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Estimation of Rainfall-Runoff using Remote Sensing and GIS in and around Singtam, East Sikkim

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ABSTRACT

Rainfall runoff is an important component contributing significantly to the hydrological cycle, design of hydrological structures and morphology of the drainage system. Estimation of the same is required in order to determine and forecast its effects. Estimation of Direct rainfall-runoff is always efficient but is not possible for most of the location at desired time. Use of remote sensing and GIS technology can be used to overcome the problem of conventional method for estimating runoff caused due to rainfall. In this paper, modified Soil conservation System (SCS) - CN model is used for rainfall-runoff estimation that considers parameter like slope, vegetation cover, area of watershed.

Keywords: Rainfall-runoff, Initial Abstraction, Hybrid Classifier, Moving Average, Soil Conservation System (SCS), Remote Sensing.

1. Introduction

Rainstorms generate runoff, and its occurrence and quantity are dependent on the characteristics of the rainfall event, i.e. the intensity, duration and distribution. Apart from these rainfall characteristics, there are number of catchment specific factors, which have a direct effect on the occurrence and volume of runoff. This includes soil type, vegetation cover, slope and catchment type. SCS-CN provides an empirical relationship for estimating initial abstraction and runoff as a function of soil type and land-use. Rainfall-runoff relationship can be visualized by the factors such as initial abstraction (I_a), direct runoff (Q), and actual retention (F). The Curve Number (CN) is an index developed by the Natural Resource Conservation Service (NRCS), to represent the potential for storm water runoff within a drainage area. The CN for a drainage basin is estimated using a combination of land use, soil, and antecedent soil moisture condition (AMC). There are four hydrologic soil groups: A, B, C and D. Group A have high infiltration rates and group D have low infiltration rates.

In this paper, we have modified existing SCS-CN hydrological model that considers parameters – slope, catchment size, vegetation and drainage length. In order to study land cover type we have used Hybrid Classifier and soil map given by National Atlas and Thematic Mapping Organization (NATMO) as input to Soil conservation System (SCS) model for rainfall-runoff estimation.

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1.1 Related Work

The SCS-CN method has been widely used to compute direct surface runoff. It has originated from plotting of direct runoff versus storm rainfall proposed by Sherman, estimation of surface runoff for un-gauged stations proposed by Mockus and graphical procedure of Andrews. Stuebe et al., Ponce and Hawkins, Michel et al.and Ramakrishnan et al. used SCS-CN method in their analysis. Bhuyan et al. studied event based watershed scale Antecedent Moisture Condition (AMC) values to adjust field-scale CNs, and to identify the hydrological parameters that provide the best estimate of AMC. Patil et al. has contributed significantly in this field using GIS based interface selected sites. Loague et al. has proposed three event-based rainfall-runoff models viz; a regression model, a unit hydrograph model, and a quasi-physical model for small upland catchments. Vos et al. have proposed an application of multi-layer feed forward ANNs for rainfall-runoff modeling in the Geer catchment (Belgium) using both daily and hourly data. Aytek et al.have proposed two techniques of artificial intelligence (AI) for rainfall runoff modeling using the artificial neural networks (ANN) and the evolutionary computation (EC). Xu et al., have also proposed back-propagation (BP) neural networks model and a distributed hydrologic model for rainfall-runoff modeling in the upper area of Huai River, China. Nayak et al. have used SCS model for modeling rainfall runoff using RS & GIS for River Bebas in Madhya Pradesh.

1.2 Study Area

The river Teesta originates from Cholamo Lake at an elevation of 5,330 m (17,487 ft) above sea level in the Himalayas. The Teesta Basin, in and around Singtam, is divided into four sub-basin- Central Teesta, Rangpo Chhu, Rongni Chhu, Lower Teesta. Figure 1 shows the watershed taken into consideration. The study area lies between 27^{o}4’48” N to 27^{o}36’00” N Latitude and 88^{o}22’12” E to 88^{o}55’12” E Longitude. The watershed has total geographical area of 1750 sq. km. The proposed watershed area covers the stretch of nearly 28 km along river Teesta between Dikchu and Rangpo.

2. Data Used

The Survey of India topographic maps no 78A/7, 78A/8, 78A/11, 78A/12, 78A/15, and 78 A/16 were used for the demarcation of the watershed line. The rainfall data of Mangan, Gangtok and Majitar from 2004 to 2009 have been used in the study. The rainfall data is collected from Meteorological Department, Sikkim. The land use and land cover map was prepared using hybrid classifier for IRS 1-C LISS III satellite imagery of East Sikkim during the year 2008 with a resolution of 23.5m approximately. The Drainage map is created for the study area using ERDAS Imagine 9.0 software. The soil information was collected from the soil map of Sikkim, published by the National Atlas and Thematic Mapping Organization (NATMO).

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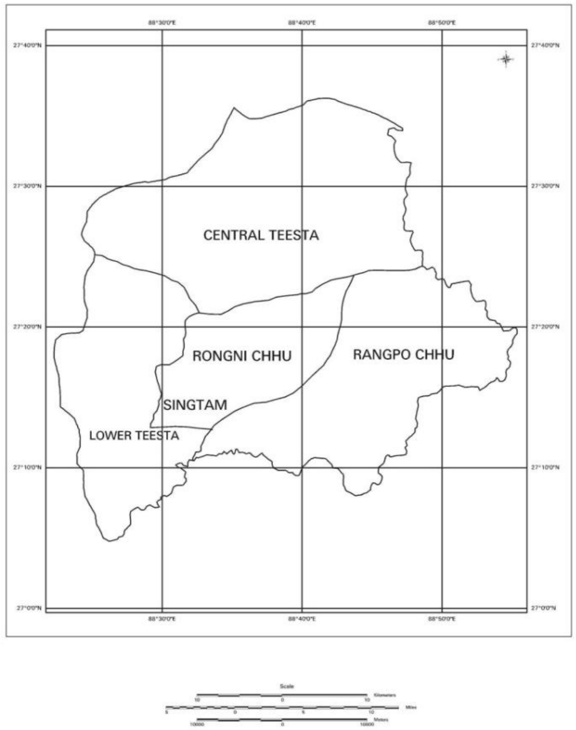

Figure 1: Study area – Watershed of East Sikkim

3. Methodology

3.1 Land cover/Land use classification

In order to study land cover/ land use pattern for the study area we have used hybrid classifier. Hybrid Classification includes the advantages of both supervised as well as unsupervised classification. For unsupervised classification, K-means clustering algorithm is used followed by Bayesian method for supervised classification.

3.2 Trend Analysis

It is a mathematical technique that uses historical results to predict future outcome. For the proposed work we have used weighted moving average method of order n. A weighted average is any average that has multiplying factors to give different weights to different data points. Mathematically,

$$WMA_M = \frac{np_M + (n-1)p_{M-1} + \dots + 2p_{(M-n)+2} + p_{(M-n)+1}}{n+(n-1)+\dots+2+1} \quad (1)$$

A common method for determining trend is to calculate a moving average of order n as the following sequence of arithmetic means:

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$$\frac{y_1+y_2+\cdots+y_n}{n}, \frac{y_2+y_3+\cdots+y_{n+1}}{n}, \ldots \quad (2)$$

3.3 Rainfall – Runoff Modeling

SCS rainfall-runoff model, developed by United States Department of Agriculture (USDA) provides an empirical relationship estimating initial abstraction and runoff as a function of soil type and land-use. The water balance equation is expressed by

$$Q = P - (I_a + F) \quad (3)$$

Where Q is direct runoff, P is rainfall, I_a is the sum of all losses before the beginning of runoff and F is retention after runoff begins. Estimation of rainfall runoff using SCS- CN model is defined by the equation given below

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

For Indian soil condition [25], the above relation is modified as,

$$I_a = 0.3S \quad (5)$$

Substituting for I_a in the generalized runoff equation produces

$$Q = \frac{(P - 0.3S)^2}{(P + 0.7\,S)} \quad (6)$$

and

$$CN = \frac{25400}{254 + S} \quad (7)$$

where Q is the runoff given precipitation depth P, S is the maximum storage depth, and CN is the runoff curve number.

The SCS rainfall runoff model is modified to include parameter – watershed area, slope, drainage length, and land cover. The equation for average runoff Q_a is defined by

$$Q_a = \sum \frac{w_i Q_1 + (1 - w_i) Q_2}{i} \quad (8)$$

where w_i is the weight assigned to watershed and i is the input parameter – i.e. watershed, slope, drainage length and land cover. Q_1 and Q_2 are the runoff of the watershed 1 and 2.

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Table 1 presents weighted average curve number for Teesta basin and its sub-basin under AMC – I and AMC- II for soil group C.

Table 1: Weighted average runoff curve number

Sub Basin in the Watershed	CN for hydrologic Soil Group- C and Moisture Condition	
	AMC I	AMC II
Lower Teesta	43	67
Rangpo Chhu	65	77
Central Teesta	76	83
Rongni Chhu	82	87

4. Results and Discussions

In present study, an attempt has been made to estimate the runoff due to rainfall occurred in Teesta basin, in and around Singtam, East Sikkim. Figure 2 shows IRS – 1C LISS III satellite data of Teesta Basin in and around Singtam of resolution 23.5m.

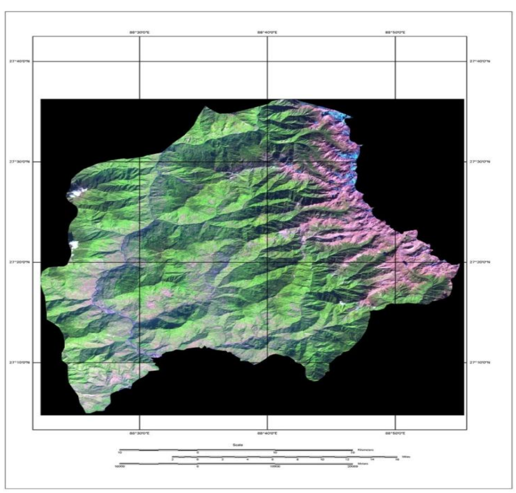

Figure 2: IRS 1C- LISS III data for Teesta Basin in and around Singtam.

Figure 3 shows the drainage map of river Teesta in an around Singtam. Figure 4 shows the land coverage type of the watershed obtained using hybrid classifier. Table 2 provides spatial distribution of the land use/ land cover in Teesta Basin in and around Singtam. For calculating the rainfall runoff, eight different locations along the river Teesta were

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selected in the study area. The longitudinal profile of Teesta river is shown in Figure 5. The rainfall runoff is calculated for each of the eight points. The SCS model is modified to include the parameter- watershed area, drainage length, land cover and slope. The factor relating initial abstraction and maximum retention is varied according to the slope, watershed area, land cover, and drainage length values.

Table 2: Spatial distribution of the land use/ land cover in Teesta Basin, in and around Singtam.

Land use class	Sub-Basin wise Area in sq.km.				Total Area in sq. km.
	Rangpo Chhu	Rongni Chhu	Lower Teesta	Central Teesta	
Forest	226.5	104.5	163	391	885.00
Settlement	129	64	107.5	133	433.50
Snow	12.5	2.5	2.5	11	28.50
Cloud	18	7.5	5	27.5	58.00
Water Bodies	68.5	76.5	98	102	345.00
Total Area	454.50	255.00	376.00	664.50	1750.00

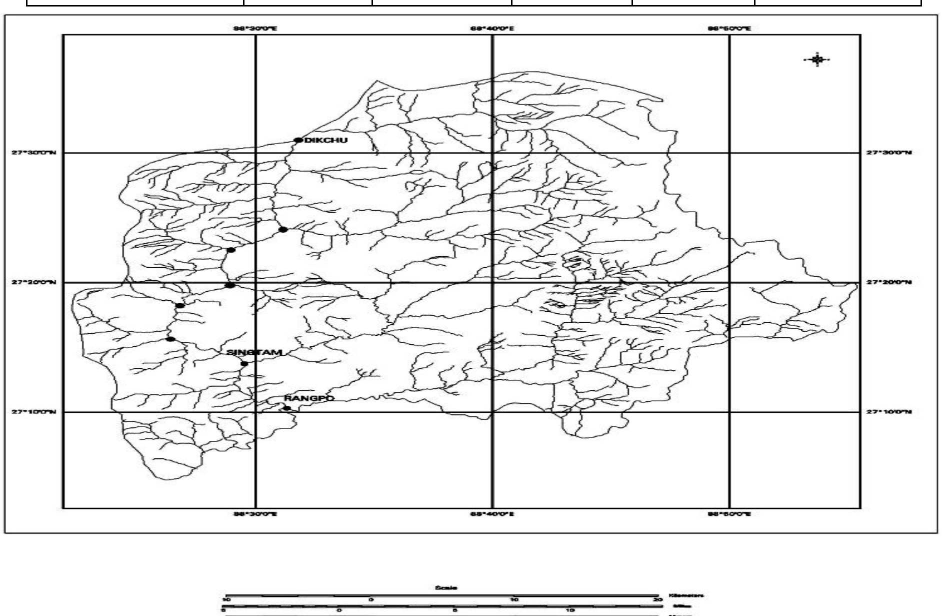

Figure 3: Drainage map of the watershed. Locations for calculating runoff are marked by points.

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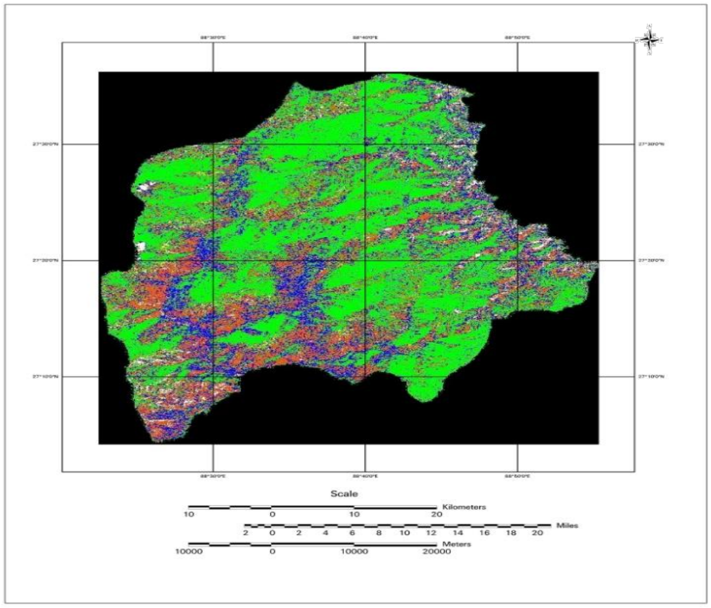

Figure 4: Land Cover/ Land Use map of Teesta Basin in and around Singtam.

The function which relates the I_a value with S contains the modified value of the factor. Using this modified I_a value, the runoff value is calculated. The figure 5 shows the longitudinal profile of the river Teesta in the study area. Height of the different locations on the river bank is plotted against the corresponding distances from a reference point (Dikchu). Table 4: Spatial distribution of the land use/ land cover in Teesta Basin, in and around Singtam.

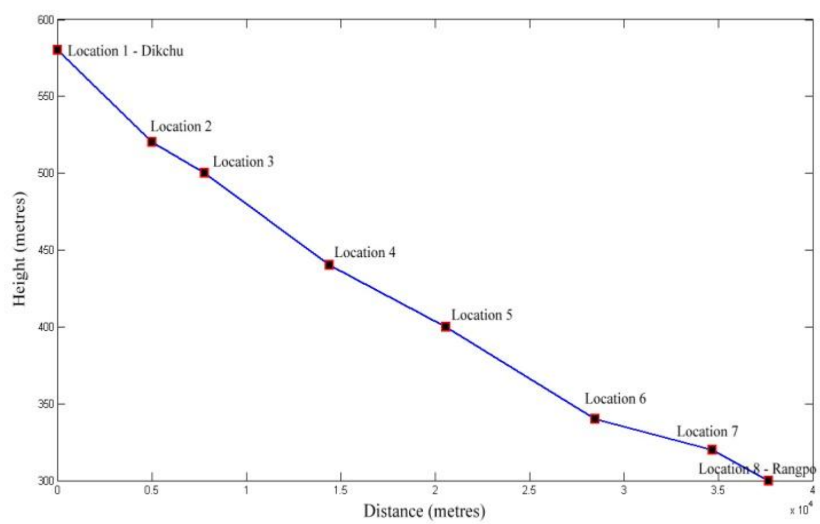

Figure 5: Longitudinal profile of the river Teesta in and around Singtam, East Sikkim.

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The runoff for the year 2009 was calculated by predicting the rainfall value for the year 2009 using trend analysis Figure 6-8 shows the runoff for three locations – Dikchu, Singtam and Majitar for the year 2009 respectively. The runoff for the three locations 1, 4 and 8 are graphically represented as follows:

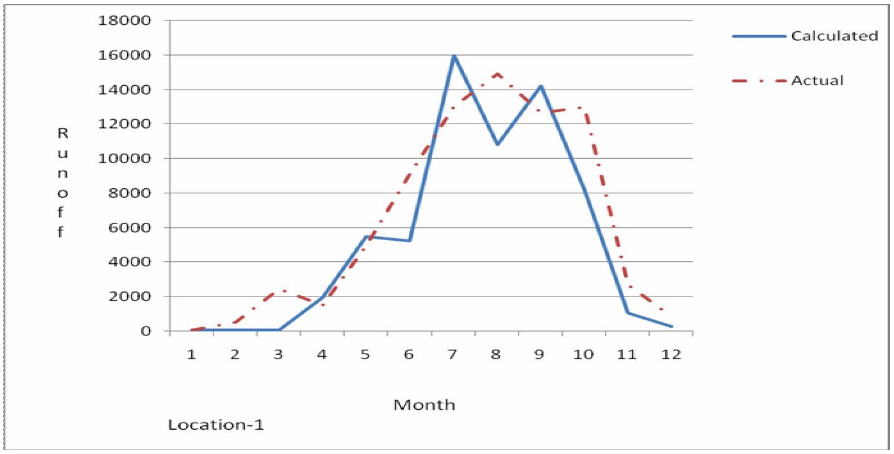

Figure 6: Rainfall-Runoff for location 1- Dikchu

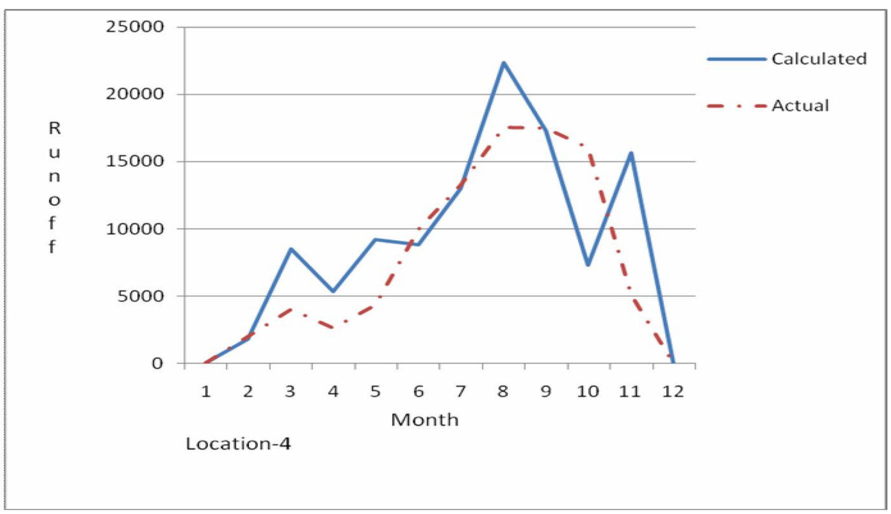

Figure 7: Rainfall-Runoff for location 4- Singtam

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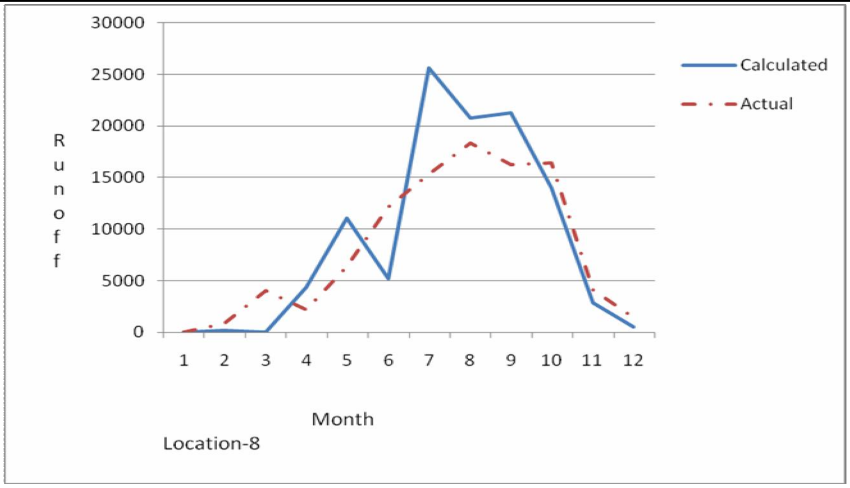

Figure 8: Rainfall-Runoff location 8- Majitar, Rangpo

5. Summary and Conclusion

Remote sensing data are of great use for the estimation of relevant hydrological data when conventional hydrological data are inadequate for the purpose of design and operation of water resources system. Remote sensing data can be used as model input for determination of catchment characteristics, such as land use/ land cover, morphology, depth elevation model, drainage etc. Hybrid classifier is used for land cover mapping, moving averaging method is used for rainfall prediction, SCS model is used for estimating runoff using land cover, soil type and predicted rainfall value. Estimated runoff is compared with the runoff calculated with the actual rainfall data for the year 2009, in general good correlation has been found between observed and computed runoff. The analysis can be extended further to assess the impact of change in land cover over a period of time on rainfall runoff and impact of change in runoff on morphology of river Teesta.

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