EFFECT OF LAND USE ON CURVE NUMBER IN STEEP WATERSHED

A DISSERTATION

Submitted in partial fulfillment of the
requirements for the award of the degree
of
MASTER OF TECHNOLOGY
in
WATER RESOURCE DEVELOPMENT (CIVIL)

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CANDIDATE’S DECLARATION

I hereby declare that the job, which is being presented in **DISSERTATION** entitled, **“EFFECT OF LAND USE ON CURVE NUMBER IN STEEP WATERSHED”**, in partial fulfillment of the requirements for the award of the degree of Master of Technology in “Water Resource Development (Civil)”, submitted to the Department of Water Resources Development and Management, Indian Institute of Technology Roorkee, India, is a genuine record of my work carried out during a period from June 2017 to May 2018 under the guidance of Dr. S.K. Mishra, Professor and Head of Department, Department of Water Resources Development and Management, and Dr. P.K. Singh, Scientist C, WRSD, National Institute of Hydrology (NIH), 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

This is to certify that the above statement made by the candidate is correct to the best of our knowledge.

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ABSTRACT

Runoff is an important and valuable variable used in the planning of water resources and design of hydraulic structures. A number of models have been developed to calculate runoff from a rainfall event. The Soil Conservation Service Curve Number (SCS-CN) methodology is one of the most widely accepted event-based methods and is extensively used for estimation of surface runoff for a known precipitation event from small ungauged agricultural watersheds. The model is satisfactorily established in hydrologic engineering. The main cause for its wide applicability lies in the fact that it is easy to use and it incorporates major runoff generation watershed characteristics: soil type, land use, surface condition and AMC. The only parameter required for methodology, the curve number CN is critical for exact runoff prediction.

According to the SCS-CN concept, the runoff quantity agricultural watershed depends on the above four major watershed characteristics. The CN values resulting from exhaustive investigations in the United States for all soil and land uses have been investigated and reported in National Engineering Handbook Chapter-4 (NEH-4). Since the initiation of SCS-CN method, only a few or no efforts appear to have been made to justify curve number rationality to watersheds in other countries. The slope was excluded in its original development and it is included as a factor in the recently developed new models. Investigations were carried out on agricultural plot of size (12.0mx3.0m) located Toda Kalyanpur, Uttarakhand, India to calculate the effect of slope, soil type, AMC and land use on the runoff and runoff curve number in selected 3 grades of 8%, 12% and 16% with same hydrologic soil group (HSG) 'A'. There were 9 plots of 3 land uses as maize, finger millet, and fallow lands for investigation.

As expected, the conclusion of land use on runoff curve number was such that the fallow lands showed the largest runoff and the CN values. With the increase of slope, the CN and runoff quantity increased and it was highest for 16% slope and fallow land. The soil was the same for all experimental plots, i.e. HSG-A. The SCS-CN parameter potential maximum retention (S) showed an inverse relation with the measured AMC value.

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GLOSSARY

A = Potential Soil Erosion; hydrologic soil group

AMC = Antecedent moisture condition (AMCI for dry, AMC II for normal and AMC III for wet condition).

B = hydrologic soil group category

C = hydrologic soil group category

D = hydrologic soil group category

CN = Curve Number

CN_2 = CN Value for AMC II

$CN_{2\alpha}$ = Slope-Adjusted CN for AMC II with slope α

f = Infiltration rate

f_c = Minimum infiltration rate

M = Soil moisture

mm = Millimeter

NEH-4 = National engineering handbook, Section-4 (Hydrology)

NRCS = Natural resources conservation service

P = Precipitation (Rainfall)

P_5 = 5-day antecedent rainfall

Q = Surface runoff

Q_{obs} = Observed direct surface runoff

Q_{comp} = Computed direct surface runoff

S = Potential maximum retention

λ = Initial abstraction coefficient

SCS = Soil Conservation Service

SCS-CN = Soil conservation service curve number

USDA = United States Department of Agriculture

VWC = Volumetric Water Content

SVL = Soil-Vegetation and Land use/land cover

θo = Antecedent moisture content

TDR = Time Domain Reflectometer

AGNPS = Agricultural Non-Point Source Pollution Model

SWAT = Soil and Water Assessment Tool

1.1 BACKGROUND

Hydrology is the science that concerns with the existence, distribution, and motion of water on the surface of the earth in space and time. Hydrologists and engineers are much focused with the estimation of runoff generated from a rainfall event. It requires in all respect whether it is for flood forecast or flood restriction or water sources assessment or design of hydraulic structures. The runoff is the principal parameter for evaluation of water yield potential of a watershed. The runoff is a function of many variables e.g. rainfall duration and intensity, soil moisture, land use, land cover, soil type and slope of the area. Thus, it depends on climatic as well as the physiographic condition of the watershed.

For runoff computation from a given precipitation, there are many more models available, but probably most used method is Soil Conservation Service Curve Number (SCS-CN) renamed as Natural Resources Conservation Service Curve Number (NRCS-CN) method. It is because almost all methods are for gauged watershed having the complicated type of access and involvement of so many variables. The SCS-method is easy and appropriate to the ungauged watershed for which least hydrologic information is needed. The SCS-CN method was first developed by Soil Conservation Service (now known as Natural Resources Conservation Service, NRCS) of United States, Department of Agriculture (USDA) in 1954 and documented in National Engineering Handbook, Hydrology Section-4 in 1956, popularly known as SCS-CN, NEH-4. The current version of NEH-4 is NEH 630 (USDA, NRCS 2003). The SCS-CN method is well accepted for calculating surface runoff from small agricultural watershed because of its limited number of parameters, i.e., only one parameter CN (Ponce and Hawkins, 1996).

The SCS-CN method converts the given rainfall into a runoff by using only parameter CN which constitutes the potential runoff of watershed distinguished by hydrological soil group (HSG), land use and treatment, surface condition and antecedent moisture condition (AMC) (Mishra and Singh, 2003a). The SCS-CN method is based on the water balance Equation and two basic hypotheses. The first proportionality concept of model relates the two orthogonal hydrological procedures of surface water and sub-surface water and the second hypothesis concerns the atmospheric process. Qualitatively, the model completely integrates all 3 vital procedures of the hydrological cycle and hence forms one of the important basic concepts of hydrology (Mishra et al., 2012).

SCS-CN method was developed in the US by carrying out complete field examination for the principal purpose of soil conservation which was mandatory to conduct under the Public law 83-566. Runoff CN (NRCS-CN, NEH-4) was derived for almost all land uses, soil types, hydrologic conditions (SCS 1964; Chow et al. 1988). However, because of its simplicity and representation of all watershed characteristics by a single parameter, the execution of CN procedure leads to the number of interpretations and confusions (Hawkins 1979; Bonzay 1989; Hjelmfelt 1991; Pilgrim and Cordery 1993). The main difficulties in the application of the SCS-CN method are the classification of HSG and determination of AMC.

Basically, SCS-CN was developed for US conditions but it is being used worldwide along with many types of research for sorting out limitations. Besides the computation of runoff, it is also used in the estimation of soil erosion and sediment yield, environment, and water quality.

Also, CN relies on land use, HSG and AMC. According to various infiltration tests conducted in the USA, soils were divided into four HSG (A to D) on the basis of their least infiltration capacity (SCS, 1986). Soil type A indicates the largest infiltration capacity, and D the least (Yan, et al., 2013). Soil depth, percolation& drainage conditions under surface also affect runoff response (Kusumasturi et al., 2007).

Despite its simplicity, the execution of CN methodology leads to a diversity of explanations and doubt due to ignorance about its drawbacks (Hawkins, 1979; Bonzay, 1989; Hjelmfelt, 1991; Pilgrim &Cordery, 1993). Complexities are mostly related to the categorization of soil group derived for US and determination of AMC which is the key of watershed wetness (Chaudhary et al., 2013). Additionally, the method does not incorporate for the effects of slope on CN and runoff. However, few methods (Sharpley and Williams, 1990, and Huang et al., 2006) integrating the slope to adjust CN for better runoff value (Huang et al., 2006) have been reported in the hydrologic literature.

AMC is calculated according to the 5-day rainfall just before event rainfall. Three types of AMC, viz., AMCI (dry), AMCII (normal) and AMC III (wet), are based on the cumulative probability of exceedance of runoff depth. Statistically, 90%, 50% and 10% cumulative probability correspond to AMCI (dry), AMCII (normal) and AMC III (wet), respectively. The effect of land use on climate or habitat loss (affecting biodiversity), the linkage between land use difference and the hydrological response has been the subject of intensive research by many researchers since 1960s (Yan et al., 2013).

Keeping in view the above, this research has been formulated to study the impacts of land slope on curve number and runoff generated from small experimental plots. The experiment plots include 3 land slopes 8%, 12%, and 16% and with different land uses. The runoff was calculated at the outlet of each plot separately. The runoff CN is calculated from the observed precipitation and runoff data for all slopes and plots. The experiment envisages investigating the effect of soil, land use, AMC and slope of the land on CN and runoff.

1.2 OBJECTIVES OF THE STUDY

The main objectives of this research work are as follows:

(a) To investigate the effects of land use on watershed runoff for steep slopes.
(b) To investigate the effects of watershed slope on CN and runoff.
(c) To test the performance of the slope adjusted SCS-CN method in predicting runoff from different land uses and slopes.

1.3 ORGANIZATION OF DISSERTATION

The contents of dissertation report are split into 6 chapters, as below:

Chapter 1:	It briefly introduces the SCS-CN methodology with objectives of the dissertation.
Chapter 2:	It gives a literature review on the topic.
Chapter 3:	It describes the site of experiment and data collection.
Chapter 4:	It describes the methodology carried out for the experiment and procedure to accomplish the work.
Chapter 5:	It analyses the data and discusses the result.
Chapter 6:	It summarizes and concludes the study.

2.1 SOIL CONSERVATION SERVICE CN (SCS-CN) METHOD

The SCS-method was established in 1954 by USDA Soil Conservation Service (Rallison, 1980). It was published in Soil Conservation Service (Now called Natural Resources Conservation Service, NRCS) National Engineering Handbook (NEH), Section-4 in 1956. Since then, it has been reviewed a number of times in 1964, 1965, 1971, 1972, 1985 and 1993. It is the most widely accepted and used model for estimating the runoff depth for a known precipitation depth from small watersheds like agricultural, forest and urban. This method is simple to understand and apply, stable and convenient for ungauged watersheds. Its implementation and acceptability have been increasing continuously because it considers almost all runoff producing watershed characteristics: soil type, land use/treatment, surface condition and AMC and these are integrated by an index CN, which the parameter of the SCS-CN methodology.

2.2 HISTORICAL PERSPECTIVE

The era of the 1930s and 1940s are supposed to be the origination of Curve Number methodology. Thousands of infiltrometer experiments were conducted in the late 1930s and early 1940s. The objective was to enhance primary data to find out the effects of watershed treatment and soil conservation measures on the rainfall-runoff procedure (Ponce and Hawkins, 1996). Flood protection Act 1954 was the main driver to develop and implement CN methodology in the United States.

Sherman (1942, 1949) had suggested relationship representing direct runoff versus storm precipitation. Building on this idea, Mockus (1949) found that the runoff from the ungauged areas depends on information on soils, land use, precipitation, storm duration and average annual temperature. Moreover, he integrated these elements into an empirical variable ‘b’ and gave a relationship between P and Q (Rallison, 1980) as:

$$Q = P\,(1-10^{-bP}) \qquad \text{(Equation 1)}$$

Andrew (1954) grouped infiltration data gathered from the different States of US and using soil texture as a soil characteristic. He eventually produced a graphical rainfall-runoff model by considering the soil texture type and quantity of surface cover and conservation practices, which were compiled into what is referred to as soil-cover complex or soil-vegetation-land use (SVL) complex (Miller and Cronshey, 1989). Subsequent to the evolution of this model along with other methods elsewhere, it was recognized that there is a need for such type of method which could be used nationally and is appropriate to the ungauged watershed. To that end, according to Rallison and Miller (1982), the methods of Mockus (1949) and Andrew (1954) were transformed and generalized to yield the present SCS-CN methodology, for which CN parameter values are presented in NEH-4 (Hydrology, 1985).

2.3 THEORETICAL PERSPECTIVE

The SCS-CN method is developed using the water balance Equation and two primary hypotheses. The first hypothesis equalizes the proportion of the actual quantity of direct surface runoff (Q) to the total precipitation (P) (or maximum potential surface runoff) to the proportion of the quantity of actual infiltration (F) to the quantity of the potential maximum retention (S). The second hypothesis relates the initial abstraction (Ia) to the potential maximum retention (S). Thus, the SCS-CN model consists of water balance Equation:

$$P = Ia + F + Q \qquad \text{(Equation 2)}$$

Proportional equality (first hypothesis)

$$\frac{Q}{(P-Ia)} = \frac{F}{S} \qquad \text{(Equation 3)}$$

Ia-S relationship (second hypothesis)

$$Ia = \lambda S \qquad \text{(Equation 4)}$$

The values of P, Q and S are given in-depth dimensions while the initial abstraction coefficient λ is dimensionless. Though the indigenous method was established in US accepted units (in.), the suitable conversion to SI units (cm) is possible (Ponce, 1989). In a particular case, the small quantity of precipitation is abstracted initially as interception, infiltration surface holding and evaporation before runoff starts and sum of these is known as initial abstraction. The fundamental hypothesis is originally a proportionality concept (Mishra and Singh, 2003a), as shown in Figure 2.1. Apparently as Q→ (P-Ia), F→ S. This proportionality validates dividing (P-Ia) into 2 components: surface water Q and sub-surface water F for known watershed characteristics.

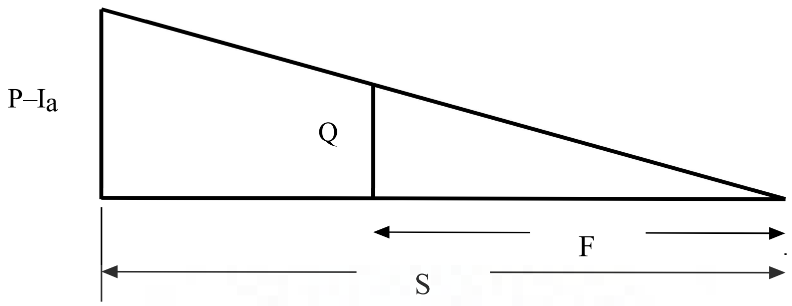

Figure 2. 1 Proportionality concept of the existing SCS-CN

The second hypothesis is a linear relationship between initial abstraction Ia and potential maximum retention S. The parameter S of the SCS-CN method relies on soil type, land use, hydrologic condition and AMC. The initial abstraction coefficient λ is routinely viewed as a regional parameter depending on geological and environmental factors (Bosznay, 1989; Ramsastri and Seth, 1985). The existing SCS-CN model assumes λ = 0.2 for pragmatic applications. Many other studies carried out in the US and other countries (SCS, 1972; Springer et al, 1980; Cazier and Hawkins, 1984; Ramsastri and Seth, 1985; Bosznay, 1989) report λ to vary in the range of (0, 0.3). However, as initial abstraction factor holds for the fewer time losses for example interception, surface storage, and infiltration before runoff starts, λ may take any value from 0 to ∞ (Mishra and Singh, 1999a). A research of Hawkins et al. (2001) proposed that the value of λ = 0.05 yields good fit and would be better applicable for use in runoff estimation.

Coupling Equations (2) and (3), the expression for Q can be written as:

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

(Equation 5)

Equation (5) is the general form of the popular SCS-CN model and it is valid for P≥ Ia, Q= 0 otherwise.

For λ = 0.2, the coupling of Equations (2) & (3) gives Q as:

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

(Equation 6)

Equation (6) is the form of the SCS-CN method. Thus, the existing SCS-CN model with λ = 0.2 is a one-parameter model for calculating the runoff from storm event rainfall. Parameter S can range $0 \leq S \leq \infty$ and it has a dimension of length. The parameter CN covers in more appealing range $0 \leq CN \leq 100$ as:

$$S = \frac{25400}{CN} - 254 \quad \text{(Equation 7)}$$

where, S is in millimeter. The distinction between S and CN is that the former is a dimensional quantity (L) whereas the latter is dimensionless. CN = 100 means a state of zero potential maximum retention (S=0) that is an impervious watershed. Conversely, CN=0 means a theoretical upper bound to potential maximum retention ($S=\infty$). It is an infinitely porous watershed. However, the experimental design values justified by practical and knowledge fall in the range (40 to 98) (Van and Mullem, 1989). According to Hawkins (1978), CN has no basic meaning; rather it is only a suitable transformation of S to map on a 0 to100 scale. It is however in contrast to Mishra and Singh (2003) explaining CN as an index of representing a watershed to indicate the runoff-producing the potential for a given 10-inch of rainfall. For a given set of precipitation and runoff data, S can be estimated from Equation (8) as:

$$S = 5(P + 2Q - \sqrt{(Q (4Q+5P))} \quad \text{(Equation 8)}$$

Notably, the SCS-CN method does not take into account the effect of slope on runoff yield and, in turn, on the resulting CN. If Equation (7) is substituted in Equation (6), the resulting rainfall-runoff relationship can be expressed as Equation (9):

$$Q = \frac{(CN (P+2)-200)^2}{CN (CN (P-8) +800)} \quad \text{(Equation 9)}$$

With a measured rainfall-runoff event and an average CN value for a watershed, application of Equation (9) is covered by limits of $P > (200/CN) - 2$ and $Q = 0$ (Ponce and Hawkins, 1996).

Worldwide, many modifications for the enhanced performance of the SCS-CN method have been suggested and continuous research is still going on. Some of them are:

- Incorporation of the effect of the slope.
- Improvement in initial abstraction ratio λ.
- Incorporation of soil moisture accounting procedure to accommodate AMC.
- Accurate calculation of Ia.
- Introduction of depression storage.

- Evaporation and Evapotranspiration.
- Enhanced applications in advanced process-based models, such as SWAT, AGNPS, KINEROS, etc.
- Urban hydrological modeling applications
- Erosion and Sediment yield modeling
- Water quality and metal partitioning

2.4 ADVANTAGES AND LIMITATIONS OF CN METHOD

Advantages

- It is simple, predictable and stable conceptual/empirical model for estimation of runoff from given rainfall depth.
- It is easy to implement and most useful for ungauged watersheds.
- It depends only one parameter CN which is an element of watershed characteristics, such as HSG, land use, hydrologic surface condition and AMC.
- It is only agency methodology involving all environmental inputs.
- It is well accepted and established a method in the US and other countries.
- Though the model was primarily developed employing data of US geographical and climatic conditions, it is equally applicable to watersheds located elsewhere.
- Since the model does not involve watershed area in its formulation, it is conceptually applicable to any size watershed.
- Since the model does not incorporate time element in its formulation, the method is conceptually applicable to events of any duration. Here, it is noted that CN values reported in NEH-4 were derived for the storms of 24 hours or less, and therefore, these values need a reduction factor while employing to the events of longer duration.
- This model is perfectly suited for agricultural lands for which it was initially intended but extended to urban sites also.

Disadvantages

- The understanding of watershed AMC is not clear and this is a limitation of model applicability.
- This model is good for agricultural watersheds, fairly good for range and poor for forest sites (Hawkins, 1984, 1993).
- Provision for spatial and temporal scale effect requires more elaboration.

- Although initial abstraction coefficient (λ) is fixed at 0.2 for practical purposes, it needs to be established for individual watersheds.
- This model does not consider the slope of the study area.
- This model is more accurate for high precipitation values.
- Theoretically, CN ranges from 0 to 100. Practically, it is taken from 40 to 98 (Van Mullem, 1989).
- Despite the fact that the CN table is widely used, the values represented in the table are not documented (Hawkins and Ward, 1998) and tested to clarify the procedure (Hjelmfelt, 1980).

2.5 FACTORS AFFECTING CN

Principal watershed features that affect the SCS-CN parameter S or CN (Equation 4) should be addressed cautiously because SCS-CN method is a single key parameter, i.e. CN. Selection of CN from NEH-4 is an important task to carry out to obtain accurate runoff estimate from a known rainfall. Following are the main watershed features that affect the value of CN as:

- Hydrological soil group (HSG)
- Land Use/treatment
- Hydrologic condition
- Antecedent moisture condition (AMC)
- Initial abstraction and climate
- Geomorphology of the watershed
- Rainfall duration and intensity, turbidity etc.

The combination of soil type, vegetation cover, and land use/treatment is known as soil-vegetation-land use (SVL) complex (Miller and Cronshey, 1989). These characteristics primarily affect the infiltration potential of a watershed. Since it is easy to convert the CN runoff method to infiltration (Mishra and Singh, 2003), it has also been stated to be an infiltration loss method (Soni and Mishra, 1985).

2.5.1 Hydrological Soil Group (HSG)

The three basic characteristics of the soil are its texture, structure, and conductivity (permeability). The soil type of an area significantly affects its runoff potential. The soil is broadly classified as sand, silt, and clay according to its texture. Infiltration capacity of soil relies on the dimension of the pores in the soil grain. Soil water content is also a very important factor influencing the infiltration capacity. A loose conductive sandy soil will have higher infiltration capacity than tightly packed and poorly conductive clay.

The SCS-CN method has identified the soils in four HSG namely A, B, C and D according to their respective infiltration capacity and transmission. As soil type changes from group A to D, the runoff potential increases and hence CN increases. The classification as described by Mishra and Singh (2003a) is presented below.

2.5.1.1 Group A

The soil exhibiting highest infiltration capacity falls under this soil group. The infiltration rate is high even if they are fully wetted. They have less runoff potential. Such soils include primarily deep, well to excessively drained sands and gravels.

2.5.1.2 Group B

The soils which have average infiltration capacity when completely wetted and consist primarily of moderately deep to deep, moderately well to well-drained soils with fines, moderately fine to moderately coarse textures, e.g. shallow loess and sandy loam. The rate of transmission is moderate of these soils.

2.5.1.3 Group C

The soils in this group have less infiltration capacity when completely wetted. These soils originally consist of a layer that obstructs the flow of water below the surface. Such soils are of relatively fine to fine textured, e.g. clayey loam, shallow sandy loam, and such soils have low organic content. These soils exhibit a low rate of transmission and hence more rate of runoff field.

2.5.1.4 Group D

The soils falling in this group shows least infiltration capacity when they are fully wetted. Such soils are primarily clay soils of high swelling potential. Soils with constant water Table with a clay layer at or near the surface, shallow soil over the nearly impermeable material. These soils exhibit the least rate of transmission. The classification made in NEH-4 is based on the assumption that (a) soils are bare (b) maximum swelling takes place (c) precipitation rate exceeds infiltration rate.

The classification is based on the assumption that the soils that are similar depth, organic matter content, structure and degree of swelling when fully wetted will respond in an essential fashion during a storm of overly high rainfall intensities. The classification according to least infiltration rates is given in Table 2.1 (McCuen, 1982). The runoff increases from group A to group D.

Table 2. 1 Description of HSG based on infiltration rate (McCuen, 1982)

Hydrological soil group (HSG)	Minimum Infiltration Rate (inch/hr)
A	0.30 – 0.45
B	0.15 – 0.30
C	0.05 – 0.15
D	0 – 0.05

TR55 (USDA, SCS 1975, 1986) provides an easier criterion based solely on texture, (Brakensiek and Rawls, 1983):

Table 2. 2 Description of HSG based on texture

HSG	Texture
A	Sand, loamy sand, sandy loam
B	Silt loam or loam
C	Sandy clay loam
D	Clay loam, silty clay loam, sandy clay, silty clay or clay

(Source: Curve Number Hydrology: State of the Practice; Report of ASCE)

2.5.2 Land Use

The land use describes the surface condition of a watershed and corresponding to the portion of coverage which ultimately connects with infiltration capacity. It includes all kinds of vegetation, litter, and mulch and fallow and, in addition, non-agricultural uses for example water bodies, roads, roofs etc. It actually affects the rate of infiltration and ultimately runoff potential rate. Vegetated lands exhibit higher infiltration rate and hence generates less runoff amount than that in barren lands which have less infiltration capacity.

The watersheds may be divided into urban lands, agricultural lands and woods, and forest. The urban area has as low or negligible permeability. It includes residential areas, pitched parking lots, streets and roads, commercial and industrial areas, developing areas, open spaces including lawns, parks etc.

The agricultural or cultivated land uses are classified as fallow land, row crops, little grain crops, closed-seeded legumes meadow, pasture, and meadow. Fallow means are agricultural land having the highest potential runoff i.e. least infiltration rate. Planting the crops in rows on contours increases infiltration and hence decreases runoff. Woods are usually small isolated groves of trees hoist for farm use. Forest generally falls under major part of the watershed. Humus formed by decaying of fallen leaves make the soil porous and it increases the infiltration capacity and runoff is decreased. Small basins are very fragile to land use (Chow, 1964).

2.5.3 Land Cover/Treatment

Land treatment is a modification of the prevailing land cover. It describes the management of cultivated agricultural lands. It also includes mechanical practices such as contouring and terracing also management practices such as crop rotation and grazing control. Also, agricultural management systems involve different varieties of tillage (moldboard plough, chisel plough). Brakensiek and Rawls (1988) reported that moldboard plough increases soil porosity by 10 – 20 % depends on the texture of soil and ultimately increasing infiltration rate. Rawls (1983) concluded that more the pesticide-free matter in soil lowers the bulk density or more will be porosity and hence infiltration goes up and runoff potential goes down.

2.5.4 Hydrologic Condition

The hydrologic state of an agricultural land is defined as of proportion of grass coverage area. The larger area of grass coverage more will be the infiltration rates and consequently less potential runoff. More grass cover area will have high infiltration and soil degradation will be less and hence said to be in best hydrologic condition. With regards to grass coverage area, the watershed can be called as a good, poor, and fair watershed. The CN is more for the poor watershed area and conversely. Depending on the areal range of grassland or native pasture whole area may be divided into the categories as per Table 2.3.

Table 2. 3 Categorization of native pasture (Source: SCS, 1971)

S. No.	Vegetation condition	Hydrologic condition
1	Heavily grazed and no mulch or plant cover less than ½ of the area.	Poor
2	Not heavily grazed and plant cover less than ½ to ¾ of the area	Fair
3	Lightly grazed and plant cover more than 3/4 of the area	Good

2.5.5 Antecedent Moisture Condition

Antecedent Moisture Condition (AMC) is the dampness of the surface or quantity of moisture available in the soil profile or alternatively the degree of saturation before the start of the rainfall. If the soil is completely wetted, then the whole rainfall amount will directly convert into the runoff without infiltration loss and when the soil is fully dry, then the situation will be opposite. Hence the soil water condition of the area greatly influences the CN value. Based on the literature, AMC of soil can be identified by these three indices: antecedent precipitation index (API), antecedent base flow index (ABFI), and soil moisture index (SMI), (Mishra and Singh 2003). The NEH (SCS, 1971) uses the antecedent 5-day precipitation as API (Table 2.4) for AMC and it is normally used in practice.

AMC is divided into three levels: AMCI, AMCII and AMC III. AMCI condition mentions to dry soil condition, AMCII means the normal or average condition whereas AMC III is mentioned as a wet condition of the watershed. CN is lowest for dry (AMCI) soil and runoff potential are least also CN is highest for wet soil (AMC III) and runoff potential is highest.

The three AMC I, AMC III and AMC II conditions of the area statistically correspond to respective 90%, 10% and 50% cumulative probability of exceedance of depth of runoff for a known precipitation (Hjelmfelt et al., 1982). SCS (1956) provides Table authentic for AMC II (normal) condition and it could be converted into any of AMC I or AMC III condition as per Table 2.5.

Incorporation of AMC in the SCS-CN method with regard to 3 AMC levels allows an acceptable sudden jump in CN- variation. To avoid these issues, Mishra and Singh (2002a) suggested an SCS-CN based Equation to estimate the AMC from 5-day antecedent precipitation for calculation of runoff.

Table 2. 4 Antecedent moisture conditions (AMC)

AMC	Total 5-days antecedent rainfall (cm)	
	Dormant Season	Growing Season
I	Less than 1.3	Less than 3.6
II	1.3 to 2.8	3.6 to 5.3
III	More than 2.8	More than 5.3

Table 2. 5 AMC Conversion Formulas

Model	AMCI	AMC III
Sobhani (1975)	$\mathrm{CN_I} = \frac{\mathrm{CN_{II}}}{2.334 - 0.01334\mathrm{CN_{II}}}$	$\mathrm{CN_{III}} = \frac{\mathrm{CN_{II}}}{0.4036 + 0.005964\mathrm{CN_{II}}}$
Mishra et al. (2008)	$\mathrm{CN_I} = \frac{\mathrm{CN_{II}}}{(2.2754 - 0.012754\mathrm{CN_{II}})}$	$\mathrm{CN_{III}} = \frac{\mathrm{CN_{II}}}{(0.430 + 0.0057\mathrm{CN_{II}})}$
Hawkins et al. (1985)	$\mathrm{CN_I} = \frac{\mathrm{CN_{II}}}{2.281 - 0.01281\mathrm{CN_{II}}}$	$\mathrm{CN_{III}} = \frac{\mathrm{CN_{II}}}{0.427 + 0.00573\mathrm{CN_{II}}}$
Chow et al. (1988)	$\mathrm{CN_I} = \frac{4.2\mathrm{CN_{II}}}{10 - 0.058\mathrm{CN_{II}}}$	$\mathrm{CN_{III}} = \frac{23\mathrm{CN_{II}}}{10 + 0.13\mathrm{CN_{II}}}$
Neitsch et al. (2002)	$\mathrm{CN_I} = \mathrm{CN_{II}} - \frac{20(100 - \mathrm{CN_{II}})}{\{100 - \mathrm{CN_{II}} + \exp[2.533 - 0.0636(100 - \mathrm{CN_{II}}]\}}$	$\mathrm{CN_{III}} = \mathrm{CN_{II}}\exp\{0.00673(100 - \mathrm{CN_{II}})\}$

2.5.6 Initial Abstraction and Climate

Initial abstraction comprises 4 distinct processes viz. interception, surface detention, evaporation, and infiltration. When rainfall begins, some part of precipitation never reaches the ground; it is intercepted by leaves of trees. Some part is evaporated back into the atmosphere. Some precipitation that attains the ground just stores in a surface depression having no flow to the outlet. All the abstracted rainfall finally goes back to the atmosphere by evaporation (Mishra and Singh, 2003). SCS-CN method is established on the objective that the runoff starts only after fulfilling the initial abstraction of the area. Evaporation is firstly governed by a meteorological factor of the area, such as temperature, radiation, sunshine, wind, humidity etc. The effect of climate is also accounted for existing SCS-CN model by initial abstraction. Higher the amount of initial abstraction, lower will be the potential runoff and vice versa.

2.5.7 Rainfall Duration, Intensity, and Turbidity

For a given precipitation amount, the runoff will be higher for higher rainfall, and the reverse is also true. If the rainfall depth is constant, the greater the intensity of rainfall less will be the time duration and vice versa. Time of contact of rain with the ground is less in high-intensity rainfall and hence the chance for infiltration is less producing more runoff.

High rainfall intensity also breaks the composition of soil and forms a layer of fine soils which clogs the pores of the soil at its surface and thus reduces the rate of infiltration and ultimately, runoff is increased, and, in turn, CN is increased. That is why barren land yields higher runoff than covered land.

Turbidity refers to impurities of water that affect infiltration by the action of clogging of soil pores and accordingly affecting the soil conductivity. Polluted water with dissolved minerals such as salts affects the soil structures and infiltration rate is affected.

2.6 EFFECT OF WATERSHED SLOPE ON CN

The slope is a principal factor determining the runoff CN. However, SCS-CN method does not consider the effect of the slope of the area on runoff production. Since the SCS-CN method was developed in the USA for computing runoff from a given precipitation mild agricultural-cultivated watersheds, slopes were generally less than 5%. Also, it is assumed that within 5% slope, CN is not affected to a large extent.

Haggard et al. (2002) executed an experiment on small plots (1.5m x 3m) having silty loam soil on 11 slopes (0%-28% in northwest Arkansas, USA, and rainfall intensity of 70 mm/hr for an hour. They found that till slope of 15%, surface runoff expanded logarithmically with a slope of plots at which steeper slopes did not yield more runoff. In Pakistan, Shafiq and Ahmad (2001) studied on plots having silt loam with different slopes (viz. 1%, 5%, 10%) under average rainfall intensity and investigated that runoff occurred 11.2 %, 18.1% and 26.6% of the precipitation amount from the slope 1%, 5%,10% slopes, respectively. Although the watershed slope plays a major role in runoff generation, very few experiments have been conducted to include the slope factor into the CN model. Philip (1991) found a decrease in infiltration on sloping land. According to him, the infiltration from a slope of 58% homogeneous and isotropic Yolo clay soil was decreased by 15% compared with a horizontal surface. Using a recession time Equation given by Woolhiser et al. (1970) based on kinematic wave approximation, Event and Dutt (1985) established that recession time decreased by 59% when the slope was raised from 1 to 15%. The decreased recession time outcome in less opportunity time for infiltration and therefore come more runoff. Sharpley and Williams (1990) developed a relationship for slope-adjusted CN as:

$$CN2\alpha = 1/3\ (CN3-CN2)\ (1-2e^{-13.86\alpha}) + CN2 \qquad \text{(Equation 10)}$$

where, CN2and CN3 are the values given in the NEH-4 Table for AMC II and AMC III respectively, and α is the slope. Sharpley and Williams (1990) method assume that CN2 tabulated in the NEH-4 Table (SCS, 1972) corresponds to 5% slope. This relationship has also been incorporated in the SWAT model. Huang et al (2006) claimed that Equation (10) does not appear to get well known in the field. In China; Huang et al. (2006) studied the effect of slope on runoff under simulated precipitation for eleven years to modify the existing SCS-CN model for slope. They developed a slope adjusted CN Equation as follows:

$$CN2\alpha = CN2\ (322.79+15.63\alpha)/\ (\alpha+323.52) \qquad \text{(Equation 11)}$$

where, $CN2\alpha$ is the slope-adjusted CN, $CN2$ is CN value given in the NEH-4 Table for AMC II and α is the slope between 14 and 140%.

Ajmal et al (2016) suggested a model estimate CN adjusting slope along with initial abstraction ratio for event-based runoff estimation from mountainous watersheds. For the study, they collected measured data of thirty-nine South Korean steep sloped watersheds. During the investigation, the performance of the proposed model was compared with the models of Huang et al. (2006) and Sharpley and Williams (1990).

2.7 CN DETERMINATION METHODS

Although SCS-CN methodology is being used worldwide, accurate estimation of CN is a matter of concern among hydrologists and water resources community (Hawkins, 1978; Hjelmfelt, 1980; Chen, 1982; Ponce & Hawkins, 1996; Mishra & Singh, 2006). Primarily, CN was generated using daily rainfall-runoff records correspondent to the highest annual flows from gauged watersheds for which information on their soils, cover and hydrologic condition was available (SCS, 1972). The rainfall (P) and runoff (Q) data were plotted on the arithmetic paper having a grid of plotted CN as shown in Fig. 2.2.

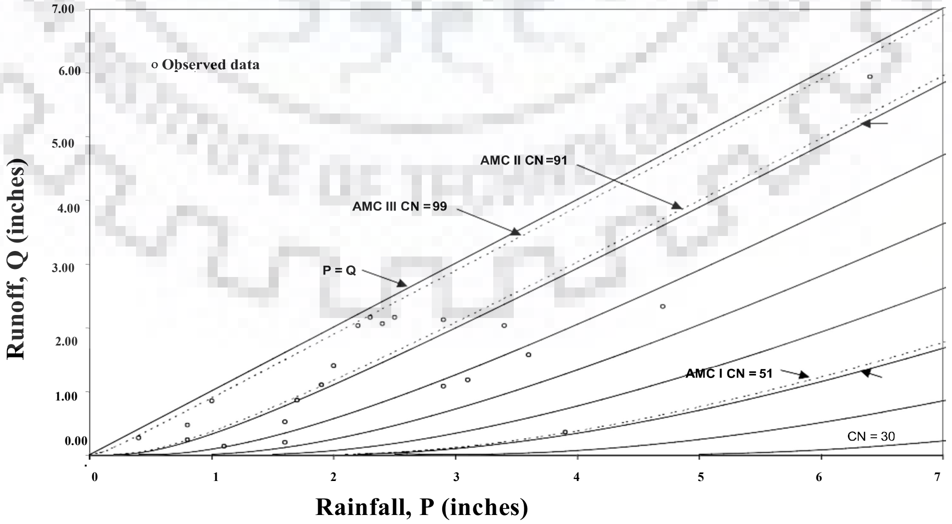

Figure 2. 2 Finding of CN for AMC I through AMC III using SCS-CN method

The CN related to the curve that divided 50% of the plotted data from the other 50% was taken as the median CN for that area. Thus, the developed CNs represent the average values for soil groups, covers, and hydrologic condition and correspond to AMC II (CNII). The higher enveloping curve was appropriate to proportionate to AMC III (CNIII) and bottom curve to AMC I (CNI). The average value was taken to respond, which was later expanded to apply AMC (Miller and Cronshey, 1989). Depending on 5-day rainfall, CNII is convertible to CNI and CNIII using the relationship in Table 2.5. However, to estimate the average CN value (CNII) mathematically from precipitation (P)-Runoff (Q) data of a gauged watershed, Hawkins (1993) suggested S (or CN) computation using the expression given below:

$$S = 5(P + 2Q - \sqrt{(Q\,(4Q+5P))} \qquad \text{(Equation 12)}$$

Another approach to estimating CN from rainfall (P) and runoff (Q) data is the rank order method (Hjelmfelt, 1980), where the P-Q data are sorted out and rearranged on rank order type to have the same return period. However, the independent runoff values are not definitely related to the causative rainfall values (Hawkins, 1993). Bonta (1997) evaluated the potential of derived distributions to determine CN from measured P-Q data, treating them as separate distributions. The derived distribution techniques resulted in an estimate of CN for broader sample sizes than the methods of Hawkins (1993) and Hjelmfelt (1980). The derived distribution procedure has potential even when data availability is limited. Schneider and McCuen (2005) found a new Log-normal frequency model to find CN from measured P-Q data. The developed method was considered to be more accurate than the rank-order method and by the above Equation of S. Recently, Mishra and Singh (2006) investigated the variation of CN with AMC and found a new power relationship between S (or CN) and 5-day precipitation. The developed CN–AMC relation is appropriate to gauged and ungauged watersheds and removes the complication of a sudden jump from one AMC level to other.

2.8 ASYMPTOTIC APPROACH

Originally the CN was expected to be constant for each watershed. Because CN varies with the volume of event rainfall that occurs at different frequencies, CN is generally a factor of the design return period interval or frequency, a fact rarely recognized in most designs. Hawkins (1993) worked extensively with recorded precipitation and runoff data. The frequency matching approach is applied to explore precipitation and runoff data. The precipitation and runoff depths are sorted one by one and then changed on a rank-ordered basis to make P : Q pairs of same return periods. The single runoffs are not surely incorporated with the primary causative rainfalls. The frequency matching approach was applied by rank ordering the data and computing S for every paired event according to Equation (12). The calculated CN for each paired event was portrayed on a scatter plot as a function of precipitation volumes.

Relying on the watershed response to the precipitation, the resulting plots fell into one of three categories. These three categories were identified as standard, violent, and complacent. The standard is the common behavior usually seen. The standard response illustrates a decreasing CN as precipitation increases. The CN decreases until an asymptotic behavior is observed for larger, more ultimate precipitation events. The violent reaction was noted in an area with arising as rainfall increases. The CN increases until an asymptotic behavior is observed at the larger, higher precipitation events. In complacent behavior, the observed CN declines steadily with expanding rainfall depth, and no asymptotic behavior was noted and it is said to be the most ambiguous among the three responses. Hawkins (1993) concluded that 80% of the areas fall under the category of either standard or violent.

Ajmal and Woong (2015) evaluated different CN determining methods to observe the impacts of CN and Ia on runoff estimation. It was found that the lower values of the initial abstraction coefficient (λ) yield better runoff estimation than the fixed λ (=0.2) as lower $\lambda < 0.2$ was also recommended by other researchers worldwide (Hawkins et al., 2001).

Mishra and Singh (2002b) developed a modified SCS-CN model to incorporate the AMC in the existing method. Jain et al. (2006b) applied SCS-CN method, its variant and the modified Mishra and Singh (2002b) model to a many more set of rainfall-runoff data by smaller to larger watersheds. It was also found that the existing SCS-CN model was better acceptable for large runoff producing agricultural watersheds than to areas having pasture land use and sandy soils. This was also confirmed with Ponce and Hawkins (1996) that the SCS-CN technique performs best on agricultural watersheds, fairly on range sites and poorly on forest sites (Hawkins, 1984; 1993). Recently, a combined study of runoff modeling using SCS-CN and GIS technique has obtained significance for the calculation of surface runoff (Amutha and Pochelvon, 2009; Soulis et al. 2009; Pradhan et al., 2010; Inayathulla et al., 2013).

Though the SCS-CN technique was originally studied for event-based rainfall-runoff modeling of ungauged watersheds, it has been implemented successfully in the field of hydrology and watershed management and environmental engineering. The fields of applications are a hydrologic simulation, the forecast of infiltration and excess rainfall rates, hydrograph simulation, metal partitioning, modeling of sediment yield and transport of urban pollutants, determination of evapotranspiration, determination of irrigation water requirement, determination of sub-surface flow etc (Mishra and Singh, 2003a). The SCS-CN model has been adopted by other hydrological models to calculate runoff, such as CREAMS (Knisel, 1980), ANSWERS (Beasley et al., 1980), AGNPS (Young et al., 1987), EPIC (Sharpley and Williams, 1980), SWAT (Neitsch et al., 2005).

3.1 GENERAL

The experimental site is located in village Toda Kalyanpur (Latitude: $29^0 50' 6''$ N, Longitude: $77^0 50' 17''$ E), District Haridwar of Uttarakhand State in India (Figure 3.1). Situated about 6.0 km south-east from IIT Roorkee, its elevation/altitude is 266 m above mean sea level, it experiences the sub-tropical climate, the monsoon rainfall occurs during the period of June to September, and rainfall varies from 1200 to 1500 mm. The average maximum temperature varies in between 20 ^oC to 40 ^oC, and relative humidity in between 35 to 97%.

Figure 3. 1 Location Map

3.2 SOIL TYPE

Soils are broadly classified as sand, silt, and clay according to soil texture. Particles sizes are divided into 3 distinct ranges to know the soil type. Sand has particle size varying from 0.05 to 2.0 mm, silt-size varies 0.002 to 0.05 mm and clay particle size is less than 0.002 mm. Soil texture is decided by the relative volumes of these materials. There are 12 textural classifications described in a textural triangle (Figure 3.2).

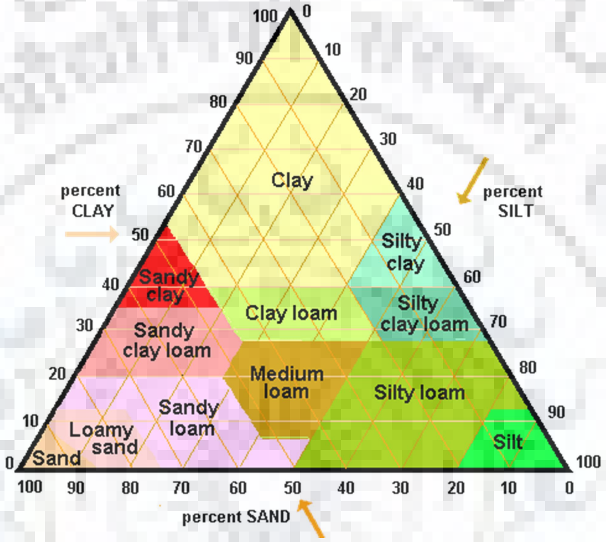

Figure 3. 2 Soil Texture category of the US Public Roads Administration

3.3 HYDROLOGIC SOIL GROUP (HSG)

The SCS-CN has classified the soil in four distinct groups according to least infiltration rates and transmission. The sandy soil has the largest infiltration rate whereas clayey soil exhibits the smallest one. Table 3.1 shows the classification.

Table 3. 1 Description of HSG (McCuen, 1982)

Hydrologic soil group	Minimum infiltration rate (inch/hr)
A	0.30 – 0.45
B	0.15 – 0.30
C	0.05 – 0.15
D	0 – 0.05

3.4 DATA STATUS

All the data used in this study were directly measured in the field and no secondary data were used from outside as it was the experimental work. The required equipments were established in the farm itself. Precipitation was measured from Ordinary Rain gauge and soil moisture was measured by- ‘Field scout TDR 300’ with a probe of 20 cm length. Double ring infiltrometer was used to determine the infiltration rate of the soil. Infiltration tests in all nine fields of all three grades were conducted using double ring infiltrometer to minimum infiltration capacity for classifying HSG. The results are given in chapter 5. The runoff accumulated by each plot was measured through the collection chamber located at the outlet of every plot connected with a converging approach channel. A soil sample from every plot was collected and analyzed in the laboratory to have the soil type.

4.1 GENERAL

The SCS-CN method is mostly used for estimation of runoff from given precipitation event especially in small agricultural watersheds. Its experimental verification for Indian conditions has not been attempted and published in the hydrologic literature, particularly at plot scale. To analyze the effect of soil, land use, AMC, and slope in Indian conditions, an experimental farm has been established by the Department of Water Resources Development & Management, IIT Roorkee in the village Toda Kalyanpur, near Roorkee, district Haridwar, India (Figure 4.2). The field has been divided into 3 different slopes at 8%, 12%, and 16% and again each slope was arranged into 3 plots having different land uses. During a precipitation event, the resulting runoff from every plot was passed through a multi-slot divisor connected through a converging channel to tank/chamber of size 1mx1mx1m at the outlet. The runoff was measured in terms of depth of storage water and multi-slot divisor was used for reducing the frequency of filling up of the chamber (Figure 4.1). The precipitation was measured by non-recording rain gauge installed at the site. For AMC of the soil, soil moisture was measured daily using TDR 300 during monsoon. In-situ double ring infiltrometer test was carried out for classifying HSG according to minimum infiltration rate.

Figure 4. 1 Multi-slot divisor

As an example, the records of rainfall, soil moisture and runoff depth for thirteen rainfall events from (Fallow land with 16%) is given in Table 4.1.

Table 4. 1 Rainfall, runoff and soil moisture content (Fallow 16%)

Event No.	Date	Rainfall (P) mm	Surface runoff depth(cm) in the outlet chamber	Previous day in-situ moisture content (θo %)
1	26-Jun-17	34.2	20.62	26.13
2	28-Jun-17	75.2	64.92	29.80
3	6-Jul-17	36.4	32.29	25.83
4	2-Aug-17	79.5	40.14	33.00
5	7-Aug-17	27.4	20.25	28.00
6	19-Aug-17	22.3	14.94	32.30
7	22-Aug-17	58.1	35.90	31.93
8	23-Aug-17	15.5	4.54	25.55
9	25-Aug-17	61.8	45.61	25.75
10	1-Sep-17	44.0	30.70	30.40
11	1-Sep-17	23.0	20.90	30.40
12	2-Sep-17	61.1	48.50	24.10
13	3-Sep-17	26.0	19.06	27.40

4.2 APPLICATION

This section deals with step-by-step procedure associated with computation of CN from observed precipitation and runoff using the slope adjusted CN from all the nine experimental plots for assessing the impacts of land use on runoff from steep watersheds.

4.2.1 A: Preparation of Experimental Plots

Three plots of three different grades were prepared viz. slopes of 8%, 12%, and 16% (Figure 4.2). Each grade of plots was sub-divided into three small plots of size 12.0 m x 3.0 m, leading to nine plots.

Figure 4. 2 Experimental plots

4.2.2 B: Measurement of Rainfall and Runoff

4.2.2.1 Rainfall

Precipitation data were measured from non-recording type rain gauge installed at the site. It was measured at every 8.30 to 9.00 AM from non-recording rain gauge (Figure 4.3). The rainfall measurement started from 19 of June 2017 and it continued till recent rainfall of 24 September 2017. Total 19 rainfall events were observed. It was also found that runoff was generated by rain events of more than 9.6 mm.

Figure 4. 3 Rainfall measurement

4.2.2.2 Runoff

Runoff accumulated for every rainfall event from every plot was obtained in a chamber of size 1mx1mx1m (Figure 4.4). Multi-slot divisor was established in the approach channel leading from plot to the chamber. Multi-slot divisor had 5 numbers of slots and runoff was collected in the chamber coming only from the middle slot and that of other slots was transferred outside the chamber so that dimension of the chamber and the cost of project reduced. The depth of runoff quantity in the tank was measured using a steel tape. Since collecting tank and conveyance passage were open to atmosphere, quantity due to direct precipitation was also deducted to estimate the actual runoff. The water volume thus measured was multiplied five times to compute actual runoff volume and it was divided by plot area to get the runoff depth.

Figure 4.4 Runoff Chamber

Figure 4.5 Chamber Cleaning work

4.2.3 Measurement of Infiltration Rate and Soil Moisture

4.2.3.1 Infiltration Test

Double ring infiltrometer tests were carried out in all nine plots to determine the minimum infiltration rate of each of the plots (Figure 4.6). According to the minimum infiltration rate of the soil, HSG of the plot was decided. Two concentric rings of 30cm and 45cm Dia. and 30cm height was inserted into the soil so that about 10cm was above the ground. Water was poured in both the rings up to a fixed level and drawdown in a certain interval of time was noted for inner ring only (Figure 4.7). The experiment was continued for at least 3 to 4 hours until two consecutive readings of the same order were obtained and it took around 9 days to finish these tests in all nine plots.

Figure 4. 6 Infiltrometer set up

Figure 4. 7 Infiltration test measurement

4.2.3.2 Antecedent moisture condition (θo)

Daily soil moisture of all plots was collected using Field scout TDR 300 with a probe length of 20 cm (Figure 4.8). Three spot point values were measured in the field and average of 3 values was calculated for soil moisture of the plot (Figure 4.2). It yielded directly the volumetric water content (VWC) in percentage. The soil holding water was preceded for the whole monsoon and remained extended for as and when necessary after the monsoon. It was definitely observed the soil moisture prior to every rain event.

Figure 4. 8 TDR 300 (with probe 20cm)

4.2.4 Soil Grain Size Analysis

Soil collected from every plot was carried to the laboratory in plastic bags (Figure 4.9). The soil was dried in an oven and mixed clearly such that structure of the soil was become disturbed. Then it was passed through the sequence of sieves for 20 minutes (Figure 4.10). The retained soil on various sieves was weighed. It was compared with the previously weighed soil sample whether the loss of weight was more than 2%. The output was tabulated and analyzed to get the part of sand, silt, and clay which was the prime concern of the experiment. It was then used to differentiate HSG obtained from the infiltrometer test.

Figure 4. 9 Soil sample collection

Figure 4. 10 Sieve analysis in the laboratory

4.2.5 Estimation of Curve Number for Experimental Plots

In this research work, CNs were estimated using (i) NEH-4 Table based on HSG and land use for all the three land use and 5% land slope, (ii) observed rainfall and runoff data from all the nine experimental plots (using Equations 7 & 8), and finally (iii) the slope adjusted CNs based on Steps (i) & (ii) (using Equation 11). The estimated CNs were finally used for runoff estimation from all nine experimental plots.

This chapter presents all the results obtained from the experiments conducted for estimating hydrologic soil group (HSG), antecedent moisture condition (θ_0). The CNs obtained from different methods as discussed in Chapter 4 were used for estimation of runoff from all nine experimental plots for all the nineteen observed storm events. The results obtained have been presented and thoroughly discussed in this chapter. A comparison has also been made between the CNs obtained from different methods. The impacts of land use/land cover and watershed slope on runoff estimation have been discussed thoroughly in this chapter.

5.1 DETERMINATION OF HSG

HSG of soil in all nine experimental plots was estimated from the minimum infiltration capacity of the soil (McCuen, 1982) as discussed in Chapter 4. The results of infiltration tests are shown in Table 5.1. The infiltration rate curves for Maize, Finger millet, and fallow lands are shown in Figure 5.1 to 5.3.

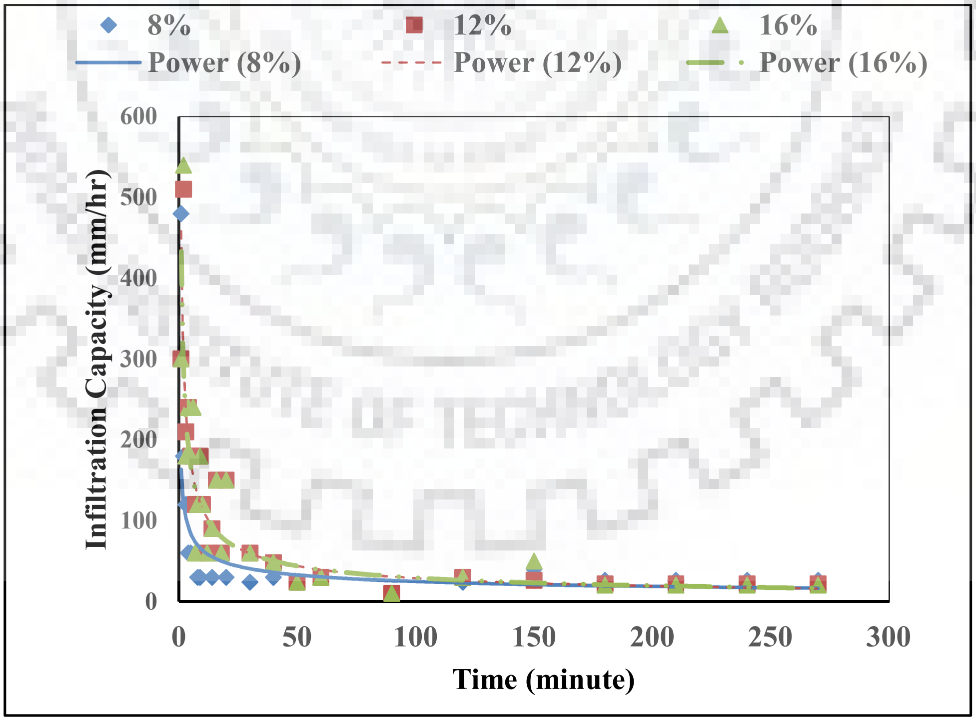

Figure 5. 1 Infiltration curve (Maize)

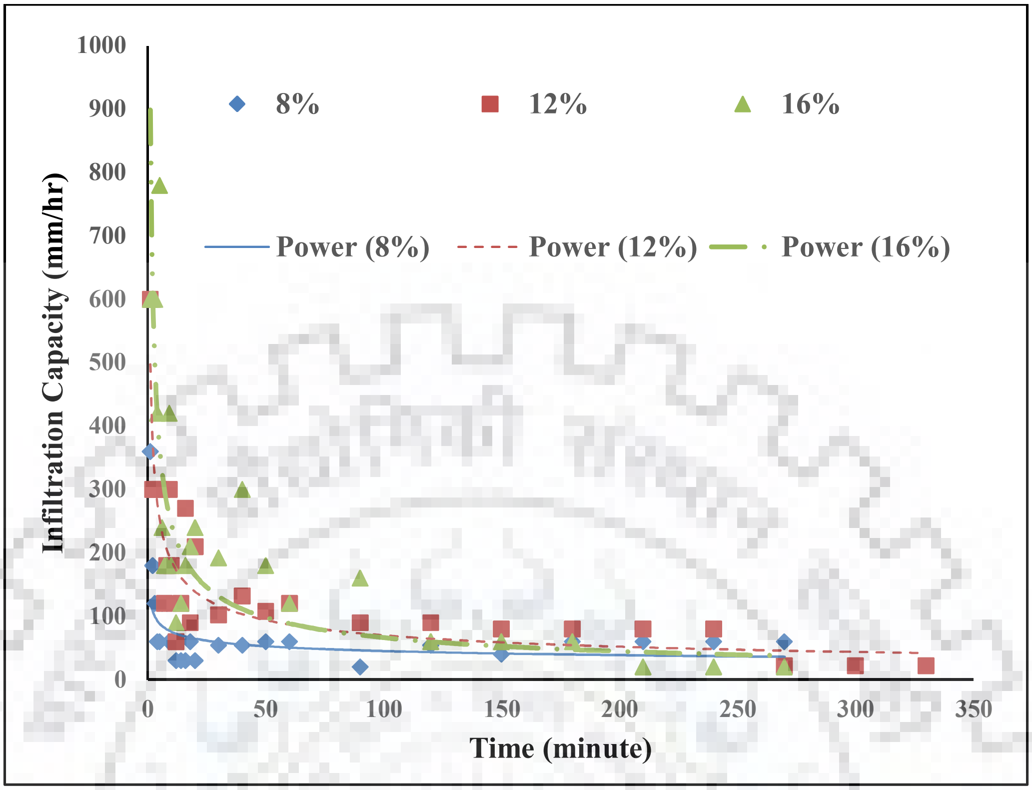

Figure 5. 2 Infiltration curve (Finger Millet)

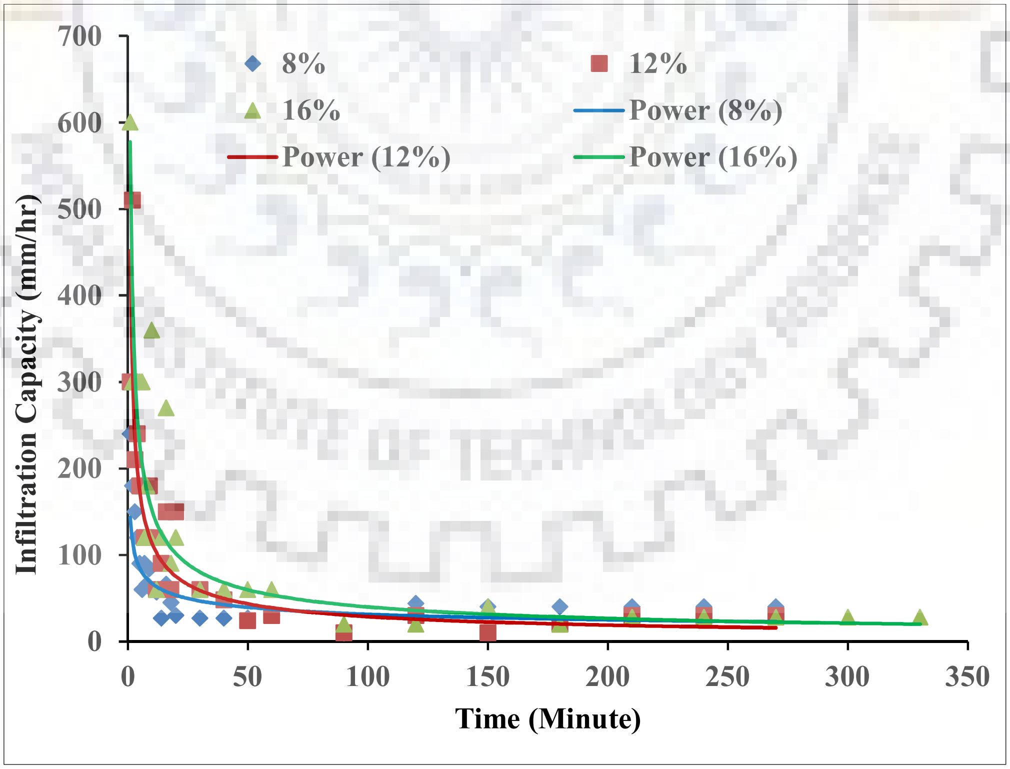

Figure 5. 3 Infiltration curve (Fallow Land)

Table 5. 1 Result of HSG computation

Slope	Plot No.	Minimum Infiltration Capacity(inch/hr)	Standard Range(inch/hr)	HSG	Methodology	Land Use
8%	4	2.36	0.30-0.45	A	Constant Head Method	Finger Millet
	5	1.02	0.30-0.45	A	Constant Head Method	Maize
	6	1.57	0.30-0.45	A	Constant Head Method	Fallow
12%	1	0.87	0.30-0.45	A	Constant Head Method	Finger Millet
	2	0.87	0.30-0.45	A	Constant Head Method	Maize
	3	1.18	0.30-0.45	A	Constant Head Method	Fallow
16%	7	0.79	0.30-0.45	A	Constant Head Method	Finger Millet
	8	0.79	0.30-0.45	A	Constant Head Method	Maize
	9	1.10	0.30-0.45	A	Constant Head Method	Fallow

5.2 ESTIMATION OF SOIL TYPE

As discussed in Chapter 4, the soil samples were collected from every plot (Figure 4.9) and were analyzed using sieve analysis in the laboratory (Figure 4.10) to find the soil type according to soil texture. The sieve analysis results are shown in Table 5.2. It can be observed from Table 5.2 that for all the plots the soil is sandy soil.

Table 5. 2 Results of sieve analysis

Slope	Plot No.	Grain Size			Soil type
		>0.6mm	<0.6 and >0.075mm	<0.075mm	
8%	4	1.49	88.92	9.58	Sandy
	5	1.78	88.32	9.90	Sandy
	6	1.63	88.74	9.62	Sandy
12%	1	1.53	88.36	10.11	Sandy
	2	1.65	88.00	10.35	Sandy
	3	0.95	88.80	10.25	Sandy
16%	7	2.53	88.26	9.21	Sandy
	8	2.43	88.35	9.21	Sandy
	9	2.32	88.69	8.99	Sandy

5.3 ESTIMATION OF CN FROM NEH-4 TABLE

Following watershed characteristics were considered while selecting representative CNs from NEH-4 Table as given here:

(a) Land use/Land cover: The land has been applied for agricultural purposes and cultivated with maize, finger millet, and fallow land.

(b) Hydrologic Condition: Hydrologic condition is defined according to how much area of the lands was being covered with grass. Initially, there was no crop in the plot 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.

(c) Hydrologic Soil Group (HSG): Hydrologic soil group was defined according to the minimum infiltration rate of the soil. It was calculated by in-situ infiltrometer tests.

(d) The NEH-Table provides CN for average, i.e. for AMCII, condition and it was assumed that it holds for slope 5%. Then slope correction was applied in CN using Equation (xi).

(e) Finally, the CNs were used to estimate runoff for all nineteen storm events.

Table 5. 3 CNsestimated usingNEH-4 Table:

Land Use	Slope	HSG	Hydrologic Condition	NEH-4 CN2	Slope adjusted CN2
Finger	8%	A	Poor	66.00	66.10
Maize		A	Poor	72.00	72.10
Fallow		A	Poor	77.00	77.10
Finger	12%	A	Poor	66.00	66.20
Maize		A	Poor	72.00	72.20
Fallow		A	Poor	77.00	77.20
Finger	16%	A	Poor	66.00	66.30
Maize		A	Poor	72.00	72.40
Fallow		A	Poor	77.00	77.40

5.4 DETERMINATION OF CN FROM RAINFALL-RUNOFF DATA

CNs were also obtained from the observed rainfall and runoff data for all 9 experimental watersheds and all nineteen storm events. The potential maximum retention (S), corresponding CN values, slope-adjusted CN values and comparison of CN values were computed for all slopes and land uses. The estimated CNs are given in Table 5.4-5.15.

Table 5. 4 Calculation of CN for Maize plots

Event No.	Date	Rainfall (P) mm	Runoff (Q) mm			Potential Max. retention (S) mm			Curve Number (CN)		
			8%	12%	16%	8%	12%	16%	8%	12%	16%
1	19-Jun-17	44.0	14.2	30.1	31.9	48.5	14.9	12.5	84.0	94.5	95.3
2	26-Jun-17	34.2	13.4	26.5	24.8	30.7	7.7	9.7	89.2	97.1	96.3
3	28-Jun-17	135.2	48.7	50.9	64.0	133.5	126.9	94.8	65.6	66.7	72.8
4	29-Jun-17	17.7	6.4	10.6	9.2	17.4	8.3	10.8	93.6	96.8	95.9
5	30-Jun-17	15.0	7.1	9.8	13.0	10.6	5.7	1.8	96.0	97.8	99.3
6	06-Jul-17	36.4	19.1	28.7	27.2	21.7	7.6	9.3	92.1	97.1	96.5
7	24-Jul-17	14.0	0.7	4.1	5.5	41.8	16.7	12.4	85.9	93.8	95.3
8	02-Aug-17	79.5	33.2	42.5	44.3	66.1	46.0	42.7	79.4	84.7	85.6
9	03-Aug-17	9.6	2.0	3.4	4.6	15.3	9.8	6.7	94.3	96.3	97.4
10	07-Aug-17	27.4	18.9	20.9	25.1	9.1	6.4	2.0	96.5	97.5	99.2
11	10-Aug-17	43.4	19.9	26.9	35.9	31.8	18.8	7.1	88.9	93.1	97.3
12	19-Aug-17	22.3	2.9	9.2	9.9	45.7	18.8	17.1	84.8	93.1	93.7
13	22-Aug-17	58.1	29.0	30.9	43.4	37.7	33.9	14.9	87.1	88.2	94.5
14	23-Aug-17	15.5	2.3	2.5	6.7	29.8	28.3	12.3	89.5	90.0	95.4
15	25-Aug-17	61.8	32.3	36.6	49.8	37.2	29.5	11.6	87.2	89.6	95.6
16	01-Sep-17	44.0	15.0	20.5	34.4	46.0	31.5	9.4	84.7	89.0	96.4
17	01-Sep-17	23.0	14.6	18.8	20.9	9.4	4.0	1.9	96.4	98.5	99.3
18	02-Sep-17	61.1	26.3	33.2	24.9	48.9	34.3	52.4	83.9	88.1	82.9
19	03-Sep-17	26.0	19.1	13.5	17.7	7.1	15.8	9.0	97.3	94.1	96.6

Table 5. 5 Calculation of CN for Finger Millet plots

Event No.	Date	Rainfall (P) mm	Runoff (Q) mm			Potential Max. retention (S) mm			Curve Number (CN)		
			8%	12%	16%	8%	12%	16%	8%	12%	16%
1	19-Jun-17	44.0	13.0	17.8	27.2	52.6	38.1	19.2	82.9	86.9	93.0
2	26-Jun-17	34.2	11.6	15.1	26.2	35.9	26.5	8.0	87.6	90.5	96.9
3	28-Jun-17	135.2	49.8	54.6	68.4	130.1	117.1	85.8	66.1	68.5	74.7
4	29-Jun-17	17.7	10.6	7.8	13.3	8.3	13.8	4.4	96.8	94.9	98.3
5	30-Jun-17	15.0	6.8	9.1	12.3	11.2	6.7	2.5	95.8	97.4	99.0
6	06-Jul-17	36.4	13.3	24.3	30.0	35.2	13.2	6.1	87.8	95.1	97.7
7	24-Jul-17	14.0	2.8	2.8	2.8	22.9	22.9	22.9	91.7	91.7	91.7
8	02-Aug-17	79.5	24.2	34.9	41.5	92.7	62.0	47.8	73.3	80.4	84.2
9	03-Aug-17	9.6	0.6	4.7	6.1	26.9	6.3	3.9	90.4	97.6	98.5
10	07-Aug-17	27.4	17.5	20.2	25.8	11.1	7.3	1.4	95.8	97.2	99.5
11	10-Aug-17	43.4	22.0	26.2	33.1	27.4	19.9	10.3	90.3	92.7	96.1
12	19-Aug-17	22.3	1.6	5.7	10.4	59.4	30.1	15.9	81.0	89.4	94.1
13	22-Aug-17	58.1	16.3	25.3	35.1	72.7	45.7	26.6	77.7	84.8	90.5
14	23-Aug-17	15.5	2.5	3.2	3.9	28.3	24.8	21.1	90.0	91.1	92.3
15	25-Aug-17	61.8	28.4	38.7	50.5	45.2	26.2	10.8	84.9	90.7	95.9
16	01-Sep-17	44.0	10.8	19.0	17.8	61.4	35.1	38.1	80.5	87.9	86.9
17	01-Sep-17	23.0	12.6	16.0	16.7	12.8	7.4	6.5	95.2	97.2	97.5
18	02-Sep-17	61.1	29.1	24.1	42.9	42.6	54.5	19.1	85.6	82.3	93.0
19	03-Sep-17	26.0	6.6	9.3	20.5	35.5	25.7	5.4	87.7	90.8	97.9

Table 5. 6 Calculation of CN for Fallow Land Plots

Event No.	Date	Rainfall (P) mm	Runoff(Q) mm			Potential Max. retention(S) mm			Curve Number (CN)		
			8%	12%	16%	8%	12%	16%	8%	12%	16%
1	19-Jun-17	44.0	12.3	20.4	29.6	55.2	31.8	15.6	82.1	88.9	94.2
2	26-Jun-17	34.2	8.1	18.1	20.6	49.0	20.1	15.7	83.8	92.7	94.2
3	28-Jun-17	135.2	46.0	56.9	64.9	141.6	111.3	92.9	64.2	69.5	73.2
4	29-Jun-17	17.7	5.0	13.3	14.7	22.0	4.4	2.8	92.0	98.3	98.9
5	30-Jun-17	15.0	5.4	10.2	10.9	14.8	5.2	4.2	94.5	98.0	98.4
6	06-Jul-17	36.4	17.8	26.1	32.3	24.4	10.8	3.7	91.3	95.9	98.6
7	24-Jul-17	14.0	1.4	2.8	4.1	32.9	22.9	16.7	88.5	91.7	93.8
8	02-Aug-17	79.5	22.1	38.2	40.1	100.4	54.6	50.6	71.7	82.3	83.4
9	03-Aug-17	9.6	0.6	3.4	5.7	26.9	9.8	4.5	90.4	96.3	98.2
10	07-Aug-17	27.4	16.0	13.3	20.2	13.5	18.5	7.3	95.0	93.2	97.2
11	10-Aug-17	43.4	20.1	19.9	34.7	31.5	31.8	8.5	89.0	88.9	96.8
12	19-Aug-17	22.3	4.6	6.4	14.9	35.2	27.3	8.0	87.8	90.3	97.0
13	22-Aug-17	58.1	23.3	33.7	35.9	50.8	28.9	25.3	83.3	89.8	90.9
14	23-Aug-17	15.5	2.5	5.3	4.5	28.3	16.1	18.7	90.0	94.0	93.1
15	25-Aug-17	61.8	38.7	31.4	45.6	26.2	38.8	16.5	90.7	86.7	93.9
16	01-Sep-17	44.0	12.2	17.8	30.7	55.7	38.1	14.1	82.0	86.9	94.8
17	01-Sep-17	23.0	14.6	13.8	20.9	9.4	10.7	1.9	96.4	96.0	99.3
18	02-Sep-17	61.1	33.2	25.7	48.5	34.3	50.3	12.3	88.1	83.5	95.4
19	03-Sep-17	26.0	13.5	10.7	19.1	15.8	22.1	7.1	94.1	92.0	97.3

Table 5. 7 Calculation of slope-adjusted CN for Maize plots

Event No.	Date	Rainfall (P) mm	Runoff (Q) mm			Curve Number (CN)			Slope-adjusted CN		
			8%	12%	16%	8%	12%	16%	8%	12%	16%
1	19-Jun-17	44.0	14.2	30.1	31.9	84.0	94.5	95.3	84.1	94.8	95.8
2	26-Jun-17	34.2	13.4	26.5	24.8	89.2	97.1	96.3	89.3	97.4	96.8
3	28-Jun-17	135.2	48.7	50.9	64.0	65.6	66.7	72.8	89.7	91.0	96.6
4	29-Jun-17	17.7	6.4	10.6	9.2	93.6	96.8	95.9	93.7	97.1	96.4
5	30-Jun-17	15.0	7.1	9.8	13.0	96.0	97.8	99.3	96.1	98.1	99.8
6	06-Jul-17	36.4	19.1	28.7	27.2	92.1	97.1	96.5	92.3	97.4	97.0
7	24-Jul-17	14.0	0.7	4.1	5.5	85.9	93.8	95.3	86.0	94.1	95.8
8	02-Aug-17	79.5	33.2	42.5	44.3	79.4	84.7	85.6	79.5	84.9	86.0
9	03-Aug-17	9.6	2.0	3.4	4.6	94.3	96.3	97.4	94.5	96.6	97.9
10	07-Aug-17	27.4	18.9	20.9	25.1	96.5	97.5	99.2	96.7	97.8	99.7
11	10-Aug-17	43.4	19.9	26.9	35.9	88.9	93.1	97.3	89.0	93.4	97.8
12	19-Aug-17	22.3	2.9	9.2	9.9	84.8	93.1	93.7	84.9	93.4	94.1
13	22-Aug-17	58.1	29.0	30.9	43.4	87.1	88.2	94.5	87.2	88.5	94.9
14	23-Aug-17	15.5	2.3	2.5	6.7	89.5	90.0	95.4	89.6	90.3	95.9
15	25-Aug-17	61.8	32.3	36.6	49.8	87.2	89.6	95.6	87.3	89.9	96.1
16	01-Sep-17	44.0	15.0	20.5	34.4	84.7	89.0	96.4	84.8	89.2	96.9
17	01-Sep-17	23.0	14.6	18.8	20.9	96.4	98.5	99.3	96.6	98.8	99.8
18	02-Sep-17	61.1	26.3	33.2	24.9	83.9	88.1	82.9	84.0	88.4	83.3
19	03-Sep-17	26.0	19.1	13.5	17.7	97.3	94.1	96.6	97.4	94.4	97.1

Table 5. 8 Calculation of slope-adjusted CN for Finger Millet plots

Event No.	Date	Rainfall (P) mm	Runoff (Q) mm			Curve Number (CN)			Slope-adjusted CN		
			8%	12%	16%	8%	12%	16%	8%	12%	16%
1	19-Jun-17	44.0	13.0	17.8	27.2	82.9	86.9	93.0	83.0	87.2	93.4
2	26-Jun-17	34.2	11.6	15.1	26.2	87.6	90.5	96.9	87.7	90.8	97.4
3	28-Jun-17	135.2	49.8	54.6	68.4	66.1	68.5	74.7	90.3	92.6	98.1
4	29-Jun-17	17.7	10.6	7.8	13.3	96.8	94.9	98.3	97.0	95.2	98.8
5	30-Jun-17	15.0	6.8	9.1	12.3	95.8	97.4	99.0	95.9	97.7	99.5
6	06-Jul-17	36.4	13.3	24.3	30.0	87.8	95.1	97.7	87.9	95.4	98.2
7	24-Jul-17	14.0	2.8	2.8	2.8	91.7	91.7	91.7	91.9	92.0	92.2
8	02-Aug-17	79.5	24.2	34.9	41.5	73.3	80.4	84.2	73.4	80.6	84.6
9	03-Aug-17	9.6	0.6	4.7	6.1	90.4	97.6	98.5	90.6	97.9	99.0
10	07-Aug-17	27.4	17.5	20.2	25.8	95.8	97.2	99.5	95.9	97.5	100.0
11	10-Aug-17	43.4	22.0	26.2	33.1	90.3	92.7	96.1	90.4	93.0	96.6
12	19-Aug-17	22.3	1.6	5.7	10.4	81.0	89.4	94.1	81.2	89.7	94.6
13	22-Aug-17	58.1	16.3	25.3	35.1	77.7	84.8	90.5	77.8	85.0	91.0
14	23-Aug-17	15.5	2.5	3.2	3.9	90.0	91.1	92.3	90.1	91.4	92.8
15	25-Aug-17	61.8	28.4	38.7	50.5	84.9	90.7	95.9	85.0	90.9	96.4
16	01-Sep-17	44.0	10.8	19.0	17.8	80.5	87.9	86.9	80.6	88.1	87.4
17	01-Sep-17	23.0	12.6	16.0	16.7	95.2	97.2	97.5	95.3	97.5	98.0
18	02-Sep-17	61.1	29.1	24.1	42.9	85.6	82.3	93.0	85.8	82.6	93.5
19	03-Sep-17	26.0	6.6	9.3	20.5	87.7	90.8	97.9	87.9	91.1	98.4

Table 5. 9 Calculation of slope-adjusted CN for Fallow land plots

Event No.	Date	Rainfall (P) mm	Runoff (Q) mm			Curve Number (CN)			Slope-adjusted CN		
			8%	12%	16%	8%	12%	16%	8%	12%	16%
1	19-Jun-17	44.0	12.3	20.4	29.6	82.1	88.9	94.2	82.2	82.4	94.7
2	26-Jun-17	34.2	8.1	18.1	20.6	83.8	92.7	94.2	84.0	84.1	94.6
3	28-Jun-17	135.2	46.0	56.9	64.9	64.2	69.5	73.2	88.5	88.6	96.9
4	29-Jun-17	17.7	5.0	13.3	14.7	92.0	98.3	98.9	92.1	92.3	99.4
5	30-Jun-17	15.0	5.4	10.2	10.9	94.5	98.0	98.4	94.6	94.8	98.9
6	06-Jul-17	36.4	17.8	26.1	32.3	91.3	95.9	98.6	91.4	91.5	99.0
7	24-Jul-17	14.0	1.4	2.8	4.1	88.5	91.7	93.8	88.6	88.8	94.3
8	02-Aug-17	79.5	22.1	38.2	40.1	71.7	82.3	83.4	71.8	71.9	83.8
9	03-Aug-17	9.6	0.6	3.4	5.7	90.4	96.3	98.2	90.6	90.7	98.7
10	07-Aug-17	27.4	16.0	13.3	20.2	95.0	93.2	97.2	95.1	95.3	97.7
11	10-Aug-17	43.4	20.1	19.9	34.7	89.0	88.9	96.8	89.1	89.3	97.2
12	19-Aug-17	22.3	4.6	6.4	14.9	87.8	90.3	97.0	87.9	88.1	97.4
13	22-Aug-17	58.1	23.3	33.7	35.9	83.3	89.8	90.9	83.4	83.6	91.4
14	23-Aug-17	15.5	2.5	5.3	4.5	90.0	94.0	93.1	90.1	90.3	93.6
15	25-Aug-17	61.8	38.7	31.4	45.6	90.7	86.7	93.9	90.8	90.9	94.4
16	01-Sep-17	44.0	12.2	17.8	30.7	82.0	86.9	94.8	82.1	82.3	95.2
17	01-Sep-17	23.0	14.6	13.8	20.9	96.4	96.0	99.3	96.6	96.8	99.8
18	02-Sep-17	61.1	33.2	25.7	48.5	88.1	83.5	95.4	88.2	88.4	95.9
19	03-Sep-17	26.0	13.5	10.7	19.1	94.1	92.0	97.3	94.3	94.4	97.8

Table 5. 10 Runoff Curve Number Comparison of maize plots

Event No.	Date	Runoff Curve Number (CN) from observed rainfall-runoff data			Runoff Curve Number (CN) from NEH-4 Table		
		8%	12%	16%	8%	12%	16%
1	19-Jun-17	84.0	94.5	95.3	72.0	72.0	72.0
2	26-Jun-17	89.2	97.1	96.3	72.0	72.0	72.0
3	28-Jun-17	89.6	90.7	96.1	72.0	72.0	72.0
4	29-Jun-17	93.6	96.8	95.9	72.0	72.0	72.0
5	30-Jun-17	96.0	97.8	99.3	72.0	72.0	72.0
6	06-Jul-17	92.1	97.1	96.5	72.0	72.0	72.0
7	24-Jul-17	85.9	93.8	95.3	72.0	72.0	72.0
8	02-Aug-17	79.4	84.7	85.6	72.0	72.0	72.0
9	03-Aug-17	94.3	96.3	97.4	72.0	72.0	72.0
10	07-Aug-17	96.5	97.5	99.2	72.0	72.0	72.0
11	10-Aug-17	88.9	93.1	97.3	72.0	72.0	72.0
12	19-Aug-17	84.8	93.1	93.7	72.0	72.0	72.0
13	22-Aug-17	87.1	88.2	94.5	72.0	72.0	72.0
14	23-Aug-17	89.5	90.0	95.4	72.0	72.0	72.0
15	25-Aug-17	87.2	89.6	95.6	72.0	72.0	72.0
16	01-Sep-17	84.7	89.0	96.4	72.0	72.0	72.0
17	01-Sep-17	96.4	98.5	99.3	72.0	72.0	72.0
18	02-Sep-17	83.9	88.1	82.9	72.0	72.0	72.0
19	03-Sep-17	97.3	94.1	96.6	72.0	72.0	72.0

Table 5. 11 Runoff Curve Number Comparison of finger millet plots

Event No.	Date	Runoff Curve Number (CN) from observed rainfall-runoff data			Runoff Curve Number (CN) from NEH-4 Table		
		8%	12%	16%	8%	12%	16%
1	19-Jun-17	82.9	86.9	93.0	66.0	66.0	66.0
2	26-Jun-17	87.6	90.5	96.9	66.0	66.0	66.0
3	28-Jun-17	90.2	92.3	97.7	66.0	66.0	66.0
4	29-Jun-17	96.8	94.9	98.3	66.0	66.0	66.0
5	30-Jun-17	95.8	97.4	99.0	66.0	66.0	66.0
6	06-Jul-17	87.8	95.1	97.7	66.0	66.0	66.0
7	24-Jul-17	91.7	91.7	91.7	66.0	66.0	66.0
8	02-Aug-17	73.3	80.4	84.2	66.0	66.0	66.0
9	03-Aug-17	90.4	97.6	98.5	66.0	66.0	66.0
10	07-Aug-17	95.8	97.2	99.5	66.0	66.0	66.0
11	10-Aug-17	90.3	92.7	96.1	66.0	66.0	66.0
12	19-Aug-17	81.0	89.4	94.1	66.0	66.0	66.0
13	22-Aug-17	77.7	84.8	90.5	66.0	66.0	66.0
14	23-Aug-17	90.0	91.1	92.3	66.0	66.0	66.0
15	25-Aug-17	84.9	90.7	95.9	66.0	66.0	66.0
16	01-Sep-17	80.5	87.9	86.9	66.0	66.0	66.0
17	01-Sep-17	95.2	97.2	97.5	66.0	66.0	66.0
18	02-Sep-17	85.6	82.3	93.0	66.0	66.0	66.0
19	03-Sep-17	87.7	90.8	97.9	66.0	66.0	66.0

Table 5. 12 Runoff Curve Number Comparison of fallow land plots

Event No.	Date	Runoff Curve Number (CN) from observed rainfall-runoff data			Runoff Curve Number (CN) from NEH-4 Table		
		8%	12%	16%	8%	12%	16%
1	19-Jun-17	82.1	82.1	94.2	77.0	77.0	77.0
2	26-Jun-17	83.8	83.8	94.2	77.0	77.0	77.0
3	28-Jun-17	88.3	88.3	96.4	77.0	77.0	77.0
4	29-Jun-17	92.0	92.0	98.9	77.0	77.0	77.0
5	30-Jun-17	94.5	94.5	98.4	77.0	77.0	77.0
6	06-Jul-17	91.3	91.3	98.6	77.0	77.0	77.0
7	24-Jul-17	88.5	88.5	93.8	77.0	77.0	77.0
8	02-Aug-17	71.7	71.7	83.4	77.0	77.0	77.0
9	03-Aug-17	90.4	90.4	98.2	77.0	77.0	77.0
10	07-Aug-17	95.0	95.0	97.2	77.0	77.0	77.0
11	10-Aug-17	89.0	89.0	96.8	77.0	77.0	77.0
12	19-Aug-17	87.8	87.8	97.0	77.0	77.0	77.0
13	22-Aug-17	83.3	83.3	90.9	77.0	77.0	77.0
14	23-Aug-17	90.0	90.0	93.1	77.0	77.0	77.0
15	25-Aug-17	90.7	90.7	93.9	77.0	77.0	77.0
16	01-Sep-17	82.0	82.0	94.8	77.0	77.0	77.0
17	01-Sep-17	96.4	96.4	99.3	77.0	77.0	77.0
18	02-Sep-17	88.1	88.1	95.4	77.0	77.0	77.0
19	03-Sep-17	94.1	94.1	97.3	77.0	77.0	77.0

Table 5. 13 Runoff Curve Number Comparison of maize with correction

Event No.	Date	Runoff Curve Number (CN) from observed rainfall-runoff data			Runoff Curve Number (CN) from NEH-4 Table		
		8%	12%	16%	8%	12%	16%
1	19-Jun-17	84.1	94.8	95.8	72.1	72.2	72.4
2	26-Jun-17	89.3	97.4	96.8	72.1	72.2	72.4
3	28-Jun-17	89.7	91.0	96.6	72.1	72.2	72.4
4	29-Jun-17	93.7	97.1	96.4	72.1	72.2	72.4
5	30-Jun-17	96.1	98.1	99.8	72.1	72.2	72.4
6	06-Jul-17	92.3	97.4	97.0	72.1	72.2	72.4
7	24-Jul-17	86.0	94.1	95.8	72.1	72.2	72.4
8	02-Aug-17	79.5	84.9	86.0	72.1	72.2	72.4
9	03-Aug-17	94.5	96.6	97.9	72.1	72.2	72.4
10	07-Aug-17	96.7	97.8	99.7	72.1	72.2	72.4
11	10-Aug-17	89.0	93.4	97.8	72.1	72.2	72.4
12	19-Aug-17	84.9	93.4	94.1	72.1	72.2	72.4
13	22-Aug-17	87.2	88.5	94.9	72.1	72.2	72.4
14	23-Aug-17	89.6	90.3	95.9	72.1	72.2	72.4
15	25-Aug-17	87.3	89.9	96.1	72.1	72.2	72.4
16	01-Sep-17	84.8	89.2	96.9	72.1	72.2	72.4
17	01-Sep-17	96.6	98.8	99.8	72.1	72.2	72.4
18	02-Sep-17	84.0	88.4	83.3	72.1	72.2	72.4
19	03-Sep-17	97.4	94.4	97.1	72.1	72.2	72.4

Table 5. 14 Runoff Curve Number Comparison of finger millet with correction

Event No.	Date	Runoff Curve Number (CN) from observed rainfall-runoff data			Runoff Curve Number (CN) from NEH-4 Table		
		8%	12%	16%	8%	12%	16%
1	19-Jun-17	83.0	87.2	93.4	66.1	66.2	66.3
2	26-Jun-17	87.7	90.8	97.4	66.1	66.2	66.3
3	28-Jun-17	90.3	92.6	98.1	66.1	66.2	66.3
4	29-Jun-17	97.0	95.2	98.8	66.1	66.2	66.3
5	30-Jun-17	95.9	97.7	99.5	66.1	66.2	66.3
6	06-Jul-17	87.9	95.4	98.2	66.1	66.2	66.3
7	24-Jul-17	91.9	92.0	92.2	66.1	66.2	66.3
8	02-Aug-17	73.4	80.6	84.6	66.1	66.2	66.3
9	03-Aug-17	90.6	97.9	99.0	66.1	66.2	66.3
10	07-Aug-17	95.9	97.5	100.0	66.1	66.2	66.3
11	10-Aug-17	90.4	93.0	96.6	66.1	66.2	66.3
12	19-Aug-17	81.2	89.7	94.6	66.1	66.2	66.3
13	22-Aug-17	77.8	85.0	91.0	66.1	66.2	66.3
14	23-Aug-17	90.1	91.4	92.8	66.1	66.2	66.3
15	25-Aug-17	85.0	90.9	96.4	66.1	66.2	66.3
16	01-Sep-17	80.6	88.1	87.4	66.1	66.2	66.3
17	01-Sep-17	95.3	97.5	98.0	66.1	66.2	66.3
18	02-Sep-17	85.8	82.6	93.5	66.1	66.2	66.3
19	03-Sep-17	87.9	91.1	98.4	66.1	66.2	66.3

Table 5. 15 Runoff Curve Number Comparison of fallow land with correction

Event No.	Date	Runoff Curve Number (CN) from observed rainfall-runoff data			Runoff Curve Number (CN) from NEH-4 Table		
		8%	12%	16%	8%	12%	16%
1	19-Jun-17	82.2	82.4	94.7	77.1	77.2	77.4
2	26-Jun-17	84.0	84.1	94.6	77.1	77.2	77.4
3	28-Jun-17	88.5	88.6	96.9	77.1	77.2	77.4
4	29-Jun-17	92.1	92.3	99.4	77.1	77.2	77.4
5	30-Jun-17	94.6	94.8	98.9	77.1	77.2	77.4
6	06-Jul-17	91.4	91.5	99.0	77.1	77.2	77.4
7	24-Jul-17	88.6	88.8	94.3	77.1	77.2	77.4
8	02-Aug-17	71.8	71.9	83.8	77.1	77.2	77.4
9	03-Aug-17	90.6	90.7	98.7	77.1	77.2	77.4
10	07-Aug-17	95.1	95.3	97.7	77.1	77.2	77.4
11	10-Aug-17	89.1	89.3	97.2	77.1	77.2	77.4
12	19-Aug-17	87.9	88.1	97.4	77.1	77.2	77.4
13	22-Aug-17	83.4	83.6	91.4	77.1	77.2	77.4
14	23-Aug-17	90.1	90.3	93.6	77.1	77.2	77.4
15	25-Aug-17	90.8	90.9	94.4	77.1	77.2	77.4
16	01-Sep-17	82.1	82.3	95.2	77.1	77.2	77.4
17	01-Sep-17	96.6	96.8	99.8	77.1	77.2	77.4
18	02-Sep-17	88.2	88.4	95.9	77.1	77.2	77.4
19	03-Sep-17	94.3	94.4	97.8	77.1	77.2	77.4

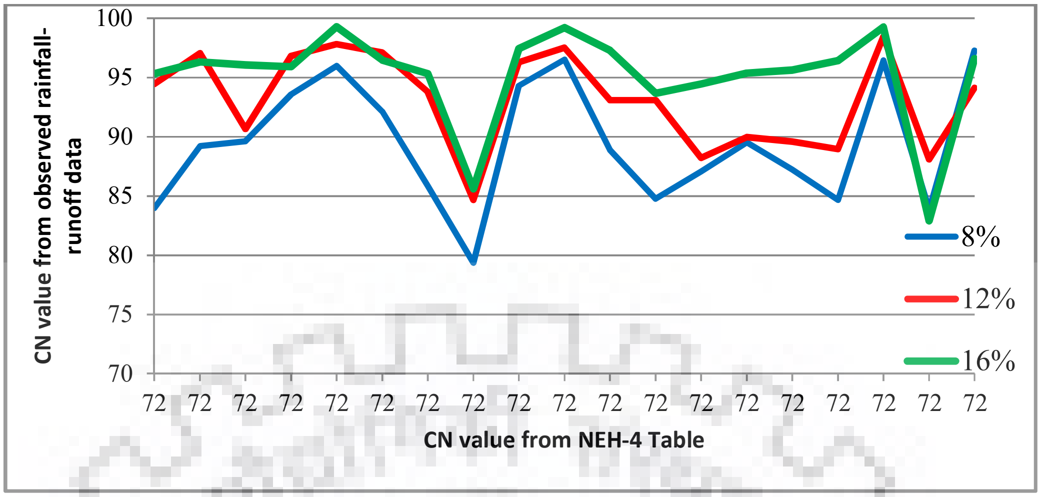

Figure 5. 4 Comparison of CN value of maize

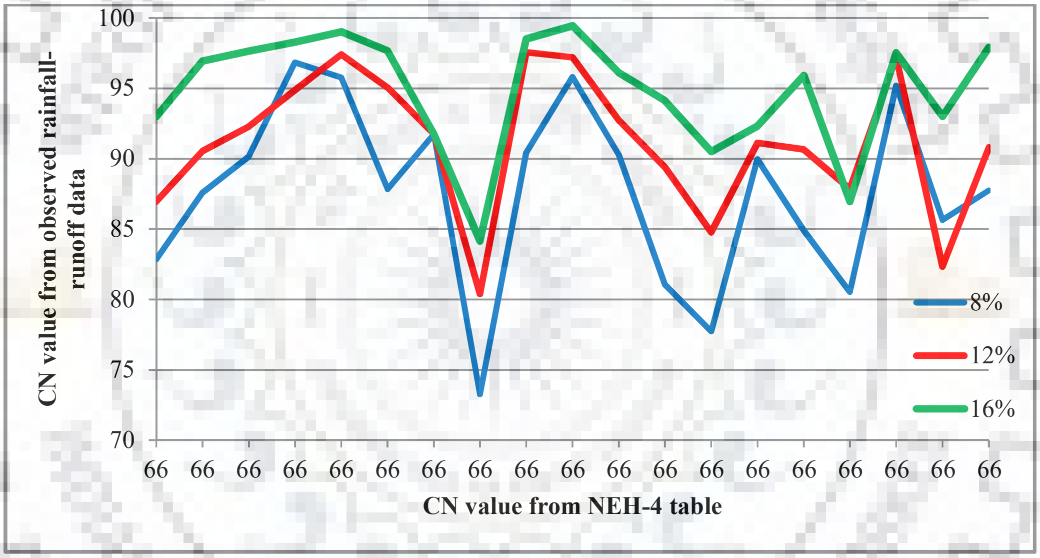

Figure 5. 5 Comparison of CN value of finger millet

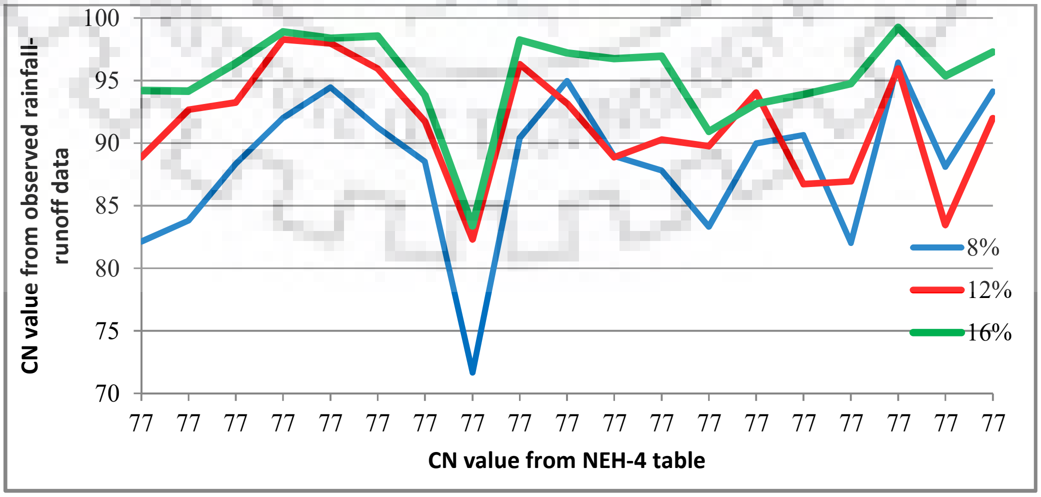

Figure 5. 6 Comparison of CN value of fallow land

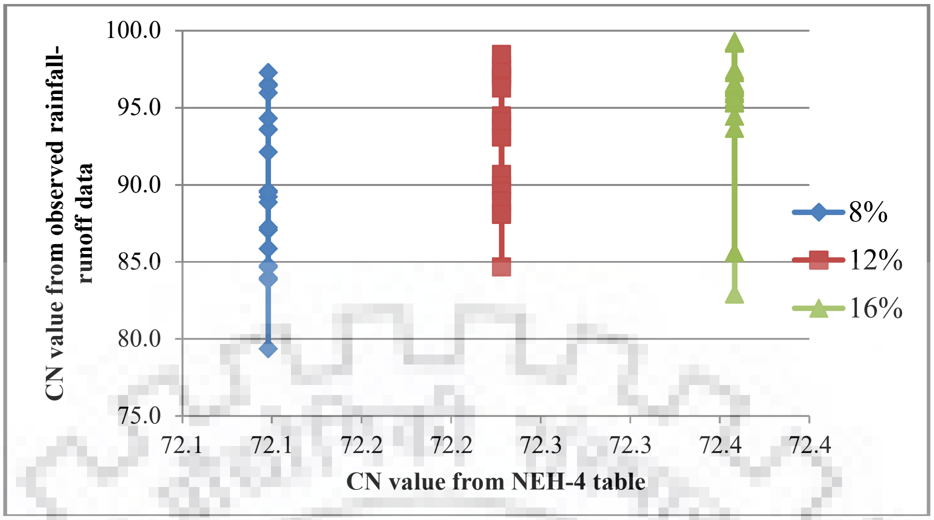

Figure 5. 7 Comparison of CN value of maize land with slope correction

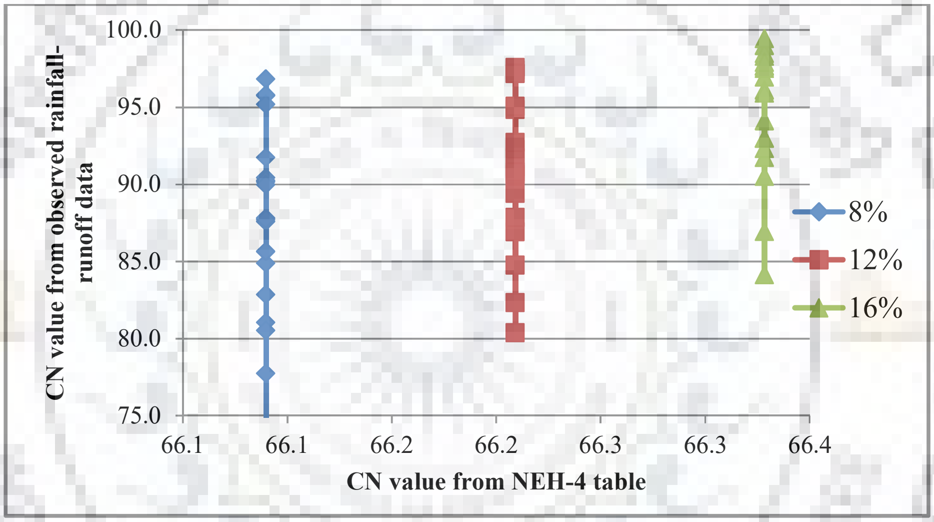

Figure 5. 8 Comparison of CN value of finger millet land with slope correction

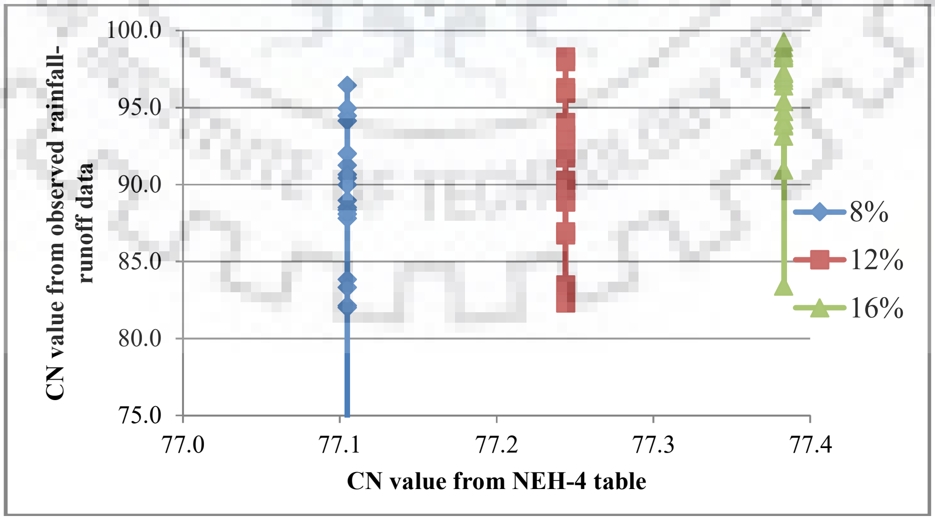

Figure 5. 9 Comparison of CN value of fallow land with slope correction

For establishing the existence of a relationship between AMC and soil moisture, potential maximum retention and AMC and CN and soil moisture to predict runoff more accurately for the soil conditions, AMCI, AMCII, and AMC III are calculated as follows:

Table 5. 16 Calculation of CN for different AMC condition for Maize

Rank(m)	CN in decreasing order (8%)	CN in decreasing order 12%)	CN in decreasing order (16%)	Prob. Of exceedance= m/(n+1)*100	Remarks
1	97.3	98.5	99.3	5.0	
2	96.5	97.8	99.3	10.0	AMC III
3	96.4	97.5	99.2	15.0	
4	96.0	97.1	97.4	20.0	
5	94.3	97.1	97.3	25.0	
6	93.6	96.8	96.6	30.0	
7	92.1	96.3	96.5	35.0	
8	89.6	94.5	96.4	40.0	
9	89.5	94.1	96.3	45.0	
10	89.2	93.8	96.1	50.0	AMCII
11	88.9	93.1	95.9	55.0	
12	87.2	93.1	95.6	60.0	
13	87.1	90.7	95.4	65.0	
14	85.9	90.0	95.3	70.0	
15	84.8	89.6	95.3	75.0	
16	84.7	89.0	94.5	80.0	
17	84.0	88.2	93.7	85.0	
18	83.9	88.1	85.6	90.0	AMCI
19	79.4	84.7	82.9	95.0	

Table 5. 17 Calculation of CN for different AMC condition for Finger Millet

Rank (m)	CN in decreasing order (8%)	CN in decreasing Order (12%)	CN in decreasing Order (16%)	Prob. Of Exceedance= m/(n+1)*100	Remarks
1	96.8	97.6	99.5	5.0	
2	95.8	97.4	99.0	10.0	AMC III
3	95.8	97.2	98.5	15.0	
4	95.2	97.2	98.3	20.0	
5	91.7	95.1	97.9	25.0	
6	90.4	94.9	97.7	30.0	
7	90.3	92.7	97.7	35.0	
8	90.2	92.3	97.5	40.0	
9	90.0	91.7	96.9	45.0	
10	87.8	91.1	96.1	50.0	AMCII
11	87.7	90.8	95.9	55.0	
12	87.6	90.7	94.1	60.0	
13	85.6	90.5	93.0	65.0	
14	84.9	89.4	93.0	70.0	
15	82.9	87.9	92.3	75.0	
16	81.0	86.9	91.7	80.0	
17	80.5	84.8	90.5	85.0	
18	77.7	82.3	86.9	90.0	AMCI
19	73.3	80.4	84.2	95.0	

Table 5. 18 Calculation of CN for different AMC condition for Fallow land

Rank(m)	CN in decreasing order (8%)	CN in decreasing order (12%)	CN in decreasing order (16%)	Prob. Of exceedance= m/(n+1)*100	Remarks
1	96.4	98.3	99.3	5.0	AMC III
2	95.0	98.0	98.9	10.0	
3	94.5	96.3	98.6	15.0	
4	94.1	96.0	98.4	20.0	
5	92.0	95.9	98.2	25.0	
6	91.3	94.0	97.3	30.0	
7	90.7	93.2	97.2	35.0	
8	90.4	93.2	97.0	40.0	
9	90.0	92.7	96.8	45.0	
10	89.0	92.0	96.4	50.0	AMC II
11	88.5	91.7	95.4	55.0	
12	88.3	90.3	94.8	60.0	
13	88.1	89.8	94.2	65.0	
14	87.8	88.9	94.2	70.0	
15	83.8	88.9	93.9	75.0	
16	83.3	86.9	93.8	80.0	
17	82.1	86.7	93.1	85.0	
18	82.0	83.5	90.9	90.0	AMC I
19	64.2	82.3	73.2	95.0	

5.5 EFFECT OF LAND USE, AMC, AND SLOPE ON CN

5.5.1 Effect of Land Use on CN

In this study, all nine experimental plots are under agricultural land use with different crops. It was cultivated with row crops like maize, close seeded legumes like finger millet and one plot in each slope were kept uncultivated as a fallow. Curve number for every land use is represented in Figure 5.10 to 5.13.

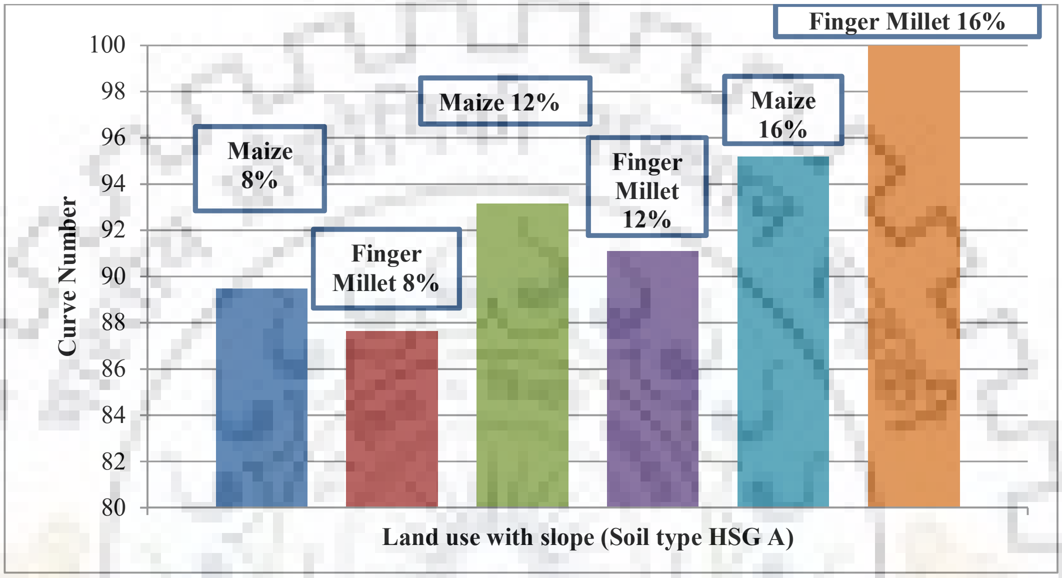

Figure 5. 10 Effect of maize and finger millet of HSG A on CN.

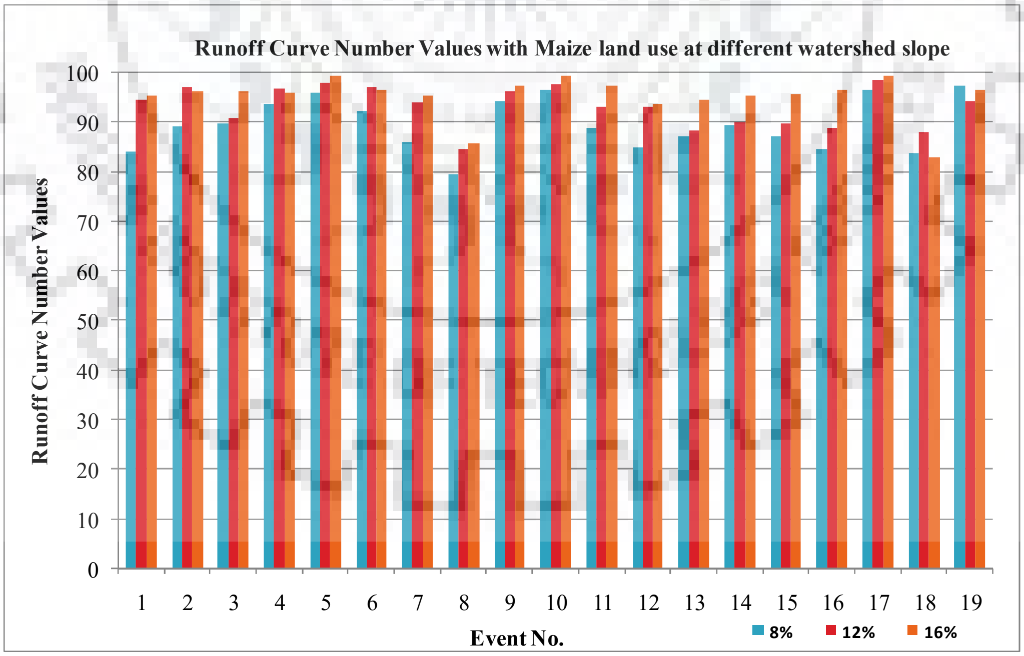

Figure 5. 11 Effect of Maize on CN in different slopes

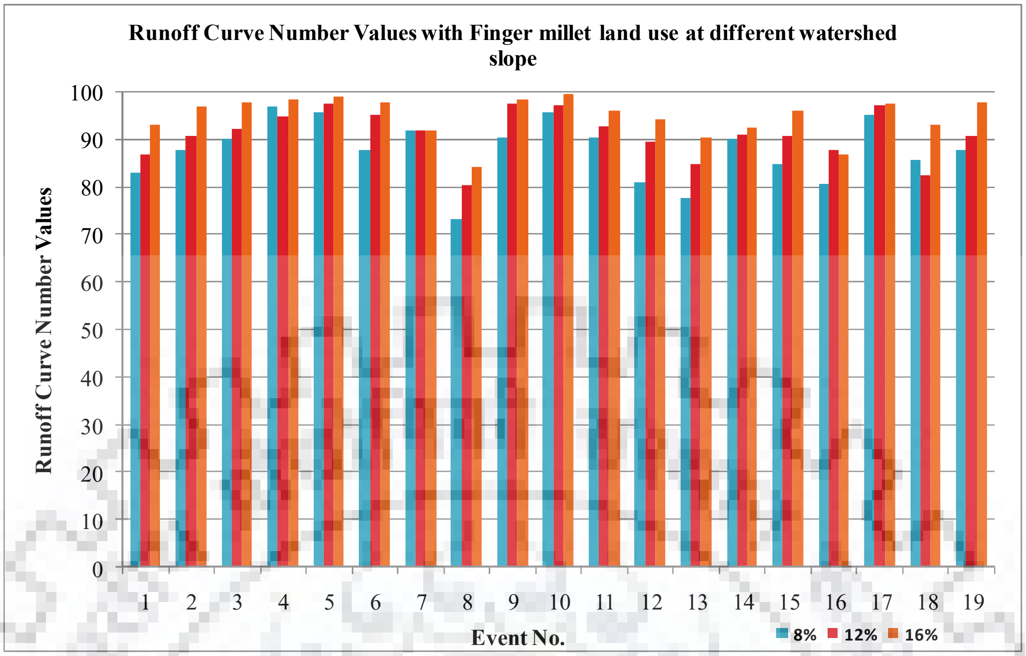

Figure 5. 12 Effect of Finger Millet on CN in different slopes

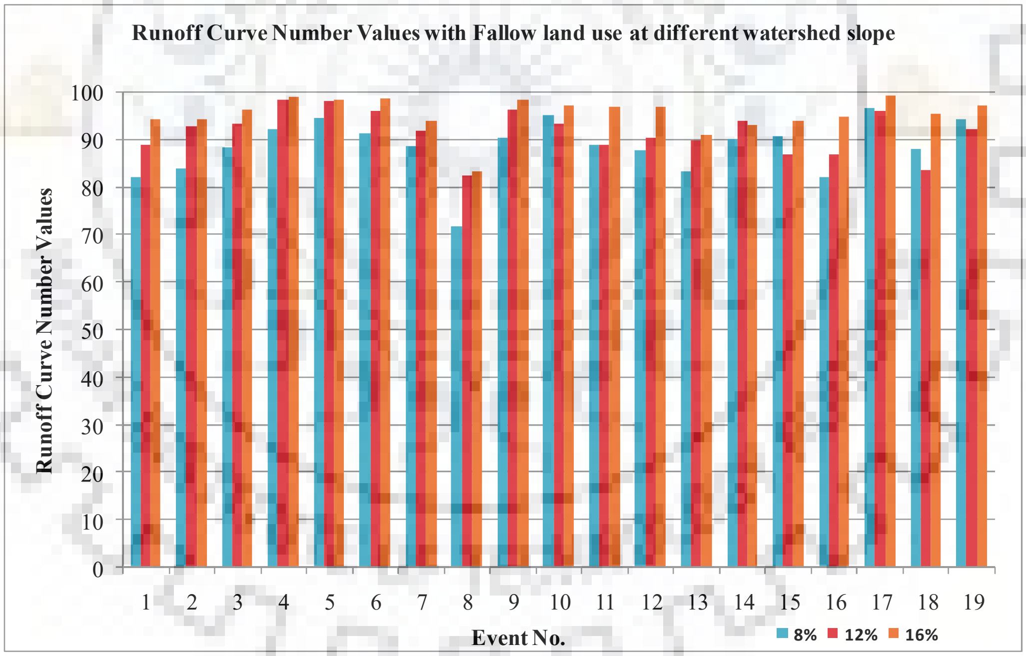

Figure 5. 13 Effect of Fallow land on CN in different slopes

It can be observed from these Figures that the fallow land has highest CN as compared to the other land uses for all slope classes. The experimental plot with 16% slope and fallow land use has highest CN among all.

5.5.2 Variation of In-Situ Soil Moisture and Potential Maximum Retention

As also mentioned above, the soil moisture capacity for all the nine plots was recorded using ‘TDR300’ on at the end of each rainfall event, designated here as the (θ_o). When plotted (Figure 5.14), CN-values are found to increase with physically measured (θ_o). Also, it is consistent with the general notion that as θo increases, S decreases or CN goes up or runoff increases.

Generally, the S-value should decrease with increase in situ soil moisture content of the soil. The relationship is established between S and θo for the fallow experimental plot as shown in Figure 5.15.

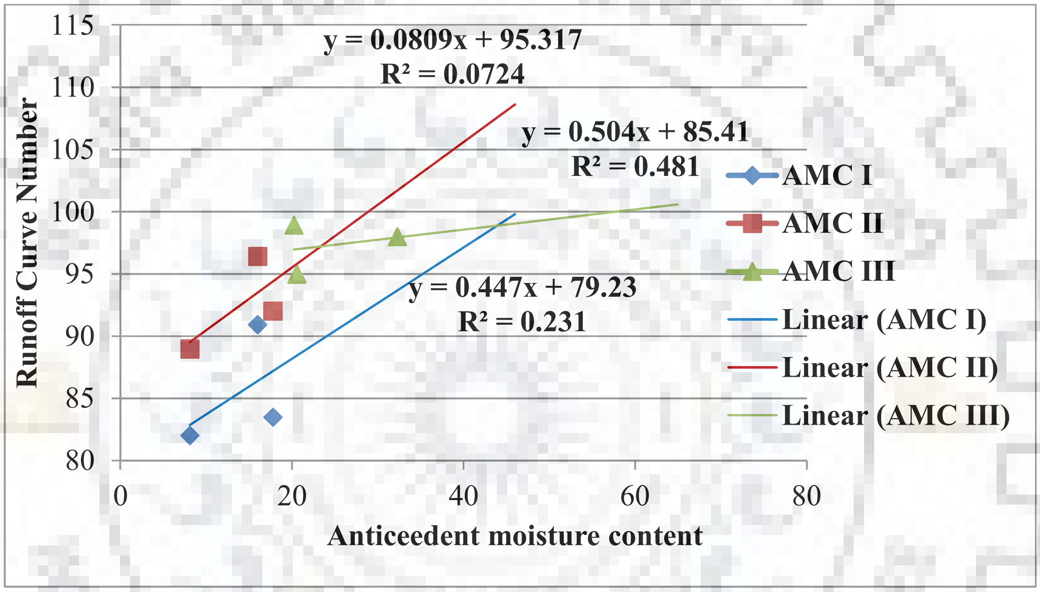

Figure 5. 14 Effect of AMC on CN (Fallow land on all slopes)

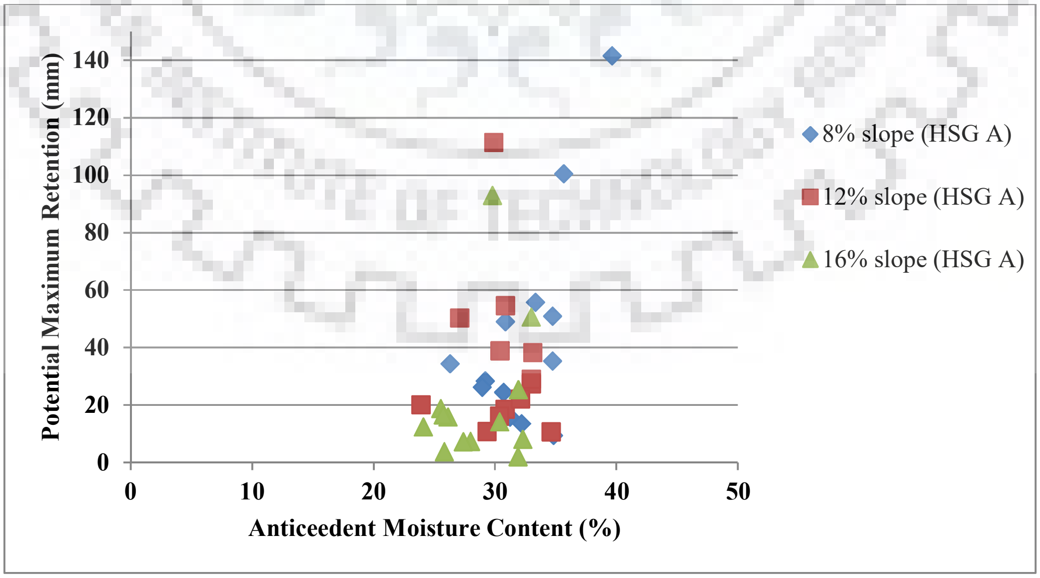

Figure 5. 15 Relation between S and AMC (θo) (Fallow)

Table 5. 19 Calculation of runoff using S and θ_o relation for Maize

P (mm)	8%				12%				16%			
	Qobs (mm)	θo (%)	Scomp (mm)	Qcomp (mm)	Qobs (mm)	θo (%)	Scomp (mm)	Qcomp (mm)	Qobs (mm)	θo (%)	Scomp (mm)	Qcomp (mm)
34.20	13.40	13.40	98.30	1.87	26.45	26.45	97.66	1.92	24.78	24.78	97.03	1.96
75.20	48.66	48.66	98.30	20.05	50.94	50.94	97.66	20.21	64.03	64.03	97.03	20.37
36.40	19.12	19.12	98.30	2.44	28.68	28.68	97.66	2.48	27.23	27.23	97.03	2.53
79.50	33.20	33.20	98.30	22.64	42.51	42.51	97.66	22.81	44.31	44.31	97.03	22.98
27.40	18.86	18.86	98.30	0.57	20.94	20.94	97.66	0.59	25.11	25.11	97.03	0.61
22.30	2.94	2.94	98.30	0.07	9.19	9.19	97.66	0.08	9.89	9.89	97.03	0.08
58.10	28.95	28.95	98.30	10.81	30.90	30.90	97.66	10.92	43.40	43.40	97.03	11.03
15.50	2.32	2.32	98.30	0.18	2.54	2.54	97.66	0.17	6.71	6.71	97.03	0.16
61.80	32.28	32.28	98.30	12.64	36.59	36.59	97.66	12.77	49.78	49.78	97.03	12.89
44.00	14.98	14.98	98.30	4.83	20.53	20.53	97.66	4.90	34.42	34.42	97.03	4.97
23.00	14.65	14.65	98.30	0.11	18.81	18.81	97.66	0.12	20.90	20.90	97.03	0.13
61.10	26.27	26.27	98.30	12.29	33.22	33.22	97.66	12.41	24.89	24.89	97.03	12.53
26.00	19.06	19.06	98.30	0.38	13.51	13.51	97.66	0.40	17.68	17.68	97.03	0.42

Table 5. 20 Calculation of runoff using S and θ_o relation for Finger Millet

P (mm)	8%				12%				16%			
	Qobs (mm)	θo (%)	Scomp (mm)	Qcomp (mm)	Qobs (mm)	θo (%)	Scomp (mm)	Qcomp (mm)	Qobs (mm)	θo (%)	Scomp (mm)	Qcomp (mm)
34.20	11.59	11.59	130.33	0.48	15.06	15.06	129.63	0.50	26.17	26.17	128.94	0.52
75.20	49.82	49.82	130.33	13.45	54.61	54.61	129.63	13.57	68.35	68.35	128.94	13.69
36.40	13.34	13.34	130.33	0.76	24.29	24.29	129.63	0.78	30.01	30.01	128.94	0.81
79.50	24.17	24.17	130.33	15.54	34.87	34.87	129.63	15.67	41.53	41.53	128.94	15.79
27.40	17.47	17.47	130.33	0.01	20.25	20.25	129.63	0.02	25.80	25.80	128.94	0.02
22.30	1.55	1.55	130.33	0.11	5.72	5.72	129.63	0.10	10.44	10.44	128.94	0.10
58.10	16.31	16.31	130.33	6.32	25.34	25.34	129.63	6.40	35.06	35.06	128.94	6.47
15.50	2.54	2.54	130.33	0.93	3.15	3.15	129.63	0.91	3.93	3.93	128.94	0.89
61.80	28.42	28.42	130.33	7.69	38.67	38.67	129.63	7.78	50.47	50.47	128.94	7.86
44.00	10.81	10.81	130.33	2.17	18.98	18.98	129.63	2.21	17.75	17.75	128.94	2.25
23.00	12.56	12.56	130.33	0.07	16.04	16.04	129.63	0.07	16.73	16.73	128.94	0.06
61.10	29.05	29.05	130.33	7.42	24.05	24.05	129.63	7.51	42.94	42.94	128.94	7.59
26.00	6.56	6.56	130.33	0.00	9.34	9.34	129.63	0.00	20.45	20.45	128.94	0.00

Table 5. 21 Calculation of runoff using S and θ_o relation for Fallow Land

P (mm)	8%				12%				16%			
	Qobs(mm)	θo (%)	Scomp (mm)	Qcomp (mm)	Qobs (mm)	θo (%)	Scomp (mm)	Qcomp (mm)	Qobs (mm)	θo (%)	Scomp (mm)	Qcomp (mm)
34.20	8.12	8.12	75.42	3.87	18.12	8.12	74.83	3.93	20.62	20.62	74.24	4.00
75.20	45.98	45.98	75.42	26.66	56.87	45.98	74.83	26.86	64.92	64.92	74.24	27.06
36.40	17.79	17.79	75.42	4.70	26.07	17.79	74.83	4.77	32.29	32.29	74.24	4.85
79.50	22.09	22.09	75.42	29.67	38.20	22.09	74.83	29.88	40.14	40.14	74.24	30.10
27.40	16.00	16.00	75.42	1.73	13.30	16.00	74.83	1.77	20.25	20.25	74.24	1.82
22.30	4.61	4.61	75.42	0.63	6.42	4.61	74.83	0.65	14.94	14.94	74.24	0.68
58.10	23.26	23.26	75.42	15.62	33.67	23.26	74.83	15.77	35.90	35.90	74.24	15.92
15.50	2.54	2.54	75.42	0.00	5.32	2.54	74.83	0.00	4.54	4.54	74.24	0.01
61.80	38.67	38.67	75.42	17.87	31.45	38.67	74.83	18.03	45.61	45.61	74.24	18.19
44.00	12.20	12.20	75.42	8.01	17.75	12.20	74.83	8.12	30.70	30.70	74.24	8.22
23.00	14.65	14.65	75.42	0.75	13.81	14.65	74.83	0.78	20.90	20.90	74.24	0.81
61.10	33.22	33.22	75.42	17.44	25.72	33.22	74.83	17.60	48.50	48.50	74.24	17.76
26.00	13.51	13.51	75.42	1.38	10.68	13.51	74.83	1.42	19.06	19.06	74.24	1.46

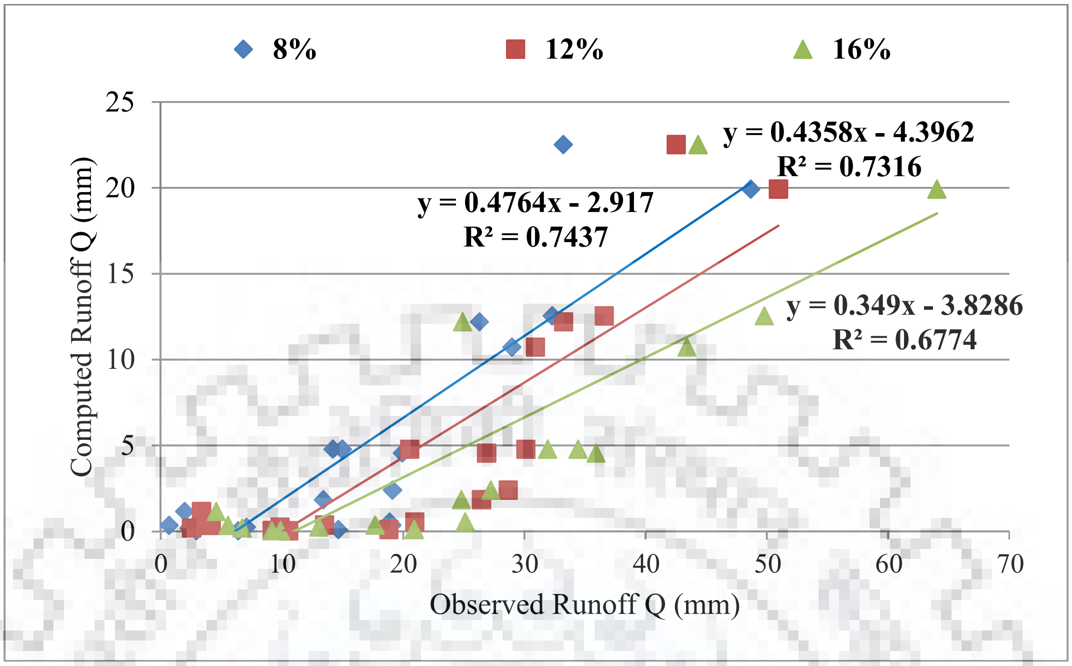

Figure 5. 16 Observed and Computed Runoff (Maize)

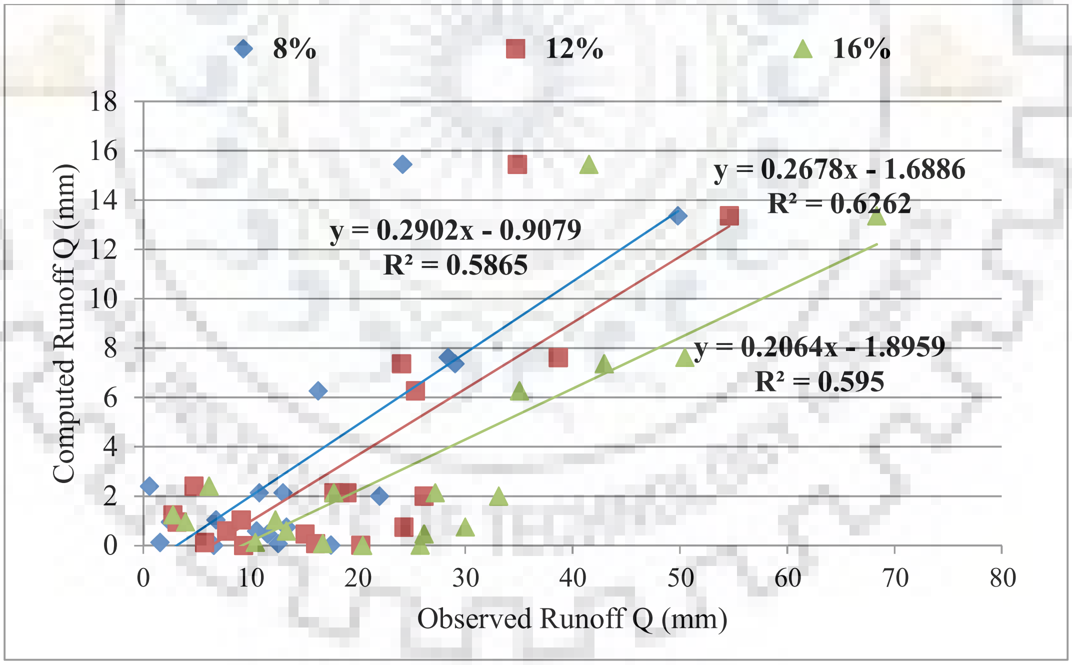

Figure 5. 17 Computed and Observed Runoff (Finger Millet)

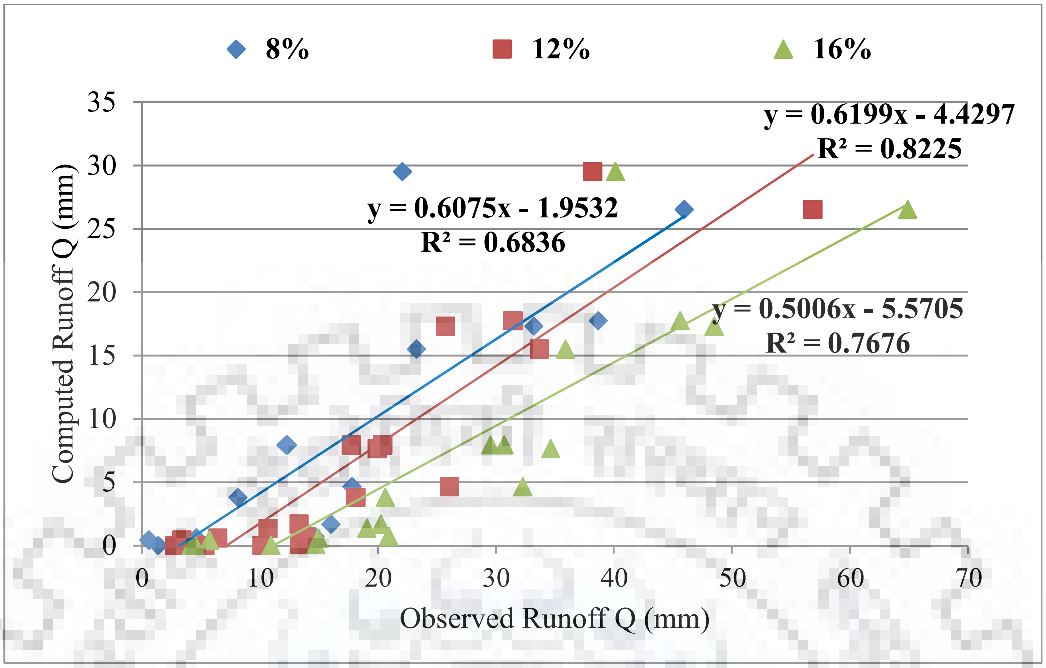

Figure 5. 18 Computed and Observed Runoff (Fallow land)

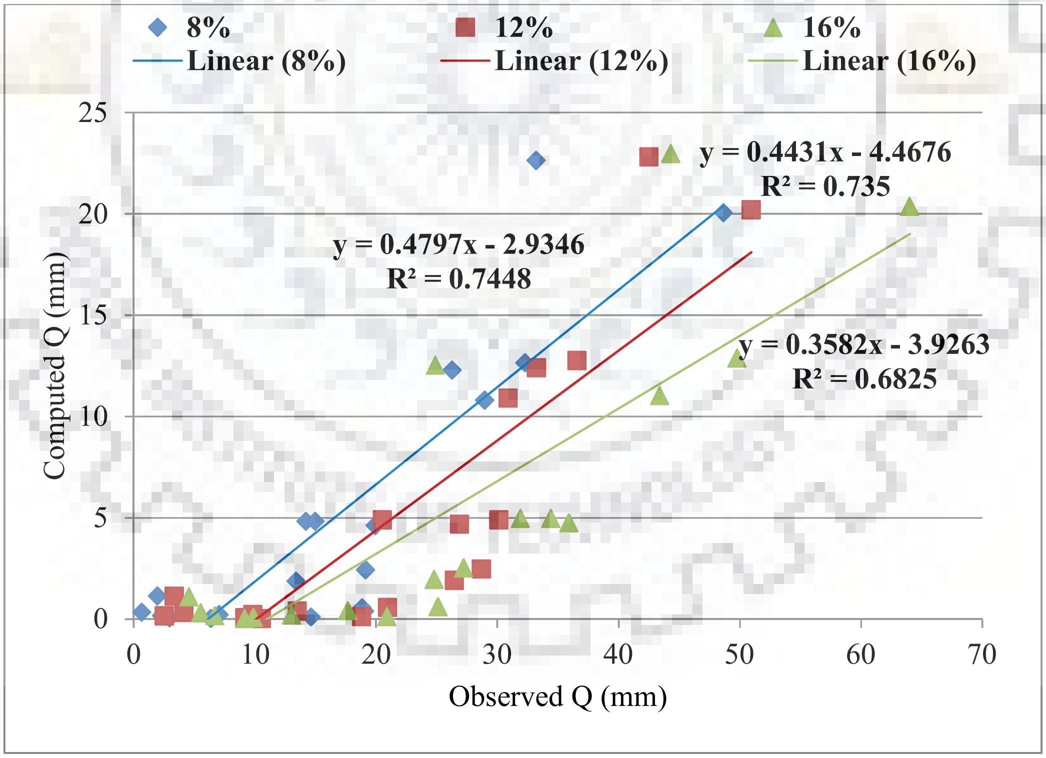

Figure 5. 19 Computed (without slope correction) and Observed Runoff for maize

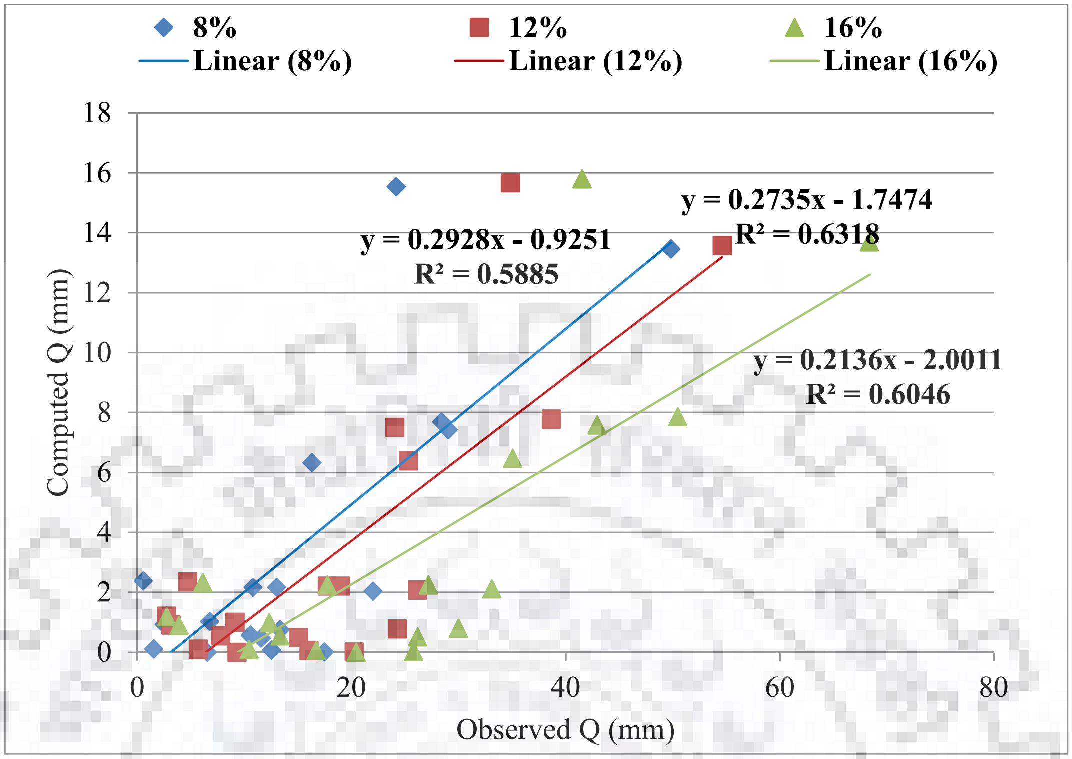

Figure 5. 20 Computed (without correction) and Observed Runoff for finger millet

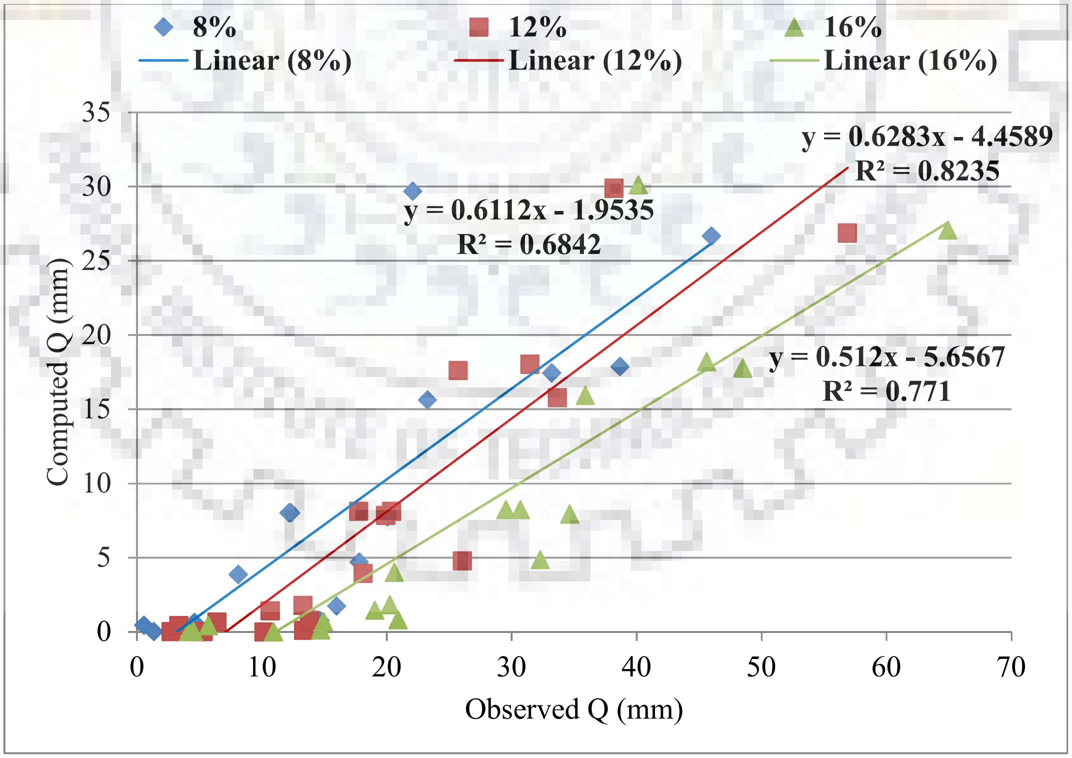

Figure 5. 21 Computed (without slope correction) and Observed Runoff for fallow

5.5.3 Effect of Slope on CN and Runoff

The effect of slope on CN and runoff is analyzed between 8% plots, 12% plots, & 16% plots. It is clear that the curve number (Figure 5.10 to 5.13) and runoff (Figure 5.16 to 5.21) values are lower for 8% plot than for 12% and 16% plot. Similarly, the curve number (Figure 5.10 to 5.13) and runoff (Figure 5.16 to 5.21) values are lower for 12% plot than 16% plot. Notably, the effect of slope on CN and runoff generation is remarkable for low rain events, largely because the opportunity time available for infiltration to occur on 8% slope was more than that on the field of 16% slope. It is also reliable with the usual expectation. The high magnitude rain events, however, do not follow such a trend, rather exhibit a reverse trend. Notably, the slope as such affects the velocity of the runoff with which it will reach the outlet, and thus, affects the opportunity time (= length of plot/velocity). Larger the slope and larger will be the velocity generated, the shorter will be the time for infiltration to occur, and therefore, more will be the runoff (or CN) generated. Thus, the larger slope is to produce larger runoff (or CN), and vice versa, which is in contrast with the observations for highest rain events.

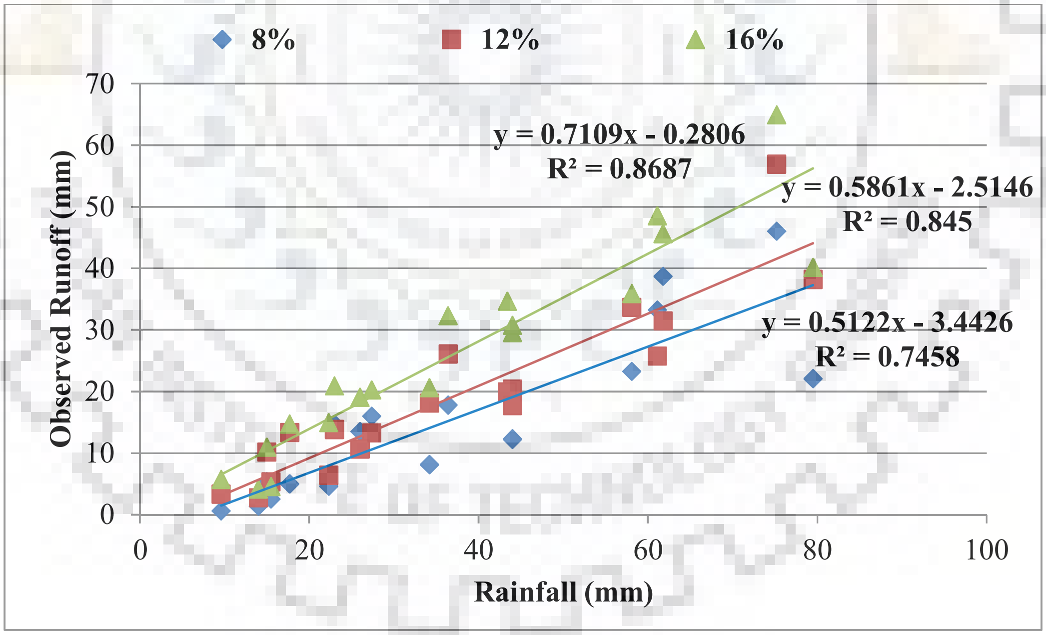

Figure 5. 22 Rainfall Vs Runoff for three slopes (Fallow Land)

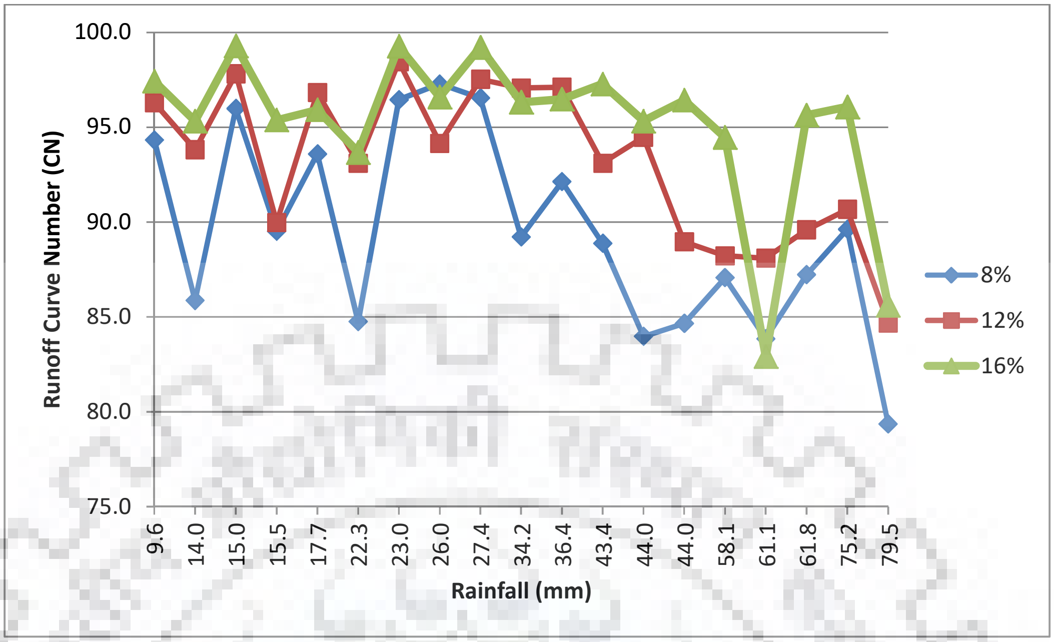

Figure 5. 23 Variation of CN with Rainfall (Maize)

The plot experiments were conducted to investigate the effects of land use on watershed runoff for steep slopes, effects of watershed slope on CN and runoff and to test the performance of the slope-adjusted SCS-CN method in predicting runoff from different land uses and slopes using SCS-CN model from natural rainfall, consequent observed runoff, and other experimental works. The field had 3 slopes of 8%, 12%, and 16% and each slope had 3 plots of size 12m x 3m. HSG of all the fields was the same as ‘A’ and initial hydrologic condition of all the fields was poor (with no grass/vegetal cover). The land use of the field was agricultural and cultivated with maize, finger millet and one plot from each slope were left fallow. The following conclusions are derived from the study:

- The outputs of the study of the effects of soil, land use, slope and AMC on runoff and CN are homogenous with the usual expectations. The SCS-CN parameter S shows a well-known inverse relation with measured AMC.
- The effect of slope is not as important as that of soil on both runoff and CN, and thus, it is viable that a plot of higher grade may give lesser runoff depends on soil type. But in our case, the plot with the highest slope generated the highest runoff as well as CN because of same soil group in all experimental plots. Therefore, the fallow land produces the highest runoff and CN from all the slopes.
- For more accurate runoff prediction, the effect of slope-adjustment was investigated significant for slopes more than 5%. In calculating the computed potential maximum retention and computed runoff, the slope adjustment formula was employed.

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