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APPLICATION OF SURFACE RUNOFF ESTIMATION USING NRCS-SCS CURVE NUMBER METHOD USING REMOTE SENSING AND GIS: A CASE STUDY OF TAVARJA LAKE CATCHMENT OF MAHARASHTRA.

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ABSTRACT

Surface runoff estimation of ungauged watershed is one of the major problem, so estimation of surface runoff using Natural Resource Conservation Service is one of the most widely used method. The hydrologic soil groups, land use land cover and slope maps were generated with GIS tools. The curve number values from NRCS- SCS CN standard tables were assigned to the intersected hydrologic soil groups and land use maps to generate CN values map. The curve number method was followed to estimate runoff depth for selected storm events in the watershed. Weighted CN value and the storage retention (S) for the entire basin of Tavarja lake catchment are estimated as 86 to 94 respectively. So it indicates that the study area is characterized by high runoff potential. Runoff values are estimated on different rainfall sections of the study area. The study ultimately leads to the development of rainfall runoff method based on NRCS-SCS- CN method. The runoff for any rainfall event occurred can be estimated by feeding the inputs into the corresponding method which would in turn be helpful on significant conservation of water in the study area.

Keywords: surface runoff, NRCS- SCS CN, LULC, AMC, HSG, RS and GIS

1. INTRODUCTION

Surface runoff is an important variable of hydrologic cycle. Rainfall excess is that portion of total rainfall that is not stored on the land surface or infiltrated into underlaying soil. It eventually comprises direct runoff to downstream rivers, streams, storm sewers and other conveyance systems. It is one of the dynamic feature of the nature that affect the flora and fauna in one hand and determinant of the rate of weathering and erosion on the other.[1] Therefore, accurate estimation of runoff from rainfall is important for land and water resource management in drainage basin of draught prone region of monsoonal belt. There are several methods available for estimation of surface runoff. Among them, the Natural Resources Conservation Service Curve Number (NRCS- SCS- CN) is most widely used method because of its simplicity, flexibility and versatility.

The surface runoff and its characteristics depend mainly on amount of precipitation, amount of infiltrated water, surface accumulation of precipitation and interception (Muchova and Antal 2013). These conditions create the rate of surface runoff and soil loss in the particular region. This method is developed by United State Department of Agriculture (USDA). The NRCS-SCS- CN method is based on water balance equation and two fundamental hypotheses. [2]The method has been widely applied to ungauged watershed systems and has proved to be rapid and accurate estimation of surface runoff. [3]

Remote sensing and GIS can be used to determine hydrologic input parameters such as soil moisture delineate landuse classes that are used to define runoff coefficients. soil is considered as a basic element in civil engineering fields. Therefore RS and GIS techniques can be used to classify the soil groups. [4], [5]

2. OBJECTIVES

1. The main objective of this study is to estimate surface runoff using NRCS- SCS- CN method.
2. To extract the impact of Land Use Land Cover (LULC) and impervious surface and soil fractions on surface runoff from remotely sensed imagery.

3. THE STUDY AREA

The area selected for present investigation is located at about 20 km. to the west of Latur city of Maharashtra. It is 6th order channel basin and can be classified as macro watershed. It is roughly elongated and bowl shaped and most of its area comes under agricultural land. Study area occupies its position in semi-arid track of Maharashtra, and therefore exhibits different kind of geomorphological features and processes.

The Tavarja lake catchment extends between 18°14'00" N to 18°24'00"N latitude and 76°15'00" E to 76°27'00" E longitude. The study area is located in Latur and Ausa tahsil's of Latur district and Osmanabad tahsil of Osmanabad district. Tavarja river basin is one of the sub basins of river Manjara. (right bank tributary of river Godavari). It is a medium size dam having the catchment area is measures about 250.52 km^2.

The average annual rainfall varies between 75 to 100 cm.with average annual temperature ranges between 27ºC to 28ºC. The average annual evaporation and evapotranspiration of the region lies between 6.60 to7.00 mm/day .Soils are black and dark black i.e. regure soils which contain high amount of humus. About 60-to70 % of the region is under cultivation. The area is characterized by moderate sloping ground. The altitude of the region varies between 610M.to700M (Tavarjaheda at the foot of the dam). The location map of the study area is shown in the figure no.1

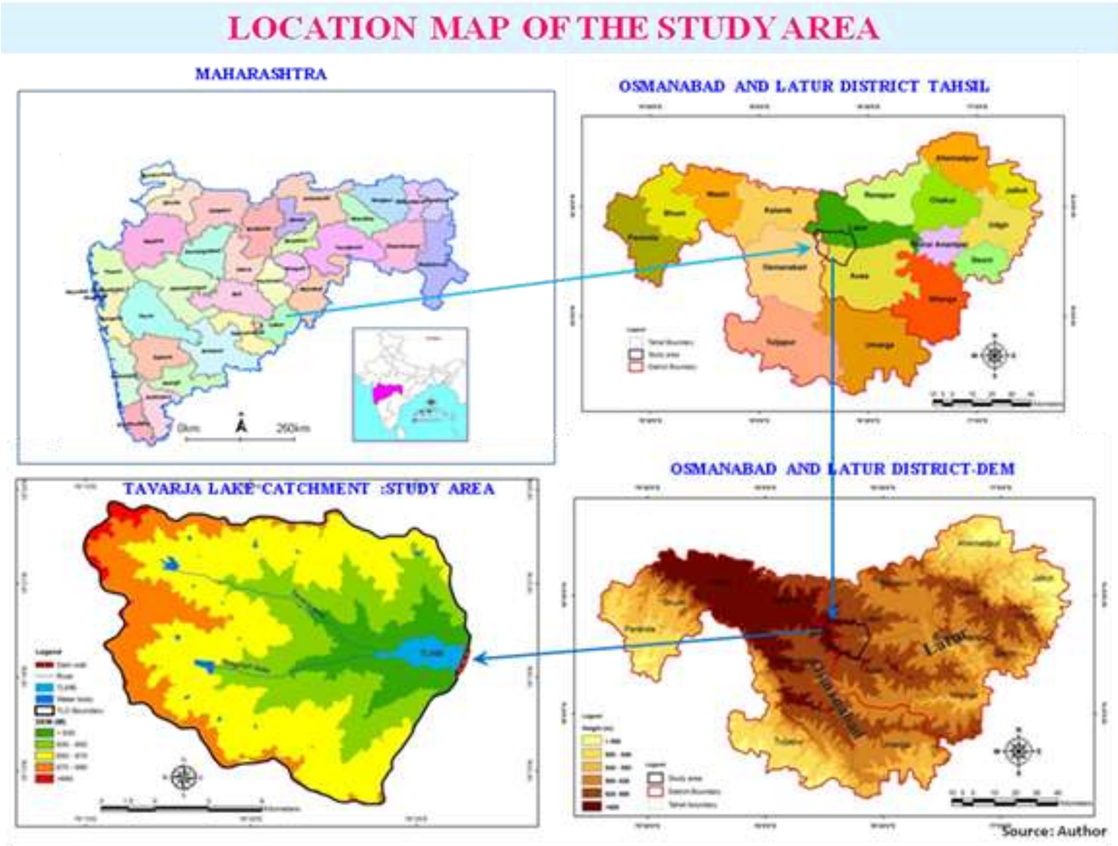


Fig.no.1. Location map of the study area (Tavarja lake catchment)

4. METHODOLOGY

The base map of the study area has been prepared from the Survey of India (SOI) toposheets numbers 56 B/3, 56 B/4, 56 B/7 and 56 B/8 on 1:50,000 scales. In the present study NRCS- SCS- CN procedure is used for estimation of surface runoff. The main imputes required to estimate annual runoff are rainfall, Hydrological Soil Group (HSG), geology, slope of the region, Land use / Land cover (LULC) and infiltration or Antecedent Moisture Condition (AMC). The details of required database and their sources are mentioned in table 1.**Table No.1 Details of required database for surface runoff**

Types of data	Details of data	Sources of data
Toposheet	56 B/3, B/4,B/7,B/8 1:50000	Survey of India (SOI)

Thematic Map	LULC	NRSA, Hyderabad.
	Soil type	Field work by author
	Hydrological Soil Groups	Infiltration rate and LULC
	Infiltration variation	Field measurement and infiltrometer
	Geology	GSI, Pune.
	Curve Numbers	NRCS, USDA
Satellite data	ASTER and SRTM data	NRSC, Hyderabad
Rainfall data	Rainfall, Global graded rainfall data, 2011	FAO- Food and Agriculture Organization

4.1. NRCS-SCS-CN Method

The NRCS-SCS-CN method is based on the water balance equation

$$Q/(P-I_a) = F/S \ldots\ldots\ldots\ldots\ldots (1)$$

Where, P= total rainfall; I_a= initial abstraction; F= cumulative infiltration or actual retention; Q= direct runoff; S= potential maximum retention or infiltration. The total retention for a storm is a function of I_a and S, so the water balance equation can be expressed as,

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

The second hypothesis relates the initial abstraction I to the potential maximum retention. Initial abstraction, I_a was assumed to be a function of maximum potential retention, S an empirical relationship between I_a and S was expressed as

$$I_a = 0.2S \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Combining the water balance equation and proportional equality hypothesis the NRCS.SCS CN method is represented as

$$Q = (P-0.1S)^2/P+0.7S \ldots\ldots. (4)$$

S= water storage/potential maximum retention/ infiltration in (mm) or inches

$$S = (25400/CN) - 254 \ldots\ldots\ldots (5)$$

CN is a dimensionless number and a function of landuse, antecedent soil moisture content and other factors effecting run off and retention of watershed for imper- vioes and water surfaces CN=100; for natural surface CN<100.

In this study, the CN are weighed with respect to micro watershed area

$$CN = \Sigma\, (CNi \times Ai)/A \ldots\ldots (6)$$

Where, CN = Weighted curse number; CNi is the curve number ranging from 1 to 100. Ai= area of sub basin with curve number CNi and A= Total area of watershed.

4.2. Generation of Hydrologic Soil Group (HSG) map

The hydrologic soil group is an attribute of the soil mapping unit (each soil mapping unit is assigned a particular hydrologic Soil group: A, B, C, and D respectively) where group 'A' is generally had the smallest runoff potential and 'D' is the greatest. Group 'B' has a moderate infiltration rate. Group 'C' have low infiltration rates when thoroughly wetted and consists chiefly of soils with a layer that impedes downward movement of water and soils with moderately fine to fine structure. Group 'D' has the highest runoff potential. HSG are based on the infiltration rate and the landuse conditions of the study area.

4.3. C N value Estimation

The CN values for the study area were generated using the landuse and HSG combination and by following the CN table given in USDA (1986). The table no.2 specifies the CN values for different landuse and HSG combinations for the catchment.

Table no.2 CN values for different Landuse and HSG combinations

Cover description		Curve numbers for HSG			
Cover type	Average impervious (%)	A	B	C	D
Agriculture	5	67	77	83	87
Barren	5	39	61	74	80
Hills	5	30	58	71	78
Natural vegetation	5	36	60	73	79
Water body	100	100	100	100	100

4.4. Antecedent Moisture Condition

The term antecedent is an indicator of watershed wetness and availability of soil storage prior to a storm taken from previous 5 day rainfall in the watershed. The NRCS-SCS-CN method uses the concept of AMC in three levels;

4.4.1. AMC I: Lowest runoff potential: watershed soils are dry enough for satisfactory cultivation to take place (dry condition)

4.4.2. AMC- II: An average condition (The CN values) for AMC-II can be covered into CN values for AMC-I and AMC-III by using the SCS standard tables.

4.4.3. AMC-III: Highest runoff potential watershed soils practically standard from antecedent rains.

5. RESULT AND DISCUSSION

The study undertaken has aided assessment of changes in surface runoff in Tavarja Lake catchment (TLC). It also helped to investigate changes in landuse especially degree of imperviousness in different part of the catchment. One of the major factors affecting surface runoff is impervious surface.

The following sections highlight the result of research;

5.1. Land Use Land Cover (LULC)

Land use and land cover information is very important in the estimation for runoff as well as soil loss. [6]Information on land use and land pattern of their spatial distribution is one of the criteria in selecting a Curve Number (CN).

In the present stud area, maximum part i.e. 165. 27 Km^2 (65.92%) area is occupied agriculture land, 38.66 Km^2 i.e. 15.42% area is occupied by fallow land, 17.64 Km^{2}i.e. 7.04% covered by barren land, whereas only 12.35 Km^2 i.e. 4.93% land is occupied by vegetation cover and built up land covered 8.98 Km^2 i.e. 3.58 % area.

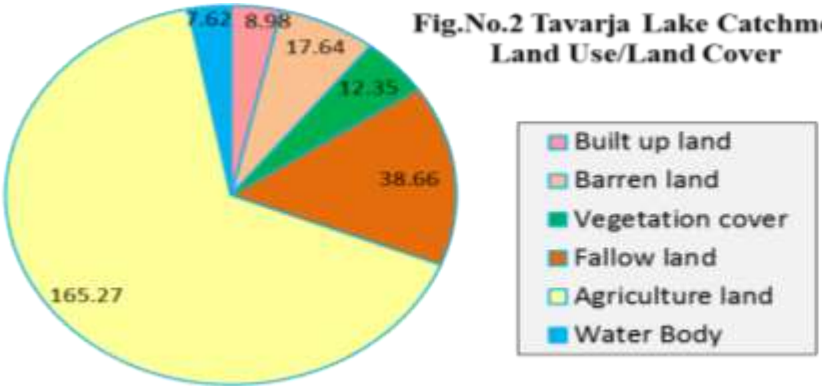
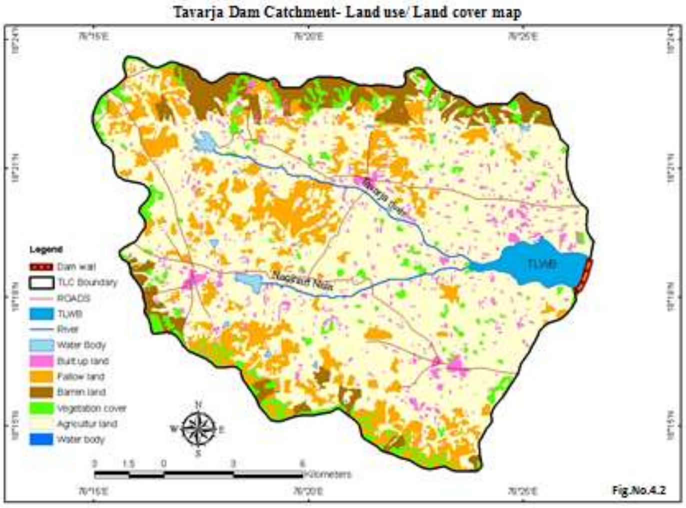


Fig.No.2 Tavarja Lake Catchment Land Use/Land Cover

Table No.3.Tavarja Lake Catchment Extent of Land Use/Land Cover category				
Sr.	**LULC**	**Total area**		
No.	**class**	**Km²**	**Ha.**	**Percentage**
1	Built up land	8.98	898	3.58
2	Barren land	17.64	1764	7.04
3	Vegetation cover	12.35	1235	4.93
4	Fallow land	38.66	3866	15.42
5	Agriculture land	165.27	16527	65.92
6	Water Body	7.62	762	3.04
Total Area		250.52	25052	**100.00**



5.2. Hydrological Soil Group (HSG)

Hydrologic soil group and variation of these groups in study area generated using GIS tool is shown in figure no.4 and fig. no. 5. All hydrologic groups including A, B, C and D were found in the tavarja lake catchment. Group A soils having low runoff potential due to high infiltration rate (5< cm/h). A group covers 3% of TLC. Group B soils having a moderately low runoff potential due to moderate infiltration rates (2 to 5 cm/h). It has occupied 9% part of the study area. Group C soils having a moderately high runoff potential due to slow infiltration rates i.e. (1 to 2 cm/h). This soil group has occupied 71 % part i.e. maximum part of the study area and finally group D is soils with a high runoff potential due to very slow infiltration rates (>2 cm/h). It covers 15% area of the study area and only 3 % area of the study area occupied by water body. The soil data layer was reclassified as a HSG map.

Fig.4. Tavarja Lake catchment: Hydrological Soil Group Variation map

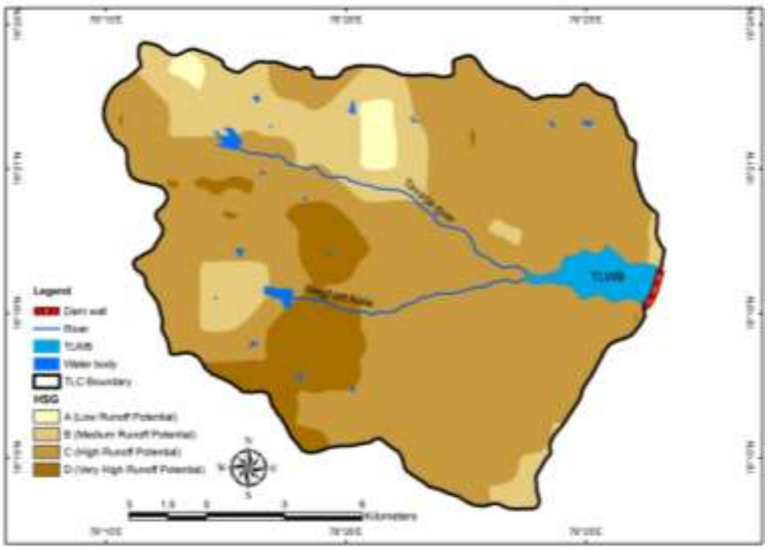


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Table No.4.2.Tawarja Lake Catchment

Extent of Hydrological Soil Group

Sr. No.	HSG	Total area Sq. Km.	Hectare	Percentage
1	A	4.53	453	1.81
2	B	37.56	3756	14.99
3	C	177.43	17743	70.82
4	D	23.38	2338	9.33
6	Water Body	7.62	762	3.04
Total area		**250.52**	**25052**	100

Fig.No.5.Tawarja Lake Catchment Extent of Hydrological Soil Group

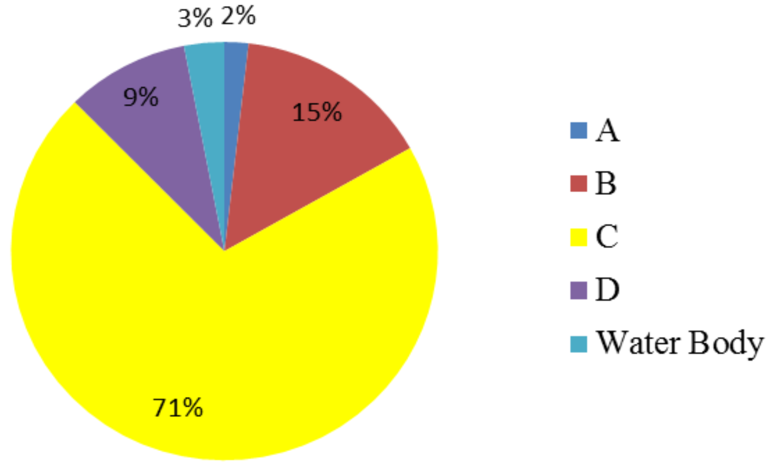

Table No.4.1.Hydrological Soil Groups

HSG	Soil Characteristics
Group A	These soils have low runoff potential and high infiltration rates even when topography wetted. They consist chiefly of deep, well to excessively drained sand or gravel and high rate of water transmission.
Group B	These soils have moderate infiltration rates when wetted and chiefly of moderately deep to deep, moderately well to well drained soils with moderately coarse texture. These soils have a moderate rate of water transmission.
Group C	These soils have low infiltration rates when thoroughly wetted and consists chiefly of soils with layer that impedes downward movement of water and soils with moderately fine to fine texture. These soils have a low rate of water transmission.

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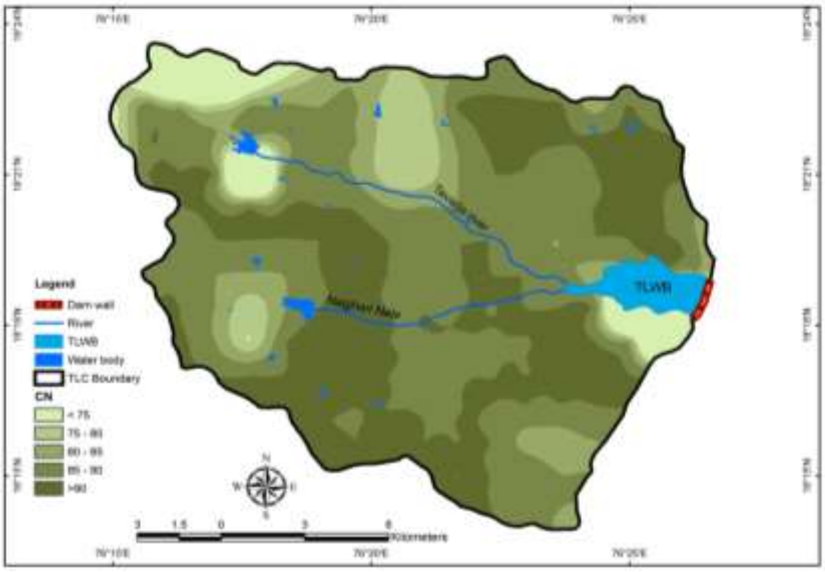
Group D	These soils have high runoff potential. They have very low infiltration rates when thoroughly wetted and consists chiefly of clay soils with high swelling potential, soils with permanent high water table , soils with clay pan or clay layer near the surface and shallow soils over nearly impervious material. These soils have a very low rate of water transmission.

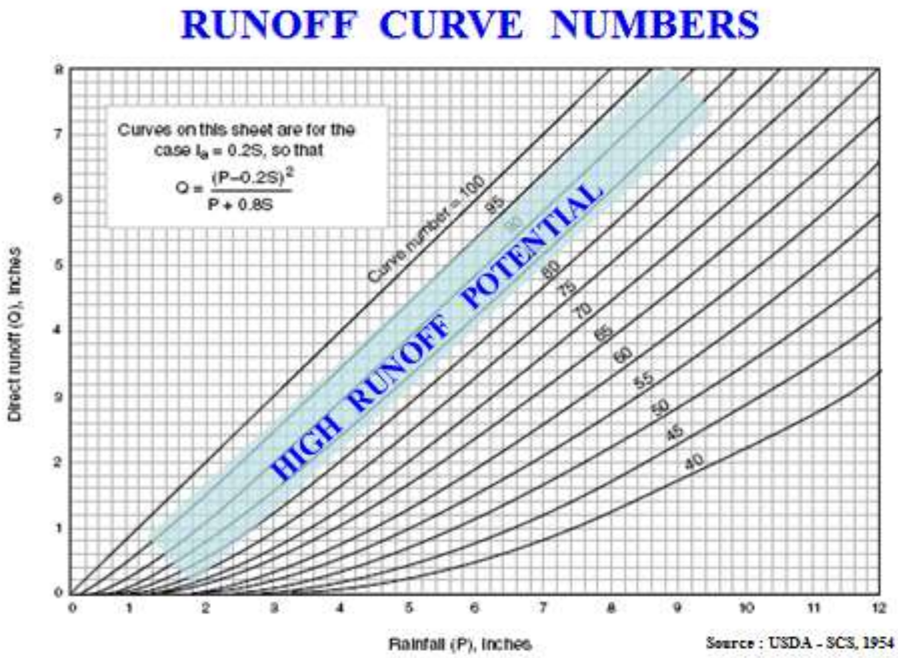
5.3. Curve Number values

The CN values for each hydraulic soil group and corresponding land use can be prepared using ARC-GIS. Hydrologic soil groups A and B lead to low CN value while the hydrologic group C and D lead to high CN value in Tavarja lake catchment. In the present study area maximum CN values lies in between 84 to 93. It indicates that maximum part of the study area characterized by high runoff potential

Fig. No.6.Tavarja Lake Catchment- Curve Number Variation

Map





5.4. Estimation of runoff depth

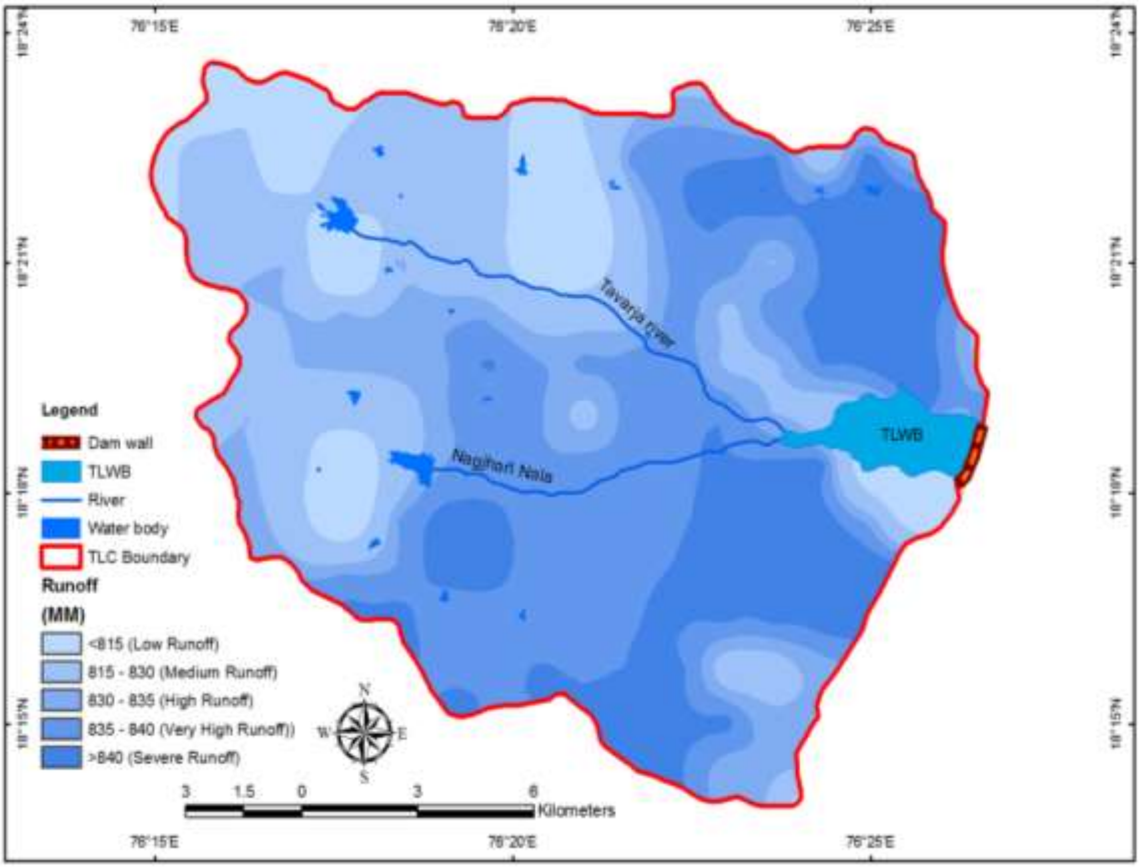
The rainfall database of study area from FAO and curve number variation were inputs to the NRCS-SCS-CN method and the runoff depth is estimated using the equation (Equation for hilly areas in Indian condition)

$$Q = (P-0.1S)^2/P+0.7S$$

Where Q is actual direct runoff (mm); P is total rainfall in (mm) and S is watershed storage (mm)

Fig. No.7.Tavarja Lake Catchment- Surface Runoff Variation Map

(Based on NRCS-SCS Curve Number method)



In the present study area severe runoff i.e > 840 mm has been observed over 50.25 Km^2 i.e. 20.06% area. Maximum part of the study area is characterized by very high type of runoff i.e. 835 to 840 mm and it covers about 63.27 Km^2 i.e. 25.26% of the total study area. High runoff (830 to 835 mm) covers an area over 36.93 Km^2 i.e. 14.74%. Medium runoff (815 to 830mm) covers 61.93 Km^2 of the study area, which is 24.72 %. Whereas low runoff covered 30.52 km^2 i.e. 12.18% part of the study area.

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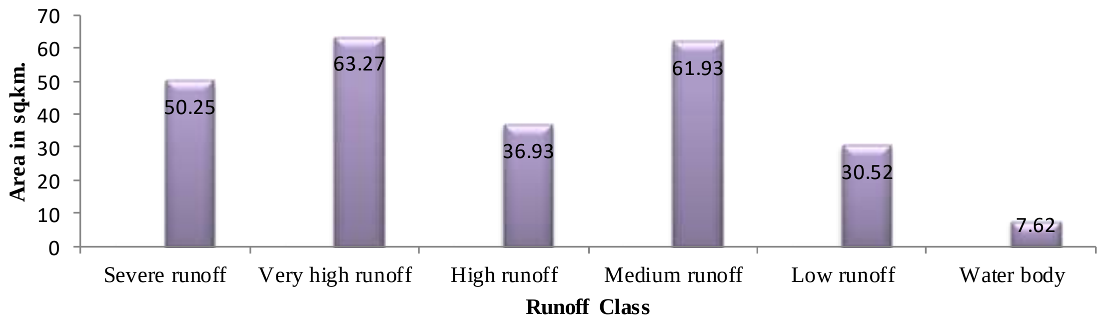
Table No.5.Tawarja Lake Catchemnt					
Extent of Runoff					
Sr.	**Runoff Category**		**Total Area**		
No.	Category	(mm)	Sq. Km.	Hectare	Percentage
1	Severe runoff	>840	50.25	5025	20.06
2	Very high runoff	835 - 840	63.27	6327	25.26
3	High runoff	830 - 835	36.93	3693	14.74
4	Medium runoff	815 - 830	61.93	6193	24.72
5	Low runoff	<815	30.52	3052	12.18
6	Water body		7.62	762	3.04
Total area			**250.52**	**25052**	**100**

Fig.No.8.Extent of Runoff



Conclusion

It is concluded that the rainfall, vegetation cover, soil condition and Land use and land cover are the most important factors in surface runoff estimation. The combination of Remote sensing and GIS and NRCS-SCS-CN method makes the runoff estimate more accurate and fast. Surface runoff varies spatially due to changes in soils, land use, slope, temporarily due to changes in soil water content etc. As runoff has a spatial variability: each and every portion of earth surface produces different volume of runoff based on their geo-hydrological environment. the surface runoff is varies time to time and space to space. In the present study area severe runoff i.e > 840 mm has been observed over 50.25 Km2 i.e. 20.06% area. Maximum part of the study area is characterized by very high type of runoff i.e. 835 to 840 mm and it covers about 63.27 Km2 i.e. 25.26% of the total study area

GIS is an efficient toll for the predation of the input data required by the NRCS-SCS-CN method; the estimated runoff using this curve number method is more acceptable then the runoff measured by the conventional method. the method has been applied for runoff estimation for ungauged watershed as like Tavarja lake catchment.

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References

1.Thakuriah Gitika and Saikia Rajan (2014) : Estimation of surface runoff using NRCS curve number procedure in Buriganga watershed, Assam ,India- A geospatial approach , International research journal of Earth sciences Vol.2 (5) 1-7

2. United States Department of Agriculture (USDA) (1972): National Engineering Handbook, Section A- Hydrology Washington DC: Soil conservation service, US Government printing office.

3. Mishra S.K., Singh V.P. (2003): Soil conservation service curve number methodology, Dordrecht, The Netherlands: Kluwer Academic publishers.

4. Melese A. M. and S.F. Shih (2002): Spatially distributed storm runoff depth estimation using Landsat images and GIS, computers and Electronics in Agriculture, Elsevier, 173-183.

5. Engman E.T. and Gurney R.J. (1991): Remote sensing in Hydrology, Champman and Hall, London 225-232.

6. Pal B. Samantha S. (2011): Estimation of Soil loss using Remote sensing and Geographic Information System (GIS) techniques: Indian journal of science and technology 1202-1207.