Stream Flow Estimation in an Ungauged Catchment of Odisha

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Abstract- **Reliable estimation of stream flow from land surface to streams and rivers in ungauged catchments is challenging and time consuming. But it is vital for practical applications such as design of drainage infrastructure, catchment management tasks like water allocation etc. In the present work a typical ungauged catchment of Odisha has been chosen as the study area having geographical area of 141.32 square kilometer. Dense forest covers almost 80% of the catchment area. The main stream which flows through the catchment is known as 'Samij' nala, which is a perennial stream. Daily rainfall values were collected from the nearest rain gauge stations to the selected catchment. The SCS-CN model, which is a conceptual model, was used for estimation of direct runoff from the catchment. This method depends on only one parameter, CN. Curve number depends up on soil type, land use/land cover, antecedent moisture content of the surface. Simulated and observed hydrographs were compared and the model shows good performance having correlation coefficients more than 0.75 for each year. This model can be useful in similar ungauged catchments with slight modification in input parameters.**

Keywords-AMC, CN, land use/land cover, rainfall-runoff, SCS-CN

I. INTRODUCTION

A Drainage basin is a metaphor for integration of hydrological processes related to surface water, groundwater, evapotranspiration etc. and the explicit coupling of hydrology, geochemistry and ecology [10].

Simple methods for predicting runoff from drainage basins are particularly important in hydrologic engineering and hydrological modelling as they are used in many hydrologic applications, such as flood design and water balance calculation models ([11],[14],[1]).

A drainage basin which has insufficient records of various hydrological observations in terms of both quantity and quality for analysis at the appropriate spatial and temporal scales and up to a good level of accuracy for application in practical fields is known as ungauged basins [10]. If the parameter of interest is not available for the required period of time for prediction or modeling, that basin is an ungauged basin with respect to that variable. Variables of interest can be rainfall, runoff, erosion rates etc. so every basin is ungauged in some respect.

The Soil Conservation Service Curve Number (SCS-CN) method was originally developed by the SCS (US Department of Agriculture), to predict direct runoff volumes for given rainfall events. This method soon became very popular for estimation of runoff from drainage basins.

Accurate and timely predictions of high and low flow events at any ungauged catchment location can provide stakeholders the information required to make strategic, informed decisions.

Many researchers ([8],[6],[15],[3],[5], [9], [4],[13] have utilized the Geographic Information System(GIS) technique to estimate runoff value using curve number method throughout the world.

In India, [8] found that land use/land cover is an important input parameter of the SCS-CN method. Reference [6] obtained a good correlation between the observed and estimated runoff using GIS and SCS-CN method. It can be observed from their study that GIS is an efficient tool which can be used to prepare most of the input parameters required for SCS-CN method. The study concluded that the integration of remote sensing, GIS and SCS-CN model provides a powerful tool for runoff simulation in small to medium watersheds [2].

It is essential to have runoff data for different catchment development and management works. But in case of ungauged catchments very little work has been previously done in this field. This study stresses on the use of GIS as an efficient tool to develop a database containing all the information of the study area which can be used for direct runoff depth estimation using the SCS-CN method.

The objective of this study is to apply the SCS-CN method with GIS for estimating runoff depth in an ungauged hilly catchment. If the correlation between the estimated and observed runoff values will be good, the SCS-CN method can be recommended for estimating runoff in other ungauged catchments of the region.

II. STUDY AREA & DATA COLLECTION

The study area for this present work is a catchment in Sundergarh district of Odisha in India named as Samijnala catchment. It is a catchment of Brahmani river basin. It ranges from longitude 85^0 07' to 85^0 14'E and latitude 21^0 52' to 22^0 05'N.Geographical extent of this catchment is 141.32 km^2.The catchment area has a hilly topography. The elevation varies from 163m to 903m from mean sea level. Catchment land cover is largely forested. Climate In the area is subtropical. The main channel which flows through the catchment is Samijnala. Besides many seasonal nalas, samijnala is a perennial stream. The soil of this catchment comes under the red soil group. Red sandy loam is the main soil in the catchment. Daily rainfall (Source: Odisha rainfall monitoring system) and discharge data were collected from the concerned office for the period of year 2009 to 2012 for validation of the model.

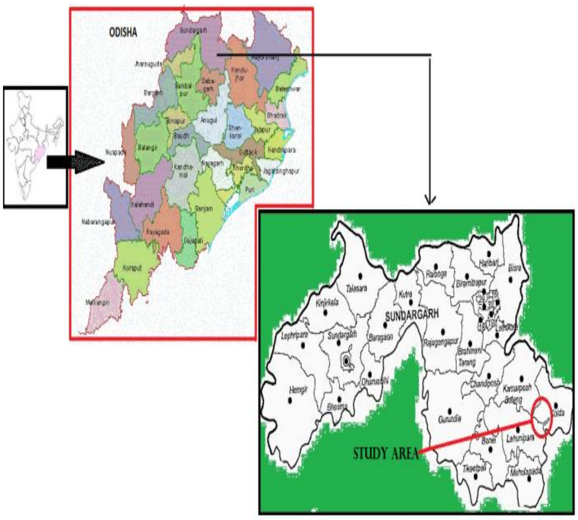

Fig 1 Location of the Study area

A time series data contains periodic components that tend to repeat over a period of time intervals which generally depends upon the seasonal changes. This behaviour of time series is known as periodicity. According to periodicity in time series, statistical characteristics also change periodically in different seasons with in the year. In order to develop a model, the periodic component must be removed from the time series. The periodic component in time series must be removed by the following formulation;

$$z_{v,\tau} = \frac{PET_{v\tau} - \mu_\tau}{\sigma_\tau} \quad (1)$$

Where $z_{v\tau}$ is the standardized flow; v is the year, τ is the time interval with in the year; μ_τ and σ_τ are respectively the population periodic mean and standard deviation of the flow time series.

Auto correlation and Partial autocorrelation analysis of the rainfall and observed discharge was carried out using STATISTICA software by taking the time series data of rainfall and observed discharge data as input from year 2009 to 2012.

The SCS-CN model performance was verified by the Nash-Sutcliffe efficiency (NSE). NSE is a normalized statistic that determines the relative magnitude of the residual variance ("noise") compared to the measured data variance ("information") [7]. NSE shows how good the plot of observed versus estimated data fits the 1:1 line. NSE was computed using the following equation.

$$E=1-\frac{\sum_{i=1}^{n}(oi-Pi)2}{\sum_{i=1}^{n}(0i-\bar{O})2} \quad (2)$$

Where O_i is the i_{th} observation for the data set to be evaluated, P_i is the i_{th} estimated data, $\bar{O}$ is the mean of observed data for the dataset, and n is the total number of observations.

The top sheet, in which the study area falls, was collected and boundary of the catchment was drawn using Arc GIS. Samijnala and its tributaries were drawn over the boundary map. SRTM 90mm Digital elevation model (DEM) data were collected (Source: http://ws.csiss.gmu.edu/DEMExplorer/). Area of interest was cut from the map and imported to Arc GIS. Overlaying the previously drawn boundary map over the DEM, the required digital elevation model for the catchment was drawn. Flow direction map was drawn taking DEM of the catchment as input. It gives a clear idea about the direction of flow within the catchment. Taking flow direction map as input, flow accumulation map was drawn using Arc GIS tools. It helps in identifying the most suitable sites for measurements of flow parameters, area contributing flow to that point and accumulation of flow at that point. Land use/land cover map was collected (Source: swat.tamu.edu).Selected portion of the map was imported to Arc GIS and land use/land cover map of the catchment was drawn. Soil map of the catchment was also drawn using the above procedure.

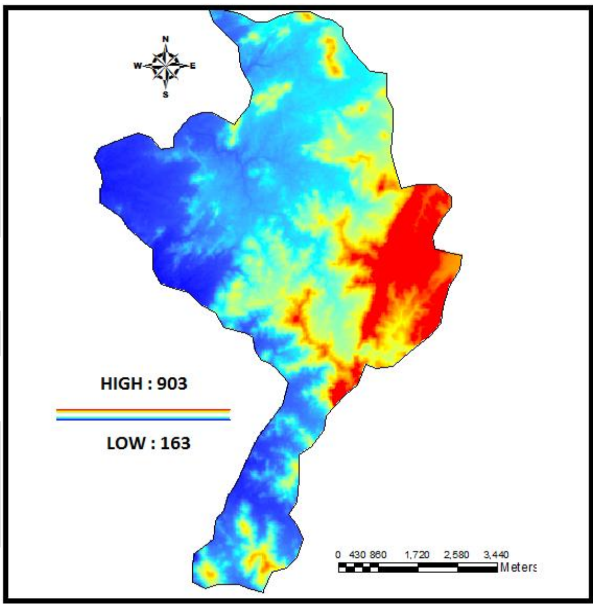

Fig 2 Digital elevation Model of the catchment

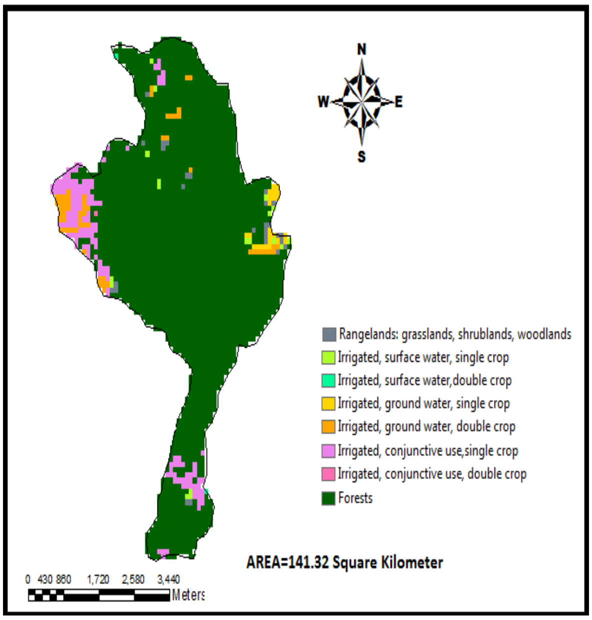

Fig 3 Land use/land covers of the catchment

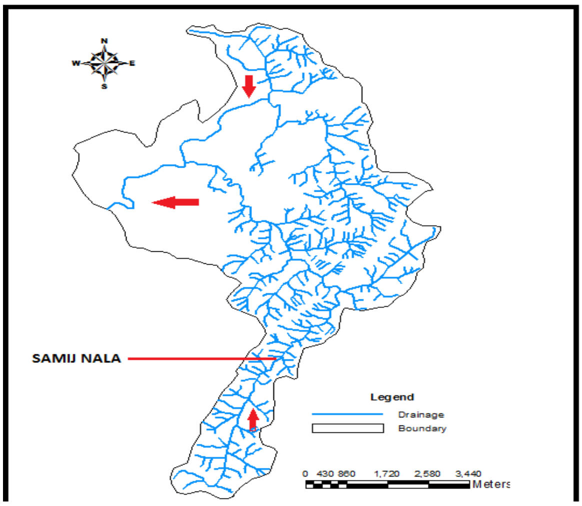

Fig 4 Drainage map of the catchment

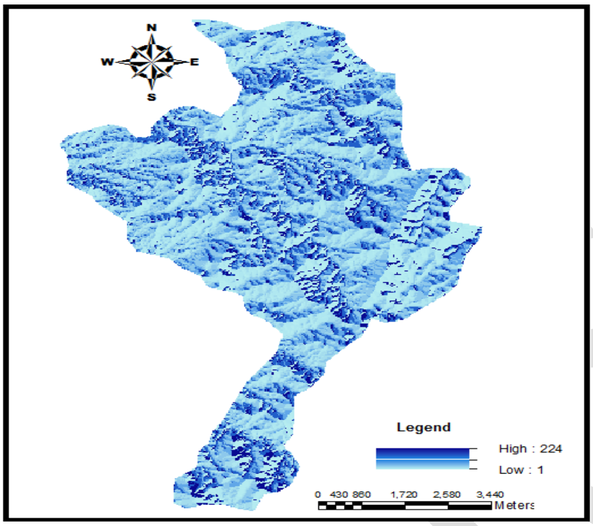

Fig 5 Flow direction map of the catchment

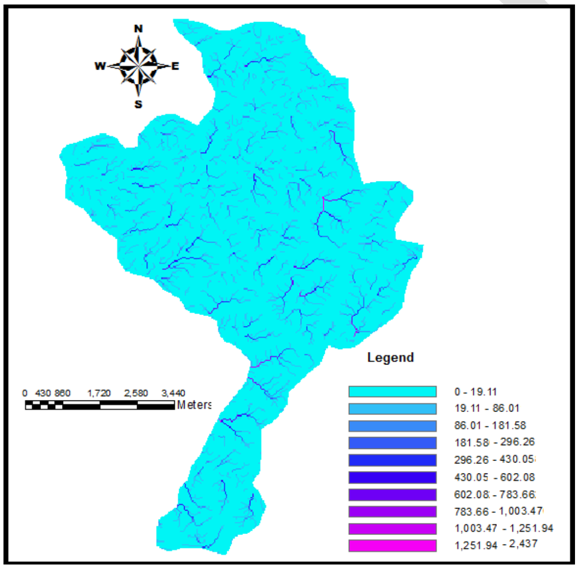

Fig 6 Flow accumulation map of catchment

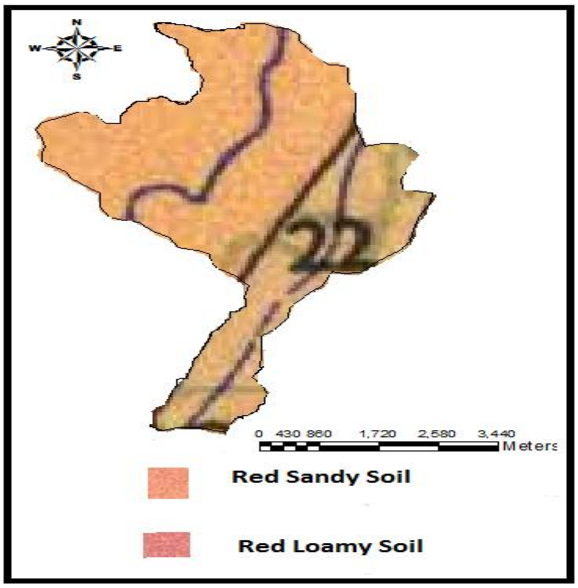

Fig 7 Soil map of the catchment

III. SCS-CN METHOD

In 1969 soil conservation services (SCS) of USA has developed the SCS-CN method. It is a simple, stable conceptual method for estimation of direct runoff depth based on rainfall depth. Predictions made by this model are accurate. It depends on only one parameter, CN. Water balance equation of the rainfall in a known interval of time is the basis of this method, which can be expressed as

$$P= I_a+F + Q \qquad (3)$$

Where P is total precipitation, I_a is initial abstraction F is the cumulative infiltration excluding I_a and Q is the direct surface runoff. Q can be calculated by the following equation;

$$Q= (P-\lambda S)^2/P+ (1-\lambda) S \quad (4)$$

Where P is daily rainfall and Q is the daily Runoff from the catchment. The parameter S represents the potential maximum retention. It depends up on the soil-vegetation-land use complex of the catchment and also up on the antecedent soil moisture content in the catchment just before the starting of the rainfall event. For convenience in practical application S (in mm) has been expressed in terms of a dimension less parameter CN (Curve number) as

$$CN =25400/(S+254) \qquad (5)$$

It is in the range of $100 \geq CN \geq 0$. A CN value of 100 represents a condition which has zero potential retention i.e. impervious catchment and CN=0 represents an infinitely abstracting catchment with $S=\infty$.The curve number CN depends upon Soil type, Land use/cover and Antecedent moisture condition [12].
To determine the value of CN in the present study, the hydrological soil classification is adopted. Soils are categorized in to four classes A, B, C, D based up on their

infiltration and other characteristics. Effective depth of soil, average clay content, infiltration characteristics and permeability; these are some of the important soil characteristics that influence hydrological classification of soils.

Group A represents low runoff potential soils where the rate of infiltration is very high even when thoroughly wetted. Deep loess, deep sand and aggregated silt come under this group.

Soils, in which rate of infiltration is moderate when thoroughly wetted, are categorized under group B. Sandy loam, red loamy soil, red sandy loam and red sandy soil are group B type of soils.

Soils having moderately high runoff potential are classified as group C type. Clayey loam, shallow sandy loam, mixed red and black soils are some examples of this category.

If runoff potential is high i.e. soils having very low infiltration rates when thoroughly wetted are group D type soils. Example -Heavy plastic clays, certain saline soils and deep black soils.

Antecedent moisture condition (AMC) refers to the initial moisture content present in the soil at the beginning of the rainfall-runoff event under consideration[12].Infiltration and initial abstraction are governed by AMC. For practical application there are three levels of AMC are recognised by SCS as follows

- AMC-I: Soils are dry but not to wilting point.
- AMC-II: Average condition
- AMC-III: It refers to saturated soil condition.

The limits of these three AMC classes are based on total rainfall magnitude in the immediate previous 5 days. The variation of CN under AMC-II, called $CN_{II.}$ The conversion of CN_{II} to other two AMC conditions can be made through the use of following equations.

For AMC-I: $CN_I = CN_{II} / (2.281-0.01281CN_{II})$ (6)

For AMC-III: $CN_{III} = CN_{II} / (0.427+0.00573CN_{II})$ (7)

Above two equations are applicable in the CN_{II}, range of 55 to 95 which covers most of the practical range. On the basis of extensive measurements in small size catchments SCS (1985) adopted $\lambda = 0.2$ as a standard value.

Considering the above mentioned parameters SCS-CN model was used in the ungauged catchment.

IV. RESULTS AND DISCUSSIONS

The self-explanatory Fig.8, 9, 10 and 11shows the correlation of the time series rainfall and observed discharge data from the year 2009 to 2012.From the figures shown below it is clear that the correlation between the observed discharge time series data is good while it is not the same for rainfall data.

SRTM 90mm digital elevation model (DEM) of the Samij catchment was drawn. It shows the large difference in elevation in the topography of the catchment. So the slope in the catchment is high due to hilly topography.

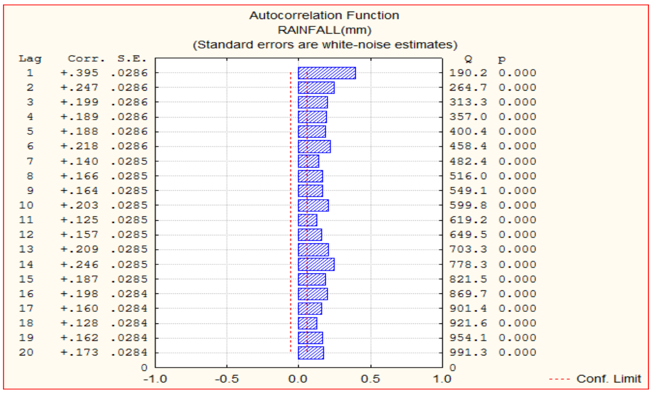

Fig 8Autocorrelation analysis of Time series Rainfall data

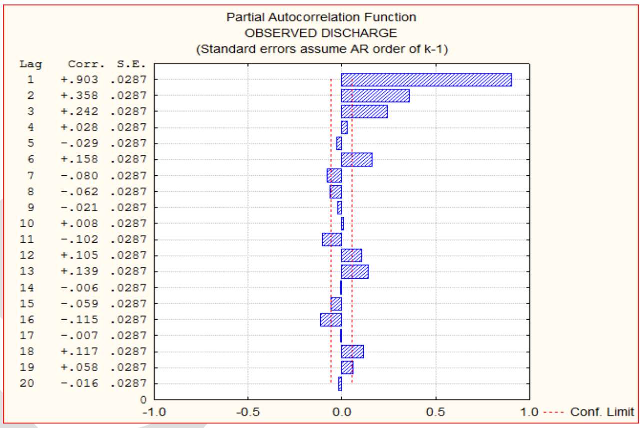

Fig 9Autocorrelation Analysis of Observed time series discharge data

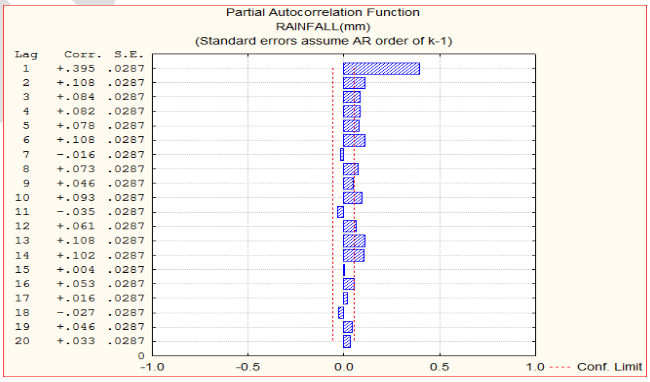

Fig 10 Partial Autocorrelation of Time series Rainfall data

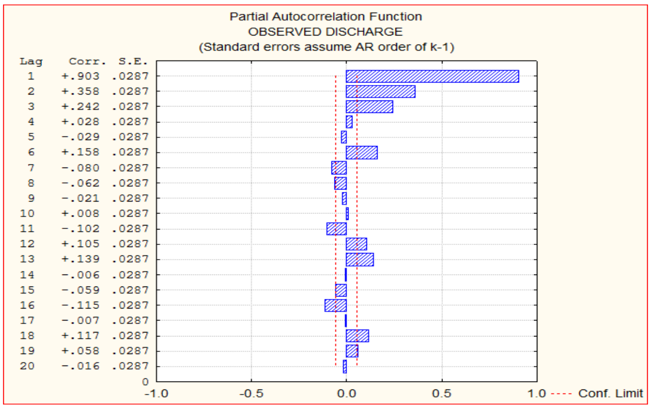

Fig 11 Partial autocorrelation of Observed Time series discharge data

Flow direction and flow accumulation maps of the catchment helps in marking the best possible places where measurements, sampling can be done in the stream. Land use/land cover map of the catchment (Fig.3) shows that more than 80% area of the catchment is covered with dense forests. Barren lands and cultivated lands are present in patches. According to the land use pattern, the whole catchment has been taken as a single unit for Runoff estimation. Red sandy Soil present in the catchment (Fig.7). So the soil class was taken as Group B, according to Hydrological soil classification. The curve number has been estimated as 40 for AMC-II condition. Curve number for other two antecedent moisture conditions I AND III were calculated using equations 6 and 7 and was found out be 22.7 and 62.5 respectively. Value of λ has been considered as 0.2.

Fig. 12shows the comparison between the observed and computed discharges for the year 2009.The correlation coefficient (r^2) value obtained here is 0.86, which is good. The r^2 value is 0.77 for the year 2010, shown in Fig.13.The result obtained for the year 2011 was the best among all 4 years.r^2 value is 0.90 for 2011(Fig.14). Fig.15 shows a comparison between the observed and computed discharge for the year 2012.0.81 is the correlation coefficient value for year 2012.

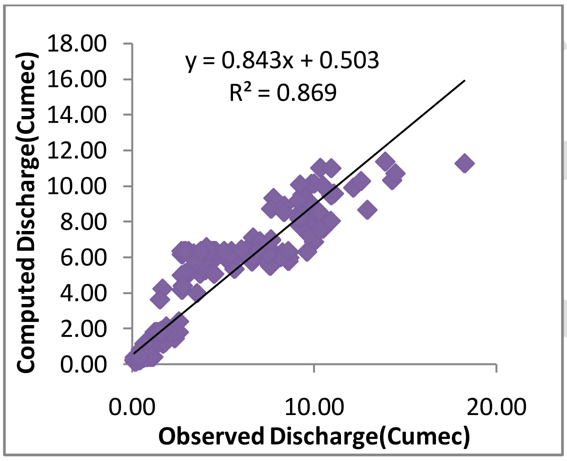

Fig 12 Comparison between computed and observed discharge for year 2009

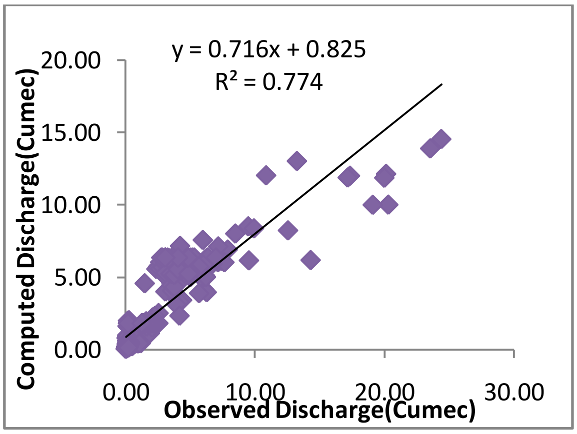

Fig 13 Comparison between computed and observed discharge for year 2010

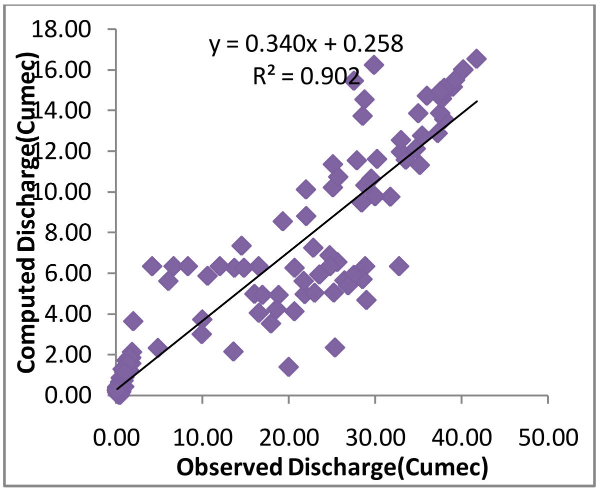

Fig 14 Comparison between computed and observed discharge for year 2011

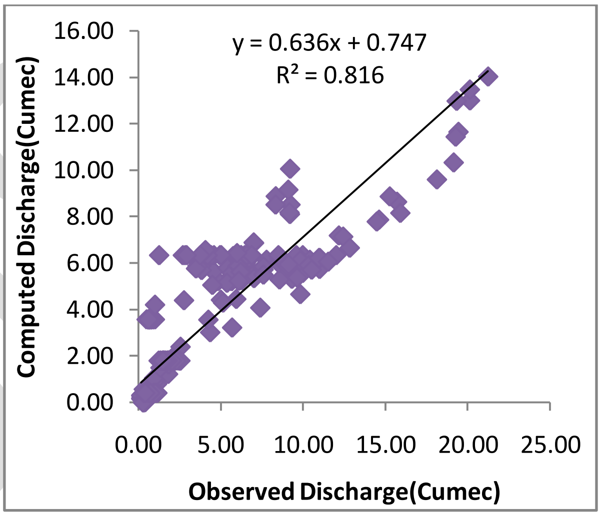

Fig 15 Comparison between computed and observed discharge for year 2012

Nash–Sutcliffe efficiencies range from $-\infty$ to 1. An efficiency of 1 (E = 1) represents a perfect match of modeled discharge to the observed one. An efficiency of 0 (E = 0) corresponds to the model predictions are as accurate as the mean of the observed discharge, whereas an efficiency less than zero (E < 0) occurs when the observed mean is a better predictor than the model. It concludes that the closer the model efficiency is to 1, the more accurate the model is. With NSE value of 0.66,the model is acceptable in the present study for this ungauged catchment.

V. CONCLUSIONS

The incorporation of SCS-CN model and GIS facilitates runoff estimation and improves the accuracy of estimated data. The correlation coefficients obtained for each year is more than 0.75 and that's good. The NSE value is 0.66, which is satisfactory. This study concludes that this method can be used for estimation of runoff in any other ungauged basins for management work purposes.

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