EFFECT OF WATERSHED CHARACTERISTICS ON RUNOFF CURVE NUMBER

A DISSERTATION

Submitted in partial fulfilment of the
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IRRIGATION WATER MANAGEMENT
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By

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CANDIDATE'S DECLARATION

I hereby declare that the work which is being presented in this dissertation, entitled, "EFFECT OF WATERSHED CHARACTERISTICS ON RUNOFF CURVE NUMBER", in partial fulfilment of the requirement for the award of the degree of Master of Technology in "Irrigation Water Management (Civil)", submitted in the Department of Water Resources Development and Management, Indian Institute of Technology, Roorkee is an authentic record of my own work carried out during a period from June 2017 to May 2018 under the supervision of Prof. S. K. Mishra, Department of Water Resource Department and Management, Indian Institute of Technology Roorkee, India, and Dr. P.K. Singh, Scientist C, National Institute of Hydrology Roorkee, India.

The matter presented in this dissertation has not been submitted by me for the award of any other degree of this or any other Institute.

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CERTIFICATE

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ABSTRACT

Estimation of runoff and sediment yield is essential for solution of a number of problems such as the design of reservoirs, dams, planning of soil conservation structures and river morphology studies. A number of models have been developed to compute runoff and sediment yield generated from rainfall event. The Soil Conservation Service Curve Number (SCS-CN) method is one of the most popular and widely used event-based methods for runoff estimation and recently it has been also coupled with the popular soil erosion models such as Universal Soil Loss Equation (USLE) and Revised Universal Soil Loss Equation (RUSLE) for sediment yield estimation.

This study explores the effects of the watershed characteristics such as soil type, land use, antecedent moisture condition, and watershed slope on the Curve Number (CN) and, in turn, on watershed runoff and sediment yield using the rainfall-runoff and sediment yield data of an experimental watershed located at Toda Kalyanpur, Roorkee, Haridwar, India (lat. 29º 50´ 6´´ N and long. 77º 50´ 17´´ E). The experimental field is sub-divided into 9 equal agricultural plots having the dimension of 12 x 3 m each. These plots were further divided into 3 groups having different slopes of 8%, 12% and 16%. 3 plots of a slope were planted with two different crops, i.e., Maize, Finger millet and one plot left as fallow land to study their comparative impacts on hydrological responses in terms of runoff and sediment yield.

In this study, a total of nineteen storm events were carefully observed for runoff and sediment yield. The sediment samples collected in the filed were analyzed in WRDM laboratory for suspended sediment concentration using oven drying method. Experiments were also conducted for estimation of initial soil moisture before storm, soil texture analysis and infiltration capacity tests using double ring infiltrometer. The hydrological soil group was however the same for all plots, as established from infiltration tests. The results show that as slope is increased from 8% to 16%, the runoff is also found to increase and hence CN. While keeping the rest of watershed characteristics the same, the Maize crop showed the highest runoff and CN as compared to the other crops. The SCS-CN parameter S showed an inverse relation with the physically measured antecedent moisture content. The trend line of the plotting of rainfall against the runoff shows that runoff increases with the increase in rainfall for the given plot. Sediment yield in the representative sample increases with increase in runoff and relatively high value of R^2 is obtained with these relations. The sediment rating curves

were also plotted between suspended sediment concentration and runoff volume with coefficient of determination greater than 0.5 for all crops and land slopes.

The runoff was estimated using the existing SCS-CN method and for estimation of the sediment yield, the model developed by (Mishra et al., 2006) was coupled with the MUSLE model. The model performance was evaluated using Nash-Sutcliffe efficiency (NSE %), the root mean square error (RMSE) and percent bias (PBIAS). The overall values of NSE, RMSE and PBIAS were found to be 90.57%, 60.55%; 0.37, 0.41; -17.34, -14.47, respectively for runoff and sediment yield prediction.

Based on the criteria of (Moriasi et al., 2007), the model was found to perform very good in runoff prediction and good in sediment yield prediction. Due to non-linearity between runoff and suspended sediment yield, the CNs estimated for runoff cannot be directly used for sediment yield estimation. An effort was also made in this study to develop a relationship between CNs estimated by using observed sediment yield and CN estimated using observed runoff for all nine plots. The developed relationships can be directly used for estimation of CNs for application in sediment yield estimation by using CNs obtained from observed rainfall-runoff data.

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ABBREVIATION

AMC	=	Antecedent Moisture content (AMC I for dry, AMC II for normal and AMC III for wet condition)
A	=	Hydrological Soil Group category
C	=	Hydrological Soil Group category, Runoff coefficient
CN	=	Curve number
CN_T	=	Curve number from the table
CN_F	=	Observed Curve number
CN_L	=	Curve number from least square fitting
CN_2	=	Curve number Value for AMC II
$CN_{2\alpha}$	=	Slope –Adjusted CN for AMC II and slope α
F	=	Infiltration rate
f_c	=	Minimum infiltration rate
GIS	=	Geographical Information System
M	=	Soil moisture
Mm	=	Millimetre
NEH-4	=	National Engineering Handbook, Section-4 (Hydrology)
NRCS	=	Natural Resources Conservation Service
NSE	=	Nash-Sutcliffe efficiency
RMSE	=	Root Mean Square Error
P	=	Precipitation (Rainfall)
Ps	=	Conservation Practice factor
P_5	=	5-day antecedent rainfall amount
PBIAS	=	Percent BIAS
Q	=	Direct surface runoff
Q_T	=	Runoff predicted using NET-4 Table CN

Q_F	=	Runoff predicted using observed median CN
Qobs	=	Observed direct surface runoff
S	=	Potential maximum retention
Qcomp	=	Computed direct surface runoff
SCS	=	Soil Conservation Service
SCS-CN	=	Soil Conservation Service Curve Number
SVL	=	Soil-Vegetation and Land use/land cover
S.Y	=	Sediment Yield
TDR	=	Time Domain Reflectometry
TR	=	Technical Release
USDA	=	United State Department of Agriculture
VWC	=	Volumetric abstraction coefficient
Λ	=	Initial abstraction coefficient
θ_o	=	Antecedent moisture content

CHAPTER I

INTRODUCTION

1.1 GENERAL

Hydrology is the science which deals with the existence, movement and distribution of water of the earth, below the earth and earth's atmosphere. As one of the branches of earth science, hydrology deals with the water in waterways and lakes, precipitation and snow, snow on the terrestrial and water underneath the earth and rocks. Hydrology has its links with meteorology, geography, measurements, science, material science and liquid mechanics. Engineers and hydrologists are highly concerned about the amount of runoff generating from a given rainfall amount. Emptying of precipitation out of catchment through the streams/channels is called runoff. Regardless of whether, it is flood control, hydraulic design, flood prediction or flood control, water resource assessment, soil loss and sediment yield, the knowledge of hydrology is required in all of these aspects. The surface excess water is most basic and vital parameter for the appraisal of watershed water yield.

There is numerous experimental formula viz. Ryves equation, Dickens formula, Inglish equation etc. are available to predict design flood from ungagged catchment which doesn't consider the environmental change it just gives an experimental assessment of the surge which might not be a right presumption in current condition. The Soil Conservation Service Curve Number (SCS-CN) method is most generally utilized technique for estimation of run-off among different model accessible. This technique is pertinent for all ungauged watershed for hydrological data. The SCS-CN method was developed by the USA in 1954 for its prevailing land use and soil conditions, however, it is being utilized all over the world, including India and Nepal for evaluating runoff depth in rural as well as urban watersheds. Other than the estimation of runoff, the method has also been utilized for estimation of soil erosion and sediment yield from watersheds.

1.2 SCS-CN METHOD

The Soil Conservation Service Curve Number (SCS-CN) method is one of the most widely used methods for runoff estimation. It is because most of the techniques available for gauged/ungauged watersheds possess multifaceted variables which are, at times, difficult to estimate or measure. On the other hand, the SCS-CN method is simple and appropriate to ungauged watersheds, for which minimum hydrologic information is required. The SCS-CN technique was developed by Soil Conservation Service (SCS) now known as Natural Resources Conservation Service, (NRCS), of United States Department of Agriculture (USDA) in 1954 and archived in National Engineering Handbook, Hydrology Section-4 out of 1956. The SCS-CN technique converts the given rainfall amount into a surface runoff by the utilization of properties which represent the runoff potential of watershed characterized by hydrologic soil type, land use and treatment, ground surface condition and antecedent moisture condition (Mishra and Singh, 2003a).

The SCS-CN method is based on a non-linear rainfall-runoff relationship that includes a variable called the runoff curve number (CN). The hydrologic soil group (HSG), Antecedent moisture condition (AMC), Hydrologic condition, Initial abstraction, land use/land cover, climate, watershed slope, rainfall duration and intensity, and Turbidity etc. are the main watershed characteristics that affect the value of CN and hence the generated runoff. The combination of soil type, vegetation cover and land use/treatment is known as soil-vegetation-land use (SVL) complex (Miller, N., and Cronshey, 1989) and play a major role in hydrological response of a catchment. These features principally affect the infiltration potential of a watershed. The SCS-CN method is also an infiltration loss model (Soni, and Mishra, 1985).

1.3 SEDIMENT YIELD

Sediment yield is defined as the total amount of sediment delivered from watershed or drainage computable at a point of reference and in a definite period of time (ASCE,1970). Sediment yield from the basin is the output form of a detachment process. Estimation of Soil losses is required for such as the design of dams and reservoirs, river morphology, design and planning of soil conservation practices, the design of established conduit for any propose such as irrigation, hydropower, navigation etc. The process of sediment yield commonly contains: (a) detachment and transportation of soil elements by rainwater, (b) the detachment and transference of soil by overflow and c) lastly deposition of soil. The sediment yield procedure may be considered to consist of two phases (a) the upland phases(b) The lowland stream or the canal phase Bennett, (1974).

Soil disintegration is a natural and complex dynamic process and happened due to the agent, viz. wind, water, gravity, and so forth. It is the yield of three procedures: detachment of soil elements by raindrop influence, separation of soil particles by surface excess flow and conveyance of these dirt particles by surface overflow. Detachment is the process in which soil particle separated from the soil and transport means movement thus obtained separate soil elements to some location from the point of detachment (Freebairn, 2014).

Recently, the SCS-CN method has been successfully coupled with the erosion and sediment yield models for estimation of sediment yield at the basin outlet. The land use change is primarily responsible for deviations in sediment delivery to downstream water bodies (Dunne, 1979). Hydrologic information can be derived from a rainfall-runoff model (SCS-CN) and it is used in the calculation of potential erosion using Universal Soil Loss Equation (USLE) or Modified USLE for determining the sediment yield.

1.4 OBJECTIVE OF THE STUDY

The objectives of this study are three-fold:

1. To determine the effects of watershed slope on runoff curve number and sediment yield.
2. To determine the effects of antecedent soil moisture on runoff curve number and sediment yield.
3. To determine the effects of watershed land use on runoff curve number and sediment yield.

1.5 ORGANIZATION OF DISSERTATION

The contents of this dissertation report are divided into five sections as listed here.

Chapter I:	It briefly presents the SCS-CN method along with major factors affecting runoff and sediment yield followed by the major objectives.
Chapter II:	It provides a comprehensive literature review pertaining to application of SCS-CN method for runoff and sediment yield estimation.

Chapter III: It defines study area, the instrumentation used and data collection and methodology adopted for the experiment and procedure to accomplish the work.

Chapter IV: This chapter presents the results obtained from this study and inferences are drawn from the results obtained. The performance of the models is also evaluated in this chapter.

Chapter V: This chapter presents summary of the results obtained and conclusion drawn along with the major finding of this study. The future scope of the research is also presented in this chapter.

CHAPTER II

REVIEW OF LITERATURE

As the objective of the study is to reconnoitre the presence of a relationship among the watershed characteristics, runoff Curve Number (CN) and sediment yield in a watershed (i.e. experimental field plots) and the SCS-CN methodology, the literature review is mainly focused on SCS-CN methodology and the various studies related to rainfall, runoff, soil erosion, and sediment yield estimation and relationship among them.

2.1 SCS-CN METHOD

The Soil Conservation Service Curve Number (SCS-CN) method is based on the water balance equation and two fundamental hypotheses expressed, as:

$$P=I_a+F+Q \tag{2.1}$$

$$\frac{Q}{(P-I_a)}=\frac{F}{S} \tag{2.2}$$

$$I_a=\lambda S \tag{2.3}$$

where, P= total precipitation (mm), Q= direct surface runoff (mm), Ia= initial abstraction (mm), S= potential maximum retention (mm), and λ= initial abstraction coefficient or abstraction ratio and its standard value is 0.2. All quantities are in-depth or volumetric units. Solving of Equations (2.1and 2.2) concludes to the standard form of the SCS-CN method as:

$$Q=\frac{(P-I_a)^2}{P+I_a+S}=\frac{(P-\lambda S)^2}{P+(1-\lambda)S} \tag{2.4}$$

Equation (2.4) is meaningful for P ≥ Ia, Q=0 otherwise.

For λ=0.2, Equation 2.4 can be written as

$$Q=\frac{(P-0.2S)^2}{P+0.8S} \tag{2.5}$$

Thus, existing Soil Conservation Service Curve Number (SCS-CN) method (Eq. 2.5) is an only parameter model for calculating surface excess from daily storm rainfall. This method was initially developed using daily rainfall-runoff records of annual extreme flows (Rallison, and Cronshey, 1979).

Since SCS-CN parameter (S) can vary in the range of (0 to ∞), dimensionless curve number (CN) is in the range, as follows:

$$S=\frac{25400}{CN}-254 \tag{2.6}$$

where, S is in mm. Equation 2.6 is solved via the quadratic formula and SCS-CN parameter S for observed rainfall-runoff data can be determined as follows Hawkins, (1993.) with λ=0.2:

$$S=5\left[(P+2Q)-\sqrt{(4Q^2+5PQ)}\right] \tag{2.7}$$

McCuen, (2002) proposed necessity of the systematic and numerical study for the identification of causes of CN variation. As the initial abstraction component explanations for surface stowing, interception, and infiltration before runoff begins, theoretically, λ can take any value of 0 to ∞ (Mishra and Singh, 1999, 2003a, 2004).

2.2 ADVANTAGE AND DISADVANTAGE OF SCS-CN METHOD

The major advantages and disadvantages of SCS-CN method can be enumerated here as:

2.2.1 Major advantages:

- This method is a simple, conventional, firm and lumped conceptual method and uses only one parameter i.e. CN for runoff estimation. It is an appropriate for un-gauged watershed.

- It is the only method available which can be applied in the most of the computer-based sophisticated hydrological models.
- It is vastly receptiveness to four readily grasped watershed characteristics such as type of soil, land use, surface condition and antecedent moisture condition.
- Only few basic vivid input parameters are required for runoff estimation.
- The method can be successfully adopted for various type of environmental modelling
- GIS and remote sensing technique for watershed management and runoff estimation can also be applied using the model.

2.2.2 Major disadvantages:

- Value of the initial abstraction coefficient λ is assumed to be fixed (0.2).
- There is no clear provision for spatial scale effects on CN that is very sensitive and governs the runoff.
- Relation between the curve number and moisture condition is distinct which results into a sudden jump in CN and abrupt change in runoff computations.
- The method does not incorporate the effect of rainfall intensity and its temporal distribution in its structural foundation.
- More importantly, it does not have any mathematical equations for antecedent moisture, which is very important in rainfall- runoff process.

2.3 MODIFIED UNIVERSAL SOIL LOSS EQUATION (MUSLE)

The USLE (Wischmeier and Smith, 1978) model is used for estimation of the potential maximum soil erosion from sheet and rill erosion and expressed as:

$$A = R\ K\ L\ S\ Ps\ C \tag{2.8}$$

where, A is yearly potential soil erosion (t ha^{-1} $year^{-1}$), (Beretta-Blanco and Carrasco-Letelier, 2017), K is soil erodibility factor (t ha $hha^{-1} MJ^{-1} mm^{-1}$), R is erosivity factor (MJ mm ha^{-1} h^{-1} $year^{-1}$), LS is the slope length and steepness factor, Ps is the supporting practice factor and C is cover management factor respectively. Out of which LS, C and Ps are dimensionless. In the above-mentioned formula (Eq. 2.8) of yearly potential soil erosion, one issue using the USLE model is that there is no direct consideration of runoff even though erosion depends on sediment being discharge with the flow, which diverges with runoff and sediment concentration (Kinnell, 2005).

A modified erosivity factor was therefore presented by (Foster et al., 1977) to take into interpretation the result of runoff shear stress in term of a product of volume and peak discharge on soil losses for a single storm. Some scholar has described that runoff is the best single needle for soil losses estimate (Kumar and Prasad, 2015), which has commanded to the development of Modified Universal Soil Loss Equation (MUSLE) (Kumar and Prasad, 2015) (Smith et al., 1984) by replacing the rainfall energy factor with a runoff factor. This was also examined by Sadeghi and Mizuyama, (2007). The equation that best fit the data was of following with a correlation of 92%. The MUSLE is expressed as:

$$Y_m = 11.8\ (Q \times q_p)^{0.56} * K * LS * C * Ps \tag{2.9}$$

where, Y_m = Sediment yield from individual storms (in Metric Tonnes), Q=Strom runoff volume in m^3, q_p=peak rate of runoff in m^3/s. The slope length and steepness factor (LS) accounts for the overland runoff length and slope. The slopes >4%, the slope length and steepness factor (LS) can be expressed as:

$$LS = L^{1/2}\ (0.0138 + 0.00974 * S + 0.001138 * S^2 \tag{2.10}$$

where, L is the length (m) of a slope from the point of origin of the overland flow to the point where the slope decreases, S is the gradient (%) over the runoff length and (Kayet et al., 2018) the cover management factor (C) determines the ground cover conditions, effect of soil conditions and general management practices on the erosion rates (Dabral et al., 2008). The K is soil erodibility factor (Gitas et al., 2009).The supporting conservation practice factor (Ps) (Kuok et al., 2013) expresses the effectiveness of erosion control practices, such as land treatment by compacting, contouring and establishing sedimentation basins. Usually, C determines the protection of the soil against the impact of rainfall and subsequent loss of soil particles, whereas Ps reflects treatments that hold eroded particles and prevent them from further transport. Ogrosky, (1957) formulated the method to evaluate the peak runoff rate by using the SCS-CN curve method as:

$$Q_P = \frac{0.0208\ A*Q}{T_{PK}} \tag{2.11}$$

where, Q_p =Peak rate of runoff, (m^3/s), A=Area in (ha), Q=Runoff depth in (cm), T_{pk}=time to peak in hr.

$$T_{PK}=0.6T_C+\sqrt{T_C} \tag{2.12}$$

T_C = Time of concentration in hr

$$T_C = \frac{L^{0.8}\left[\left(\frac{1000}{CN}\right)-9\right]^{0.7}}{4407\left(S_g\right)^{0.5}} \tag{2.13}$$

where, L is longest flow length, CN is curve number and Sg is the average slope of the watershed in m/m.

A study was conducted by (Gao et al., 2012) by incorporating antecedent moisture condition (AMC) in runoff production in the SCS-CN model and considering the direct effect of runoff on soil loss by adopting a rainfall-runoff erosivity factor in the RUSLE model. The effects of AMC, slope and initial abstraction on CN as well as those of vegetation cover on the cover-management factor of RUSLE, were also considered in this study. It was found the modified SCS-CN model was accurate in predicting event runoff with Nash-Sutcliffe model efficiency (EF) over 0.85. Therefore, the coupling the modified SCS-CN method and RUSLE model appears to be appropriate for evaluating hydrological effects of restoring vegetation.

Sadeghi and Mizuyama, (2007) used Modified Universal Soil Loss Equation (MUSLE) for estimating sediment yield from Khanmirza watershed (395 km^2) located in western Iran. The researchers found the model performed satisfactorily. (Arekhi et al., 2012) estimated sediment yield of the Kengir watershed in Iyvan City, Ilam Province, Iran by using the Modified Universal soil losses equation. The runoff factor of MUSLE was computed using the measured values of runoff and peak rate of runoff at the outlet of the watershed. Sediment yield at the outlet of the study watershed was simulated for six storm events and validated with the measured values. The high coefficient of determination value (0.99) indicates that MUSLE model sediment yield predictions are satisfactory for practical purposes. (Gitas et al., 2009) tested the workability of MUSLE for assessing the risks of erosion in N. Chalkidiki, Greece.

Sporton, (2009) integrated the Modified Universal Soil Loss Equation (MUSLE) in a Geographic Information System (GIS) framework in the form of a tool called Arc-MUSLE. Arc-MUSLE applies the MUSLE equation, curve number, and graphical peak discharge methods. Outputs of the Arc-MUSLE tool include curve number, runoff, peak flow, and soil loss for a rainfall event within a watershed. The model helps prioritization of critical soil erosion areas and the improvement of water and soil conservation efforts.

(Sadeghi et al., 2007) evaluated the applicability of the deterministic model MUSLE in the Mie small steeply reforested watershed. The model was tested and calibrated using accurate continuous suspended sediment data collected during eight rainfall storm events. The study finds efficient application of the revised MUSLE in estimating storm-wise sediment yield with a high level of agreement of beyond 88%, an acceptable estimation error of some 14% and a non-significant difference in mean values. (Pongsai et al., 2010) calibrated and validated MUSLE in event-based sediment yield estimation using the S factor of the classic USLE on slopes with 9 and 16% inclination at Khun Satan Research Station, Department of National Parks, Wildlife and Plant Conservation, Thailand.

(Kinnell et al., 2010) found that MUSLE considers the effects of soil, crop, and crop management on sediment concentration separately from the effects of runoff. Because the USLE does consider only rainfall factor and hence new values for K, C, and P need to be determined for use with MUSLE. The USLE and MUSLE are equally effective in predicting erosion for impervious conditions but the efficiency of the USLE decreases as the proportion of the rain infiltrating increases, while that of the MUSLE does not.

(Pongsai et al., 2010) used MUSLE model for Amameh catchment and found satisfactorily performance for the prediction of sediment yield. (Smith et al. 2017) found that MUSLE can be a useful tool for estimating sediment yields from watersheds. Moreover, results with the mixed land-use watersheds (containing both grassland and cropland subwatersheds) supported to the view that MUSLE has utility on a multiple as well as individual watershed bases.

Recently (Sadeghi et al., 2014) reviewed the applications of MUSLE model for erosion and sediment yield estimation. They found that although the MUSLE model is capable to model erosion and sediment yield process, however, review of the correct values and exact variables will lead towards further refinements and hence further studies and investigations are needed to draw a comprehensive conclusion.

2.4 USLE COUPLED SCS-CN-BASED SEDIMENT YIELD MODEL

For the first time, SCS-CN based sediment yield model was developed by (Mishra et al., 2006) for predicting the runoff and sediment yield from a watershed. In this method, the coupling of the SCS-CN model with universal soil losses equation (USLE) is based on three hypotheses:

1. Runoff coefficient is equal to the degree of saturation;
2. Potential maximum retention can be expressed in term of USLE parameters; and
3. The sediment yield delivery ratio is equal to the runoff coefficient.

After coupling SCS-CN with USLE, the simplest model is expressed as:

$$Q=\frac{P^2}{P+S} \tag{2.14a}$$

$$Y=\frac{AP}{P+S} \tag{2.14b}$$

(Mishra et al., 2006) proposed the model after conducting an experiment at different 12 watersheds (India) and USA watersheds (98 storm events). For all watersheds, the computed sediment yield was found to have a good arrangement with observed sediment yield.

However, as discussed above, that runoff is the best single indicator for soil losses and hence there is a further scope for further refinement in the model developed by (Mishra et al., 2006) and MUSLE model can be a best choice in place of USLE model.

CHAPTER III

MATERIALS AND METHODS

The methodologies used in this study proceeds with a brief description of study area, collection of rainfall-runoff and suspended sediment yield data, conducting infiltration tests, measurement of antecedent soil moisture, particle size analysis and finally development and application of SCS-CN based sediment yield model for sediment yield estimation and application of existing SCS-CN model for runoff estimation.

3.1 STUDY AREA DESCRIPTION

The experimental site is situated in town Toda Kalyanpur (29° 50' 6" N, Longitude: 77° 50' 17" E) nearby Roorkee, Haridwar District of Uttarakhand State in India (Fig. 3.1). It is around 6 km south-east of IIT Roorkee. Its altitude is 266 meters above mean ocean level (MSL). The region encounters the sub-tropical atmosphere. The rainfall occurs between the month of June to September and ranges from 1200 to 1500 mm.

3.2 EXPERIMENTATION AND DATA COLLECTION

The SCS-CN method estimates runoff depth from given rainfall event particularly from small agricultural watersheds. In any case, its experimental confirmation for Indian soil was not attempted and has not been reported in hydrologic literature. To determine the effect of soil, land use, AMC and slope of the watershed in Indian conditions, an experimental farm has been developed in the town Toda Kalyanpur, nearby Roorkee, Haridwar district, India (Fig. 3.1). The land plot has been separated into three distinct slopes at 8%, 12% and 16% and again each slope was divided into 3 plots having different land use viz. maize, finger millet and fallow land (Fig. 3.1) during a rainfall incident, the subsequent runoff from each plot was transmitted to its outlet through a a multi-opening divisor fitted in channel joining tank/chamber of size 1mx1mx1m.

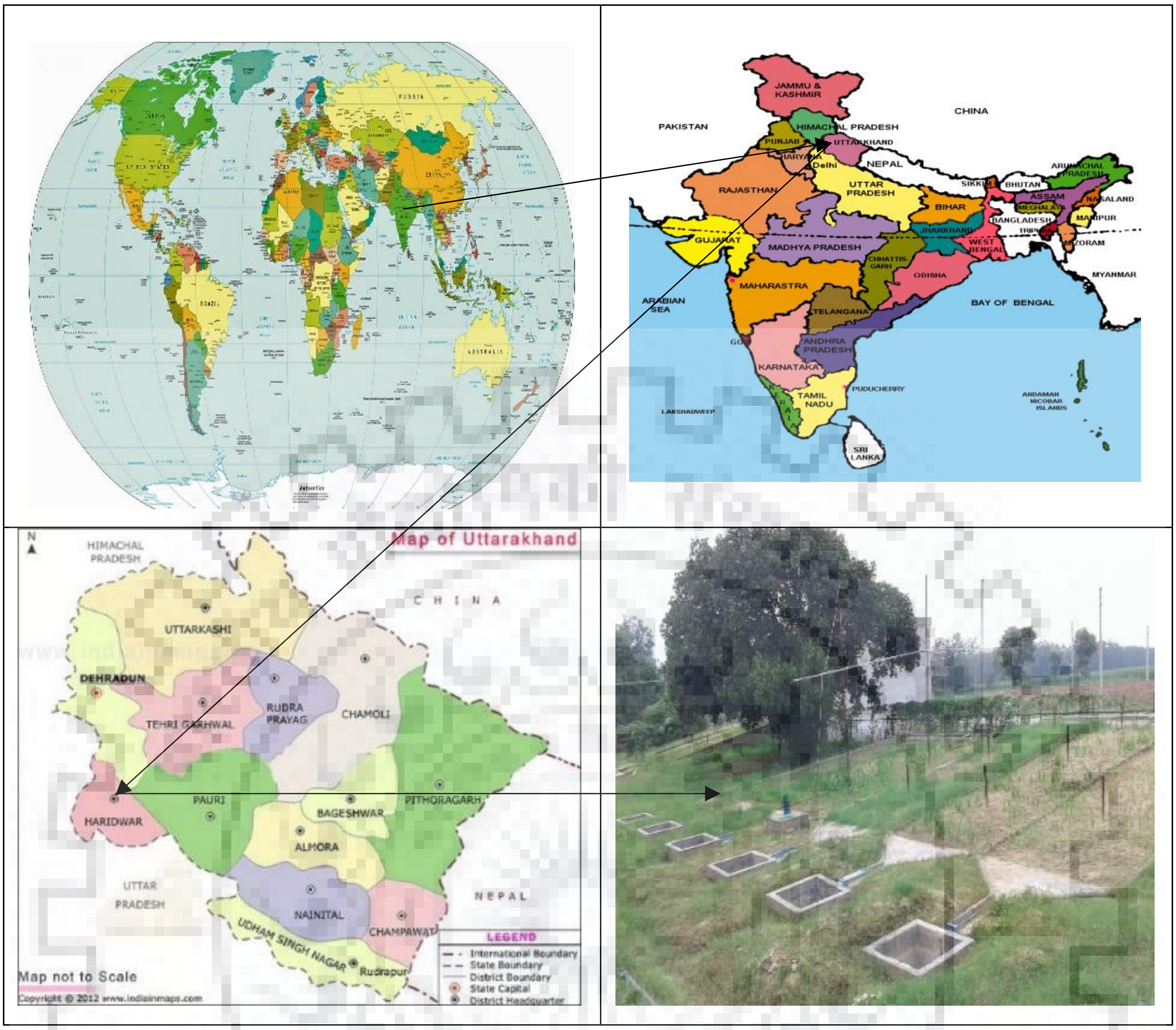

Figure 3.1 Location of Experimental Farm

Figure 3.2 Experimental Plots

The runoff was measured in terms of depth of runoff water stockpiling and multi-opening divisor was utilized for reducing the recurrence of topping off of the tank/chamber (Fig. 3.2). The rainfall was measured by standard rain gage and also self- recording rainfall gage introduced at the site. For calculation of the AMC of the soil, soil moisture was measured daily using TDR 300. In-situ double ring infiltration tests were directed for grouping HSG on the basis of minimum rate of infiltration.

3.2.1 Measurement and collection of Rainfall (P)

In the experimental watersheds, the precipitation is in the form of rainfall only. Rainfall information was gathered from two rain gauges introduced at the site itself. One rain gauge was of normal also called non-recording rain gauge. The other was self-recording rain gauge. Precipitation was measured at each 8.30 to 9.00 AM as and from normal rain gauge also when required (Fig. 3.3). The deliberate information was confirmed with the information got from self-recording rain gauge. The rainfall estimation began from first of June 2017 and it proceeded till late rainfall of September 2017. Add up to rainfall 19 event (aside from 79.5 mm and 9.6 mm extraordinary occasions) were measured. All of them could deliver quantifiable runoff. It was additionally watched that runoff was created just by more than 9 mm rainfall.

Figure 3.3 Non-Recording Rain gauge station

3.2.2 Runoff (Q)

Runoff generated by every rainfall event from the individual plot was collected in a storage tank of size 1mx1mx1m (Fig. 3.4). Multi-slot divisor was orchestrated in the approach channel driving from plot to the chamber. Multi-slot divisor had five equivalent number of spaces and overflow was gathered in the chamber coming just through centre opening and that of different spaces was redirected outside the chamber with the goal that size of the chamber and a definitive cost of work could be limited. The depth of runoff water volume in the chamber was measured with a steel tape. Since collection chamber and convey channel was kept under the open sky, the volume of water because of direct rainfall contribution was also deducted for precision in runoff measurements. The measured runoff volume was multiplied five times to get actual runoff water volume and it was divided by plot area to get the runoff depth.

3.2.3 Antecedent Soil Moisture Content (θ_0%)

Antecedent moisture content (AMC) (in situ soil moisture θ_0%) of each land plot was measured with the help instrument soil moisture meter (TDR300, with probe length 20cm) (Fig. 3.5) AMC data were taken at three different points (tail, middle and head) and the average value was calculated for every plot. The TDR300 gave directly volumetric water content in percentage.

Figure 3.4 Collection Chamber with the multi-slot divisor

Figure 3.5 TDR300 (With 20cm probe)

3.2.4 Suspended Sediment Yield Sampling and Analysis

For estimation of suspended sediment yield, the water samples were collected in 1 litre bottle and were analysed in WRDM laboratory. Oven drying method was used to estimate the concentration of sediments in water samples. (Fig. 3.6).

Figure 3.6 Sample preparation (a) and SY measurement by the instrument (b)

3.2.5 Infiltration Capacity of Soil

Double ring infiltrometer tests were directed in every one of the 9 plots to know the minimum rate of infiltration of each of them. On the basis of least infiltration rate of the soil, hydrologic soil group (HSG) of the plot was chosen. The result are given in Table.3.1 The infiltration curve for maize crops is also shown in Fig. 3.7

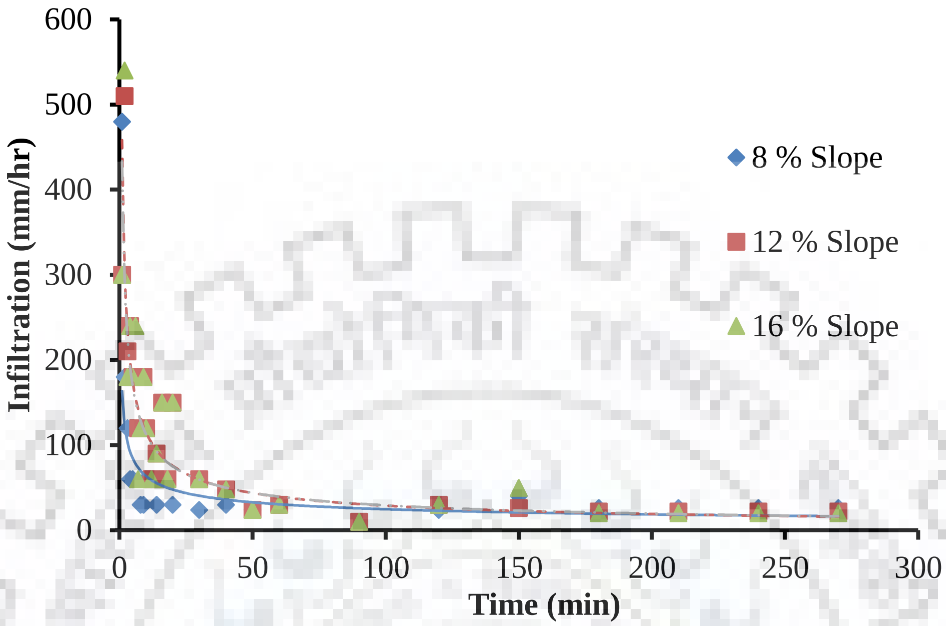

Figure 3.7 Infiltration capacity curve of maize crops at different slope

Table 3.1 Infiltration capacity for different Plots

Sl. No.	Slope	Plot No.	Min. Infiltration Capacity (mm/hr)	Standard Range (mm/hr)	HSG	Land Use
1	8%	4	26	7.62-11.43	A	Maize
2		5	22	7.62-11.43	A	Finger millet
3		6	20	7.62-11.43	A	Fallow land
4	12%	1	60	7.62-11.43	A	Maize
5		2	22	7.62-11.43	A	Finger millet
6		3	20	7.62-11.43	A	Fallow land
7	16%	7	40	7.62-11.43	A	Maize
8		8	30	7.62-11.43	A	Finger millet
9		9	28	7.62-11.43	A	Fallow land

3.2.6 Grain Size analysis of Soil

A soil sample from each plot was collected according to the standards (expelling topsoil and burrowed one foot beneath) and conveyed to a lab in plastic bundles. The soil was dried in a dry oven and mixed tenderly so the structure of the soil was exasperated. At that point, it was screened through the arrangement of sieves for no less than 20 minutes (Fig. 3.8). The retained mass on various sieves was weighed and noted. It was ensured that the soil loss was not more than 2%. The outcome is shown in Table 3.2.

Figure 3.8 Sieve analysis test

Table 3.2 Sieve analysis results

Slope	Plot No.	Grain Size (%)			Soil type
		>0.6 mm	<0.6 and >0.075 mm	<0.075 mm	
12%	1	1.53	88.35	10.12	Sandy
	2	1.65	88.01	10.34	Sandy
	3	0.95	88.80	10.25	Sandy
8%	4	1.49	88.91	9.60	Sandy
	5	1.78	88.32	9.9	Sandy
	6	1.64	88.00	9.36	Sandy
16%	7	2.53	88.27	9.2	Sandy
	8	2.44	88.65	8.91	Sandy
	9	2.32	88.69	8.99	Sandy

3.3 PROCEDURE FOR CN ESTIMATION

3.3.1 From NEH-4 Table

The following information was used for estimation of CN from NEH-4 Table as:

- Land use/Land cover: The land had been used for agricultural purposes and cultivated with maize, finger millet and a fallow land.
- Hydrologic Condition: Hydrologic condition is defined by the point that how much area of the lands was being covered with grass. Initially, there was no crop in the field rather sandy soil was mixed with the previous soil. Hence, initially, the hydrologic condition of the agricultural soil in our case could be taken as Poor.
- Hydrologic Soil Group (HSG): Hydrologic soil group was defined on the basis of the minimum infiltration rate of the soil. It was computed by in-situ infiltration test.
- The NEH-table provides CN for average i.e. for AMC II condition and it was assumed for slope 5%.

3.3.2 Using Observed Rainfall-Runoff Data and SCS-CN Method

Procedure-related to the estimation of the CN from measured rainfall and runoff is as follows:

- Nine plots each of size 12mx3m were prepared for three different slopes i.e. 8%, 12% and 16%.
- Each slope plot has been used cultivaion of maize and finger millet crop and one left as fallow land.
- For rainfall measurement, ordinary and self-recording raingauges were used and runoff depth was measured directly from the chamber by inserting scale in which approaching channel was fitted with the multi-slot divisor.
- Antecedent soil moisture with TDR was recorded before each rainfall event.
- Curve number was derivative for each plot from observed rainfall and runoff using SCS-CN method (Eqs. 2.6 & 2.7) for each plot. The average value represents the AMCII curve number for the respective watershed (plot). A comparison was also made between the CNs estimated by the methods at 3.3.1 & 3.2.1.

3.4 MUSLE COUPLED SCS-CN BASED SEDIMENT YIELD ESTIMATION

Here, the coupling of the SCS-CN method and MUSLE model is based on fact that that runoff is the best single indicator for soil losses and hence in this research work the 'A' has been replaced by Modified Universal Soil Loss Equation (MUSLE) (Y_m) as:

$$Y=\frac{Y_m P}{P+S} \tag{3.1}$$

where, Q= runoff (mm), Y= sediment yield (kg), Ym= potential maximum sediment yield (kg), P= rainfall (mm), and S= Potential maximum retention (mm). This is the proposed model for sediment yield estimation.

The utility of this coupling lies to the fact that the potential maximum sediment yield can be easily estimated using the observed runoff and peak flow rate. Ultimately, the coupling of the MUSLE with the SCS-CN method will generate the net sediment yield observed at the watershed outlet as the SCS-CN method facilitates the routing of potential maximum sediment yield through single linear reservoir to the watershed outlet.

Alternatively, Eq. (3.1) can be expressed as:

$$Y=\frac{\left[11.8*\left(Q*q_p\right)^{0.56} K*LS*C*P_S*P\right]}{P+S} \tag{3.2}$$

where, Y = sediment yield at the outlet from individual storms (in Metric Tonnes), Q = Strom runoff volume in m^3, q_p=peak rate of runoff in m^3/s. The slope length and steepness factor (LS) accounts for the overland runoff length and slope. C= Crop management factor, Ps = Conservation practice factor, P= rainfall (mm) and S= potential maximum retention (mm).

3.5 GOODNESS OF FIT STATISTICS

The goodness of fit statistics of the SCS-CN based runoff and sediment yield model was evaluated in terms of Nash and Sutcliffe Efficiency (NSE), Root Mean Square Error (RMSE), and Percent Bias (PBIAS) as discussed here.

3.5.1 Nash and Sutcliffe Efficiency (NSE)

The Nash and Sutcliffe (1970) coefficient of efficiency was calculated in percentage (%) as (Tables 4.13 and 4.21):

$$\text{Efficiency } (\eta) = (1-D_1/D_0) * 100 \quad (3.3)$$

where, D1 is the sum of the square of deviation between observed and computed sediment yield and D0 is the sum of the square of deviation of the observed data about the observed mean.

An NSE (%) value of 100 indicates perfect agreement of computed values with observed values and decreasing values indicate poorer agreement. NSE (%) equal to 0 indicates that the model estimates are as precise as the average of the observed data implying that the model predicts no better than the average of the observed data (Coffey et al., 2004). (Moriasi et al., 2007) established a performance criterion for model evaluation where NSE > 0.50 or 50% (satisfactory) was considered as threshold. According to Ritter and Muñoz-Carpena, (2013), a model is judged to be 'very good' if NSE ≥ 0.90 (90%), 'good' if 0.90 (90%) > NSE ≥ 0.80 (80%), 'acceptable' if 0.80 (80%) > NSE ≥ 0.65 (65%) and 'unsatisfactory' if 0.65 (65%) > NSE. We found the coefficient of efficiency by using SCS-CN based sediment yield model were found for runoff NSE 90.57% that's means model very good but sediment yield i.e. 60.55% means unsatisfactory.

3.5.2 Root Mean Square Error (RMSE)

The value of RMSE equal to 0 shows a perfect agreement between observed and estimated values. The lower the RMSE, the better is the model's performance and vice versa. The PBIAS measures model's tendency to underestimate or overestimate values by following formula.

$$\text{RMSE} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(Q_{obs} - Q_{comp}\right)_i^2} \quad (3.4)$$

where, Q_{obs} is the observed value, Q_{comp} is the computed value in a watershed, N is the total number of rainfall-runoff events, and i is an integer varying from 1 to N. We found the RMSE in runoff model 0.37 and sediment model 0.41 shown in Table 4.13 and 4.21 respectively. Which are satisfactory.

3.5.3 Percent Bias (PBIAS)

PBIAS evaluated by following relation as below

$$BIAS=\left[\frac{\sum_{i=1}^{N}\left(Q_{obs}-Q_{comp}\right)_i}{\sum_{i=1}^{N}\left(Q_{obs}\right)_i}\right] \tag{3.5}$$

where, Q_{obs} is the observed value, Q_{comp} is the computed value in a watershed, N is the total number of rainfall-runoff events, and i is an integer varying from 1 to N.

Negative (positive) value of PBIAS indicates model overestimation (underestimation) whereas a value of zero shows perfect fit (Moriasi et al., 2007). For the hydrologic models, performance was indicated as 'unsatisfactory' if PBIAS > ±25%, 'fair' if ±15% ≤ PBIAS ≤ ± 25%, 'good' if ±10% ≤ PBIAS < ±15% and 'very good' if PBIAS < ±10% (Moriasi et al., 2007). We found the PBIAS in runoff model -17.34% and sediment model -14.47% shown in Table 4.13 and 4.21 respectively. The performance of model is good.

CHAPTER IV

RESULTS AND DISCUSSION

4.1 DETERMINATION OF CN FROM NEH-4 TABLE

As discussed in Chapter III, CN values were derived from NEH-4 Table. The estimated CNs were further adjusted for slope of the plots using (Huang et al., 2006) relationship:

$$CN_{2\alpha} = CN_2 \frac{322.79+15.63\alpha}{\alpha+323.52} \tag{4.1}$$

Final estimates of CNs are given in Table 4.1.

Table 4.1 Curve Number from NEH-4

Crops	Slope	NEH-4 CN	Corrected NEH-4 CN
Maize	8%	72	72.10
Finger millet		61	61.08
Fallow land		77	77.10
Maize	12%	72	72.23
Finger millet		61	61.19
Fallow land		77	77.24
Maize	16%	72	72.36
Finger millet		61	61.30
Fallow land		77	77.38

Total 19 numbers of monsoon rainfall-runoff events were collected and analysed in this study. Table 4.2 shows the observed rainfall and runoff from all the nine watersheds and for all the nineteen storm events. Tables 4.3-4.5 shows the natural CNs computed using observed rainfall and runoff for all the nine experiment plots using Eq. (2.6) and Eq. (2.7).

The CN value by using S from observed Rainfall (P) and Runoff (Q) via (Eqs. 2.6 and 2.7) corresponds to AMC II (CN II). The CNs for three AMCs were derived considering CN values corresponding to 90%, 50% and 10% cumulative probability of exceedance to AMC I through AMC III respectively as shown in Table 4.6.

Table 4.2 Summary of the Observed Rainfall-Runoff data

Event No.	Date	Rainfall (mm)	Runoff (Q) mm 8% slope			Runoff (Q) mm 12% slope			Runoff (Q) mm 16% slope		
			Maize	Finger Millet	Fallow Land	Maize	Finger Millet	Fallow Land	Maize	Finger Millet	Fallow Land
			plot-4	plot-5	plot-6	plot-1	plot-2	plot-3	plot-7	plot-8	plot-9
1	19-Jun-17	44.00	14.21	13.03	12.31	30.12	17.75	20.39	31.92	27.20	29.56
2	26-Jun-17	34.20	13.40	11.59	8.12	26.45	15.06	18.12	24.78	26.17	20.62
3	28-Jun-17	75.20	48.66	49.82	45.98	50.94	54.61	56.87	64.03	68.35	64.92
4	29-Jun-17	17.70	6.39	10.56	5.00	10.56	7.78	13.34	9.17	13.34	14.72
5	30-Jun-17	15.00	7.06	6.78	5.39	9.83	9.14	10.17	13.03	12.33	10.94
6	6-Jul-17	36.40	19.12	13.34	17.79	28.68	24.29	26.07	27.23	30.01	32.29
7	24-Jul-17	14.00	0.67	2.75	1.36	4.14	2.75	2.75	5.53	2.75	4.14
8	2-Aug-17	79.50	33.20	24.17	22.09	42.51	34.87	38.20	44.31	41.53	40.14
9	3-Aug-17	9.60	1.96	0.57	0.57	3.35	4.74	3.35	4.57	6.13	5.71
10	7-Aug-17	27.40	18.86	17.47	16.00	20.94	20.25	13.30	25.11	25.80	20.25
11	10-Aug-17	43.40	19.93	22.01	20.07	26.87	26.18	19.93	35.90	33.12	34.65
12	19-Aug-17	22.30	2.94	1.55	4.61	9.19	5.72	6.42	9.89	10.44	14.94
13	22-Aug-17	58.10	28.95	16.31	23.26	30.90	25.34	33.67	43.40	35.06	35.90
14	23-Aug-17	15.50	2.32	2.54	2.54	2.54	3.15	5.32	6.71	3.93	4.54
15	25-Aug-17	61.80	32.28	28.42	38.67	36.59	38.67	31.45	49.78	50.47	45.61
16	1-Sep-17	44.00	14.98	10.81	12.20	20.53	18.98	17.75	34.42	17.75	30.70
17	1-Sep-17	23.00	14.65	12.56	14.65	18.81	16.04	13.81	20.90	16.73	20.90
18	2-Sep-17	61.10	26.27	29.05	33.22	33.22	24.05	25.72	24.89	42.94	48.50
19	3-Sep-17	26.00	19.06	6.56	13.51	13.51	9.34	10.68	17.68	20.45	19.06

Table 4.3 Computation of CN of Maize Crops (Natural Events)

Event No.	Date	Rainfall (mm)	Runoff (Q) mm			Potential Max. Retention (S)			Curve Number (CN)		
			8%	12%	16%	8%	12%	16%	8%	12%	16%
			plot-4	plot-1	plot-7	plot-4	plot-1	plot-7	plot-4	plot-1	plot-7
1	19-Jun-17	44.00	14.21	30.12	31.92	48.49	14.87	12.47	83.97	94.47	95.32
2	26-Jun-17	34.20	13.40	26.45	24.78	30.71	7.67	9.72	89.21	97.07	96.31
3	28-Jun-17	75.20	48.66	50.94	64.03	29.43	26.14	10.39	89.62	90.67	96.07
4	29-Jun-17	17.70	6.39	10.56	9.17	17.41	8.32	10.80	93.59	96.83	95.92
5	30-Jun-17	15.00	7.06	9.83	13.03	10.62	5.68	1.81	95.99	97.81	99.29
6	6-Jul-17	36.40	19.12	28.68	27.23	21.70	7.56	9.28	92.13	97.11	96.48
7	24-Jul-17	14.00	0.67	4.14	5.53	41.83	16.75	12.45	85.86	93.82	95.33
8	2-Aug-17	79.50	33.20	42.51	44.31	66.06	45.98	42.68	79.36	84.67	85.61
9	3-Aug-17	9.60	1.96	3.35	4.57	15.28	9.79	6.68	94.33	96.29	97.44
10	7-Aug-17	27.40	18.86	20.94	25.11	9.12	6.45	2.03	96.54	97.52	99.21
11	10-Aug-17	43.40	19.93	26.87	35.90	31.80	18.82	7.11	88.87	93.10	97.28
12	19-Aug-17	22.30	2.94	9.19	9.89	45.69	18.83	17.14	84.75	93.10	93.68
13	22-Aug-17	58.10	28.95	30.90	43.40	37.72	33.92	14.89	87.07	88.22	94.46
14	23-Aug-17	15.50	2.32	2.54	6.71	29.75	28.29	12.31	89.51	89.98	95.38
15	25-Aug-17	61.80	32.28	36.59	49.78	37.19	29.51	11.59	87.23	89.59	95.64
16	1-Sep-17	44.00	14.98	20.53	34.42	46.04	31.52	9.42	84.66	88.96	96.43
17	1-Sep-17	23.00	14.65	18.81	20.90	9.35	4.00	1.87	96.45	98.45	99.27
18	2-Sep-17	61.10	26.27	33.22	24.89	48.91	34.32	52.37	83.85	88.10	82.91
19	3-Sep-17	26.00	19.06	13.51	17.68	7.11	15.78	8.95	97.28	94.15	96.60

Table 4.4 Computation of CNs for Finger Millet plot (Natural Events)

Event No.	Date	Rainfall (mm)	Runoff (Q) mm			Potential Max. Retention (S)			Curve Number (CN)		
			8%	12%	16%	8%	12%	16%	8%	12%	16%
			plot-5	plot-2	plot-8	plot-5	plot-2	plot-8	plot-5	plot-2	plot-8
1	19-Jun-17	44.00	13.03	17.75	27.20	52.56	38.14	19.16	82.85	86.94	92.99
2	26-Jun-17	34.20	11.59	15.06	26.17	35.94	26.53	8.00	87.60	90.54	96.95
3	28-Jun-17	75.20	49.82	54.61	68.35	27.73	21.24	6.09	90.16	92.28	97.66
4	29-Jun-17	17.70	10.56	7.78	13.34	8.32	13.77	4.40	96.83	94.86	98.30
5	30-Jun-17	15.00	6.78	9.14	12.33	11.24	6.74	2.54	95.76	97.41	99.01
6	6-Jul-17	36.40	13.34	24.29	30.01	35.22	13.17	6.07	87.82	95.07	97.67
7	24-Jul-17	14.00	2.75	2.75	2.75	22.87	22.87	22.87	91.74	91.74	91.74
8	2-Aug-17	79.50	24.17	34.87	41.53	92.74	62.02	47.82	73.25	80.37	84.15
9	3-Aug-17	9.60	0.57	4.74	6.13	26.88	6.32	3.88	90.43	97.57	98.50
10	7-Aug-17	27.40	17.47	20.25	25.80	11.11	7.30	1.39	95.81	97.21	99.46
11	10-Aug-17	43.40	22.01	26.18	33.12	27.40	19.93	10.27	90.26	92.72	96.12
12	19-Aug-17	22.30	1.55	5.72	10.44	59.40	30.07	15.89	81.05	89.41	94.11
13	22-Aug-17	58.10	16.31	25.34	35.06	72.73	45.66	26.65	77.74	84.76	90.50
14	23-Aug-17	15.50	2.54	3.15	3.93	28.29	24.77	21.10	89.98	91.12	92.33
15	25-Aug-17	61.80	28.42	38.67	50.47	45.19	26.18	10.82	84.89	90.66	95.91
16	1-Sep-17	44.00	10.81	18.98	17.75	61.38	35.09	38.14	80.54	87.86	86.94
17	1-Sep-17	23.00	12.56	16.04	16.73	12.81	7.37	6.46	95.20	97.18	97.52
18	2-Sep-17	61.10	29.05	24.05	42.94	42.59	54.54	19.12	85.64	82.32	93.00
19	3-Sep-17	26.00	6.56	9.34	20.45	35.51	25.71	5.43	87.73	90.81	97.91

Table 4.5 Computation of CN for Fallow Land (Natural Events)

Event No.	Date	Rainfall (mm)	Runoff (Q) mm			Potential Max. Retention (S)			Curve Number (CN)		
			8%	12%	16%	8%	12%	16%	8%	12%	16%
			plot-6	plot-3	plot-9	plot-6	plot-3	plot-9	plot-6	plot-3	plot-9
1	19-Jun-17	44.00	12.31	20.39	29.56	55.25	31.83	15.64	82.13	88.86	94.20
2	26-Jun-17	34.20	8.12	18.12	20.62	48.97	20.09	15.72	83.84	92.67	94.17
3	28-Jun-17	75.20	45.98	56.87	64.92	33.53	18.42	9.47	88.34	93.24	96.41
4	29-Jun-17	17.70	5.00	13.34	14.72	22.03	4.40	2.81	92.02	98.30	98.91
5	30-Jun-17	15.00	5.39	10.17	10.94	14.84	5.21	4.17	94.48	97.99	98.38
6	6-Jul-17	36.40	17.79	26.07	32.29	24.35	10.75	3.72	91.25	95.94	98.56
7	24-Jul-17	14.00	1.36	2.75	4.14	32.92	22.87	16.75	88.52	91.74	93.82
8	2-Aug-17	79.50	22.09	38.20	40.14	100.41	54.56	50.55	71.67	82.32	83.40
9	3-Aug-17	9.60	0.57	3.35	5.71	26.88	9.79	4.53	90.43	96.29	98.25
10	7-Aug-17	27.40	16.00	13.30	20.25	13.45	18.52	7.30	94.97	93.20	97.21
11	10-Aug-17	43.40	20.07	19.93	34.65	31.49	31.80	8.49	88.97	88.87	96.77
12	19-Aug-17	22.30	4.61	6.42	14.94	35.22	27.33	7.99	87.82	90.28	96.95
13	22-Aug-17	58.10	23.26	33.67	35.90	50.85	28.95	25.32	83.32	89.77	90.93
14	23-Aug-17	15.50	2.54	5.32	4.54	28.29	16.09	18.70	89.98	94.04	93.14
15	25-Aug-17	61.80	38.67	31.45	45.61	26.18	38.82	16.52	90.66	86.74	93.89
16	1-Sep-17	44.00	12.20	17.75	30.70	55.68	38.14	14.07	82.02	86.94	94.75
17	1-Sep-17	23.00	14.65	13.81	20.90	9.35	10.66	1.87	96.45	95.97	99.27
18	2-Sep-17	61.10	33.22	25.72	48.50	34.32	50.27	12.27	88.10	83.48	95.39
19	3-Sep-17	26.00	13.51	10.68	19.06	15.78	22.07	7.11	94.15	92.01	97.28

Table 4.6 Curve Number for all rainfall-runoff events

Rank (m)	Descending Order CNs value for different Slope and having different crops									Probability of Exceedence = m/(n+1)*100	AMC
	Plot @8%			Plot @12%			Plot @16%				
	Plot no:4	Plot no:5	Plot no:6	Plot no:1	Plot no:2	Plot no:3	Plot no:7	Plot no:8	Plot no:9		
	Maize	Finger Millet	Fallow Land	Maize	Finger Millet	Fallow Land	Maize	Finger Millet	Fallow Land		
1	97.28	96.83	96.45	98.45	97.57	98.30	99.29	99.46	99.27	5.0	
2	96.54	95.81	94.48	97.81	97.41	97.99	99.27	99.01	98.91	10.0	**III**
3	96.45	95.76	94.15	97.52	97.21	92.01	99.21	98.50	98.38	15.0	
4	95.99	95.20	92.02	96.83	97.18	96.29	97.28	98.30	98.25	20.0	
5	94.33	91.74	90.66	96.29	94.86	95.97	96.60	97.91	96.41	25.0	
6	89.51	90.43	90.43	94.15	95.07	95.94	96.48	97.67	97.28	30.0	
7	93.59	90.26	89.98	93.82	92.72	83.48	96.43	97.52	97.21	35.0	
8	92.13	89.98	88.34	97.11	91.74	94.04	96.31	96.95	96.77	40.0	
9	87.23	87.82	88.52	93.10	90.81	93.20	95.92	96.12	95.39	45.0	
10	**89.21**	**87.73**	**94.97**	**93.10**	**90.66**	**93.24**	**95.64**	**95.91**	**94.20**	**50.0**	**II**
11	88.87	87.60	88.10	97.07	90.54	86.74	95.38	94.11	94.17	55.0	
12	87.07	90.16	87.82	90.67	89.41	91.74	95.33	97.66	93.89	60.0	
13	89.62	84.89	88.97	89.98	92.28	90.28	95.32	93.00	93.82	65.0	
14	85.86	85.64	83.84	89.59	86.94	89.77	94.46	92.99	98.56	70.0	
15	84.75	82.85	83.32	88.96	91.12	88.87	96.07	92.33	96.95	75.0	
16	84.66	81.05	82.02	94.47	82.32	86.94	93.68	91.74	94.75	80.0	
17	83.97	80.54	91.25	88.22	84.76	88.86	97.44	90.50	93.14	85.0	
18	83.85	77.74	82.13	88.10	87.86	92.67	85.61	86.94	90.93	90.0	**I**
19	79.36	73.25	71.67	84.67	80.37	82.32	82.91	84.15	83.40	95.0	
CNIII	**96.54**	**95.81**	**94.48**	**97.81**	**97.41**	**97.99**	**99.27**	**99.01**	**98.91**		
CNII	**88.87**	**87.60**	**88.10**	**97.07**	**90.54**	**86.74**	**95.38**	**94.11**	**94.17**		
CNI	**83.85**	**77.74**	**82.13**	**88.10**	**87.86**	**92.67**	**85.61**	**86.94**	**90.93**		

4.2 EFFECT OF LAND SLOPE, LAND USE AND ANTECEDENT SOIL MOISTURE ON RUNOFF AND CURVE NUMBER

This section discusses the effects of watershed slope, land use/land cover and antecedent soil moisture on runoff generation and hence CN using the observed data from experimental plots.

4.2.1 Effect of Watershed Slope on Runoff

The graphs were drawn between observed rainfall and runoff for Maize crop, Finger millet crop and fallow land having slope 8%, 12% and 16% depict the significant correlation between P and Q (Fig. 4.1 to 4.3). The plotting of rainfall against runoff for maize, finger millet and fallow land for 8%, 12% and 16% slope shows that as the slope is increasing, the runoff is also increasing for a given HSG and crop type.

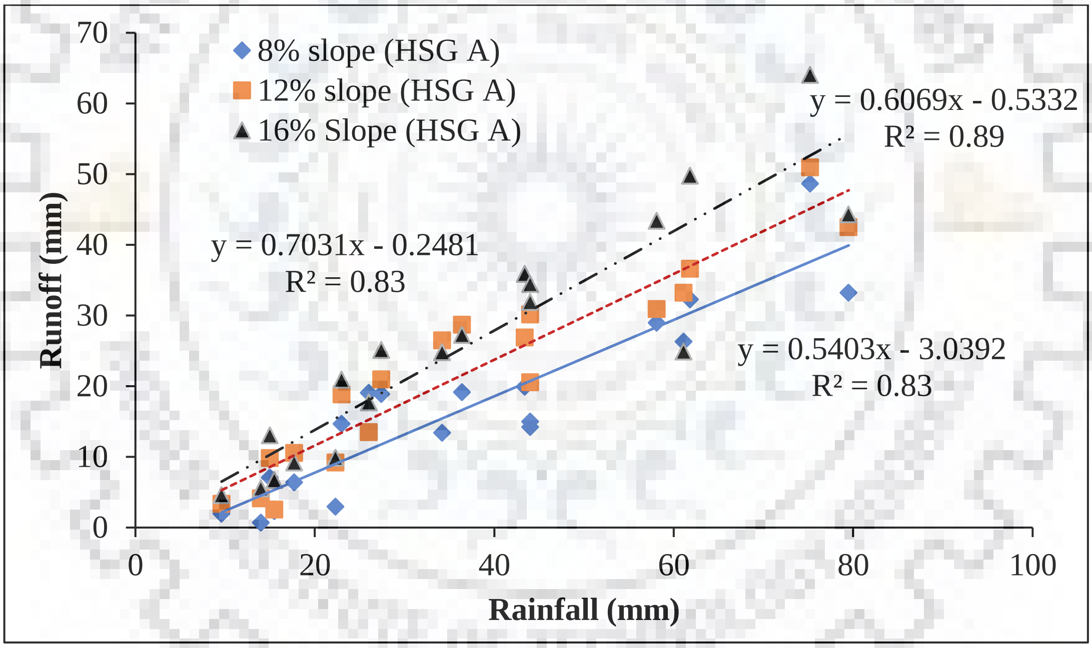

Figure 4.1 Rainfall vs runoff for Maize crop

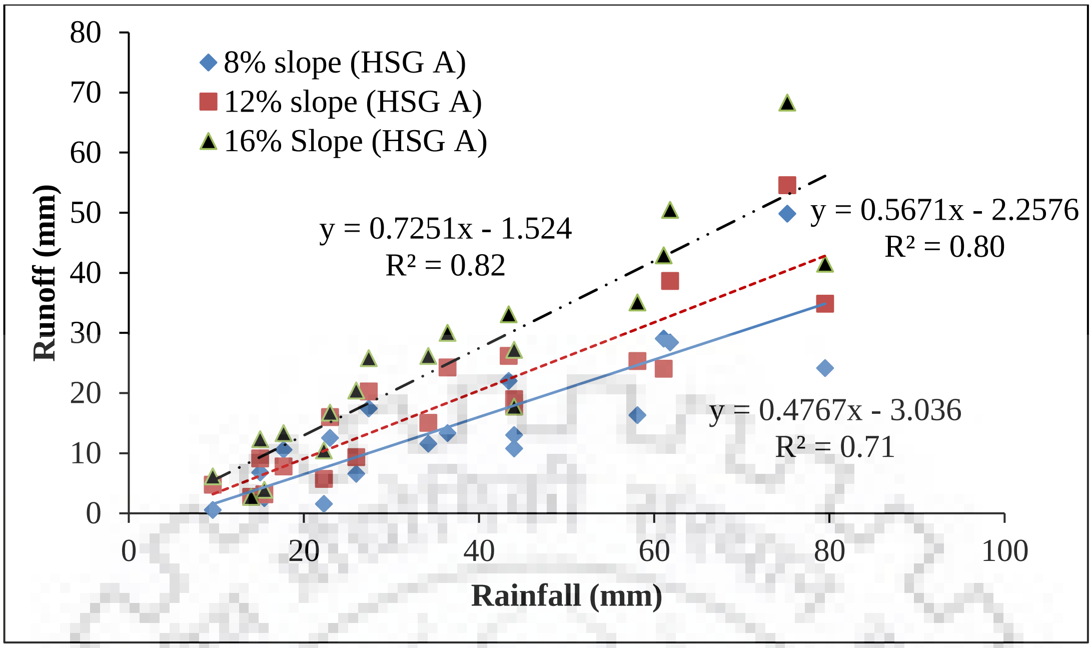

Figure 4.2 Rainfall vs runoff for Finger millet crop

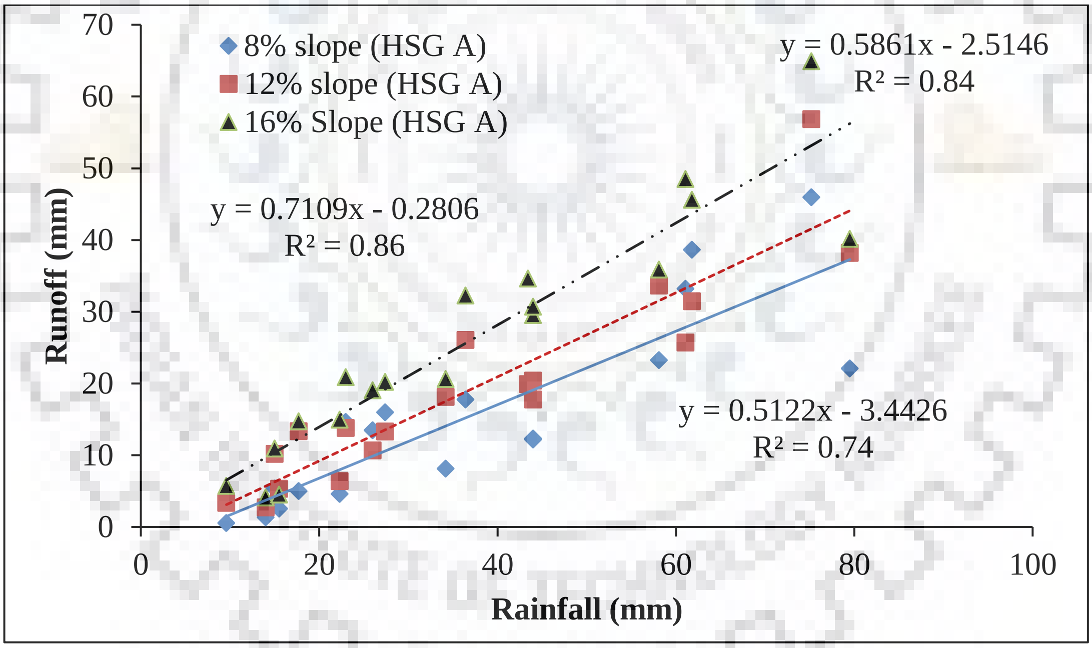

Figure 4.3 Rainfall vs runoff for Fallow land

4.2.2 Effect of Slope on Curve Number

In this experiment, the land was cultivated with Maize crop, Finger millet crop and one plot in each slope was kept uncultivated as a fallow. Curve number for each land use is represented in Fig. 4.4. It can be observed that 16% slope generated more runoff than other slopes for all the crops did.

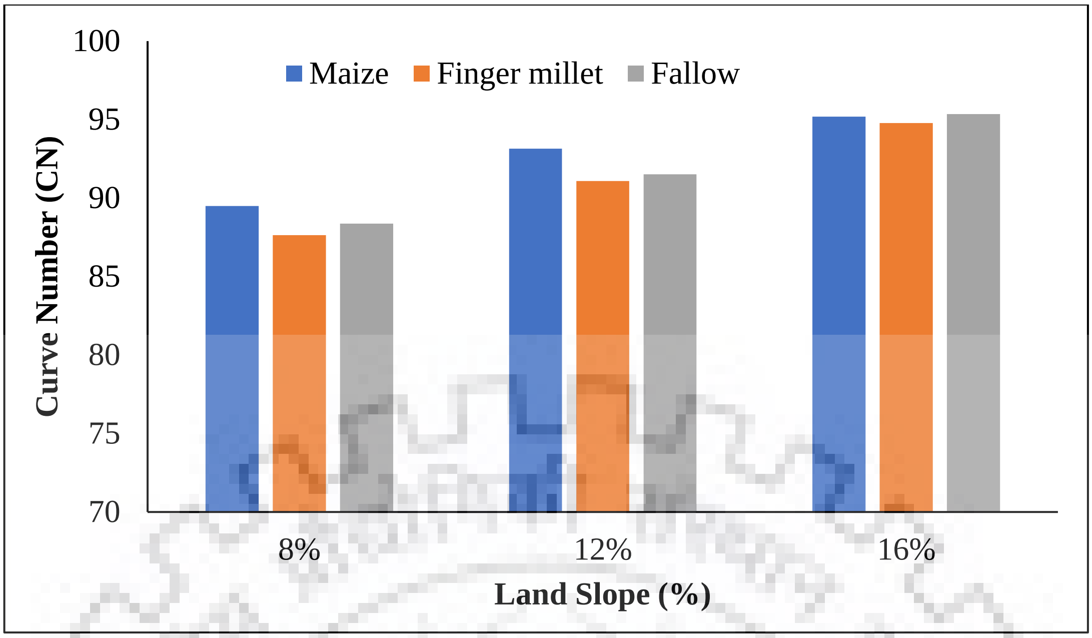

Figure 4.4 Effect of slope on Curve Number

The relation between curve number and slope (%) at different AMC condition of different crop viz. maize (Fig. 4.5), Finger millet (Fig. 4.6) And Fallow land (Fig 4.7) are also shown. It can be easily inferred from these Figures that higher slope shows higher curve number and higher AMC value also shows higher curve number and vice versa.

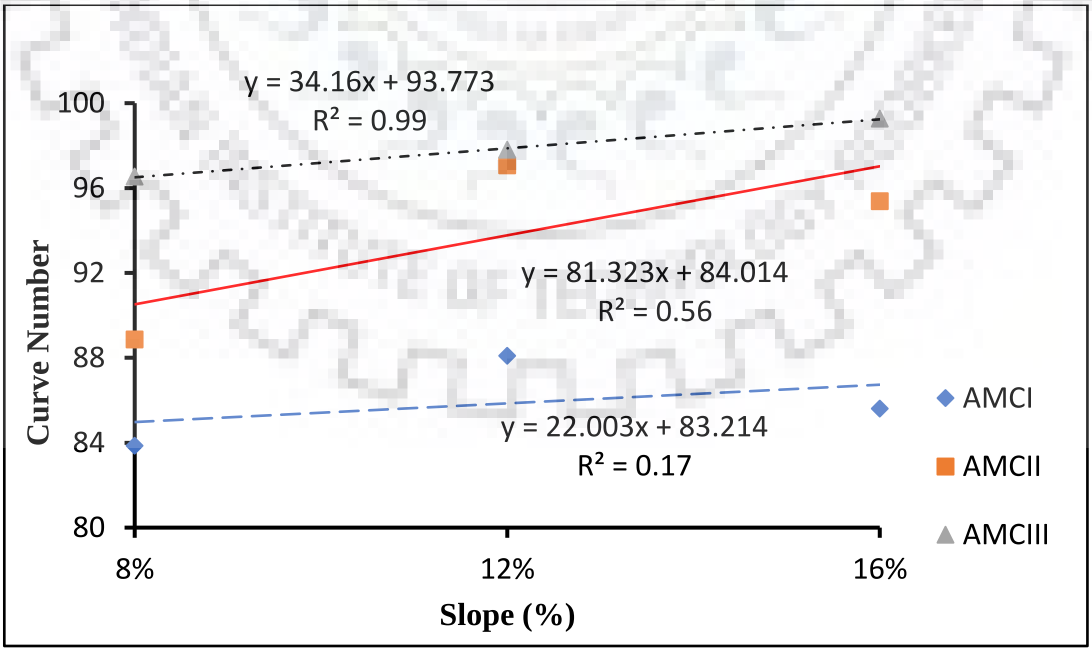

Figure 4.5 Effect of slope on Curve number at AMC condition of Maize

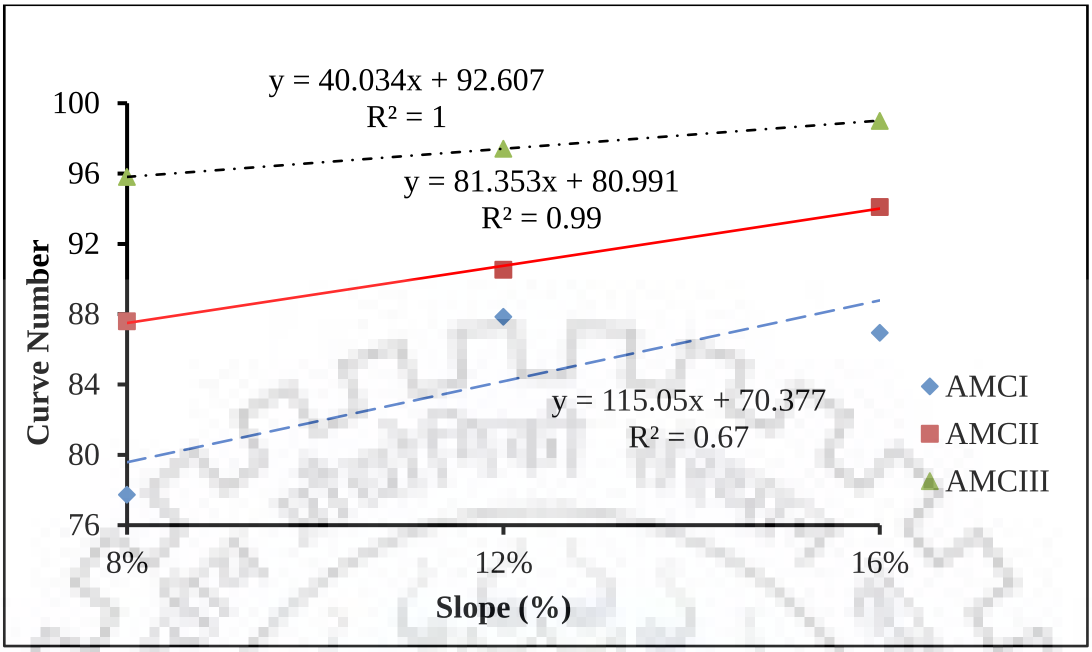

Figure 4.6 Effect of slope on Curve number at AMC condition of Finger millet

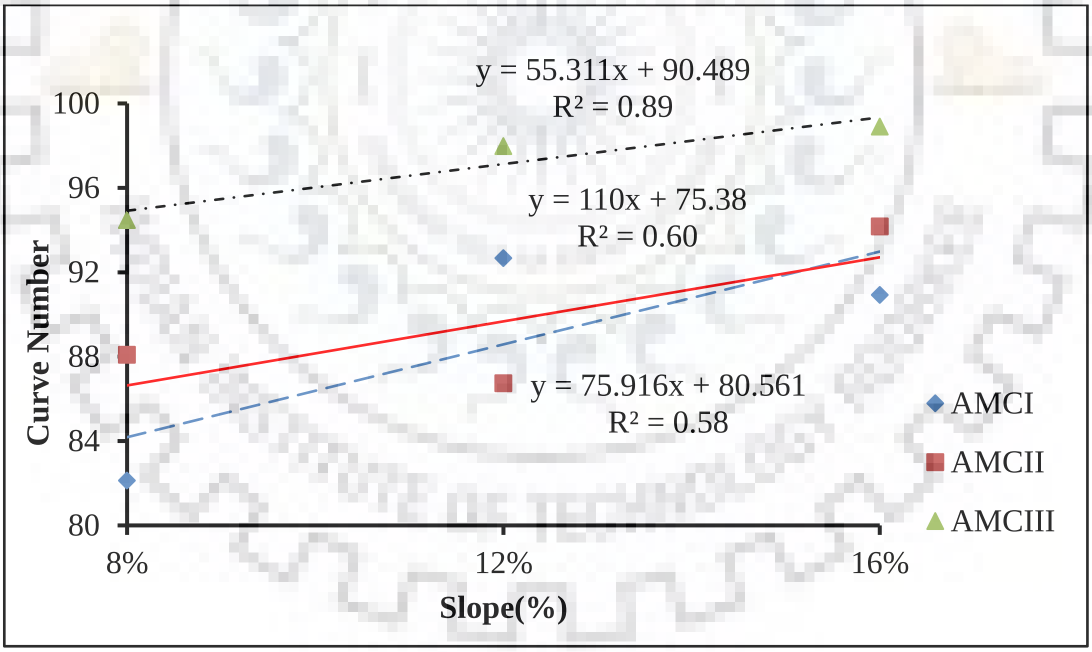

Figure 4.7 Effect of slope on Curve number at AMC condition of the Fallow land

4.2.3 Effect of land use on Curve Number

The relation between Curve Number and land use at different slopes is shown in Fig. 4.8. Maize Crop generates more runoff than Finger millet crops and fallow land. In this study, for the slope of 16%, Maize land had the highest runoff and CN. It was seen that fallow land produced almost equal runoff and, in turn, CN and Finger millet relatively low runoff and CN as well because of a dense canopy.

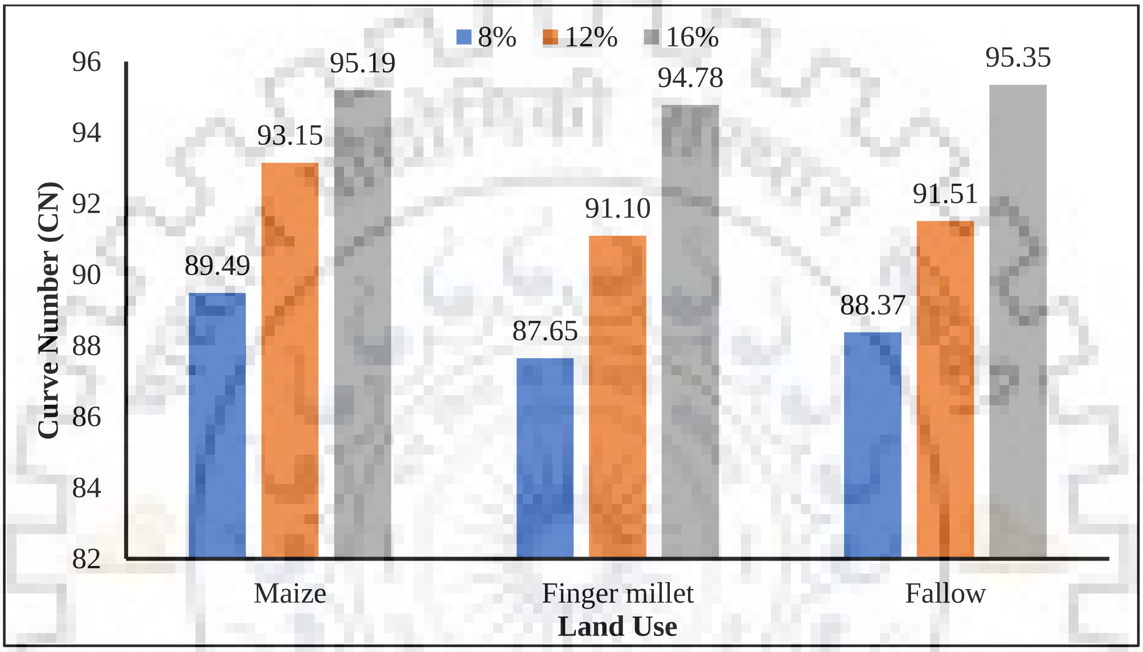

Figure 4.8 Effect of land use on Curve Number

4.2.4 Relation between Curve Number (CN) and AMC (θ_0%)

As discussed in Chapter 3, the antecedent soil moisture content (θ_0%) was observed prior to rainfall event using TDR300. Tables 4.7 to 4.9 indicate the values of CN of three different grades i.e. 8%, 12% and 16% of the experimental farm under three AMC conditions of different land uses and these are plotted in Figs. 4.9 - 4.11. These CNs for three AMCs were derived considering CN values corresponding to 90%, 50%, and 10% cumulative probability of exceedance (Table 4.6) to AMC I through AMC III, respectively (Figs. 4.9 to 4.11).

Table 4.7 Statistical derivation of CNs of maize crops

AMC	Curve Number (CN) for plots of grade		
	8%	12%	16%
III	96.54	97.81	99.27
II	88.87	97.07	95.38
I	83.85	88.10	85.61

Table 4.8 Statistical derivation of CNs of Finger millet

AMC	Curve Number (CN) for plots of grade		
	8%	12%	16%
III	95.81	97.41	99.01
II	87.60	90.54	94.11
I	77.74	87.86	86.94

Table 4.9 Statistical derivation of CNs of Fallow land

AMC	Curve Number (CN) for plots of grade		
	8%	12%	16%
III	94.48	97.99	98.91
II	88.10	86.74	94.17
I	82.13	92.67	90.93

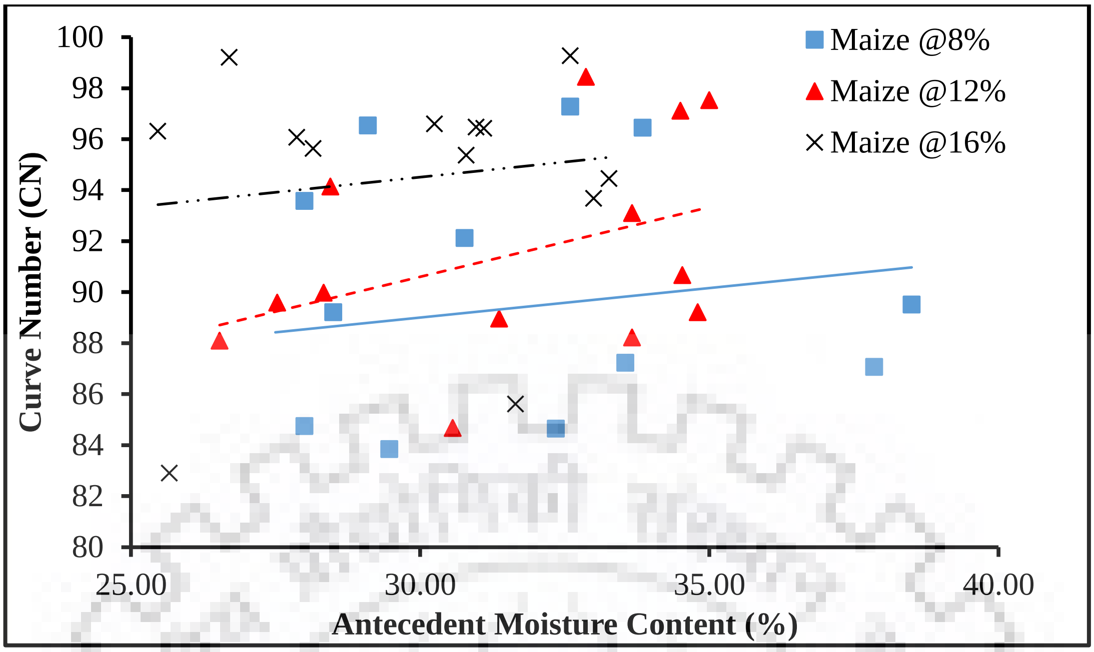

Figure 4.9 Relation between Curve number and AMC Maize Crops

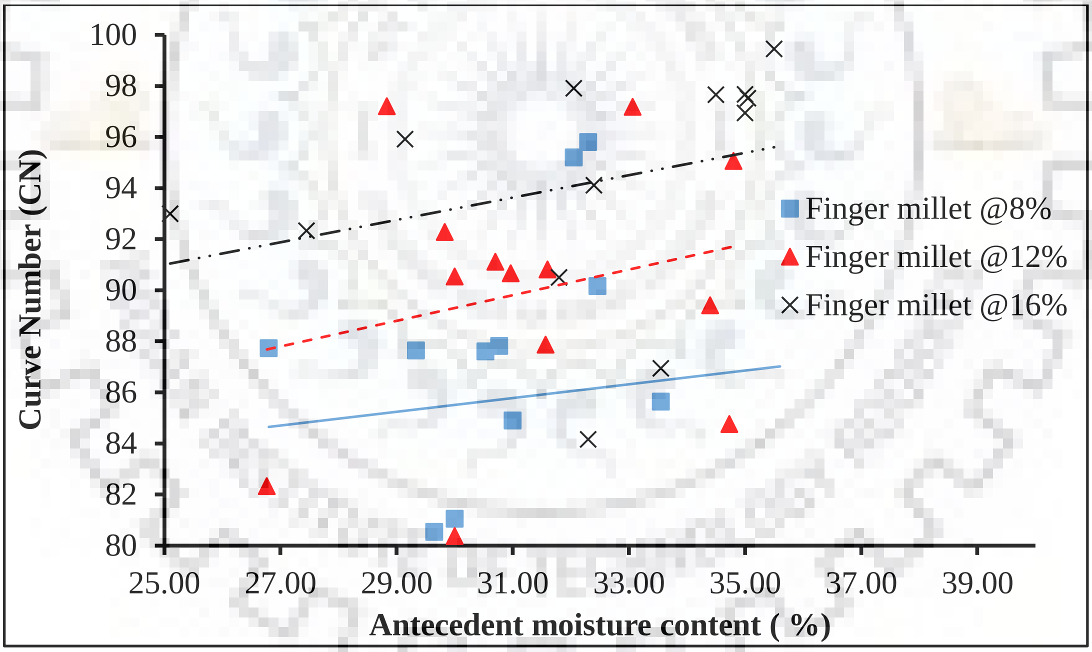

Figure 4.10 Relation between Curve Number and AMC Finger millet Crop

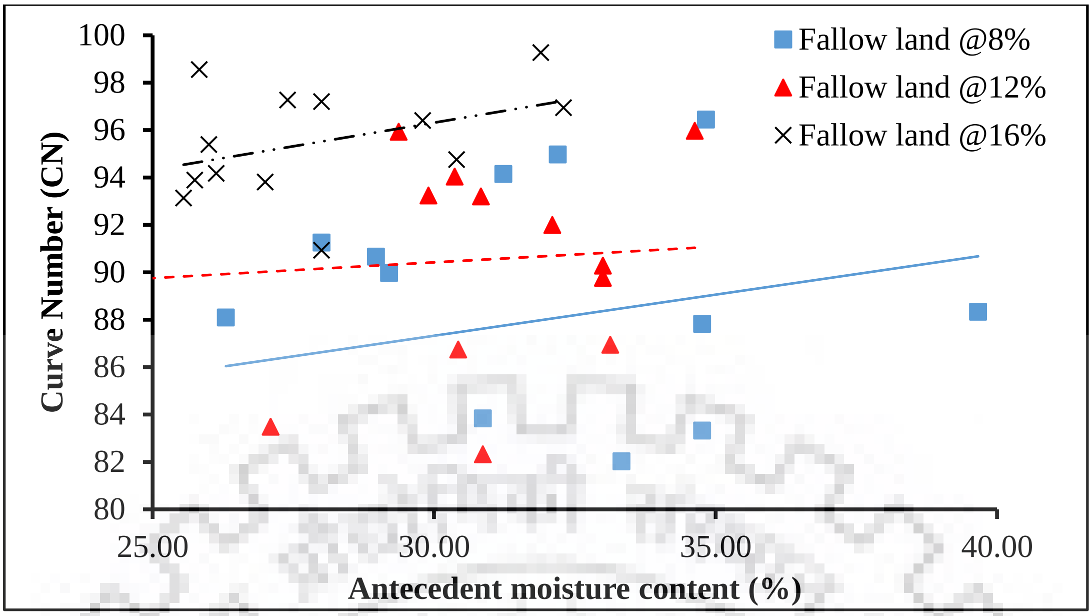

Figure 4.11 Relation between Curve Number and AMC fallow land

4.3 SCS-CN BASED RUNOFF AND SEDIMENT YIELD MODELLING

4.3.1 Modelling Runoff using SCS-CN Method

The observed runoff was collected by using collection chamber at the end of each experiment plot as discussed in Chapter 3. The runoff was predicted using existing SCS-CN method (Eq. 2.5). The model computed runoff and observed values are presented for Maize (Table. 4.10), Finger millet (Table. 4.11) and Fallow land (Table. 4.12). Graphically, the results are also shown for maize in Figs. 4.12, 4.13 and 4.14; for Finger millet in Figs. 4.15, 4.16 and 4.17; and for fallow land in Figs. 4.18, 4.19 and 4.20. The coefficient of determination (R^2) of all land uses was found to be greater than 0.96.

It can be observed from Figures 4.12 to 4.20 that there is a good agreement between observed and computed runoff for all the nine experimental plots. The goodness-of-fit of statistics was further evaluated using NSE, RMSE and PBIAS as the results are shown in Table 4.13. It can be observed from Table 4.13 that overall NSE is 90.57% with RMSE and PBIAS as 0.37 and -17.34%, respectively. The results show that the model performs very good, consistent with the work of (Moriasi et al., 2007), in simulating runoff from the experimental plots.

Table 4.10: Observed and Computed Runoff (mm) for Maize Crops

Event S. No.	Event Date	Rainfall (mm)	Observed Runoff (mm)			S			Computed Runoff (mm)		
			8% slope	12% slope	16 % slope	8%	12%	16%	8%	12% slope	16 % slope
			plot-4	plot-1	plot-7	plot-4	plot-1	plot-7	plot-4	plot-1	plot-7
1	19-Jun-17	44.00	14.21	30.12	31.92	48.49	14.87	12.47	20.93	32.89	34.29
2	26-Jun-17	34.20	13.40	26.45	24.78	30.71	7.67	9.72	18.02	27.93	26.63
3	28-Jun-17	75.20	48.66	50.94	64.03	29.43	26.14	10.39	54.05	55.80	66.07
4	29-Jun-17	17.70	6.39	10.56	9.17	17.41	8.32	10.80	8.92	12.04	10.99
5	30-Jun-17	15.00	7.06	9.83	13.03	10.62	5.68	1.81	8.78	10.88	13.39
6	6-Jul-17	36.40	19.12	28.68	27.23	21.70	7.56	9.28	22.81	30.14	29.01
7	24-Jul-17	14.00	0.67	4.14	5.53	41.83	16.75	12.45	3.51	6.37	7.41
8	2-Aug-17	79.50	33.20	42.51	44.31	66.06	45.98	42.68	43.42	50.37	51.73
9	3-Aug-17	9.60	1.96	3.35	4.57	15.28	9.79	6.68	3.70	4.75	5.66
10	7-Aug-17	27.40	18.86	20.94	25.11	9.12	6.45	2.03	20.56	22.18	25.51
11	10-Aug-17	43.40	19.93	26.87	35.90	31.80	18.82	7.11	25.05	30.27	37.29
12	19-Aug-17	22.30	2.94	9.19	9.89	45.69	18.83	17.14	7.31	12.09	12.61
13	22-Aug-17	58.10	28.95	30.90	43.40	37.72	33.92	14.89	35.23	36.69	46.25
14	23-Aug-17	15.50	2.32	2.54	6.71	29.75	28.29	12.31	5.31	5.49	8.64
15	25-Aug-17	61.80	32.28	36.59	49.78	37.19	29.51	11.59	38.58	41.83	52.04
16	1-Sep-17	44.00	14.98	20.53	34.42	46.04	31.52	9.42	21.50	25.64	36.24
17	1-Sep-17	23.00	14.65	18.81	20.90	9.35	4.00	1.87	16.35	19.59	21.27
18	2-Sep-17	61.10	26.27	33.22	24.89	48.91	34.32	52.37	33.93	39.13	32.90
19	3-Sep-17	26.00	19.06	13.51	17.68	7.11	15.78	8.95	20.42	16.18	19.34

Table 4.11: Observed and Computed Runoff (mm) for Finger Millet crops

Event S.N	Event Date	Rainfall (mm)	Observed Runoff (mm)			S			Computed Runoff (mm)		
			8% slope	12% slope	16 % slope	8% slope	12% slope	16 % slope	8% slope	12% slope	16 % slope
			plot-5	plot-2	plot-8	plot-5	plot-2	plot-8	plot-5	plot-2	plot-8
1	19-Jun-17	44.00	13.03	17.75	27.20	52.56	38.14	19.16	20.05	23.57	30.65
2	26-Jun-17	34.20	11.59	15.06	26.17	35.94	26.53	8.00	16.68	19.26	27.71
3	28-Jun-17	75.20	49.82	54.61	68.35	27.73	21.24	6.09	54.94	58.64	69.56
4	29-Jun-17	17.70	10.56	7.78	13.34	8.32	13.77	4.40	12.04	9.96	14.18
5	30-Jun-17	15.00	6.78	9.14	12.33	11.24	6.74	2.54	8.57	10.35	12.83
6	6-Jul-17	36.40	13.34	24.29	30.01	35.22	13.17	6.07	18.50	26.73	31.20
7	24-Jul-17	14.00	2.75	2.75	2.75	22.87	22.87	22.87	5.32	5.32	5.32
8	2-Aug-17	79.50	24.17	34.87	41.53	92.74	62.02	47.82	36.69	44.66	49.64
9	3-Aug-17	9.60	0.57	4.74	6.13	26.88	6.32	3.88	2.53	5.79	6.84
10	7-Aug-17	27.40	17.47	20.25	25.80	11.11	7.30	1.39	19.49	21.64	26.08
11	10-Aug-17	43.40	22.01	26.18	33.12	27.40	19.93	10.27	26.60	29.74	35.10
12	19-Aug-17	22.30	1.55	5.72	10.44	59.40	30.07	15.89	6.09	9.50	13.02
13	22-Aug-17	58.10	16.31	25.34	35.06	72.73	45.66	26.65	25.80	32.53	39.83
14	23-Aug-17	15.50	2.54	3.15	3.93	28.29	24.77	21.10	5.49	5.97	6.56
15	25-Aug-17	61.80	28.42	38.67	50.47	45.19	26.18	10.82	35.70	43.41	52.59
16	1-Sep-17	44.00	10.81	18.98	17.75	61.38	35.09	38.14	18.37	24.48	23.57
17	1-Sep-17	23.00	12.56	16.04	16.73	12.81	7.37	6.46	14.77	17.42	17.96
18	2-Sep-17	61.10	29.05	24.05	42.94	42.59	54.54	19.12	36.00	32.28	46.54
19	3-Sep-17	26.00	6.56	9.34	20.45	35.51	25.71	5.43	10.99	13.07	21.51

Table 4.12: Observed and Computed Runoff (mm) for Fallow land

Event S.N	Event Date	Rainfall (mm)	Observed Runoff (mm)			S			Computed Runoff (mm)		
			8% slope	12% slope	16 % slope	8% slope	12% slope	16 % slope	8% slope	12% slope	16 % slope
			plot-6	plot-3	plot-9	plot-6	plot-3	plot-9	plot-6	plot-3	plot-9
1	19-Jun-17	44.00	12.31	20.39	29.56	55.25	31.83	15.64	19.51	25.53	32.46
2	26-Jun-17	34.20	8.12	18.12	20.62	48.97	20.09	15.72	14.06	21.54	23.43
3	28-Jun-17	75.20	45.98	56.87	64.92	33.53	18.42	9.47	52.01	60.41	66.79
4	29-Jun-17	17.70	5.00	13.34	14.72	22.03	4.40	2.81	7.89	14.18	15.28
5	30-Jun-17	15.00	5.39	10.17	10.94	14.84	5.21	4.17	7.54	11.13	11.74
6	6-Jul-17	36.40	17.79	26.07	32.29	24.35	10.75	3.72	21.81	28.10	33.03
7	24-Jul-17	14.00	1.36	2.75	4.14	32.92	22.87	16.75	4.18	5.32	6.37
8	2-Aug-17	79.50	22.09	38.20	40.14	100.41	54.56	50.55	35.13	47.14	48.60
9	3-Aug-17	9.60	0.57	3.35	5.71	26.88	9.79	4.53	2.53	4.75	6.52
10	7-Aug-17	27.40	16.00	13.30	20.25	13.45	18.52	7.30	18.38	16.35	21.64
11	10-Aug-17	43.40	20.07	19.93	34.65	31.49	31.80	8.49	25.15	25.05	36.30
12	19-Aug-17	22.30	4.61	6.42	14.94	35.22	27.33	7.99	8.65	10.02	16.42
13	22-Aug-17	58.10	23.26	33.67	35.90	50.85	28.95	25.32	30.98	38.78	40.46
14	23-Aug-17	15.50	2.54	5.32	4.54	28.29	16.09	18.70	5.49	7.61	7.02
15	25-Aug-17	61.80	38.67	31.45	45.61	26.18	38.82	16.52	43.41	37.96	48.76
16	1-Sep-17	44.00	12.20	17.75	30.70	55.68	38.14	14.07	19.42	23.57	33.34
17	1-Sep-17	23.00	14.65	13.81	20.90	9.35	10.66	1.87	16.35	15.72	21.27
18	2-Sep-17	61.10	33.22	25.72	48.50	34.32	50.27	12.27	39.13	33.52	50.88
19	3-Sep-17	26.00	13.51	10.68	19.06	15.78	22.07	7.11	16.18	14.06	20.42

Table 4.13: Runoff performance evaluation of Sediment yield model based SCS-CN

E.N	Date	Rainfall (mm)	Observed Runoff (mm)	Computed Runoff (mm)	D1	D0	Q_{obs}-Q_{cal}	$(Q_{obs}-Q_{cal})^2$	Nash Sutcliffe Efficiency (1-D_1/D_0)	RMSE	PBIAS
1	19-Jun-17	44.00	196.492	239.88	1882.42	121.75	-43.387	1882.42	**90.57%**	**0.37**	**-17.34%**
2	26-Jun-17	34.20	164.316	195.27	958.07	446.95	-30.953	958.07			
3	28-Jun-17	75.20	504.184	538.28	1162.39	101586.65	-34.094	1162.39			
4	29-Jun-17	17.70	90.858	105.47	213.60	8949.13	-14.615	213.60			
5	30-Jun-17	15.00	84.665	95.21	111.24	10159.12	-10.547	111.24			
6	6-Jul-17	36.40	218.816	241.31	506.16	1112.79	-22.498	506.16			
7	24-Jul-17	14.00	26.850	49.11	495.68	25156.22	-22.264	495.68			
8	2-Aug-17	79.50	321.021	407.38	7457.98	18377.47	-86.360	7457.98			
9	3-Aug-17	9.60	30.967	43.07	146.55	23867.32	-12.106	146.55			
10	7-Aug-17	27.40	177.962	191.82	192.17	56.19	-13.863	192.17			
11	10-Aug-17	43.40	238.660	270.55	1016.98	2830.48	-31.890	1016.98			
12	19-Aug-17	22.30	65.712	95.70	899.32	14338.99	-29.989	899.32			
13	22-Aug-17	58.10	272.794	326.55	2889.99	7627.70	-53.759	2889.99			
14	23-Aug-17	15.50	33.583	57.57	575.25	23065.77	-23.984	575.25			
15	25-Aug-17	61.80	351.934	394.28	1793.03	27714.57	-42.344	1793.03			
16	1-Sep-17	44.00	178.121	226.13	2305.23	53.83	-48.013	2305.23			
17	1-Sep-17	23.00	149.039	160.70	135.90	1326.29	-11.658	135.90			
18	2-Sep-17	61.10	287.863	344.31	3186.73	10486.92	-56.451	3186.73			
19	3-Sep-17	26.00	129.855	152.17	497.77	3091.61	-22.311	497.77			
Average			**185.46**	**217.62**							
Sum			**3523.69**	**4134.78**	**26426.44**	**280369.75**	**-611.08**	**26426.44**			

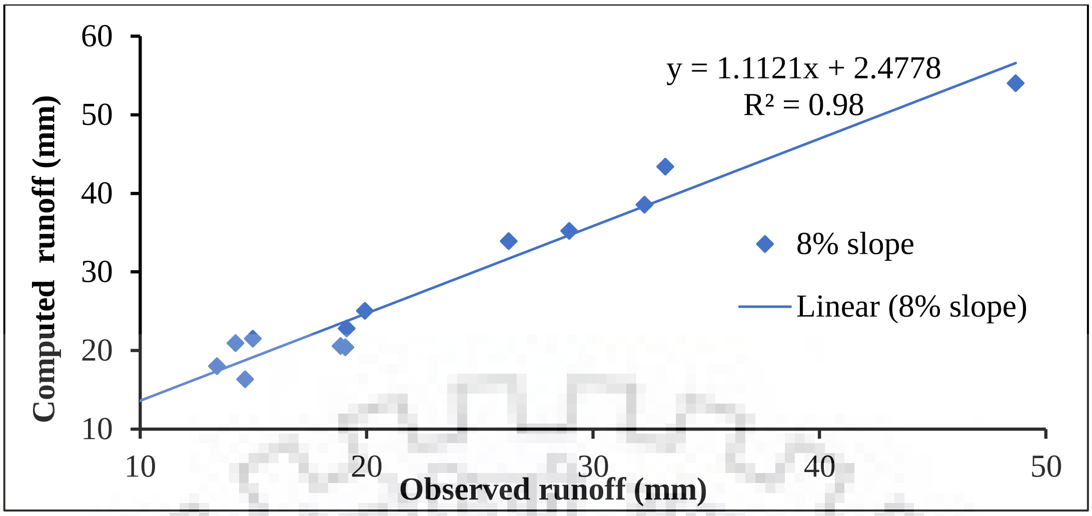

Figure 4.12 Comp. Vs Obs. Runoff of Maize Crops 8% slope

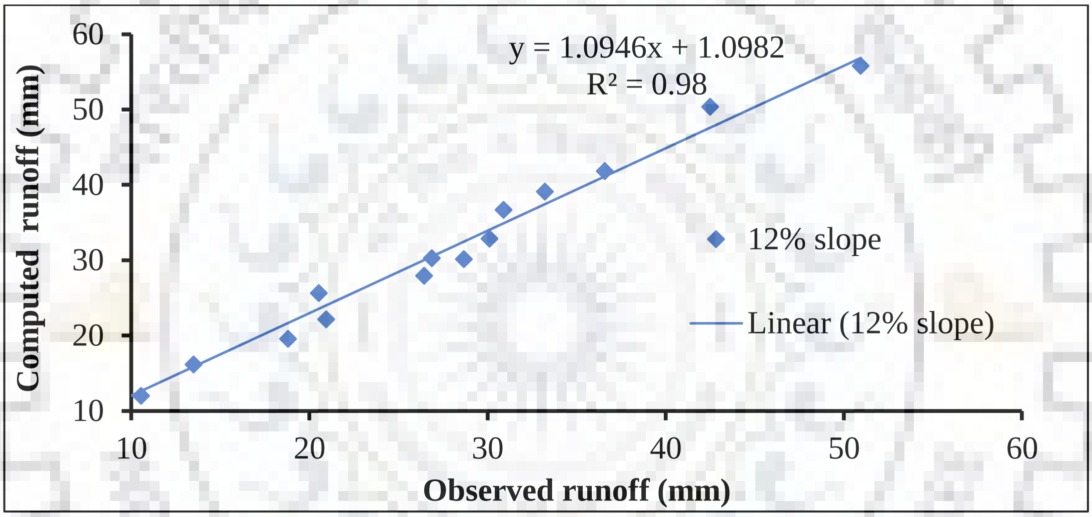

Figure 4.13 Comp. Vs Obs. Runoff of Maize Crops 12% slope

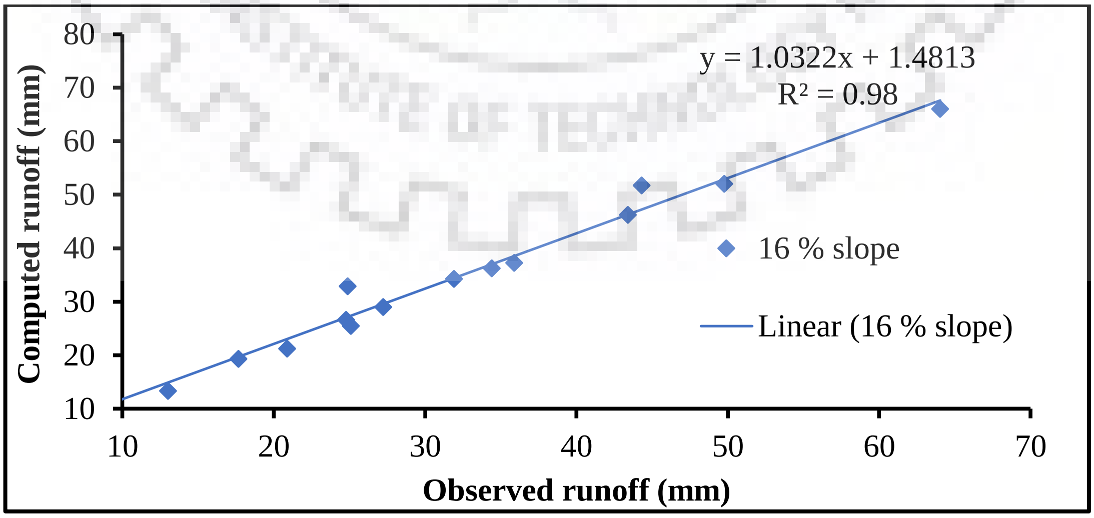

Figure 4.14 Comp. Vs Obs. Runoff of Maize Crops 16% slopes

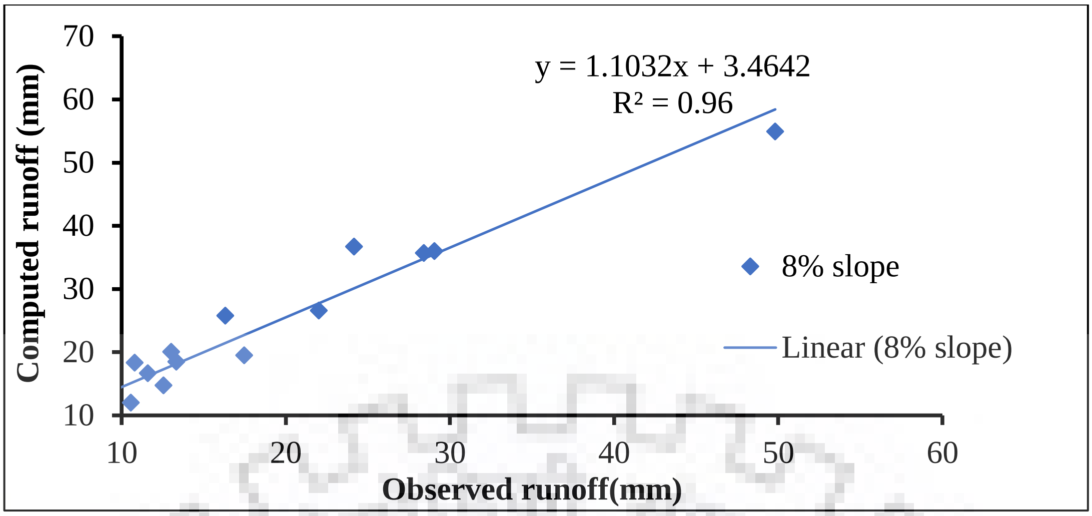

Figure 4.15 Comp. Vs Obs. Runoff of Finger millet 8% slope

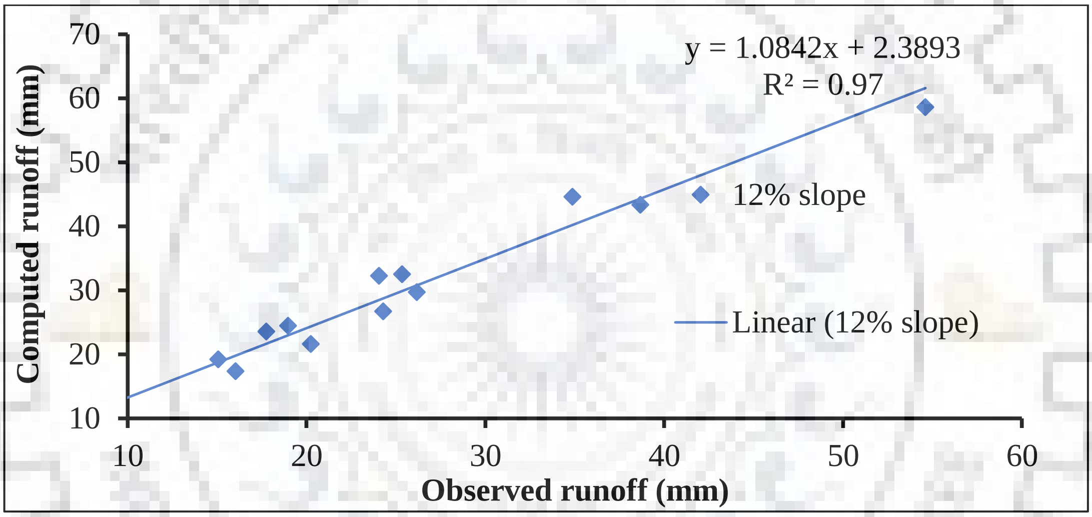

Figure 4.16 Comp. Vs Obs. Runoff of Finger millet 12% slope

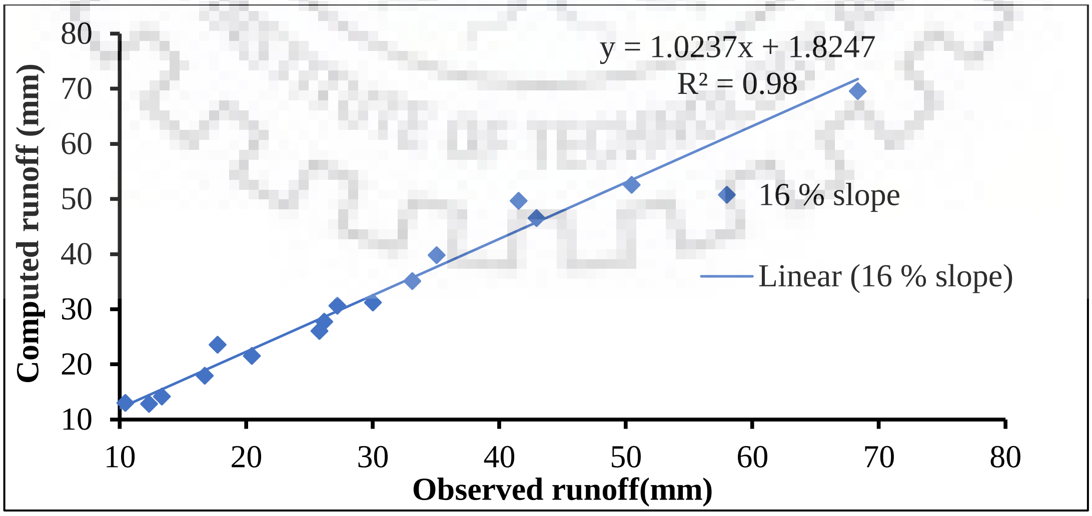

Figure 4.17 Comp. Vs Obs. Runoff of Finger millet 16% slopes

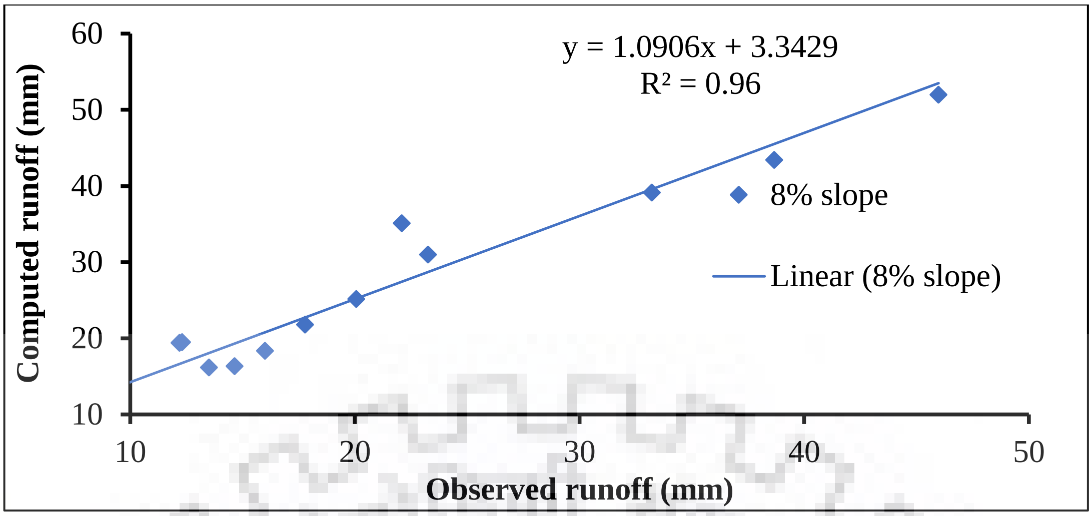

Figure 4.18 Comp. Vs Obs. Runoff of Fallow land 8% slope

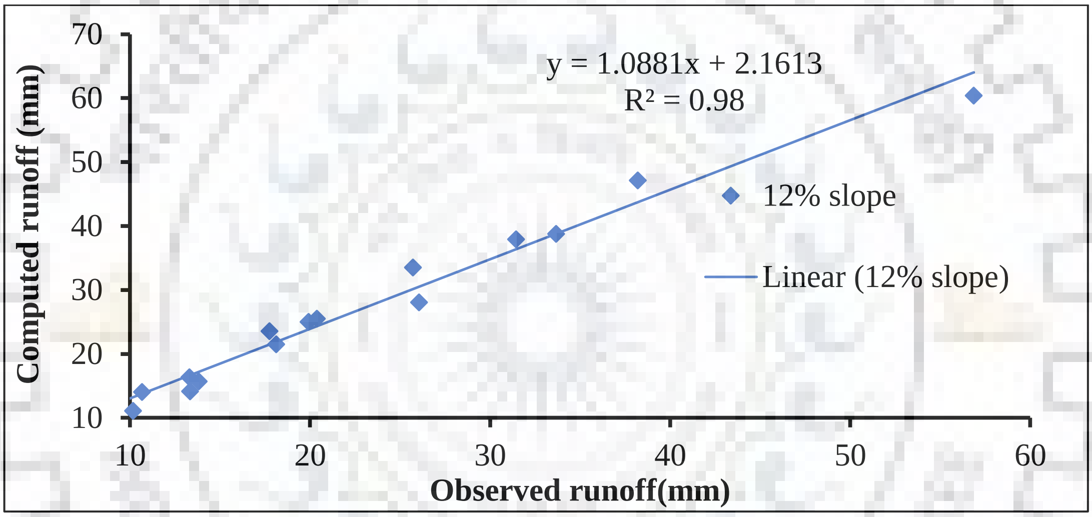

Figure 4.19 Comp. Vs Obs. Runoff of Fallow land 12% slope

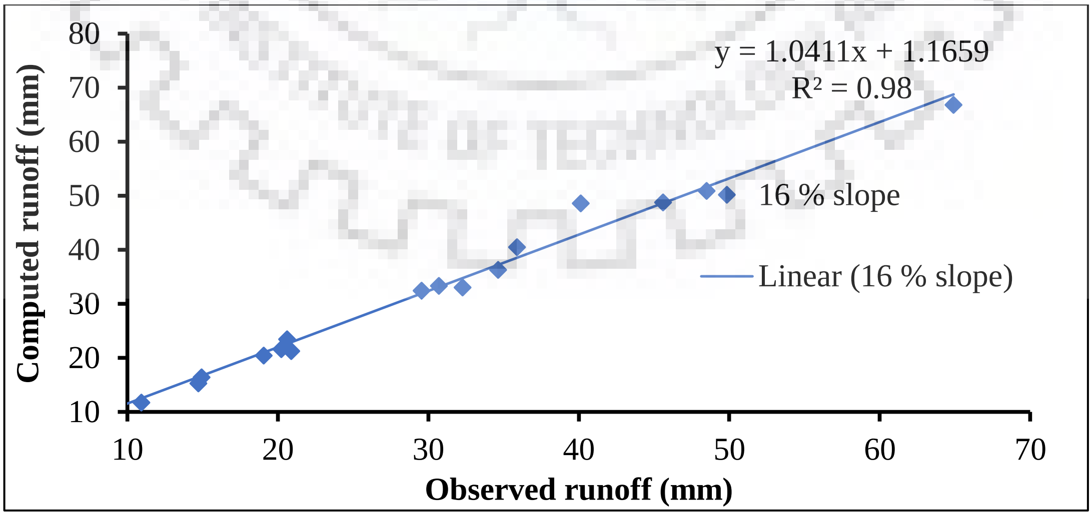

Figure 4.20 Comp. Vs Obs. Runoff of Fallow land 16% slope

4.4 MUSLE COUPLED SCS-CN-BASED SEDIMENT YIELD MODEL

The MUSLE coupled SCS-CN model (Eq. 3.2) has been used for estimation of sediment yield. A brief discussion has been presented on the observed runoff and sediment yield data and sediment rating curves in this section. The model computed sediment yield has been finally compared with the observed sediment yield using different goodness-of-fit indices as mentioned in Chapter III. Due to non-linearity between runoff and sediment yield, the CNs estimated for runoff may not be equally applicable for sediment yield estimation. Keeping in view this fact, an effort has been made in this section to develop a correlation between CNs estimated by using sediment yield and runoff data for all the nine plots.

4.4.1 Observed Runoff and Sediment Yield

The data for rainfall, runoff and sediment yield were collected for the months of June to October as discussed in Chapter III. During the season, Maize and Finger millet crops were cultivated and the other left as fallow land. Firstly, the values of total sediment yield from the plot Maize having slope 8%,12% and 16% were 39.04 kg, 77.45 kg and 145.45 kg, respectively. Notably, the last is higher than the plot with 12% and 8% slope for the same crop and same hydrological group. Secondly, the values of total sediment yield from the plot with Finger millet having slopes 8%, 12% and 16% were 27.26 kg, 90.58 kg and 140.74 kg, respectively. Lastly, for the fallow land, sediment yield values from slopes of 8%, 12% and 16% were 34.44 kg, 84.02 kg and 152.03 kg, respectively. The data shows that higher slope lands yield higher sediment and coverage of vegetation also affect the sediment yield. In our experiment, fallow land produces more sediment yield than maize crops and finger millet. The event wise rainfall-runoff and sediment losses data for the all land cover with three different slopes is showed in Table 4.14 to Table 4.16.

Table 4.14 Observed runoff and sediment yield for Maize crop

E.N	Date	Rainfall (mm)	Runoff (m^3) Maize crops			Sediment Yield (kg)		
			8%	12%	16%	8%	12%	16%
1	19-Jun-17	44.00	0.51	1.08	1.15	3.03	10.12	23.01
2	26-Jun-17	34.20	0.48	0.95	0.89	2.65	8.29	13.88
3	28-Jun-17	75.20	1.75	1.83	2.31	20.76	27.23	40.17
4	29-Jun-17	17.70	0.23	0.38	0.33	0.76	2.28	4.42
5	30-Jun-17	15.00	0.25	0.35	0.47	0.35	0.56	2.62
6	6-Jul-17	36.40	0.69	1.03	0.98	2.62	8.98	14.04
7	24-Jul-17	14.00	0.02	0.15	0.20	0.05	0.54	0.30
8	2-Aug-17	79.50	1.20	1.53	1.60	4.98	10.87	25.61
9	3-Aug-17	9.60	0.07	0.12	0.16	0.03	0.07	0.02
10	7-Aug-17	27.40	0.68	0.75	0.90	0.32	0.83	1.64
11	10-Aug-17	43.40	0.72	0.97	1.29	0.77	2.56	4.53
12	19-Aug-17	22.30	0.11	0.33	0.36	0.07	0.21	1.13
13	22-Aug-17	58.10	1.04	1.11	1.56	0.56	1.26	5.40
14	23-Aug-17	15.50	0.08	0.09	0.24	0.04	0.10	0.36
15	25-Aug-17	61.80	1.16	1.32	1.79	0.55	0.93	2.51
16	1-Sep-17	44.00	0.54	0.74	1.24	0.22	0.80	2.18
17	1-Sep-17	23.00	0.53	0.68	0.75	0.12	0.12	1.50
18	2-Sep-17	61.10	0.95	1.20	0.90	1.00	1.43	1.62
19	3-Sep-17	26.00	0.69	0.49	0.64	0.16	0.24	0.51
Total			**11.70**	**15.11**	**17.76**	**39.04**	**77.45**	**145.45**

Table 4.15: Observed runoff and sediment yield for Finger millet

E.N	Date	Rainfall (mm)	Runoff (m^3) Maize crops			Sediment Yield (kg)		
			8%	12%	16%	8%	12%	16%
1	19-Jun-17	44	0.47	0.64	0.98	1.66	14.31	25.19
2	26-Jun-17	34.2	0.42	0.54	0.94	1.32	9.19	14.59
3	28-Jun-17	75.2	1.79	1.97	2.46	16.18	25.00	37.82
4	29-Jun-17	17.7	0.38	0.28	0.48	0.80	1.54	5.70
5	30-Jun-17	15	0.24	0.33	0.44	0.48	0.68	1.71
6	6-Jul-17	36.4	0.48	0.87	1.08	2.16	13.18	14.23
7	24-Jul-17	14	0.10	0.10	0.10	0.12	0.43	0.32
8	2-Aug-17	79.5	0.87	1.26	1.50	2.67	9.92	22.96
9	3-Aug-17	9.6	0.02	0.17	0.22	0.01	0.17	0.28
10	7-Aug-17	27.4	0.63	0.73	0.93	0.18	0.64	1.82
11	10-Aug-17	43.4	0.79	0.94	1.19	0.25	3.26	2.87
12	19-Aug-17	22.3	0.06	0.21	0.38	0.04	0.18	1.19
13	22-Aug-17	58.1	0.59	0.91	1.26	0.07	0.82	5.40
14	23-Aug-17	15.5	0.09	0.11	0.14	0.03	0.08	0.07
15	25-Aug-17	61.8	1.02	1.39	1.82	0.55	0.79	1.80
16	1-Sep-17	44	0.39	0.68	0.64	0.17	0.96	1.42
17	1-Sep-17	23	0.45	0.58	0.60	0.16	0.10	1.13
18	2-Sep-17	61.1	1.05	0.87	1.55	0.38	0.89	1.82
19	3-Sep-17	26	0.24	0.34	0.74	0.03	0.24	0.42
Total			**10.08**	**12.91**	**17.44**	**27.26**	**90.58**	**140.74**

Table 4.16 Observed runoff and sediment yield for Fallow land

E.N	Date	Rainfall (mm)	Runoff (m^3) Maize crops			Sediment Yield (kg)		
			8%	12%	16%	8%	12%	16%
1	19-Jun-17	44	0.44	0.73	1.06	2.24	10.14	22.03
2	26-Jun-17	34.2	0.29	0.65	0.74	1.66	5.06	12.77
3	28-Jun-17	75.2	1.66	1.46	2.34	16.87	31.82	44.06
4	29-Jun-17	17.7	0.18	0.48	0.53	0.78	2.77	7.51
5	30-Jun-17	15	0.19	0.37	0.39	0.20	0.44	3.55
6	6-Jul-17	36.4	0.64	0.94	1.16	5.50	10.59	15.70
7	24-Jul-17	14	0.05	0.10	0.15	0.04	0.20	0.65
8	2-Aug-17	79.5	0.80	1.38	1.45	3.80	11.74	21.50
9	3-Aug-17	9.6	0.02	0.12	0.21	0.01	0.05	0.12
10	7-Aug-17	27.4	0.58	0.48	0.73	0.14	1.16	1.62
11	10-Aug-17	43.4	0.72	0.72	1.25	0.24	3.94	5.43
12	19-Aug-17	22.3	0.17	0.23	0.54	0.26	0.52	1.48
13	22-Aug-17	58.1	0.84	1.21	1.29	0.44	1.39	6.93
14	23-Aug-17	15.5	0.09	0.19	0.16	0.08	0.18	0.13
15	25-Aug-17	61.8	1.39	1.13	1.64	0.41	0.48	1.39
16	1-Sep-17	44	0.44	0.64	1.11	0.15	1.32	1.80
17	1-Sep-17	23	0.53	0.50	0.75	0.16	0.17	1.38
18	2-Sep-17	61.1	1.20	0.93	1.75	1.33	1.88	3.38
19	3-Sep-17	26	0.49	0.38	0.69	0.14	0.17	0.59
Total			**10.70**	**12.64**	**17.93**	**34.44**	**84.02**	**152.03**

4.5 Development of Stage-Discharge Relationships

The relationship between runoff and sediment yield was established using the observed runoff-sediment data collected throughout the study period for all the nineteen storm events and all the nine plots planted with maize, finger millet and fallow land. The observed runoff and sediment data for maize crop are given in Table 4.14, for finger millet in Table.4.15 and for fallow land in Table 4.16. The sediment rating curves were also drawn between the observed sediment and discharge for all nine plots and crops and these are shown in Figures 4.21 to 4.29. These rating curves can be used for estimation of sediment for a given discharge. It can also be inferred from Table 4.14 to 4.16 that higher density and higher canopy crop (Finger millet) has the lowers turn off and sediment yield. For all crops in different land use the sediment rating curve are shown in Figure 4.21 to 4.29. The coefficient of determination R^2 of maize crops in 8 %, 12% and 16% slopes are 0.55, 0.55 and 0.60, respectively. For Finger millet crops in 8 %, 12% and 16% slopes, R2-values are 0.54, 0.42 and 0.56, respectively. Similarly, the Fallow land yielded R^2 values as 0.5, 0.58 and 0.52, respectively.

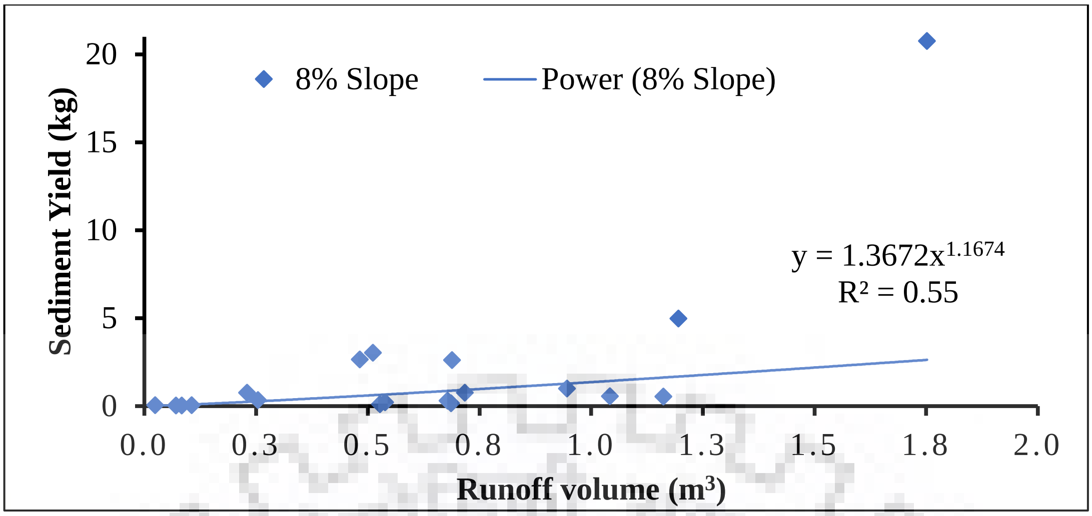

Figure 4.21 Sediment rating curve of Maize Crops 8% slope

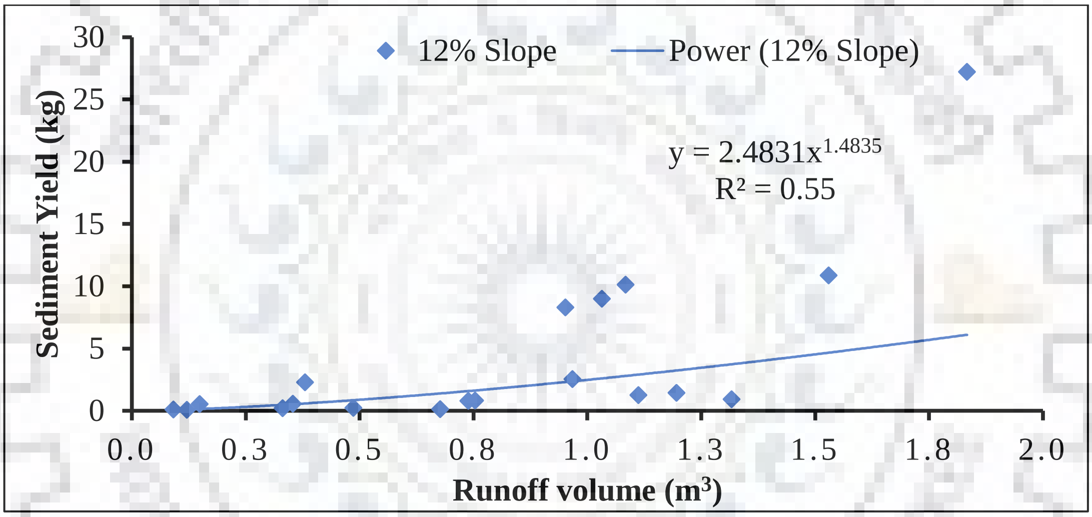

Figure 4.22 Sediment rating curve of Maize Crops 12% slope

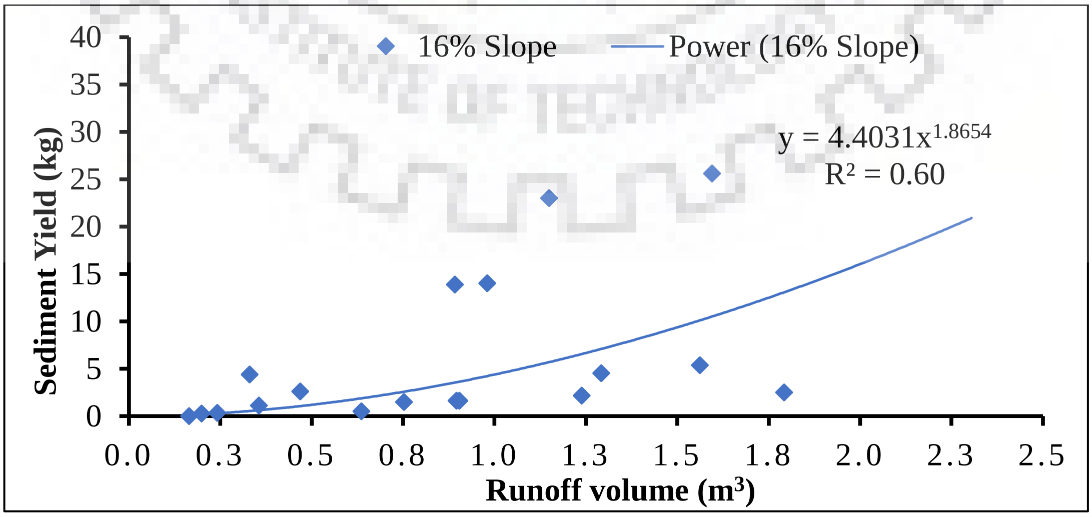

Figure 4.23 Sediment rating curve of Maize Crops 16% slope

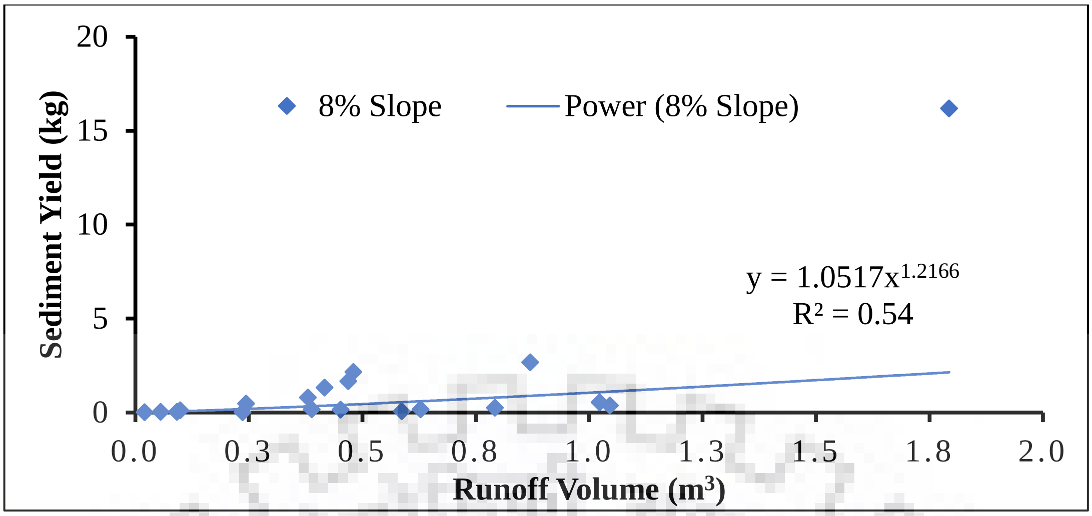

Figure 4.24 Sediment rating curve of Finger Millet 8% slope

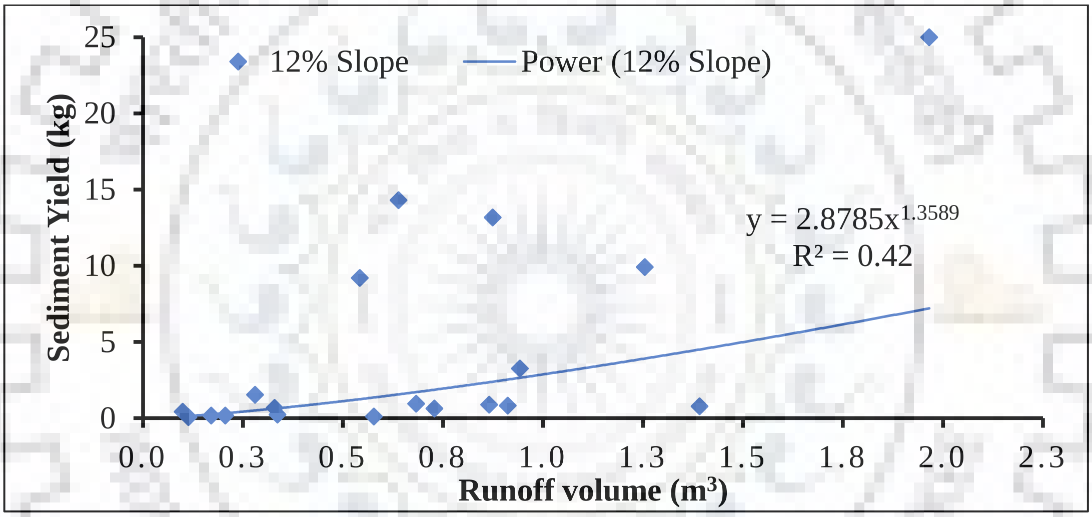

Figure 4.25 Sediment rating curve of Finger Millet 12% slope

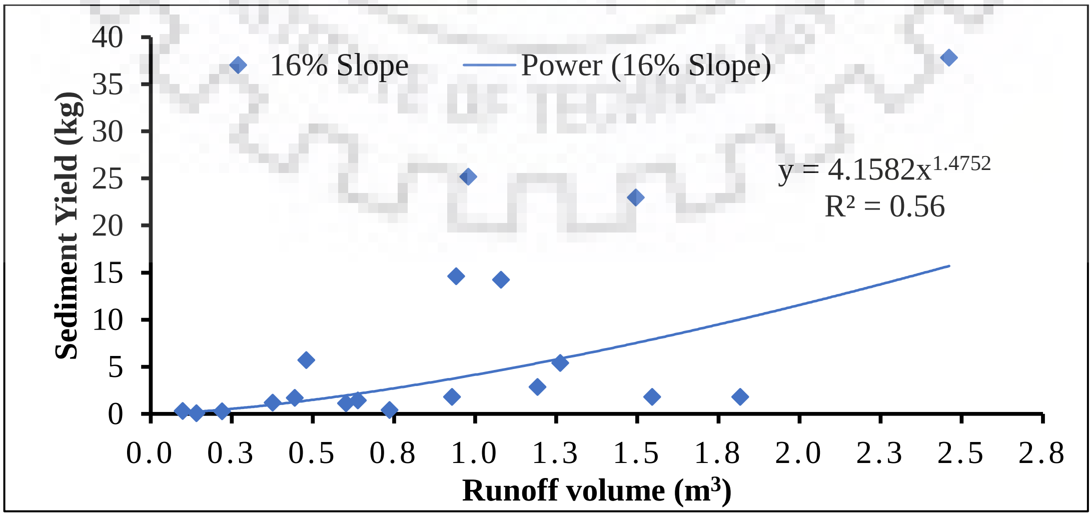

Figure 4.26 Sediment rating curve of Finger Millet 16% slope

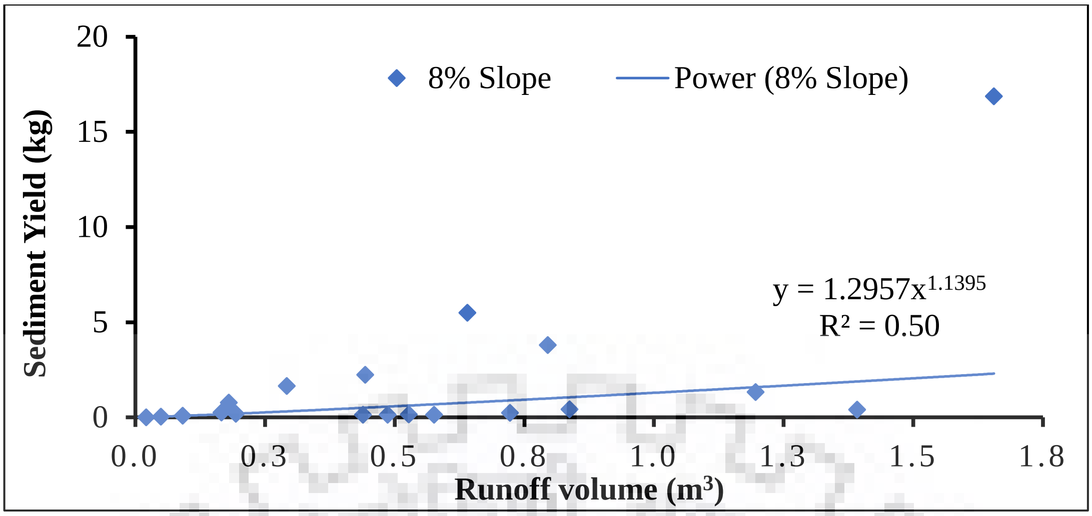

Figure 4.27 Sediment rating curve of Fallow land 8% slope

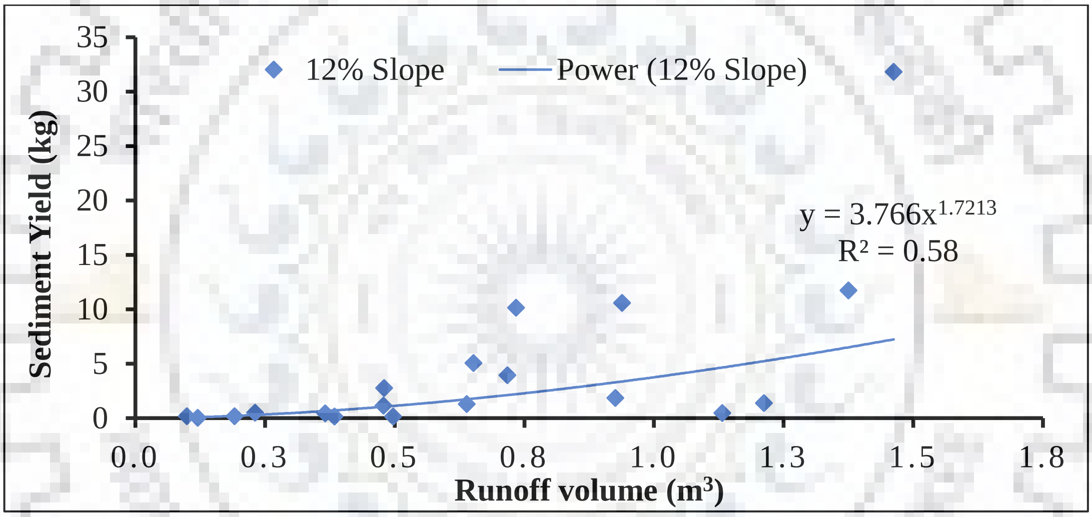

Figure 4.28 Sediment rating curve of Fallow land 12% slope

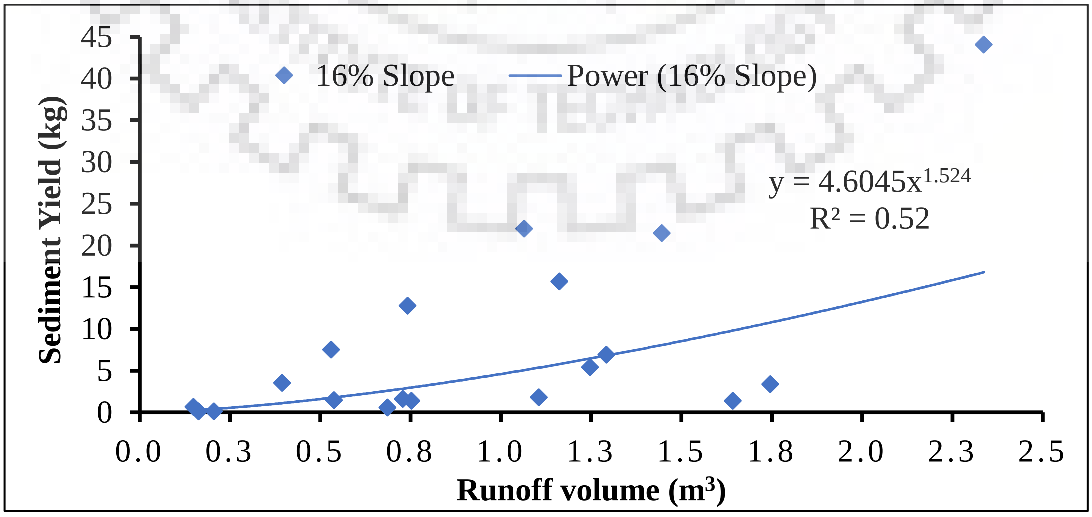

Figure 4.29 Sediment rating curve of Fallow land 16% slope

4.6 Modelling of Sediment Yield Using SCS-CN Based Sediment Yield Model

Prediction of runoff and soil loss under different land covers is fundamental to quantitatively evaluate the hydrological responses of watersheds. As discussed in Chapter III, the Soil Conservation Service curve number (SCS-CN) and Modified Universal Soil Loss Equation (MUSLE) models have been used to estimate sediment yield. The sediment yield estimated by MUSLE has been routed using SCS-CN method to get the sediment yield at the outlet of each experimental plot. The model computed sediment yield for all nine experimental plots is given in Table 4.17 to Table 4.19, and Table 4.20 shows the summary of potential sediment yield.

Graphically, the comparison between the observed and model computed sediment yield is also shown in Figures 4.30 to 4.39. It can be observed from these figures that their coefficient of determination (R^2) of maize crops 8%, 12% and 16% slopes are 0.88, 0.82 and 0.46, respectively. For finger millet crops in 8%, 12% and 16% slopes, R2 values are 0.81, 0.52 and 0.39, respectively. Similarly, in Fallow land, R^2 values in 8%, 12% and 16% slopes are 0.37, 0.70 and 0.41, respectively. We found fallow land having a lower value of R^2. As discussed in Chapter III, the goodness-of-fit of the model was evaluated using NSE, RMSE and PBIAS. The results (Table 4.21) show that the NSE of the proposed model is 60.55%, and RMSE and PBIAS are 0.41 and -14.47%, respectively. According to the criteria of (Moriasi et al., 2007), the performance of the model can be rated as 'Good' model performance.

Table 4.17: Observed and Computed Sediment Yield (kg) of maize crops

E.N	Date	Rainfall (mm)	Potential maximum Sediment (Kg)			S			Computed Sediment (kg) $Y=\frac{Y_mP}{P+S}$			Observed Sediment (kg)		
			8%	12%	16%	8%	12%	16%	8%	12%	16%	8%	12%	16%
			plot-4	plot-1	plot-7	plot-4	plot-1	plot-7	plot-4	plot-1	plot-7	plot-4	plot-1	plot-7
1	19-Jun-17	44.00	2.99	8.44	22.43	48.49	14.87	12.47	1.42	6.31	17.48	3.03	10.12	23.01
2	26-Jun-17	34.20	2.96	7.59	13.73	30.71	7.67	9.72	1.56	6.20	10.69	2.65	8.29	13.88
3	28-Jun-17	75.20	33.65	50.00	32.99	29.43	26.14	10.39	15.78	37.10	28.99	20.76	27.23	40.17
4	29-Jun-17	17.70	3.65	2.70	3.73	17.41	8.32	10.80	1.84	1.84	2.32	0.76	2.28	4.42
5	30-Jun-17	15.00	4.22	2.54	5.86	10.62	5.68	1.81	2.47	1.84	5.23	0.35	0.56	2.62
6	6-Jul-17	36.40	3.05	8.32	12.74	21.70	7.56	9.28	1.91	6.89	10.16	2.62	8.98	14.04
7	24-Jul-17	14.00	0.07	0.91	2.10	41.83	16.75	12.45	0.02	0.41	1.11	0.05	0.54	0.30
8	2-Aug-17	79.50	4.93	11.03	19.14	66.06	45.98	42.68	2.69	6.99	12.46	4.98	10.87	25.61
9	3-Aug-17	9.60	0.25	0.74	1.75	15.28	9.79	6.68	0.09	0.37	1.03	0.03	0.07	0.02
10	7-Aug-17	27.40	3.20	5.89	12.20	9.12	6.45	2.03	2.40	4.77	11.36	0.32	0.83	1.64
11	10-Aug-17	43.40	3.07	7.28	17.60	31.80	18.82	7.11	1.77	5.08	15.12	0.77	2.56	4.53
12	19-Aug-17	22.30	0.34	2.19	3.93	45.69	18.83	17.14	0.11	1.19	2.22	0.07	0.21	1.13
13	22-Aug-17	58.10	4.57	8.02	20.83	37.72	33.92	14.89	2.77	5.06	16.58	0.56	1.26	5.40
14	23-Aug-17	15.50	0.28	0.50	2.61	29.75	28.29	12.31	0.10	0.18	1.45	0.04	0.10	0.36
15	25-Aug-17	61.80	5.17	9.84	24.72	37.19	29.51	11.59	3.23	6.66	20.81	0.55	0.93	2.51
16	1-Sep-17	44.00	2.13	5.12	16.55	46.04	31.52	9.42	1.04	2.98	13.64	0.22	0.80	2.18
17	1-Sep-17	23.00	2.41	5.31	9.95	9.35	4.00	1.87	1.71	4.53	9.20	0.12	0.12	1.50
18	2-Sep-17	61.10	3.96	8.68	9.76	48.91	34.32	52.37	2.20	5.56	5.26	1.00	1.43	1.62
19	3-Sep-17	26.00	3.28	3.42	7.87	7.11	15.78	8.95	2.58	2.13	5.85	0.16	0.24	0.51
Total Sediment Kg									**45.69**	**106.08**	**190.95**	**39.04**	**77.45**	**145.45**

Table 4.18: Observed and Computed Sediment Yield (kg) of Finger millet crops

E.N	Date	Rainfall (mm)	Potential maximum Sediment (Kg)			S			Computed Sediment (kg) $Y=\frac{Y_m P}{P+S}$			Observed Sediment (kg)		
			8%	12%	16%	8%	12%	16%	8%	12%	16%	8%	12%	16%
			plot-5	plot-2	plot-8	plot-5	plot-2	plot-8	plot-5	plot-2	plot-8	plot-5	plot-2	plot-8
1	19-Jun-17	44.00	1.83	5.22	14.85	52.56	38.14	19.16	0.83	2.80	10.35	1.66	14.31	25.19
2	26-Jun-17	34.20	1.69	4.53	15.09	35.94	26.53	8.00	0.82	2.55	12.23	1.32	9.19	14.59
3	28-Jun-17	75.20	17.80	19.58	44.76	27.73	21.24	6.09	9.54	15.27	41.40	16.18	33.19	37.82
4	29-Jun-17	17.70	3.44	2.29	7.26	8.32	13.77	4.40	2.34	1.29	5.81	0.80	1.54	5.70
5	30-Jun-17	15.00	2.06	2.85	6.74	11.24	6.74	2.54	1.18	1.97	5.76	0.48	0.68	1.71
6	6-Jul-17	36.40	1.98	8.22	17.81	35.22	13.17	6.07	1.01	6.03	15.26	2.16	13.18	14.23
7	24-Jul-17	14.00	0.35	0.68	1.12	22.87	22.87	22.87	0.13	0.26	0.43	0.12	0.43	0.32
8	2-Aug-17	79.50	3.35	10.41	21.55	92.74	62.02	47.82	1.55	5.85	13.45	2.67	9.92	22.96
9	3-Aug-17	9.60	0.06	1.37	3.05	26.88	6.32	3.88	0.02	0.83	2.17	0.01	0.17	0.28
10	7-Aug-17	27.40	2.97	6.93	15.53	11.11	7.30	1.39	2.12	5.47	14.78	0.18	0.64	1.82
11	10-Aug-17	43.40	3.57	8.65	19.38	27.40	19.93	10.27	2.19	5.93	15.68	0.25	3.26	2.87
12	19-Aug-17	22.30	0.17	1.51	5.16	59.40	30.07	15.89	0.05	0.64	3.02	0.04	0.18	1.19
13	22-Aug-17	58.10	2.24	7.60	19.12	72.73	45.66	26.65	1.00	4.26	13.11	0.07	0.82	5.40
14	23-Aug-17	15.50	0.32	0.79	1.69	28.29	24.77	21.10	0.11	0.30	0.71	0.03	0.08	0.07
15	25-Aug-17	61.80	4.47	13.03	30.97	45.19	26.18	10.82	2.58	9.15	26.36	0.55	0.79	1.80
16	1-Sep-17	44.00	1.45	5.68	8.56	61.38	35.09	38.14	0.61	3.16	4.59	0.17	0.96	1.42
17	1-Sep-17	23.00	2.04	5.34	9.23	12.81	7.37	6.46	1.31	4.04	7.21	0.16	0.10	1.13
18	2-Sep-17	61.10	4.62	6.99	24.78	42.59	54.54	19.12	2.72	3.70	18.87	0.38	0.89	1.82
19	3-Sep-17	26.00	0.89	2.66	11.64	35.51	25.71	5.43	0.38	1.34	9.63	0.03	0.24	0.42
Total Sediment Kg									**30.48**	**74.83**	**220.82**	**27.26**	**90.58**	**140.74**

Table 4.19: Observed and Computed Sediment Yield (kg) of Fallow land

E.N	Date	Rainfall (mm)	Potential maximum Sediment (Kg)			S			Computed Sediment (kg) $Y=\frac{Y_m P}{P+S}$			Observed Sediment (kg)		
			8%	12%	16%	8%	12%	16%	8%	12%	16%	8%	12%	16%
			plot-6	plot-3	plot-9	plot-6	plot-3	plot-9	plot-6	plot-3	plot-9	plot-6	plot-3	plot-9
1	19-Jun-17	44.00	1.42	5.19	11.05	55.25	31.83	15.64	0.63	3.01	8.16	2.24	10.14	22.03
2	26-Jun-17	34.20	0.91	4.77	7.38	48.97	20.09	15.72	0.37	3.00	5.06	1.66	5.06	12.77
3	28-Jun-17	75.20	6.64	14.33	27.59	33.53	18.42	9.47	4.59	11.51	24.50	16.87	31.82	44.06
4	29-Jun-17	17.70	0.58	3.69	5.47	22.03	4.40	2.81	0.26	2.96	4.72	0.78	2.77	7.51
5	30-Jun-17	15.00	0.65	2.71	3.88	14.84	5.21	4.17	0.33	2.01	3.04	0.20	0.44	3.55
6	6-Jul-17	36.40	2.37	7.51	13.09	24.35	10.75	3.72	1.42	5.80	11.88	5.50	10.59	15.70
7	24-Jul-17	14.00	0.13	0.57	1.22	32.92	22.87	16.75	0.04	0.22	0.55	0.04	0.20	0.65
8	2-Aug-17	79.50	2.49	9.78	13.72	100.41	54.56	50.55	1.10	5.80	8.39	3.80	11.74	21.50
9	3-Aug-17	9.60	0.05	0.76	1.87	26.88	9.79	4.53	0.01	0.38	1.27	0.01	0.05	0.12
10	7-Aug-17	27.40	2.22	3.40	7.58	13.45	18.52	7.30	1.49	2.03	5.98	0.14	1.16	1.62
11	10-Aug-17	43.40	2.64	5.06	13.74	31.49	31.80	8.49	1.53	2.92	11.49	0.24	3.94	5.43
12	19-Aug-17	22.30	0.50	1.45	5.37	35.22	27.33	7.99	0.19	0.65	3.95	0.26	0.52	1.48
13	22-Aug-17	58.10	2.93	9.20	13.16	50.85	28.95	25.32	1.56	6.14	9.16	0.44	1.39	6.93
14	23-Aug-17	15.50	0.26	1.23	1.34	28.29	16.09	18.70	0.09	0.60	0.61	0.08	0.18	0.13
15	25-Aug-17	61.80	5.62	8.23	17.89	26.18	38.82	16.52	3.95	5.06	14.12	0.41	0.48	1.39
16	1-Sep-17	44.00	1.41	4.35	11.63	55.68	38.14	14.07	0.62	2.33	8.81	0.15	1.32	1.80
17	1-Sep-17	23.00	2.05	3.69	8.15	9.35	10.66	1.87	1.46	2.52	7.53	0.16	0.17	1.38
18	2-Sep-17	61.10	4.60	6.35	19.59	34.32	50.27	12.27	2.94	3.49	16.31	1.33	1.88	3.38
19	3-Sep-17	26.00	1.81	2.61	7.09	15.78	22.07	7.11	1.13	1.41	5.57	0.14	0.17	0.59
Total Sediment Kg									**23.72**	**61.84**	**151.10**	**34.44**	**84.02**	**152.03**

Table 4.20: Summary of MUSLE Potential Sediment yield (Kg)

Event No.	Natural Event Date	Rainfall (mm)	Potential Sediment Yield (Y_m) in Kg								
			Slope 8%			Slope 12%			Slope 16%		
			Maize	Finger millet	Fallow land	Maize	Finger millet	Fallow land	Maize	Finger millet	Fallow land
1	19-Jun-17	44.00	2.99	1.83	1.42	8.44	5.22	5.19	22.43	14.85	11.05
2	26-Jun-17	34.20	2.96	1.69	0.91	7.59	4.53	4.77	13.73	15.09	7.38
3	28-Jun-17	75.20	33.65	17.80	6.64	50.00	19.58	14.33	32.99	44.76	27.59
4	29-Jun-17	17.70	3.65	3.44	0.58	2.70	2.29	3.69	3.73	7.26	5.47
5	30-Jun-17	15.00	4.22	2.06	0.65	2.54	2.85	2.71	5.86	6.74	3.88
6	6-Jul-17	36.40	3.05	1.98	2.37	8.32	8.22	7.51	12.74	17.81	13.09
7	24-Jul-17	14.00	0.07	0.35	0.13	0.91	0.68	0.57	2.10	1.12	1.22
8	2-Aug-17	79.50	4.93	3.35	2.49	11.03	10.41	9.78	19.14	21.55	13.72
9	3-Aug-17	9.60	0.25	0.06	0.05	0.74	1.37	0.76	1.75	3.05	1.87
10	7-Aug-17	27.40	3.20	2.97	2.22	5.89	6.93	3.40	12.20	15.53	7.58
11	10-Aug-17	43.40	3.07	3.57	2.64	7.28	8.65	5.06	17.60	19.38	13.74
12	19-Aug-17	22.30	0.34	0.17	0.50	2.19	1.51	1.45	3.93	5.16	5.37
13	22-Aug-17	58.10	4.57	2.24	2.93	8.02	7.60	9.20	20.83	19.12	13.16
14	23-Aug-17	15.50	0.28	0.32	0.26	0.50	0.79	1.23	2.61	1.69	1.34
15	25-Aug-17	61.80	5.17	4.47	5.62	9.84	13.03	8.23	24.72	30.97	17.89
16	1-Sep-17	44.00	2.13	1.45	1.41	5.12	5.68	4.35	16.55	8.56	11.63
17	1-Sep-17	23.00	2.41	2.04	2.05	5.31	5.34	3.69	9.95	9.23	8.15
18	2-Sep-17	61.10	3.96	4.62	4.60	8.68	6.99	6.35	9.76	24.78	19.59
19	3-Sep-17	26.00	3.28	0.89	1.81	3.42	2.66	2.61	7.87	11.64	7.09

Table 4.21: Sediment yield performance evaluation of Sediment yield model based SCS-CN

E.N	Date	Rainfall (mm)	Observed Sediment (kg)	Computed Sediment (kg)	D1	D0	$S_{obs}-S_{cal}$	$(S_{obs}-S_{cal})^2$	Nash Sutcliffe Efficiency $(1-D_1/D_0)$	RMSE	PBIAS
1	19-Jun-17	44.00	111.737	50.98	3691.01	4914.67	60.754	3691.01	**60.55%**	**0.41**	**-14.47%**
2	26-Jun-17	34.20	69.419	42.49	725.34	772.11	26.932	725.34			
3	28-Jun-17	75.20	268.108	188.68	6308.33	51291.36	79.425	6308.33			
4	29-Jun-17	17.70	26.568	23.37	10.23	226.93	3.198	10.23			
5	30-Jun-17	15.00	10.587	23.83	175.36	963.82	-13.242	175.36			
6	6-Jul-17	36.40	86.992	60.35	709.66	2057.52	26.639	709.66			
7	24-Jul-17	14.00	2.658	3.17	0.26	1519.02	-0.513	0.26			
8	2-Aug-17	79.50	114.036	58.28	3109.33	5242.34	55.761	3109.33			
9	3-Aug-17	9.60	0.768	6.17	29.20	1669.90	-5.403	29.20			
10	7-Aug-17	27.40	8.344	50.41	1769.28	1108.11	-42.063	1769.28			
11	10-Aug-17	43.40	23.853	61.70	1432.38	316.10	-37.847	1432.38			
12	19-Aug-17	22.30	5.074	12.03	48.31	1336.50	-6.951	48.31			
13	22-Aug-17	58.10	22.279	59.64	1395.86	374.54	-37.361	1395.86			
14	23-Aug-17	15.50	1.068	4.16	9.55	1645.48	-3.091	9.55			
15	25-Aug-17	61.80	9.409	91.92	6807.91	1038.35	-82.510	6807.91			
16	1-Sep-17	44.00	9.023	37.77	826.41	1063.36	-28.747	826.41			
17	1-Sep-17	23.00	4.859	39.51	1200.71	1352.30	-34.651	1200.71			
18	2-Sep-17	61.10	13.730	61.05	2239.13	778.57	-47.319	2239.13			
19	3-Sep-17	26.00	2.502	30.01	756.81	1531.20	-27.510	756.81			
Average			**41.63**	**47.66**							
Sum			**791.02**	**905.52**	**31245.06**	**79202.16**	**-114.50**	**31245.06**			

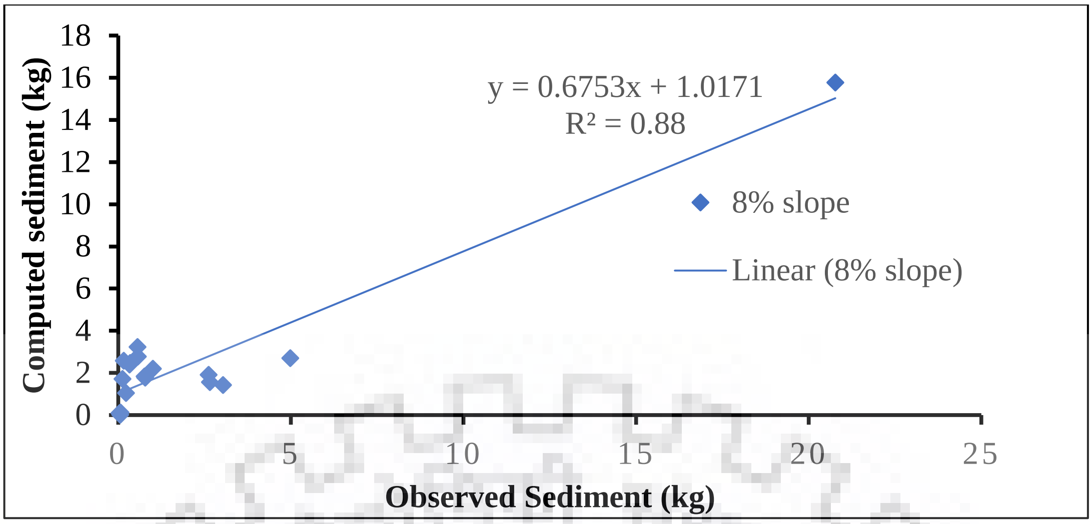

Figure 4.30 Comp. Vs Obs. Sediment yield of Maize Crops 8% slopes

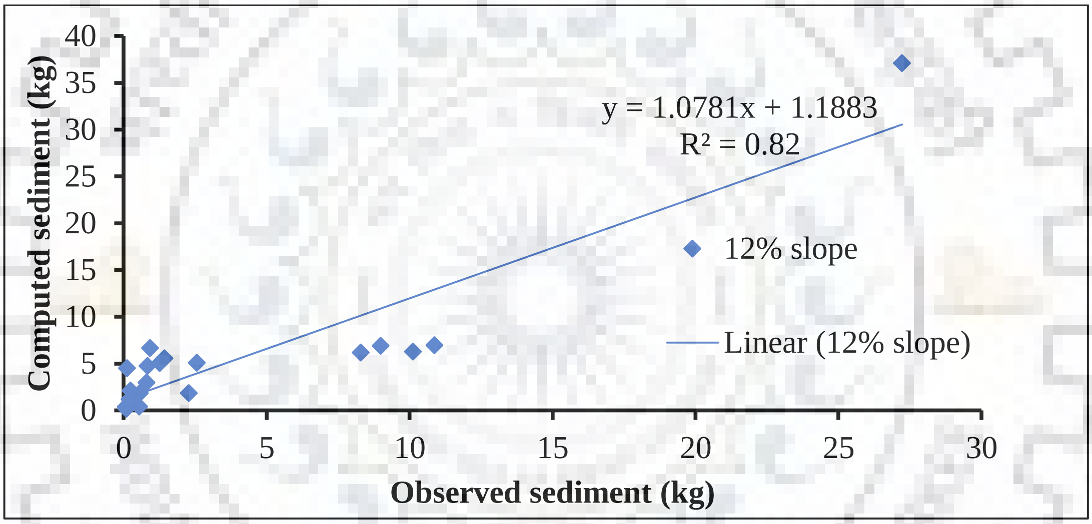

Figure 4.31 Comp. Vs Obs. Sediment yield of Maize Crops 12% slopes

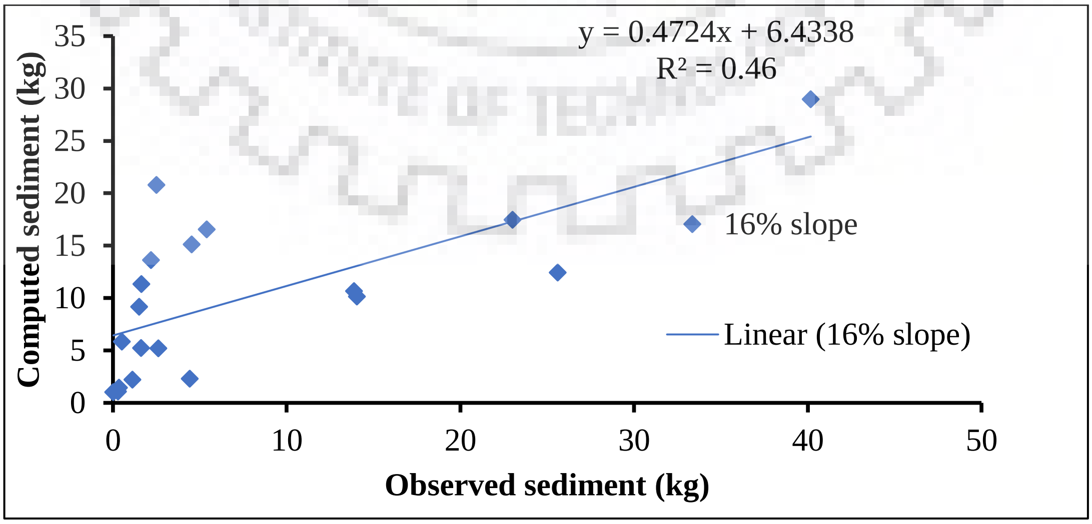

Figure 4.32 Comp. Vs Obs. Sediment yield of Maize Crops 16% slopes

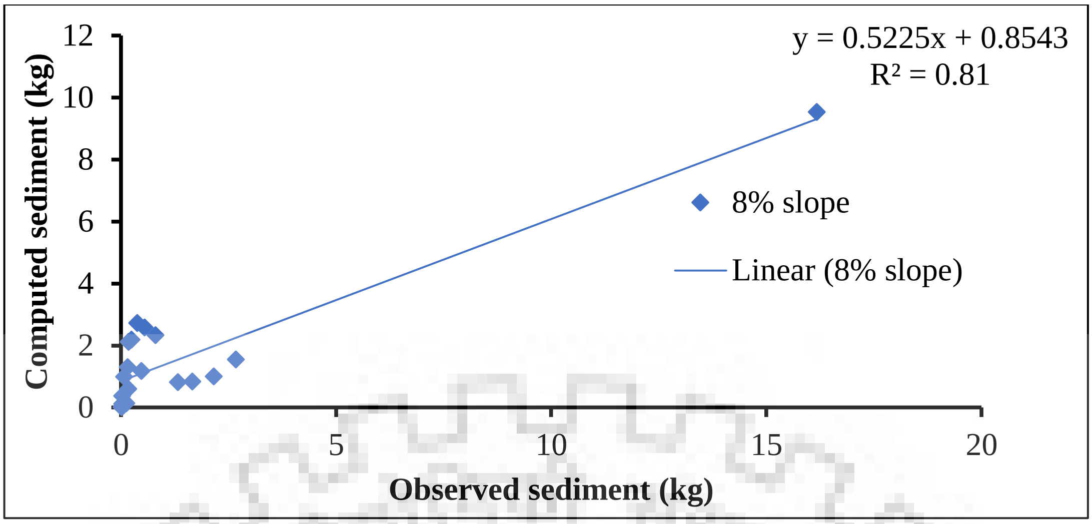

Figure 4.33 Comp. Vs Obs. Sediment yield of Finger millet 8% slopes

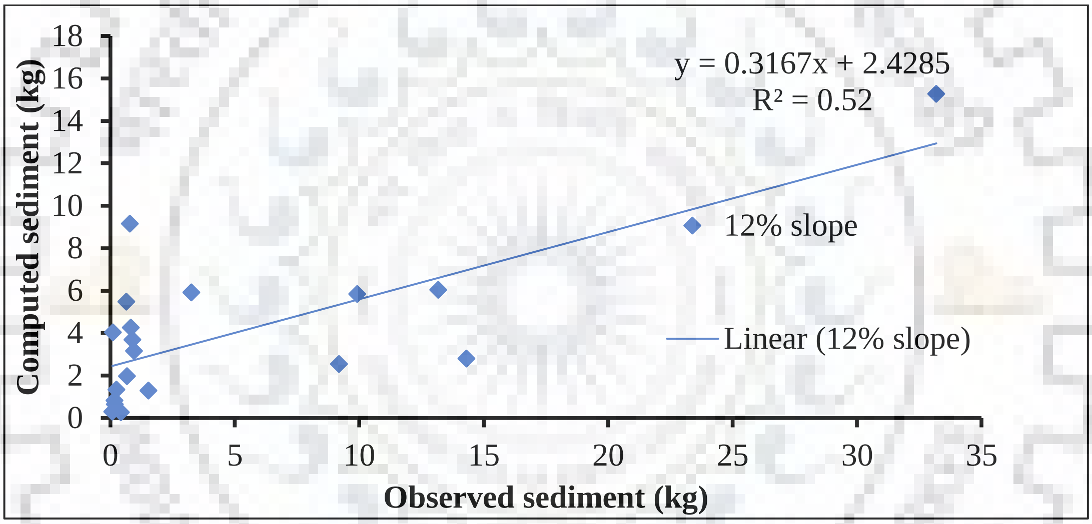

Figure 4.34 Comp. Vs Obs. Sediment yield of Finger millet 12% slopes

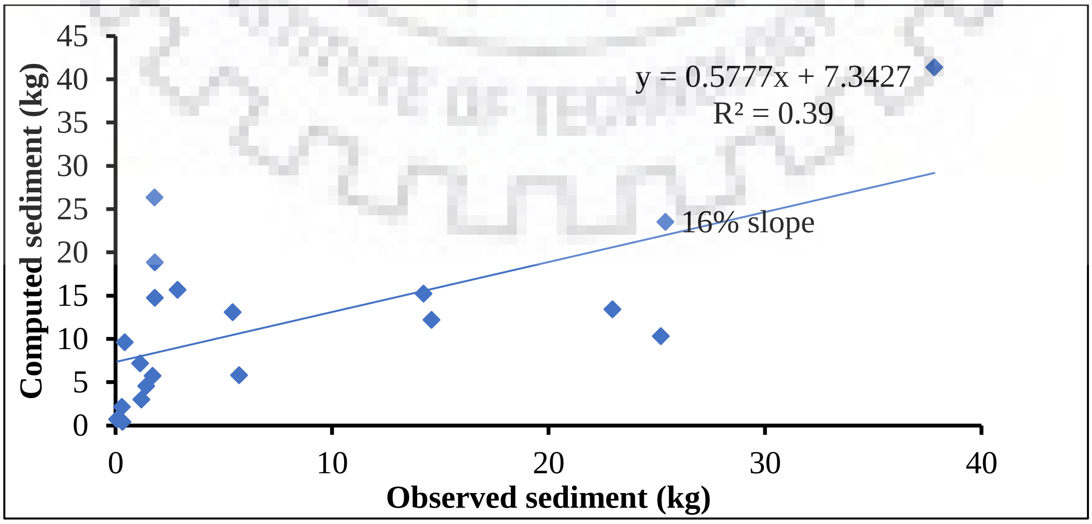

Figure 4.35 Comp. Vs Obs. Sediment yield of Finger millet 16% slopes

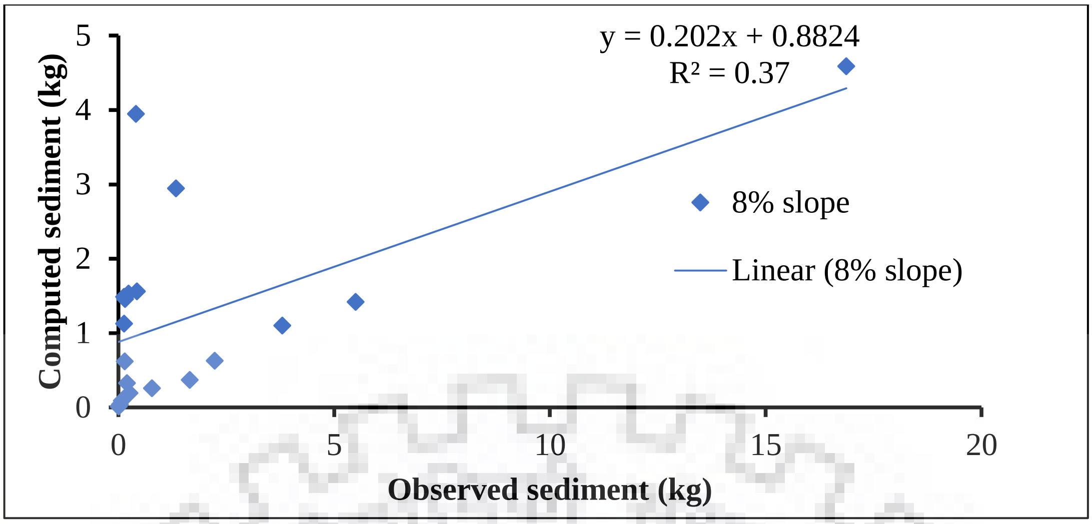

Figure 4.36 Comp. Vs Obs. Sediment yield of Fallow land 8% slopes

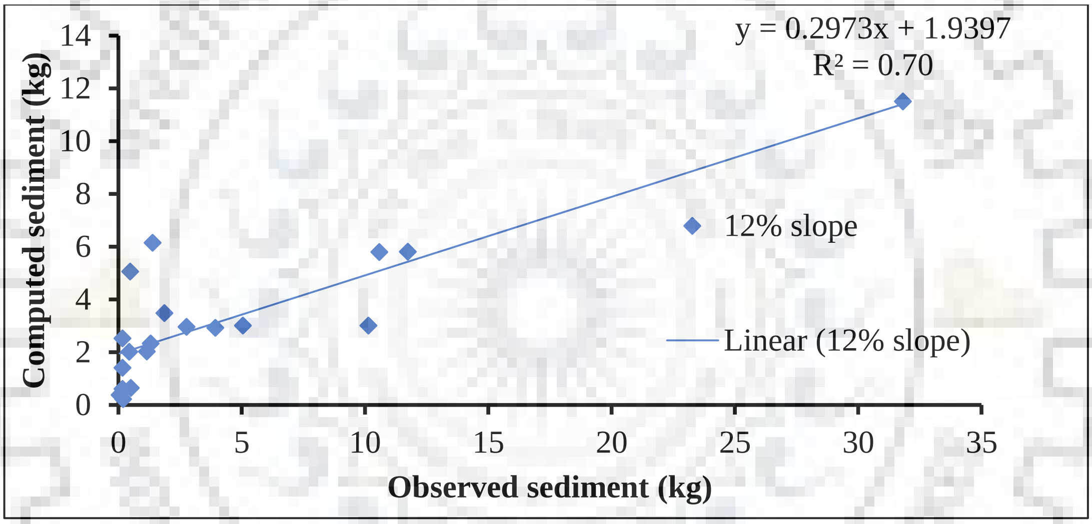

Figure 4.37 Comp. Vs Obs. Sediment yield of Fallow land 12% slopes

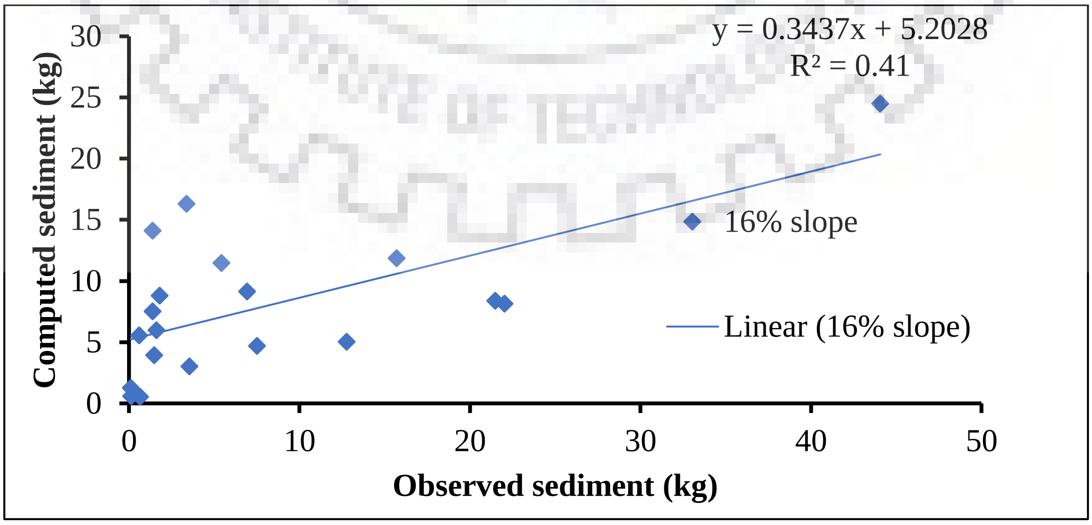

Figure 4.38 Comp. Vs Obs. Sediment yield of Fallow land 16% slopes

4.7 COMPARISON BETWEEN SEDIMENT YIELD BASED CN AND OBSERVED CN

Due to non-linearity between runoff and sediment yield, the CNs estimated for runoff may not be useful for sediment yield estimation. Keeping in view this fact, an effort has been made in this study to develop a correlation between CNs estimated by using sediment yield and runoff data for all the nine plots.

Rearranging of SCS-CN based sediment yield model (Eq. 2.14b) yields the expression for S as:

$$Y = \frac{Y_m P}{P+S} \tag{4.1}$$

$$S = \frac{Y_m P}{Y} - P \tag{4.2}$$

where Y_m= Potential sediment Yield (kg), P=Rainfall (mm), S=Maximum potential retention (mm) and Y= sediment Yield (kg). Eq. (4.2) is used to estimate CN using Eq. (2.6). The sediment yield based computed CN is compared with CN from NEH-4. The results are shown in Tables 4.22, 4.23 and 4.24 and Figures 4.39, 4.40 and 4.41 The relation between CNs (computed using SCS-CN method and NEH-4 table) is satisfactory as the coefficient of determination (R^2) for maize, finger millet and fallow land are found to be 0.97, 0.99 and 0.97, respectively.

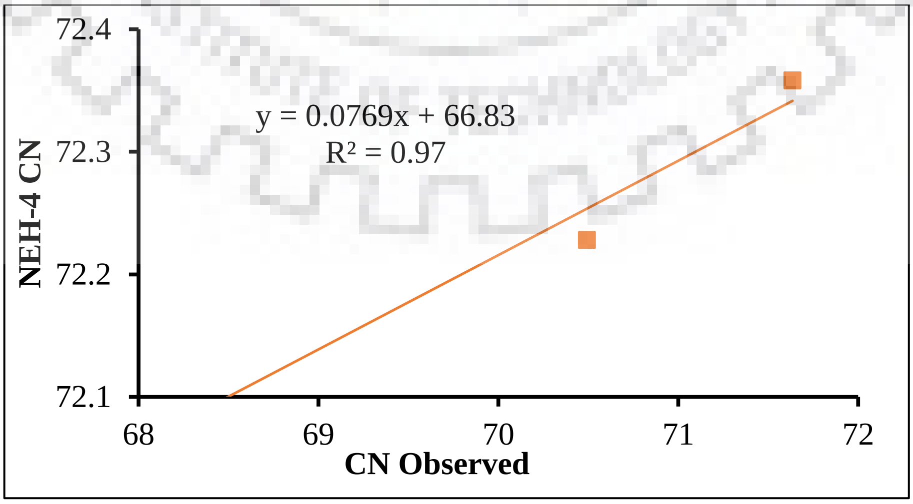

Figure 4.39 NEH-4 CN vs CN observed of Maize Crops

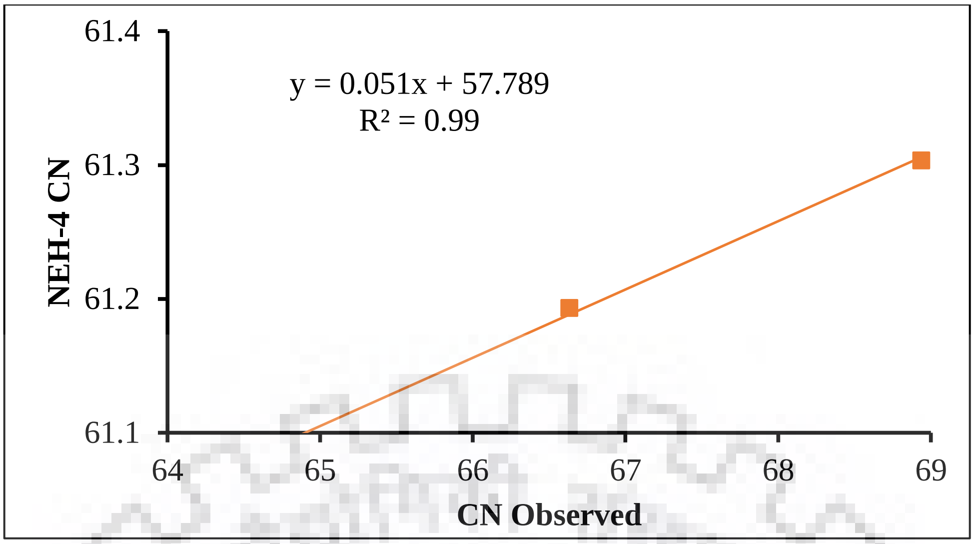

Figure 4.40 NEH-4 CN vs CN observed of Finger Millet

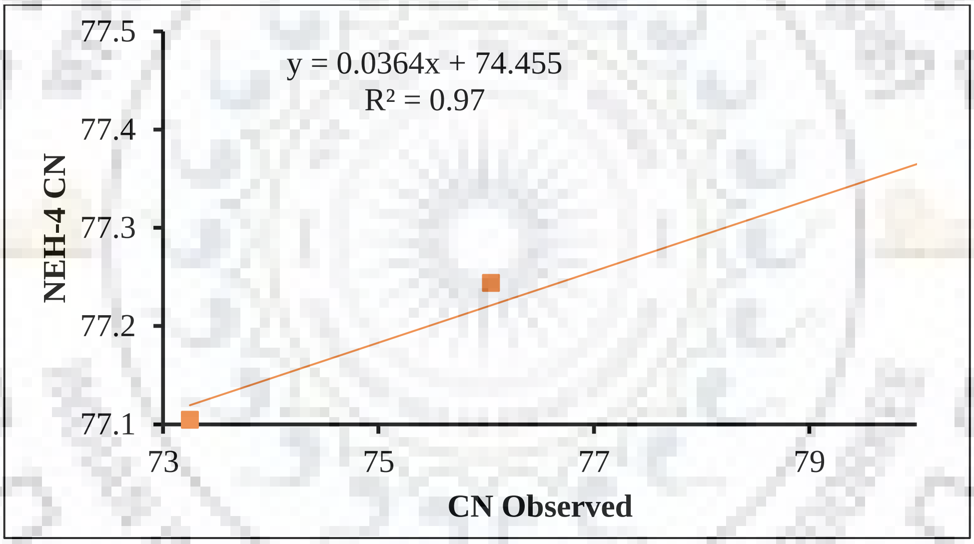

Figure 4.41 NEH-4 CN vs CN observed of Fallow Land

Table 4.22: Computed CN using sediment yield data: Maize crops

E.N.	Natural Event Date	Rainfall (mm)	Maize @ Slope 8%				Maize @ 12%Slope				Maize @16% Slope			
			Potential S.Y. (kg)	S.Y. Obs. (kg)	S	CN	Potential S.Y. (kg)	S.Y. Obs. S.Y.(kg)	S	CN	Potential S.Y. (kg)	S.Y Obs. (kg)	S	CN
1	19-Jun-17	44.00	2.99	3.03	-0.66	100.0	8.44	10.12	-7.34	100.0	22.43	23.01	-1.11	100.0
2	26-Jun-17	34.20	2.96	2.65	4.05	98.4	7.59	8.29	-2.88	100.0	13.73	13.88	-0.39	100.0
3	28-Jun-17	75.20	33.65	20.76	46.67	84.5	50.00	27.23	62.91	80.1	32.99	40.17	-13.44	100.0
4	29-Jun-17	17.70	3.65	0.76	67.30	79.1	2.70	2.28	3.26	98.7	3.73	4.42	-2.76	100.0
5	30-Jun-17	15.00	4.22	0.35	168.34	60.1	2.54	0.56	52.42	82.9	5.86	2.62	18.61	93.2
6	6-Jul-17	36.40	3.05	2.62	6.05	97.7	8.32	8.98	-2.69	100.0	12.74	14.04	-3.36	101.3
7	24-Jul-17	14.00	0.07	0.05	3.94	98.5	0.91	0.54	9.31	96.5	2.10	0.30	83.97	75.2
8	2-Aug-17	79.50	4.93	4.98	-0.79	100.0	11.03	10.87	1.15	99.5	19.14	25.61	-20.07	100.0
9	3-Aug-17	9.60	0.25	0.03	66.21	79.3	0.74	0.07	87.45	74.4	1.75	0.02	994.01	20.4
10	7-Aug-17	27.40	3.20	0.32	247.24	50.7	5.89	0.83	166.02	60.5	12.20	1.64	176.97	58.9
11	10-Aug-17	43.40	3.07	0.77	128.46	66.4	7.28	2.56	80.18	76.0	17.60	4.53	125.24	67.0
12	19-Aug-17	22.30	0.34	0.07	93.84	73.0	2.19	0.21	207.86	55.0	3.93	1.13	55.32	82.1
13	22-Aug-17	58.10	4.57	0.56	412.34	38.1	8.02	1.26	311.80	44.9	20.83	5.40	166.02	60.5
14	23-Aug-17	15.50	0.28	0.04	101.75	71.4	0.50	0.10	60.48	80.8	2.61	0.36	97.92	72.2
15	25-Aug-17	61.80	5.17	0.55	514.90	33.0	9.84	0.93	594.18	29.9	24.72	2.51	547.01	31.7
16	1-Sep-17	44.00	2.13	0.22	377.45	40.2	5.12	0.80	235.95	51.8	16.55	2.18	289.40	46.7
17	1-Sep-17	23.00	2.41	0.12	437.01	36.8	5.31	0.12	963.07	20.9	9.95	1.50	129.19	66.3
18	2-Sep-17	61.10	3.96	1.00	182.09	58.2	8.68	1.43	309.78	45.1	9.76	1.62	306.27	45.3
19	3-Sep-17	26.00	3.28	0.16	509.70	33.3	3.42	0.24	345.74	42.4	7.87	0.51	375.90	40.3
Avg.CN						**68.35**				**70.49**				**71.64**

Table 4.23: Computed CN using sediment yield data: Finger Millet

E.N.	Natural Event Date	Rainfall (mm)	Finger millet @ 8% slope				Finger millet @ 8% slope				Finger millet @ 8% slope			
			Potential S.Y. (kg)	S.Y. Obs. (kg)	S	CN	Potential S.Y. (kg)	S.Y. Obs. (kg)	S	CN	Potential S.Y. (kg)	S.Y. Obs. (kg)	S	CN
1	19-Jun-17	44.00	1.83	1.66	4.5	98.3	5.2	14.3	-27.9	100.0	14.9	25.2	-18.1	100.0
2	26-Jun-17	34.20	1.69	1.32	9.4	96.4	4.5	9.2	-17.4	100.0	15.1	14.6	1.2	99.5
3	28-Jun-17	75.20	17.80	16.18	7.6	97.1	19.6	33.2	-30.8	100.0	44.8	37.8	13.8	94.9
4	29-Jun-17	17.70	3.44	0.80	58.0	81.4	2.3	1.5	8.6	96.7	7.3	5.7	4.8	98.1
5	30-Jun-17	15.00	2.06	0.48	49.6	83.7	2.9	0.7	48.3	84.0	6.7	1.7	44.1	85.2
6	6-Jul-17	36.40	1.98	2.16	-3.0	101.2	8.2	13.2	-13.7	100.0	17.8	14.2	9.2	96.5
7	24-Jul-17	14.00	0.35	0.12	26.4	90.6	0.7	0.4	8.2	96.9	1.1	0.3	34.4	88.1
8	2-Aug-17	79.50	3.35	2.67	20.2	92.6	10.4	9.9	3.9	98.5	21.5	23.0	-4.9	100.0
9	3-Aug-17	9.60	0.06	0.01	43.0	85.5	1.4	0.2	66.1	79.4	3.1	0.3	93.7	73.0
10	7-Aug-17	27.40	2.97	0.18	433.4	37.0	6.9	0.6	267.9	48.7	15.5	1.8	207.1	55.1
11	10-Aug-17	43.40	3.57	0.25	581.8	30.4	8.6	3.3	71.7	78.0	19.4	2.9	250.1	50.4
12	19-Aug-17	22.30	0.17	0.04	65.3	79.5	1.5	0.2	164.4	60.7	5.2	1.2	74.9	77.2
13	22-Aug-17	58.10	2.24	0.07	1791.5	12.4	7.6	0.8	477.2	34.7	19.1	5.4	147.5	63.3
14	23-Aug-17	15.50	0.32	0.03	140.6	64.4	0.8	0.1	136.9	65.0	1.7	0.1	342.6	42.6
15	25-Aug-17	61.80	4.47	0.55	442.4	36.5	13.0	0.8	964.0	20.9	31.0	1.8	1000.1	20.3
16	1-Sep-17	44.00	1.45	0.17	331.7	43.4	5.7	1.0	216.5	54.0	8.6	1.4	222.2	53.3
17	1-Sep-17	23.00	2.04	0.16	275.4	48.0	5.3	0.1	1149.5	18.1	9.2	1.1	164.3	60.7
18	2-Sep-17	61.10	4.62	0.38	680.8	27.2	7.0	0.9	418.5	37.8	24.8	1.8	771.6	24.8
19	3-Sep-17	26.00	0.89	0.03	884.7	22.3	2.7	0.2	256.5	49.8	11.6	0.4	692.4	26.8
Avg.CN						**64.6**				**66.63**				**68.9**

Table 4.24 Computed CN using sediment yield data: Fallow Land

E.N.	Natural Event Date	Rainfall (mm)	Fallow Land @ Slope 8%				Fallow Land @ 12%Slope				Fallow Land @16% Slope			
			Potential S.Y. (kg)	S.Y. Obs. (kg)	S	CN	Potential S.Y. (kg)	S.Y. Obs. (kg)	S	CN	Potential S.Y. (kg)	S.Y. Obs. (kg)	S	CN
1	19-Jun-17	44.00	1.42	2.24	-16.1	100.0	5.2	10.1	-21.5	100.0	11.1	22.0	-21.9	100.0
2	26-Jun-17	34.20	0.91	1.66	-15.5	100.0	4.8	5.1	-1.9	100.0	7.4	12.8	-14.4	100.0
3	28-Jun-17	75.20	6.64	16.87	-45.6	100.0	14.3	31.8	-41.3	100.0	27.6	44.1	-28.1	100.0
4	29-Jun-17	17.70	0.58	0.78	-4.5	100.0	3.7	2.8	5.9	97.7	5.5	7.5	-4.8	100.0
5	30-Jun-17	15.00	0.65	0.20	33.6	100.0	2.7	0.4	76.5	76.9	3.9	3.5	1.4	99.4
6	6-Jul-17	36.40	2.37	5.50	-20.7	100.0	7.5	10.6	-10.6	100.0	13.1	15.7	-6.0	100.0
7	24-Jul-17	14.00	0.13	0.04	36.4	87.5	0.6	0.2	26.1	90.7	1.2	0.6	12.3	95.4
8	2-Aug-17	79.50	2.49	3.80	-27.3	100.0	9.8	11.7	-13.2	100.0	13.7	21.5	-28.7	100.0
9	3-Aug-17	9.60	0.05	0.01	47.0	84.4	0.8	0.1	127.7	66.5	1.9	0.1	144.1	63.8
10	7-Aug-17	27.40	2.22	0.14	419.1	37.7	3.4	1.2	52.7	82.8	7.6	1.6	100.7	71.6
11	10-Aug-17	43.40	2.64	0.24	432.7	37.0	5.1	3.9	12.3	95.4	13.7	5.4	66.3	79.3
12	19-Aug-17	22.30	0.50	0.26	20.7	92.5	1.4	0.5	40.3	86.3	5.4	1.5	58.4	81.3
13	22-Aug-17	58.10	2.93	0.44	333.1	43.3	9.2	1.4	325.4	43.8	13.2	6.9	52.2	82.9
14	23-Aug-17	15.50	0.26	0.08	33.1	88.5	1.2	0.2	92.4	73.3	1.3	0.1	147.2	63.3
15	25-Aug-17	61.80	5.62	0.41	779.4	24.6	8.2	0.5	1004.0	20.2	17.9	1.4	732.3	25.8
16	1-Sep-17	44.00	1.41	0.15	375.0	40.4	4.4	1.3	101.1	71.5	11.6	1.8	240.2	51.4
17	1-Sep-17	23.00	2.05	0.16	270.7	48.4	3.7	0.2	464.7	35.3	8.1	1.4	112.7	69.3
18	2-Sep-17	61.10	4.60	1.33	149.4	63.0	6.4	1.9	145.8	63.5	19.6	3.4	293.0	46.4
19	3-Sep-17	26.00	1.81	0.14	315.2	44.6	2.6	0.2	369.5	40.7	7.1	0.6	285.0	47.1
Avg.CN						**73.25**				**76.04**				**80.74**

CHAPTER V

SUMMARY AND CONCLUSIONS

The Soil Conservation Service Curve Number (SCS-CN) method has been widely used worldwide to model rainfall–runoff processes. It is a simple and an empirical hydrological model for estimation of direct surface runoff from a given rainfall event. While applying the SCS-CN method, the parameter CN is usually determined from NEH-4 Tables using two inputs mainly soil types and land use/land cover (LULC). However, the hydrological response of a watershed is affected by several other parameters such as soil moisture condition, soil type/infiltration characteristics, watershed slope. Other than these parameters, the watershed slope is one of the important parameters, which effects the estimation of direct surface runoff depth to a larger extent. Recently, the SCS-CN method has also been utilized for modelling watershed sediment yield by coupling with widely used erosion models such as USLE and RUSLE.

The SCS-CN method was developed by United State Department of Agriculture (USDA) and is being utilized around the world. However, its performance for small experimental catchments varying in land use/land cover, watershed slope and AMC conditions has not been tested in Indian conditions. Secondly, the applicability of the MUSLE model with the SCS-CN has not been tested for sediment yield modelling. The study was conducted in experimental farm having three different land uses (maize and finger millet crops and fallow land) and three different land slopes (8%, 12% and 16%) to find the answer of the research questions.

While conducting the study, an extensive data was collected by experimentation. Tests were conducted for estimation of soil infiltration rate of all the nine plots. The soil moisture before the storm event was estimated using TDR 300 with 20 cm probe. The soil samples were also collected for particle size analysis. The sediment samples were collected from all nine plots and these were analysed in WRDM laboratory for estimation of suspended sediment concentration.

The impacts of watershed slope, antecedent soil moisture, and land use/land cover was examined for behavioural pattern of CN and resulting runoff. The existing SCS-CN model was applied for estimation of watershed runoff. As far as sediment yield modelling is concerned, a simplified coupling of SCS-CN and MUSLE model has been proposed and tested for its applicability utilising the storm generated sediment yield data of nineteen events. The performance of the models was tested using goodness-of-fit statistics in terms of NSE, RMSE and PBIAS.

Due to non-linearity between runoff and sediment yield, the CNs estimated for runoff cannot be used for sediment yield estimation. Keeping this in view, a correlation between CNs estimated is developed using sediment yield and runoff data for all nine plots. The developed relationships can be directly used for estimation of CNs for application in sediment yield estimation by using the CNs obtained from observed rainfall-runoff data.

The following conclusion are drawn from this study.

1. Land use affects the runoff and CN depending upon the coverage of land. Fallow land produces higher runoff with higher CN than do Maize and Finger millet crops.

2. A very good agreement was observed between computed and observed runoff showing high R2 (>0.96) for all crops. The Nash Sutcliffe Efficiency (NSE) was found to be 90.57%, which is very good. Similarly, RMS and PBIAS were 0.37 and -17.34%, respectively, indicating a good fit.

3. For all land uses and slopes, as runoff increases, sediment yield increases, and vice versa.

4. Fallow land produces more yield than do Maize crops and Finger millet. Thus, as the coverage of land increases sediment yield decreases, and vice versa.

5. The MUSLE coupled SCS-CN model performed very well in predicting sediment yield from small experimental plots. NSE of the proposed model was 60.55% with RMSE and PBIAS as 0.41 and -14.47%, respectively. According to the criteria of (Moriasi et al., 2007), the model performance can be rated as ‘Good’.

6. The relationship developed between CNs (computed using sediment yield) and NEH-4 Table is useful and can be applied for estimation of CNs for given NEH-4 Table CNs to be applied for estimation of sediment yield using SCS-CN method. R^2 for Maize, Finger millet and Fallow land are 0.97, 0.99 and 0.97, respectively, which indicate satisfactory fits.

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