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Estimation of Surface Runoff using NRCS Curve number procedure in Buriganga Watershed, Assam, India - A Geospatial Approach

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Abstract

Estimation of surface runoff using Natural Resources Conservation Service - Curve Number (NRCS-CN) is one of the most widely used method. The GIS and remote sensing techniques facilitate accurate estimation of surface runoff from watershed. In the present study an attempted has been made to evaluate the applicability off Natural Resources Service Curve Number method using GIS and Remote sensing technique in a micro watershed Buriganga, Assam. In the study, hydrologic soil groups, land use and slope map bas been generated using GIS tools. Further, hydrological modeling in GIS with the aid of Remote Sensing technology is a powerful tool for system investigation of runoff generation in geo-hydrologic environment. To generate CN values map, the CN values from NRCS Standard Tables were allotted to intersected hydrologic soil groups and land use maps and then to estimate runoff depth for selected storm events in the micro watershed. The results of NRCS-CN method in runoff estimate can be used in humid watersheds management and conservation purposes.

Keywords: Runoff, GIS, remote sensing, *NRCS-CN*, land use.

Introduction

The term 'precipitaion' denotes different forms of atmospheric water that reaches the earth surface. Runoff is the flowing of precipitated water in the catchment area through a channel after satisfying all surface and sub surface losses[1]. After being evaporated, percolation through soil, rocks and surplus water flow over the surface through the stream channel is term as runoff. It is one of the dynamic feature of the nature that affect the flora and fauna in one hand and a determinant of the rate of weathering and erosion on the other. Therefore, accurate estimation of runoff from rainfall is important for land and water resource management in a drainage basin of humid monsoonal belt. Last few decades it is evident that study of hydrological behavior in river basins has been given due importance not only for understanding of fluvial geomorphic processes but also for proper water resource management. The information regarding runoff generation on the particular geo-environment is needed in dealing with many watershed development and management problem. In this context, there has been a growing need to study, understand and quantify the impact of major land use changes on hydrologic regime, both water quantity and quality[2]. In recent years GIS and Remote Sensing tools has facilitates the estimation of runoff from watershed and gained increasing attention among the scientists[3]. Hydrological modeling in GIS with the aid of Remote Sensing technology is a powerful tool of system investigation for runoff generation in geo-hydrologic environment. There are several methods available for estimation of runoff. Among them, the Natural Resources Conservation Services Curve Number (NRCS-CN) is most widely used method because of its simplicity, flexibility and versatility for small areas. But, in large areas such as river basin and watersheds, the implementation of this method becomes a tedious and time consuming matter. And it also concerning matter that the land use and land cover is a dynamic entity changes with time and space, has direct bearing on runoff generation by their retention and absorption mechanism. In this method land Use/Land Cover classes are integrated with the hydrologic soil groups in GIS to estimate weighted CN. The estimated weighted CN for the entire area can be used to compute runoff. The runoff values can be checked with the observed data. In the present paper an attempt has been made to estimate annual runoff of Buriganga watershed, Assam (India) using NRCS curve number equation using GIS for the year 2006.

Study area: The Buriganga watershed lies in an area between 26°7′12″ N to 26°18′ N latitude and 92°49′12″ E to 92°56′24″ E longitude. It is a tributary stream of river Jamuna. The river Buriganga is draining through an area of 126 km^2 from its source up to its confluence with the Jamuna River. Out of the total basin area, about 72.15 km^2 area lies in Karbi Anglong and remaining 53.88 km^2 of area lies in Nagaon district of Assam. The length of the basin is 20 kilometer and breath is 10 kilometer. The location map of Buriganga watershed is shown in figure 1. Geologically, Buriganga watershed is a part of drainage basin area of the Brahmaputra River. It comprises of Quaternary, Tertiary and Mesozoic sediments folded over the Achaean basement rocks. The North and North eastern part of the basin is occupied by by Karbi plateau and southern part comprises of alluvial plain.

Methodology

Scientific enquiry into fluvio geomorphic processes has direct link to runoff generation, and resultant land degradation caused by this moving water in surface and ground water flow. There are various hydrological models to estimate the surface water runoff. But most of the models in these groups are very tedious and time & money consuming. Soil and Water Assessment Tool (SWAT) provides two methods for estimation of surface runoff i.e. the NRCS-CN procedure (1972) and the Green and Ampt Infiltration method (1911). In the present study NRCS Curve Number procedure is used for estimation of surface runoff. The main inputs required to estimate annual runoff are rainfall, soil, geology, slope, land use/land cover and antecedent moisture condition. The details of required database and their sources are mentioned in table 1. Figure 2 is the boundary map of Buriganga watershed which is delineated from SOI, toposheet scale 1:50,000. 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 recent development of geo-spatial technology has given incredible opportunity to approximation the volume of runoff in a very cogent manner. In this paper, it is investigated how the geo-spatial technology can implement for estimation of runoff with some modification of NRCS curve number equation. The modification is done to fit the parameters of runoff into the GIS and Remote Sensing arena[4]. The Remote Sensing data has the ability to provide spatial-temporal measurement of many hydrological variables, which is quite tedious, time consuming and expensive to measure with available traditional methods and tools.

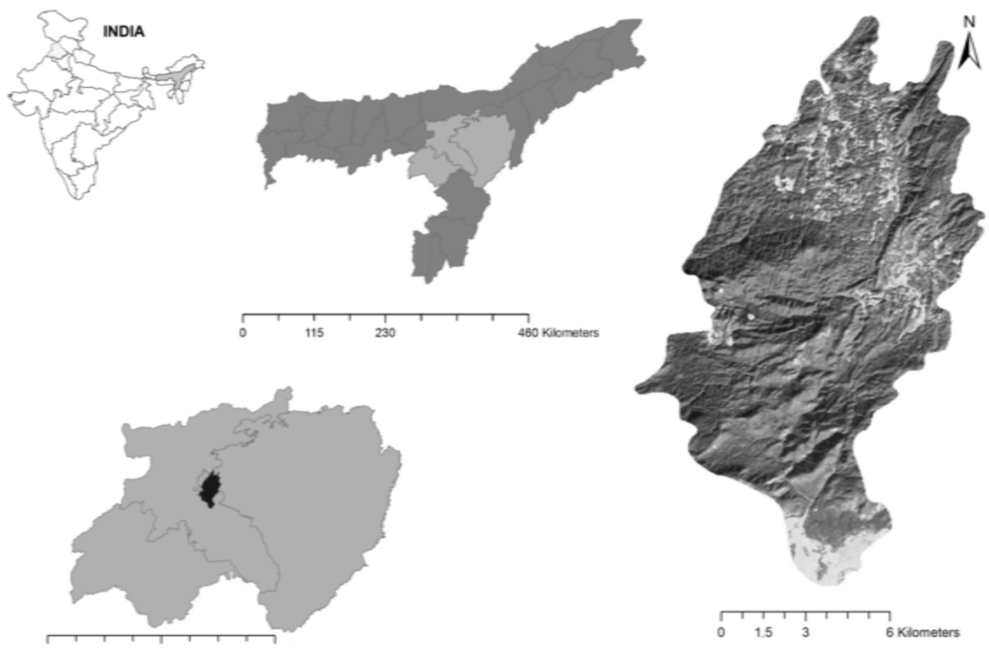


Figure-1
Location Map of Buriganga Basin

Table- 1
Details of data sets

Type of Data	Details of Data	Source of Data
Toposheets	83 [B/15, B/16] at 1:50,000 scale.	Survey of India (SOI)
Thematic maps	Soil	National Bureau of Soil Survey and Land Use Planning, Nagpur, India
	Geology	Geological Survey of India (GSI)
Satellite data	IRS LISS IV, 2006, 5 meter resolution	National Remote Sensing Agency (NRSA), Hyderabad
	SRTM data, 2006, 90 meter resolution	NASA Satellite data
Daily and hourly Rainfall	Dry period (Dec, Jan, Feb, and Mar) Recharge period (April, May, Oct, and Nov) Wet period (June, July, Aug, and Sep)	Rainfall stations: Kondali tea Estate, Hojai, Diphu, and Nonoi Tea estate.

Figure-2

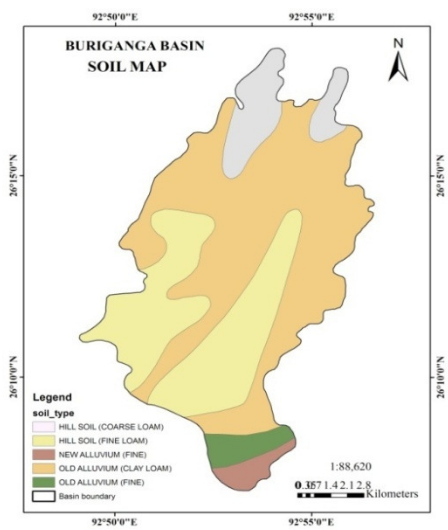


Figure-3

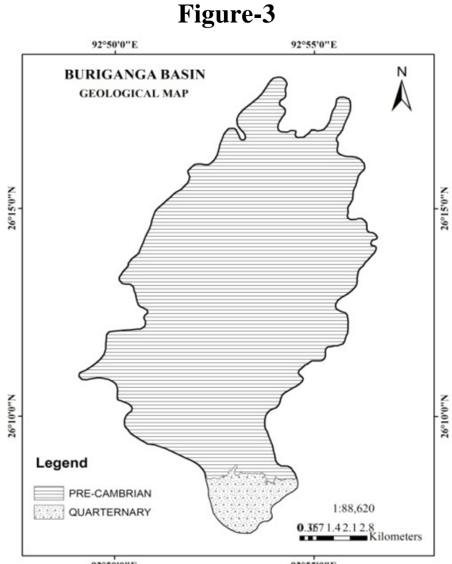
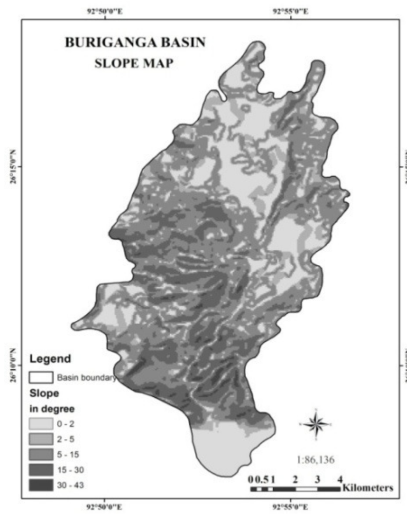


Figure-4



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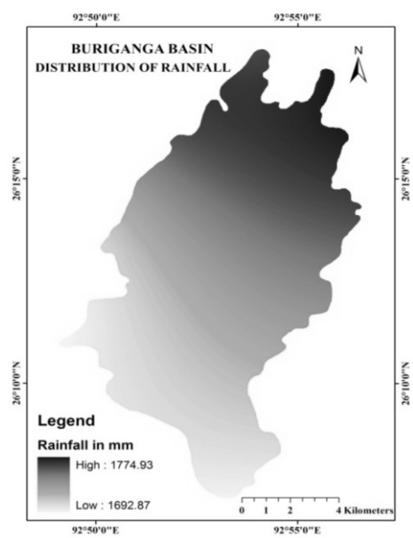

Figure-6

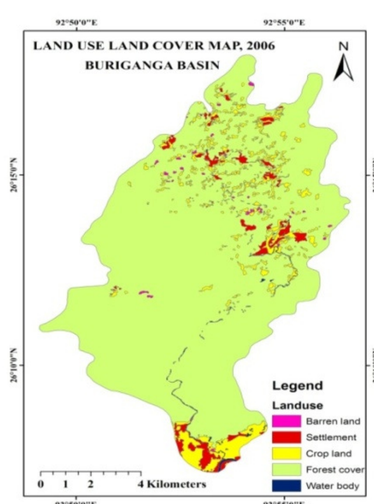

Figure-7

In the NRSC runoff equation, the ratio of amount of actual retention to watershed storage is equal to the ratio of actual direct runoff to the effective rainfall and mathematical form[5]-

$$\mathrm{FS} = \frac{\mathrm{Q}}{(\mathrm{P-I})} \quad (1)$$

Where, F= Actual Retention (in mm); S = Watershed Storage or Retention (in mm); Q = Actual Direct Runoff (in mm); P = Total Rainfall (in mm); I = Initial Abstraction (in mm).

The total retention for a storm consists of Initial Abstraction, I and Actual Retention, F. So the conservation of mass equation can be expressed in the form of water balance equation-

$$\mathrm{F} = (\mathrm{P} - \mathrm{I}) - \mathrm{Q} \quad (2)$$

Substituting equation 2 for F in equation 1 results-

$$(\mathrm{P} - \mathrm{I}) - \frac{\mathrm{Q}}{\mathrm{S}} = \frac{\mathrm{Q}}{(\mathrm{P-I})} \quad (3)$$

Solving for the total storm runoff, Q and results in the runoff equation-

$$\mathrm{Q} = \frac{(\mathrm{P-I})^2}{(\mathrm{P-I})} + \mathrm{S} \quad (4)$$

To eliminate the necessity of estimating both parameters I and S in the above equation, the relation between I and S was developed by analyzing rainfall-runoff data for many small watersheds. Initial Abstraction, I was assumed to be a function of the maximum potential retention, S. An empirical relationship between I and S was expressed as-

$$\mathrm{I} = 0.2\mathrm{S} \quad (5)$$

The rainfall-runoff relationship is obtained by substituting equation 5 for initial abstraction into equation 4

$$\mathrm{Q} = \frac{(\mathrm{P-0.2S})^2}{(\mathrm{P+0.8S})} \qquad \mathrm{P} \geq 0.2\mathrm{S} \quad (6)$$

S is retention parameter. Retention parameter has change spatially with changes in soils, land use, and slope and temporarily due to changes in soil water content and it is defined mathematically as-

$$\mathrm{S} = 25.4\left(\frac{1000}{\mathrm{CN-10}}\right) \quad (7)$$

Where, CN is the curve number for the time period. It is a dimensionless runoff index which is determine based on hydrologic soil group (HSG), land use, land treatment, hydrologic conditions and antecedent moisture condition (AMC). CN values range between 1 and 100. Higher the value of CN indicates higher the surface runoff. In this study, CN values have been done from the soil texture (Percentage of Sand, Silt and Clay in each soil) and remote sensing images. The equation use for calculating CN is expressed as-

$$\mathrm{CN} = \left\{\ln\left[\left(\frac{\mathrm{Sa}}{\mathrm{C}}\right) + \left(\frac{\mathrm{Sa}}{\mathrm{Si}}\right) + \left(\frac{\mathrm{Si}}{\mathrm{Sa}}\right) + \left(\frac{\mathrm{Si}}{\mathrm{C}}\right) + \left(\frac{\mathrm{C}}{\mathrm{Sa}}\right) + \left(\frac{\mathrm{C}}{\mathrm{Si}}\right) + 3\right] \times [\mathrm{CI} \times 0.4]\right\} \quad (8)$$

Where, Sa= % of Sand, C= % of Clay, Si= % of Silt, and CI= Composite remote sensing image.

This equation calculates CN values for average Antecedent Moisture Condition (AMC). Traditionally CN values have been calculated from empirical observation of hydrological soil groups and land use and land cover classes, where 5% slope is under consideration[6].

This procedure is expensive in terms of time and money, and also the accuracy of the work may be questioned in larger watersheds; as land use and land cove have heterogeneous character same times changes in 20 meters in spatial context and one fortnight in temporal context. Thus in spite of use the traditional NRSC CN values the equation is proposed to calculate CN values in GIS platform. Going through the calculations it is found that the values of CN highly resemble with traditional method about more than 85% accuracy. The most advantage of this equation is its flexibility in spatial temporal context.

The present equation calculates CN for AMCII. AMC is an indicator of watershed wetness and availability of soil storage prior to a storm. Three levels of AMC are used- AMC I for dry, AMC II for normal, and AMC III for wet conditions. The Curve Numbers (CN) for the AMCI and AMCIII with the mathematical equations-

$$\mathrm{CN_1} = \mathrm{CN_2} - \frac{(100-\mathrm{CN_2})}{[100-\mathrm{CN_2}+\exp(2.533-0.0636\times(100-\mathrm{CN_2}))]} \quad (9)$$

$$\mathrm{CN_3} = \mathrm{CN_2} \times \exp[0.00673 \times (100 - \mathrm{CN_2})] \quad (10)$$

The equation also computes CN values only for 5% slope. In order to make the present CN values reliable to other slope values the slope parameter of the area have to incorporated with it, the mathematical formula for slope adjustment is as given in the section as given by Willams to the CN values to different slopes (CN_{2S} slope adjusted CN values for AMCII) [7].

$$\mathrm{CN_{2S}} = \left[\left(\frac{\mathrm{CN_3}-\mathrm{CN_2}}{3}\right) \times \left(1 - 2\exp(-13.86 \times \mathrm{Slope})\right) + \mathrm{CN_2}\right] \quad (11)$$

Now to avail the CN_{1S} and CN_{3S} flow the equation 9 and 10 with only one change that CN_2 with CN_{2S}.

Results and Discussion

Different relevant GIS layers are prepared for each sequence equations of SWAT and subsequently final runoff estimation has been prepared in raster grid by grid format and total volume of runoff is calculate with the help of Arc GIS Spatial Analysis tool.

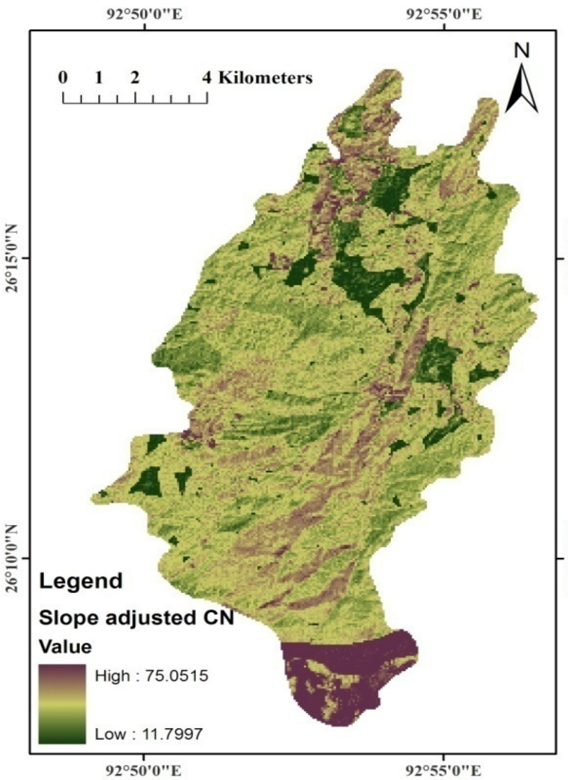

Figure- 8
Slope adjusted Curve Number for AMC II

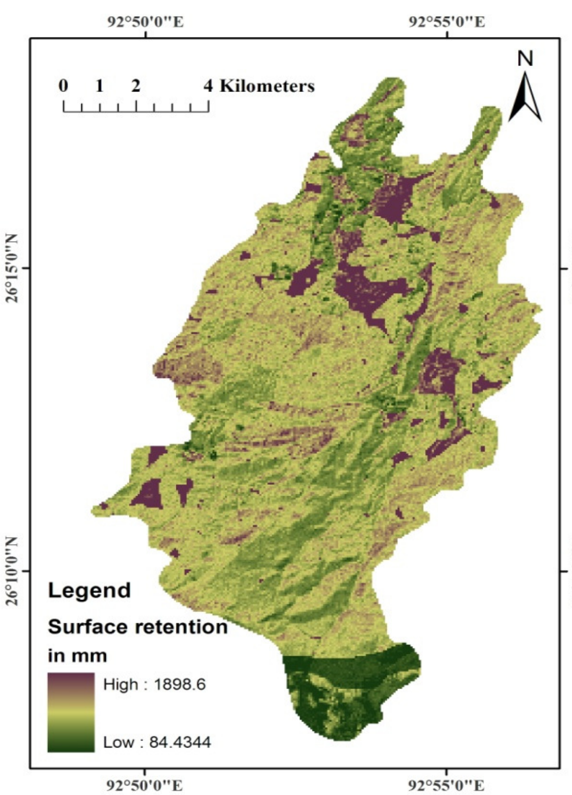

Figure- 9
Surface retention of AMC II

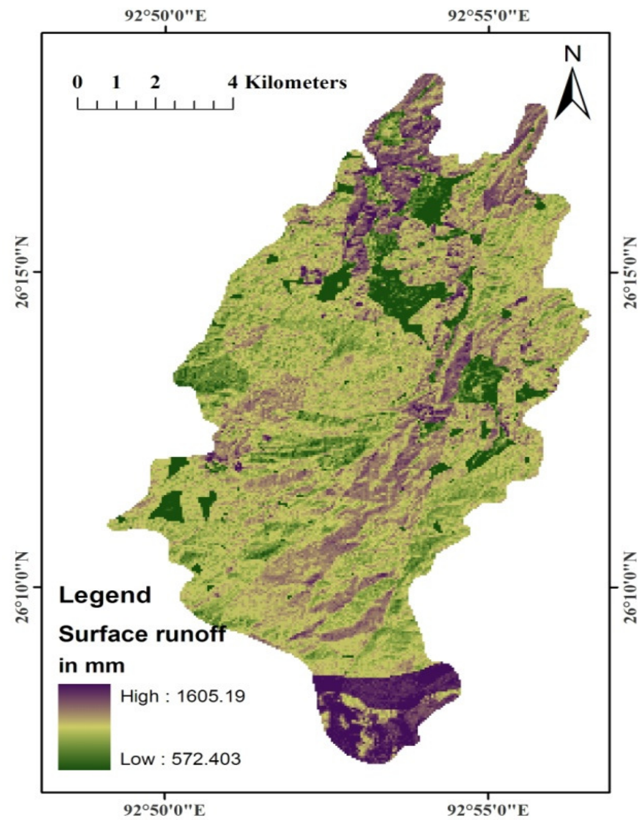

Figure- 10
Surface runoff map

For present study NRCS Curve Number procedure has been used for estimating surface runoff depth with the aid of Satellite Remote sensing data base. Runoff varies spatially due to changes in soils, land use, slope and 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 base on their geo-hydrological environment. The Surface Runoff is varied time to time and place to place. It is estimated from figure- 10 that the mean annual surface runoff of the study area is varies from 572.40 mm to 1605.19 mm. CN values and Surface retention capacity calculated by using equations of 7, 8, 9, 10, and 11. The slope adjusted CN maps of the region derived from IRS P6 LISS 3 image of 2006 with the aid of slope parameter, figure 8 demonstrated slope adjusted CN values of AMC II and accordingly the surface retention capacity, and figure 9 of the basin area in spatial manner calculated. The CN values and surface retention capacity shows that there is a negative relationship among them. Higher CN values indicates for potentiality of higher runoff while higher surface retention values reveals that how much the surface can retain amount of rainfall fall on it.

It is observed from the figure 7 that the Buriganga watershed has five land use and land cover categories. They are vegetation cover, crop land, settlement, barren land and water bodies. The change of land use is considered to be one of the major factors in causing surface runoff. Dense vegetation cover facilitates low surface runoff conditions where as surface runoff is relatively high in sparse vegetation cover and bare surface. In table 2, Surface runoffs of different land use are estimated. Mean annual surface runoff of forest cover areas are estimated 1073.21 mm and high in high in crop land and barren land.

Table-2
Average annual surface runoff in different vegetation cover

Land use	Area (in km^2)	Mean Annual Rainfall (in mm)	Mean Annual Runoff (in mm)
Barren land	0.41	1744.06	1127.28
Built up	3.07	1732.79	1123.02
Crop land	8.64	1735.88	1133.18
Forest cover	112.79	1733.00	1073.21
Water body	0.56	1719.50	1135.12

In figure 5, the estimated slope of the Buriganga watershed varies from 0^o to 43^o. The slope angles have been categorized into five classes of slope (0^o-2^o), gentle slope (2^o-5^o), moderate slope (5^o-15^o), steep slope (15^o-30^o) and very steep slope (above 30^o). Average annual surface runoff is low in low slope category (0^o-2^o) estimated as 1025.50 mm which facilitate alluvial plain, gentle slope and better recharge conditions whereas surface runoff is high in high slope (30^o- 43^o) categories estimated as 1093.24 mm. Surface runoff is relatively very high in 2^o-5^o slope category rather than slope category above 30 due to the coverage of small area only 1.60 km^2 under high slope category.

Table-3
Average annual surface runoff in different slope category

Average Slope (in Degrees)	Area (in km^2)	Mean Annual Rainfall (in mm)	Mean Annual Runoff (in mm)
Below 2	26.55	1737.11	1025.50
2-5	18.08	1741.16	1116.58
5-15	54.47	1735.05	1093.24
15-30	25.03	1720.63	1077.02
30-43	1.60	1710.19	1095.52

Soil is another important factor for variation of surface runoff. In figure 3, the clay loam soil in the foothill terrain of the southern part of the study area where lithology being permeable, there is high probability to recharge and most of the surface water are infiltrated and flow as sub surface runoff. Annual average surface runoff of this soil type is estimated as 1037.53 mm where as the soil condition being impermeable in coarse loam, there is little chance of recharge and most of the water flows as surface runoff estimated as 1147 mm which is shown in table 4.

Table-4
Average annual surface runoff in different soil condition

Soil Type	Area (in km^2)	Mean Annual Rainfall (in mm)	Mean Annual Runoff (in mm)
Old Alluvium (Clay Loam)	67.34	1741.12	1037.53
Hill soil (fine loam)	39.91	1716.18	1093.08
New alluvium (fine)	7.14	1700.76	1284.83
Hill soil (coarse loam)	11.35	1765.99	1147.00

The estimated sub watershed level surface runoff of the study area is shown in table 5. It is observed that in upstream region of Buriganga watershed estimated with low mean annual surface runoff of 1031.04 mm. High mean annual surface runoff is estimated in Buriganga downstream above 1109 mm. Due to the dense vegetation cover in Buriganga upstream facilitates low surface runoff conditions where as surface runoff is relatively high in downstream of Buriganga where vegetation covers is sparse with exposed surface.

Table- 5
Average annual surface runoff in different sub watershed

Sub Watershed	Area (in km^2)	Mean Annual Rainfall (in mm)	Mean Annual Runoff (in mm)
Buriganga head	42.95	1720.03	1109.96
Anjakpni	20.20	1762.64	1075.57
Theodang	9.36	1766.40	1074.01
Donghaplang	5.28	1756.72	1069.13
Longbackcrui	15.51	1727.15	1081.30
Longsami	16.74	1708.44	1053.10
Buriganga Upstream	15.67	1735.68	1031.04

Conclusion

An integrated remote sensing and GIS based methodology has successfully demonstrated for estimation of runoff in Buriganga watershed. It may be concluded that the rainfall, slope, vegetation cover, soil condition are considered to be important factors in surface runoff. The entire watershed receives relatively a good amount of rainfall. However, comparing with the runoff map, recharge is relatively low on the northern part due to the presence of dissected hilly hard rock terrain with moderate to high degree of slope, the suitability is poor due to the lithology being impermeable, there is little chance of recharge and most of the water flows as runoff. The study shows that the southern part of Buriganga basin having high surface runoff covered by exposed or bare surface to crop land in gentle slope. Therefore, these areas are prone to soil erosion. At sub watershed level observation, high mean annual surface runoff is estimated in Buriganga downstream above 1109 mm. This runoff potential can be used for the artificial recharge by constructing the Nala Bundies and Farm ponds at suitable sites of these sub watersheds. Also, constructing the structures like check dams' water can be stored. It will be helpful for the dry summer days to be used as drinking water as well as agricultural purposes.

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