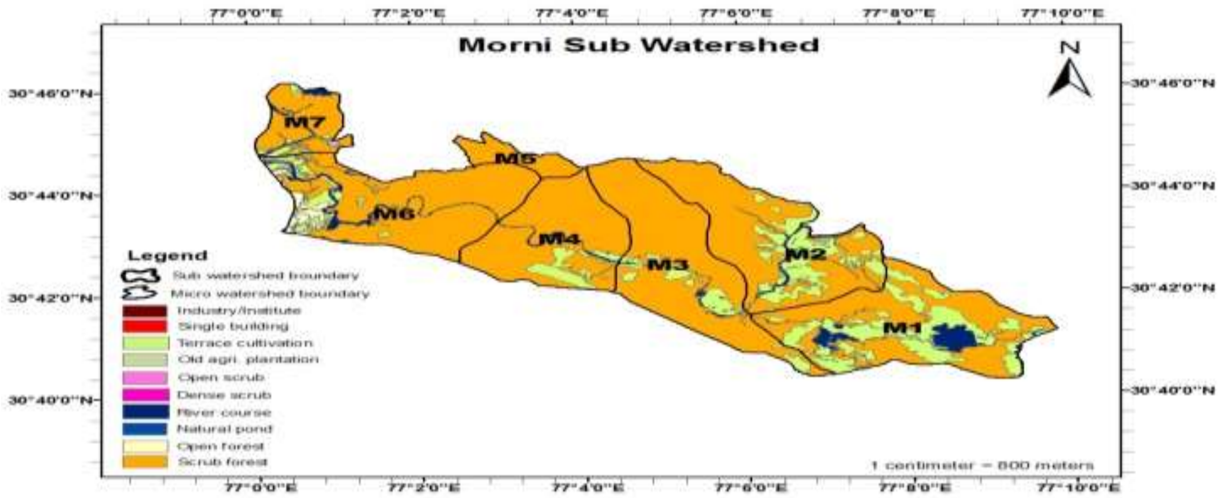

Fig. 4.1 Land Use/Land Cover Map

The study area constitutes of different land use and land cover as shown in Fig. 4.1, about 78.18% of area is covered by forest (Open forest and Scrub forest), 16.31% of area is occupied by agricultural land (Terrace cultivation and Old agricultural plantation), 0.06% and 0.24% is under built up area/settlement and scrub land, respectively and rest of the 5.21% of the area is found to be under water bodies viz. natural pond and river courses. It was found that Scrub forest is the predominant land cover with in the classification of forest land, accounting about three fourth (77.23%) or 5059.76 ha of the total geographical area and which was found maximum in M3 (1083.62ha) followed by M6 (1038.94 ha) micro sub watershed. Area under water bodies (river course) is greater in M1 (126.45 ha) micro sub watershed. Scrub land covers few area only in M6 (5.64ha) and M7 (10.23 ha) micro sub watershed.

4.2 Digital Elevation Model (DEM)

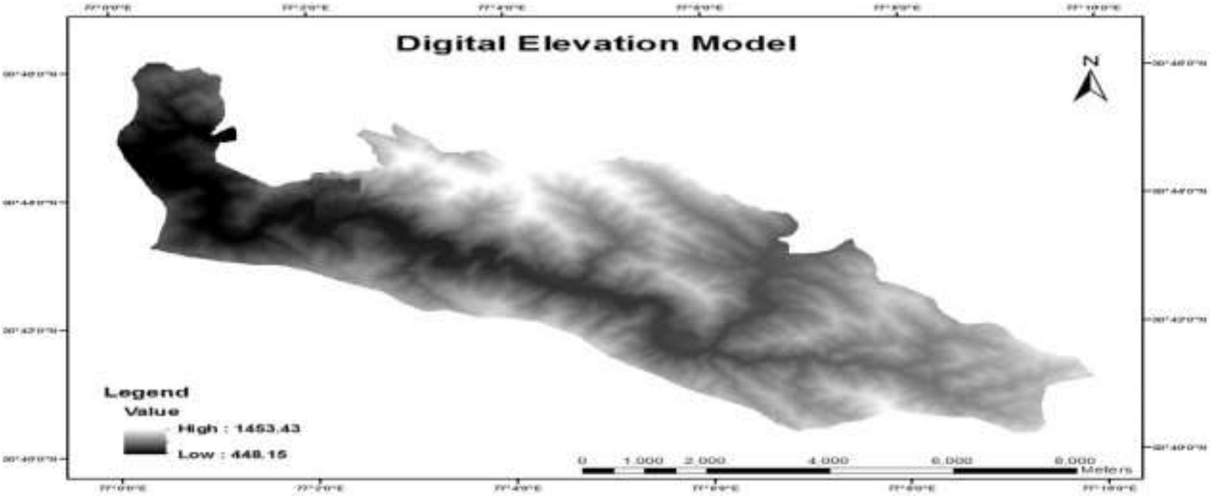

Fig. 4.2 Digital Elevation Model

It was found that the topography of the study area varies from 448.15 to 1453.43m (Fig. 3) above mean sea level. Result shows that topography of sub watershed has a series of hills and ridges towards northern and southern east part of the area whereas western part has less undulating topography. Most of the drain flow was observed toward southern direction and connected together in one main stream at southern east part of study area.

4.3 Soil Texture and Geology of Study Area

Soil texture was very important factor in the study. Therefore, Fig. 4.3 clarify the soil texture classification i.e. Clayey & loamy, Coarse loamy, Fine loamy, Loamy and a small area covered by water body and habitation was assumed as rocky surface due to unavailability of data. Based upon the soil texture, Hydrologic soil map was prepared.

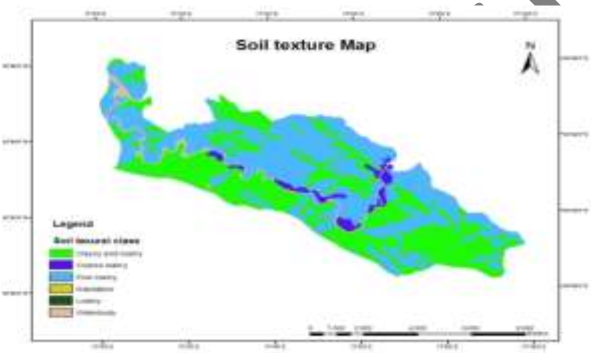

Fig.4.3 Soil Texture Map

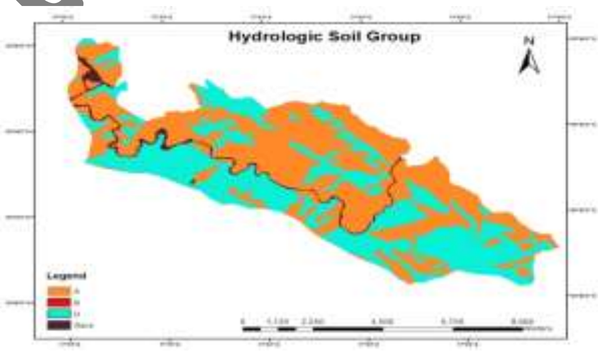

Fig. 4.4 Hydrologic Soil Group Map

Geology of the sub watershed was categorized in to mainly four class (Fig. 4.5) i.e Nahan Formation Lower Siwalik, Subathu Formation, Pinjore Formation Upper Siwalik, Kasauli/ Dagshai Formation Dharamshala Group which covers 2.13%, 32.81%, 0.39% and 64.68% of the total area of research work.

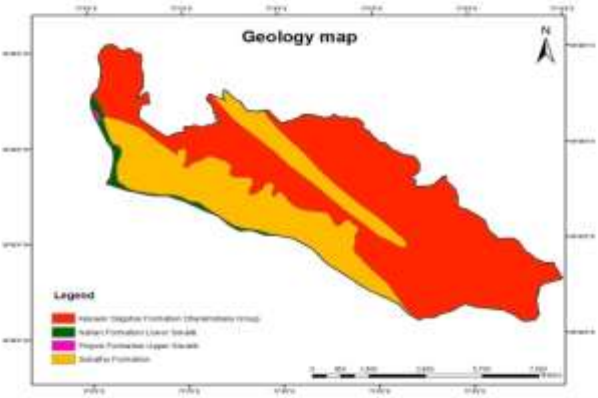

Fig. 4.5 Geology Map

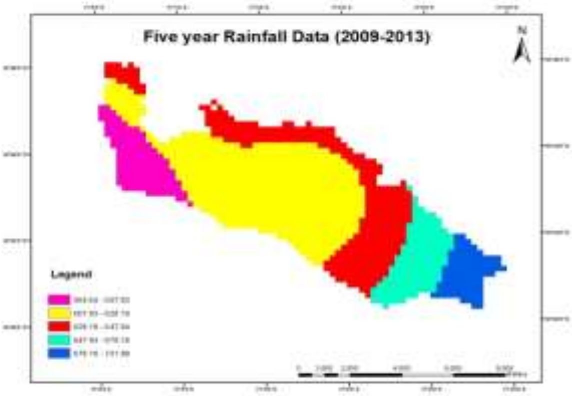

Fig. 4.6 Rainfall map (2009-2013)

4.4 Rainfall Data

Interpolation process is called to obtain the unknown points from the known points. The unknown pixels are estimating by averaging the known points of the near each pixel and values that are closer to the centre of pixel and has higher weight in estimating unknown value. In this study, raster map of rainfall (Figure 7) was obtained from average annual rainfall of five year (2009-2013) data. Results show that annual rainfall data varies from 564.64mm to721.99mm. Lowest annual rainfall never goes below from 549.5mm from 2009 to 2013. It was found that maximum rainfall occurred in eastern region and mini towards southern west part of the study area.

In addition to the 5-year rainfall data, annual rainfall for 2008 was also considered for more accuracy then it was found that the average annual rainfall for a period of 6 year (2008-2013) is 720.68mm. During the year 2008, rainfall was noted as maximum (1222mm) followed by 2013 (709.6mm) and minimum in 2011 (623.5mm).

Curve number varies from 0-100. Zero CN describes the hydrological response only with infiltration whereas about 100 are assigned to water bodies. As soon as CN is increased runoff will also increase. By intersecting the land use/land cover map and soil map the curve number was assigned to each combination of land use and soil type. Weighted CN was found as 59.78 for AMC-II condition. Using conversion factor (Table 4.6) AMC-III was calculated as 77.71 based upon total 5-days antecedent rainfall period. Abstraction ratio (Iα) was determined as 14.33 from potential maximum soil moisture retention (S).

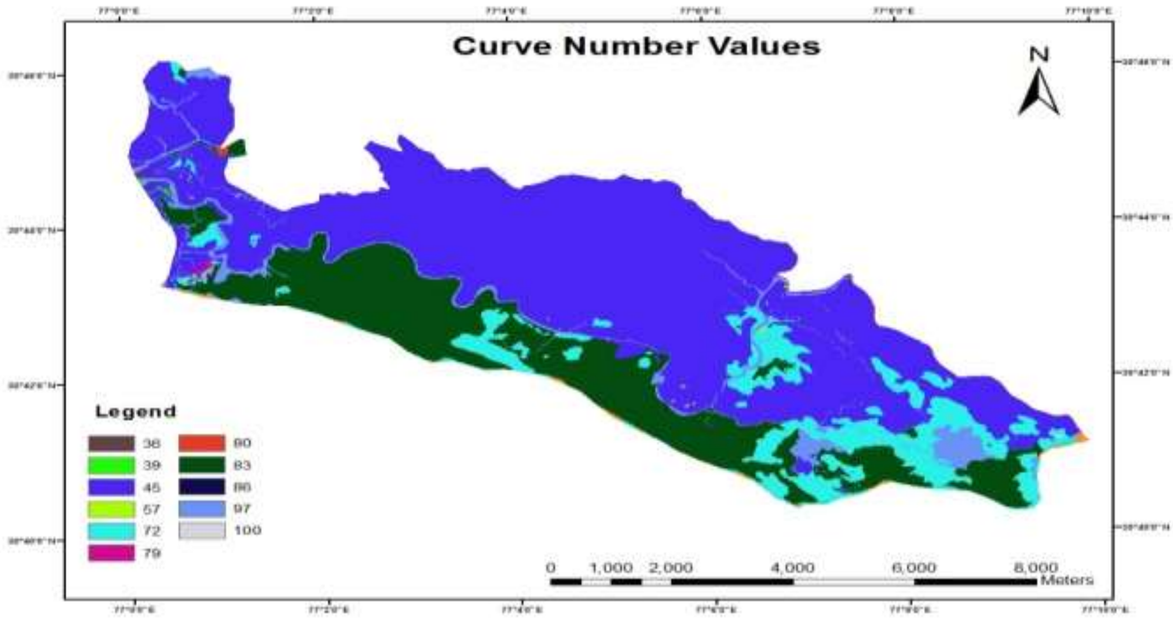

Fig. 4.7 Curve Number Values

From SCS curve number method runoff discharge for the six year (2008-2013) was calculated as shown in table 7, using annual rainfall data. The maximum, minimum and average runoff was estimated as 1140.04mm (2008), 545.07mm (2011) and 641.94 respectively.

Table-4.7 Annual Rainfall and Runoff for Sub Watershed

Year	**Annual rainfall, mm**	**Runoff (Q), mm**
2008	1222	1140.04
2009	399.5	324.77
2010	707.4	628.14
2011	623.5	545.07
2012	662.1	583.27
2013	709.6	630.32

Fig. 4.8 indicates the rainfall runoff relationship for the Morni sub watershed which indicates a linear relation between rainfall and runoff value. It can be seen from the fig. 4.8 that rate of runoff discharge is directly proportional to the rainfall amount. The rainfall and runoff are strongly correlated with a correlation coefficient (R^2) value equal to 0.90.

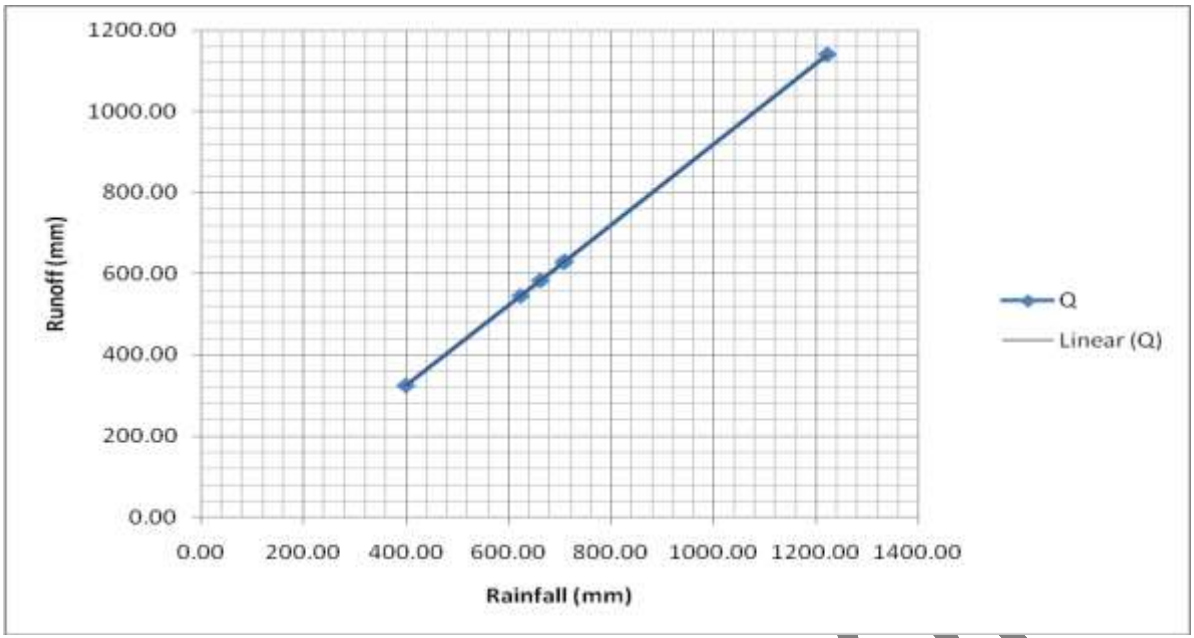

Fig. 4.8 Rainfall Runoff Relationship for Morni Sub Watershed

CONCLUSION AND SUMMARY

In the present study, the methodology for determination of runoff for Morni sub watershed using GIS and SCS-CN method was described. This approach could be used in this sub watershed for planning of various conservations measures. The results of this study suggest that the use of GIS, to provide a variety of maps, including maps of land use/land cover and watershed curve number map, is suitable to calculate the runoff discharge of a sub watershed. The calculations and results, based on the SCS method, shows that the average annual runoff is 641.94mm at an annual average rainfall of 720.68mm in the total area watershed area of 6551.40ha.

It was concluded that rainfall and runoff has a very good relationship with a correlation coefficient of 0.90. Surface runoff of the watershed is very good with respect to the annual rainfall, so this water can be stored by recommending various site suitability based water harvesting structures for its maximum utilization and also it will reduce soil erosion up to some extent as well as increase the social status by planning some development measure policies.

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