SIMULATION OF RAINFALL RUNOFF USING SCS &RRL (CASE STUDY TADEPALLI MANDAL)

P .Sundar kumar, K.Hanuma.Rishi

Department of Civil Engineering, K L University, Vaddeswaram, Guntur Dist, Andhra Pradesh, India

psundarkumar@kluniversity.in, rishihanuma@gmail.com.

Abstract— Rainfall data was collected for last five years including 2012 up to September in Tadepalli mandal Guntur district Andhrapradesh. The watershed is located in a geographical area between 16.4667°N latitudes and 80.6000°E longitudes. The rainfall data was collected from the nearby rain gauge which is located in an area of 61.5 sq km. SCS-CN method was used to calculate rainfall runoff using multiple linear regressions. In SCS-CN method different parameters like soil information, rainfall, storm duration, soil texture, type & amount of vegetation cover and conservation practices were considered. Based on the soil classification the given area falls under group C. Then the runoff is computed for different areas, namely barren land, industrial area, built-up, aquaculture, agricultural, forest and hilly areas. IRS-P4-LISS IV data was used to study the land use/land cover pattern of Tadepalli Mandal. The land use/land cover patterns were visually interpreted and digitized using ERDAS IMAGINE software. The study observed that agriculture area (46.72%) is dominant in Tadepalli Mandal. The raster data is processed in ERDAS and geo-referenced and then LU/LC map, drainage map, contour map, DEM (digital elevation model) is generated in GIS. Estimated runoff using SCS-CN & RRL is computed with runoff, simulated and actual rainfall data. In years 2008, 2009, 2010, 2011, 2012. In general good co-relation (r^2 =0.76) has been bound between observed and computed runoff.

Keywords— Watershed, Land use/land cover , SCS-CN, RRL, Runoff, Rainfall runoff modelling, DEM, ERDAS.

INTRODUCTION

INDIA has only 4% of the world's freshwater with 16% of world's population and 10% of its cattle. In the total geographical area of 329Mha,47% is cultivated, 23% forest,7% non-agricultural use area,23% waste land. So the use of available water should be done efficiently to meet the people's needs. In order to have accurate idea of available water runoff is to be computed. Hydrological modeling is a powerful technique of hydrologic system investigation for both the research hydrologists and the practicing water resources engineers involved in the planning and development of integrated approach for management of water resources.

Hydrologic models are symbolic or mathematical representation of known or assumed functions expressing the various components of a hydrologic cycle**. Le Bao Trung** used Soil and Water Assessment Tool (SWAT) distributed parameter model for the simulation of runoff and tested on daily and monthly basis for estimating surface runoff and sediment yield for small watershed. A rainfall-runoff model is a mathematical model describing the rainfall - runoff relations of a catchment area, drainage basin or watershed. More precisely, it produces the surface runoff hydrograph as a response to a rainfall hydrograph as input. In other words, the model calculates the conversion of rainfall into runoff. A rainfall runoff model can be really helpful to the present work in the case of calculating discharge from a basin. The transformation of rainfall into runoff over a catchment is known to be very complex hydrological phenomenon, as this process is highly nonlinear, time- varying and spatially distributed. Over the years researchers have developed many models to simulate this process. Based on the problem statement and on the complexities involved, these models are categorized as empirical, black-box, conceptual or physically-based distributed models. Physically based distributed models are very complex and required too many data and tedious for the application purpose.

Computer simulation of catchment water balance for estimating runoff from rainfall began in the early 1960s **(**Boughton, 2005**).** It is now the major technology for management of water resources and for hydrological design work, and many different models are available for use. It is a common adage that, if given good quality data, any of the modern water balance models will give good quality results, but none will give good results with poor quality data. In other words, the results from rainfall-runoff modelling are more dependent on the quality of the input data than on the model. There is evidence for this in at least two major modelling studies undertaken in Australia. **Nathan and McMahon (1990a, b)** calibrated the SFB model on 168 catchments, 250 km^2 in area, in south-eastern mainland Australia. Rainfall data for the study were provided by the Bureau of Meteorology and runoff data by the main stream flow measuring authorities in New South Wales and Victoria. The model was found to be satisfactory in these words: ‘‘Overall, it is concluded that the SFB model is robust and simple to use, and given good input data, it is generally possible to achieve an acceptable calibration’’. The data were commented on in these words: ‘‘.calibration results with (a coefficient of determination) less than 0.6 or (overall difference between observed and simulated flow volumes) greater thanG10% are generally too poor to be considered acceptable and are of little practical benefit; approximately 37% of the calibrations undertaken fall into this category. These poor calibration results were generally associated with catchments in which the water balance problems infer that the rainfall and evaporation data were not representative of catchment conditions’’.

The quality of more than one-third of data in this study was too poor to be useable. This is not a criticism of the authorities providing the data. It serves to demonstrate how difficult it is to get input data of sufficient quality to be able to model the water balance of catchment areas.

RESEARCH SIGNIFICANCE

India has 2% of world’s land, 4% of fresh water, 16% of population and 10% of cattle. From the total geographical area of 329Mha, the land use reported for different purposes has been 47% for cultivation, 23% for forests, 7% for non-agri use and 23% as unutilized. The percapita land availability 50 years back was 0.9 ha and it could be only 0.14ha in 2050.Inorder to meet the consequences, there is an urgent need for the optimal utilization of the rain water available. In this direction, rainfall –runoff model will help in knowing the amount of runoff so that the alternate cropping pattern can be suggested for the available water.

OBJECTIVES

The scope and objectives of the present project are:

- To delineate Tadepalli mandal and extraction of land use/land cover using RS & GIS
- To determine runoff potential in Tadepalli mandal using SCS method.
- Compute runoff model using SCS-CN.
- To develop and test the performance of SCS-CN models for simulation of runoff at Tadepalli mandal.

Fig: 1 Location map

Study Area

Tadepalli mandal is situated in the 16.4667°N latitudes and 80.6000°E longitudes.It is having a total geographical area of 11000 ha,out of which the total cultivated area is 3300 ha. It consists of 12 villages namely

1. Tadepalli
2. Undavalli
3. Penumaka
4. Krishnanagar
5. Vaddeswaram
6. Kolanukonda
7. Ippatnam
8. Mellampudi
9. Kunchanpalli
10. Pratur
11. Gudimenda
12. Chirravuru

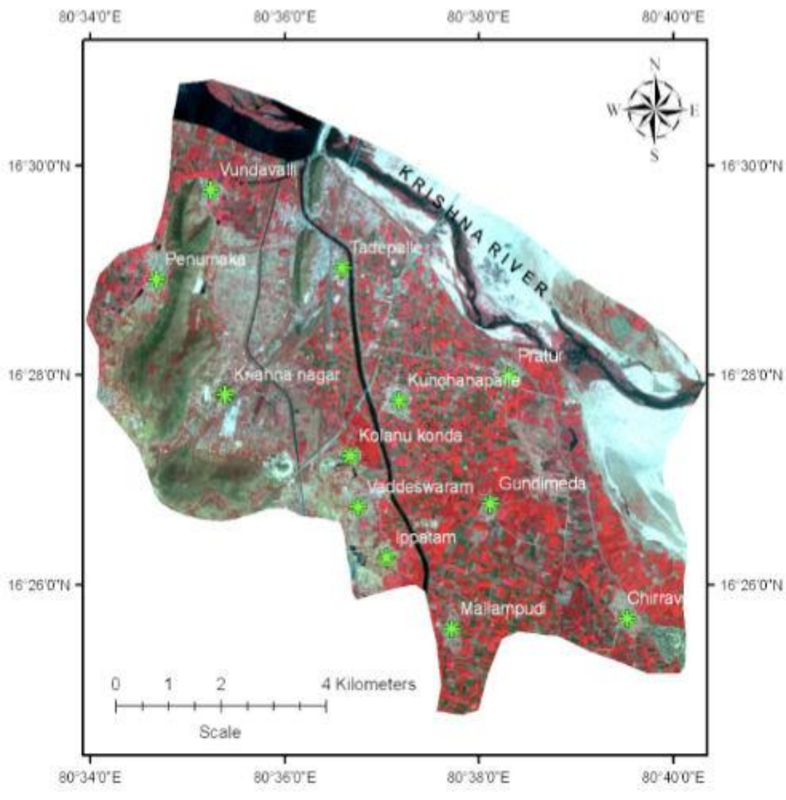

Fig: 2 Imagery of the study area

SCS-CN METHOD OF ESTIMATING RUNOFF VOLUME

SCS-CN method developed by Soil Conservation Services (SCS) of USA in 1969 is a simple, predictable and stable conceptual method for estimation of direct runoff depth based on storm rainfall depth. It relies on only one parameter, CN. Currently, it is a well established method, having been widely accepted for use in USA and many other countries. The details of the method are described in the section. The SCS-CN method is based on the water balance equation and two fundamental hypotheses. The first hypothesis equates the ratio of the amount of direct surface runoff Q to the total rainfall P (or maximum potential surface to the runoff) with the ratio of the amount of infiltration Fc amount of the potential maximum retention S. The second to the potential hypothesis relates the initial abstraction Ia maximum retention. Thus, the SCS-CN method consisted of the following equations

(a) Water balance equation:

Proportional equality $P = Ia + Fc + Q$ …..............(1)

Hypothesis $Q/(P - Ia) = Fc/S$ ....(2)

I - S hypothesis: $Ia = \lambda S$ ....(3)

Where,

P is the total rainfall, Ia the initial abstraction, Fc the cumulative infiltration excluding Ia, Q the direct runoff, S the potential maximum retention or infiltration and λ the regional parameter dependent on geologic and climatic factors ($0.1<\lambda<0.3$).

Solving equation (2)

$Q = (P - Ia)2/(P - Ia + S)$ ....…(4)

$Q = (P - \lambda S)2/(P - (\lambda - 1)S)$ …..........................(5)

The relation between Ia and S was developed by analyzing the rainfall and runoff data from experimental small watersheds and is expressed as Ia=0.2S. Combining the water balance equation and proportional equality hypothesis, the SCS-CN method is represented as

$Q = (P - 0.2S)2/(P + 0.8S)$ ….........................(6)

The potential maximum retention storage S of watershed is related to a CN, which is a function of land use, land treatments, soil type and antecedent moisture condition of watershed. The CN is dimensionless and its value varies from 0 to 100.The S-value in mm can be obtained from CN by using the relationship

$S = (25400/CN) - 254$ …………………………(7)

Estimation of mean rainfall over the basin

The daily rainfall data for raining months (May, June, July, August, and September) of the year were used to estimate daily runoff. The four years (2008, 2009, 2010, 2012) daily rainfall data of two rain gauge station was used to estimate runoff. The rain gauge represent only point sampling of the areal distribution of rainfall but rainfall over the catchment is never uniform. Therefore to identify which rain gauge stations contribute to mean annual rainfall over the entire Buckingham canal a Thesien polygon method was used. The Arc-GIS software was used to develop polygon and to calculate the area of polygons for more accuracy. The Thiessen weightage for each raingauge station was calculated and used to calculate mean areal rainfall over the area. The statistic of Thesien polygon of buchingam cannel basin. It was observed that tadepalli raingauge station has most influence in the basin followed by tadepalli. The raingauge station tadepalli has least influence in the basin. Thesien polygon statistic of Buckingham canal

Curve Number map

Curve number is the governing factor, which predominantly affect the runoff amount which flows over the land after satisfying all loses. Although curve number itself having no physical meaning but also plays an important role in defining hydrological response. Curve number varies from 0 to 100. Zero curve number describes the hydrological response only with infiltration. All the rainfall water will infiltrate to become subsurface flow. Whereas 100 curve number describes the hydrological responses of no infiltration. All the rainfall water will flow as surface flow as soil is in saturation limit that happens in continuous rainfall events. As 100 curve number is given to water bodies. CN values lies between 0-100 contribute the flow in both forms. As soon as CN is increased, runoff from that watershed will also increase. As explained earlier CN is derived from Land use/Land cover classification and hydrological soil group the land use coverage and soil coverage were merged using *UNION* command of Arc-GIS software. Using ARC-GIS software total 78 polygons were developed. All these polygons having a particular land use and a hydrologic soil group and then curve numbers were assigned to these polygons. Thus a curve number coverage was generated in which different polygons had different curve number values. The pictorial presentation of CN for various land cover and Hydrological soil group is presented spatial distribution of Curve Number of Buckingham canal

Estimation of Runoff

The distributed CN technique was used to estimate runoff for Buckingham canal. An initial abstraction (I_a) of 0.2S was used, where S is the maximum potential retention discussed in section The CN value for each polygon was used to calculate maximum potential retention S for each polygon by using Equation 3.11. Then runoff of each polygon was estimated with the help of Equation The daily runoff of all raining months May, June, July, August, September were estimated for 4 year period (2008-,2009,2010,2011,2012) using daily rainfall data of these months. The daily runoff was converted into monthly runoff. The graphical representations of monthly runoff potential for years (2008, 2009, 2010, 2011, and 2012) were presented in respectively.The spatial distribution of runoff depth in wet year, dry year and normal year is presented in the respectively.

Land Use/ Land Cover Classification

Indian Remote Sensing satellite digital image with specifications described under section were classified using maximum likelihood classifier. The classified images of Buckingham canal are presented The graphical representations of LU/LC statistics of theBuckingham canal are also given whereas tabular form is displayed in which shows comparative analysis of land covers variation in basin.As seen fromit was found that the Buckingham canal comprises of eight different types of LU/LC. However, the major land use is agriculture (64.72%) followed by Plantation (19.44%). Other LU/LCs comprising of water bodies, barren land, reserve forest, hilly areas, aquaculture and settlement account for about 16% of the total area of the watershed. The basin has 5.51 % barren land, 4.55 % hilly areas,1.58% reserved forest, 0.82 % water tanks and aquaculture is also present in that area (0.26 %). Buckingham canal 3.12 % area is covered by settlement.

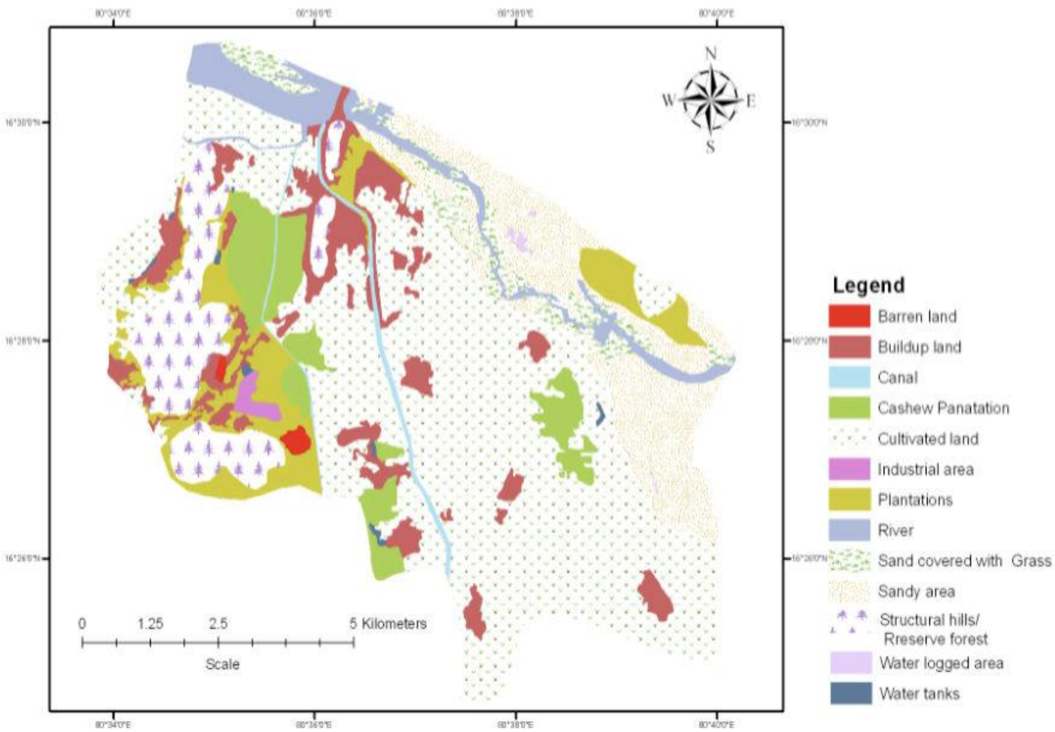

Fig: 3 Land use/Land cover

Data Input and Software Used

To achieve the above objectives, daily precipitation and runoff data for period of ten years (1998,2009,2010,2011,2012), soil data, topographic maps and satellite imagery of the study area are collected. ERDAS IMAGINE 8.5 and ARC GIS 9.2 software packages were used for analyzing the data. MATLAB 2009a was used to run the code which was developed to find optimized AWBM model.

The Survey of India toposheets covering the study area were scanned, rectified and digitized for elevation contours, drainage network, and prominent land cover using ARC-GIS software. The river basin was divided into micro-units (micro basins) using Arc-Swat software. All geomorphologic parameters like canal parameters were extracted using Arc-GIS. The IRS satellite images for the year 2010 were classified using supervised classification (after several ground truth verifications) withmaximum likelihood classification algorithm in ERDAS IMAGINE software.

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Table: 1 Land use/Land cover classification statistic of Buckingham canal

Land use/Land cover classes	Area (Km^2)	Area (%)
Barren Land	3.388	5.51
Settlement	1.91	3.12
Water Tanks	0.504	0.82
Agriculture	39.802	64.72
Hilly Area	2.79	4.55
Plantation	11.95	19.44
Reserve Forest	0.9717	1.58
Aquaculture	0.159	0.26
Total	61.466	100

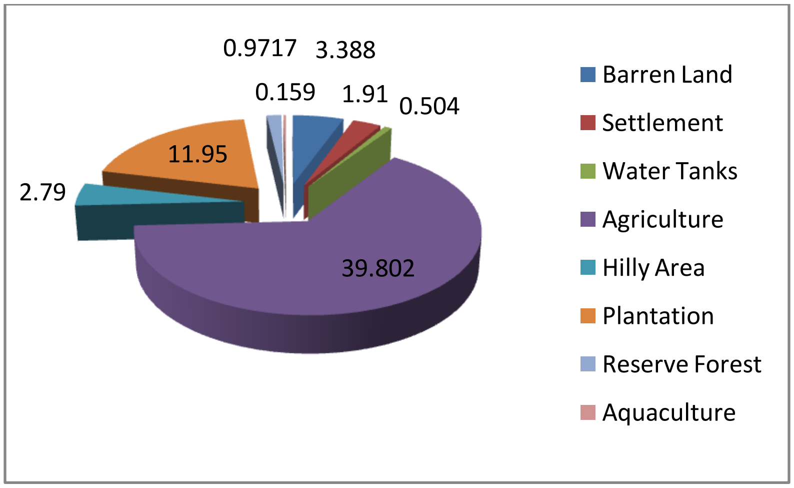

Fig: 4 Land use/ land cover statistics of tadepalli watershed and its sub watersheds

Spatial and Temporal Variation in Rainfall

Daily rainfall data was collected from one rain gauge station of Buckingham canal for a period of 2008, 2009,2010,2011,2012. Graphically these data were represented as plots of magnitude vs chronological time in the form of a bar diagram It was observed from the Figure that rainfall varies with respect to space and time in the Buckingham canal. Based on this plots we can analysis of rainfalls of a time period in the area and can provide the information of average annual rainfall of that time period, information of wet years, dry years and normal years. The average annual rainfall calculated and present with bar diagram, as horizontal line

The years which were above than average annual rainfall are the wet years.25 % departure from the average annual rainfall was also calculated and presented with bar diagram, as horizontal line shown in. The years which were below than 25 % departure from the average annual rainfall are the dry years. The years which were in between average annual rainfall and 25 % departure from the average annual rainfall were classified as normal years. Based on the analysis of rainfalls2008, 2009,2010,2011,2012 in the study area, the year 2010 was characterized as the 'wet year' because the station has a rainfall above than average annual rainfall, the year 2008 as the 'dry year' because the rainfall at most of the station was below 25 % departure from the average annual rainfall and the year 2009.2011 as the 'normal year' because rainfall at five stations were more than average annual rainfall, only one station have rainfall less than average annual rainfall but more than 25 % departure from the average annual rainfall.

Graphically representation of mean monthly rainfall vs months provides the information about the rainy months of the year. Therefore, Mean monthly rainfall of each month was calculated for year 2008,2009,2010,2011,2012and bar diagram of mean monthly rainfall vs months was plotted as shown identify rainy months of the year. It was observed from the that only six months (May, June, July, August, September and October) are the raining months of the year and able to produce considerable amount of runoff in the area

Data Input and Software Used

To achieve the above objectives, daily precipitation and runoff data for period of ten years (2008, 2009, 2010, 2011, and 2012), soil data, topographic maps and satellite imagery of the study area are collected. ERDAS IMAGINE 8.5 and ARC GIS 9.2 software packages were used for analyzing the data. MATLAB 2009a was used to run the code which was developed to find optimized AWBM model.

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Table: 2 Average, Observed and RRL values for years 2008, 2009, 2010, 2011, 2012.

Month	2008	2009	2010	2011	2012	Average	Observed	RRL
January	4.2	0	0	0	0	4.2	0	0
February	0	0	0	36.4	0	36.4	59	0
March	0	0	0	0	3.6	3.6	15	25
April	7.4	0	13	35.4	5.8	61.6	60	0
May	0	104.8	292.2	10.8	15.4	423.2	189	257.89
June	90.6	5.6	97.6	96.6	112.2	402.6	19	122
July	221.84	122.8	423.8	327.2	240.6	1336.24	210	191.568
August	170.8	235.2	468.2	290.6	150	1314.8	370	366.912
September	159.8	215.4	300.2	18.2	300	993.6	370	336.024
October	179	64	193.8	56.4	79	572.2	79	99.84
November	33.8	145.8	84.8	0	100	364.4	400	227.448
December	0	0	103	2.4	0	105.4	97	0

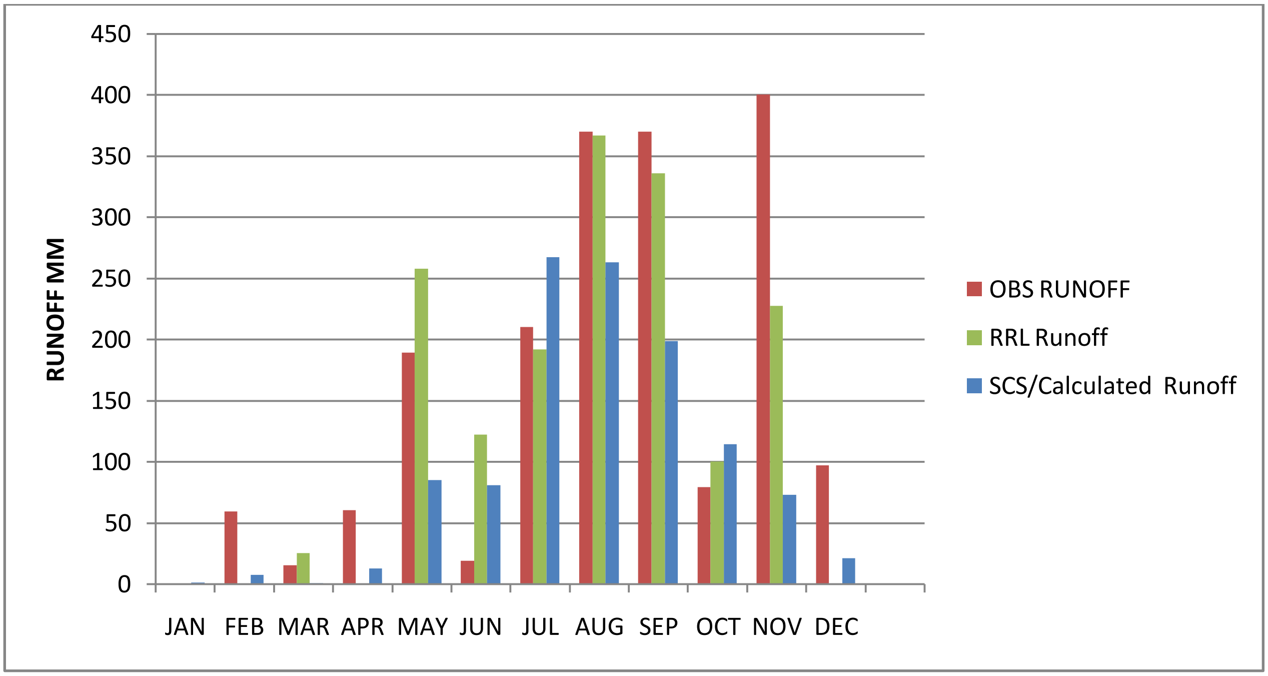

Fig: 6 Observed (OBS) Runoff, RRL Runoff, and SCS/Calculated Runoff

. Results and Discussion:

1. The average monthly rainfall calculated was more for months may, June, July, August, September.
2. The Observed rainfall was more in months July, august, September and November.
3. The year 2010 is the wet year compared to all five years.
4. 2009, 2011 had the least rainfall compared to all the years.
5. The RRL values were more in the months May, July, August, September and November.

Conclusion:

1. Based on the annual rainfall analysis at one rain gauge station of the study area for period 2008,2009,2010,2011,2012 , the year 2010 can be characterized as the 'wet year', the year 2009,2012 as the 'dry years' and the year 2012 as the 'normal year'.
2. Based on the mean monthly rainfall analysis at one rain gauge station of the study area for period
3. 2008,2009,2010,2011,2012 , the months May, June, July, August, September and October are characterized as raining months of the year.

Future scope

The estimation of runoff can be calculated by using RRL and SCS- CN methods for different areas and by further detailed process by using different methods.

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