Estimation of Runoff for Agricultural Watershed and Silt Load Assessment

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ABSTRACT : *Water is the most important component of the environment because it links together the atmosphere, soil, vegetation, drainage streams & reservoirs. 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 effective water quality management, it is important to assess changes in input loads rather than concentrations. For analysis the rainfall and land use data were used along with the infiltration rate for the estimation of the runoff for the study area. The distributed hydrologic and soil erosion modeling system is used to simulate continuous water balance and soil loss in Vena catchment throughout all seasons. The present research primarily aims at evaluating various characteristics rainfall runoff and silt load assessment by conducting analysis of silt load for Vena catchment. This paper deals with rainfall –runoff analyses using different methods and silt load assessment using universal soil loss equation (USLE).*

Keywords: *Rainfall, Runoff, Soil erosion, Watershed, SCS Model, Modified SCS Model, Mockus Model, USLE.*

I. INTRODUCTION

Silt or Sediment in a stream is considered to be its greatest pollutant. It flows into the streams from Point sources and non-point (non-measurable) sources of the land mass along with runoff. Nonpoint source pollution cannot be traced back to a single origin or source such as storm-water runoff, water runoff from urban areas or failed septic systems. This sediment in runoff water, after settlement, fills the bed of rivers, and reservoirs, contaminate the water bodies and reduces their storage capacities. Suspended sediment degrades the quality of water in streams and reservoirs because it is not palatable and along with it, it also acts as the main carrier of organic and inorganic particles of chemicals which stay stuck to sediment particles. Effective control of soil losses requires implementation of the best management practices in critical erosion prone areas of the watershed. The use of physically based distributed models, remote sensing technique and geographical information system can assist management agencies in both identifying most vulnerable erosion prone areas and selecting appropriate management scenarios. The analysis of critical area of Non-point source pollution is attributed to Ake Sivertun and Lars Prange (2003). Their work presents a method to perform analyses for reveal critical erosion and non-point source pollution areas using the advantages of a GIS. They stated the formula for estimation of the long-term annual soil loss in [tons/ha]. Jingjie Zhang and Sven Erik Jorgensen (2005) simplified the method of presentation of Modeling of point and non-point nutrient loadings from a watershed area. They proposed Nutrient Loading Model (NLM) accounted for the loadings from industrial and municipal wastewaters, atmospheric deposition and runoff from the drainage area. They tested the model using data from Lake Glumso, Denmark, with a drainage area of about 1054.9 ha and with known annual loadings into the lake in 1978, 1982 and 2000. The model may be applicable for estimating nutrient loadings from drainage areas, when observations in general are not available. It can also be used to examine the current conditions and test the effects of management and planning scenarios within a watershed. S. Shrestha et.al (2006) evaluated the annualized agricultural nonpoint source model for a watershed in the Siwalik Hills of Nepal. They determine the predictive capability of Annualized Agricultural Nonpoint Source (AnnAGNPS) model with respect to runoff volume, peak flows, and sediment yield from a 130.8 ha watershed area. Suthipong Sthiannopkao et.al (2007) reported that the transformation of forestlands to agricultural areas and the encroachment of riverbanks within the Phong watershed have caused severe soil erosion. Strong storms in rainy season exacerbate the problem of soil erosion. Soil erosion affects water utility by increasing the turbidity in the Phong River and also by decreasing the water storage capacity of small reservoirs for the upstream residents, as well as that of the Ubolratana Dam in Thailand. They focused on the problem of soil erosion and its effect on water supply in the Phong watershed. Their main objectives are to describe the situation of soil erosion in the upper Phong watershed based on data collected from several local and national organizations and to evaluate the impacts of soil erosion on municipal water supply in Khon Kaen City, which uses the Phong River as a source of raw water. Raveendra K. Rai and B. S. Mathur (2007) carried out extensive experimental work on Event-Based Soil Erosion Modeling for Small Watersheds**.** Their study deals with the estimation of sediment yields and sedimentographs of small watersheds. They proposed mathematical Model which is based on simultaneous solution of flow dynamics followed by dynamic erosions. They proposed that the rainfall-runoff-sediment model as developed was applied to 34 storm events registered over six small watersheds located in different climatic regions of India and the United States. Their model has satisfactorily reproduced the runoff hydrographs and the sedimentographs. S. Shrestha et.al (2008) reported on the estimating pollutant export coefficients and regression models to more complex mechanistic models for water quality monitoring data. Their results are encouraging especially given the pressing need to identify appropriate management practices to improve the water quality within the catchment.

They investigate most of the estimated pollutant export coefficients are significant at α equal to 0.05 and the landuse categories used in the multiple regression models explained more than 85% variability in loadings. Baihua Fu, Lachlan T.H. Newham and C.E. Ramos-Scharron (2010) reviewed on surface erosion and sediment delivery models for unsealed roads. They reported that provides for assessing road erosion and sediment delivery models and it includes an overview of road erosion and sediment delivery processes and that states that how they are commonly represented in models. The present study includes a wide range of sediment load assessment and rainfall-runoff analysis of the Hinganghat River Gauging Station of Wardha District on Vena River. The rainfall, runoff & sediment data for the period of 2007 to 2012 is considered for analysis. The total runoff is computed manually and compares its results with SCS Method, Modified SCS Method and Mockus Method. The annual Soil loss in Vena River is computed manually and compares its results by USLE (Universal Soil Loss Equation).

II. THEORETICAL CONCEPT

A. *Study Area*

The study area, named Hinganghat watershed, is located at Wardha city. Watershed area having a geographical area of 4109 square kilometer on Vena River, 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 20^0 32' 58"N and longitude78^0 48' 00" E. The extent of Catchment Lat 21.032^0 N, Lon.78.299^0E left to 20.650^0N, 79.367^0E, right & Lat.21.208^0N, Lon 78.736^0 E top to 20.545^0 N 78.809^0E bottom. 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).

B. *Data and its sources*

Rainfall data of eight raingauge stations in and around the catchment of Hinganghat River gauging stations under Hydrology Project Division, Nagpur viz (i) Arvi (ii) Hamdapur (iii) Hinganghat (iv) Kanholibara (v) Talegaon (vi) Wadgaon (vii) Wardha and (viii) Warud Bagaji and also Hinganghat River Gauging station for 6 year period i.e. 2007 to 2012 is used for calculating the basin runoff and compare it with SCS, Modified SCS and Mockus method. Sediment data of Hinganghat Water Quality Level-I Laboratory under Hydrology Project Division, Nagpur for 6 year period i.e. 2007-2012 is used for sediment study purpose.

C. *Rainfall-Runoff Analysis using SCS Method:*

To calculation of runoff in Vena catchment it is more convenient to use SCS method, Modified SCS method and Mockus method. The origin of the SCS-CN method can be traced to the proposal of Sherman (1942) on plotting direct runoff versus storm rainfall, and the subsequent work of Mockus (1949) on estimating surface runoff for ungauged watersheds using information on soil, land use, antecedent rainfall, storm duration, and average annual temperature. The Soil Conservation Service (SCS) method is widely used to estimate runoff from small- to medium-sized watersheds. The most critical assumption of the SCS method is that the ratio of the actual retention to the potential retention is the same as the ratio of actual runoff to potential runoff, but this assumption has not been theoretically nor empirically justified. The SCS 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 F amount of the potential maximum retention S. The second to the potential hypothesis relates the initial abstraction I_a maximum retention. Following equation shows estimation of runoff using SCS method.

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

Where,

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

D. *Rainfall-Runoff Analysis using Modification in SCS-CN Method*

The SCS-CN method was modified through theoretical analogy and redevelopment to estimate subsurface drainage flow from rainfall. The analogical theory is that when accumulated subsurface drainage flow is plotted versus accumulated infiltration, subsurface drainage flow starts after some infiltration has accumulated and the relationship becomes asymptotic to a line of 45 ° slope, just as the generalized SCS rainfall-runoff relationship. Modification of the SCS-CN method is introduced and developed to determine the curve numbers for subsurface drainage flow. In the process of defining curve numbers for drainage flow, it was found that the curve number varied not only with season but also with rainfall amount.

$$\frac{Q}{P} = \frac{P}{S+\left[\frac{1}{2}\right]P} \qquad (2)$$

$$Q = \frac{(P-Ia)\times P}{S+a\,(P-Ia)} \qquad (3)$$

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$$\frac{Q}{P} = \frac{P^2}{S+aP}$$

Where a = coefficient replacing 1/2 in (2); and P = P - Ia. The first derivative of (3) with respect to P leads to

$$\frac{\partial Q}{\partial P} = \frac{\frac{P}{S}\left[2+a\frac{P}{S}\right]}{\left[1+a\frac{P}{S}\right]^2} \quad (4)$$

Here again, if $\frac{\partial Q}{\partial P} \to 0$, either $P \to 0$ or $S \to \infty$ and if $\frac{\partial Q}{\partial P} = 1$

$$a = \frac{1}{2} - \frac{S}{P} + \sqrt{\frac{1}{4} + \frac{S}{P}} \quad (5)$$

Where the - sign before the square root sign in (5) is omitted. a =1/2 (for a modified method) at P/S = 0.8284; as $S/P \to 0$, $a \to 1$ (or the general form reduces to the existing SCS method). For $-\frac{\partial Q}{\partial P} = 0$, either $P = 0$ or $S = \infty$, S=surface maximum retention, and P=rainfall in mm . The variation of a with S/P is shown in the Fig. 2

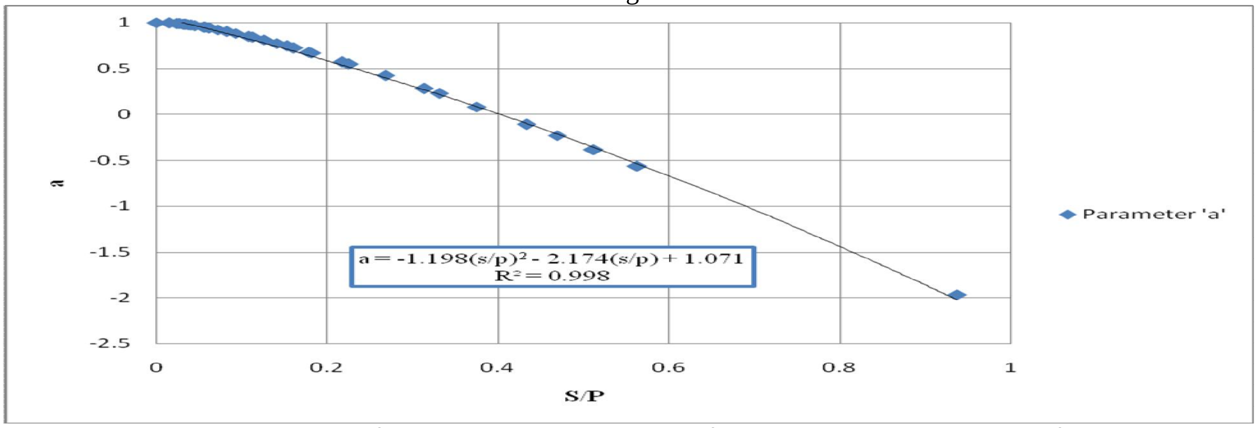

Fig.1 Variation of parameter 'a' with S/P ratio (Surface maximum retention (mm) / rainfall (mm))

E. Rainfall-Runoff Analysis using Mockus Method

The empirical rainfall-runoff relation expressed by Mockus (1949) as follows:

$$Q = (P - Ia)(1 - 10^{-bP}) \quad (6)$$

Where, $b = \frac{1}{S} \times \frac{1}{\mathrm{Loge}10}$ (7)

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 construed 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 initial abstraction *Ia* was found to be approximately 0.2S (Sherman, L. K. 1942). And the potential retention S becomes the only parameter for the method. The potential retention S is commonly expressed in terms of a runoff curve number (CN) through the relationship given below:

$$CN = \frac{25400}{254+S} \quad (8)$$

Where S, 25400, and 254 are given in mm. The SCS method is therefore also known as the SCS CN method. (By knowing land used pattern CN is determined.)

TABLE 1: The Present Land Used Pattern for 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	

F. Silt Load Assessment Using Universal Soil Loss Equation (USLE)

The USLE was developed in the U.S. based on soil erosion data collected beginning in the 1930s by the U.S. Department of Agriculture (USDA) Soil Conservation Service). The Universal Soil Loss Equation (USLE) provides a convenient way to estimate the rate of soil loss on land so that the loss of soil rate is compares with district's standards. The USLE takes into account the major factors that influence soil erosion by rainfall: rainfall patterns, soil types, slope steepness, and management and conservation practices. It was developed by the Agricultural Research Service, the state experiment stations, and the Soil Conservation Service (SCS), using research data from many research stations, including work at Dixon Springs, Urbana, and Elwood, Illinois. (Wischmeier, W. H., and D. D. Smith, 1960) were analyzed more than 10,000 plot years of data and used to develop the equation in the early 1960s. The USLE represents the average annual rate of soil loss due to splash, sheet, and rill erosion. It does not estimate soil erosion from gullies or stream banks or the amount of sediment reaching streams. It will not reflect the average soil erosion rate for the entire field unless the segment you chose represents the field. Taking estimates on several field segments will give a better idea of the scope of erosion problems. The equation is simple to use. Once determined the values for each of the five factors, and multiply them then annual soil loss for the catchment is calculated by using following equation:

$$A = R \times K \times LS \times C \times P \qquad (9)$$

Where,

R =rainfall factor,

K = soil erodibility factor,

LS = length and steepness of slope factor,

C = cropping and management factor,

P = conservation practices factor,

A = the computed average annual soil erosion loss in tons per acre. After determined 'A' by USLE comparison is made with actual annual soil loss in the Vena catchment. 'A' should be within a range of plus or minus 20 percent of your actual average annual erosion on the field segment.

III. ANALYTICAL OBSERVATION OF SILT LOAD FOR 6 YEARS (FROM 2007 TO 2012) AT HINGANGHAT WATERSHED AREA :

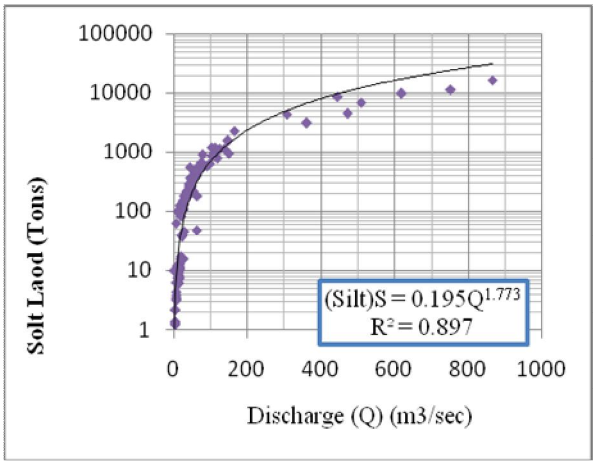

Fig.2.Variation of Discharge/day (m3/sec) verses Silt Load/day (tons) for Year 2007

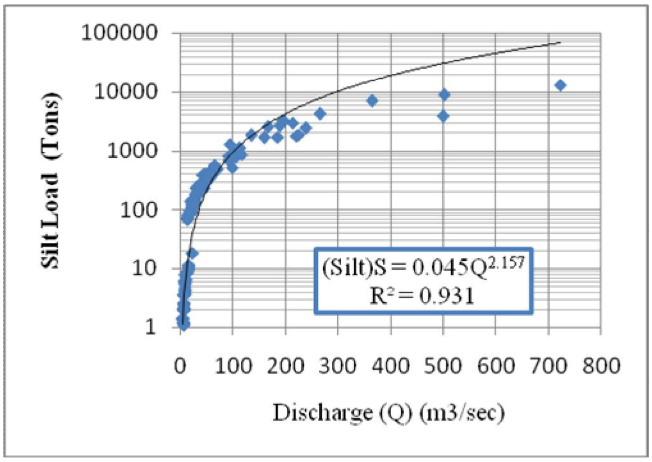

Fig.3.Variation of Discharge/day (m3/sec) verses Silt Load/day (tons) for Year 2008

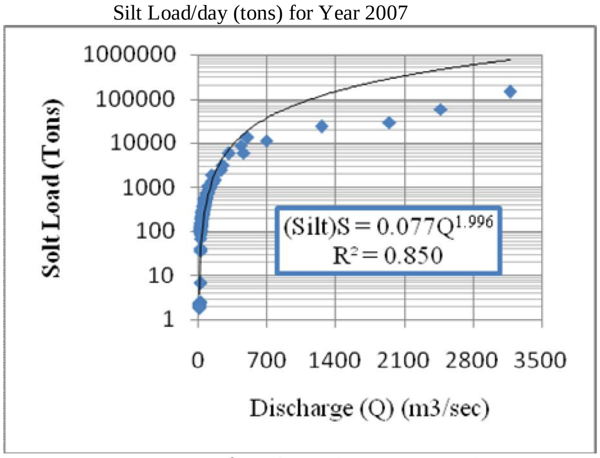

Fig.4.Variation of Discharge/day (m3/sec) with Silt Load/day (tons) for Year 2009

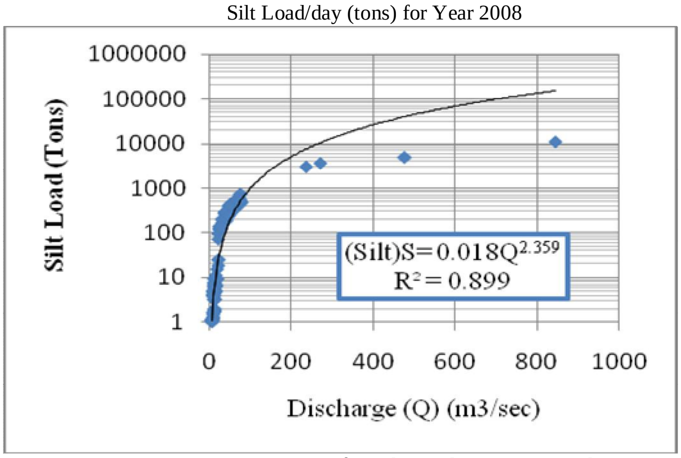

Fig.5.Variation of Discharge/day (m3/sec) with Silt Load/day (tons) for Year 2010

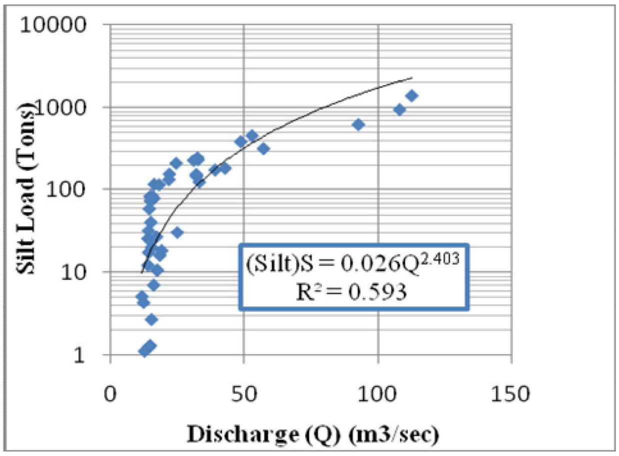

Fig.6.Variation of Discharge/day (m3/sec) with Silt Load/day (tons) for Year 2011

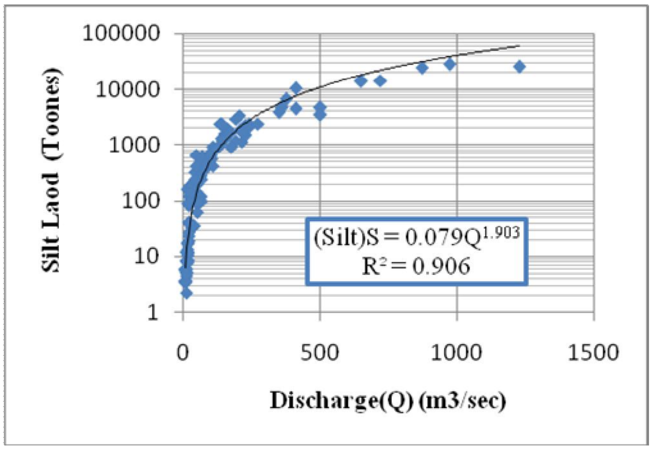

Fig 7.Variation of Discharge/day (m3/sec) with Silt Load/day (tons) for Year 2012

IV. ANALYSIS AND MEASUREMENT OF SILT LOSS

Observation is carried out for the year 2007 to 2012 as shown in fig.2, 3, 4, 5, 6, and 7. The analysis for silt load for the entire catchment consists of twice daily discharge at morning 8.30 am and at evening 5.30 pm and sampling of sediment fragments at morning 8.30 am. The annual Soil loss for each year from 2007 to 2012 for Hinganghat Watershed is computed manually by collecting the sediment samples from Vena River using integrated sediment sampler (in one liter bottle). After sampling is done the sample is bring in the lab and the tasting of sample (sediment in water) is performed in lab (Water Quality Level-I Laboratory under Hydrology Project Division, Nagpur). The filters used for testing have a pore size of 0.45 µm in which sediment particles are trap and water is removed. The trapped sediment particles are them dried and weighed using digital weighing machine. After calculating silt load in one liter it than converted into the quantum discharge for one day, by multiplying silt load for one liter into total daily discharge, which gives total silt load in river for one day in tons. Likewise for each year the silt load is computed manually shown in table 2 (of column 2). After computation of actual silt load for each year it then computed using USLE. After computing the silt load using USLE it is found that the silt load using the USLE is less as compare to actual silt load with percentage difference of 3.04 % shown in table 2 (Column 4 and 6) .

TABLE 2 Difference between Actual Annual Silt load & Silt load by USLE for period from Year 2007-2012 in Vena catchment (Hinganghat Watershed Area).

Year	Actual Total Silt Load (in Tons)	Cumulative Total Silt Load (in Tons)	Total Silt Load USLE Model (in Tons)	Cumulative Total Silt Load USLE Model	Percentage Difference
1	2	3	4	5	6
2007	142675	142675	138337.68	138337	3.04
2008	82579	225254	80068.60	218405	3.04
2009	349854	575108	339218.44	557623	3.04
2010	32344	607452	31360.74	588983	3.04
2011	7037	614489	6823.08	595806	3.04
2012	244727	859216	237287.30	833093	3.04

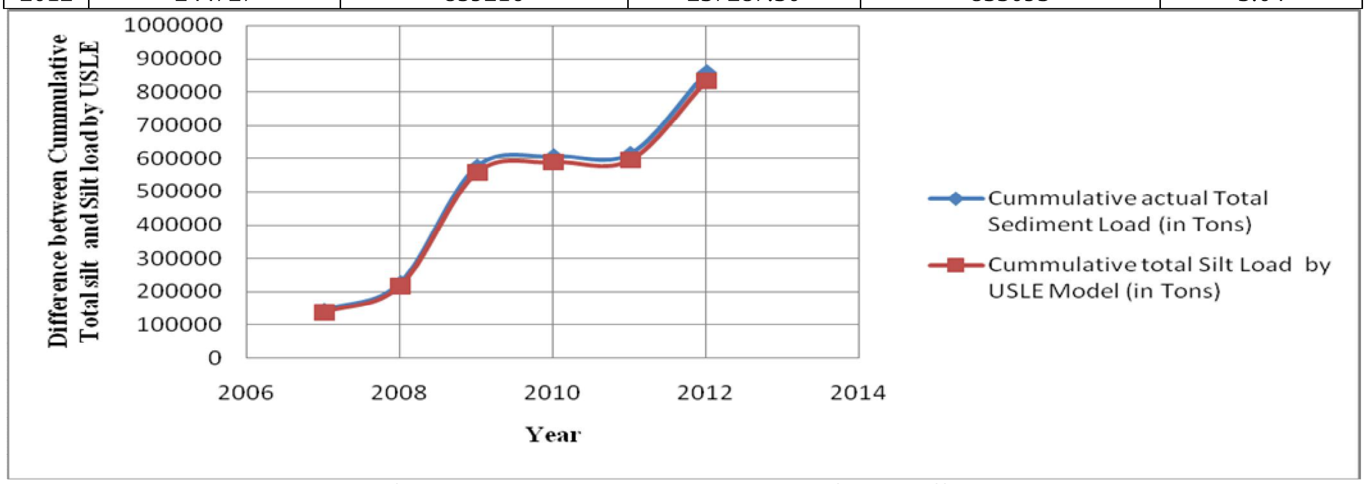

Fig.8 Comparison of Silt load observed & silt load by USLE for the different year in Tons/Year (2007-2012)

TABLE 3 Comparison of Observed Runoff with SCS, Modified SCS and Mockus Method for Hinganghat Watershed

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]
1	2	3	4	5	7	8	9	10	11	12
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

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 on Hinganghat Rain Gauge stations of catchment area as shown in Table 3.From Table 3.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 relationship given in fig 10 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 ±10%. Fig 9 shows variation rainfall with observed Runoff, estimated runoff by SCS Model, Modified SCS Model and Mockus Model. By analysis and from Table 2 it is observed that in Year 2009 the loss of silt is very more. Fig.8 and Table 2.shows difference between actual Annual Silt load and Annual Silt load by USLE in Tons/Year with percentage difference of 3.04 % for period 2007-2012 (Year) in Vena catchment.

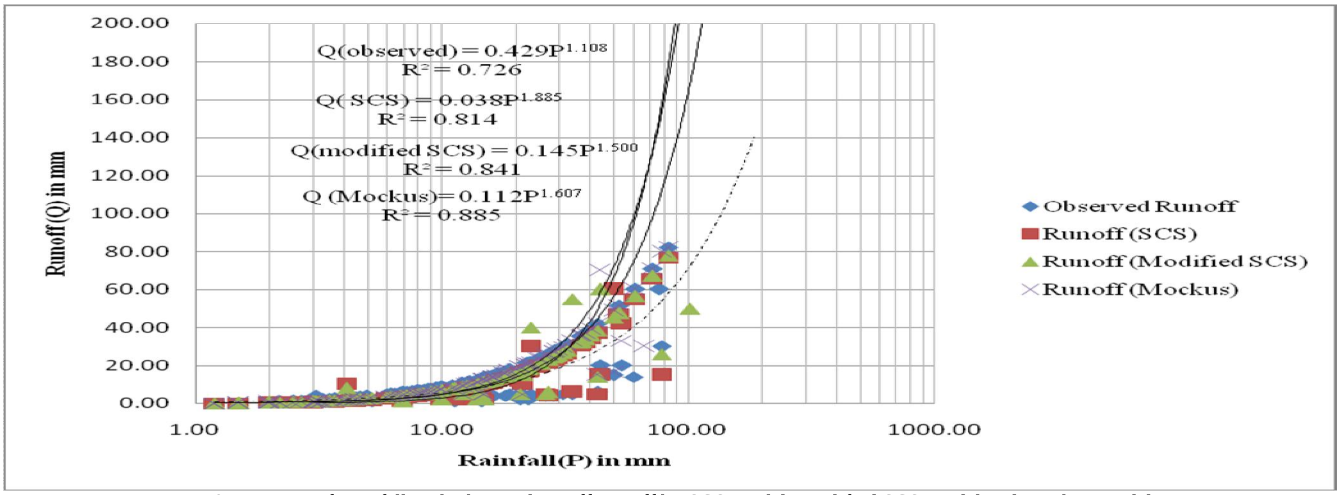

Fig 9 Variation of Rainfall with observed runoff, runoff by SCS Model, Modified SCS Model and Mockus Model.

The relationship between Rainfall (mm) and Runoff (mm) by considering three models is graphically represented in Fig 9.The relationship obtained by regression analysis for the maximum value of Runoff by these models is shown in equation 10, 11, 12, 13:

A. *Relationship between Observed Runoff and Rainfall*

$$Q\ (observed) = 0.429P^{1.108}, \quad \text{With } R^2 = 0.726 \qquad (10)$$

B. *Relationship between Runoff by SCS Model and Rainfall*

$$Q\ (SCS) = 0.038P^{1.885}, \quad \text{With } R^2 = 0.814 \qquad (11)$$

C. *Relationship between Runoff by Modified SCS Model and Rainfall*

$$Q\ (modified\ SCS) = 0.145P^{1.500}, \quad \text{With } R^2 = 0.841 \qquad (12)$$

D. *Relationship between Runoff by Mockus Model and Rainfall*

$$Q\ (Mockus) = 0.112P^{1.607}, \quad \text{With } R^2 = 0.885 \qquad (13)$$

VI. VALIDATION OF DATA

The validation of proposed analysis for runoff has been done by comparing the value of observed Runoff and estimated runoff by different models is presented in the paper. Eight Rain Gauges stations have been taken up for validation. Fig 10 shows the comparison of data of Observed Runoff and Runoff by SCS Model, Modified SCS Model and Mockus model. It can be obtained from Fig.10 the percentage difference between observed runoff and runoff by Models is well within range of ±10%. Also the validation of Silt load in Vena Catchment has been done by comparing the value of Observed Silt load with Silt load by USLE (Universal Soil Loss Equation). Fig.8 shows the difference between actual Silt load and computed Silt load by using Universal Soil Loss Equation (USLE) for catchment area. From Table 2 It is observed by applying the Universal Soil Loss Equation (USLE) for the catchment area the silt load is reduced up to 3.04%

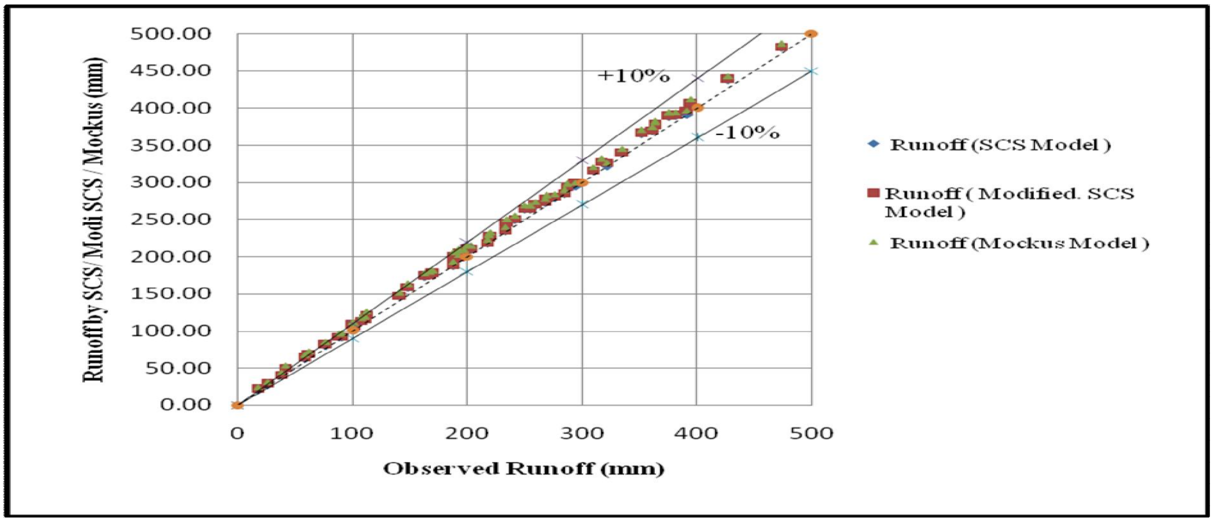

Fig. 10 Comparison of Observed Runoff and Estimated Runoff using SCS Model, Modified SCS Model and Mockus Model.

VII. CONCLUSION

The different methods were used to determine runoff and silt load assessment for Hinganghat rain gauge station for Vena catchment. The study is conducting on important parameter affecting the silt loss and discharge from the catchment area. The analysis of runoff is done by comparing observed runoff with existing model. Based on experimental data and observation of rainfall and runoff at Hinganghat River Gauging Station, the following conclusion are drawn

1. The analysis of runoff is done by comparing observed runoff and using different model, the percentage difference between observed runoff and runoff by Models is well within range of ±10%.
2. After applying the Universal Soil Loss Equation (USLE) for the catchment area the silt load is reduced up to 3.04%.
3. The efficiency of SCS Model is highest then Modified SCS Model and Mockus model.
4. The model efficiency increases by considering more number of catchment & SCS model is best for this catchment area.

NOTATION

R =rainfall factor
K = soil erodibility factor
LS = length and steepness of slope factor
C = cropping and management factor
P = conservation practices factor
A = the computed average annual soil erosion loss in tons per acre
P = the total rainfall (mm),
Ia = the initial abstraction,
CN= curve number
b =runoff coefficient (dimensionless)
F = the cumulative infiltration excluding Ia,
Q= the direct runoff, (mm)
S= the potential maximum retention or infiltration (mm) and
λ=the regional parameter dependent on geologic and climatic factors ($0.1<\lambda<0.3$).
AMC= Antecedent moisture content
$Ratio^1$= Runoff by Mockus Model (Q_{mockus})/Observed Runoff ($Q_{observed}$)
$Ratio^2$= Runoff by Modified SCS Model ($Q_{modi.SCS}$)/Observed Runoff ($Q_{observed}$)
$Ratio^3$= Runoff by SCS Model (Q_{SCS})/Observed Runoff ($Q_{observed}$)
SCS= soil Conservation service

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