

Analysis of Rainfall Runoff for Agricultural Watershed Area

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Abstract : Watershed, catchment and drainage basin are synonymous terms, describing an area surrounded by a ridge line, which drains its runoff through a single outlet. When it is referred to as an area that contributes its runoff to a stream or a river, it is called the catchment of that stream or river. For effective and good water quality management, it is necessary to assess changes in input loads rather than concentrations. The present research primarily aims at evaluating various rainfall runoff characteristics on agricultural watershed area by considering eight rain gauge station of Vena catchment located in Hinganghat District. This paper deals with comparison of observed runoff with SCS Model, Modified SCS Model, and Mockus Model.

Keywords: Rainfall-Runoff, Hinganghat Watershed, Mockus method, Modified SCS Method, SCS Method,

I. Introduction

Water is very useful parameter of the environment because it is connected with the soil, drainage streams, river, reservoirs, catchment, basin, vegetation, and atmosphere. Water is the principal carrier of sediment & chemical pollutants. Some of the important parameters of study of the effects of watershed management projects are soil erosion & sediment level in streams. For good and fruitful water quality management, it is necessary to analyse changes in input loads rather than concentrations. Different models are used to find the runoff from a watershed. The present watershed area having a geographical area of 4109 square kilometer and the average annual rainfall is around 1314.56 mm. The rainfall, land use, soil classification, infiltration rate data were used for the estimation of the runoff for the study area also the runoff is computed using SCS Model, Modified SCS Model & MOCKUS Model and comparison is made between observed runoff and runoff by these three models. Three hydrologic runoff modeling system is used to induce continuous water balance in Vena catchment throughout all seasons for study period from year 2008 to 2012.

The first detailed probe of SCS method was done by Sherman (1942, 1949) by giving graphical representation between direct runoff with storm rainfall. Andrews (1954) introduced a graphical process for analyzing runoff from rainfall for combinations of the amount of vegetative cover, soil pattern and type, and conservation practices. Mockus (1949) performed the extensive experimental work on surface runoff for ungauged watersheds he used information for his research work on antecedent rainfall, storm duration, soil, average annual temperature, and land use pattern. Ritter and Gardner (1991) reported on application of the SCS model to watersheds in central Pennsylvania from his analysis he repossess surface coal mines. Svoboda (1991) applied the curve number concept to assess the soil-moisture content, and simultaneously, the rainfall bestow to direct runoff and ground water. Hawkins (1996) performed experimental analysis which gives that the SCS method could be explained and used in inclined area hydrology and could predict the contributing area he suggested the estimation of curve numbers from analysis and empirical data. Surendra Kumar Mishra and Vijay P. Singh (2011) introduced some modification of SCS-CN method and derived analytically which is based on the Mockus method analyzed, they proposed modification and a general form of the SCS-CN method using data from five watersheds, the existing SCS-CN method, the proposed modification, and the Mockus method are compared. For their analysis they found that the modified version is to be more accurate than the current version.

This paper describes a use of hydrologic-erosion model for targeted field and data collection program to analyse rainfall-runoff relationship. The main objective of research work is to investigate and identify the significance of parameters to analyse runoff in respect to rainfall, by considering eight rain gauge discharge station (Arvimothi, Hamdapur, Hinganghat, Kanholibara, Wadgaon, Wardha and Warudbaji) on Vena River catchment of Hinganghat River Gauging Station of Wardha District.

II. Study Area

Hinganghat is a city in the Wardha district in the Indian state of Maharashtra shown in Fig.1. The study area, named Hinganghat watershed, is located at Wardha city. The watershed having a geographical area of 4109 square kilometer, Figure (1) shows the study area and its location. Physiographically, the watershed is divided into plan and pediments. Elevation in the watershed ranges from 550 to 820 m above mean sea level. Hinganghat is location at latitude of $20^{\circ} 32' 58''\text{N}$ and longitude $78^{\circ} 48' 00''\text{E}$. The extent of Catchment Lat 21.032°N , Lon. 78.299°E left to 20.650°N , 79.367°E , right & Lat. 21.208°N , Lon 78.736°E top to 20.545°N 78.809°E bottoms. The average annual precipitation at Hinganghat area for the last five years is approximately 1314.56 mm. About 90% of this rainfall is received from November to April, and the major land use/land cover categories in the watershed are: Forest area, agricultural area, and mixed area (Data obtained from Hydrology project division, Nagpur).

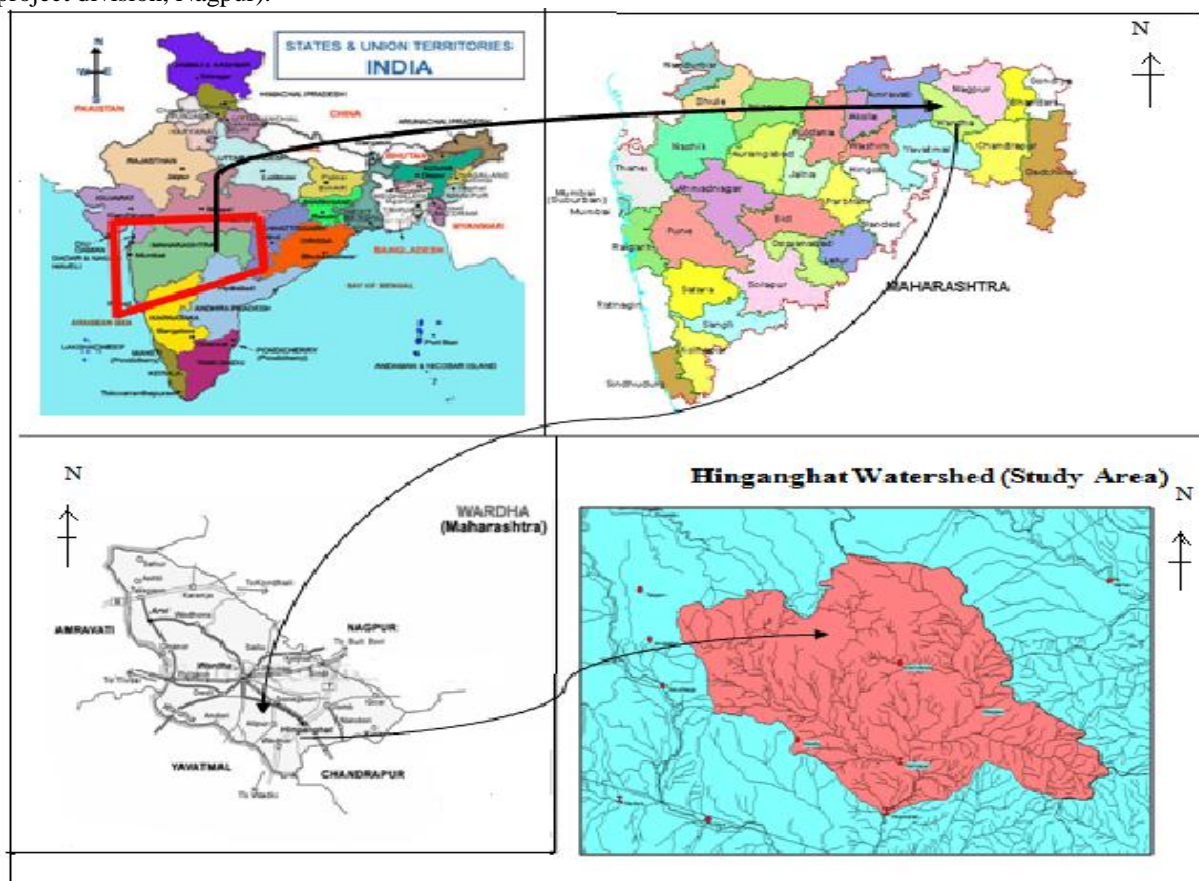


Fig.:1 Location of the Study Area (Hinganghat Watershed)

III. Mathematical Models Used For Rainfall-Runoff Analysis:

For calculation of runoff in Vena catchment it is more convenient to use SCS model and Mockus model. The Soil Conservation Service (SCS) model is most commonly used to estimate and analysed runoff from small- to medium-sized watershed area. The most critical limitation of the SCS model is that the ratio of the actual retention to the potential retention is same as ratio of actual runoff to potential runoff, but this limitation has not been experientially or theoretically proved by any one. The SCS Model is based on the two fundamental conjecture and water balance equation. The first conjecture equates the ratio of the amount of direct surface runoff Q to the total rainfall P with the ratio of the amount of infiltration and potential maximum retention S . The second conjecture relates the initial abstraction I_a maximum retention.

[1] The SCS-CN Model

Following equation gives estimation of runoff using SCS method.

$$Q = \frac{(P-I_a)^2}{P-I_a+S} \quad (1)$$

Where, P = the total rainfall, I_a = the initial abstraction, Q = the direct runoff and S = the potential maximum retention or infiltration.

[2] **Modification in SCS-CN Method**

The SCS model was modified through theoretical composition and re-explicated to estimate subsurface drainage flow from rainfall. The composed theory is that when accumulated subsurface drainage flow is plotted versus accrued infiltration, subsurface drainage flow starts after some infiltration has accrued and the relationship becomes relating to a line of 45 ° slope, just as the common SCS rainfall-runoff relationship. Modification of the SCS-CN method is introduced and produced to estimate the CN for subsurface drainage flow. In the method of defining CN for drainage flow, it was observed that the curve number varied with rainfall amount.

$$Q = \frac{(P-Ia) \times P}{S+a(P-Ia)} \quad (2)$$

$$a = \frac{1}{2} - \frac{S}{P} + \sqrt{\frac{1}{4} + \frac{S}{P}} \quad (3)$$

Where, $a = 1/2$ (for a modified method), Ia = the initial abstraction, Q = the direct runoff S =surface maximum retention, and P =rainfall in mm.

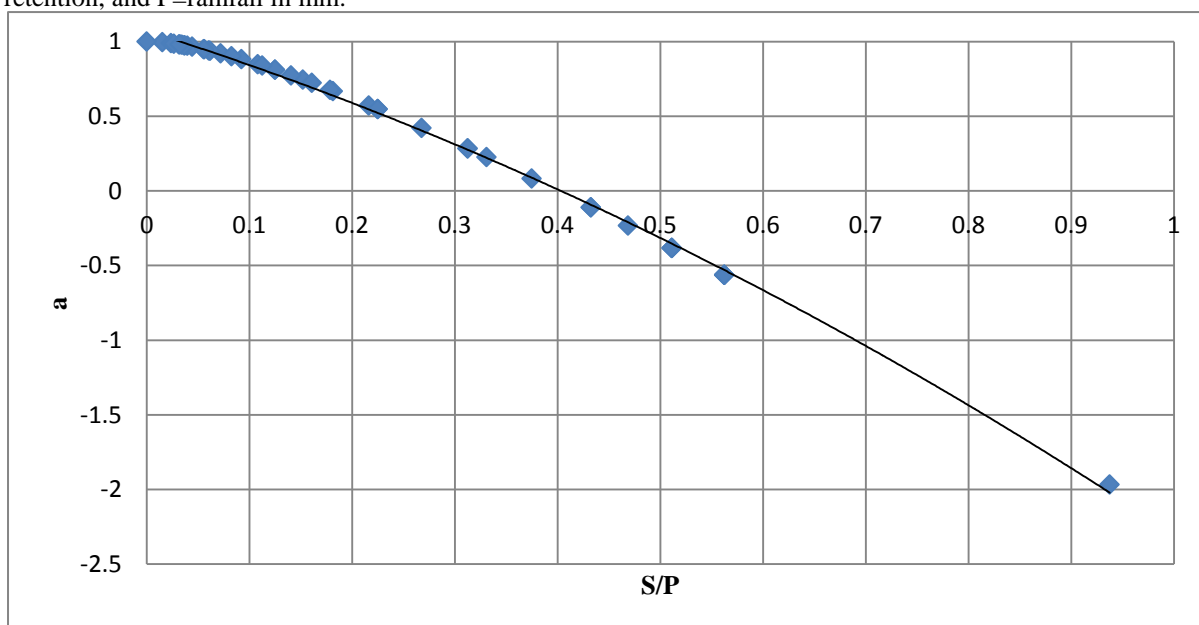


Fig.. 2 Variation of modified SCS parameter ‘a’ with S/P ratio (Surface maximum retention / rainfall in mm)

The SCS Model conjecture [1] is developed from the derived rainfall-runoff relation which is expressed by Mockus (1949) as follows:

$$Q = (P - Ia)(1 - 10^{-bp}) \quad (4)$$

Where, $b = \frac{1}{S} \times \frac{1}{\text{Loge}10}$

Where, P = the total rainfall (mm), Q = the direct runoff (mm), Ia and b = fitting coefficient (an index that depends on an antecedent moisture condition, vegetative cover, land use, time of year, storm duration, and soil type). The parameter b can be interpreted as a reasonable variation of CN, with the difference that the latter is a non-dimensional quantity in a given system of units, and the former a dimensional quantity. The potential maximum retention S is commonly explained in terms of a runoff curve number (CN) through the relationship given below:

$$CN = \frac{25400}{254+S} \quad (5)$$

Where S , 25400, and 254 are given in mm. By knowing land used pattern CN is determined

Table 1: The Present Land Used Pattern for Hinganghat Watershed Area

Sr. No.	Land Use / Cover Category	Area (Sq. Km)	Total Geological Area (in %)
1	Agricultural Land (AL)	3491	84.959
2	Forest Land (FL)	606	14.748
3	Mixed Land (ML)	12	0.292
	Total Area	4109	

IV. Comparison Of Observed Runoff With Existing Models:

To compare observed runoff results with the SCS method Eq. (1), the modified method Eq. (2) and Mockus method Eq. (4). For given $K=Q/P$ which explains the functional behavior of the SCS-CN method.

Table 2. Comparison of Observed Runoff with SCS, Modified SCS and Mockus Method For Station Arvimothe

Year	Observed				Mockus Method		Modified SCS Method		SCS Method	
	P (mm)	Q(mm)	K=Q/P	S	Q(mm)	Ratio ¹	Q(mm)	Ratio ²	Q(mm)	Ratio ³
2008	26.11	24.99	0.957	1.125	28.346	1.1344	23.96	0.9588	21.76	0.8707
2009	16.30	15.18	0.931	2.5	14.229	0.9377	13.21	0.8706	12.19	0.8036
2010	14.43	13.30	0.922	1.125	12.099	0.9096	11.31	0.8504	10.18	0.7653
2011	25.81	24.69	0.956	1.125	23.711	0.9605	22.12	0.8960	20.80	0.8425
2012	11.93	10.81	0.906	1.125	9.638	0.8917	8.81	0.8152	7.66	0.7087

Table 3. Comparison of Observed Runoff with SCS, Modified SCS and Mockus Method For Station Hamdapur

Year	Observed				Mockus Method		Modified SCS Method		SCS Method	
	P (mm)	Q(mm)	K=Q/P	S	Q(mm)	Ratio ¹	Q(mm)	Ratio ²	Q(mm)	Ratio ³
2008	11.85	10.73	0.905	1.125	9.619	0.8969	9.01	0.8401	8.07	0.7524
2009	10.50	9.38	0.893	1.125	8.158	0.8701	7.66	0.8171	6.68	0.7124
2010	22.39	21.26	0.950	1.125	20.543	0.9662	18.90	0.8888	17.73	0.8339
2011	19.64	18.51	0.943	1.125	17.771	0.9600	16.47	0.8895	14.76	0.7976
2012	15.00	13.88	0.925	1.125	12.826	0.9244	11.71	0.8440	10.50	0.7571

Table 4. Comparison of Observed Runoff with SCS, Modified SCS and Mockus Method For Station Hinganghat

Year	Observed				Mockus Method		Modified SCS Method		SCS Method	
	P (mm)	Q(mm)	K=Q/P	S	Q(mm)	Ratio ¹	Q(mm)	Ratio ²	Q(mm)	Ratio ³
2008	15.48	14.36	0.927	1.125	13.19	0.9190	12.48	0.8692	11.46	0.7984
2009	21.14	20.02	0.947	1.125	19.04	0.9513	17.74	0.8864	16.58	0.8282
2010	29.24	28.11	0.962	1.125	27.37	0.9735	25.29	0.8997	23.91	0.8506
2011	17.12	16.00	0.934	1.125	15.12	0.9452	13.91	0.8693	12.81	0.8010
2012	11.74	10.62	0.904	1.125	9.35	0.8802	8.75	0.8242	7.67	0.7227

Table 5. Comparison of Observed Runoff with SCS, Modified SCS and Mockus Method For Station Kanholibara

Year	Observed				Mockus Method		Modified SCS Method		SCS Method	
	P (mm)	Q(mm)	K=Q/P	S	Q(mm)	Ratio ¹	Q(mm)	Ratio ²	Q(mm)	Ratio ³
2008	17.50	16.38	0.936	1.125	15.37	0.9384	14.32	0.8748	13.26	0.8095
2009	19.50	18.38	0.942	1.125	17.52	0.9537	16.03	0.8723	14.79	0.8049
2010	19.69	18.57	0.943	1.125	17.76	0.9566	16.26	0.8756	15.08	0.8124
2011	23.24	22.11	0.952	1.125	21.27	0.9618	19.71	0.8913	18.50	0.8369
2012	20.45	19.33	0.945	1.125	18.32	0.9476	17.17	0.8884	16.06	0.8308

Table 6. Comparison of Observed Runoff with SCS, Modified SCS and Mockus Method For Station Wadgaon

Year	Observed				Mockus Method		Modified SCS Method		SCS Method	
	P (mm)	Q(mm)	K=Q/P	S	Q(mm)	Ratio ¹	Q(mm)	Ratio ²	Q(mm)	Ratio ³
2008	29.82	28.69	0.962	1.125	27.99	0.9754	25.80	0.8990	24.40	0.8504
2009	24.25	23.13	0.954	1.125	22.17	0.9588	20.51	0.8869	19.17	0.8290
2010	24.96	23.84	0.955	1.125	22.90	0.9606	21.27	0.8920	19.95	0.8370
2011	24.96	23.84	0.955	2.125	23.90	1.0025	22.27	0.9340	20.95	0.8789
2012	16.17	15.04	0.930	1.125	13.80	0.9172	12.99	0.8638	11.86	0.7883

Table 7. Comparison of Observed Runoff with SCS, Modified SCS and Mockus Method For Station Wardha

Year	Observed				Mockus Method		Modified SCS Method		SCS Method	
	P (mm)	Q(mm)	K=Q/P	S	Q(mm)	Ratio ¹	Q(mm)	Ratio ²	Q(mm)	Ratio ³
2008	16.52	15.40	0.932	1.125	14.43	0.9373	13.43	0.8725	12.38	0.8042
2009	15.06	13.93	0.925	1.125	13.01	0.9339	11.90	0.8544	10.82	0.7769
2010	29.60	28.48	0.962	1.125	27.79	0.9760	25.68	0.9019	24.36	0.8554
2011	17.03	15.90	0.934	1.125	14.95	0.9402	13.81	0.8683	12.70	0.7986
2012	13.12	12.00	0.914	1.125	10.63	0.8862	9.81	0.8176	8.51	0.7095

Table 8. Comparison of Observed Runoff with SCS, Modified SCS and Mockus Method For Station Warudbaji

Year	Observed				Mockus Method		Modified SCS Method		SCS Method	
	P (mm)	Q(mm)	K=Q/P	S	Q(mm)	Ratio ¹	Q(mm)	Ratio ²	Q(mm)	Ratio ³
2008	18.59	17.47	0.939	1.125	16.73	0.9579	15.15	0.8672	13.95	0.7987
2009	24.30	23.18	0.954	1.125	22.28	0.9615	20.66	0.8915	19.40	0.8369
2010	19.67	18.55	0.943	1.125	17.39	0.9377	16.19	0.8729	14.92	0.8042
2011	36.27	35.14	0.969	1.125	34.24	0.9743	32.59	0.9275	31.37	0.8926
2012	9.77	8.64	0.885	1.125	7.27	0.8415	6.80	0.7865	5.67	0.6559

Table 9. Performance Evaluation of models showing Standard error and Coefficient of Determination

GD Station Name	Standard error(mm)			Coefficient of Determination		
	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
Arvimothi	0.5406	5.5116	9.4511	0.9998	0.9820	0.9471
Hamdapur	2.7893	5.7758	9.2383	0.9933	0.9712	0.9264
Hinganghat	2.9059	6.3108	9.6185	0.9950	0.9765	0.9454
Kanholibara	2.6112	6.5051	9.8506	0.9964	0.9779	0.9493
Wadgaon	2.6542	7.4146	11.2048	0.9974	0.9797	0.9537
Wardha	2.8215	6.3893	9.7724	0.9949	0.9739	0.9390
Warudbaji	0.7909	1.0656	1.7172	0.9962	0.9802	0.9540

V.Results And Discussions

A comparative analysis of the observed runoff is made with SCS method, the modified version of SCS, and the Mockus method was performed using eight rain gauge stations of catchment area as shown in Table 2,3,4,5,6,7,8. From Table 2,3,4,5,6,7,8 it is observed that the runoff by SCS model is very less as compare to other models so by considering more number of catchment we can further increase the model efficiency & from analysis it is found that SCS model is best for this catchment area. The resulting standard errors and coefficients of determination are shown in Table 9. As the standard error is dimensional it cannot be used for inter comparison of a model's performance to various applications. Fig. 3 shows variation rainfall with observed Runoff, estimated runoff by SCS Model, Modified SCS Model and Mockus Model. The relationship given in Fig. 4 shows that comparison of data between observed runoff and runoff by SCS Model, Modified SCS Model and Mockus model that the percentage difference is well within $\pm 10\%$. By considering all eight rain gauge station it is observed that the average annual rainfall for the catchment is about 1314.56 mm and the average runoff at catchment 104.95 mm. It is evident that the average annual runoff is much less as compared to average annual rainfall of the watershed

under study. This clearly indicates that runoff is being trapped by various water impounding bodies in the watershed such as minor, medium and major dams, KT weirs etc. Lower Wuna, Bor and Dham are some among them.

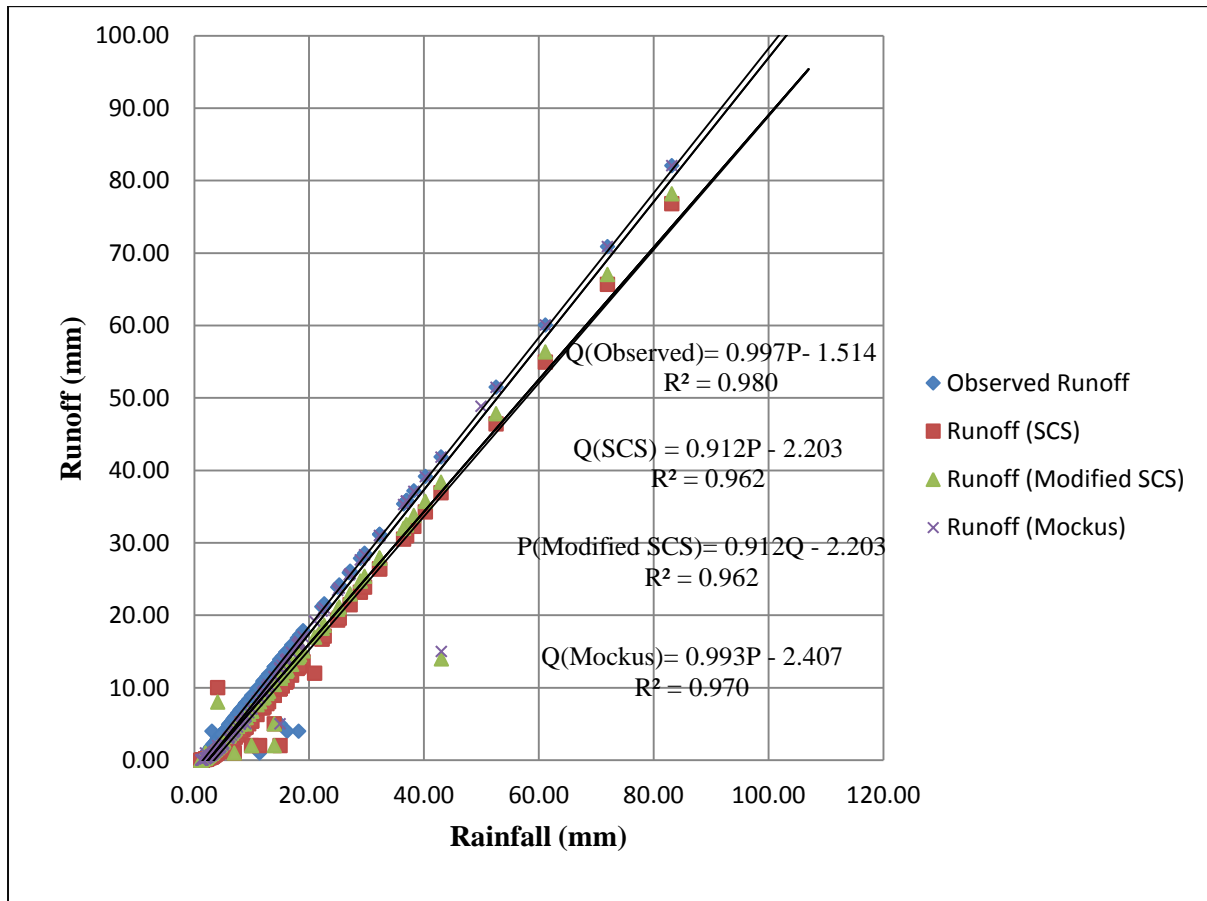


Fig. 3 Variation of Rainfall with observed runoff, runoff by SCS Model, Modified SCS Model and Mockus Model

VI. Equation Generated to Calculate Runoff in Vena Catchment

After performing experimental analysis the relationship between Rainfall (mm) and Runoff (mm) by considering three models is graphically represented in Fig 3. The relationship obtained by regression analysis for the maximum value of Runoff by these models is shown in equation 5, 6, 7 and 8:

A. Relationship between Observed Runoff and Rainfall
 $Q(\text{Observed}) = 0.997P - 1.514$ with $R^2 = 0.980$ (5)

B. Relationship between Runoff by SCS Model and Rainfall
 $Q(\text{SCS}) = 0.912P - 2.203$ with $R^2 = 0.962$ (6)

C. Relationship between Runoff by Modified SCS Model and Rainfall
 $Q(\text{Modified SCS}) = 0.912P - 2.203$ with $R^2 = 0.962$ (7)

D. Relationship between Runoff by Mockus Model and Rainfall
 $Q(\text{Mockus}) = 0.993P - 2.407$ with $R^2 = 0.970$ (8)

VII. Validation Of Data

The validation of proposed analysis for runoff has been done by comparing the value of observed Runoff and Runoff by SCS Model, Modified SCS Model and Mockus model presented in this research paper. The observed runoff and estimated runoff by different models is presented in the paper Eight Rain Gauges stations have been taken up for validation. Fig.3 shows Variation of Rainfall with observed runoff, runoff by SCS Model, Modified SCS Model and Mockus Model. It can be obtained from Fig.4 the percentage difference between observed runoff and runoff by Models is well within range of $\pm 10\%$. Table (9) explains performance evaluation showing Standard error and Coefficient of Determination of three models.

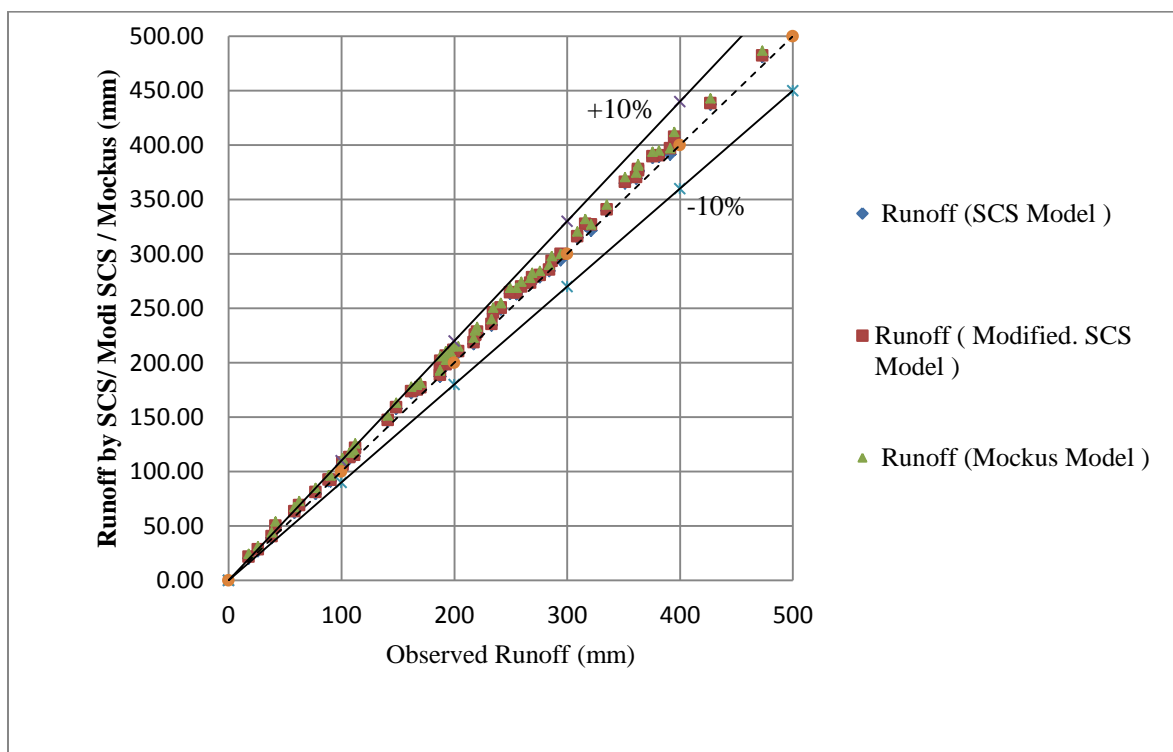


Fig. 4 Combined Graph shows Percentage Variation of observed Runoff with estimated runoff using SCS Model, Modified SCS Model and Mockus Model

VII. Conclusion

The different methods were used to determine runoff for eight rain gauge station in Hinganghat watershed area. The study is conducting on important parameter affecting the discharge from the catchment area. The analysis of runoff is done by comparing observed runoff with SCS Model modified SCS model and Mockus Model, the percentage difference between observed runoff and runoff by Models is well within range of $\pm 10\%$. The rainfall- runoff analysis clearly indicates that availability of runoff at Hinganghat River Gauging Station is low, which discourages any further construction of water bodies in the watershed.

NOTATION

P = the total rainfall (mm),

Ia = the initial abstraction,

CN= curve number

b = fitting coefficient (dimensionless)

Q= the direct runoff, (mm)

S= the potential maximum retention or infiltration (mm) and

Ratio¹= Runoff by Mockus Model (Q_{mockus})/Observed Runoff (Q_{observed})

Ratio²= Runoff by Modified SCS Model ($Q_{\text{modi.SCS}}$)/Observed Runoff (Q_{observed})

Ratio³= Runoff by SCS Model (Q_{SCS})/Observed Runoff (Q_{observed})

Model 1=SCS Model

Model 2=Modified SC S Model

Model 3=Mockus Model

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