APPLICATION OF MODIFIED SCS-CN METHOD

A DISSERTATION

Submitted in partial fulfillment of the requirements for the award of the degree

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In

WATER RESOURCES DEVELOPMENT (CIVIL)

By

NABEEN KUMAR SHRESTHA

(17548017)

DEPARTMENT OF WATER RESOURCES DEVELOPMENT AND MANAGEMENT

INDIAN INSTITUTE OF TECHNOLOGY, ROORKEE

ROORKEE-247667 (INDIA)

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INDIAN INSTITUTE OF TECHNOLOGY, ROORKEE

CANDIDATE'S DECLARATION

I hereby declare that the work, which is being presented in this dissertation entitled, **"APPLICATOIN OF MODIFIED SCS-CN METHOD"**, in partial fulfillment of the requirements for the award of degree of **Master of Technology** in **"Water Resources Development (Civil)"**, submitted to the Department of Water Resources Development and Management, Indian Institute of Technology Roorkee, India, is a genuine record of my own work carried out during a period from June 2018 to May 2019 under the guidance of **Dr. S.K. Mishra**, Professor of Department of Water Resources Development and Management (WRD&M), and **Dr. P. K. Singh**, Scientist D, Water Resources Systems Division (WRSD), National Institute of Hydrology, Roorkee, India.

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

Place: Roorkee

Date: May 2019

Nabeen Kumar Shrestha

Enrollment No.17548017

CERTIFICATE

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

Dr. P.K. Singh
Scientist D,
Water Resources Systems Division
National Institute of Hydrology
Roorkee –247677, India
Date: May 2019

Dr. S.K. Mishra
Professor
Department of Water Resources Development & Management
Indian Institute of Technology
Roorkee –247677, India
Date: May 2019

ABSTRACT

Agricultural experimental field was used for application of the modified (MS 2002) SCS-CN model on the data from a study area located in Toda Kalyanpur, Roorkee, Haridwar, Uttarakhand (latitude: 29°50'5.17"N, longitude: 77°55'15.60"E). For experiment, 9 plots were constructed each having three plots of 8%, 12% and 16% slopes. Each plot had size of 12m x 3m and connected to collection chamber of size 1m x 1m x 1m with approach channel to observe the runoff generated. A five slotted flow divisor made of thin steel plate was installed just upstream of the chamber which allowed runoff to collection chamber from only one slot to reduce the size of chamber. Similarly, an ordinary rain gauge (ORG) was also installed to measure daily rainfall (mm).

The degree of complexity of runoff generation is very high, dynamic in nature and influenced by many interrelated physical factors. These physical factors vary temporally as well as spatially and cause uncertainty in runoff prediction. Therefore, predicting the runoff generated by rainfall accurately becomes a more challenging work. At the same time accurate prediction of runoff is prerequisite for the effective management and development of water resources. Thus, there exist a number of methods being used to estimate the runoff. The existing and modified SCS-CN methods are the two methods among many others. These methods are used because of their easy use and based on single input parameter curve number (CN), which incorporates all the physical factors affecting the runoff. CN, the key parameter of SCS-CN method, is a function of hydrological condition, land use/land cover, soil type, soil moisture and hydrological soil group. Therefore, determining the accurate value of CN is the most important work in CN hydrology. Similarly, prediction of accurate initial abstraction ratio (λ) as well as best performing model are other important works for obtaining improved results.

After the experimental study, the curve number observed (CN_{obs}) from the existing SCS-CN model employing frequency matching method was higher than that from the modified SCS-CN model. Similarly, the optimized curve number (CN_{opti}) calculated using existing SCS-CN method was higher than modified (MS 2002) SCS-CN model and therefore, the existing SCS-CN model will yield higher runoff than modified SCS-CN model (MS 2002).

Initial abstraction ratio (λ) computed by optimization technique using P-Q data has been found 0 as minimum and 0.05 as a maximum for both existing and modified SCS-CN

models. The value of λ did not match with standard value of λ=0.2, given by SCS (1985) which indicates that use of constant value of λ=0.2 may not give good results.

Nash and Sutcliffe efficiency (NSE) is the most appropriate method of evaluating model performance. NSE of two models i.e. modified (MS 2002) and existing SCS-CN model have been computed by two methods, using CN from NEH-4 table and using optimized λ and CN. While using CNs from NEH-4 table, NSE of modified (MS 2002) is found greater than the existing model, except in plot nos. 3 and 6 (Table 4.19). Similarly, using optimization technique, NSE of the modified model is found greater than the existing model in all plots (Table 4.18). Thus, the modified model (MS 2002) is more efficient than the existing model.

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Nabeen Kumar Shrestha

Enrolment No. 17548017

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ABBREVIATION

AFM	Asymptotic Fitting Method
AMC	Antecedent Moisture Condition / Antecedent Moisture Content
CN	Curve Number
CN(A)	Curve Number corresponding to HSG A
CN(B)	Curve Number corresponding to HSG B
CN(C)	Curve Number corresponding to HSG C
CN(D)	Curve Number corresponding to HSG D
$CN_2\alpha$	Curve Number corresponding to AMC II and slope α
CN_{II}	Curve Number corresponding to AMC II
$CN_{II}o$	Observed Curve Number corresponding to AMC II
CN_{NEH}	Curve Number obtained from NEH-4 table
CN_{obs}	Observed Curve Number
CN_{Opti}	Curve Number obtained from optimization technique
HSG	Hydrologic Soil Group
IWM	Irrigation Water Management
LSM	Least Square Method
LU	Land cover practice index.
LULC	Land Use Land Cover
NEH	National Engineering Hand book
NIH	National Institute of Hydrology
NRCS	Natural Resource Conservation Service
NSE	Nash and Sutcliffe Efficiency
ORG	Ordinary Rain Gauge
PBIAS	Percentage Bias
RMSE	Root Mean Square Error
SCS-CN	Soil Conservation Service Curve Number
SRRG	Self-Recording Rain Gauge
TDR	Time Domain Reflectometry
TR	Technical Release
USDA	United State Department of Agriculture
VWC	Volumetric Water Content
WRD	Water Resource Development

SYMBOL

C	Runoff coefficient
F	Total infiltration
fc	Infiltration capacity (mm/hr)
F_c	Static infiltration
F_d	Dynamic infiltration
I_a	Initial abstraction
K	Seasonal index, a function of time and temperature of the year
M	Soil Moisture
M^*	Ratio of soil moisture to rainfall $\left(\frac{M}{P}\right)$
^oC	Degree Centigrade
P	Rainfall
P_5	5 days antecedent rainfall
Pe	Effective rainfall
Q	Rainfall
Qc	Computed runoff
Qo	Observed runoff
S	Potential Maximum retention
S_{abs}	Absolute Potential Maximum retention
S_r	Degree of saturation
t_p	Time of ponding
T_s	Time of storm
V_a	Volume of air
V_s	Volume of Solid
V_w	Volume of water
λ	Initial abstraction ratio

CHAPTER 1

1. INTRODUCTION

1.1 Background and Significance of Study

Water is the most valuable natural resources which plays vital role in the development of the society, country and whole world. About 71% of earth crust has covered by the water and 97% of earth's water has been hold by the ocean. Out of total water of earth only 3% is fresh water and remaining 97% water is saline. All the glacier, icecaps, ground water and surface water come under the 3% fresh water. Glacier and icecaps hold 68.7%, ground water holds 30.1%, surface water holds 0.3% and others hold 0.9% of total fresh water of universe (3%). Similarly, lakes have 87%, wetlands have 11% and rivers have only 2% of total surface water (0.3%) (Subramanya, 2018). Since river has least fraction of available water and its main input is precipitation, it is very important to know the method and process of transformation from rainfall to runoff. There are various methods of transformation which determine the runoff generated from precipitation. The Clark method (Clark, 1945), Snyder method (Snyder, 1938), and Soil Conservation Service Curve Number (SCS-CN) method (SCS, 1956), are some of the well-known method.

The Soil Conservation Service Curve Number (SCS-CN) method is one of the widely used methods for calculating runoff volume from rainfall in ungauged watershed. The main causes of its popularity are its simplicity, easiness to understand and apply, and stable to predict excess runoff from ungauged catchment. It incorporates most of the runoff producing watershed characteristics, like type of soil, land use land cover, hydrologic soil group and antecedent moisture condition. The soil conservation service curve number (SCS-CN) method was first developed in 1954 and was documented in section no. 4 of National Engineering Handbook (NEH-4) and published in 1956 by Soil Conservation Service, Department of Agriculture, United State. The SCS-CN method was originally developed for small agricultural watersheds and has been extended and applied to rural, forest and urban watersheds also. After the evolution of SCS-CN method it has been revised many times in the year 1964, 1965, 1971, 1972, 1985 and 1993. Now a day SCS-CN is known as Natural Resource Conservation Service (NRCS) method.

1.2 Problem Definition

For the sustainable planning, development and management of water resource in any watershed, study of relation between rainfall and runoff is very essential factor. Many literatures point out that SCS-CN method developed by USDA is widely accepted and used method to calculate the rainfall generated runoff both in plot scale and watershed scale. In SCS-CN method several important hydrological parameters have been incorporated in single parameter curve number (CN) (Garen & Moore, 2005). However, it has some limitations like it overlooks impact of temporal and spatial variation of rainfall intensity, effect of morphometric parameters of catchment area and effect of dynamic process like soil surface temperature, evapotranspiration. Due to these reasons, the CN has not determined accurately (Ponce and Hawkins 1996; McCutcheon, 2006; Tedela, 2009; Garen and Moore 2005; Hjemfelt 1991; Jacobs, Myers, and Whitfield 2003; King et al., 1999; Michel et al., 2005). Some evidence show that the hydraulic structures designed by using existing SCS-CN method results over estimation of cost of the structures by billions of dollars (Schneider and McCuen 2005).

Value of CN derived by USDA was for agricultural watershed having slope 5%. But the country like India and Nepal have the watershed having different slope other than 5%. So, it is necessary to verify whether the CN and initial abstraction ratio given by USDA will comply with Indian context or not. That's why experimental plot having slope 8%, 12% and 16% have been constructed to explore the variability and suitability of the CNs for different initial abstractions. There are nine plots which are divided into 3 cluster having 8%, 12% and 16% slope. Each slope contains 3 plots each having size 12m x 3m. Maize crop had grown in 3 plots, Finger Millet had grown in another 3 plots and remaining 3 plots had been left as Fallow land each having slope 8%, 12% and 16% individually. A detailed description will be given in the forthcoming chapters.

1.3 Modified SCS-CN Method

The existing SCS-CN method was single variable (CN) rainfall runoff modeling method. During the passage of time it had been realized that some modification is necessary in existing SCS-CN method. Mishra and Singh (1999) conducted research on existing SCS-CN method and proposed the general form of the modified model. Again, Mishra and

Singh (2002) incorporated antecedent moisture content of soil to modify the existing SCS-CN method.

1.4 Research Gap

The following are the research gaps identified:

1. Incorporation of antecedent moisture content to compute Curve Number (CN).
2. Incorporation of antecedent moisture content to compute rainfall generated runoff.
3. Optimization of initial abstraction ratio (λ) and CN (or S).
4. Relationship between initial abstraction ratio (λ) and CN (or S) computed using Modified SCS-CN model.

1.5 Objectives of the Study

The objectives of this study have been set as:

1. To determine the Curve Number (CN) from different methods for modified and existing SCS-CN model in different slope and LULC.
2. To determine initial abstraction ratio (λ) using optimization technique in different slope and LULC.
3. To compare the efficiency of modified and existing SCS-CN model in different slope and LULC.

1.6 Organization of Dissertation

This dissertation consists of five different chapters which describes their respective subject matter.

Chapter 1: Introduction

It describes about the historical background of the SCS-CN method along with how this method was evolved, why it is widely used in the world. We can find the brief overview of the experimental setup prepared for the study and necessity of experiment carried out. It also gives the short introduction of modified SCS-CN method. Similarly, objectives have been listed in this chapter.

Chapter 2: Literature Review

It gives the information about the researches carried out by different researcher in SCS-CN method considering different aspects since the beginning to till date. This shows that different researchers have tried to make SCS-CN model more efficient and versatile in all kind of watershed.

Chapter 3: Materials and Methodology

It describes about devices and instruments used to collect the data along with location of study area. We can find the information about different types of data collected during experimental work such as daily rainfall, rainfall generated runoff, antecedent moisture content, soil type, hydrological group of soil, infiltration capacity of soil. On another hand it also describes principle of SCS-CN method, factors affecting CN and its advantage/disadvantage, methods used to carry out the study and its limitations.

Chapter 4: Analysis, Result and Discussion

It contains analysis of all the collected data, application of the existing and the modified SCS-CN models, their outcomes and graphical representation of results. It also describes about comparison among the results obtained from different methods.

Chapter 5: Summary and Conclusion

It gives the concise information about the study, results obtained from analysis and conclusion.

CHAPTER 2

2. LITERATURE REVIEW

Literature review is important for research work since it gives the broad knowledge about the related research topics. It plays the vital role to find the research gap and shows the way to find our objectives of the study. Existing and Modified (MS 2002) SCS-CN models have been used to fulfill the objectives of study. That's why the literatures related with SCS-CN method have been reviewed.

2.1 Development of SCS-CN Method

In late 1930's and early 1940's extreme need for hydrologic data for design of conservation practice was felt and eventually, the Soil Conservation Service (SCS) was established under the United States Department of Agriculture (USDA). The major objectives of the SCS were to set up demonstration conservation project and evaluate the design and construction of soil and water conservation practices and hence the SCS-CN was originated. The soil conservation Act of 1935 had been changed the name of the agency to Soil Conservation Service (SCS). With passage of Flood Control Act of 1936 (Public Law 74-738), the Department of Agriculture was authorized to carry out surveys and investigations of watersheds to install measures for retarding runoff and water flow and preventing soil erosion. The first effort was to obtain infiltration rate at many locations (The conservation effort in the 1920's and 1930's was a scientific effort, yet hydrology for agricultural areas was an emerging science). SCS realized that there was a need to obtain hydrologic data and to establish a simple procedure for estimating runoff.

Using sprinkler type infiltrometer, thousands of infiltration tests on field plot of size 6' wide and multiple of 12' long had been carried out during late 1930's and early 1940's. Using these infiltration data, a rational method for estimation of runoff under various cover conditions was developed. For that purpose, three private consultants W.W. Horner, R.E. Horton and R.K. Sherman were hired. Horton, (1933) characterized the infiltration capacity from curves and Horner et al., (1940) focused on the development of infiltration capacity from small catchment data.

Andrews, (1954) grouped infiltrometer data from Texas, Oklahoma, Arkansas and Louisiana had been found that soil texture class was the only consistent characteristics within each group. Andrews had developed a graphical procedure for estimating direct runoff for a combination of soil texture, type and amount of cover, and conservation practice. In 1955 G.W. Musgrave had described a hydrologic classification of soils depending upon their infiltration rate. It had been grouped all soils into four basic groups depending on the minimum infiltration capacity, and based on laboratory tests and soil texture. The four groups were A B C and D with sand in group A with highest infiltration capacity, and clay in group D with least infiltration capacity.

2.2 Historical Development of SCS-CN Rainfall-Runoff Model

Sherman, (1942) and Sherman, (1949) might be the first person to propose rainfall runoff relation by plotting direct runoff versus rainfall. By using concept of Sherman, Mockus, (1949) published a rainfall-runoff model given as below:

$$Q = P_e[1 - 10^{-bP_e}] \quad \text{Eq. 2.1}$$

where,

Q = Direct runoff in inch

P_e = Effective rainfall (Rainfall excluding initial abstraction) in inch.

b = an index related to catchment and rainfall characteristics. It is given by,

$$b = \frac{0.0374(10)^{0.229P_5}(LU)^{1.061}}{K^{1.99}Ts^{1.333}(10)^{2.271\left(\frac{K_h}{T_s}\right)}}$$

where,

P_5 = 5-day antecedent rainfall (inches) prior to the onset of the event.

LU = Land cover practice index.

K = Seasonal index, a function of time and temperature of the year.

T_s= Storm duration

K_h = Soil index (inches/hr)

Andrews, (1954) established a graphical method to calculate runoff from rainfall for combinations of soil type and texture, the quantity of vegetative cover, and conservation practices. All of these factors are combined into parameter called as the soil-cover complex or soil-vegetation-land use complex (Miller & Cronshey, 1989). Therefore, empirical rainfall-runoff relation of Mockus, (1949) and the soil-vegetation-land complex of Andrews, (1954) constituted the building blocks of the SCS-CN method described in the Soil Conservation Service (SCS) National Engineering Handbook (NEH) Section 4 (''Hydrology'' 1985). Rallison & Miller, (1982) concisely explained the SCS-CN method as a graphical transformation and generalization of the works of Andrews, (1954) and Mockus, (1949). Hjemfelt (1991) presented a broad discussion of the method, including the tradition of the method, the derivation of curve numbers (CNs) from rainfall-runoff data, and the interpretation of antecedent moisture conditions (AMCs). Ritter and Gardner (1992) explained application of the SCS-CN method to catchment located on reclaimed shallow coal mines in central Pennsylvania.

2.3 Factors Affecting CN

The characteristics of watershed affect the parameter CN of the SCS-CN model. Selection of CN from NEH-4 table is the most sensitive work to be done to determine accurate runoff due to given rainfall. Following are main characteristics of watershed which affects the value of CN.

- Hydrological soil group (HSG)
- Antecedent moisture condition (AMC)
- Land use land cover
- Hydrologic condition of watershed
- Rainfall intensity and duration
- Turbidity
- Agricultural management practices
- Initial abstraction and climate
- Soil moisture (M)

2.3.1 Hydrological soil group (HSG)

Soil conservation service divided the soils into four hydrological soil groups (HSGs). These are A, B, C and D according to their respective infiltration capacity and transmissivity. When soil group changes from A to D, CN increases and hence surface runoff will also increase. A brief description of HSGs is being given here as follows.

Group A (low runoff potential):

This soil has the properties of high rate of infiltration (0.76 to 1.14 cm/hr) though it is in wet condition. The transmissivity of this kind of soil is very high due to its porous nature. Deep sand, deep loess and aggregated silt are the common example of this type of soil. These soils have more than 90% sand or gravel. The properties of hydrological soil group A are shown in Table 2.1 below (**NEH-360**)

Table 2.1 Properties of hydrological soil group A

Properties	Ranges
Textures	< 10% clay > 90% sand or gravel or both
Saturated hydraulic conductivity of all soil layer	> 40 micrometer per second
Depth of any impermeable layer	> 50 cm
Depth of water table	> 60 cm
Soil profile depth	> 100 cm to water impermeable layer
Saturated hydraulic conductivity of soil layer within 100 cm	Exceeds 10 micrometer per second

Group B (moderately low runoff potential):

This soil has the properties of moderate rate of infiltration (0.38 to 0.76 cm/hr) though it is in wet condition. The transmissivity of this kind of soil is moderately high due to its moderate porous nature. Shallow sand and shallow loess are the common example of this type of soil. These soils have 10 to 20 % clay and 50 to 90 % sand. The properties of hydrological soil group A are shown in Table 2.2 below (**NEH-360**)

Table 2.2 Properties of hydrological soil group B

Properties	Ranges
Textures	10% to 20% clay 50% to 90% sand or loam, silt loam or silt
Saturated hydraulic conductivity between surface and 50 cm	10 to 40 micrometer per second
Depth of any impermeable layer	> 50 cm
Depth of water table	> 60 cm

Properties	Ranges
Soil profile depth	100 cm to water impermeable layer
Saturated hydraulic conductivity of soil layer within 100 cm	Exceeds 4 micrometer per second but less than 10 micrometer per second.

<u>Group C (moderately high runoff potential):</u>

This soil has the properties of low rate of infiltration (0.12 to 0.38 cm /hr) though it is in wet condition. The transmissivity of this kind of soil is moderately low due to its low porosity. Shallow sandy loam, clay loam and red sandy loam are the common example of this type of soil. These soils have 20 to 40 % clay, less than 50 % sand and remaining loam, silt loam, sandy clay loam, clay loam etc. The properties of hydrological soil group A are shown in Table 2.3 below (**NEH-360**)

Table 2.3 Properties of hydrological soil group C

Properties	Ranges
Textures	20% to 40% clay <50% sand or >35% rock fragment Loam, silt loam sandy clay loam, silty loam
Saturated hydraulic conductivity between surface and 50 cm	1 to 10 micrometer per second
Depth of any impermeable layer	> 50 cm
Depth of water table	> 60 cm
Soil profile depth	100 cm to water impermeable layer
Saturated hydraulic conductivity of soil layer within 100 cm	Exceeds 0.4 micrometer per second but less than 4 micrometer per second.

<u>Group D (high runoff potential):</u>

This soil has the properties of low rate of infiltration (0 to 0.12 cm/hr) though it is in wet condition. The transmissivity of this kind of soil is very low due to its low porosity. Clay, black cotton soil and saline soil are the common example of this type of soil. These soils have greater than 40 % clay and less than 50 % sand.

The classification made in NEH-4 is based on presumption that (i) soil is bare (ii) maximum swelling of soil takes place (iii) intensity of rainfall exceeds infiltration rate.

The classification had been made based on soil of similar depth, organic matter content, structure and degree of swelling when saturated and will respond in an essentially fashion during a storm of excessively high rainfall intensities. The classification of soil based on minimum rate of infiltration and based on texture (**TR-55 USDA, SCS 1975, 1986, NEH-360**) has been shown in Table 2.4 and Table 2.5 respectively.

Table 2.4 Hydrological soil group of soil based on infiltration rate

Hydrological Soil Group (HSG)	Minimum infiltration rate (cm/hr)
A	0.76 – 1.14
B	0.38 – 0.76
C	0.12 – 0.38
D	0 – 0.12

Table 2.5 Hydrological soil group of soil based on texture (NEH-360)

Hydrological Soil Group (HSG)	Texture
A	< 10% clay > 90% sand or gravel or both Sand, loamy sand, sandy loam
B	10% to 20% clay 50% to 90% sand or loam, silt loam or silt
C	20% to 40% clay <50% sand or >35% rock fragment Loam, silt loam sandy clay loam, silty loam
D	Clay loam, silty clay loam, sandy clay, silty clay or clay.

(Source: Curve Number Hydrology NEH-360)

2.3.2 Antecedent Moisture Condition (AMC)

Antecedent moisture condition (AMC) is defined as the moisture content present in the soil at the beginning of the rainfall event. If soil is fully wet or saturated all rain water will transformed into runoff without getting loss as infiltration. But if the soil is not fully wet or saturated some or all part of rain water may get infiltrated into the ground and rainwater may or may not get transformed into runoff. Hence, moisture available in soil prior to rainfall event affects curve number CN. AMCs are divided into three categories as given below.

AMC-I:

In this type, soil is dry but the moisture content will not reach up to the wilting point. Satisfactory cultivation can be done in this condition. In AMC-I, very low runoff can be expected.

AMC-II:

In this type, soil has average moisture condition. In this condition fair amount runoff can be expected. The CN given in NEH-4 table corresponds to AMC-II.

AMC-III:

Enough rainfall has occurred within immediate past 5 days. So, the soil is in saturated condition. In this condition, maximum runoff can be expected.

Integration of AMC in the existing SCS-CN method in terms of three AMCs exhibit sudden jump in CN. To avoid sudden jump in CN, Mishra and Sing (2002) introduced SCS-CN based equation to determine antecedent moisture from 5 days antecedent rainfall. Table 2.6 shows the AMCs according to P_5.

Table 2.6 Antecedent soil moisture condition (AMC)

AMC Type	Total rain in previous 5 days	
	Dormant season	Growing season
I	Less than 13 mm	Less than 36 mm
II	13 to 28 mm	36 to 53 mm
III	More than 28 mm	More than 53 mm

(Source: Soil Conservation Service Curve Number (SCS-CN) Methodology by Mishra and Singh, 2003).

2.3.3 Land Use / Land Cover

Land use land cover describes the watershed cover and includes every kind of vegetation, litter and mulch, and fallow as well as nonagricultural uses, such as water surfaces, roads, roofs, etc. A forest soil, rich in organic matter, allows greater infiltration than a paved one in urban areas.

Urban land:

Urban lands are covered by building, road, railway, pavement etc., which are impervious in nature. Its imperviousness reduces the infiltration capacity of the land and produces the high runoff. Urban land has the high value of CN.

Agriculture land:

The land in which crop can be grown is classified as the agriculture land. It is categorized into cultivated and uncultivated land. Uncultivated land has the higher runoff potential than the cultivated land and CN value as well.

Wood and forest land:

The forest having coniferous tree has higher runoff potential and CN value than deciduous tree. Herbaceous forest exhibit the highest runoff potential or CN value and Oak-aspen forest shows the lowest runoff potential.

2.3.4 Hydrologic Condition of Watershed

The hydrologic condition of watershed is defined as percentage land coverage area. Larger the area covered by grass or crop, more will be the infiltration, produces less surface runoff which results less soil erosion. Such hydrological condition is said to be good hydrologic condition of watershed. It is said good because it conserves soil from erosion. Similarly, lesser the area covered by grass or crop, less will be the infiltration, produces more surface runoff which results more soil erosion. Such hydrological condition is said to be poor hydrologic condition of watershed. It is said poor because it does not help to conserve soil from erosion.

The CN will be the highest for poor, average for fair, and the lowest for good condition, leading to categorize the hydrologic condition into three groups: good, fair, and poor, depending on the areal extent of grasslands or native pasture or range, as shown in Table 2.7.

Table 2.7 Classification of native pasture or range

Vegetation condition	Hydrologic condition	Infiltration	CN
Heavily grazed and no mulch or plant cover less than 50% of the area.	Poor	low	high
Not heavily grazed and plant cover is in 50-75% of the area.	Fair	average	average
Lightly grazed and plant cover in more than 75% of the area.	Good	high	low

(Source: SCS, 1971).

2.3.5 Rainfall Intensity and Duration

For a given rainfall amount, the runoff will be more in high rainfall intensity and vice versa. If the rainfall depth is constant, the greater the rainfall intensity, lesser will be the time duration and vice versa. Time of contact of rain with ground is less in high intensity rainfall; hence opportunity for infiltration is less producing more runoff.

High intensity rainfall also breaks down the soil structure and forms a layer of fine soils which clog the pores of the underneath soil reducing the infiltration and porosity, ultimately S is decreased, in turn CN is increased. That is why barren land produces more runoff than covered land. Relation between rainfall intensity and curve number have shown in Table 2.8 below.

Table 2.8 Relationship between intensity of rainfall and curve number (CN)

Rainfall intensity	CN
Higher	high
Lower	Low

2.3.6 Turbidity

Turbidity refers to impurities of water that affect infiltration by the process of clogging of soil pores and consequently affecting the soil conductivity. Contaminated water with dissolved minerals, such as salts, affects the soil structures and subsequently reduces the infiltration which increases value of CN.

2.3.7 Agricultural Management Practices

Agricultural management system consists of various type of tillage, surface cover, vegetation and organic matter present in the soil. Land treatment is a change in existing land use land cover which includes contouring, different type of tillage, terracing and management practice such as crop rotation and grazing control. Various tillage practice such as chisel plough, moldboard plough and no plough extremely affect the infiltration. Moldboard plough may increase soil porosity from 10-20%, depending on the soil texture, and increases infiltration rates over non-tilled soils Brakensiek & Rawls, (1988). Higher the organic matter present in soil lower will be the bulk density which increases porosity and infiltration and in turn increases S or decreases CN (Rawls et al., 1983).

2.3.8 Initial Abstraction and Climate

Initial abstraction consists of interception, surface detention, evaporation and infiltration. When rainfall occurred some part of it never reaches to the ground, they are intercepted by leaves and branches of plants and trees. Some parts are held by surface detention, some parts are held by infiltration and finally goes back into the atmosphere due to evaporation. Therefore, initial abstraction depends on evaporation and since, S also includes initial abstraction it gets affected by evaporation. Evaporation is primarily governed by meteorological factors of watershed such as temperature, radiation, sunshine hour, wind and humidity which describe the climate.

Therefore, the effect of the climatic condition of the watershed is accounted by the SCS-CN method in terms of the initial abstraction. The higher is the amount of initial abstraction, the lower will be the runoff for a given rainfall amount in a watershed and vice versa. Thus, the initial abstraction reduces the runoff potential of the watershed and, in turn, the curve number (CN). The temperature also affects the viscosity of water, which, in turn, affects, to some extent, the surface tension and finally curve number (CN).

2.3.9 Soil Moisture (M)

Soil consists of air, water and soil solid. The volume of solid (Vs) is constant where as volume of air (V_a=S) and volume of water (V_w=M) i.e. moisture varies time to time but the sum of volume of air and volume of water remains unchanged i.e. volume of void

(V_v = Sabs). As the volume of moisture increases, volume of air will decrease, that means potential maximum retention (S) of soil decreases. As S decreases curve number (CN) will increases, that means as soil moisture increases, CN increases

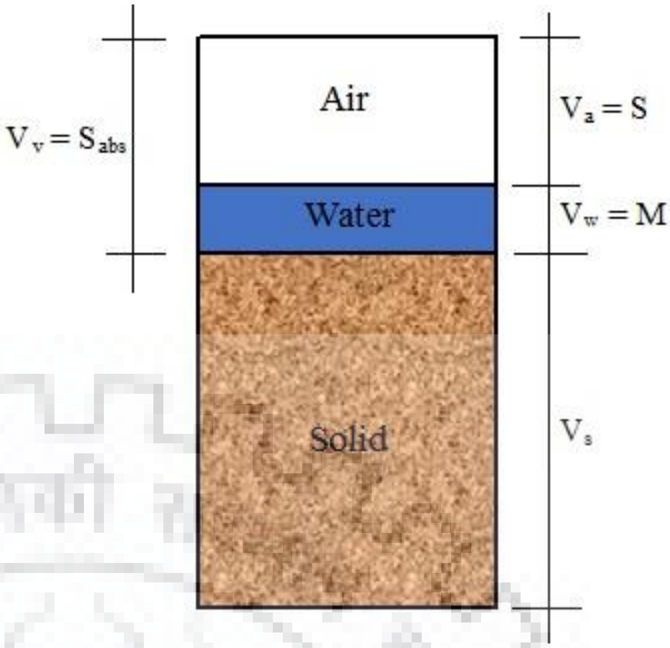


Figure 2.1 Three phase diagram of soil

2.4 Conversion of CN with Respect to AMC and HSG

The Soil Conservation Service related the variation of CN with three levels of AMCs they are AMC I, AMC II, and AMC III. Mathematically these relationships are expressed as

Ponce and Hawkins 1996):

$$CN_I = \frac{CN_{II}}{2.281 - 0.01281CN_{II}} \quad \text{Eq. 2.2}$$

$$CN_{III} = \frac{CN_{II}}{0.427 + 0.00573CN_{II}} \quad \text{Eq. 2.3}$$

Sobhani (1975):

$$CN_I = \frac{CN_{II}}{2.334 - 0.01334CN_{II}} \quad \text{Eq. 2.4}$$

$$CN_{III} = \frac{CN_{II}}{0.4036 + 0.005964CN_{II}} \quad \text{Eq. 2.5}$$

Chow et al. (1988):

$$CN_I = \frac{4.2CN_{II}}{10 - 0.058CN_{II}} \quad \text{Eq. 2.6}$$

$$CN_{III} = \frac{23CN_{II}}{10 + 0.13CN_{II}} \quad \text{Eq. 2.7}$$

Mishra et al. (2008):

$$CN_I = \frac{CN_{II}}{2.2754 - 0.012754CN_{II}} \quad \text{Eq. 2.8}$$

$$CN_{III} = \frac{CN_{II}}{0.43 + 0.0057CN_{II}} \quad \text{Eq. 2.9}$$

While developing NEH-4 CN tables from inadequate sets of specific land use/land cover and soil type, the transformation of CN between different HSGs was generalized by a graphical relationship developed by Mockus called the "Curve Number Aligner" and is represented by the following equations (Rallison, 1978, and Enderlin & Markowitz, 1962):

$$\text{CN(A)} = -60.8 + 1.6083 * \text{CN(B)} \quad \text{Eq. 2.10}$$

$$\text{CN(C)} = 34.0 + 0.6600 * \text{CN(B)} \quad \text{Eq. 2.11}$$

$$\text{CN(D)} = 47.2 + 0.5283 * \text{CN(B)} \quad \text{Eq. 2.12}$$

Statistically AMC I, AMC II and AMC III are found to represent 90%, 50% and 10% cumulative probability of exceedance of runoff depth for a given rainfall respectively (Hjelmfelt, 1982).

To derive the average CN values for AMC II mathematically from the event-based rainfall runoff data of a gauged watershed, (Hawkins, 1993) suggested S (or CN) computation using the following equation.

$$S = 5[P + 2Q - \sqrt{(4Q^2 + 5PQ)}] \quad \text{Eq. 2.13}$$

where, S = Event based maximum potential retention (mm); P = Rainfall (mm); and Q = Runoff (mm).

2.5 Existing SCS-CN Method

The water balance equation as well as two fundamental hypotheses are the basic components of SCS-CN method. The first hypothesis states that ratio of the actual amount of direct surface runoff (Q) to the rainfall (P-I_a) will be equal to ratio of the amount of cumulative infiltration (F) excluding I_a to the amount of the potential maximum retention (S). Similarly, according to second hypothesis, initial abstraction (I_a) is directly proportional to the potential maximum retention (S). Thus, the SCS-CN method consists of:

(a) water balance equation:

$$P = I_a + F + Q \qquad \text{Eq. 2.14}$$

(b) Proportional equality hypothesis:

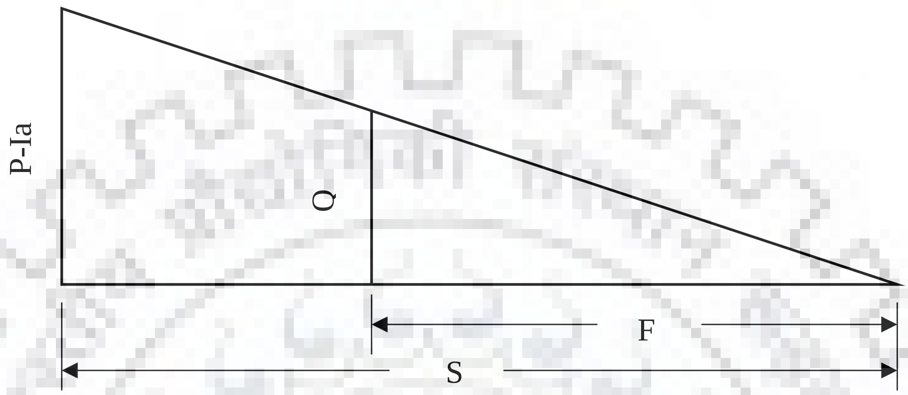


Figure 2.2 Proportionality concept of SCS-CN method

$$\frac{Q}{P - I_a} = \frac{F}{S} \qquad \text{Eq. 2.15}$$

(c) I_a-S hypothesis:

Initial abstraction is directly proportional to the potential maximum retention.

$$Ia = \lambda S \qquad \text{Eq. 2.16}$$

where, P = total rainfall (mm), I_a = initial abstraction (mm), F = Cumulative infiltration excluding I_a, (mm) Q = Direct runoff (mm), and S = Potential maximum retention (mm) or infiltration, also called potential post-initial abstraction retention (McCuen 2002).

The basic hypothesis of SCS-CN method is the proportionality concept. From this hypothesis we can conclude that as Q tends to (P-I_a), F tends to S. This proportionality allows partitioning of (P-I_a) into two part as surface water (Q) and subsurface water (F). The second hypothesis of the SCS-CN method Eq. 2.16 shows direct relation between initial abstraction to the potential maximum retention. It is based on the results of the plot between I_a and S.

Parameter S of the SCS-CN method depends on the land use, soil type, antecedent moisture condition (AMC) and hydrologic condition. The initial abstraction I_a accounts for the short-term losses, such as surface storage, interception and infiltration. Parameter λ is a regional parameter dependent on climatic and geologic factors (Bosznary 1989 ; Ramasastri & Seth, 1985). The existing SCS-CN method assumes λ to be equal to 0.2 for practical use. Many other studies carried out in the United States and other countries (SCD, 1972; Springer et al., 1980; Cazier & Hawkins, 1984) report λ to vary in the range of (0, 0.3).

Combining Eq. 2.14 and Eq. 2.15, the popular form of the SCS-CN method is obtained as:

$$Q = \frac{(P - I_a)^2}{P - I_a + S} \qquad (if\ P > Ia) \qquad \text{Eq. 2.17}$$

Q = 0, otherwise

For λ=0.2 Eq. 2.17 will be changed into the following form:

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \qquad (if\ P > 0.2S) \qquad \text{Eq. 2.18}$$

Therefore, the existing SCS-CN method (Eq. 2.18) is a single-parameter model for calculating direct runoff from daily rainfall.

Mockus, (1964) [In: Rallison, 1980] explained the physical importance of parameter S of Eq. 2.18 as follows: "Maximum potential retention S is that constant and is the maximum difference of (P-Q) that can occur for the given storm and watershed conditions. S is limited either by the infiltration rate at the soil surface or the amount of water stored in the soil profile, whichever gives the lesser S value. Since infiltration rates at the soil surface are strongly affected by the rainfall impact, they are strongly affected by the rainfall intensity."

Since the parameter S in Eq. 2.18 can vary in the range of $0 \leq S \leq \infty$, it has been mapped into a dimensionless curve number (CN), varying in the range $0 \leq CN \leq 100$, as follows:

$$S = \frac{25400}{CN} - 254 \qquad \text{Eq. 2.19}$$

The distinction between S and CN is that the parameter S is a dimensional quantity [L] whereas the CN is a non-dimensional quantity. Though CN theoretically varies in the range $0 \leq CN \leq 100$, practically it has been found that it varies from 40 to 98 (Van Mullem, 1989).

2.6 Development of Modified SCS-CN Method (Mishra and Singh (MS), 2002)

Mishra and Singh (1999) investigate on the existing SCS-CN method and presented a revised form of the existing SCS-CN model as:

$$Q = \frac{(P - I_a)^2}{S + 0.5(P - I_a)} \qquad (if\ P > Ia) \qquad \text{Eq. 2.20}$$

Q = 0 otherwise

where,

Q = Runoff in mm

P = Rainfall in mm

I_a = Initial abstraction in mm

S = Maximum potential retention in mm.

In general form, above equation can be written as:

$$Q = \frac{(P - I_a)^2}{S + a(P - I_a)} \qquad (if\ P > Ia) \qquad \text{Eq. 2.21}$$

Q = 0 otherwise

where, a = Constant.

Using the runoff coefficient ($C=Q/(P-I_a)$) is equal to degree of saturation ($C=S_r$) concept, Mishra and Singh (2002) modified the existing SCS-CN equation of direct runoff for antecedent moisture M. Mishra and Singh modified proportionality equality equation for antecedent moisture as:

$$\frac{Q}{P - I_a} = \frac{F + M}{S + M}$$ Eq. 2.22

where M = antecedent moisture (mm). Substitution of Eq. *2.22* into Eq. *2.14* leads to

$$Q = \frac{(P - Ia)(P - Ia + M)}{(P - Ia + S + M)} \qquad (if\ P > Ia)$$ Eq. 2.23

Q = 0 otherwise.

where, M = antecedent moisture content in mm and it can be either measured or calculated using following formula:

$$M = 0.5[-(1 + \lambda)S + \sqrt{(1 - \lambda)^2 S^2 + 4P_5 S}\,]$$ Eq. 2.24

Here after, Eq. 2.23 (the modified SCS-CN method) is named as Mishra and Singh (MS) (2002) model. This method advantageously gets rid of sudden jumps in CNs and hence in determination of runoff by incorporating antecedent moisture content M which replace the three AMCs. It does not exhibit an explicit dependency of initial abstraction I_a on antecedent moisture content M. Further, in this method, S is optimized as a parameter, which is, in fact, a varying quantity depending on M for a given watershed.

According to (Mishra and Singh, 2004), by assuming λ equal to 0.2, M can be computed as:

$$M = 0.5[-1.2S + \sqrt{0.64S^2 + 4P_5 S}\,]$$ Eq. 2.25

To find the value of M, we should know the value of S first. So, S can be determined by following expression:

$$\frac{S}{P} = \frac{[4\lambda + 2C - \lambda C] - \sqrt{(2 - \lambda)^2 C^2 + 16\lambda}}{4\lambda^2}$$ Eq. 2.26

But if we have measured values of M from field, we can use following equation.

$$S = \frac{P}{2\lambda^2}\Big[[(2+M^*)\lambda + (1-\lambda)C] - \sqrt{(\lambda M^*)^2 + (1-\lambda)^2 C^2 + 2\lambda C\{2+(1+\lambda)M^*\}}\Big] \qquad \text{Eq. 2.27}$$

where M* = M/P.

Sahu et al. (2010) also developed a modified SCS-CN model by defining $S = S_0 - M$, where S_0 = absolute max. retention capacity, a watershed characteristic. The necessity of this new parameter (S_0) first felt and used by (Mishra and Singh, 1999) in their study (symbolized as S_{abs}). The developed form of the model is expressed as:

$$Q = \frac{(P - I_a)(P - I_a + M)}{P - I_a + S_0} \qquad if\ P > Ia \qquad \text{Eq. 2.28}$$

Q = 0 otherwise

The initial abstraction I_a is expressed as:

$$Ia = \lambda(S_0 - M) \qquad \text{Eq. 2.29}$$

Thus, Eq. 2.29 describes I_a depends upon the antecedent moisture, which is close to reality (Michel et al. 2005). Higher the value of antecedent moisture, the lower will be the initial abstraction, and vice versa.

Following equations were developed by Sahu et al., (2010) to calculate M as:

$$M = \beta\left[\frac{(P_5 - \lambda S_0)S_0}{(P_5 - \lambda S_0) + S_0}\right] \qquad for\ P_5 > \lambda S_0 \qquad \text{Eq. 2.30}$$

$$M = 0, \qquad for\ P_5 \le \lambda S_0 \qquad \text{Eq. 2.31}$$

Eq. 2.30 gives continuous values of the antecedent moisture for every value of P_5 without any abrupt change in its values, and therefore they are more rational regular expressions for determining M.

Mishra and Singh (2002a) stated that F can be divided in to the static infiltration (F_c) and dynamic infiltration (F_d). The F_c occurs largely due to gravity, and F_d due to capillarity. It was also found that the effect of Fc on direct runoff Q is similar to that of initial abstraction I_a. Based on this concept, they proposed the modified proportionality equality and the equivalent runoff equation are as:

$$\frac{Q}{P - I_a - F_c} = \frac{(F_d + M)}{S + M} \qquad \text{Eq. 2.32}$$

$$Q = \frac{(P - I_a - F_c)(P - I_a - F_c + M)}{P - I_a - F_c + M + S} \qquad if\ P \geq Ia + F_c \qquad \text{Eq. 2.33}$$

Q = 0, otherwise.

Using $S = S_0 - M$, above equation can be re-written as:

$$Q = \frac{(P - I_a - F_c)(P - I_a - F_c + M)}{P - I_a - F_c + S_0} \qquad if\ P \geq Ia + F_c \qquad \text{Eq. 2.34}$$

As in the case of original SCS-CN method S varies, the parameter S_0 will vary in the range of $0 \leq S_0 \leq \infty$. Therefore, it is expressed in terms of dimensionless curve number (CN_0), which varies $0 \leq CN_0 \leq 100$, as follows:

$$S_0 = \frac{25400}{CN_0} - 254 \qquad \text{Eq. 2.35}$$

For practical purpose, antecedent moisture M can be calculated from Eq. 2.30 and I_a from Eq. 2.29. The determination of F_c requires knowledge of rate of minimum infiltration, which depends on type of soil. Generally, data during rainfall runoff events are available with a rainfall-runoff data set and the infiltration due to gravity i.e. static infiltration F_c continues during almost the whole rainfall period except for the period of time to ponding t_p which is very small and can be neglected. An expression for F_c can be written as:

$$F_c = f_c * T_s \qquad \text{Eq. 2.36}$$

where F_c is in millimeters; f_c = minimum infiltration rate (mm/h) and T_s = storm duration (hr). The ultimate rate of infiltration achieved after saturation of the upper layer of the soil profile, i.e., after time to ponding, is F_c. The time required to attain this situation depends on the properties of soil.

2.7 Mishra et al. (2006) SCS-CN Model

Mishra et al. (2006) incorporated the antecedent soil moisture ''M' in the Ia-S relationship so Eq. 2.16 is rewritten as:

$$Ia = \frac{\lambda S^2}{S + M} \qquad \text{Eq. 2.37}$$

In above equation, when the soil is completely dry, value of M will be zero (Mishra & Singh, 2003) and Eq. 2.37 will become same as Eq. 2.16. It means Eq. 2.16 is the special case of Eq. 2.37.

Substituting Eq. 2.37 in Eq. 2.28, the resulting expression of the developed model will be:

$$Q = \frac{\left(P - \frac{\lambda S^2}{S + M}\right)\left(P - \frac{\lambda S^2}{S + M} + M\right)}{P - \frac{\lambda S^2}{S + M} + S + M} \qquad \text{Eq. 2.38}$$

In this model, antecedent moisture content (M) can be estimated using Eq. 2.24.

2.8 Slope Adjustment of CN

While using CN values from NEH-4 table for the watershed other than 5% slope, it is required to convert those CNs according to the slope of watershed. For that (Williams, 1990) carried out investigation and gave relation for slope adjustment to CN. But later it was found that (Williams, 1990) relation has not been intensively verified while doing field verification (Huang, Gallichand, Wang, & Goulet, 2006). Because of this (Huang et al., 2006) developed their own simplified relation and verified experimentally in Chinese watershed. It was found that the runoff calculated by using CN adjusted by relation given by Huang et al., (2006) was lesser than observed runoff because of choosing constant terms in their relation empirically. It was required to verify with measured rainfall runoff data. Then, Ajmal, Waseem, Ahn, & Kim, (2016) took 39 watersheds in Korea and parameterized as ‘a’ and ‘b’. By using least square error objective function they found the value of ‘a’ and ‘b’ and produce slope adjustment relation for CN. It was seen in some literature that Ajmal et al., (2016) performs better than other two models. A summary of all the three models is given in Table 2.9.

Table 2.9 Slope adjustment formulae given by different authors

SN.	Author/s	Slope adjusted CN_2
1	Sharply and Williams (1990)	$CN_{2\alpha} = \frac{1}{3}(CN_3 - CN_2)(1 - 2e^{-13.86\alpha}) + CN_2$
2	Huang et al. (2006)	$CN_{2\alpha} = CN_2\left(\frac{322.79 + 15.63\alpha}{\alpha + 323.522}\right)$
3	Ajmal et al. (2016)	$CN_{2\alpha} = CN_2\left(\frac{1.927\alpha + 2.1327}{\alpha + 2.1791}\right)$

2.9 Advantages and Limitations of SCS-CN Method

Although the SCS-CN method (SCS, 1956) is the most popular method for computing direct surface runoff from a given rainfall storm, it has some advantages and limitations which are enumerated as follows:

2.9.1 Advantages

- It is simple, predictable and stable conceptual method for estimation of runoff from given rainfall depth.
- It relies on only one parameter i.e. curve number (CN) which is a function of watershed characteristics like, Hydrologic soil group, land use, hydrologic surface condition, and antecedent moisture condition (AMC).
- It is easy to apply and most useful for ungauged watershed.
- This method is best suited for agricultural lands as it was initially intended, but extended to unban sites also.
- It is the only agency methodology which incorporates all environmental inputs.
- It is well established method in USA and in other countries as well.

2.9.2 Limitations

- It was originally developed in US geographical and climatic condition; some caution is required to use elsewhere.
- There is a lack of clear guidance regarding the use of antecedent moisture condition (AMC).
- This method is best suited for agricultural lands, but fairly for range and poorly for forest sites (Hawkins, 1984, 1993).
- This method has no explicit provision for spatial and temporal scale effect.
- It is assumed to apply for small and mid-size watersheds.
- Initial abstraction coefficient (λ) is fixed as 0.2 for practical purposes, for other values additional research is needed.
- This method does not contain any expression for rainfall duration and intensity.
- This method does not consider about the slope of the catchment.
- This method is more accurate for extreme rainfall condition.
- Theoretical value of CN can be from 0 to 100, but practically it is taken from 40 to 98 (Van Mullem, 1989).

CHAPTER 3

3. MATERIAL AND METHODOLOGY

This chapter briefly discusses about the study area, data used and the SCS-CN based models used in this research work.

3.1 Study Area

The study area is located at Toda, Kalyanpur, Roorkee, Haridwar, Uttarakhand (Latitude is 29°50'5.17"N and Longitude is 77°55'15.60"E) as shown in Fig 3.1. Its altitude from the mean sea level is 266m. The study area is situated at the sub-tropical region. It has experienced lowest temperature of -0.7 ^{o}C in winter season and highest temperature of 48 ^{o}C at summer season as per meteorological data from 1979 to 2017. Monsoon season starts from the month of June and ends in the month of September. To effectively address the objectives envisaged in this research work, a total of nine plots were constructed making cluster of three plots having 8%, 12% and 16% slope each. Different types of land use land cove were given to each cluster of experimental plots viz. maize, finger millet and fallow land. The arrangement was made in such a way that rainfall generated runoff would be collected into the collection chamber from each plot to their respective collection chamber. Out of five slots, each collection chamber got the runoff from only one flow divider slot to reduce the size of the collection chamber. Otherwise size of collection chamber would be extremely large to accommodate the heavy rainfall. So (1x1x1) m^3 sized collection chamber was constructed to reduce the cost of experimental plot.

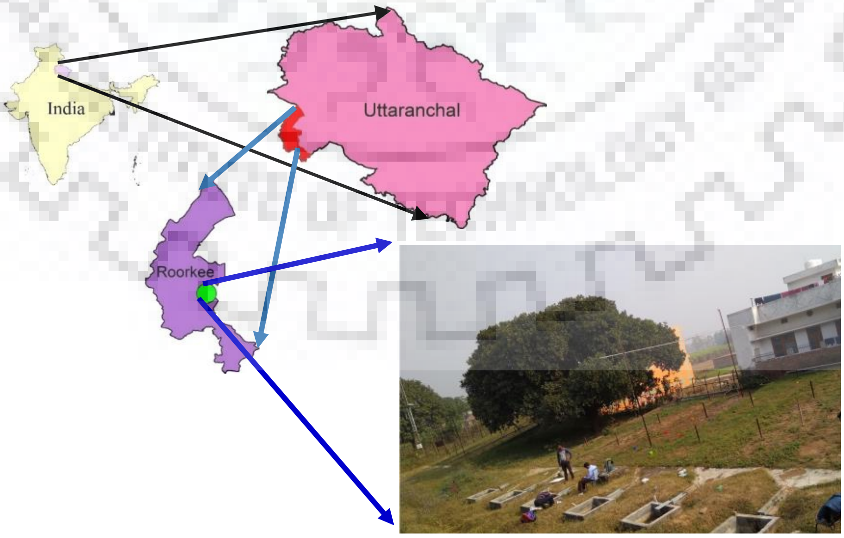


Figure 3.1 Location map of study area

3.2 Experimental Setup

Experimental setup was prepared by constructing 9 plots, each having dimension 3m x12m. Those nine plots had been divided into three cluster having 8%, 12% and 16% slope. Each cluster consists of three plots having different land use land cover, i.e., Maize crop (grown in three plots having 8%, 12% and 16% slope), Finger Millet (grown in three plots having 8%, 12% and 16% slope), and the remaining three plots were left as Fallow land. The arrangement was made in such a way that runoff generated from each plot is collected into their respective collection chamber as shown in Fig 3.2. Multi slot flow divisor with trace rack was provided just upstream of collection chamber to reduce the size of collection chamber because runoff was collected from only one slot and remaining 4 slots discharged outside the chamber. The purpose of providing trace rack in front of multi slot was to prevent it from clogging.

Figure 3.2 Experimental Plot

3.3 Device Used for Data Collection

3.3.1 Rain Gauge

Two types of rain gauges are available to measure the rainfall. One is ordinary rain gauge (ORG) and another is self-recording rain gauge (SRRG). The non-recording type rain gauge is extensively used in country like India and Nepal since it is simple and easy to installation. It consists of circular receiving area connected with funnel, collecting vessel and standard measuring cylinder. Receiving funnel and collecting vessel are enclosed into the metallic container as shown in Fig 3.3.

Figure 3.3 Ordinary type rain gauge

The rain water collected into the vessel is measured by suitably graduated measuring cylinder with an accuracy up to 0.1 mm.

Self-recording rain gauge records the continuous plot between time versus rainfall and provide important data of rainfall intensity and duration for hydrological analysis. These are the electromechanical instrument and it does not need manual observation. This type of instrument can be coupled with telemetering and data of remote area can easily be acquired at the base station.

Following are some of self-recording type rain gauge:

- Tipping bucket type.
- Weighing bucket type.
- Syphon type

3.3.2 Soil Moisture Meter (TDR 300)

Daily soil moisture content of the soil was measured using time domain reflectometry (TDR 300) which gives the volumetric water content (VWC). The probe having length of 12 cm (4.7") was used during the whole period of experimental data collection. TDR works under the principle of travel time of wave emitting from the probe and return back to the sensor. The velocity of wave in soil depends on bulk dielectric permittivity of soil matrix. Due to difference in soil matrix in different place, the travel time of wave differs place to place which results different volumetric water content of soil. TDR takes the elliptical sampling volume 3 cm out from the probe and gives average soil moisture over the length of probe. The field scout TDR 300 has been shown in Fig 3.4.

Figure 3.4 Field Scout TDR 300

Figure 3.5 Display unit of TDR 300

3.3.3 Double Ring Infiltrometer

Infiltration capacity (f_c) of soil plays vital role in the hydrological process. Runoff due to rainfall highly depends on the infiltration capacity of soil and infiltration capacity depends on the soil characteristics. Infiltration capacity of soil defines the hydrological soil group (A, B, C and D) and surface runoff depends on the curve number (CN), at the same time curve number will be different for different hydrological soil group (HSG) which ultimately gives different surface runoff (Q). So, infiltration test is essential to be carried out.

There are various methods of determining infiltration capacity of soil. Out of them widely used method is using flooding type infiltrometer. Flooding type infiltrometer is divided into single ring infiltrometer and double ring infiltrometer. We have used double ring infiltrometer in our field experiment as shown in Fig 3.6. Double ring infiltrometer consists of two concentric cylindrical ring having outer ring dia. 45 cm, inner ring dia. 30cm and height 30cm. Generally, 20cm of ring will be sunk down into the ground leaving 10cm above the ground surface.

Figure 3.6 Double ring infiltrometer

3.3.4 Multi-Slot Divisor with Collection Chamber

The arrangement was made in such a way that rainfall generated runoff would be collected into the collection chamber from each plot to their respective collection chamber. Multi-slot flow divisor was made of steel plate with odd number of slots. Size of slot has been fixed in such a way that maximum intensity of rainfall will be regulated without overtopping multi-slot channel. In our case, five slots were made and collection chamber was fed by only one slot to reduce the size of the chamber. Otherwise size of collection chamber would be extremely large to accommodate the heavy rainfall generated runoff. So

(1x1x1) m^3 sized collection chamber was constructed by using brick masonry to reduce the cost of experimental work as shown in Fig 3.7.

Figure 3.7 Multi-Slot flow divisor with collection chamber

3.3.5 Indian Standard Sieve

Indian standard sieve having sieve size 2mm, 1mm, 600-micron, 400-micron, 300-micron, 225-micron, 150-micron, 90-micron, 75-micron, 63 micron and pan at bottom is used for classification of soil. Soil sample from all the nine plots were carried out and sieve analysis was performed by shaking sieve about 10 minute using mechanical sieve shaker. Standard sieve with mechanical sieve shaker has been shown in Fig 3.8.

Figure 3.8 Sieve with mechanical sieve shaker

3.3.6 Drying Oven

Drying oven was used to dry weight of sediment sample carried out by rainfall generated runoff. It was also used to dry the soil sample to find the dry density and to carry out sieve analysis of soil. Oven was operated in standard temperature of 105^{o}C for 24 hours. Fig 3.9 shows the drying oven used in laboratory while doing experiment.

Figure 3.9 Drying oven

3.3.7 Weighing Machine

Weighing machine (Fig 3.10) was used to find the dry weight of sediment sample, core cutter soil sample and weight of soil retained on each sieve. The weighing machine used to weight sediment sample was highly sensitive. It was capable of measuring milligram.

Figure 3.10 Weighing machine

3.3.8 Graduated Beaker

Graduated beakers (Fig.3.11) are used to measure the volume of sediment laden water. We have used 500 ml capacity beaker instead of 1000 ml because time taken to evaporate all the water in oven will be less and our objective of finding weight of sediment per liter will not affect by it.

Figure 3.11 Graduated beaker

3.4 Data Collection

Various data will be acquired to determine the CN and rainfall generated runoff using the existing and MS model from experimental field plots. The procedure of data acquisition is being briefly described in the forthcoming sections.

3.4.1 Rainfall (P)

Ordinary rain gauge (ORG) was installed near the experimental field as shown in Fig. 3.12. Rainfall was measured within 8:30 to 9 AM every day since there was no self-recording rain gauge (SRRG). The measurement of rainfall data was started from 28 June 2018 and was continued till 29 Sep 2018. During that period, we found 32 rainfall events, out of which 19 events were runoff generating events. Among that 19 runoff generating events, one event on the date of 13 Aug 2018 was very heavy and recorded as 210 mm. Unfortunately, runoff generated by that rainfall could not accommodate by the collection chamber and overtopped that's why we were compelled to omit that event and could not include in analysis. It has been observed that 7.3 mm or more rainfall produced runoff. Rainfall data has been shown in Appendix A, Table A1.

When there was no natural rainfall and it was felt that crop needed water, artificial rainfall had been made by using 10 HP electric pump and spray nozzle as shown in Fig. 3.13.

Figure 3.12 Ordinary rain gauge

Figure 3.13 Artificial rainfall

3.4.2 Runoff (Q)

The arrangement was made in such a way that the runoff generated by rainfall event from each experimental plot was collected to their respective collection chamber (1m x1m x1m) through approach channel as shown in Fig.3.14. Out of five slot of flow divisor, flow was allowed to enter into the collection chamber from only one slot. Flow through remaining four slots was allowed to discharge into the drainage channel. Since the collection chamber was open to sky, direct rain water also contributed to increase the volume of water in collection chamber. Similarly, the impervious triangular portion at the tail end of experimental plot also contributed to add up the volume. That's why it was essential to deduct the extra volume of water added from direct rainfall and from impervious triangular part and deducted from the measured volume to maintain the accuracy of data. After deduction, the volume of water collected in chamber was multiplied by five to get total runoff volume and divided by area of each plot to get the runoff depth. Runoff data are shown in Appendix A, Table A1.

Figure 3.14 Collection chamber

3.4.3 Sediment Yield

The suspended sediments carried out by the rainfall generated runoff were collected in the collection chamber. The collected turbid water was stirred to mix the sediment particle with water homogeneously (Fig. 3.15) and approximately 1 liter of that sediment laden water was collected in bottle. It was carried to the laboratory, measured the 500 ml of sample and put into the oven (Figure 3.16) for 24 hour maintaining temperature of 105^{o}C. After 24-hour, residual sediment sample was weighted and converted into kg per liter. Then total weight of sediment was computed multiplying by total volume of runoff (Appendix B, Table B1-B3).

Figure 3.15 Making homogeneous mixture of sediment and water

Figure 3.16 Drying oven

3.4.4 Antecedent Moisture Content (M)

Daily moisture content (M) was recorded by using field scout TDR 300 with probe length 12 cm. For the better representation to experimental plot, data were taken at head, middle and tail end of the sloped plot (Fig. 3.17) and mean of three values was taken as representative soil moisture for that particular plot and event. TDR 300 gives volumetric water content (VWC) in percentage directly so that we need not bother to take soil sample and dried using oven. Moisture content of the soil is shown in Appendix C, Table C1.

Figure 3.17 Measuring soil moisture using TDR 300

3.4.5 Infiltration Test

Infiltration capacity of soil was determined by conducting double ring infiltrometer test in all the nine plots. Double ring infiltrometer consists of 30 cm high two concentric steel cylinder having dia. 45cm and 30cm was used for this purpose. These cylinders were driven into the ground making top horizontal as shown in Fig. 3.18. Clean water was poured into both rings up to fixed level (Fig. 3.19) without disturbing soil surface as far as possible and drawdown of inner ring was recorded in fix time interval with the help of measuring scale. Data was taken in short interval of time at the beginning of test and gradually increased the time interval while test went on. Tests were carried out till 2 or 3 consecutive reading were equal in equal time interval. Time taken to get constant reading depends upon type of soil. Sandy soil takes longer time than clayey soil. We spent 5 to 6 hours to get constant reading in our experimental field. Infiltrometer test was carried out to determine the hydrological soil group for experimental plots and the recorded data is given in Appendix D, Table D1-D5. Without knowing hydrological soil group, we could not select the proper CN for prediction of surface runoff using the SCS-CN method.

Figure 3.18 Double ring infiltrometer

Figure 3.19 Conducting infiltration test

3.4.6 Sieve Analysis

Indian standard sieve of sieve size 2mm, 1mm, 600-micron, 400-micron, 300-micron, 225-micron, 150-micron, 90-micron, 75-micron, 63 micron and pan at bottom were used for textural classification of soil as shown in Fig. 3.20. After sieving the soil, USDA texture triangle (Fig. 3.22) was used to find the type of soil. Sieve analysis data are shown in Appendix E, Table E1-E3.

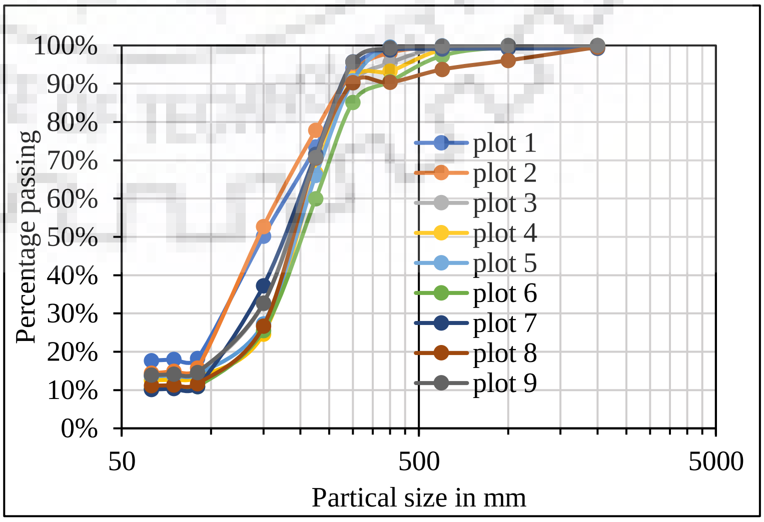


Figure 3.20 Particle size distribution of soil

Figure 3.21 Sieve analysis of soil sample

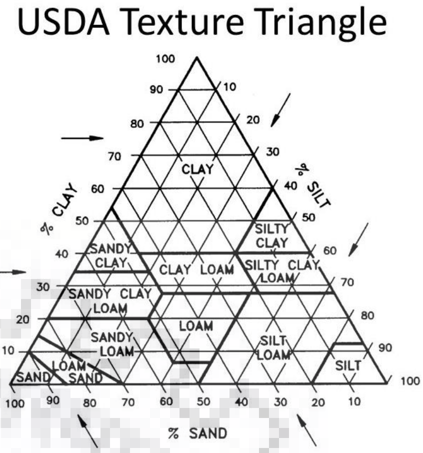


Figure 3.22 United State Department of Agriculture texture triangle

Limitations Associated with Data Collection:

1. Non uniform entry of runoff from all slots of divisor into the collection chamber due to obstruction caused by debris, channelization of sediment at immediate u/s of slots.
2. Some of the collection chamber had been found leaked while taking data. Two third data were already taken while it was noticed.
3. Due to dismantled boundary between plots, runoff flew from one plot to another.
4. Sink hole had also been observed in experimental plot, which was hidden in bush and could not be noticed.

3.5 Methods of CN Estimation

Various methods of CN determination from P-Q data can be found in literatures but most common and widely used methods are National Engineering Handbook 4 (NEH-4) method recommended by SCS (Hawkins et al., 2009; SCS, 1964, 1972), least square method (LSM/ NSE maximization) **Hawkins et al., 2002**) and asymptotic fitting method (AFM) (Hawkins 1993; Hawkins et al., 2009). Besides these, NEH-4 table can be used to obtain CN value according to hydrological soil group, hydrological conditions and land use/land cover. Calculation of CNs using various methods is shown in Appendix F, Table F1-F27.

3.5.1 NEH-4 Formula (Frequency Matching) Method

Curve number (CN) of all runoff generating events is calculated by using Eq. 2.13, Eq. 2.19 and Eq. 2.27. All the CNs are arranged in descending order and ranks are assigned starting from 1 to ‘n’. Probability of exceedance has been computed by using following equation.

$$Probablity\ of\ exceedance = \frac{m}{n+1} x100 \qquad \text{Eq. 3.1}$$

where, m = Rank and n = total no of event.

CN value corresponding to 90%, 50% and 10% probability of exceedance gives the CN for AMC III, AMC II and AMC I respectively (Hawkins et al., 2009; SCS, 1964, 1972). In some cases, interpolation may be required to find exactly 90%, 50% and 10% probability of exceedance.

3.5.2 NSE Maximization Method

In NSE maximization method, parameters λ and S are computed by iterative procedure using observed P-Q data and Eq. 3.2. This process is called optimization. If we optimize the value of S keeping λ constant it is called one-way optimization and if we optimize the value of both λ and S it is called two-way optimization. The objective of optimization is to determine the value of λ and S such that following objective function should be maximum. For maximization, GRG non-linear algorithm is used.

$$NSE = 1 - \left[\frac{\sum_{i=1}^{n}(Q_O - Q_C)^2}{\sum_{i=1}^{n}(Q_O - \overline{Q_O})^2}\right] = Maximum \qquad \text{Eq. 3.2}$$

where, Q_o is observed runoff, Q_c is computed runoff and others have usual meaning as explained in previous chapter.

3.5.3 Asymptotic Determination of CN

Originally, CN was expected to be constant for each watershed, but it varies with magnitude of rainfall that occurs at different frequencies. The CN is generally a function of the design return period interval or frequency, a fact rarely recognized in most designs. Hawkins worked extensively with recorded rainfall and runoff data sets.

The procedure for the asymptotic determination of observed watershed CN is presented as follows (Hawkins, 1993).

i. Rainfall and runoff depths are independently arranged in decreasing order.
ii. Calculate CN for each pair by using Eq. 2.19 and Eq. 2.27
iii. Plot the resulting curve number with respect to the corresponding precipitations.
iv. Define the curve number from the asymptotic behavior as standard, violent or complacent.

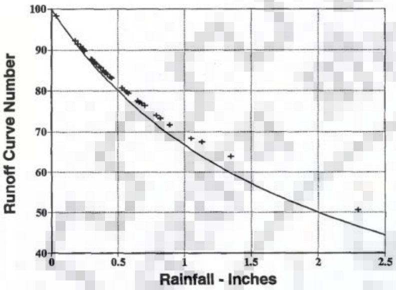


Figure 3.23 Complacent Behavior

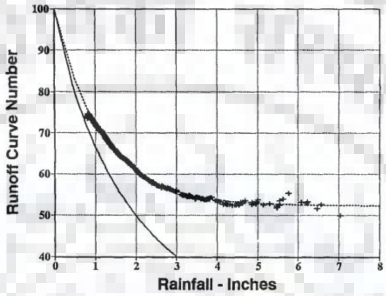


Figure 3.24 Standard Response

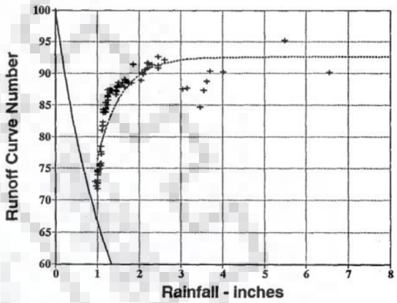


Figure 3.25 Violent Response

Following three variations are generally observed:

1. First variation is complacent behavior, in which the observed CN decline steadily with increase in rainfall depth and no appreciable tendency to achieve a stable value (Fig. 3.23)
2. Second variation is most common standard behavior. The observed CN decline with increasing storm size and approach or maintain a near constant value with increasing large storm (Fig. 3.24)
3. Third variation is violent behavior at low rainfall in which the observed CN rise suddenly and asymptotically approach a constant value. There is often accompanying complacent behavior at low rainfall (Fig. 3.25).

3.6 Performance Evaluation Statistics

This section briefly describes about the efficacy of the models.

3.6.1 Nash and Sutcliffe Efficiency (NSE)

NSE measures the relative magnitude of residual variance of observed and computed data (Nash and Sutcliffe, 1970). It shows how well the observed and computed data fit to 1:1 line. NSE is given by following equation.

$$NSE = 1 - \left[\frac{\sum_{i=1}^{n}(Q_O - Q_C)^2}{\sum_{i=1}^{n}(Q_O - \overline{Q_O})^2}\right] \quad \text{Eq. 3.3}$$

where, Q_o is observed value, Q_c is computed value, $\overline{Q_o}$ is observed mean value and n is number of observations.

The value of NSE ranges from 0 to 1 with 1 being optimal value. NSE equal to 0 indicates that the model estimates are as precise as average of observed data implying that the model predicts no better than the average of observed data (Coffey, Workman, Taraba, & Fogle, 2004). A model is said to be very good if NSE $\geq$ 0.90, goof if NSE lies between 0.80 to 0.90, acceptable if NSE lies between 0.65 to 0.80 and unsatisfactory if NSE $\leq$ 0.65 (Ritter and Muñoz 2013).

3.6.2 Root Mean Square Error (RMSE)

RMSE is another way of evaluating performance of model which measures how much error is there between observed and computed value. Its value ranges from 0 to large positive value. Lower the value of RMSE, better will be the performance of model. It is given by Eq. 3.4.

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(Q_o - Q_c)^2} \quad \text{Eq. 3.4}$$

where, Q_o is observed value, Q_c is computed value and n is number of observations.

3.6.3 Percentage BIAS

PBIAS predicts the average tendency of computed value whether it is greater or lesser than observed value (Gupta et al., 1999). It ranges from some -ve to +ve value giving 0 as perfect value of PBIAS. Positive value shows underestimation and negative values shows overestimation by model (Gupta et al., 1999). It is given by Eq. 3.5.

$$PBIAS = \left[\frac{\sum_{i=1}^{n}(Q_O - Q_C)}{\sum_{i=1}^{n} Q_O}\right] X\ 100 \qquad \text{Eq. 3.5}$$

where, Q_o is observed value, Q_c is computed value and n is number of observations.

In hydrological modeling using SWAT, performance of model is said to be unsatisfactory if PBIAS $> \pm$ 25% fair if PBIAS lies between $\pm$15% to $\pm$25%, good if PBIAS lies between $\pm$10% to $\pm$15%, and very good if PBIAS $< \pm$ 10% (Moriasi et al., 2007). But for the SCS-CN model, it has not been categorized as in the case of SWAT.

3.6.4 Comparison of Model Efficiency

The existing and modified SCS-CN method will be applied in this study to test their efficacy in runoff prediction for experimental plots with varying slopes and land use land cover. The general expressions of the existing and the modified SCS-CN method are given below.

Existing model

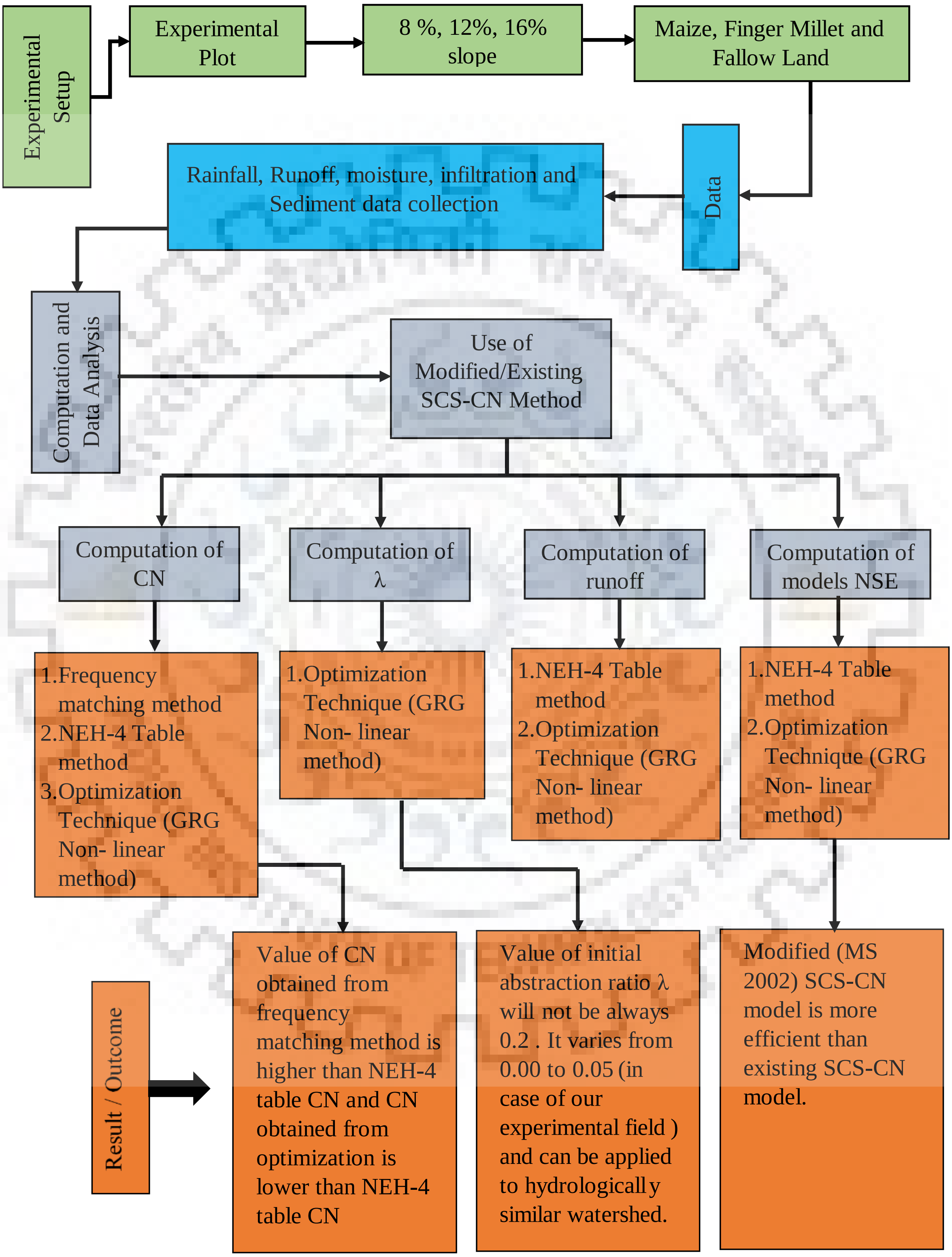
$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \qquad (if\ P > 0.2S) \qquad \text{Eq. 3.6}$$

Modified Model (MS 2002)

$$Q = \frac{(P - Ia)(P - Ia + M)}{(P - Ia + S + M)} \qquad (if\ P > Ia) \qquad \text{Eq. 3.7}$$

The goodness of fit of these models will be evaluated using the statistical indices as discussed in the previous sections.

FLOW CHART


Experimental Setup
Experimental Plot
8 %, 12%, 16% slope
Maize, Finger Millet and Fallow Land
Data
Rainfall, Runoff, moisture, infiltration and Sediment data collection
Computation and Data Analysis
Use of Modified/Existing SCS-CN Method
Computation of CN
Computation of λ
Computation of runoff
Computation of models NSE
1.Frequency matching method 2.NEH-4 Table method 3.Optimization Technique (GRG Non- linear method)
1.Optimization Technique (GRG Non- linear method)
1.NEH-4 Table method 2.Optimization Technique (GRG Non- linear method)
1.NEH-4 Table method 2.Optimization Technique (GRG Non- linear method)
Result / Outcome
Value of CN obtained from frequency matching method is higher than NEH-4 table CN and CN obtained from optimization is lower than NEH-4 table CN
Value of initial abstraction ratio λ will not be always 0.2 . It varies from 0.00 to 0.05 (in case of our experimental field) and can be applied to hydrologically similar watershed.
Modified (MS 2002) SCS-CN model is more efficient than existing SCS-CN model.

CHAPTER 4

4. ANALYSIS, RESULTS AND DISCUSSION

4.1 General

This chapter deals with the general analysis of the data observed from the experimental plots established in Toda Kalyanpur Roorkee. Nine plots having slope of 8%, 12% and 16% (each 3 consecutive plots) were prepared for observing rainfall, runoff, soil moisture, infiltration and soil type. The CNs were estimated using the different methods and compared with the NEH-4 Table. Finally, the performance of the modified SCS-CN method with varying initial abstraction coefficient, land slope and land use land cover will be tested with the existing SCS-CN model.

4.2 Status of Data

For the purpose of this study, all the data required has been measured and collected directly from the experimental farm and secondary data has not been used. Essential equipment and instrument have been either installed in the farm or carried to farm as and when needed. Rainfall was measured by ordinary rain gauge, runoff was measured using collection chamber, soil moisture was measured by TDR-300 with probe length 12 cm, infiltration rate was measured by double ring infiltrometer, soil type was determined by sieve analysis.

4.3 Characteristics of Rainfall

The data observation was started from 2nd July 2018 and ended on 25 Sep 2018. During the observation, a total of 32 rainfall events were recorded out of which, 19 events were runoff generating and remaining 13 events were non-runoff generating events. Unfortunately, out of 19 runoff generating events, one event was so heavy that the collection chambers were filled up fully and spilled out. So, we omitted that event and 18 events were taken in analysis. The minimum and maximum rainfall depths which produced runoff were 7.3 mm and 129.4 mm. Table 4.1 shows the frequency distribution of the observed rainfall events.

Table 4.1 Frequency distribution of rainfall events

Rainfall (mm)	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	100-110	110-120	120-130
No. of event	14	7	4	1	1	2	0	0	0	0	0	1	1

4.4 Relationship Between Rainfall and Runoff

Observed rainfall as well as corrected runoff data was arranged according to the event date and cumulative rainfall and cumulative runoff form each plot was computed. Then runoff coefficient (C) (Table 4.2) of each plot was determined by taking ratio of runoff to rainfall. It has been found that runoff coefficient varied from 0.19 to 0.57. Finger Millet and Fallow land reflects lower values of C as compared to the Maize crop. It has also been found that the correlation between rainfall and runoff is good, showing minimum and maximum coefficient of determination R^2 0.77 (Finger Millet of 16% slope) and 0.96 (Finger Millet of 12% slope) respectively. The relationship between rainfall and runoff has been shown graphically in Fig. 4.1-4.3 for different plots and land use land cover.

Table 4.2 The values of runoff coefficient (C) for different land slopes and land use land cover

Description	Total rainfall (mm)	Maize			Finger Millet			Fallow land		
		8%	12%	16%	8%	12%	16%	8%	12%	16%
Total runoff (mm)	653	224.48	287	377.85	128.03	172.24	289.37	131.45	175.48	248.26
Runoff coefficient (C)		0.34	0.43	0.57	0.19	0.26	0.44	0.2	0.26	0.38

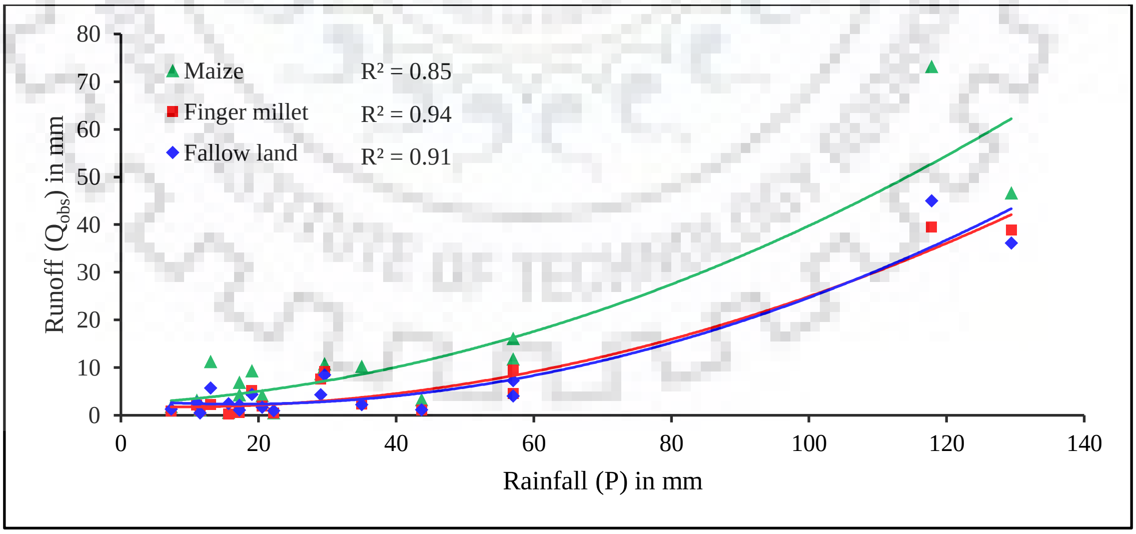


Figure 4.1 Rainfall runoff relationship for 8% slope plot

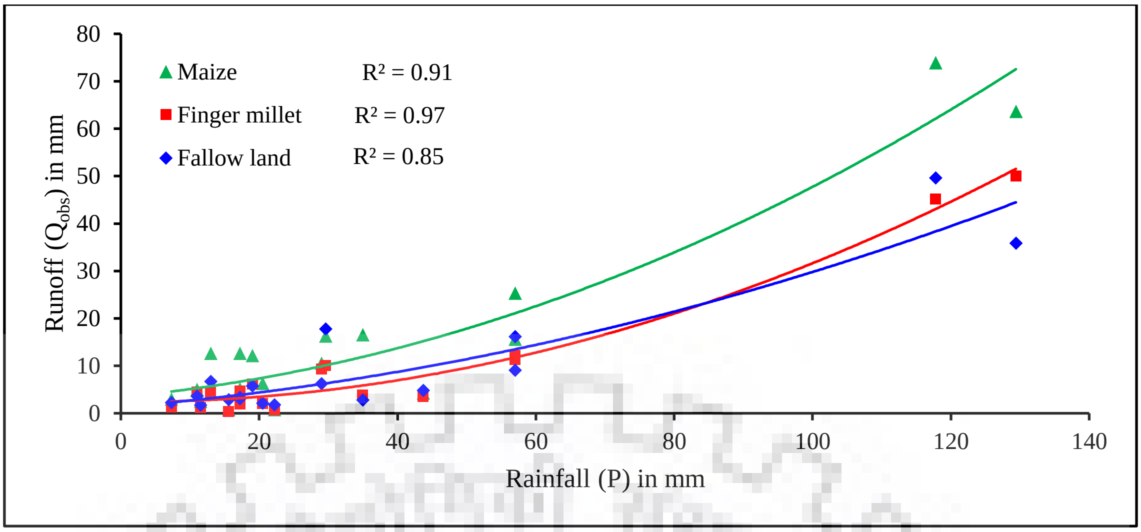


Figure 4.2 Rainfall runoff relationship for 12% slope plot

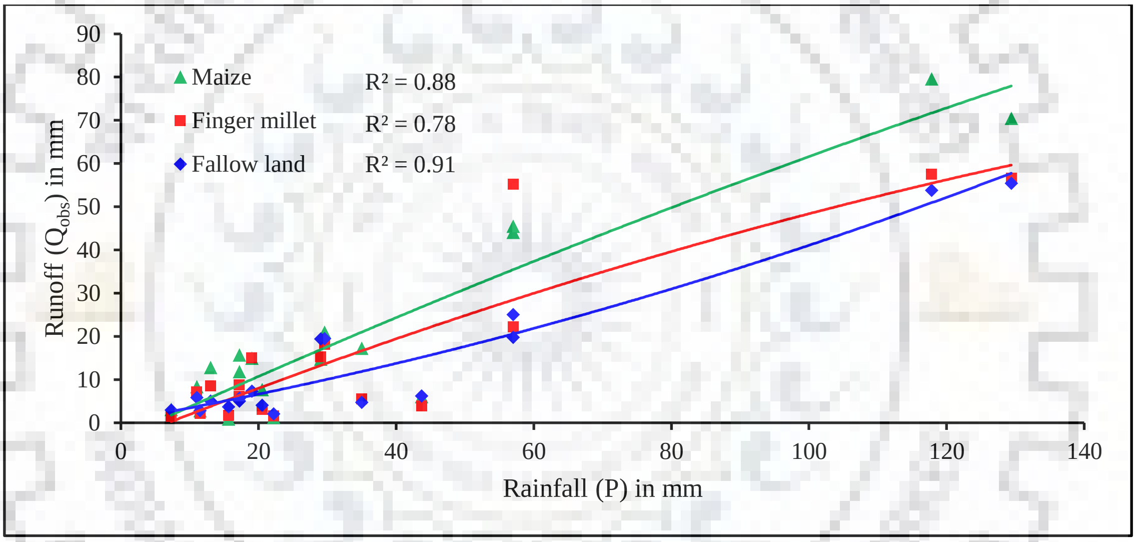


Figure 4.3 Rainfall runoff relationship for 16% slope plot

4.5 Hydrological Soil Group (HSG) Analysis

As discussed in section 3.3.3, double ring infiltrometer was used to determine minimum rate of infiltration. The HSG was determined by minimum rate of infiltration of soil called infiltration capacity (f_c). Double ring infiltrometer having diameter of inner and outer ring 30cm and 45cm was used in all nine plots to determine infiltration capacity of soil. The results of the test have been shown in Table 4.3. The results show that most of the plots fall in HSG A and may be categorized as low runoff producing watersheds.

Table 4.3 Determination of hydrological soil group (HSG)

Slope	Land Use	Inf. Capacity (cm/hr)	HSG	Method Used	Hydrological soil classification (cm/hr)
8% slope	Maize	5.00	A	Double ring infiltrometer	0.76 – 1.14=A 0.38 – 0.76=B 0.12 – 0.38=C 0.00 – 0.12=D
	Finger millet	1.40	A		
	Fallow land	0.70	B		
12% slope	Maize	1.50	A		
	Finger millet	2.00	A		
	Fallow land	3.40	A		
16% slope	Maize	6.00	A		
	Finger millet	3.30	A		
	Fallow land	1.50	A		

Above table shows that all the experimental plots have minimum rate of infiltration greater than 0.76 cm/hr and lies in hydrological soil group A except fallow land of 8% slope. Being minimum infiltration rate of fallow land of 8% slope 0.7 cm/hr it lies in hydrological soil group B. The infiltration capacity curves of three different slopes (8%, 12% and 16%) having different land cover (Maize, Finger Millet and Fallow land) are shown in Fig. 4.4-4.6.

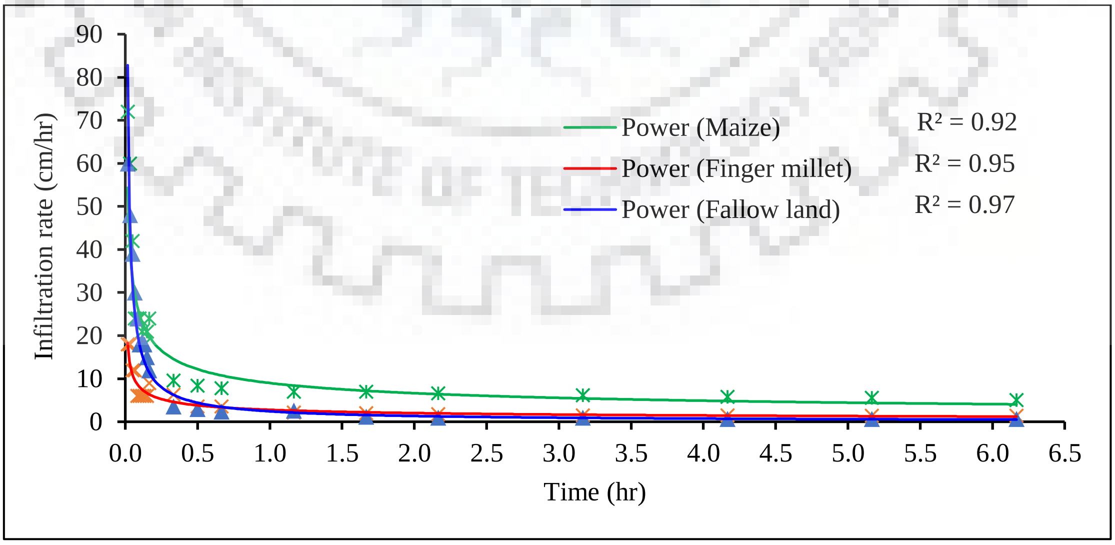


Figure 4.4 Infiltration capacity curve of 8% slope plot

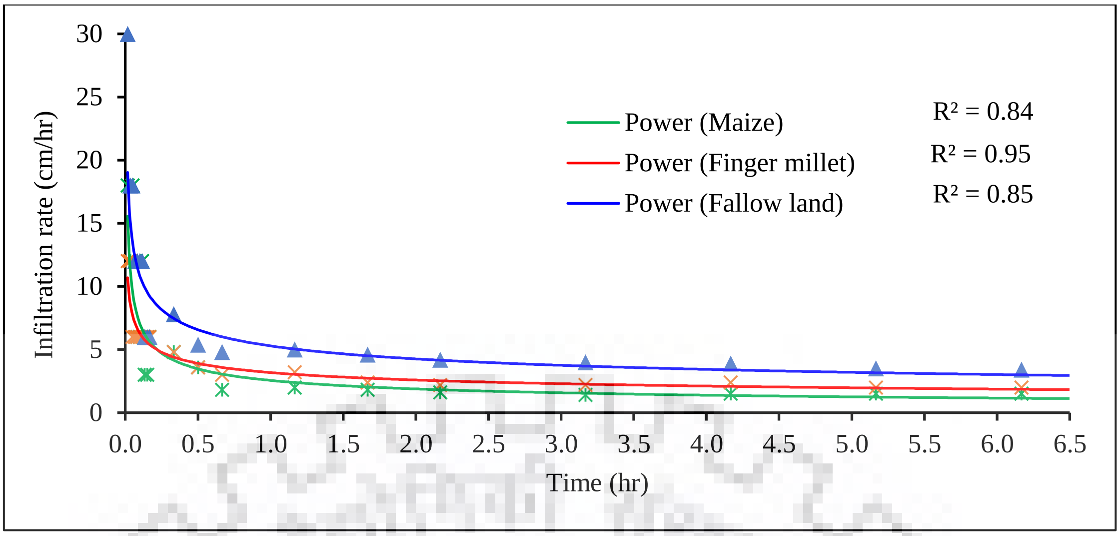


Figure 4.5 Infiltration capacity curve for 12% slope plot

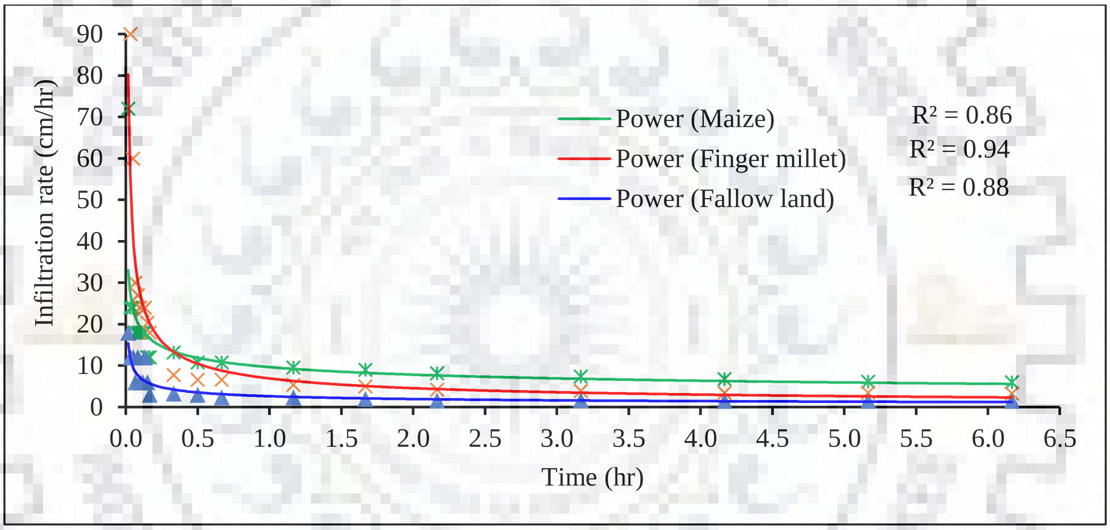


Figure 4.6 Infiltration capacity curve for 16% slope plot

4.6 Determination of Curve Number (CN)

This section discusses about the CN estimation using different methods as briefly discussed in Section 3.5.

4.6.1 Using NEH-4 Table

Type of land use land cover and hydrological soil group are pre-requisite information to determine the CN from NEH-4 Table. Table 4.4 shows the LULC and hydrological soil group of experimental plots as well as their corresponding curve number taken from NEH-4 Table. As mentioned in the Section 2.8, Ajmal. et al. (2016) performs best as compared to the Sharpley and Williams (1190) and Huang et al. (2006) models, and hence it has been used in this study for slope corrections. The hydrologic condition of all the plots have been taken as Poor as shown in Fig. 4.7 & 4.8.

Table 4.4 CN from NEH-4 Table

Slope	Land Use	HSG	Hydrologic condition	Land treatment	CN_2 without slope correction	CN_2 with slope correction
8%	Maize	A	poor	Straight row	72.00	72.88
	Finger millet	A	poor	Straight row	65.00	65.79
	Fallow land	B	poor	Straight row	86.00	87.05
12%	Maize	A	poor	Straight row	72.00	74.03
	Finger millet	A	poor	Straight row	65.00	66.83
	Fallow land	A	poor	Straight row	86.00	88.42
16%	Maize	A	poor	Straight row	72.00	75.13
	Finger millet	A	poor	Straight row	65.00	67.83
	Fallow land	A	poor	Straight row	86.00	89.74

Figure 4.7 Hydrologic condition of Maize

Figure 4.8 Hydrologic condition of Fallow land and Finger Millet

4.6.2 From Observed Rainfall Runoff Data (Frequency Matching Method)

Potential maximum retention (S) has been computed from observed rainfall (P) and observed runoff (Q_{obs}) using Eq. 2.13 and

Eq. *2.27*. After computing S, CN has been computed using Eq. 2.20. Computation of CN for all (9) experimental plots have been shown in Table 4.5 to Table 4.10. Notably, λ has been taken as 0.2 for use in modified SCS-CN (MS model).

Table 4.5 Computation of CN for 8% slope plot using MS model for λ = 0.2

Date	Rain Fall (P) in mm	Observed runoff (Q_{obs})			Potential maximum retention (S)			Curve number (CN_{obs})		
		Maize	Finger Millet	Fallow Land	Maize	Finger Millet	Fallow Land	Maize	Finger Millet	Fallow Land
03-Jul-18	57.00	16.11	4.49	7.27	86.40	172.51	138.15	74.61	59.55	64.77
04-Jul-18	11.00	3.20	2.09	2.64	26.21	33.34	30.02	90.64	88.39	89.43
27-Jul-18	57.00	11.85	9.49	4.07	105.98	125.82	176.93	70.55	66.87	58.94
28-Jul-18	129.40	46.71	38.80	36.16	147.44	175.62	190.89	63.27	59.12	57.09
29-Jul-18	35.00	10.31	2.39	2.25	60.60	122.73	128.07	80.73	67.42	66.47
01-Aug-18	19.00	9.36	5.20	4.36	17.11	31.98	37.76	93.68	88.81	87.05
05-Aug-18	13.00	11.27	2.24	5.71	2.88	35.41	17.27	98.87	87.76	93.63
06-Aug-18	20.50	4.20	1.98	1.70	47.86	67.02	70.72	84.14	79.12	78.22
12-Aug-18	7.30	1.86	0.89	1.30	18.89	26.24	24.25	93.07	90.63	91.28
25-Aug-18	11.50	1.15	1.01	0.46	40.15	42.44	49.05	86.35	85.68	83.81
26-Aug-18	17.20	6.95	0.56	2.09	25.16	75.47	56.29	90.98	77.09	81.85
31-Aug-18	117.80	73.22	39.47	45.02	57.32	144.11	122.54	81.58	63.80	67.45
02-Sep-18	29.60	10.84	9.17	8.48	41.33	51.22	51.63	86.00	83.21	83.10
03-Sep-18	29.00	8.74	7.63	4.29	52.08	58.62	76.63	82.98	81.24	76.82
07-Sep-18	17.20	4.31	0.98	1.11	37.27	66.99	64.02	87.20	79.13	79.86
23-Sep-18	15.60	0.60	0.19	2.41	59.37	71.14	40.24	81.05	78.12	86.32
24-Sep-18	43.70	3.28	1.06	1.19	134.14	176.81	174.43	65.44	58.95	59.28
25-Sep-18	22.20	0.52	0.39	0.94	97.92	101.51	91.75	72.17	71.44	73.46

Table 4.6 Computation of CN for 12% slope plot using MS model for λ = 0.2

Date	Rain Fall (P) in mm	Observed runoff (Q_{obs})			Potential maximum retention (S)			Curve number (CN_{obs})		
		Maize	Finger Millet	Fallow Land	Maize	Finger Millet	Fallow Land	Maize	Finger Millet	Fallow Land
03-Jul-18	57.00	25.32	12.13	16.15	51.53	107.91	85.20	83.13	70.18	74.88
04-Jul-18	11.00	5.00	4.45	3.61	17.65	20.92	25.16	93.50	92.39	90.98
27-Jul-18	57.00	15.60	11.29	9.07	87.70	113.63	128.38	74.33	69.09	66.42
28-Jul-18	129.40	63.66	50.05	35.88	97.43	137.79	189.20	72.27	64.83	57.31
29-Jul-18	35.00	16.56	3.78	2.81	34.72	107.59	118.25	87.97	70.24	68.23
01-Aug-18	19.00	12.14	6.17	5.75	10.09	28.18	29.80	96.17	90.01	89.49
05-Aug-18	13.00	12.65	4.32	6.68	0.53	22.98	13.84	99.79	91.70	94.83
06-Aug-18	20.50	6.28	2.05	2.12	35.71	66.43	65.59	87.67	79.26	79.47

Date	Rain Fall (P) in mm	Observed runoff (Q_{obs})			Potential maximum retention (S)			Curve number (CN_{obs})		
		Maize	Finger Millet	Fallow Land	Maize	Finger Millet	Fallow Land	Maize	Finger Millet	Fallow Land
12-Aug-18	7.30	2.97	1.30	2.27	13.53	22.70	18.37	94.94	91.79	93.25
25-Aug-18	11.50	2.54	1.15	1.71	28.04	39.92	36.23	90.05	86.41	87.51
26-Aug-18	17.20	12.64	1.95	3.06	8.24	56.98	44.13	96.85	81.67	85.19
31-Aug-18	117.80	73.91	45.16	49.60	54.81	122.86	111.98	82.25	67.39	69.40
02-Sep-18	29.60	16.26	10.01	17.78	23.80	45.34	22.19	91.43	84.85	91.96
03-Sep-18	29.00	10.54	9.29	6.24	40.36	48.89	65.42	86.28	83.85	79.51
07-Sep-18	17.20	5.14	4.59	3.34	31.25	35.86	44.58	89.04	87.62	85.06
23-Sep-18	15.60	0.74	0.33	2.83	59.73	66.02	36.13	80.96	79.37	87.54
24-Sep-18	43.70	4.25	3.56	4.81	125.50	130.91	118.39	66.93	65.98	68.20
25-Sep-18	22.20	0.80	0.66	1.77	94.17	95.30	79.30	72.95	72.71	76.20

Table 4.7 Computation of CN for 16% slope plot using MS model for $\lambda = 0.2$

Date	Rain Fall (P) in mm	Observed runoff (Q_{obs})			Potential maximum retention (S)			Curve number (CN_{obs})		
		Maize	Finger Millet	Fallow Land	Maize	Finger Millet	Fallow Land	Maize	Finger Millet	Fallow Land
03-Jul-18	57.00	44.07	55.18	19.77	15.52	1.85	67.77	94.24	99.27	78.93
04-Jul-18	11.00	8.34	7.09	5.84	5.74	8.84	13.34	97.79	96.63	95.01
27-Jul-18	57.00	45.46	22.13	25.04	13.19	62.14	51.53	95.06	80.34	83.13
28-Jul-18	129.40	70.46	56.57	55.46	81.57	114.24	119.35	75.69	68.97	68.03
29-Jul-18	35.00	17.25	5.45	4.75	31.88	86.39	95.07	88.84	74.62	72.76
01-Aug-18	19.00	14.92	14.92	7.28	5.19	5.24	23.04	97.99	97.97	91.68
05-Aug-18	13.00	12.79	8.49	5.02	0.31	8.64	19.72	99.87	96.71	92.79
06-Aug-18	20.50	7.67	3.09	4.06	29.50	55.76	48.62	89.59	81.99	83.93
12-Aug-18	7.30	3.11	1.44	2.97	12.23	22.49	13.29	95.40	91.86	95.02
25-Aug-18	11.50	2.82	2.12	2.82	25.52	30.92	25.86	90.87	89.14	90.75
26-Aug-18	17.20	15.70	8.75	5.00	2.50	19.33	34.83	99.02	92.92	87.94
31-Aug-18	117.80	79.60	57.52	53.77	46.86	89.23	98.30	84.42	74.00	72.09
02-Sep-18	29.60	20.98	18.06	19.45	14.50	19.73	18.20	94.59	92.79	93.31
03-Sep-18	29.00	14.71	15.27	19.43	28.12	26.51	15.65	90.03	90.54	94.19
07-Sep-18	17.20	11.81	6.11	5.70	9.47	27.73	30.76	96.40	90.15	89.19
23-Sep-18	15.60	0.88	1.71	3.66	56.00	45.53	29.48	81.93	84.79	89.60
24-Sep-18	43.70	6.06	3.83	6.19	106.44	128.96	104.24	70.46	66.32	70.90
25-Sep-18	22.20	1.22	1.64	2.05	86.53	80.79	74.76	74.58	75.86	77.26

Table 4.8 Computation of CN for 8% slope plot using the existing SCS-CN method

Date	Rain Fall (P) in mm	Observed runoff (Q_{obs})			Potential maximum retention (S)			Curve number (CN_{obs})		
		Maize	Finger Millet	Fallow Land	Maize	Finger Millet	Fallow Land	Maize	Finger Millet	Fallow Land
03-Jul-18	57.00	44.07	55.18	19.77	70.95	145.48	118.77	78.16	63.58	68.13
04-Jul-18	11.00	8.34	7.09	5.84	13.35	18.36	15.62	95.00	93.25	94.20
27-Jul-18	57.00	45.46	22.13	25.04	89.69	103.09	150.61	73.90	71.13	62.77
28-Jul-18	129.40	70.46	56.57	55.46	127.32	152.88	162.64	66.61	62.42	60.96
29-Jul-18	35.00	17.25	5.45	4.75	42.01	93.88	95.76	85.80	73.01	72.62
01-Aug-18	19.00	14.92	14.92	7.28	12.55	24.30	27.89	95.29	91.26	90.10
05-Aug-18	13.00	12.79	8.49	5.02	1.58	23.04	10.12	99.38	91.68	96.16
06-Aug-18	20.50	7.67	3.09	4.06	32.57	48.36	51.34	88.63	84.00	83.18
12-Aug-18	7.30	3.11	1.44	2.97	9.89	15.54	12.68	96.25	94.23	95.24
25-Aug-18	11.50	2.82	2.12	2.82	26.74	28.18	35.97	90.47	90.01	87.59
26-Aug-18	17.20	15.70	8.75	5.00	14.88	56.45	36.68	94.46	81.81	87.38
31-Aug-18	117.80	79.60	57.52	53.77	50.65	125.22	108.82	83.37	66.97	70.00
02-Sep-18	29.60	20.98	18.06	19.45	28.67	33.93	36.41	89.85	88.21	87.46
03-Sep-18	29.00	14.71	15.27	19.43	34.10	38.32	56.02	88.16	86.89	81.93
07-Sep-18	17.20	11.81	6.11	5.70	23.62	48.86	47.00	91.49	83.86	84.38
23-Sep-18	15.60	0.88	1.71	3.66	49.27	60.55	29.43	83.75	80.75	89.61
24-Sep-18	43.70	6.06	3.83	6.19	113.48	152.27	148.90	69.11	62.51	63.04
25-Sep-18	22.20	1.22	1.64	2.05	77.85	81.77	68.46	76.54	75.64	78.76

Table 4.9 Computation of CN for 12% slope plot using the existing SCS-CN method

Date	Rain Fall (P) in mm	Observed runoff (Q_{obs})			Potential maximum retention (S)			Curve number (CN_{obs})		
		Maize	Finger Millet	Fallow Land	Maize	Finger Millet	Fallow Land	Maize	Finger Millet	Fallow Land
03-Jul-18	57.00	44.07	55.18	19.77	43.71	88.27	70.79	85.31	74.21	78.20
04-Jul-18	11.00	8.34	7.09	5.84	8.17	9.50	11.93	96.88	96.39	95.51
27-Jul-18	57.00	45.46	22.13	25.04	72.91	92.63	105.79	77.69	73.27	70.59
28-Jul-18	129.40	70.46	56.57	55.46	85.70	117.90	163.72	74.77	68.29	60.80
29-Jul-18	35.00	17.25	5.45	4.75	24.57	78.76	88.71	91.17	76.33	74.11
01-Aug-18	19.00	14.92	14.92	7.28	7.66	20.83	22.25	97.07	92.42	91.94
05-Aug-18	13.00	12.79	8.49	5.02	0.29	13.93	8.03	99.88	94.80	96.93
06-Aug-18	20.50	7.67	3.09	4.06	23.75	47.67	47.00	91.44	84.19	84.38
12-Aug-18	7.30	3.11	1.44	2.97	6.26	12.68	8.34	97.59	95.24	96.82
25-Aug-18	11.50	2.82	2.12	2.82	17.35	26.74	22.15	93.60	90.47	91.97
26-Aug-18	17.20	15.70	8.75	5.00	4.66	37.87	29.90	98.19	87.02	89.46
31-Aug-18	117.80	79.60	57.52	53.77	49.58	108.43	96.88	83.66	70.08	72.38

Date	Rain Fall (P) in mm	Observed runoff (Q_{obs})			Potential maximum retention (S)			Curve number (CN_{obs})		
		Maize	Finger Millet	Fallow Land	Maize	Finger Millet	Fallow Land	Maize	Finger Millet	Fallow Land
02-Sep-18	29.60	20.98	18.06	19.45	16.31	31.17	13.71	93.96	89.06	94.87
03-Sep-18	29.00	14.71	15.27	19.43	28.32	32.21	44.56	89.96	88.74	85.07
07-Sep-18	17.20	11.81	6.11	5.70	20.38	22.46	28.31	92.57	91.87	89.97
23-Sep-18	15.60	0.88	1.71	3.66	46.69	55.71	26.80	84.47	82.01	90.45
24-Sep-18	43.70	6.06	3.83	6.19	102.81	110.17	97.51	71.18	69.74	72.25
25-Sep-18	22.20	1.22	1.64	2.05	71.20	74.29	56.41	78.10	77.37	81.82

Table 4.10 Computation of CN for 16% slope plot using the existing SCS-CN method

Date	Rain Fall (P) in mm	Observed runoff (Q_{obs})			Potential maximum retention (S)			Curve number (CN_{obs})		
		Maize	Finger Millet	Fallow Land	Maize	Finger Millet	Fallow Land	Maize	Finger Millet	Fallow Land
03-Jul-18	57.00	44.07	55.18	19.77	12.80	1.55	58.49	95.20	99.39	81.28
04-Jul-18	11.00	8.34	7.09	5.84	2.66	4.34	6.43	98.96	98.32	97.53
27-Jul-18	57.00	45.46	22.13	25.04	11.20	51.71	44.37	95.77	83.08	85.12
28-Jul-18	129.40	70.46	56.57	55.46	72.47	101.37	104.03	77.80	71.47	70.94
29-Jul-18	35.00	17.25	5.45	4.75	23.11	65.75	70.71	91.66	79.43	78.22
01-Aug-18	19.00	14.92	14.92	7.28	4.00	4.00	17.50	98.44	98.44	93.55
05-Aug-18	13.00	12.79	8.49	5.02	0.17	4.97	11.86	99.93	98.08	95.53
06-Aug-18	20.50	7.67	3.09	4.06	19.39	39.20	33.31	92.90	86.63	88.40
12-Aug-18	7.30	3.11	1.44	2.97	5.91	11.89	6.26	97.72	95.52	97.59
25-Aug-18	11.50	2.82	2.12	2.82	16.06	19.56	16.06	94.05	92.84	94.05
26-Aug-18	17.20	15.70	8.75	5.00	1.33	10.80	20.89	99.47	95.92	92.40
31-Aug-18	117.80	79.60	57.52	53.77	41.22	78.91	87.04	86.03	76.29	74.47
02-Sep-18	29.60	20.98	18.06	19.45	9.02	13.26	11.14	96.57	95.03	95.79
03-Sep-18	29.00	14.71	15.27	19.43	18.30	17.21	10.38	93.27	93.65	96.07
07-Sep-18	17.20	11.81	6.11	5.70	5.75	17.21	18.48	97.78	93.65	93.21
23-Sep-18	15.60	0.88	1.71	3.66	44.45	34.87	22.53	85.10	87.92	91.85
24-Sep-18	43.70	6.06	3.83	6.19	87.33	107.17	86.37	74.41	70.32	74.62
25-Sep-18	22.20	1.22	1.64	2.05	63.74	57.97	53.33	79.93	81.41	82.64

CNs corresponding to different AMCs are determined by frequency analysis. In this method all the CNs are arranged in descending order and rank is assigned. Probability of exceedance is computed and CN corresponding to probability of exceedance 90%, 50% and 10% are taken as AMC I, AMC II and AMC III respectively (Table 4.11 & Table 4.12)

Table 4.11 Computation of CN for different AMCs using Modified SCS-CN method (frequency matching technique) λ=0.2

Rank (m)	Slope of plot 12%			Slope of plot 8%			Slope of plot 16%			Probability of Exceedance = m/(n+1)
	Maize	Finger Millet	Fallow Land	Maize	Finger Millet	Fallow Land	Maize	Finger Millet	Fallow Land	
1	99.79	92.39	94.83	98.87	90.63	93.63	99.87	99.27	95.02	5%
2	96.85	91.79	93.25	93.68	88.81	91.28	99.02	97.97	95.01	11%
3	96.17	91.70	91.96	93.07	88.39	89.43	97.99	96.71	94.19	16%
4	94.94	90.01	90.98	90.98	87.76	87.05	97.79	96.63	93.31	21%
5	93.50	87.62	89.49	90.64	85.68	86.32	96.40	92.92	92.79	26%
6	91.43	86.41	87.54	87.20	83.21	83.81	95.40	92.79	91.68	32%
7	90.05	84.85	87.51	86.35	81.24	83.10	95.06	91.86	90.75	37%
8	89.04	83.85	85.19	86.00	79.13	81.85	94.59	90.54	89.60	42%
9	87.97	81.67	85.06	84.14	79.12	79.86	94.24	90.15	89.19	47%
10	87.67	79.37	79.51	82.98	78.12	78.22	90.87	89.14	87.94	53%
11	86.28	79.26	79.47	81.58	77.09	76.82	90.03	84.79	83.93	58%
12	83.13	72.71	76.20	81.05	71.44	73.46	89.59	81.99	83.13	63%
13	82.25	70.24	74.88	80.73	67.42	67.45	88.84	80.34	78.93	68%
14	80.96	70.18	69.40	74.61	66.87	66.47	84.42	75.86	77.26	74%
15	74.33	69.09	68.23	72.17	63.80	64.77	81.93	74.62	72.76	79%
16	72.95	67.39	68.20	70.55	59.55	59.28	75.69	74.00	72.09	84%
17	72.27	65.98	66.42	65.44	59.12	58.94	74.58	68.97	70.90	89%
18	66.93	64.83	57.31	63.27	58.95	57.09	70.46	66.32	68.03	95%
AMC III	**97.14**	**91.85**	**93.40**	**94.19**	**88.99**	**91.51**	**99.10**	**98.10**	**95.01**	**10%**
AMC II	**87.82**	**80.52**	**82.28**	**83.56**	**78.62**	**79.04**	**92.55**	**89.64**	**88.56**	**50%**
AMC I	**71.73**	**65.86**	**65.50**	**65.22**	**59.10**	**58.75**	**74.16**	**68.70**	**70.61**	**90%**

Table 4.12 Computation of CN for different AMCs using Existing SCS-CN method (frequency matching technique) λ=0.2

Rank m	Slope of plot 12%			Slope of plot 8%			Slope of plot 16%			Probability of Exceedance = m/(n+1)
	Maize	Finger Millet	Fallow Land	Maize	Finger Millet	Fallow Land	Maize	Finger Millet	Fallow Land	
1	99.88	96.39	96.93	99.38	94.23	96.16	99.93	99.39	97.59	99.88
2	98.19	95.24	96.82	96.25	93.25	95.24	99.47	98.44	97.53	98.19
3	97.59	94.80	95.51	95.29	91.68	94.20	98.96	98.32	96.07	97.59
4	97.07	92.42	94.87	95.00	91.26	90.10	98.44	98.08	95.79	97.07

Rank m	Slope of plot 12%			Slope of plot 8%			Slope of plot 16%			Probability of Exceedance = m/(n+1)
	Maize	Finger Millet	Fallow Land	Maize	Finger Millet	Fallow Land	Maize	Finger Millet	Fallow Land	
5	96.88	91.87	91.97	94.46	90.01	89.61	97.78	95.92	95.53	96.88
6	93.96	90.47	91.94	91.49	88.21	87.59	97.72	95.52	94.05	93.96
7	93.60	89.06	90.45	90.47	86.89	87.46	96.57	95.03	93.55	93.60
8	92.57	88.74	89.97	89.85	84.00	87.38	95.77	93.65	93.21	92.57
9	91.44	87.02	89.46	88.63	83.86	84.38	95.20	93.65	92.40	91.44
10	91.17	84.19	85.07	88.16	81.81	83.18	94.05	92.84	91.85	91.17
11	89.96	82.01	84.38	85.80	80.75	81.93	93.27	87.92	88.40	89.96
12	85.31	77.37	81.82	83.75	75.64	78.76	92.90	86.63	85.12	85.31
13	84.47	76.33	78.20	83.37	73.01	72.62	91.66	83.08	82.64	84.47
14	83.66	74.21	74.11	78.16	71.13	70.00	86.03	81.41	81.28	83.66
15	78.10	73.27	72.38	76.54	66.97	68.13	85.10	79.43	78.22	78.10
16	77.69	70.08	72.25	73.90	63.58	63.04	79.93	76.29	74.62	77.69
17	74.77	69.74	70.59	69.11	62.51	62.77	77.80	71.47	74.47	74.77
18	71.18	68.29	60.80	66.61	62.42	60.96	74.41	70.32	70.94	71.18
AMC III	**98.35**	**95.35**	**96.83**	**96.56**	**93.34**	**95.33**	**99.51**	**98.53**	**97.53**	**98.35**
AMC II	**91.30**	**85.60**	**87.26**	**88.39**	**82.83**	**83.78**	**94.62**	**93.24**	**92.12**	**91.30**
AMC I	**74.41**	**69.59**	**69.61**	**68.86**	**62.50**	**62.58**	**77.46**	**71.35**	**74.11**	**74.41**

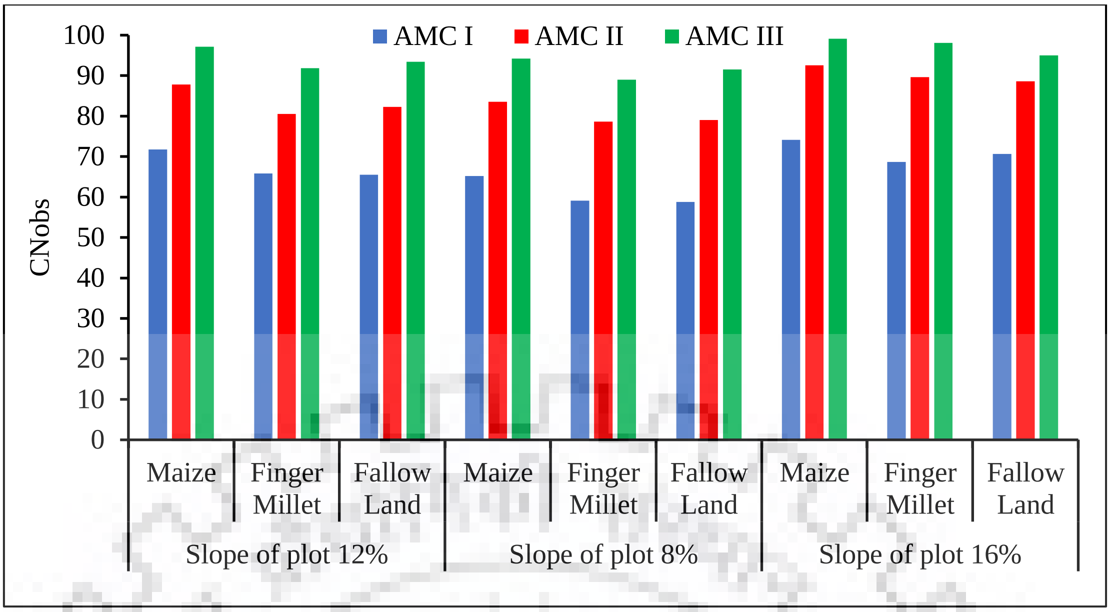


Figure 4.9 Observed CN (CN_{obs}) using MS 2002 model

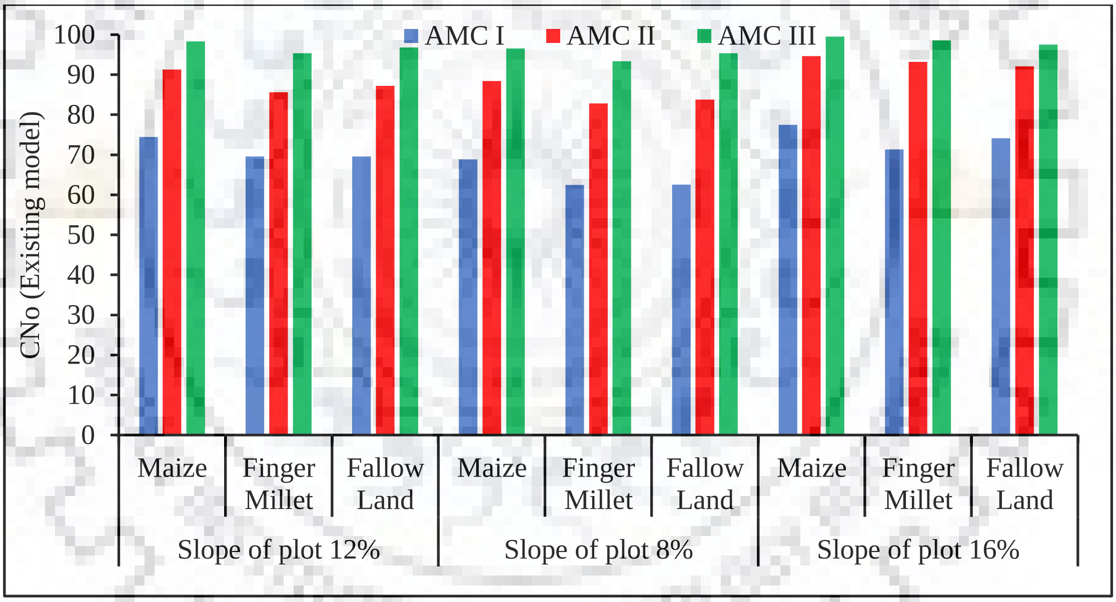


Figure 4.10 Observed curve number (CN_{obs}) using Existing SCS-CN model

It can be seen from Fig. 4.9 & 4.10 and Table 4.11 & Table 4.12 that the observed CNs using the existing SCS-CN model are higher than those obtained from modified SCS-CN model derived from same observed P-Q data.

4.6.3 From Optimization of CN (or S) and λ

In this method, the value of initial abstraction (λ) and maximum potential retention S (or CN) are optimized by optimization technique with NSE as objective function. The

Generalized Reduced Gradient (GRG) non-linear method is a generalization of the reduced gradient method by allowing nonlinear constraints and arbitrary bounds on the variables. For the optimization of CN & λ maximization of NSE was set as an objective function and value of CN (or S) & λ were set in such a way that their value must be greater or equal to zero. After getting value of S, the CN was computed using Eq. 2.19. As an example, the calculations steps are shown in Table 4.13 &

Table *4.14* for 12% slope with Maize crop for both the MS model and existing SCS-CN model, respectively. The results for the rest of the experimental plots using both the models are shown in Appendix F, Table F10 to Table F23.

Table 4.13 Computation of CN, λ and NSE using modified SCS-CN for Maize crop (12% slope)

Rainfall (P) (mm)	Observed runoff (Q_{obs}) (mm)	Antecedent moisture content (M) (mm)	CN_{opti}	λ	S (mm)	Q_{comp} (mm)	(Q_o-Q_c)	$(Q_o-Q_c)^2$	$(Q_o-Q_m)^2$
57.00	25.32	14.35	70.63	0.01	105.60	22.36	2.96	8.77	87.98
11.00	5.00	28.26				2.64	2.35	5.56	119.68
57.00	15.60	17.88				23.02	-7.41	55.02	0.11
129.40	63.66	24.19				75.84	-12.17	148.34	2277.19
35.00	16.56	21.96				11.75	4.81	23.14	0.38
19.00	12.14	8.35				3.58	8.56	73.32	14.44
13.00	12.65	15.24				2.45	10.20	104.13	10.82
20.50	6.28	18.34				5.12	1.15	1.33	93.31
7.30	2.97	20.16				1.25	1.72	2.96	168.22
11.50	2.54	15.36				2.05	0.48	0.23	179.56
17.2	12.64	20.22				4.14	8.50	72.33	10.89
117.8	73.91	16.2				65.06	8.84	78.26	3360.52
29.6	16.26	20.28				9.02	7.23	52.34	0.1
29	10.54	20.04				8.73	1.80	3.27	29.16
17.2	5.14	16.7				3.83	1.31	1.71	116.64
15.6	0.74	11.52				2.88	-2.13	4.57	231.04
43.7	4.25	18.57				15.65	-11.39	129.92	136.65
22.2	0.8	26.01				6.53	-5.72	32.79	229.21
Sum	287.00					Sum	21.09	797.99	7065.90
Mean	15.94					NSE=	89%		
						RMSE=	8.93		
						PBIAS	7%		

Table 4.14 Computation of CN, λ and NSE using existing SCS-CN for Maize crop (12% slope)

Rainfall (P) (mm)	Observed runoff (Q_{obs}) (mm)	CN_{opti}	λ	S	Q_{comp}	(Q_o-Q_c)	$(Q_o-Q_c)^2$	$(Q_o-Q_m)^2$
57.00	25.32	74.27	0.020	88.00	21.30	4.01	16.13	87.98
11.00	5.00				0.88	4.12	16.99	119.68
57.00	15.60				21.30	-5.70	32.52	0.11
129.40	63.66				75.55	-11.89	141.41	2277.19
35.00	16.56				9.11	7.44	55.45	0.38
19.00	12.14				2.82	9.31	86.78	14.44
13.00	12.65				1.27	11.37	129.43	10.82
20.50	6.28				3.29	2.98	8.93	93.31
7.30	2.97				0.33	2.64	6.97	168.22
11.50	2.54				0.97	1.56	2.46	179.56
17.2	12.64				2.30	10.33	106.81	10.89
117.8	73.91				65.99	7.91	62.67	3360.52
29.6	16.26				6.69	9.56	91.56	0.1
29	10.54				6.44	4.10	16.81	29.16
17.2	5.14				2.30	2.83	8.03	116.64
15.6	0.74				1.88	-1.14	1.3	231.04
43.7	4.25				13.54	-9.28	86.24	136.65
22.2	0.8				3.85	-3.05	9.31	229.21
Sum	287.00				Sum	47.10	879.80	7065.90
Mean	15.94				NSE=	88%		
					RMSE=	9.38		
					PBIA=	16%		

Table 4.15 & Table 4.16 also shows the optimized values of CN and λ and their goodness-of-fit statistics in terms of NSE, RMSE and PBIAS for both the models and all the nine plots. Fig 4.11 also shows the comparison between the CN_{opti} values using the existing and MS model.

Table 4.15 Optimized values of CN, λ and the values of NSE, RMSE and PBIAS using existing SCS-CN model

Slope	Land use	No. of events	CN_{opti}	λ	S	NSE	RMSE	PBIAS
12%	Maize	18	74.27	0.020	88.00	88%	9.38	16%
	Finger millet	18	54.60	0.010	211.20	94%	4.39	20%
	Fallow land	18	57.47	0.003	187.97	79%	7.82	11%

Slope	Land use	No. of events	CN_{opti}	λ	S	NSE	RMSE	PBIAS
8%	Maize	18	58.75	0.003	187.97	81%	10.48	27%
	Finger millet	18	59.39	0.050	173.65	88%	5.44	-1%
	Fallow land	18	41.91	0.000	352.00	86%	6.04	24%
16%	Maize	18	82.79	0.000	52.80	81%	13.15	14%
	Finger millet	18	67.09	0.000	124.57	67%	14.55	28%
	Fallow land	18	65.88	0.030	131.55	83%	8.81	28%

Table 4.16 Optimized values of CN, λ, and the values of NSE, RMSE and PBIAS using modified SCS-CN (MS 2002) model

Slope	Land use	No. of events	CN_{opti}	λ	S	NSE	RMSE	PBIAS
12%	Maize	18	53.42	0.01	105.60	89%	8.93	7%
	Finger millet	18	45.86	0.00	280.47	95%	4.11	12%
	Fallow land	18	53.83	0.05	217.83	79%	7.76	25%
8%	Maize	18	49.92	0.01	176.00	83%	9.86	13%
	Finger millet	18	37.69	0.00	422.40	90%	4.85	16%
	Fallow land	18	31.33	0.00	422.40	86%	6.13	16%
16%	Maize	18	79.47	0.04	64.86	83%	12.69	15%
	Finger millet	18	67.24	0.00	140.80	70%	13.97	20%
	Fallow land	18	56.21	0.00	176.00	88%	7.42	18%

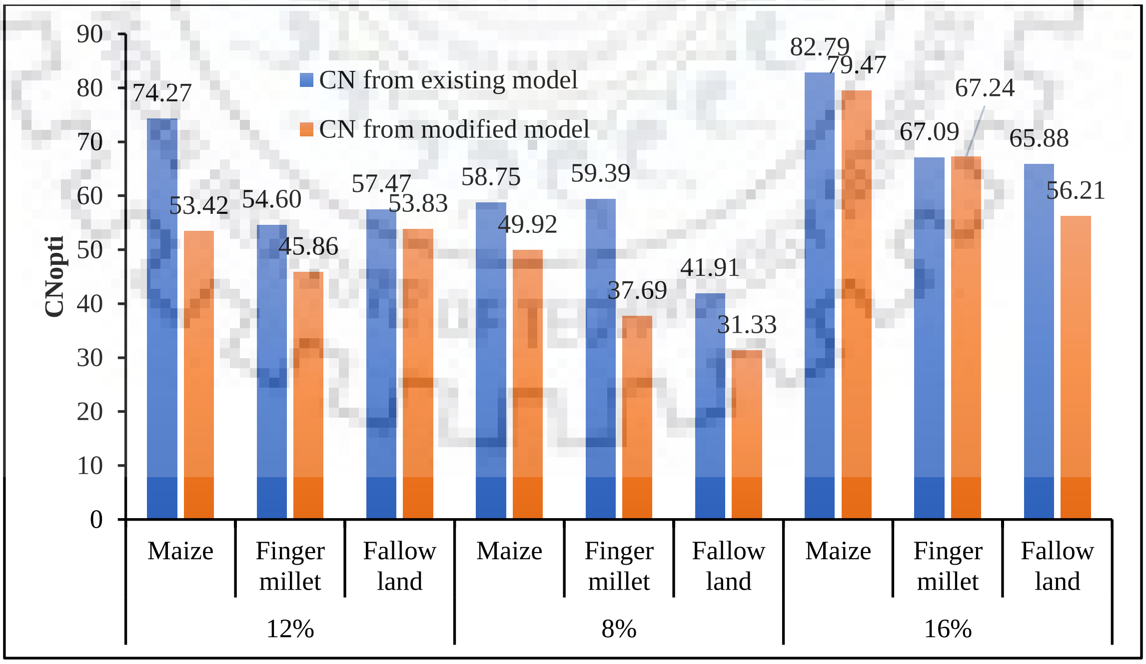


Figure 4.11 CN_{opti} determined from existing and modified (MS 2002) SCS-CN model

From Fig 4.11 and Table 4.15 & Table 4.16, it is observed that the value of CN_{opti} using the existing SCS-CN model is always greater than CN_{opti} determined from modified (MS 2002) SCS-CN model. This may be attributed to the fact the existing SCS-CN model does not include the volume of water or the soil moisture before the onset of storm event, resulting into the lower values of S than that of modified model. As the S and CN are inversely proportional to each other, a lower value of S gives higher value of CN.

4.7 Relationship Between Rainfall (P) and Curve Number (CN)

The relationship between P and CN has always been a topic of discussion in CN hydrology. As discussed in Section 3.5.3, there may be three types of the watersheds' behavior depending upon the P and CN variations, i.e., *Complacent*, *Standard and Violent*. In this study also, the variation of CN with P was explored for all the nine plots with varying slope and land use land cover and for all the eighteen storm events. As an example, Fig 4.12-4.17 show the variation of CN_{obs} with P for the modified as well as existing SCS-CN method. As shown in Figs. 4.12-4.17 the CN_{obs} decline with increasing storm size and approach or maintain a near constant value with increasing large storm. According to Hawkins (1993), this behavior of the experimental plots may be classified as '*Standard*'

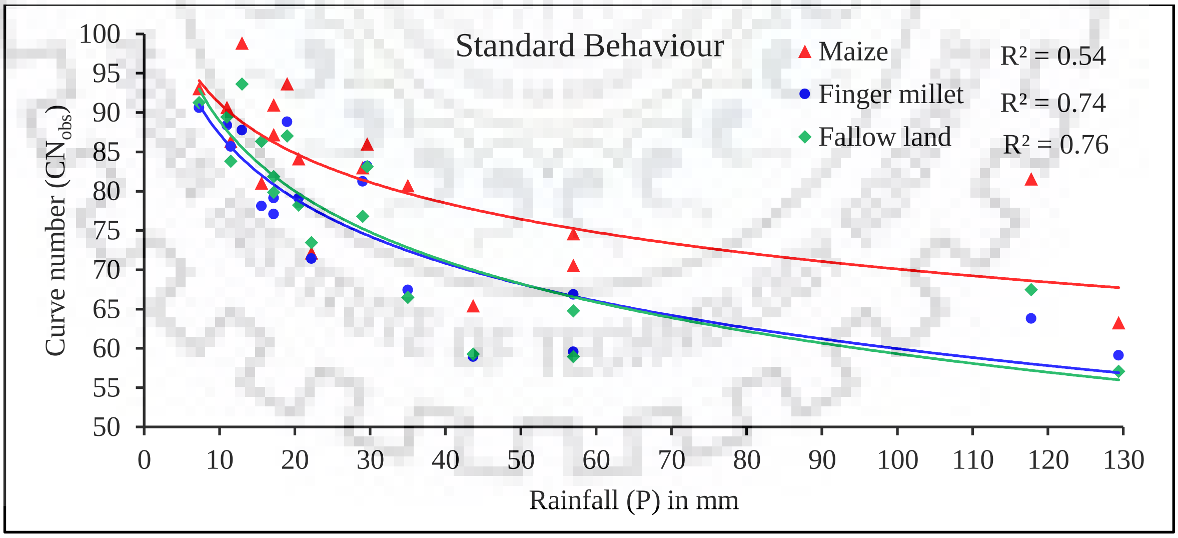


Figure 4.12 CN-P response for 8% slope plot using modified SCS-CN model

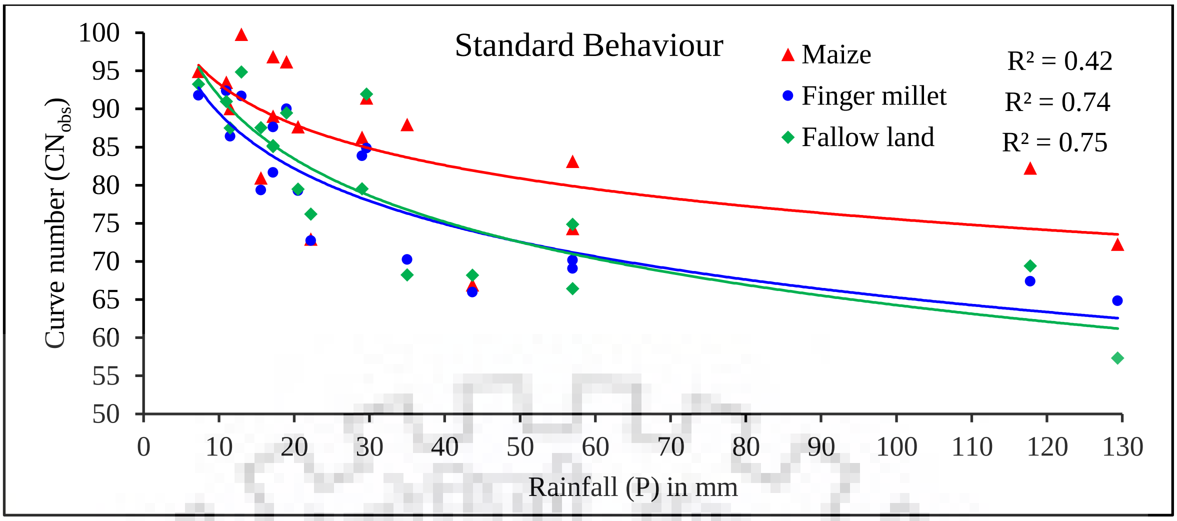


Figure 4.13 CN-P response for 12% slope plot using modified SCS-CN model

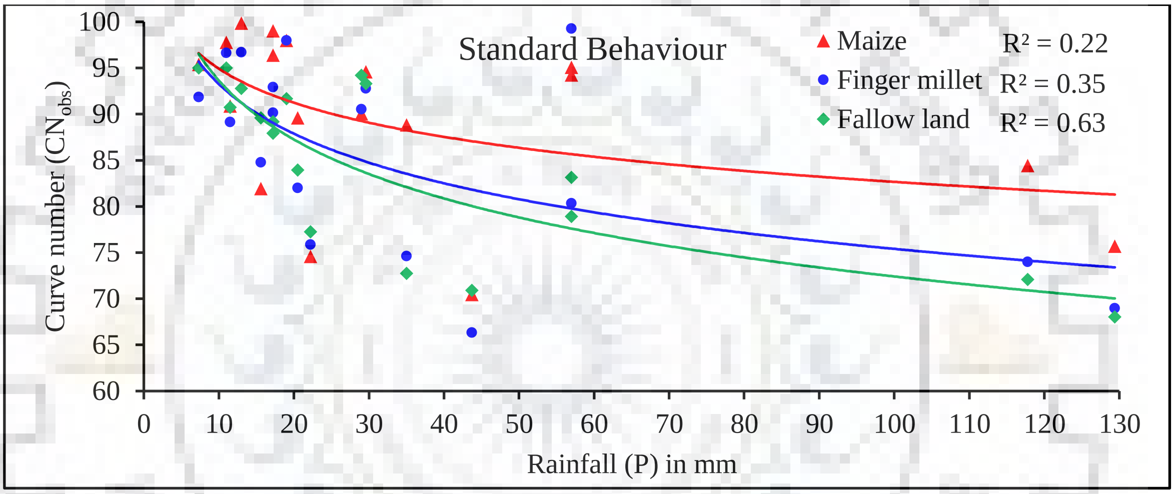


Figure 4.14 CN-P response for 16% slope plot using modified SCS-CN model

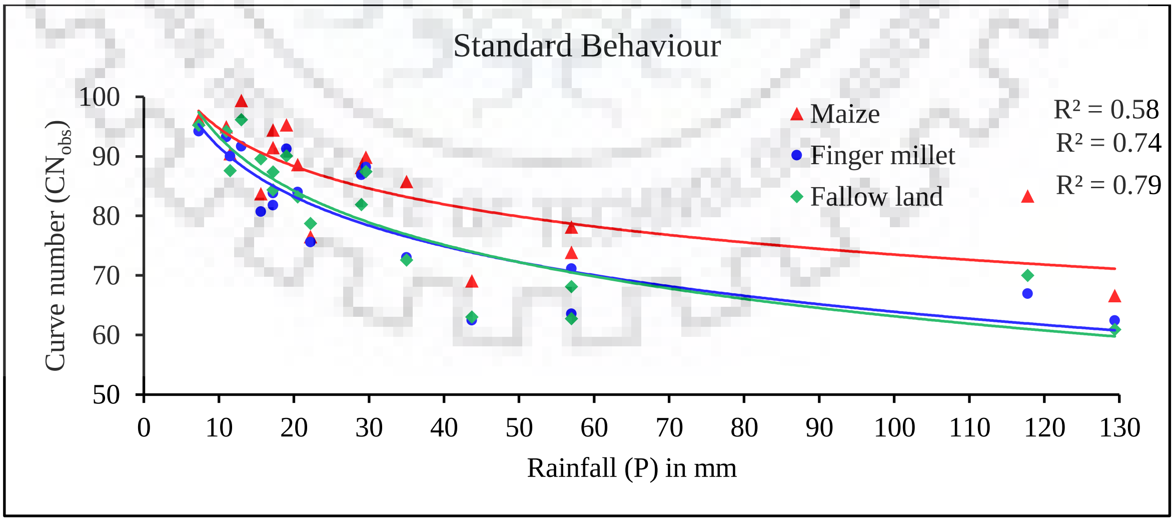


Figure 4.15 CN-P response for 8% slope plot using existing SCS-CN model

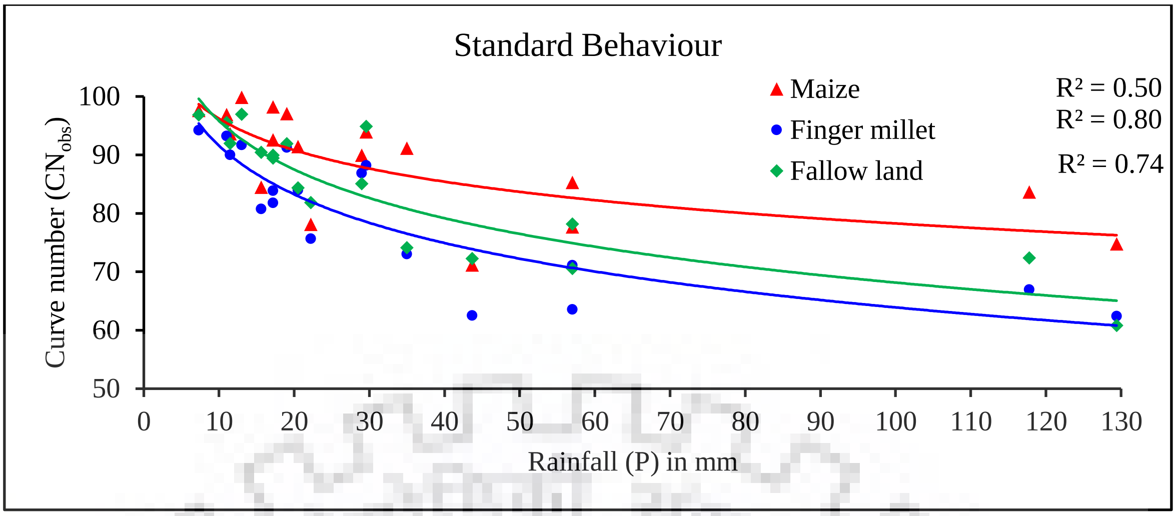


Figure 4.16 CN-P response for 12% slope plot using existing SCS-CN model

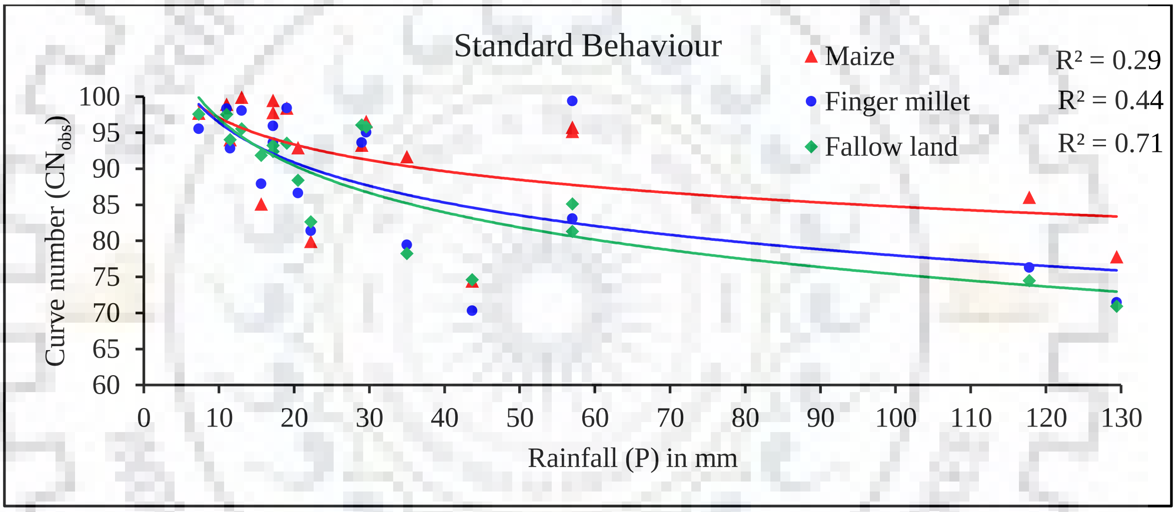


Figure 4.17 CN-P response for 16% slope plot using existing SCS-CN model

4.8 Effect of Slope, Land Use/Cover and AMC (M) on CN

This section briefly discusses the effects of plot slope, land use land / land cover and antecedent moisture content on CN to distinguish their relative impacts on the runoff generation process.

4.8.1 Effect of slope and Land Use/Cover on CN

All the plots of our experimental farm were agricultural land. Two type of crop namely Maize and Finger Millet were planted and one plot was left as Fallow land in each slope (8%, 12% and 16%). Well known to the fact that CN is affected by canopy cover, population of plant and type of plant which intercepts the rainwater by their leaf as well as branches and obstruct the surface runoff too. This phenomenon provides the greater time lag to runoff, allowing more time to infiltrate into the soil resulting into low runoff. On the other hand, wide spaced crop does not provide more lag time and produces high runoff. Similarly, as the watershed slope is increased the CN is also increased for different types of the land uses.

The observed CNs (CN_{obs}) were estimated by using both the existing and the modified SCS-CN method based on the concept of frequency matching method. Fig 4.18 & 4.19 shows the variation of CN_{obs} with land use land cover for three different slopes for existing and the modified SCS-CN method. It can be observed from Figures 4.18 & 4.19 that the existing SCS-CN method consistently computes higher CNs as compared to the modified SCS-CN method and hence as mentioned by Schneider and McCuen (2005) that the existing SCS-CN method always overestimates the runoff, whereas the modified SCS-CN method has lower values of CNs and hence improved predictability.

Runoff and CN is directly proportional to each other so that higher CN means high runoff and vice versa. In this study it has been seen that Maize crop exhibit highest CN for all three-slope plot, since it is wide spaced crop as compared with Finger Millet and Fallow land (Figures 4.18 & 4.19). The Finger Millet plots have lower values of CN_{obs} as compared to the Fallow land plot.

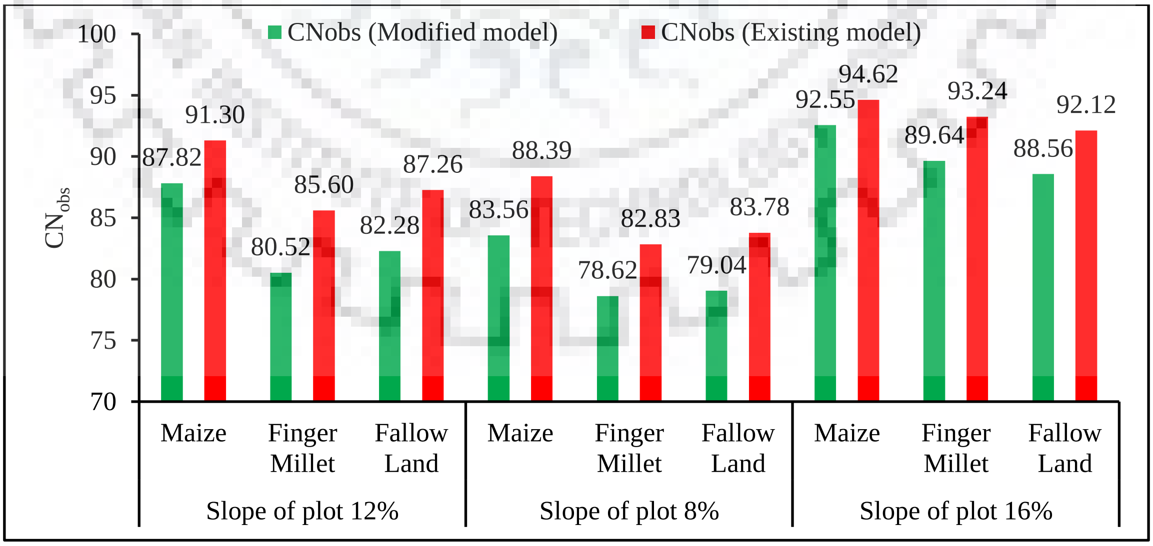


Figure 4.18 Variation of CN_{obs} with different slopes and land use land cover (using frequency matching technique)

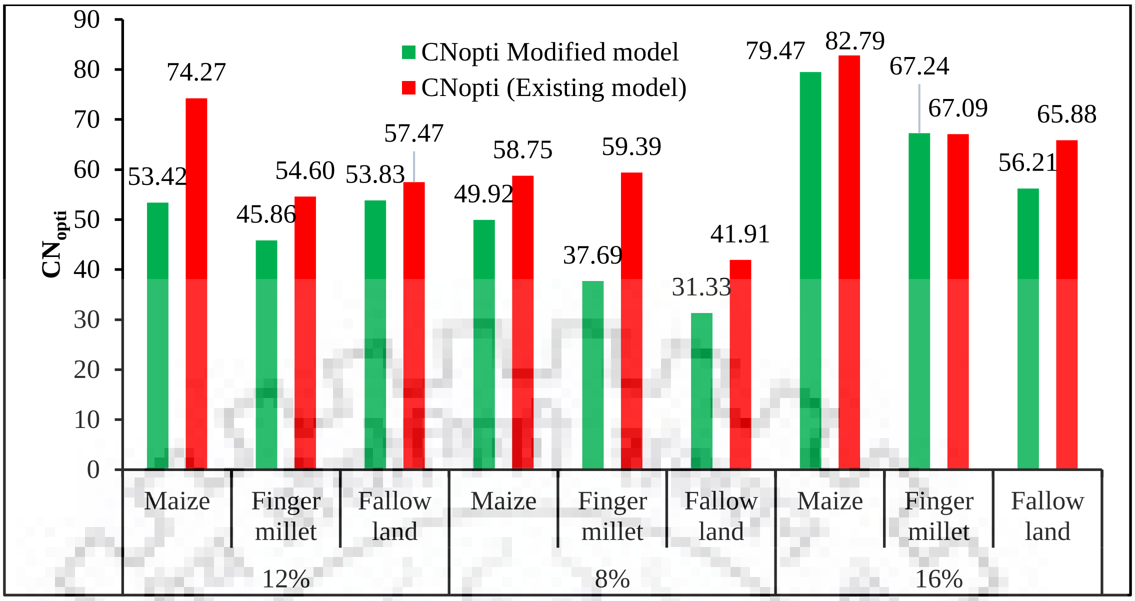


Figure 4.19 Variation of CN_{opti} with different slopes and land use land cover (using optimization technique)

4.8.2 Effect of antecedent moisture content (M) on CN

Moisture is the amount of water present in the void of soil. According to three phase diagrams of soil, soil consists of soil solid, volume of water and volume of air. Sum of volume of water (V_w=M) and volume of air (V_a) present in total volume is represented by absolute potential maximum retention (S_{abs}) and volume of air (V_a) is represented by potential maximum retention (S). But according to soil mechanics,

$$V_v = V_w + V_a \quad \text{Eq. 4.1}$$

It means

$$S_{abs} = M + S \quad \text{Eq. 4.2}$$

As S_{abs} is constant for a particular soil, Eq. 4.2 shows that there will be an inverse relationship between S and M. At the same time as S decreases CN will increase and vice versa. When we plot graph between CN_{obs} and M, we found same trend as discussed (Fig 4.20-4.22).

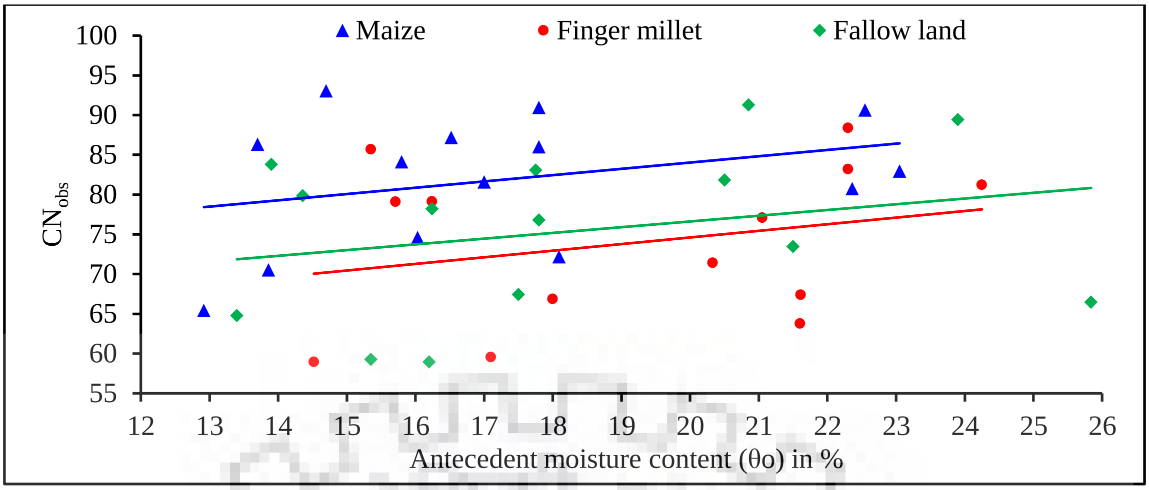


Figure 4.20 Variation of CN_{obs} with M for 8% slope plot

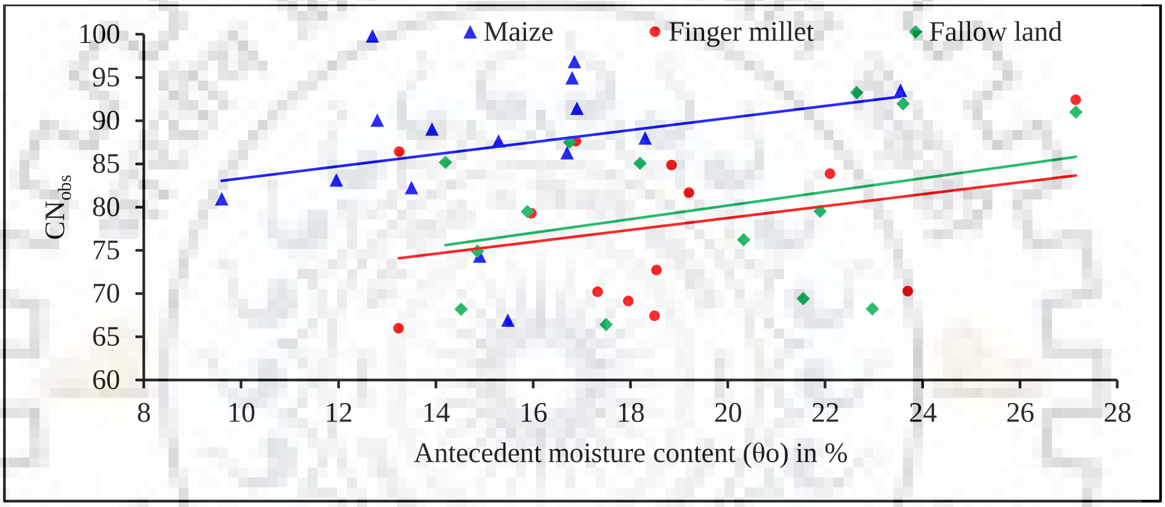


Figure 4.21 Variation of CN_{obs} with M for 12% slope plot

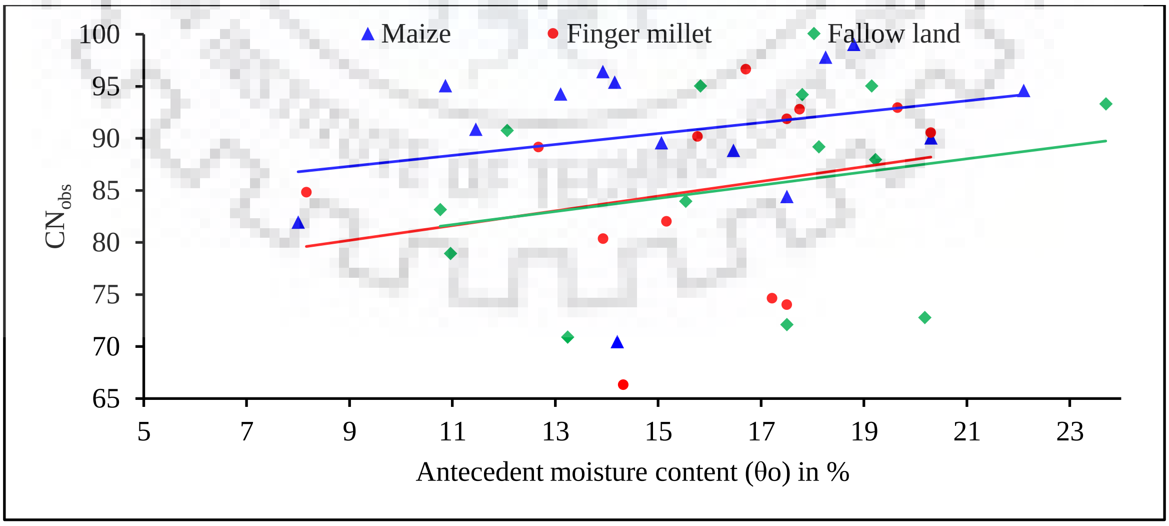


Figure 4.22 Variation of CN_{obs} with M for 16% slope plot

4.9 Comparison of CNs Estimated Using Different Techniques

As discussed above, CNs were derived from observed P-Q data using frequency matching method (CN_{obs}) as well as optimization of S and λ (CN_{opti}) for both existing and modified SCS-CN method and by using NEH-4 Table (CN_{NEH-4}) as per land use, land cover characteristics, type of crop and hydrological soil group. Estimated values of CN_{opti}, CN_{obs} and CN_{NEH-4} are shown in Table 4.17. The slope corrected CN_{NEH-4} values are also shown in Table 4.17.

Table 4.17 Values of CNs computed from different methods

Slope %	Land Use	CN_{obs}		CN_{opti}		CN_{NEH-4}	
		Existing SCS-CN Method	Modified (MS 2002) Method	Existing SCS-CN Method	Modified (MS 2002) Method	Without slope adjustment	With slope adjustment
12%	Maize	91.30	87.82	74.27	70.63	72.00	74.03
	Finger millet	85.60	80.52	54.60	47.52	65.00	66.83
	Fallow land	87.26	82.28	57.47	53.85	77.00	79.17
8%	Maize	88.39	83.56	58.75	59.07	72.00	72.88
	Finger millet	82.83	78.62	59.39	37.55	65.00	65.79
	Fallow land	83.78	79.04	41.91	37.55	86.00	87.05
16%	Maize	94.62	92.55	82.79	79.66	72.00	75.13
	Finger millet	93.24	89.64	67.09	64.34	65.00	67.83
	Fallow land	92.12	88.56	65.88	59.07	77.00	80.35

While plotting combo chart between NEH-4 Table CN (CN_{NEH-4}), observed CN (CN_{obs}) and optimized CN (CN_{opt}) using both existing and modified SCS-CN model, it is found that the observed CN is higher and optimized CN is lower than NEH-4 Table CN. The differences between observed and optimized CN may be attributed to the considerations of constant initial abstraction ratio (λ=0.2 for observed CN) and variable initial abstraction ratio (λ varies plot to plot for optimized CN), respectively. The NEH-4 Tabulated CNs are very approximate estimates of the CNs for a given land use land cover, hydrologic condition and HSG.

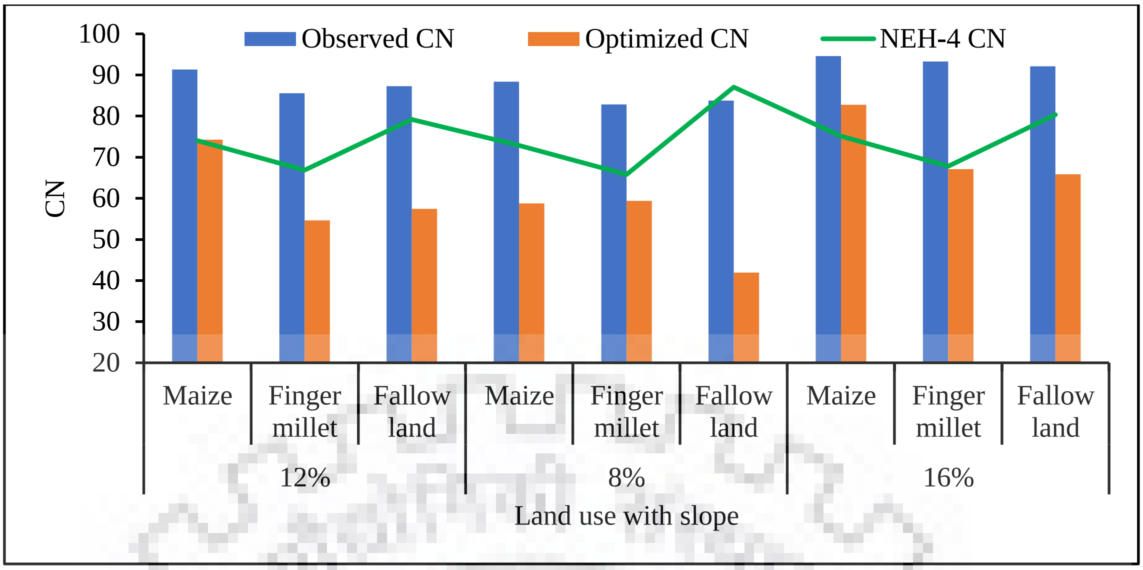


Figure 4.23 Comparison of CNs obtained from different methods (for existing model)

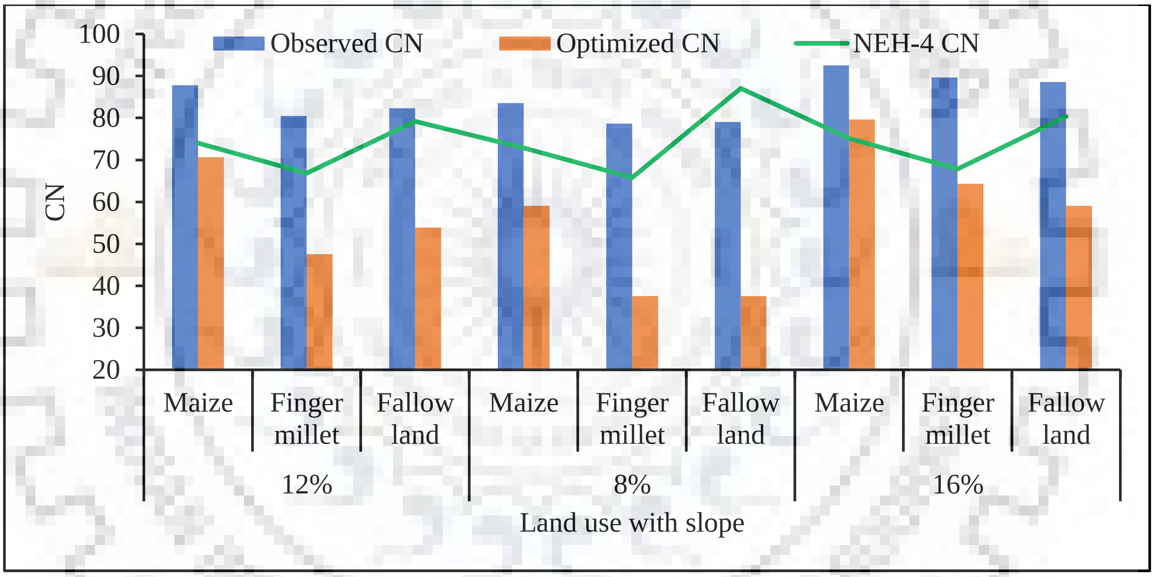


Figure 4.24 Comparison of CNs obtained from different methods (using MS 2002 model)

4.10 Goodness–of-Fit Statistics of the Existing and Modified (MS 2002) and Existing SCS-CN Method for Runoff Estimation

This section deals with the testing the efficacy of the modified and existing SCS-CN method using goodness-of-fit statistics in terms of NSE, RMSE and PBIAS for all the nine plots and for all the eighteen storm events. Notably, the CNs are estimated using the optimization technique and NEH-4 Table with slope corrections.

4.10.1 Using CN_{opt} Technique

As discussed previously in Section 4.6.3, all the 18 storm events were taken for optimization of parameter S and λ. In this method, a trial value of S (or CN_{opti}) and λ are given as initial random value to compute the runoff (Q_{comp}) using the existing and the modified SCS-CN method. Since we already have observed runoff, now we have a pair of observed and computed runoff data set. Using this data set, the goodness-of-fit statistics was evaluated in terms of NSE, RMSE, and PBIAS and the results are given in Table 4.18. It can be observed from Table 4.18 that the modified SCS-CN method has consistently higher values of NSE and lower values of RMSE and PBIAS as compared to the existing SCs-CN method.

Table 4.18 Goodness-of-fit statistics of existing and modified (MS 2002) SCS-CN model using optimization technique.

Plot No.	Slope %	Land Use	Optimization technique							
			Existing model				Modified (MS 2002) model			
			λ	NSE	RMSE	PBIAS	λ	NSE	RMSE	PBIAS
1	12%	Maize	0.020	88%	9.38	16%	0.010	89%	8.93	7%
2		Finger millet	0.010	94%	4.39	20%	0.000	95%	4.11	12%
3		Fallow land	0.003	79%	7.82	11%	0.050	79%	7.76	25%
4	8%	Maize	0.003	81%	10.48	27%	0.010	83%	9.86	13%
5		Finger millet	0.050	88%	5.44	-1%	0.003	90%	4.85	16%
6		Fallow land	0.000	86%	6.04	24%	0.001	86%	6.13	16%
7	16%	Maize	0.000	81%	13.15	14%	0.040	83%	12.69	15%
8		Finger millet	0.000	67%	14.55	28%	0.002	70%	13.97	20%
9		Fallow land	0.030	83%	8.81	28%	0.000	88%	7.42	18%

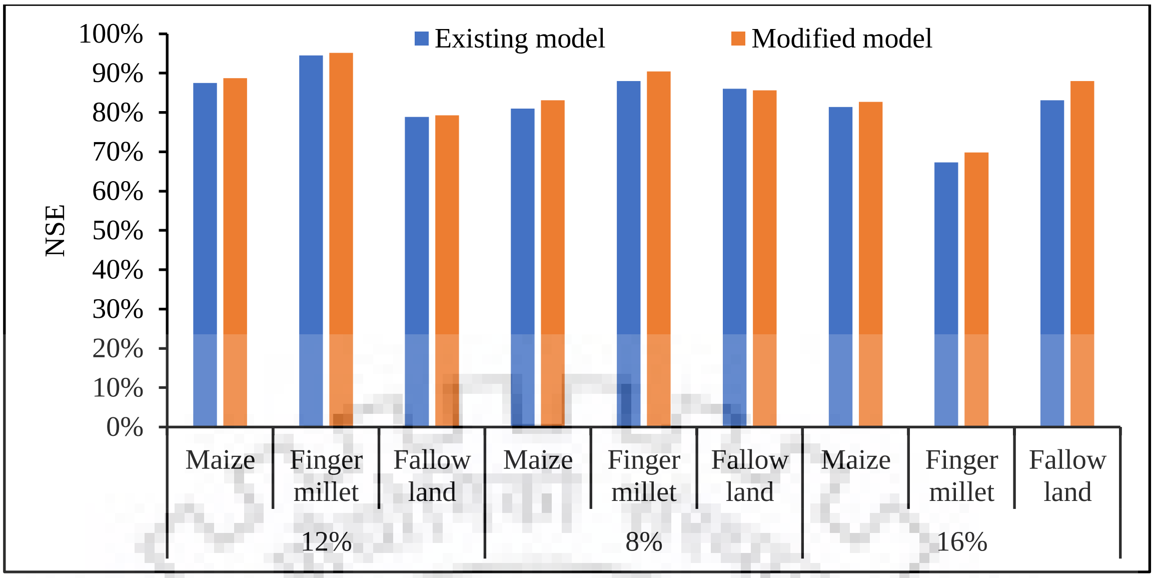


Figure 4.25 NSE of modified (MS 2002) and existing SCS-CN model (by optimization)

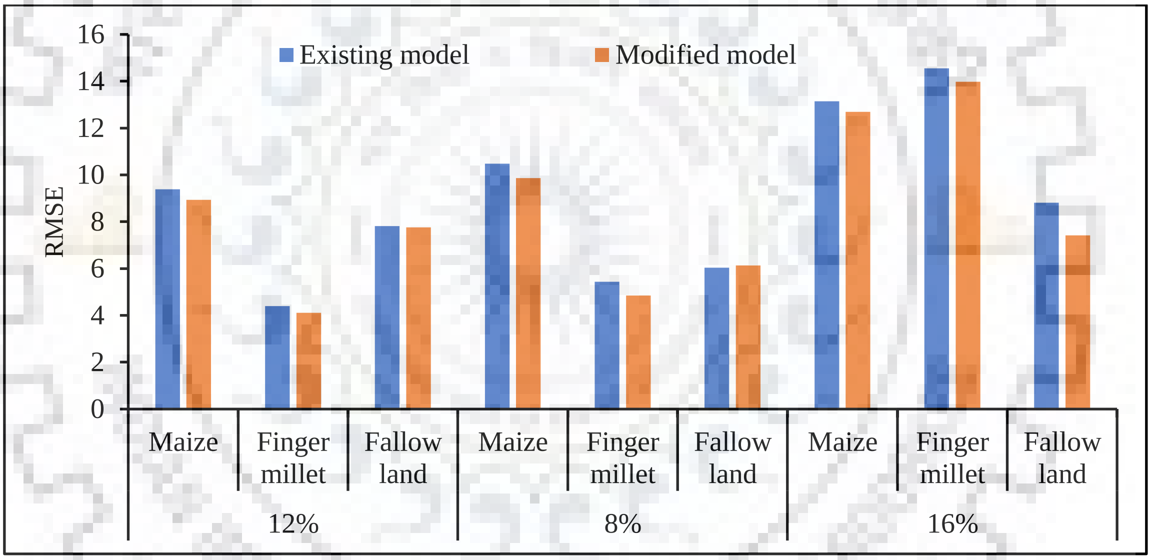


Figure 4.26 RMSE of modified (MS 2002) and existing SCS-CN model (by optimization)

A graphical comparison between the observed and computed runoff using the existing and the modified SCS-CN method is also given in Fig 4.27-35. There is a good correlation between computed and observed runoff for both existing and modified SCS-CN model.

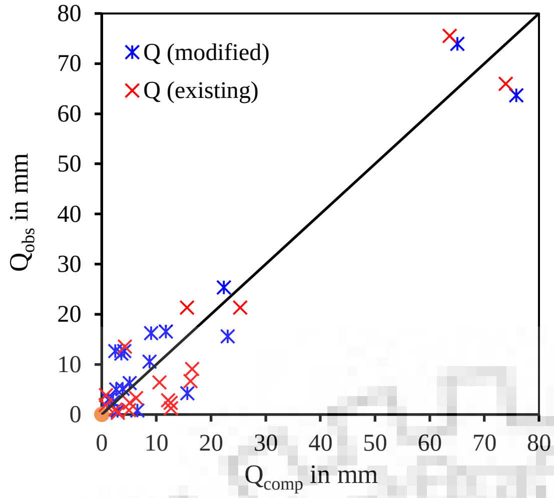


Figure 4.27 Comparison between Q_{obs} and Q_{comp} runoff for Maize (slope12%) using optimization technique.

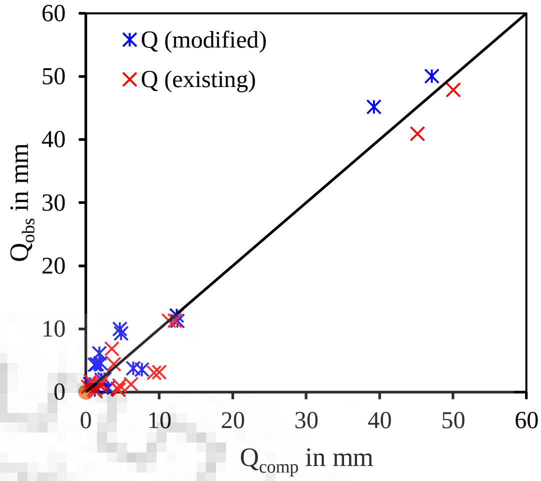


Figure 4.28 Comparison between Q_{obs} and Q_{comp} runoff for Finger Millet (slope12%) using optimization technique.

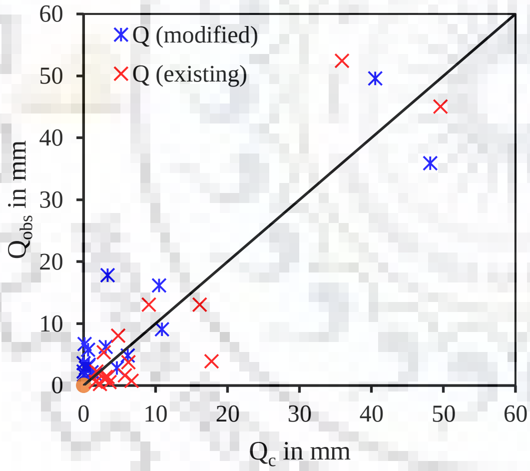


Figure 4.29 Comparison between Q_{obs} and Q_{comp} runoff for Fallow land (slope12%) using optimization technique.

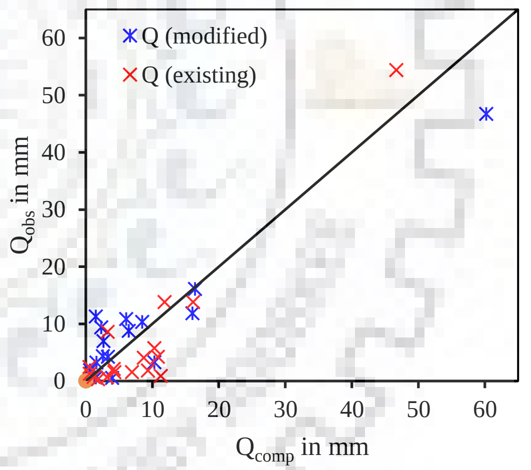


Figure 4.30 Comparison between Q_{obs} and Q_{comp} runoff for Maize (slope 8%) using optimization technique.

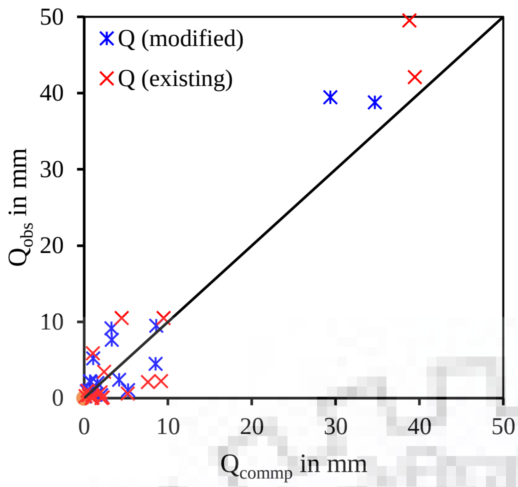


Figure 4.31 Comparison between Q_{obs} and Q_{comp} runoff for Finger Millet (slope 8%) using optimization technique.

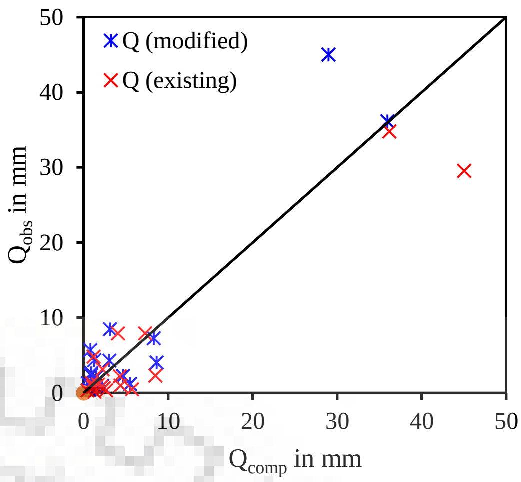


Figure 4.32 Comparison between Q_{obs} and Q_{comp} runoff for Fallow land (slope 8%) using optimization technique.

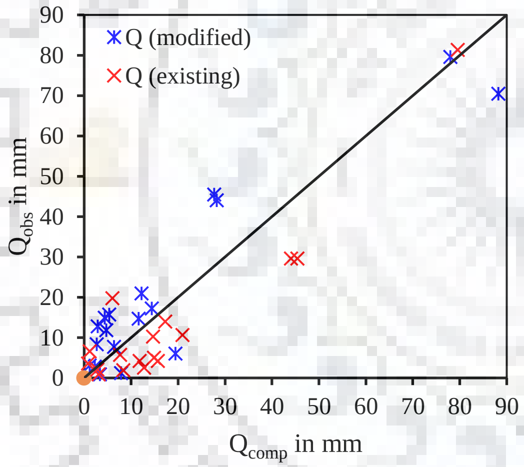


Figure 4.33 Comparison between Q_{obs} and Q_{comp} runoff for Maize (slope 16%) using optimization technique.

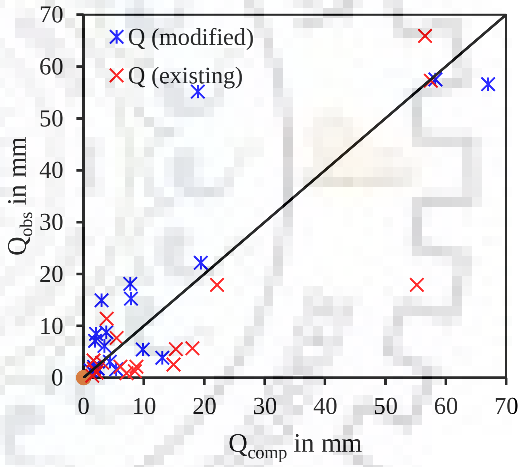


Figure 4.34 Comparison between Q_{obs} and Q_{comp} runoff for Finger Millet (slope 16%) using optimization technique.

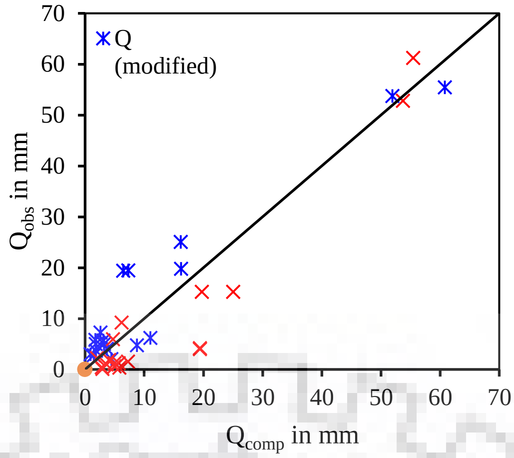


Figure 4.35 Comparison between Q_{obs} and Q_{comp} runoff for Fallow land (slope 16%) using optimization technique.

4.10.2 Using CN_{NEH-4} Technique

Based on the P_5 values, AMC I, AMC II and AMC III have been determined assuming growing season and the CN_{NEH-4} values were converted to CN-I & CN-III using Eq. 2.8 & Eq. 2.9 Mishra et al., (2008). Since the CNs in NEH-4 Table corresponds for watersheds having slope 5%, all the CNs were adjusted according to our experimental plot slope i.e. to slope 8%, 12% and 16% by using equation given by Ajmal et al., (2016) (Table 2.9). The runoff was computed for the slope corrected CN_{NEH-4} values (Table 4.4) using the existing and the modified SCS-CN method. The Computational steps are shown in Appendix G, Table G1-G2. The goodness-of-fit statistics in terms of NSE, RMSE and PBIAS is shown in Table 4.19.

Table 4.19 Goodness-of-fit statistics of existing and modified (MS 2002) SCS-CN model (Runoff Q_{comp} calculated using CN_{NEH-4})

Plot No.	Slope %	Land Use	NEH-4 table (λ=0.2)					
			Existing model			Modified (MS 2002) model		
			NSE	RMSE	PBIAS	NSE	RMSE	PBIAS
1	12%	Maize	59%	12.67	54%	69%	11.01	39%
2		Finger Millet	52%	9.70	52%	60%	8.83	19%
3		Fallow land	79%	5.80	-3%	63%	7.67	-29%
4	8%	Maize	75%	9.04	46%	83%	7.45	25%
5		Finger Millet	64%	6.97	41%	66%	6.84	-3%
6		Fallow land	-29%	13.67	-112%	-84%	16.35	-146%

Plot No.	Slope %	Land Use	NEH-4 table (λ=0.2)					
			Existing model			Modified (MS 2002) model		
			NSE	RMSE	PBIAS	NSE	RMSE	PBIAS
7	16%	Maize	31%	18.84	62%	42%	17.24	50%
8		Finger Millet	15%	17.53	69%	27%	16.23	51%
9		Fallow land	71%	8.62	21%	71%	8.58	4%

Observed and computed runoff have been plotted as shown in Fig. 4.36-4.44. It has been found satisfactory correlation between computed and observed runoff for both existing and modified SCS-CN method. Most of the plotting points does not lie on line of perfect fit which indicates that the model either over estimate or under estimate runoff than observed one.

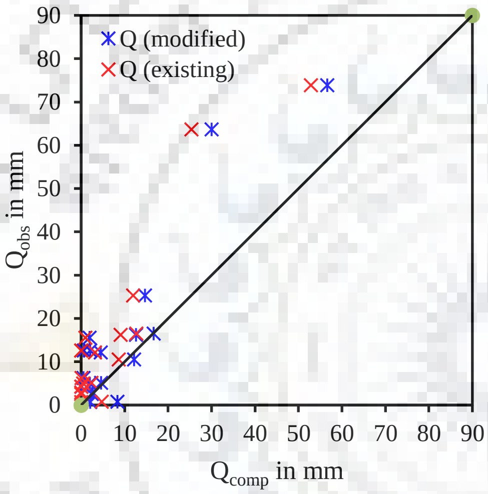


Figure 4.36 Comparison between Q_{obs} and Q_{comp} runoff for Maize (slope 12%) using NEH-4 technique.

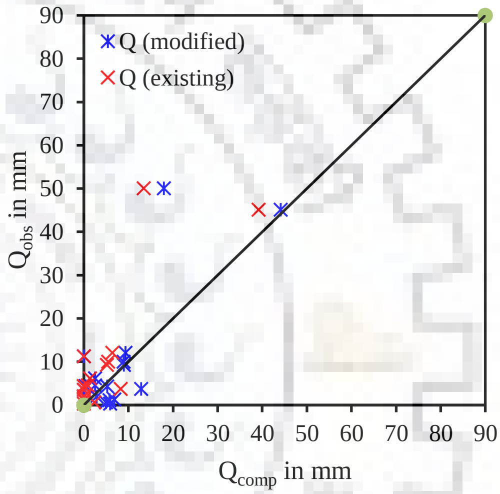
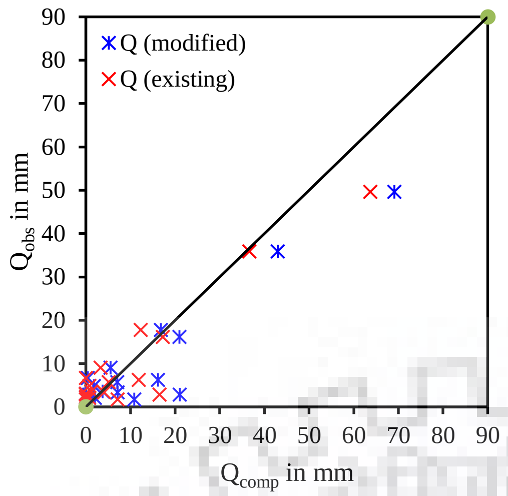


Figure 4.37 Comparison between Q_{obs} and Q_{comp} runoff for Finger Millet (slope 12%) using NEH-4 technique.



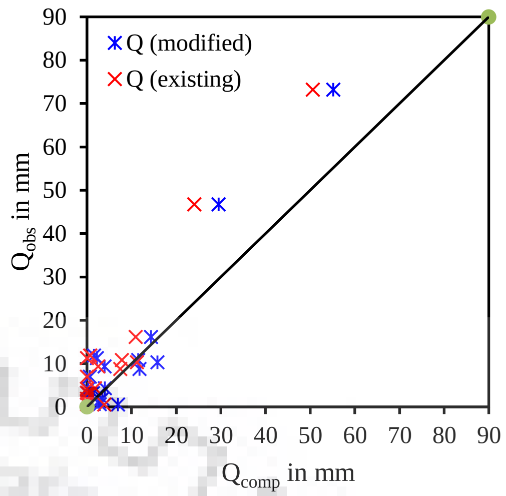
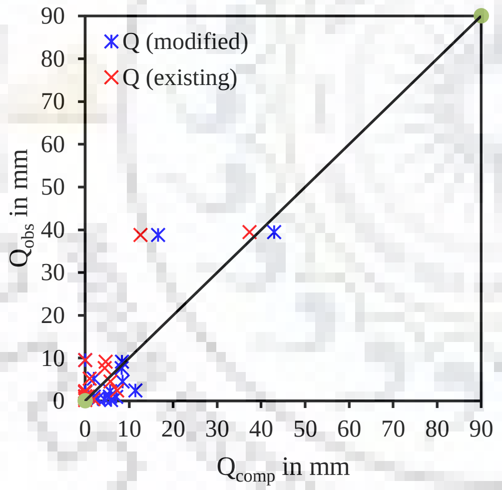


Figure 4.38 Comparison between Q_{obs} and Q_{comp} runoff for Fallow land (slope 12%) using NEH-4 technique.

Figure 4.39 Comparison between Q_{obs} and Q_{comp} runoff for Maize (slope 8%) using NEH-4 technique.



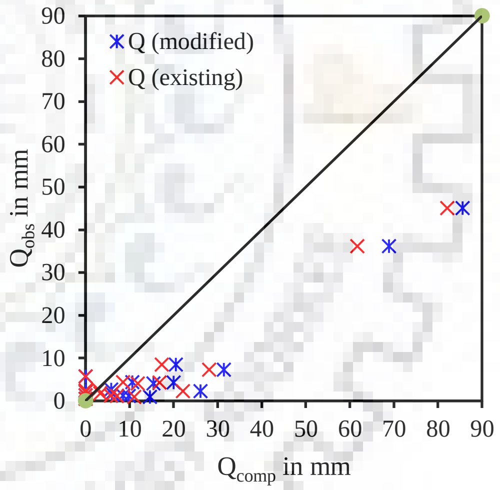


Figure 4.40 Comparison between Q_{obs} and Q_{comp} runoff for Finger Millet (slope 8%) using NEH-4 technique.

Figure 4.41 Comparison between Q_{obs} and Q_{comp} runoff for Fallow land (slope 8%) using NEH-4 technique.

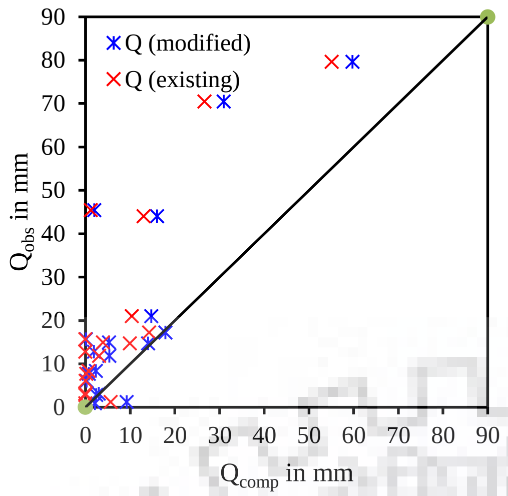


Figure 4.42 Comparison between Q_{obs} and Q_{comp} runoff for Maize (slope 16%) using NEH-4 technique.

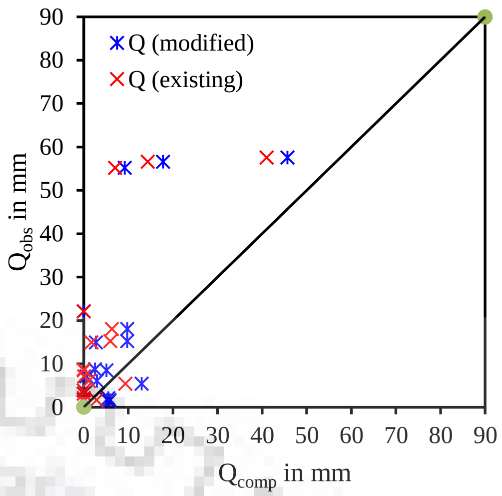


Figure 4.43 Comparison between Q_{obs} and Q_{comp} runoff for Finger Millet (slope 16%) using NEH-4 technique.

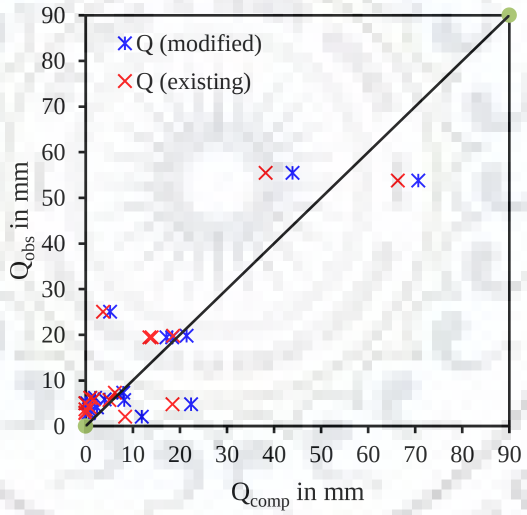


Figure 4.44 Comparison between Q_{obs} and Q_{comp} runoff for Fallow land (slope 16%) using NEH-4 technique.

Table 4.18 shows the variation of initial abstraction ratio (λ) from 0.00 to 0.05 both in existing and modified SCS-CN method with different land use / land cover. It indicates that constant value of λ=0.2 may not be appropriate in all cases. Similarly, Table 4.18 also shows NSE of modified (MS 2002) model obtained from optimization technique is greater than existing model indicating modified model is better than existing model. But, Table 4.19 shows some absurd value of NSE like -29%, 15%. It may be due to limitation of experimental plot and its devices which influence the data collected from it.

CHAPTER 5

5. SUMMARY AND CONCLUSION

To fulfil the objective, an experiment was carried out in agricultural experimental farm located in Toda, Kalyanpur, Roorkee, Haridwar, Uttarakhand. Experimental farm was constructed by making 9 plots having different slopes (8%, 12% and 16%) and each slope had three plots of size 12m x 3m. Maize and Finger Millet were grown in three different slope plot and one plot was left as Fallow land in each slope plot as shown in Fig. 3.2 in Chapter 3. An ordinary rain gauge was installed to record the daily rainfall data in experimental farm. On the other hand, the arrangement had been made in such a way that the rainfall generated runoff from each plot would collect in collection chamber (size 1m x 1m x 1m). Flow divisor having 5 slots (odd number) was installed just upstream of the collection chamber and allowed flow from only one slot into the chamber to reduce the chamber size. From this setup rainfall and runoff data were collected. Total 32 rainfall events were observed during the experiment and only 19 events were runoff generating event. Since one event was extremely heavy, that was flooded over and could not be included in analysis.

Other type of data was also collected from the experimental farm like soil moisture, soil type, hydrologic soil group and sediment data. Everyday soil moisture was measured with TDR-300 (probe length 12cm) to find the soil moisture before the rainfall event. Soil sample was carried out and oven dried for 24 hours at a temperature of 105 ^oC. Then sieve analysis was performed to determine the type of soil. In our case, we found sandy soil in all plots. Similarly, double ring infiltrometer test was carried out in all 9 plots to find the hydrologic soil group according to infiltration capacity of soil. We found minimum rate of infiltration between 0.76 and 1.14 cm/hr which correspond to hydrologic soil group A except in plot number 6 (Fallow land of 8% slope). Minimum rate of infiltration of plot number 6 had been found in between 0.38 and 0.76 cm/hr which corresponds to hydrological group B. In the same manner, for collecting sediment (soil erosion) data, approximate 1 litter of sediment laden water was collected, transported to IWM IIT Roorkee laboratory, measured 500 ml of sample and oven dried for 24 hours at 105 ^oC. Then residual soil solid was weighted to find sediment concentration. After analyzing all these data, following results have been found.

Curve number (CN) determined from frequency matching technique, using existing and modified SCS-CN method ranges from 82.83 to 94.62 and 78.62 to 92.55 respectively. Likewise, CN determined from optimization technique using existing and modified SCS-CN method ranges from 41.91 to 82.79 and 37.55 to 79.66 respectively. Initial abstraction ratio (λ) obtained from optimization technique using Generalized Reduced Gradient (GRG) non-linear algorithm has found 0.00 as minimum and 0.05 as maximum both in existing and modified SCS-CN method.

NSE of existing and modified SCS-CN method calculated from optimization technique ranges from 67% to 94% and 70% to 94% where as RMSE ranges from 4.39 to 14.55 and 4.11 to 13.97 respectively. Similarly, NSE of existing and modified SCS-CN method calculated from NEH-4 technique (taking CN from NEH-4 table to estimate calculated runoff) ranges from 15% to 79% and 27% to 83% where as RMSE ranges from 5.8 to 18.84 and 6.84 to 17.24 respectively.

From the present study, the following conclusions have been drawn:

- Observed curve number (CN_{obs}) calculated from modified SCS-CN (using frequency matching method) has higher value than CN from NEH-4 table.
- Optimized curve number (CN_{opti}) calculated from optimization of S and λ has lower value than CN from NEH-4 table.
- Observed curve number (CN_{obs}) obtained from modified (MS 2002) SCS-CN model is lesser than value of CN_{obs} from existing SCS-CN model when calculated using frequency matching method.
- Value of initial abstraction ratio (λ) has found from 0 to 0.05 for steep slope watershed and does not match with generalized value 0.2 given by USDA. So, it will be better to have experimental value of λ for particular watershed for precise hydrologic modeling.
- Since NSE of modified (MS 2002) SCS-CN model is higher than that of existing SCS-CN model and RMSE of modified (MS 2002) SCS-CN model is lower than that of existing SCS-CN model, modified SCS-CN model is more efficient than existing SCS-CN model.
- As the slope of watershed increases, CN also increases. Similarly, as soil moisture (M) increases, CN also increases.

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APPENDIX A

RAINFALL RUNOFF DATA

Runoff volume collected in collection chamber = x m^3

Runoff volume generated from impervious triangular portion = y m^3

Direct rainfall volume into the collection chamber = z m^3

Runoff volume generated from (12m x 3m) plot = [(x-y)*5-z] m^3 [5 is no. of slot]

Runoff depth generated from (12m x 3m) plot = $\left(\frac{((x-y)*5-z)}{(12\text{m x }3\text{m})}\right) * 1000$ mm

Table A1. Event wise Rainfall Runoff data for 18 storm events

Date	Rainfall (P) (mm)	Actual Observed Runoff (Q_{obs}) in mm								
		Maize			Finger Millet			Fallow land		
		8%	12%	16%	8%	12%	16%	8%	12%	16%
03-Jul-18	57.00	16.11	25.32	44.07	4.49	12.13	55.18	7.27	16.15	19.77
04-Jul-18	11.00	3.20	5.00	8.34	2.09	4.45	7.09	2.64	3.61	5.84
27-Jul-18	57.00	11.85	15.60	45.46	9.49	11.29	22.13	4.07	9.07	25.04
28-Jul-18	129.40	46.71	63.66	70.46	38.80	50.05	56.57	36.16	35.88	55.46
29-Jul-18	35.00	10.31	16.56	17.25	2.39	3.78	5.45	2.25	2.81	4.75
01-Aug-18	19.00	9.36	12.14	14.92	5.20	6.17	14.92	4.36	5.75	7.28
05-Aug-18	13.00	11.27	12.65	12.79	2.24	4.32	8.49	5.71	6.68	5.02
06-Aug-18	20.50	4.20	6.28	7.67	1.98	2.05	3.09	1.70	2.12	4.06
12-Aug-18	7.30	1.86	2.97	3.11	0.89	1.30	1.44	1.30	2.27	2.97
25-Aug-18	11.50	1.15	2.54	2.82	1.01	1.15	2.12	0.46	1.71	2.82
26-Aug-18	17.20	6.95	12.64	15.70	0.56	1.95	8.75	2.09	3.06	5.00
31-Aug-18	117.80	73.22	73.91	79.60	39.47	45.16	57.52	45.02	49.60	53.77
02-Sep-18	29.60	10.84	16.26	20.98	9.17	10.01	18.06	8.48	17.78	19.45
03-Sep-18	29.00	8.74	10.54	14.71	7.63	9.29	15.27	4.29	6.24	19.43
07-Sep-18	17.20	4.31	5.14	11.81	0.98	4.59	6.11	1.11	3.34	5.70
23-Sep-18	15.60	0.60	0.74	0.88	0.19	0.33	1.71	2.41	2.83	3.66
24-Sep-18	43.70	3.28	4.25	6.06	1.06	3.56	3.83	1.19	4.81	6.19
25-Sep-18	22.20	0.52	0.80	1.22	0.39	0.66	1.64	0.94	1.77	2.05

APPENDIX B

SEDIMENT DATA

Table B1. Sediment yield data observed in the experimental plots

Sampling date: 3 July 2018

Plot no	Runoff Vol. mm	Wt. of bowl (gm)	Wt. of bowl + sediment (gm)	sediment t/ha
1	25.32	88.495	90.387	0.958
2	12.13	301.523	303.922	0.581
3	16.15	95.477	96.991	0.489
4	16.11	295.454	296.877	0.458
5	4.49	87.272	89.302	0.182
6	7.27	286.832	288.154	0.192
7	44.07	255.182	257.12	1.708
8	55.18	296.642	298.835	2.420
9	19.77	85.572	88.467	1.144

Sampling date: 04 July 2018

Plot no	Runoff Vol. mm	Wt. of bowl (gm)	Wt. of bowl + sediment (gm)	Sediment t/ha
1	5	88.725	89.922	0.119
2	4.45	301.519	305.04	0.313
3	3.61	95.572	98.172	0.187
4	3.2	91.135	92.964	0.117
5	2.09	87.296	88.681	0.057
6	2.64	286.865	287.505	0.033
7	8.34	255.174	257.837	0.444
8	7.09	296.625		
9	5.84	92.065	94.844	0.324

Sampling date: 27 July 2018

Plot no	Runoff Vol. mm	Wt. of bowl (gm)	Wt. of bowl + sediment (gm)	sediment t/ha
1	15.6	88.725	89.175	0.140
2	11.29	301.519	301.972	0.102
3	9.07	95.572	95.965	0.071
4	11.85	91.135	91.417	0.066
5	9.49	87.296	87.923	0.119
6	4.07	286.865	287.05	0.015
7	45.46	255.174	255.401	0.206
8	22.13	296.625	297.015	0.172
9	25.04	92.065	92.653	0.294

Sampling date: 28 July 2018

Plot no	Runoff Vol. mm	Wt. of bowl (gm)	Wt. of bowl + sediment (gm)	sediment t/ha
1	63.66	88.725	89.384	0.839
2	50.05	301.519	302.415	0.896
3	35.88	95.572	96.015	0.317
4	46.71	91.135	91.88	0.695
5	38.8	87.296	88.081	0.609
6	36.16	286.865	287.156	0.210
7	70.46	255.174	256.307	1.596
8	56.57	85.573	87.517	2.199
9	55.46	92.065	93.652	1.760

Sampling date: 29 July 2018

Plot no	Runoff Vol. mm	Wt. of bowl (gm)	Wt. of bowl + sediment (gm)	sediment t/ha
1	16.56	88.725	89.1	0.124
2	3.78	301.519	302.965	0.109
3	2.81	95.572	95.841	0.015
4	10.31	91.135	91.586	0.092
5	2.39	87.296	87.893	0.028
6	2.25	286.865	287.276	0.018
7	17.25	255.174	256.761	0.547
8	5.45	296.625	298.547	0.209
9	4.75	92.065	93.16	0.104

Sampling date: 1 Aug 2018

Plot no	Runoff Vol. mm	Wt. of bowl (gm)	Wt. of bowl + sediment (gm)	sediment t/ha
1	12.14	88.725	89.665	0.228
2	6.17	301.519	302.853	0.164
3	5.75	95.572	96.29	0.082
4	9.36	91.135	92.004	0.162
5	5.2	87.296	90.422	0.325
6	4.36	286.865	287.468	0.052
7	14.92	255.174	256.59	0.422
8	14.92	296.625	299.623	0.894
9	7.28	92.065	93.672	0.233

Table B2. Sediment yield data observed in the experimental plots

Sampling date: 6 Aug 2018

Plot no	Runoff Vol. mm	Wt. of bowl (gm)	Wt. of bowl + sediment (gm)	sediment t/ha
1	12.65	88.725	89.705	0.247
2	4.32	301.519	303.09	0.135
3	6.68	95.572	96.851	0.170
4	11.27	91.135	92.981	0.416
5	2.24	87.296	88.645	0.060
6	5.71	286.865	287.715	0.097
7	12.79	255.174	257.245	0.529
8	8.49	296.625	298.547	0.326
9	5.02	92.065	93.405	0.134

Sampling date: 6 Aug 2018

Plot no	Runoff Vol. mm	Wt. of bowl (gm)	Wt. of bowl + sediment (gm)	sediment t/ha
1	6.28	88.725	89.365	0.080
2	2.05	301.519	302.817	0.053
3	2.12	95.572	96.21	0.027
4	4.2	91.135	92.106	0.081
5	1.98	87.296	88.58	0.050
6	1.7	286.865	287.575	0.024
7	7.67	255.174	256.301	0.172
8	3.09	296.625	297.684	0.065
9	4.06	92.065	93.005	0.076

Sampling date: 12 Aug 2018

Plot no	Runoff Vol. mm	Wt. of bowl (gm)	Wt. of bowl + sediment (gm)	sediment t/ha
1	2.97	88.725	90.267	0.091
2	1.3	301.519	303.006	0.038
3	2.27	95.572	96.525	0.043
4	1.86	91.135	94.776	0.135
5	0.89	87.296	92.68	0.095
6	1.3	286.865	288.528	0.043
7	3.11	255.174	257.364	0.136
8	1.44	296.625	299.334	0.078
9	2.97	92.065	95.45	0.201

Sampling date: 25 Aug 2018

Plot no	Runoff Vol. mm	Wt. of bowl (gm)	Wt. of bowl + sediment (gm)	sediment t/ha
1	2.54	88.725	89.405	0.034
2	1.15	301.519	301.576	0.001
3	1.71	95.572	95.901	0.011
4	1.15	91.135	92.065	0.021
5	1.01	87.296	87.795	0.010
6	0.46	286.865	287.082	0.001
7	2.82	255.174	256.065	0.050
8	2.12	296.625	297.695	0.045
9	2.82	92.065	93.475	0.079

Sampling date: 26 Aug 2018

Plot no	Runoff Vol. mm	Wt. of bowl (gm)	Wt. of bowl + sediment (gm)	Sediment t/ha
1	12.64	88.725	89.34	0.155
2	1.95	301.519	301.932	0.016
3	3.06	95.572	95.93	0.021
4	6.95	91.135	91.713	0.080
5	0.56	87.296	88.096	0.008
6	2.09	286.865	286.96	0.003
7	15.7	255.174	255.532	0.112
8	8.75	296.625	297.412	0.137
9	5	92.065	94.249	0.218

Sampling date: 31 Aug 2018

Plot no	Runoff Vol. mm	Wt. of bowl (gm)	Wt. of bowl + sediment (gm)	sediment t/ha
1	73.91	88.725	89.181	0.674
2	45.16	301.519	301.871	0.317
3	49.6	95.572	95.843	0.268
4	73.22	91.135	91.667	0.779
5	39.47	87.296	88.272	0.770
6	45.02	286.865	287.954	0.980
7	79.6	255.174	255.743	0.905
8	57.52	296.625	297.403	0.895
9	53.77	92.065	93.351	1.382

Table B3. Sediment yield data observed in the experimental plots

Sampling date: 02 Sep 2018

Plot no	Runoff Vol. mm	Wt. of bowl (gm)	Wt. of bowl + sediment (gm)	sediment t/ha
1	16.26	88.725	88.91	0.060
2	10.01	301.519	301.95	0.086
3	17.78	95.572	95.752	0.064
4	10.84	91.135	91.562	0.092
5	9.17	87.296	87.833	0.098
6	8.48	286.865	287.056	0.032
7	20.98	255.174	255.823	0.272
8	18.06	296.625	297.136	0.184
9	19.45	92.065	92.936	0.338

Sampling date: 03 Sep 2018

Plot no	Runoff Vol. mm	Wt. of bowl (gm)	Wt. of bowl + sediment (gm)	sediment t/ha
1	10.54	88.725	89.033	0.064
2	9.29	301.519	301.721	0.037
3	6.24	95.572	95.754	0.022
4	8.74	91.135	91.553	0.073
5	7.63	87.296	87.843	0.083
6	4.29	286.865	286.93	0.005
7	14.71	255.174	255.492	0.093
8	15.27	296.625	296.84	0.065
9	19.43	92.065	92.71	0.250

Sampling date: 07 Sep 2018

Plot no	Runoff Vol. mm	Wt. of bowl (gm)	Wt. of bowl + sediment (gm)	sediment t/ha
1	5.14	88.725	89.468	0.076
2	4.59	301.519	302.145	0.057
3	3.34	95.572	95.973	0.026
4	4.31	91.135	91.815	0.058
5	0.98	87.296	87.83	0.010
6	1.11	286.865	286.862	0.000
7	11.81	255.174	255.657	0.114
8	6.11	296.625	297.081	0.055
9	5.7	92.065	92.947	0.100

Sampling date: 23 Sep 2018

Plot no	Runoff Vol. mm	Wt. of bowl (gm)	Wt. of bowl + sediment (gm)	sediment t/ha
1	0.74	88.725	88.903	0.002
2	0.33	301.519	301.57	0.000
3	2.83	95.572	95.8	0.012
4	0.6	91.135	91.454	0.003
5	0.19	87.296	87.638	0.001
6	2.41	286.865	286.912	0.002
7	0.88	255.174	255.666	0.008
8	1.71	296.625	297.156	0.018
9	3.66	92.065	92.312	0.018

Sampling date: 24 Sep 2018

Plot no	Runoff Vol. mm	Wt. of bowl (gm)	Wt. of bowl + sediment (gm)	sediment t/ha
1	4.25	88.725	88.694	-0.002
2	3.56	301.519	301.574	0.003
3	4.81	95.572	95.704	0.012
4	3.28	91.135	91.38	0.016
5	1.06	87.296	87.665	0.007
6	1.19	286.865	286.885	0.000
7	6.06	255.174	255.228	0.006
8	3.83	296.625	296.682	0.004
9	6.19	92.065	92.314	0.030

Sampling date: 25 Sep 2018

Plot no	Runoff Vol. mm	Wt. of bowl (gm)	Wt. of bowl + sediment (gm)	sediment t/ha
1	0.8	88.725	88.799	0.001
2	0.66	301.519	301.824	0.004
3	1.77	95.572	95.845	0.009
4	0.52	91.135	91.507	0.003
5	0.39	87.296	87.854	0.004
6	0.94	286.865	286.905	0.000
7	1.22	255.174	255.411	0.005
8	1.64	296.625	297.033	0.013
9	2.05	92.065	92.429	0.014

APPENDIX C

DAILY SOIL MOISTURE DATA

Table C1. Daily Soil Moisture Data

Date	Soil moisture measured by TDR 300 (probe length 12cm) VWC (%)								
	Slope of plot 12%			Slope of plot 8%			Slope of plot 16%		
	Maize	Finger Millet	Fallow Land	Maize	Finger Millet	Fallow Land	Maize	Finger Millet	Fallow Land
28-Jun-2018	9.80	11.60	12.73	26.85	20.33	5.15	16.20	9.53	7.30
29-Jun-2018	6.40	9.76	11.46	12.90	13.16	5.60	7.76	5.60	7.43
30-Jun-2018	5.90	8.50	9.70	12.16	10.56	4.16	6.56	5.20	7.36
01-Jul-2018	8.93	12.91	12.28	14.09	13.83	8.78	9.83	8.41	9.16
02-Jul-2018	11.96	17.33	14.86	16.03	17.10	13.40	13.10	11.63	10.96
03-Jul-2018	23.55	27.15	27.15	22.55	22.30	23.90	18.25	16.70	19.15
04-Jul-2018	23.55	20.65	28.30	24.45	18.85	18.70	21.00	13.60	17.25
05-Jul-2018	9.90	16.25	17.20	19.30	18.85	15.50	14.35	11.10	13.65
06-Jul-2018	9.55	17.10	13.45	16.05	12.50	12.40	11.30	8.30	10.95
07-Jul-2018	10.10	11.90	12.90	12.76	8.60	12.33	8.86	10.00	8.43
08-Jul-2018	9.71	11.63	13.42	13.88	8.73	11.43	8.18	8.41	7.41
09-Jul-2018	9.33	11.36	13.95	15.00	8.86	10.53	7.50	6.83	6.40
10-Jul-2018	11.06	14.63	10.46	10.26	7.76	8.30	5.63	5.60	5.93
11-Jul-2018	11.73	11.20	10.30	9.93	7.30	7.40	6.20	4.76	7.66
12-Jul-2018	9.13	10.26	11.63	11.96	10.60	11.36	8.93	6.30	8.16
13-Jul-2018	7.20	9.53	9.10	9.03	6.50	6.93	8.73	6.46	7.42
14-Jul-2018	5.83	10.10	9.53	9.83	7.73	10.33	7.46	8.36	8.50
15-Jul-2018	10.83	11.40	13.16	13.90	13.03	10.46	9.60	10.33	8.33
16-Jul-2018	9.72	14.86	11.46	15.00	11.73	8.03	11.23	13.53	7.55
17-Jul-2018	11.03	16.23	14.76	17.96	13.80	13.86	12.50	11.70	10.33
18-Jul-2018	8.16	14.50	13.40	12.73	12.40	11.26	8.53	9.00	7.90
19-Jul-2018	11.83	11.83	10.60	13.43	9.26	8.70	9.13	9.70	7.13
20-Jul-2018	6.36	17.23	14.36	12.30	11.16	10.10	6.53	9.06	6.06
21-Jul-2018	13.46	18.83	13.83	15.53	21.16	15.70	10.86	11.43	9.40
22-Jul-2018	13.70	14.63	14.53	12.00	17.56	13.56	12.93	12.60	11.63
23-Jul-2018	10.50	16.76	11.76	11.93	12.70	15.00	7.73	10.90	8.90
24-Jul-2018	12.63	16.16	14.13	11.23	16.83	9.70	8.53	7.13	7.53
25-Jul-2018	13.50	16.33	13.30	13.20	16.40	13.86	9.50	13.20	7.63
26-Jul-2018	14.90	17.96	17.50	13.86	18.00	16.20	10.86	13.93	10.76
27-Jul-2018	20.16	26.10	25.30	24.63	23.80	28.46	18.13	18.96	22.23
28-Jul-2018	18.30	23.70	22.97	22.36	21.61	25.84	16.46	17.21	20.18
29-Jul-2018	12.37	16.02	15.53	15.12	14.61	17.47	11.13	11.64	13.65
30-Jul-2018	9.28	12.01	11.65	11.34	10.96	13.10	8.34	8.73	10.23
31-Jul-2018	6.96	9.01	8.73	8.50	8.22	9.82	6.26	6.54	7.67
01-Aug-2018	16.22	18.20	17.93	17.71	17.43	18.98	15.54	15.82	16.91
02-Aug-2018	12.16	13.65	13.45	13.28	13.07	14.24	11.65	11.86	12.68
03-Aug-2018	9.12	10.23	10.08	9.96	9.80	10.68	8.74	8.89	9.51

Date	Soil moisture measured by TDR 300 (probe length 12cm) VWC (%)								
	Slope of plot 12%			Slope of plot 8%			Slope of plot 16%		
	Maize	Finger Millet	Fallow Land	Maize	Finger Millet	Fallow Land	Maize	Finger Millet	Fallow Land
04-Aug-2018	12.70	13.27	13.19	13.13	13.05	13.49	12.51	12.59	12.90
05-Aug-2018	15.29	15.97	15.88	15.80	15.71	16.24	15.06	15.16	15.53
06-Aug-2018	18.09	18.89	18.78	18.69	18.58	19.21	17.82	17.93	18.37
07-Aug-2018	17.40	22.63	19.93	23.40	23.20	19.80	16.10	16.90	13.40
08-Aug-2018	16.23	15.60	19.83	17.60	18.30	17.86	13.46	13.86	12.66
09-Aug-2018	15.90	18.20	17.66	15.32	18.76	13.70	16.23	15.96	13.33
10-Aug-2018	16.95	19.05	19.70	19.05	19.25	16.70	15.05	15.87	15.46
11-Aug-2018	16.80	14.55	22.65	14.70	15.05	20.85	14.15	17.50	15.82
12-Aug-2018	13.65	20.15	20.85	18.30	22.10	19.05	21.95	20.50	21.22
13-Aug-2018	24.10	24.65	24.65	23.70	28.95	21.95	22.10	22.02	22.06
14-Aug-2018	18.85	20.45	21.75	21.00	19.95	16.70	17.95	17.32	17.63
15-Aug-2018	14.70	20.15	17.40	16.15	18.10	18.58	15.60	17.09	16.34
16-Aug-2018	14.50	17.30	15.95	17.75	18.50	22.80	17.00	19.90	18.45
17-Aug-2018	12.70	16.90	18.15	15.60	13.80	14.30	13.40	13.85	13.62
18-Aug-2018	12.40	15.70	14.50	13.40	14.35	12.70	12.90	12.80	12.85
19-Aug-2018	14.85	14.55	14.15	11.25	14.15	15.45	13.80	14.62	14.21
20-Aug-2018	9.80	16.30	17.25	10.55	10.90	14.05	12.35	13.20	12.77
21-Aug-2018	13.60	13.20	11.70	13.40	13.10	11.60	13.80	12.70	13.25
22-Aug-2018	11.10	10.20	14.50	15.05	11.80	15.45	13.80	14.62	14.21
23-Aug-2018	11.65	13.05	15.95	12.70	14.35	13.80	11.25	12.52	11.88
24-Aug-2018	12.80	13.25	16.75	13.70	15.35	13.90	11.45	12.67	12.06
25-Aug-2018	16.85	19.20	14.20	17.80	21.05	20.50	18.80	19.65	19.22
26-Aug-2018	17.95	20.20	21.05	18.30	23.20	23.20	23.10	23.15	23.12
27-Aug-2018	13.65	14.50	21.35	18.30	19.60	16.30	18.90	17.60	18.25
28-Aug-2018	11.25	14.50	18.30	15.25	17.05	16.50	14.15	15.32	14.73
29-Aug-2018	13.60	18.65	18.20	14.55	22.45	15.60	18.15	16.87	17.51
30-Aug-2018	13.50	18.50	21.55	17.00	21.60	17.50	17.50	17.50	17.50
31-Aug-2018	14.50	22.10	25.90	23.15	27.20	25.70	22.65	24.17	23.41
01-Sep-2018	16.90	18.85	23.60	17.80	22.30	17.75	22.10	17.75	23.70
02-Sep-2018	16.70	22.10	21.90	23.05	24.25	17.80	20.30	20.30	17.80
03-Sep-2018	21.10	25.40	26.10	26.95	23.35	26.80	21.35	22.45	24.65
04-Sep-2018	15.80	19.60	22.80	18.70	20.80	19.95	16.30	19.80	19.80
05-Sep-2018	17.40	21.10	22.75	20.65	20.30	17.95	17.40	19.70	22.65
06-Sep-2018	13.92	16.88	18.20	16.52	16.24	14.36	13.92	15.76	18.12
07-Sep-2018	19.73	22.10	23.16	21.81	21.59	20.08	19.73	21.20	23.09
08-Sep-2018	14.50	19.40	19.95	21.75	21.45	19.95	19.95	17.35	20.50
09-Sep-2018	15.40	19.87	18.50	16.30	21.40	14.50	15.95	18.50	18.85
10-Sep-2018	13.80	15.50	20.30	13.80	17.40	17.40	13.60	10.25	15.90
11-Sep-2018	13.75	15.10	16.70	15.10	14.20	10.90	14.50	12.90	10.35
12-Sep-2018	14.15	10.50	17.27	17.70	18.30	17.50	17.00	15.45	15.00
13-Sep-2018	14.50	16.20	17.70	15.70	17.70	18.70	14.70	13.30	15.25

Date	Soil moisture measured by TDR 300 (probe length 12cm) VWC (%)								
	Slope of plot 12%			Slope of plot 8%			Slope of plot 16%		
	Maize	Finger Millet	Fallow Land	Maize	Finger Millet	Fallow Land	Maize	Finger Millet	Fallow Land
14-Sep-2018	12.70	16.55	16.10	15.60	12.70	14.70	17.75	10.30	10.10
15-Sep-2018	12.00	13.85	13.85	12.80	14.60	14.70	13.30	11.35	11.80
16-Sep-2018	13.50	11.30	14.50	10.50	13.40	15.30	9.50	10.30	9.50
17-Sep-2018	13.20	11.30	14.20	11.20	13.20	14.90	10.50	10.50	9.20
18-Sep-2018	12.80	10.90	14.20	11.30	12.90	13.90	10.50	10.40	9.50
19-Sep-2018	12.00	10.20	14.00	9.80	11.30	15.20	7.50	7.60	10.20
20-Sep-2018	11.60	12.00	12.70	8.20	10.90	12.30	10.20	10.50	8.90
21-Sep-2018	12.00	8.50	10.50	8.00	10.50	11.80	10.00	10.20	8.50
22-Sep-2018	9.60	6.80	8.40	6.40	8.40	9.44	8.00	8.16	6.80
23-Sep-2018	15.48	13.24	14.52	12.92	14.52	15.35	14.20	14.32	13.24
24-Sep-2018	21.68	18.54	20.33	18.09	20.33	21.50	19.88	20.06	18.54
25-Sep-2018	17.62	15.07	16.53	14.70	16.53	17.47	16.16	16.31	15.07
26-Sep-2018	15.86	13.56	14.87	13.23	14.87	15.72	14.54	14.68	13.56
27-Sep-2018	14.73	13.77	13.13	14.39	12.93	15.91	16.56	11.85	13.80
28-Sep-2018	14.82	16.07	14.74	14.74	13.59	14.59	12.97	12.96	14.57
29-Sep-2018	12.07	13.52	15.70	12.17	13.03	12.89	12.24	9.23	14.70
30-Sep-2018	12.71	15.57	16.23	13.97	9.70	10.94	12.92	14.01	13.62

APPENDIX D

INFILTRATION TEST DATA

Outer dia. of ring = 45 cm, Inner dia. of ring = 30 cm, Height of ring = 30 cm

Table D1: Infiltration test data

Maize of 12 % slope (15/11/1018)					Finger millet of 12 % slope (15/11/1018)				
Cumulative Time (min)	Cumulative Time (hr)	Incremental Time (hr)	Infiltration Depth (cm)	Infiltration rate (cm/hr)	Cumulative Time (min)	Cumulative Time (hr)	Incremental Time (hr)	Infiltration Depth (cm)	Infiltration rate (cm/hr)
1.00	0.02	0.02	0.30	18.00	0.00	0.00		0.00	0.00
2.00	0.03	0.02	0.20	12.00	1.00	0.02	0.02	0.20	12.00
3.00	0.05	0.02	0.30	18.00	2.00	0.03	0.02	0.20	12.00
4.00	0.07	0.02	0.20	12.00	3.00	0.05	0.02	0.10	6.00
5.00	0.08	0.02	0.10	6.00	4.00	0.07	0.02	0.10	6.00
6.00	0.10	0.02	0.10	6.00	5.00	0.08	0.02	0.10	6.00
7.00	0.12	0.02	0.20	12.00	6.00	0.10	0.02	0.10	6.00
8.00	0.13	0.02	0.05	3.00	7.00	0.12	0.02	0.10	6.00
9.00	0.15	0.02	0.05	3.00	8.00	0.13	0.02	0.10	6.00
10.00	0.17	0.02	0.10	6.00	9.00	0.15	0.02	0.10	6.00
20.00	0.33	0.17	0.80	4.80	10.00	0.17	0.02	0.10	6.00
30.00	0.50	0.17	0.60	3.60	20.00	0.33	0.17	0.80	4.80
40.00	0.67	0.17	0.30	1.80	30.00	0.50	0.17	0.60	3.60
70.00	1.17	0.50	1.00	2.00	40.00	0.67	0.17	0.50	3.00
100.00	1.67	0.50	0.90	1.80	70.00	1.17	0.50	1.60	3.20
130.00	2.17	0.50	0.80	1.60	100.00	1.67	0.50	1.20	2.40
190.00	3.17	1.00	1.40	1.40	130.00	2.17	0.50	1.10	2.20
250.00	4.17	1.00	1.50	1.50	190.00	3.17	1.00	2.20	2.20
310.00	5.17	1.00	1.50	1.50	250.00	4.17	1.00	2.40	2.40
370.00	6.17	1.00	1.50	1.50	310.00	5.17	1.00	2.00	2.00
400.00	6.67	0.50	0.75	1.50	370.00	6.17	1.00	2.00	2.00
					400.00	6.67	0.50	1.00	2.00

Table D2: Infiltration test data

Fallow land of 12 % slope (16/11/1018)					Maize of 8% slope (15/11/1018)				
Cumulative Time (min)	Cumulative Time (hr)	Incremental Time (hr)	Infiltration Depth (cm)	Infiltration rate (cm/hr)	Cumulative Time (min)	Cumulative Time (hr)	Incremental Time (hr)	Infiltration Depth (cm)	Infiltration rate (cm/hr)
0.00	0.00		0.00	0.00	0.00	0.00	0.00	0.00	
1.00	0.02	0.02	0.50	30.00	1.00	0.02	0.02	1.20	72.00
2.00	0.03	0.02	0.30	18.00	2.00	0.03	0.02	1.00	60.00
3.00	0.05	0.02	0.30	18.00	3.00	0.05	0.02	0.70	42.00
4.00	0.07	0.02	0.20	12.00	4.00	0.07	0.02	0.40	24.00

Fallow land of 12 % slope (16/11/1018)					Maize of 8% slope (15/11/1018)				
Cumulative Time (min)	Cumulative Time (hr)	Incremental Time (hr)	Infiltration Depth (cm)	Infiltration rate (cm/hr)	Cumulative Time (min)	Cumulative Time (hr)	Incremental Time (hr)	Infiltration Depth (cm)	Infiltration rate (cm/hr)
5.00	0.08	0.02	0.20	12.00	5.00	0.08	0.02	0.40	24.00
6.00	0.10	0.02	0.20	12.00	6.00	0.10	0.02	0.40	24.00
7.00	0.12	0.02	0.20	12.00	7.00	0.12	0.02	0.35	21.00
8.00	0.13	0.02	0.10	6.00	8.00	0.13	0.02	0.30	18.00
9.00	0.15	0.02	0.10	6.00	9.00	0.15	0.02	0.35	21.00
10.00	0.17	0.02	0.10	6.00	10.00	0.17	0.02	0.40	24.00
20.00	0.33	0.17	1.30	7.80	20.00	0.33	0.17	1.60	9.60
30.00	0.50	0.17	0.90	5.40	30.00	0.50	0.17	1.40	8.40
40.00	0.67	0.17	0.80	4.80	40.00	0.67	0.17	1.30	7.80
70.00	1.17	0.50	2.50	5.00	70.00	1.17	0.50	3.50	7.00
100.00	1.67	0.50	2.30	4.60	100.00	1.67	0.50	3.50	7.00
130.00	2.17	0.50	2.10	4.20	130.00	2.17	0.50	3.30	6.60
190.00	3.17	1.00	4.00	4.00	190.00	3.17	1.00	6.20	6.20
250.00	4.17	1.00	3.90	3.90	250.00	4.17	1.00	5.80	5.80
310.00	5.17	1.00	3.50	3.50	310.00	5.17	1.00	5.60	5.60
370.00	6.17	1.00	3.40	3.40	370.00	6.17	1.00	5.10	5.10
400.00	6.67	0.50	1.70	3.40	400.00	6.67	0.50	2.50	5.00

Table D3: Infiltration test data

Finger millet of 8 % slope (16/11/1018)					Fallow land of 8% slope (16/11/1018)				
Cumulative Time (min)	Cumulative Time (hr)	Incrementa l Time (hr)	Infiltration Depth (cm)	Infiltration rate (cm/hr)	Cumulative Time (min)	Cumulative Time (hr)	Incrementa l Time (hr)	Infiltration Depth (cm)	Infiltration rate (cm/hr)
1.00	0.02	0.02	0.30	18.00	0.00	0.00			
2.00	0.03	0.02	0.30	18.00	1.00	0.02	0.02	1.00	60.00
3.00	0.05	0.02	0.20	12.00	2.00	0.03	0.02	0.80	48.00
4.00	0.07	0.02	0.20	12.00	3.00	0.05	0.02	0.65	39.00
5.00	0.08	0.02	0.10	6.00	4.00	0.07	0.02	0.50	30.00
6.00	0.10	0.02	0.10	6.00	5.00	0.08	0.02	0.40	24.00
7.00	0.12	0.02	0.10	6.00	6.00	0.10	0.02	0.30	18.00
8.00	0.13	0.02	0.10	6.00	7.00	0.12	0.02	0.31	18.60
9.00	0.15	0.02	0.10	6.00	8.00	0.13	0.02	0.30	18.00
10.00	0.17	0.02	0.15	9.00	9.00	0.15	0.02	0.25	15.00
20.00	0.33	0.17	1.05	6.30	10.00	0.17	0.02	0.20	12.00
30.00	0.50	0.17	0.60	3.60	20.00	0.33	0.17	0.60	3.60
40.00	0.67	0.17	0.60	3.60	30.00	0.50	0.17	0.50	3.00
70.00	1.17	0.50	1.10	2.20	40.00	0.67	0.17	0.40	2.40
100.00	1.67	0.50	1.00	2.00	70.00	1.17	0.50	1.30	2.60
130.00	2.17	0.50	0.90	1.80	100.00	1.67	0.50	0.60	1.20

Finger millet of 8 % slope (16/11/1018)					Fallow land of 8% slope (16/11/1018)				
Cumulative Time (min)	Cumulative Time (hr)	Incrementa l Time (hr)	Infiltration Depth (cm)	Infiltration rate (cm/hr)	Cumulative Time (min)	Cumulative Time (hr)	Incrementa l Time (hr)	Infiltration Depth (cm)	Infiltration rate (cm/hr)
190.00	3.17	1.00	1.50	1.50	130.00	2.17	0.50	0.50	1.00
250.00	4.17	1.00	1.50	1.50	190.00	3.17	1.00	1.00	1.00
310.00	5.17	1.00	1.40	1.40	250.00	4.17	1.00	0.70	0.70
370.00	6.17	1.00	1.40	1.40	310.00	5.17	1.00	0.70	0.70
					370.00	6.17	1.00	0.70	0.70

Table D4: Infiltration test data

Maize of 16 % slope (17/11/1018)					Finger millet of 16% slope (17/11/1018)				
Cumulative Time (min)	Cumulative Time (hr)	Incremental Time (hr)	Infiltration Depth (cm)	Infiltration rate (cm/hr)	Cumulative Time (min)	Cumulative Time (hr)	Incremental Time (hr)	Infiltration Depth (cm)	Infiltration rate (cm/hr)
1.00	0.02	0.02	1.20	72.00	0.00	0.00			
2.00	0.03	0.02	0.40	24.00	1.00	0.02	0.02	1.70	102.00
3.00	0.05	0.02	0.40	24.00	2.00	0.03	0.02	1.50	90.00
4.00	0.07	0.02	0.30	18.00	3.00	0.05	0.02	1.00	60.00
5.00	0.08	0.02	0.30	18.00	4.00	0.07	0.02	0.50	30.00
6.00	0.10	0.02	0.30	18.00	5.00	0.08	0.02	0.45	27.00
7.00	0.12	0.02	0.30	18.00	6.00	0.10	0.02	0.40	24.00
8.00	0.13	0.02	0.30	18.00	7.00	0.12	0.02	0.39	23.40
9.00	0.15	0.02	0.20	12.00	8.00	0.13	0.02	0.40	24.00
10.00	0.17	0.02	0.20	12.00	9.00	0.15	0.02	0.34	20.40
20.00	0.33	0.17	2.20	13.20	10.00	0.17	0.02	0.30	18.00
30.00	0.50	0.17	1.80	10.80	20.00	0.33	0.17	1.30	7.80
40.00	0.67	0.17	1.80	10.80	30.00	0.50	0.17	1.10	6.60
50.00	0.83	0.17	1.80	10.80	40.00	0.67	0.17	1.10	6.60
70.00	1.17	0.33	3.20	9.60	70.00	1.17	0.50	2.70	5.40
100.00	1.67	0.50	4.50	9.00	100.00	1.67	0.50	2.50	5.00
130.00	2.17	0.50	4.10	8.20	130.00	2.17	0.50	2.10	4.20
160.00	2.67	0.50	3.80	7.60	190.00	3.17	1.00	3.90	3.90
190.00	3.17	0.50	3.70	7.40	250.00	4.17	1.00	3.50	3.50
220.00	3.67	0.50	3.60	7.20	310.00	5.17	1.00	3.50	3.50
250.00	4.17	0.50	3.40	6.80	370.00	6.17	1.00	3.30	3.30
280.00	4.67	0.50	3.20	6.40					
310.00	5.17	0.50	3.10	6.20					
340.00	5.67	0.50	3.05	6.10					
370.00	6.17	0.50	3.00	6.00					

Table D5: Infiltration test data

Fallow land of 16 % slope (17/11/1018)									
Cumulative Time (min)	Cumulative Time (hr)	Incremental Time (hr)	Infiltration Depth (cm)	Infiltration rate (cm/hr)					
1.00	0.02	0.02	0.30	18.00					
2.00	0.03	0.02	0.20	12.00					
3.00	0.05	0.02	0.20	12.00					
4.00	0.07	0.02	0.10	6.00					
5.00	0.08	0.02	0.20	12.00					
6.00	0.10	0.02	0.10	6.00					
7.00	0.12	0.02	0.10	6.00					
8.00	0.13	0.02	0.20	12.00					
9.00	0.15	0.02	0.10	6.00					
10.00	0.17	0.02	0.05	3.00					
20.00	0.33	0.17	0.55	3.30					
30.00	0.50	0.17	0.50	3.00					
40.00	0.67	0.17	0.40	2.40					
70.00	1.17	0.50	1.20	2.40					
100.00	1.67	0.50	1.00	2.00					
130.00	2.17	0.50	0.80	1.60					
190.00	3.17	1.00	1.70	1.70					
250.00	4.17	1.00	1.55	1.55					
310.00	5.17	1.00	1.55	1.55					
370.00	6.17	1.00	1.50	1.50					

APPENDIX E

SIEVE ANALYSIS DATA

Table E1: Sieve analysis data of different plots.

Plot no 1

sieve size (micron)	Wt. of Soil retained (gm)	Soil retained on sieve (%)	Cumu-lative retain on sieve (%)	Soil passing from sieve (%)
2000	2	0.18%	0.18%	99.82%
1000	0.868	0.08%	0.26%	99.74%
600	0.696	0.06%	0.33%	99.67%
400	10.64	0.98%	1.31%	98.69%
300	50.573	4.66%	5.97%	94.03%
225	223	20.56%	26.53%	73.47%
150	253	23.32%	49.85%	50.15%
90	346	31.89%	81.74%	18.26%
75	3.167	0.29%	82.03%	17.97%
63	2.936	0.27%	82.30%	17.70%
pan	192	17.70%	100.0%	0.00%
sum	1084.88			

Plot no 2

sieve size (micron)	Wt. of Soil retained (gm)	Soil retained on sieve (%)	Cumu-lative retain on sieve (%)	Soil passing from sieve (%)
2000	2.802	0.26%	0.26%	99.74%
1000	0.132	0.01%	0.27%	99.73%
600	1.069	0.10%	0.37%	99.63%
400	16.199	1.51%	1.89%	98.11%
300	54	5.04%	6.92%	93.08%
225	163	15.21%	22.14%	77.86%
150	270	25.20%	47.33%	52.67%
90	396	36.96%	84.29%	15.71%
75	8.601	0.80%	85.09%	14.91%
63	5.766	0.54%	85.63%	14.37%
pan	154	14.37%	100.0%	0.00%
sum	1071.57			

Plot no 3

Sieve size (micron)	Wt. of Soil retained (gm)	Soil retained on sieve (%)	Cumulative retain on sieve (%)	Soil passing from sieve (%)
2000	0.476	0.04%	0.04%	99.96%
1000	0.365	0.03%	0.08%	99.92%
600	3.954	0.37%	0.45%	99.55%
400	43.867	4.10%	4.55%	95.45%
300	55.955	5.23%	9.79%	90.21%
225	200.164	18.72%	28.51%	71.49%
150	416	38.91%	67.42%	32.58%
90	196	18.33%	85.76%	14.24%
75	4.392	0.41%	86.17%	13.83%
63	2.886	0.27%	86.44%	13.56%
pan	145	13.56%	100.0%	0.00%
sum	1069.06			

Plot no 4

Sieve size (micron)	Wt. of Soil retained (gm)	Soil retained on sieve (%)	Cumulative retain on sieve (%)	Soil passing from sieve (%)
2000	0.065	0.01%	0.01%	99.99%
1000	5.496	0.51%	0.52%	99.48%
600	6.97	0.65%	1.16%	98.84%
400	59.984	5.58%	6.74%	93.26%
300	21.606	2.01%	8.75%	91.25%
225	264	24.54%	33.28%	66.72%
150	453	42.10%	75.39%	24.61%
90	121	11.25%	86.63%	13.37%
75	6.709	0.62%	87.26%	12.74%
63	2.112	0.20%	87.45%	12.55%
pan	135	12.55%	100.0%	0.00%
sum	1075.94			

Table E2: Sieve analysis data of different plots.

Plot no 5

sieve size (micron)	Wt. of Soil retained (gm)	Soil retained on sieve (%)	Cumulative retain on sieve (%)	Soil passing from sieve (%)
2000	0	0.00%	0.00%	100.0%
1000	0.078	0.01%	0.01%	99.99%
600	0.867	0.08%	0.09%	99.91%
400	3.823	0.35%	0.44%	99.56%
300	94.452	8.75%	9.19%	90.81%
225	267	24.73%	33.92%	66.08%
150	419	38.81%	72.73%	27.27%
90	142	13.15%	85.88%	14.12%
75	2.954	0.27%	86.15%	13.85%
63	2.531	0.23%	86.39%	13.61%
pan	147	13.61%	100.0%	0.00%
sum	1079.71			

Plot no 6

sieve size (micron)	Wt. of Soil retained (gm)	Soil retained on sieve (%)	Cumulative retain on sieve (%)	Soil passing from sieve (%)
2000	1.765	0.16%	0.16%	99.84%
1000	3.437	0.32%	0.48%	99.52%
600	23.565	2.18%	2.67%	97.33%
400	73.108	6.78%	9.45%	90.55%
300	58.782	5.45%	14.90%	85.10%
225	271	25.13%	40.02%	59.98%
150	372	34.49%	74.51%	25.49%
90	157	14.56%	89.07%	10.93%
75	3.028	0.28%	89.35%	10.65%
63	3.873	0.36%	89.71%	10.29%
pan	111	10.29%	100.0%	0.00%
sum	1078.56			

Plot no 7

Sieve size (micron)	Wt. of Soil retained (gm)	Soil retained on sieve (%)	Cumulative retain on sieve (%)	Soil passing from sieve (%)
2000	8.232	0.77%	0.77%	99.23%
1000	0.372	0.03%	0.81%	99.19%
600	1.052	0.10%	0.91%	99.09%
400	3.024	0.28%	1.19%	98.81%
300	32.759	3.08%	4.27%	95.73%
225	257	24.13%	28.39%	71.61%
150	366	34.36%	62.75%	37.25%
90	281	26.38%	89.13%	10.87%
75	5.071	0.48%	89.61%	10.39%
63	2.704	0.25%	89.86%	10.14%
pan	108	10.14%	100.0%	0.00%
sum	1065.21			

Plot no 8

Sieve size (micron)	Wt. of Soil retained (gm)	Soil retained on sieve (%)	Cumulative retain on sieve (%)	Soil passing from sieve (%)
2000	4.551	0.42%	0.42%	99.58%
1000	37.355	3.48%	3.90%	96.10%
600	25.337	2.36%	6.27%	93.73%
400	36.474	3.40%	9.66%	90.34%
300	0.42	0.04%	9.70%	90.30%
225	212	19.75%	29.46%	70.54%
150	471	43.89%	73.34%	26.66%
90	161	15.00%	88.34%	11.66%
75	4.15	0.39%	88.73%	11.27%
63	1.214	0.11%	88.84%	11.16%
pan	119.745	11.16%	100.0%	0.00%
sum	1073.25			

Table E3: Sieve analysis data of different plots.

Plot no 9

sieve size (micron)	Wt. of Soil retained (gm)	Soil retained on sieve (%)	Cumulative retain on sieve (%)	Soil passing from sieve (%)
2000	0.044	0.00%	0.00%	100.00%
1000	0.193	0.02%	0.02%	99.98%
600	1.574	0.15%	0.17%	99.83%
400	5.997	0.56%	0.72%	99.28%
300	39.548	3.67%	4.39%	95.61%
225	268	24.87%	29.26%	70.74%
150	410	38.04%	67.30%	32.70%
90	195	18.09%	85.39%	14.61%
75	5.312	0.49%	85.89%	14.11%
63	2.126	0.20%	86.08%	13.92%
pan	150	13.92%	100.00%	0.00%
sum	1077.79			

APPENDIX F

CALCULATION OF CURVE NUMBER (CN)

Table F1. Calculation of CN_{obs} for 8% slope plot (Modified model)

Date	Rainfall (P) mm	8% slope plot								
		Runoff (Q) mm			S (modified model)			CN (modified model)		
		M	FM	FL	M	FM	FL	M	FM	FL
03-Jul-2018	57.00	16.11	4.49	7.27	86.40	172.51	138.15	74.61	59.55	64.77
04-Jul-2018	11.00	3.20	2.09	2.64	26.21	33.34	30.02	90.64	88.39	89.43
27-Jul-2018	57.00	11.85	9.49	4.07	105.98	125.82	176.93	70.55	66.87	58.94
28-Jul-2018	129.40	46.71	38.80	36.16	147.44	175.62	190.89	63.27	59.12	57.09
29-Jul-2018	35.00	10.31	2.39	2.25	60.60	122.73	128.07	80.73	67.42	66.47
01-Aug-2018	19.00	9.36	5.20	4.36	17.11	31.98	37.76	93.68	88.81	87.05
05-Aug-2018	13.00	11.27	2.24	5.71	2.88	35.41	17.27	98.87	87.76	93.63
06-Aug-2018	20.50	4.20	1.98	1.70	47.86	67.02	70.72	84.14	79.12	78.22
12-Aug-2018	7.30	1.86	0.89	1.30	18.89	26.24	24.25	93.07	90.63	91.28
25-Aug-2018	11.50	1.15	1.01	0.46	40.15	42.44	49.05	86.35	85.68	83.81
26-Aug-2018	17.20	6.95	0.56	2.09	25.16	75.47	56.29	90.98	77.09	81.85
31-Aug-2018	117.80	73.22	39.47	45.02	57.32	144.11	122.54	81.58	63.80	67.45
02-Sep-2018	29.60	10.84	9.17	8.48	41.33	51.22	51.63	86.00	83.21	83.10
03-Sep-2018	29.00	8.74	7.63	4.29	52.08	58.62	76.63	82.98	81.24	76.82
07-Sep-2018	17.20	4.31	0.98	1.11	37.27	66.99	64.02	87.20	79.13	79.86
23-Sep-2018	15.60	0.60	0.19	2.41	59.37	71.14	40.24	81.05	78.12	86.32
24-Sep-2018	43.70	3.28	1.06	1.19	134.14	176.81	174.43	65.44	58.95	59.28
25-Sep-2018	22.20	0.52	0.39	0.94	97.92	101.51	91.75	72.17	71.44	73.46

M = Maize, FM = Finger Millet, FL = Fallow Land

Table F2. Calculation of CN_{obs} for 12% slope plot (Modified model)

Date	Rainfall (P) mm	12% slope plot								
		Runoff (Q) mm			S (modified model)			CN (modified model)		
		M	FM	FL	M	FM	FL	M	FM	FL
03-Jul-2018	57.00	25.32	12.13	16.15	51.53	107.91	85.20	83.13	70.18	74.88
04-Jul-2018	11.00	5.00	4.45	3.61	17.65	20.92	25.16	93.50	92.39	90.98
27-Jul-2018	57.00	15.60	11.29	9.07	87.70	113.63	128.38	74.33	69.09	66.42
28-Jul-2018	129.40	63.66	50.05	35.88	97.43	137.79	189.20	72.27	64.83	57.31
29-Jul-2018	35.00	16.56	3.78	2.81	34.72	107.59	118.25	87.97	70.24	68.23
01-Aug-2018	19.00	12.14	6.17	5.75	10.09	28.18	29.80	96.17	90.01	89.49
05-Aug-2018	13.00	12.65	4.32	6.68	0.53	22.98	13.84	99.79	91.70	94.83

Date	Rainfall (P) mm	12% slope plot								
		Runoff (Q) mm			S (modified model)			CN (modified model)		
		M	FM	FL	M	FM	FL	M	FM	FL
06-Aug-2018	20.50	6.28	2.05	2.12	35.71	66.43	65.59	87.67	79.26	79.47
12-Aug-2018	7.30	2.97	1.30	2.27	13.53	22.70	18.37	94.94	91.79	93.25
25-Aug-2018	11.50	2.54	1.15	1.71	28.04	39.92	36.23	90.05	86.41	87.51
26-Aug-2018	17.20	12.64	1.95	3.06	8.24	56.98	44.13	96.85	81.67	85.19
31-Aug-2018	117.80	73.91	45.16	49.60	54.81	122.86	111.98	82.25	67.39	69.40
02-Sep-2018	29.60	16.26	10.01	17.78	23.80	45.34	22.19	91.43	84.85	91.96
03-Sep-2018	29.00	10.54	9.29	6.24	40.36	48.89	65.42	86.28	83.85	79.51
07-Sep-2018	17.20	5.14	4.59	3.34	31.25	35.86	44.58	89.04	87.62	85.06
23-Sep-2018	15.60	0.74	0.33	2.83	59.73	66.02	36.13	80.96	79.37	87.54
24-Sep-2018	43.70	4.25	3.56	4.81	125.50	130.91	118.39	66.93	65.98	68.20
25-Sep-2018	22.20	0.80	0.66	1.77	94.17	95.30	79.30	72.95	72.71	76.20

M = Maize, FM = Finger Millet, FL = Fallow Land

Table F3. Calculation of CN_{obs} for 16% slope plot (Modified model)

Date	Rainfall (P) mm	16% slope plot								
		Runoff (Q) mm			S (modified model)			CN (modified model)		
		M	FM	FL	M	FM	FL	M	FM	FL
03-Jul-2018	57.00	44.07	55.18	19.77	15.52	1.85	67.77	94.24	99.27	78.93
04-Jul-2018	11.00	8.34	7.09	5.84	5.74	8.84	13.34	97.79	96.63	95.01
27-Jul-2018	57.00	45.46	22.13	25.04	13.19	62.14	51.53	95.06	80.34	83.13
28-Jul-2018	129.40	70.46	56.57	55.46	81.57	114.24	119.35	75.69	68.97	68.03
29-Jul-2018	35.00	17.25	5.45	4.75	31.88	86.39	95.07	88.84	74.62	72.76
01-Aug-2018	19.00	14.92	14.92	7.28	5.19	5.24	23.04	97.99	97.97	91.68
05-Aug-2018	13.00	12.79	8.49	5.02	0.31	8.64	19.72	99.87	96.71	92.79
06-Aug-2018	20.50	7.67	3.09	4.06	29.50	55.76	48.62	89.59	81.99	83.93
12-Aug-2018	7.30	3.11	1.44	2.97	12.23	22.49	13.29	95.40	91.86	95.02
25-Aug-2018	11.50	2.82	2.12	2.82	25.52	30.92	25.86	90.87	89.14	90.75
26-Aug-2018	17.20	15.70	8.75	5.00	2.50	19.33	34.83	99.02	92.92	87.94
31-Aug-2018	117.80	79.60	57.52	53.77	46.86	89.23	98.30	84.42	74.00	72.09
02-Sep-2018	29.60	20.98	18.06	19.45	14.50	19.73	18.20	94.59	92.79	93.31
03-Sep-2018	29.00	14.71	15.27	19.43	28.12	26.51	15.65	90.03	90.54	94.19
07-Sep-2018	17.20	11.81	6.11	5.70	9.47	27.73	30.76	96.40	90.15	89.19
23-Sep-2018	15.60	0.88	1.71	3.66	56.00	45.53	29.48	81.93	84.79	89.60
24-Sep-2018	43.70	6.06	3.83	6.19	106.44	128.96	104.24	70.46	66.32	70.90
25-Sep-2018	22.20	1.22	1.64	2.05	86.53	80.79	74.76	74.58	75.86	77.26

M = Maize, FM = Finger Millet, FL = Fallow Land

Table F4. Calculation of CN_{obs} for 8% slope plot (Existing model)

Date	Rainfall (P) mm	8% slope plot								
		Runoff (Q) mm			S (Existing model)			CN (Existing model)		
		M	FM	FL	M	FM	FL	M	FM	FL
03-Jul-2018	57.00	16.11	4.49	7.27	70.95	145.48	118.77	78.16	63.58	68.13
04-Jul-2018	11.00	3.20	2.09	2.64	13.35	18.36	15.62	95.00	93.25	94.20
27-Jul-2018	57.00	11.85	9.49	4.07	89.69	103.09	150.61	73.90	71.13	62.77
28-Jul-2018	129.40	46.71	38.80	36.16	127.32	152.88	162.64	66.61	62.42	60.96
29-Jul-2018	35.00	10.31	2.39	2.25	42.01	93.88	95.76	85.80	73.01	72.62
01-Aug-2018	19.00	9.36	5.20	4.36	12.55	24.30	27.89	95.29	91.26	90.10
05-Aug-2018	13.00	11.27	2.24	5.71	1.58	23.04	10.12	99.38	91.68	96.16
06-Aug-2018	20.50	4.20	1.98	1.70	32.57	48.36	51.34	88.63	84.00	83.18
12-Aug-2018	7.30	1.86	0.89	1.30	9.89	15.54	12.68	96.25	94.23	95.24
25-Aug-2018	11.50	1.15	1.01	0.46	26.74	28.18	35.97	90.47	90.01	87.59
26-Aug-2018	17.20	6.95	0.56	2.09	14.88	56.45	36.68	94.46	81.81	87.38
31-Aug-2018	117.80	73.22	39.47	45.02	50.65	125.22	108.82	83.37	66.97	70.00
02-Sep-2018	29.60	10.84	9.17	8.48	28.67	33.93	36.41	89.85	88.21	87.46
03-Sep-2018	29.00	8.74	7.63	4.29	34.10	38.32	56.02	88.16	86.89	81.93
07-Sep-2018	17.20	4.31	0.98	1.11	23.62	48.86	47.00	91.49	83.86	84.38
23-Sep-2018	15.60	0.60	0.19	2.41	49.27	60.55	29.43	83.75	80.75	89.61
24-Sep-2018	43.70	3.28	1.06	1.19	113.48	152.27	148.90	69.11	62.51	63.04
25-Sep-2018	22.20	0.52	0.39	0.94	77.85	81.77	68.46	76.54	75.64	78.76

M = Maize, FM = Finger Millet, FL = Fallow Land

Table F5: Calculation of CN_{obs} for 12% slope plot (Existing model)

Date	Rainfall (P) mm	12% slope plot								
		Runoff (Q) mm			S (Existing model)			CN (Existing model)		
		M	FM	FL	M	FM	FL	M	FM	FL
03-Jul-2018	57.00	25.32	12.13	16.15	43.71	88.27	70.79	85.31	74.21	78.20
04-Jul-2018	11.00	5.00	4.45	3.61	8.17	9.50	11.93	96.88	96.39	95.51
27-Jul-2018	57.00	15.60	11.29	9.07	72.91	92.63	105.79	77.69	73.27	70.59
28-Jul-2018	129.40	63.66	50.05	35.88	85.70	117.90	163.72	74.77	68.29	60.80
29-Jul-2018	35.00	16.56	3.78	2.81	24.57	78.76	88.71	91.17	76.33	74.11
01-Aug-2018	19.00	12.14	6.17	5.75	7.66	20.83	22.25	97.07	92.42	91.94
05-Aug-2018	13.00	12.65	4.32	6.68	0.29	13.93	8.03	99.88	94.80	96.93
06-Aug-2018	20.50	6.28	2.05	2.12	23.75	47.67	47.00	91.44	84.19	84.38
12-Aug-2018	7.30	2.97	1.30	2.27	6.26	12.68	8.34	97.59	95.24	96.82
25-Aug-2018	11.50	2.54	1.15	1.71	17.35	26.74	22.15	93.60	90.47	91.97
26-Aug-2018	17.20	12.64	1.95	3.06	4.66	37.87	29.90	98.19	87.02	89.46

Date	Rainfall (P) mm	12% slope plot								
		Runoff (Q) mm			S (Existing model)			CN (Existing model)		
		M	FM	FL	M	FM	FL	M	FM	FL
31-Aug-2018	117.80	73.91	45.16	49.60	49.58	108.43	96.88	83.66	70.08	72.38
02-Sep-2018	29.60	16.26	10.01	17.78	16.31	31.17	13.71	93.96	89.06	94.87
03-Sep-2018	29.00	10.54	9.29	6.24	28.32	32.21	44.56	89.96	88.74	85.07
07-Sep-2018	17.20	5.14	4.59	3.34	20.38	22.46	28.31	92.57	91.87	89.97
23-Sep-2018	15.60	0.74	0.33	2.83	46.69	55.71	26.80	84.47	82.01	90.45
24-Sep-2018	43.70	4.25	3.56	4.81	102.81	110.17	97.51	71.18	69.74	72.25
25-Sep-2018	22.20	0.80	0.66	1.77	71.20	74.29	56.41	78.10	77.37	81.82

M = Maize, FM = Finger Millet, FL = Fallow Land

Table F6: Calculation of CN_{obs} for 16% slope plot (Existing model)

Date	Rainfall (P) mm	16% slope plot								
		Runoff (Q) mm			S (Existing model)			CN (Existing model)		
		M	FM	FL	M	FM	FL	M	FM	FL
03-Jul-2018	57.00	44.07	55.18	19.77	12.80	1.55	58.49	95.20	99.39	81.28
04-Jul-2018	11.00	8.34	7.09	5.84	2.66	4.34	6.43	98.96	98.32	97.53
27-Jul-2018	57.00	45.46	22.13	25.04	11.20	51.71	44.37	95.77	83.08	85.12
28-Jul-2018	129.40	70.46	56.57	55.46	72.47	101.37	104.03	77.80	71.47	70.94
29-Jul-2018	35.00	17.25	5.45	4.75	23.11	65.75	70.71	91.66	79.43	78.22
01-Aug-2018	19.00	14.92	14.92	7.28	4.00	4.00	17.50	98.44	98.44	93.55
05-Aug-2018	13.00	12.79	8.49	5.02	0.17	4.97	11.86	99.93	98.08	95.53
06-Aug-2018	20.50	7.67	3.09	4.06	19.39	39.20	33.31	92.90	86.63	88.40
12-Aug-2018	7.30	3.11	1.44	2.97	5.91	11.89	6.26	97.72	95.52	97.59
25-Aug-2018	11.50	2.82	2.12	2.82	16.06	19.56	16.06	94.05	92.84	94.05
26-Aug-2018	17.20	15.70	8.75	5.00	1.33	10.80	20.89	99.47	95.92	92.40
31-Aug-2018	117.80	79.60	57.52	53.77	41.22	78.91	87.04	86.03	76.29	74.47
02-Sep-2018	29.60	20.98	18.06	19.45	9.02	13.26	11.14	96.57	95.03	95.79
03-Sep-2018	29.00	14.71	15.27	19.43	18.30	17.21	10.38	93.27	93.65	96.07
07-Sep-2018	17.20	11.81	6.11	5.70	5.75	17.21	18.48	97.78	93.65	93.21
23-Sep-2018	15.60	0.88	1.71	3.66	44.45	34.87	22.53	85.10	87.92	91.85
24-Sep-2018	43.70	6.06	3.83	6.19	87.33	107.17	86.37	74.41	70.32	74.62
25-Sep-2018	22.20	1.22	1.64	2.05	63.74	57.97	53.33	79.93	81.41	82.64

M = Maize, FM = Finger Millet, FL = Fallow Land

Table F7: Calculation of average CN_{obs} using frequency matching method (Modified method)

Rank m	Slope of plot 12%			Slope of plot 8%			Slope of plot 16%			PE = m/ (n+1)	AMC
	M	FM	FL	M	FM	FL	M	FM	FL		
1	99.79	92.39	94.83	98.87	90.63	93.63	99.87	99.27	95.02	5%	
2	96.85	91.79	93.25	93.68	88.81	91.28	99.02	97.97	95.01	11%	
3	96.17	91.70	91.96	93.07	88.39	89.43	97.99	96.71	94.19	16%	
4	94.94	90.01	90.98	90.98	87.76	87.05	97.79	96.63	93.31	21%	
5	93.50	87.62	89.49	90.64	85.68	86.32	96.40	92.92	92.79	26%	
6	91.43	86.41	87.54	87.20	83.21	83.81	95.40	92.79	91.68	32%	
7	90.05	84.85	87.51	86.35	81.24	83.10	95.06	91.86	90.75	37%	
8	89.04	83.85	85.19	86.00	79.13	81.85	94.59	90.54	89.60	42%	
9	87.97	81.67	85.06	84.14	79.12	79.86	94.24	90.15	89.19	47%	
10	87.67	79.37	79.51	82.98	78.12	78.22	90.87	89.14	87.94	53%	
11	86.28	79.26	79.47	81.58	77.09	76.82	90.03	84.79	83.93	58%	
12	83.13	72.71	76.20	81.05	71.44	73.46	89.59	81.99	83.13	63%	
13	82.25	70.24	74.88	80.73	67.42	67.45	88.84	80.34	78.93	68%	
14	80.96	70.18	69.40	74.61	66.87	66.47	84.42	75.86	77.26	74%	
15	74.33	69.09	68.23	72.17	63.80	64.77	81.93	74.62	72.76	79%	
16	72.95	67.39	68.20	70.55	59.55	59.28	75.69	74.00	72.09	84%	
17	72.27	65.98	66.42	65.44	59.12	58.94	74.58	68.97	70.90	89%	
18	66.93	64.83	57.31	63.27	58.95	57.09	70.46	66.32	68.03	95%	
	97.14	**91.85**	**93.40**	**94.19**	**88.99**	**91.51**	**99.10**	**98.10**	**95.01**	**10%**	**AMC III**
	87.82	**80.52**	**82.28**	**83.56**	**78.62**	**79.04**	**92.55**	**89.64**	**88.56**	**50%**	**AMC II**
	71.73	**65.86**	**65.50**	**65.22**	**59.10**	**58.75**	**74.16**	**68.70**	**70.61**	**90%**	**AMC I**

PE = Probability of Exceedance

M = Maize, FM = Finger Millet, FL = Fallow Land

Table F8: Calculation of average CN_{obs} using frequency matching method (Existing method)

Rank m	Slope of plot 12%			Slope of plot 8%			Slope of plot 16%			PE = m/(n+1)	AMC
	M	FM	FL	M	FM	FL	M	FM	FL		
1	99.88	96.39	96.93	99.38	94.23	96.16	99.93	99.39	97.59	5%	
2	98.19	95.24	96.82	96.25	93.25	95.24	99.47	98.44	97.53	11%	
3	97.59	94.80	95.51	95.29	91.68	94.20	98.96	98.32	96.07	16%	
4	97.07	92.42	94.87	95.00	91.26	90.10	98.44	98.08	95.79	21%	
5	96.88	91.87	91.97	94.46	90.01	89.61	97.78	95.92	95.53	26%	
6	93.96	90.47	91.94	91.49	88.21	87.59	97.72	95.52	94.05	32%	
7	93.60	89.06	90.45	90.47	86.89	87.46	96.57	95.03	93.55	37%	
8	92.57	88.74	89.97	89.85	84.00	87.38	95.77	93.65	93.21	42%	
9	91.44	87.02	89.46	88.63	83.86	84.38	95.20	93.65	92.40	47%	

Rank m	Slope of plot 12%			Slope of plot 8%			Slope of plot 16%			PE = m/(n+1)	AMC
	M	FM	FL	M	FM	FL	M	FM	FL		
10	91.17	84.19	85.07	88.16	81.81	83.18	94.05	92.84	91.85	53%	
11	89.96	82.01	84.38	85.80	80.75	81.93	93.27	87.92	88.40	58%	
12	85.31	77.37	81.82	83.75	75.64	78.76	92.90	86.63	85.12	63%	
13	84.47	76.33	78.20	83.37	73.01	72.62	91.66	83.08	82.64	68%	
14	83.66	74.21	74.11	78.16	71.13	70.00	86.03	81.41	81.28	74%	
15	78.10	73.27	72.38	76.54	66.97	68.13	85.10	79.43	78.22	79%	
16	77.69	70.08	72.25	73.90	63.58	63.04	79.93	76.29	74.62	84%	
17	74.77	69.74	70.59	69.11	62.51	62.77	77.80	71.47	74.47	89%	
18	71.18	68.29	60.80	66.61	62.42	60.96	74.41	70.32	70.94	95%	
	98.35	**95.35**	**96.83**	**96.56**	**93.34**	**95.33**	**99.51**	**98.53**	**97.53**	**10%**	**AMC III**
	91.30	**85.60**	**87.26**	**88.39**	**82.83**	**83.78**	**94.62**	**93.24**	**92.12**	**50%**	**AMC II**
	74.41	**69.59**	**69.61**	**68.86**	**62.50**	**62.58**	**77.46**	**71.35**	**74.11**	**90%**	**AMC I**

PE = Probability of Exceedance

M = Maize, FM = Finger Millet, FL = Fallow Land

Table F9: Curve Number from NEH-4 Table (AMC conversion by Mishra et al. 2008)

AMC	HSG A	HSG A	HSG A	HSG A	HSG A	HSG B	HSG A	HSG A	HSG A
	Maize	Finger Millet	Fallow Land	Maize	Finger Millet	Fallow Land	Maize	Finger Millet	Fallow Land
AMC I	53.05	44.93	59.53	53.05	44.93	72.97	53.05	44.93	59.53
AMC II	72.00	65.00	77.00	72.00	65.00	86.00	72.00	65.00	77.00
AMC III	85.67	81.19	88.61	85.67	81.19	93.45	85.67	81.19	88.61

Table F10: Calculation of CN and λ (optimization using GRG Non-Linear algorithm) for maize of 8% slope plot (Modified model)

SN	Rainfall (P) (mm)	Observed runoff (Q_o) (mm)	AMC (mm)	CN_{opti}	λ	S (mm)	Q_{comp} (mm)	(Q_o-Q_c)	$(Q_o-Q_c)^2$	$(Q_o-Q_m)^2$
1	57.00	16.11	19.24	59.07	0.01	176	16.42	-0.31	0.09	13.24
2	11.00	3.20	27.06				1.58	1.62	2.62	85.93
3	57.00	11.85	16.63				16.02	-4.16	17.36	0.38
4	129.40	46.71	29.55				60.22	-13.50	182.44	1172.37
5	35.00	10.31	26.83				8.46	1.85	3.42	4.66
6	19.00	9.36	10.20				2.33	7.03	49.48	9.67
7	13.00	11.27	15.75				1.49	9.77	95.56	1.44
8	20.50	4.20	18.96				3.31	0.89	0.79	68.39
9	7.30	1.86	17.64				0.64	1.21	1.47	112.57
10	11.50	1.15	16.44				1.26	-0.11	0.01	128.14
11	17.2	6.95	21.36				2.67	4.27	18.31	30.47
12	117.8	73.22	20.4				50.67	22.54	508.33	3690.56

SN	Rainfall (P) (mm)	Observed runoff (Q_o) (mm)	AMC (mm)	CN_{opti}	λ	S (mm)	Q_{comp} (mm)	(Q_o-Q_c)	$(Q_o-Q_c)^2$	$(Q_o-Q_m)^2$
13	29.6	10.84	21.36				6.08	4.75	22.63	2.65
14	29	8.74	27.66				6.48	2.26	5.12	13.91
15	17.2	4.31	19.82				2.58	1.73	3.00	66.58
16	15.6	0.6	7.68				1.51	-0.90	0.82	140.89
17	43.7	3.28	15.5				10.32	-7.03	49.55	84.45
18	22.2	0.52	21.7				3.95	-3.42	11.75	142.80
	Sum	224.48					Sum	28.49	972.75	5769.10
	Mean	12.47					NSE	83%		
							RMSE	9.86		
							PBIAS	13%		

Table F11: Calculation of CN and λ (optimization using GRG Non-Linear algorithm) for Finger Millet of 8% slope plot (Modified model)

SN	Rainfall (P) (mm)	Observed runoff (Q_o) (mm)	AMC (mm)	CN_{opti}	λ	S (mm)	Q_{comp} (mm)	(Q_o-Q_c)	$(Q_o-Q_c)^2$	$(Q_o-Q_m)^2$
1	57.00	4.49	20.52	37.55	0.003	422.4	8.52	-4.03	16.26	6.86
2	11.00	2.09	26.76				0.77	1.31	1.73	25.20
3	57.00	9.49	21.60				8.62	0.86	0.74	5.66
4	129.40	38.80	28.56				34.67	4.12	17.05	1004.25
5	35.00	2.39	25.93				4.17	-1.78	3.18	22.27
6	19.00	5.20	9.86				1.09	4.11	16.91	3.64
7	13.00	2.24	15.66				0.71	1.52	2.32	23.71
8	20.50	1.98	18.85				1.59	0.38	0.15	26.31
9	7.30	0.89	18.06				0.33	0.56	0.31	38.68
10	11.50	1.01	18.42				0.65	0.35	0.12	37.21
11	17.2	0.56	25.26				1.42	-0.85	0.73	42.90
12	117.8	39.47	25.92				29.39	10.08	101.62	1047.16
13	29.6	9.17	26.76				3.27	5.90	34.82	4.24
14	29	7.63	29.1				3.29	4.34	18.84	0.27
15	17.2	0.98	19.48				1.23	-0.25	0.06	37.57
16	15.6	0.19	10.08				0.78	-0.59	0.35	47.88
17	43.7	1.06	17.42				5.27	-4.20	17.69	36.60
18	22.2	0.39	24.39				2.03	-1.63	2.68	45.15
	Sum	128.03				Sum		20.20	235.56	2455.56
	Mean	7.11					NSE	90%		
							RME	4.85		
							PBIS	16%		

Table F12: Calculation of CN and λ (optimization using GRG Non-Linear algorithm) for Fallow land of 8% slope plot (Modified model)

SN	Rainfall (P) (mm)	Observed runoff (Q_o) (mm)	AMC (mm)	CN_{opti}	λ	S (mm)	Q_{comp} (mm)	(Q_o-Q_c)	$(Q_o-Q_c)^2$	$(Q_o-Q_m)^2$
1	57.00	7.27	16.08	37.55	0.001	422.4	8.30	-1.03	1.06	0.00
2	11.00	2.64	28.68				0.90	1.74	3.02	21.71
3	57.00	4.07	19.44				8.63	-4.55	20.78	10.43
4	129.40	36.16	34.15				35.93	0.22	0.05	832.89
5	35.00	2.25	31.00				4.65	-2.39	5.74	25.50
6	19.00	4.36	11.78				1.25	3.11	9.69	8.64
7	13.00	5.71	16.18				0.80	4.90	24.09	2.52
8	20.50	1.70	19.48				1.72	-0.01	0.00	31.36
9	7.30	1.30	25.02				0.48	0.81	0.66	36.00
10	11.50	0.46	16.68				0.68	-0.22	0.04	46.78
11	17.2	2.09	24.6				1.50	0.59	0.35	27.14
12	117.8	45.02	21				28.96	16.05	257.79	1422.79
13	29.6	8.48	21.3				3.11	5.36	28.78	1.39
14	29	4.29	21.36				3.02	1.26	1.60	9.06
15	17.2	1.11	17.23				1.25	-0.14	0.01	38.31
16	15.6	2.41	11.32				0.90	1.51	2.29	23.91
17	43.7	1.19	18.42				5.52	-4.32	18.71	37.33
18	22.2	0.94	25.8				2.20	-1.26	1.59	40.44
	Sum	131.45					Sum	21.63	376.25	2616.20
	Mean	7.30					NSE	86%		
							RMSE	6.13		
							PBIAS	16%		

Table F13: Calculation of CN and λ (optimization using GRG Non-Linear algorithm) for maize of 12% slope plot (Modified model)

SN	Rainfall (P) (mm)	Observed runoff (Q_o) (mm)	AMC (mm)	CN_{opti}	λ	S (mm)	Q_{comp} (mm)	(Q_o-Q_c)	$(Q_o-Q_c)^2$	$(Q_o-Q_m)^2$
1	57.00	25.32	14.35	70.63	0.01	105.60	22.36	2.96	8.77	87.98
2	11.00	5.00	28.26				2.64	2.35	5.56	119.68
3	57.00	15.60	17.88				23.02	-7.41	55.02	0.11
4	129.40	63.66	24.19				75.84	-12.17	148.34	2277.19
5	35.00	16.56	21.96				11.75	4.81	23.14	0.38
6	19.00	12.14	8.35				3.58	8.56	73.32	14.44
7	13.00	12.65	15.24				2.45	10.20	104.13	10.82
8	20.50	6.28	18.34				5.12	1.15	1.33	93.31
9	7.30	2.97	20.16				1.25	1.72	2.96	168.22
10	11.50	2.54	15.36				2.05	0.48	0.23	179.56
11	17.2	12.64	20.22				4.14	8.50	72.33	10.89
12	117.8	73.91	16.2				65.06	8.84	78.26	3360.52

SN	Rainfall (P) (mm)	Observed runoff (Q_o) (mm)	AMC (mm)	CN_{opti}	λ	S (mm)	Q_{comp} (mm)	(Q_o-Q_c)	$(Q_o-Q_c)^2$	$(Q_o-Q_m)^2$
13	29.6	16.26	20.28				9.02	7.23	52.34	0.1
14	29	10.54	20.04				8.73	1.80	3.27	29.16
15	17.2	5.14	16.7				3.83	1.31	1.71	116.64
16	15.6	0.74	11.52				2.88	-2.13	4.57	231.04
17	43.7	4.25	18.57				15.65	-11.39	129.92	136.65
18	22.2	0.8	26.01				6.53	-5.72	32.79	229.21
	sum	287.00					Sum	21.09	797.99	7065.90
	Mean	15.94					NSE	89%		
							RMSE	8.93		
							PBIAS	7%		

Table F14: Calculation of CN and λ (optimization using GRG Non-Linear algorithm) for Finger Millet of 12% slope (Modified model)

SN	Rainfall (P) (mm)	Observed runoff (Q_o) (mm)	AMC (mm)	CN_{opti}	λ	S (mm)	Q_{comp} (mm)	(Q_o-Q_c)	$(Q_o-Q_c)^2$	$(Q_o-Q_m)^2$
1	57.00	12.13	20.80	47.52	0.0	280.47	12.38	-0.24	0.06	6.6
2	11.00	4.45	32.58				1.48	2.97	8.82	26.11
3	57.00	11.29	21.55				12.47	-1.18	1.39	2.99
4	129.40	50.05	31.32				47.14	2.91	8.47	1639.44
5	35.00	3.78	28.44				6.46	-2.67	7.16	33.4
6	19.00	6.17	10.81				1.83	4.34	18.87	11.49
7	13.00	4.32	15.92				1.22	3.10	9.64	27.45
8	20.50	2.05	19.16				2.54	-0.48	0.23	56.4
9	7.30	1.30	17.46				0.59	0.70	0.5	68.22
10	11.50	1.15	15.90				1.02	0.12	0.01	70.72
11	17.2	1.95	23.04				2.16	-0.20	0.04	57.91
12	117.8	45.16	22.2				39.22	5.93	35.25	1267.36
13	29.6	10.01	22.62				4.65	5.36	28.77	0.2
14	29	9.29	26.52				4.79	4.49	20.23	0.07
15	17.2	4.59	20.25				2.03	2.56	6.57	24.7
16	15.6	0.33	8.16				1.22	-0.88	0.78	85.19
17	43.7	3.56	15.88				7.66	-4.09	16.78	36
18	22.2	0.66	22.24				3.04	-2.37	5.64	79.21
	sum	172.24					Sum	20.37	169.21	3493.46
	Mean	9.56					NSE	95%		
							RMSE	4.11		
							PBIAS	12%		

Table F15: Calculation of CN and λ (optimization using GRG Non-Linear algorithm) for Fallow land of 12% slope plot (Modified model)

S N	Rainfall (P) (mm)	Observed runoff (Q_o) (mm)	AMC (mm)	CN_{opti}	λ	S (mm)	Q_{comp} (mm)	(Q_o-Q_c)	$(Q_o-Q_c)^2$	$(Q_o-Q_m)^2$
1	57.00	16.15	17.83	53.85	0.05	217.64	10.47	5.67	32.22	41.08
2	11.00	3.61	32.58				0.02	3.59	12.92	37.57
3	57.00	9.07	21.00				10.87	-1.80	3.24	0.44
4	129.40	35.88	30.36				48.14	-12.26	150.34	683.29
5	35.00	2.81	27.56				4.63	-1.81	3.30	48.02
6	19.00	5.75	10.47				0.64	5.11	26.12	15.92
7	13.00	6.68	15.82				0.16	6.51	42.49	9.36
8	20.50	2.12	19.05				1.12	1.00	1.00	58.06
9	7.30	2.27	27.18				0.00	2.27	5.15	55.80
10	11.50	1.71	20.10				0.05	1.65	2.74	64.48
11	17.2	3.06	17.04				0.61	2.44	5.99	44.62
12	117.8	49.6	25.86				40.51	9.08	82.58	1588.81
13	29.6	17.78	28.32				3.33	14.45	208.90	64.64
14	29	6.24	26.28				3.07	3.17	10.05	12.25
15	17.2	3.34	21.84				0.72	2.61	6.84	40.96
16	15.6	2.83	10.08				0.30	2.52	6.39	47.74
17	43.7	4.81	17.42				6.15	-1.34	1.80	24.30
18	22.2	1.77	24.39				1.60	0.17	0.03	63.52
	Sum	175.48					Sum	43.03	602.10	2900.86
	Mean	9.74					NSE	79%		
							RMSE	7.76		
							PBIS	25%		

Table F16: Calculation of CN and λ (optimization using GRG Non-Linear algorithm) for Maize of 16% slope plot (Modified model)

S N	Rainfall (P) (mm)	Observed runoff (Q_o) (mm)	AMC (mm)	CN_{opti}	λ	S (mm)	Q_{comp} (mm)	(Q_o-Q_c)	$(Q_o-Q_c)^2$	$(Q_o-Q_m)^2$
1	57.00	44.07	15.72	79.66	0.04	64.86	28.26	15.80	249.83	532.68
2	11.00	8.34	21.90				2.68	5.66	32.07	160.02
3	57.00	45.46	13.03				27.73	17.72	314.27	598.78
4	129.40	70.46	21.75				88.27	-17.80	317.09	2447.28
5	35.00	17.25	19.75				14.44	2.80	7.87	13.98
6	19.00	14.92	7.51				4.42	10.50	110.26	36.84
7	13.00	12.79	15.01				2.93	9.86	97.22	67.24
8	20.50	7.67	18.07				6.39	1.28	1.64	177.42
9	7.30	3.11	16.98				1.18	1.93	3.72	319.69

S N	Rainfall (P) (mm)	Observed runoff (Q_o) (mm)	AMC (mm)	CN_{opti}	λ	S (mm)	Q_{comp} (mm)	(Q_o-Q_c)	$(Q_o-Q_c)^2$	$(Q_o-Q_m)^2$
10	11.50	2.82	13.74				2.30	0.51	0.26	330.14
11	17.2	15.7	22.56				5.32	10.37	107.73	27.98
12	117.8	79.6	21				78.04	1.55	2.42	3435.13
13	29.6	20.98	26.52				12.21	8.77	76.91	0.00
14	29	14.71	24.36				11.59	3.11	9.71	39.43
15	17.2	11.81	16.7				4.75	7.05	49.77	84.27
16	15.6	0.88	9.6				3.36	-2.48	6.15	404.41
17	43.7	6.06	17.04				19.43	-13.37	178.77	222.90
18	22.2	1.22	23.85				7.87	-6.64	44.16	390.85
	Sum	377.85					Sum	56.62	1609.85	9289.04
	Mean	20.99					NSE	83%		
							RMSE	12.69		
							PBIAS	15%		

Table F17: Calculation of CN and λ (optimization using GRG Non-Linear algorithm) for Finger Millet of 16% slope plot (Modified model)

S N	Rainfall (P) (mm)	Observed runoff (Q_o) (mm)	AMC (mm)	CN_{opti}	λ	S (mm)	Q_{comp} (mm)	(Q_o-Q_c)	$(Q_o-Q_c)^2$	$(Q_o-Q_m)^2$
1	57.00	55.18	13.96	64.34	0.002	140.8	18.96	36.22	1312.23	1529.59
2	11.00	7.09	20.04				1.92	5.16	26.71	80.64
3	57.00	22.13	16.71				19.44	2.68	7.23	36.72
4	129.40	56.57	22.75				67.00	-10.43	108.79	1640.25
5	35.00	5.45	20.65				9.80	-4.34	18.91	112.78
6	19.00	14.92	7.84				2.97	11.94	142.79	1.32
7	13.00	8.49	15.10				2.10	6.39	40.85	57.45
8	20.50	3.09	18.19				4.33	-1.24	1.54	168.48
9	7.30	1.44	21.00				1.16	0.27	0.07	214.03
10	11.50	2.12	15.20				1.77	0.34	0.12	194.60
11	17.2	8.75	23.58				3.78	4.97	24.70	53.58
12	117.8	57.52	21				58.28	-0.75	0.57	1718.10
13	29.6	18.06	21.3				7.75	10.30	106.23	3.96
14	29	15.27	24.36				7.86	7.40	54.87	0.64
15	17.2	6.11	18.91				3.43	2.67	7.17	99.20
16	15.6	1.71	9.79				2.32	-0.60	0.36	206.20
17	43.7	3.83	17.18				13.06	-9.23	85.26	149.81
18	22.2	1.64	24.07				5.40	-3.75	14.11	208.22
	Sum	289.37					Sum	58.00	1952.51	6475.57
	Mean	16.07					NSE	70%		
							RMSE	13.97		
							PBIS	20%		

Table F18: Calculation of CN and λ (Optimization using GRG Non-Linear algorithm) for Fallow land of 16% slope (Modified model)

SN	Rainfall (P) (mm)	Observed runoff (Q_o) (mm)	AMC (mm)	CN_{opti}	λ	S (mm)	Q_{comp} (mm)	(Q_o-Q_c)	$(Q_o-Q_c)^2$	$(Q_o-Q_m)^2$
1	57.00	19.77	13.15	59.07	0.00	176	16.24	3.52	12.42	35.76
2	11.00	5.84	22.98				1.78	4.05	16.48	63.20
3	57.00	25.04	12.91				16.20	8.83	78.06	126.56
4	129.40	55.46	26.67				60.82	-5.35	28.69	1736.38
5	35.00	4.75	24.21				8.81	-4.06	16.48	81.72
6	19.00	7.28	9.20				2.62	4.65	21.67	42.38
7	13.00	5.02	15.48				1.81	3.20	10.29	76.91
8	20.50	4.06	18.63				3.73	0.33	0.10	94.67
9	7.30	2.97	18.98				0.95	2.02	4.08	117.07
10	11.50	2.82	14.47				1.48	1.34	1.79	120.34
11	17.2	5	23.06				3.20	1.79	3.23	77.26
12	117.8	53.77	21				51.94	1.83	3.34	1598.40
13	29.6	19.45	28.44				7.34	12.10	146.63	32.03
14	29	19.43	21.36				6.45	12.97	168.43	31.80
15	17.2	5.7	21.74				3.12	2.58	6.67	65.44
16	15.6	3.66	8.16				1.86	1.80	3.25	102.61
17	43.7	6.19	15.88				11.05	-4.86	23.63	57.76
18	22.2	2.05	22.24				4.48	-2.42	5.88	137.82
	Sum	248.26					Sum	44.32	551.12	4598.11
	Mean	13.79					NSE	88%		
							RMSE	7.42		
							PBIAS	18%		

Table F19: Calculation of CN and λ (optimization using GRG Non-Linear algorithm) for Maize of 8% slope plot (Existing model)

SN	Rainfall (P) (mm)	Observed runoff (Q_o) (mm)	CN_{opti}	λ	S (mm)	Q_{comp} (mm)	(Q_o-Q_c)	$(Q_o-Q_c)^2$	$(Q_o-Q_m)^2$
1	57.00	16.11	58.75	0.00	178.37	13.80	2.30	5.31	13.24
2	11.00	3.20				0.64	2.56	6.55	85.93
3	57.00	11.85				13.80	-1.95	3.81	0.38
4	129.40	46.71				54.40	-7.69	59.20	1172.37
5	35.00	10.31				5.74	4.56	20.87	4.66
6	19.00	9.36				1.83	7.53	56.71	9.67
7	13.00	11.27				0.88	10.38	107.88	1.44
8	20.50	4.20				2.11	2.08	4.35	68.39
9	7.30	1.86				0.29	1.57	2.47	112.57
10	11.50	1.15				0.70	0.45	0.20	128.14

SN	Rainfall (P) (mm)	Observed runoff (Q_o) (mm)	CN_{opti}	λ	S (mm)	Q_{comp} (mm)	(Q_o-Q_c)	$(Q_o-Q_c)^2$	$(Q_o-Q_m)^2$
11	17.2	6.95				1.51	5.43	29.56	30.47
12	117.8	73.22				46.85	26.36	695.18	3690.56
13	29.6	10.84				4.21	6.62	43.91	2.65
14	29	8.74				4.06	4.68	21.94	13.91
15	17.2	4.31				1.51	2.79	7.82	66.58
16	15.6	0.6				1.25	-0.65	0.42	140.89
17	43.7	3.28				8.60	-5.31	28.29	84.45
18	22.2	0.52				2.46	-1.93	3.75	142.80
	Sum	224.48				Sum	59.78	1098.22	5769.10
	Mean	12.47				NSE=	81%		
						RMSE=	10.48		
						PBIAS=	27%		

Table F20: Calculation of CN and λ (optimization using GRG Non-Linear algorithm) for Finger Millet of 8% slope plot (Existing model)

SN	Rainfall (P) (mm)	Observed runoff (Q_o) (mm)	CN_{opti}	λ	S (mm)	Q_{comp} (mm)	(Q_o-Q_c)	$(Q_o-Q_c)^2$	$(Q_o-Q_m)^2$
1	57.00	4.49	59.39	0.05	173.65	10.52	-6.02	36.32	6.86
2	11.00	2.09				0.03	2.05	4.24	25.20
3	57.00	9.49				10.52	-1.02	1.05	5.66
4	129.40	38.80				49.50	-10.70	114.58	1004.25
5	35.00	2.39				3.46	-1.07	1.15	22.27
6	19.00	5.20				0.58	4.62	21.35	3.64
7	13.00	2.24				0.10	2.13	4.55	23.71
8	20.50	1.98				0.75	1.22	1.50	26.31
9	7.30	0.89				0.01	0.87	0.77	38.68
10	11.50	1.01				0.04	0.96	0.93	37.21
11	17.2	0.56				0.40	0.16	0.02	42.90
12	117.8	39.47				42.11	-2.63	6.95	1047.16
13	29.6	9.17				2.25	6.92	47.90	4.24
14	29	7.63				2.13	5.50	30.27	0.27
15	17.2	0.98				0.40	0.58	0.33	37.57
16	15.6	0.19				0.26	-0.07	0.00	47.88
17	43.7	1.06				5.88	-4.81	23.19	36.60
18	22.2	0.39				0.98	-0.58	0.34	45.15
	Sum	128.03				Sum	-1.89	295.44	2455.56
	Mean	7.11				NSE	88%		
						RMSE	5.44		
						PBIAS	-1%		

Table F21: Calculation of CN and λ (optimization using GRG Non-Linear algorithm) for Fallow land of 8% slope plot (Existing model)

SN	Rainfall (P) (mm)	Observed runoff (Q_o) (mm)	CN_{opti}	λ	S (mm)	Q_{comp} (mm)	(Q_o-Q_c)	$(Q_o-Q_c)^2$	$(Q_o-Q_m)^2$
1	57.00	7.27	41.91	0.00	352.0	7.94	-0.67	0.45	0.00
2	11.00	2.64				0.33	2.30	5.32	21.71
3	57.00	4.07				7.94	-3.87	14.98	10.43
4	129.40	36.16				34.78	1.38	1.90	832.89
5	35.00	2.25				3.16	-0.91	0.83	25.50
6	19.00	4.36				0.97	3.38	11.47	8.64
7	13.00	5.71				0.46	5.24	27.53	2.52
8	20.50	1.70				1.13	0.57	0.32	31.36
9	7.30	1.30				0.15	1.15	1.32	36.00
10	11.50	0.46				0.36	0.09	0.00	46.78
11	17.2	2.09				0.80	1.28	1.66	27.14
12	117.8	45.02				29.53	15.48	239.81	1422.79
13	29.6	8.48				2.29	6.18	38.25	1.39
14	29	4.29				2.21	2.08	4.34	9.06
15	17.2	1.11				0.80	0.30	0.09	38.31
16	15.6	2.41				0.66	1.74	3.05	23.91
17	43.7	1.19				4.82	-3.63	13.20	37.33
18	22.2	0.94				1.32	-0.37	0.14	40.44
	Sum	131.45				Sum	31.72	364.66	2616.20
	Mean	7.30				NSE	86%		
						RMSE	6.04		
						PBIAS	24%		

Table F22: Calculation of CN and λ (optimization using GRG Non-Linear algorithm) for maize of 12% slope plot (Existing model)

SN	Rainfall (P) (mm)	Observed runoff (Q_o) (mm)	CN_{opti}	λ	S (mm)	Q_{comp} (mm)	(Q_o-Q_c)	$(Q_o-Q_c)^2$	$(Q_o-Q_m)^2$
1	57.00	25.32	74.27	0.020	88.0	21.30	4.01	16.13	87.98
2	11.00	5.00				0.88	4.12	16.99	119.68
3	57.00	15.60				21.30	-5.70	32.52	0.11
4	129.40	63.66				75.55	-11.89	141.41	2277.19
5	35.00	16.56				9.11	7.44	55.45	0.38
6	19.00	12.14				2.82	9.31	86.78	14.44
7	13.00	12.65				1.27	11.37	129.43	10.82
8	20.50	6.28				3.29	2.98	8.93	93.31
9	7.30	2.97				0.33	2.64	6.97	168.22
10	11.50	2.54				0.97	1.56	2.46	179.56

SN	Rainfall (P) (mm)	Observed runoff (Q_o) (mm)	CN_{opti}	λ	S (mm)	Q_{comp} (mm)	(Q_o-Q_c)	$(Q_o-Q_c)^2$	$(Q_o-Q_m)^2$
11	17.2	12.64				2.30	10.33	106.81	10.89
12	117.8	73.91				65.99	7.91	62.67	3360.52
13	29.6	16.26				6.69	9.56	91.56	0.1
14	29	10.54				6.44	4.10	16.81	29.16
15	17.2	5.14				2.30	2.83	8.03	116.64
16	15.6	0.74				1.88	-1.14	1.3	231.04
17	43.7	4.25				13.54	-9.28	86.24	136.65
18	22.2	0.8				3.85	-3.05	9.31	229.21
	Sum	287.00				Sum	47.10	879.80	7065.90
	Mean	15.94				NSE	88%		
						RMSE	9.38		
						PBIAS	16%		

Table F23: Calculation of CN and λ (optimization using GRG Non-Linear algorithm) for Finger Millet of 12% slope plot (Existing model)

SN	Rainfall (P) (mm)	Observed runoff (Q_o) (mm)	CN_{opti}	λ	S (mm)	Q_{comp} (mm)	(Q_o-Q_c)	$(Q_o-Q_c)^2$	$(Q_o-Q_m)^2$
1	57.00	12.13	54.60	0.01	211.20	11.32	0.80	0.65	6.6
2	11.00	4.45				0.36	4.09	16.73	26.11
3	57.00	11.29				11.32	-0.03	0	2.99
4	129.40	50.05				47.87	2.18	4.76	1639.44
5	35.00	3.78				4.43	-0.65	0.42	33.4
6	19.00	6.17				1.25	4.91	24.2	11.49
7	13.00	4.32				0.53	3.78	14.33	27.45
8	20.50	2.05				1.47	0.57	0.33	56.4
9	7.30	1.30				0.12	1.17	1.38	68.22
10	11.50	1.15				0.40	0.75	0.56	70.72
11	17.2	1.95				1.01	0.94	0.89	57.91
12	117.8	45.16				40.94	4.21	17.78	1267.36
13	29.6	10.01				3.17	6.84	46.84	0.2
14	29	9.29				3.04	6.25	39.1	0.07
15	17.2	4.59				1.01	3.58	12.84	24.7
16	15.6	0.33				0.81	-0.47	0.23	85.19
17	43.7	3.56				6.84	-3.28	10.77	36
18	22.2	0.66				1.74	-1.08	1.17	79.21
	Sum	172.24				Sum	34.56	192.98	3493.46
	Mean	9.56				NSE	94%		
						RMSE	4.39		
						PBIAS	20%		

Table F24: Calculation of CN and λ (optimization using GRG Non-Linear algorithm) for Fallow land of 12% slope plot (Existing model)

SN	Rainfall (P) (mm)	Observed runoff (Q_o) (mm)	CN_{opti}	λ	S (mm)	Q_{comp} (mm)	(Q_o-Q_c)	$(Q_o-Q_c)^2$	$(Q_o-Q_m)^2$
1	57.00	16.15	57.47	0.003	187.97	13.03	3.11	9.72	41.08
2	11.00	3.61				0.55	3.06	9.37	37.57
3	57.00	9.07				13.03	-3.96	15.69	0.44
4	129.40	35.88				52.39	-16.51	272.72	683.29
5	35.00	2.81				5.33	-2.52	6.36	48.02
6	19.00	5.75				1.65	4.10	16.83	15.92
7	13.00	6.68				0.77	5.90	34.90	9.36
8	20.50	2.12				1.91	0.20	0.04	58.06
9	7.30	2.27				0.23	2.03	4.14	55.80
10	11.50	1.71				0.60	1.10	1.22	64.48
11	17.2	3.06				1.35	1.70	2.91	44.62
12	117.8	49.6				45.03	4.56	20.85	1588.81
13	29.6	17.78				3.89	13.89	193.06	64.64
14	29	6.24				3.74	2.50	6.26	12.25
15	17.2	3.34				1.35	1.98	3.94	40.96
16	15.6	2.83				1.11	1.71	2.94	47.74
17	43.7	4.81				8.05	-3.24	10.50	24.30
18	22.2	1.77				2.23	-0.46	0.21	63.52
	Sum	175.48				Sum	19.15	611.66	2900.86
	Mean	9.74				NSE	79%		
						RMSE	7.82		
						PBIAS	11%		

Table F25: Calculation of CN and λ (optimization using GRG Non-Linear algorithm) for Maize of 16% slope plot (Existing model)

SN	Rainfall (P) (mm)	Observed runoff (Q_o) (mm)	CN_{opti}	λ	S (mm)	Q_{comp} (mm)	(Q_o-Q_c)	$(Q_o-Q_c)^2$	$(Q_o-Q_m)^2$
1	57.00	44.07	82.79	0.00	52.80	29.59	14.47	209.66	532.68
2	11.00	8.34				1.90	6.44	41.51	160.02
3	57.00	45.46				29.59	15.86	251.85	598.78
4	129.40	70.46				91.90	-21.44	459.71	2447.28
5	35.00	17.25				13.95	3.29	10.87	13.98
6	19.00	14.92				5.03	9.89	97.85	36.84
7	13.00	12.79				2.57	10.22	104.48	67.24
8	20.50	7.67				5.73	1.93	3.75	177.42
9	7.30	3.11				0.89	2.22	4.94	319.69

SN	Rainfall (P) (mm)	Observed runoff (Q_o) (mm)	CN_{opti}	λ	S (mm)	Q_{comp} (mm)	(Q_o-Q_c)	$(Q_o-Q_c)^2$	$(Q_o-Q_m)^2$
10	11.50	2.82				2.06	0.76	0.58	330.14
11	17.2	15.7				4.23	11.47	131.64	27.98
12	117.8	79.6				81.34	-1.74	3.03	3435.13
13	29.6	20.98				10.63	10.34	107.06	0.00
14	29	14.71				10.28	4.42	19.61	39.43
15	17.2	11.81				4.23	7.58	57.51	84.27
16	15.6	0.88				3.56	-2.67	7.17	404.41
17	43.7	6.06				19.79	-13.72	188.49	222.90
18	22.2	1.22				6.57	-5.35	28.63	390.85
	Sum	377.85				Sum	53.97	1728.34	9289.04
	Mean	20.99				NSE	81%		
						RMSE	13.15		
						PBIAS	14%		

Table F26: Calculation of CN and λ (optimization using GRG Non-Linear algorithm) for Finger Millet of 16% slope plot (Existing model)

SN	Rainfall (P) (mm)	Observed runoff (Q_o) (mm)	CN_{opti}	λ	S (mm)	Q_{comp} (mm)	(Q_o-Q_c)	$(Q_o-Q_c)^2$	$(Q_o-Q_m)^2$
1	57.00	55.18	67.09	0.00	124.57	17.89	37.28	1390.23	1529.59
2	11.00	7.09				0.89	6.19	38.40	80.64
3	57.00	22.13				17.89	4.23	17.94	36.72
4	129.40	56.57				65.93	-9.36	87.62	1640.25
5	35.00	5.45				7.68	-2.22	4.95	112.78
6	19.00	14.92				2.51	12.40	153.89	1.32
7	13.00	8.49				1.23	7.26	52.72	57.45
8	20.50	3.09				2.90	0.19	0.03	168.48
9	7.30	1.44				0.40	1.03	1.07	214.03
10	11.50	2.12				0.97	1.14	1.31	194.60
11	17.2	8.75				2.09	6.66	44.39	53.58
12	117.8	57.52				57.26	0.26	0.07	1718.10
13	29.6	18.06				5.68	12.37	153.18	3.96
14	29	15.27				5.48	9.79	95.91	0.64
15	17.2	6.11				2.09	4.02	16.18	99.20
16	15.6	1.71				1.74	-0.02	0.00	206.20
17	43.7	3.83				11.35	-7.51	56.53	149.81
18	22.2	1.64				3.36	-1.71	2.95	208.22
	Sum	289.37				Sum	82.00	2117.37	6475.57
	Mean	16.07				NSE	67%		
						RMSE	14.55		
						PBIAS	28%		

Table F27: Calculation of CN and λ (optimization using GRG Non-Linear algorithm) for Fallow land of 16% slope plot (Existing model)

SN	Rainfall (P) (mm)	Observed runoff (Q_o) (mm)	CN_{opti}	λ	S (mm)	Q_{comp} (mm)	(Q_o-Q_c)	$(Q_o-Q_c)^2$	$(Q_o-Q_m)^2$
1	57.00	19.77	65.88	0.03	131.55	15.25	4.52	20.45	35.76
2	11.00	5.84				0.36	5.48	30.04	63.20
3	57.00	25.04				15.25	9.79	95.90	126.56
4	129.40	55.46				61.24	-5.77	33.38	1736.38
5	35.00	4.75				5.93	-1.18	1.39	81.72
6	19.00	7.28				1.55	5.73	32.88	42.38
7	13.00	5.02				0.58	4.43	19.68	76.91
8	20.50	4.06				1.85	2.20	4.88	94.67
9	7.30	2.97				0.08	2.88	8.33	117.07
10	11.50	2.82				0.41	2.40	5.80	120.34
11	17.2	5				1.21	3.78	14.34	77.26
12	117.8	53.77				52.82	0.94	0.90	1598.40
13	29.6	19.45				4.19	15.26	232.98	32.03
14	29	19.43				4.01	15.42	237.83	31.80
15	17.2	5.7				1.21	4.48	20.13	65.44
16	15.6	3.66				0.95	2.71	7.35	102.61
17	43.7	6.19				9.23	-3.03	9.21	57.76
18	22.2	2.05				2.22	-0.17	0.03	137.82
	Sum	248.26				Sum	69.87	775.50	4598.11
	Mean	13.79				NSE	83%		
						RMSE	8.81		
						PBIAS	28%		

APPENDIX G

RUNOFF CALCULATION

Table G1: Computation of Runoff (Q_{comp}) using modified (MS 2002) SCS-CN model

Date	Rain-fall (P) (mm)	P5 (mm)	AMC	Q Computed (Modified SCS-CN) $Q = \frac{(P - Ia)(P - Ia + M)}{(P - Ia + S + M)}$								
				Maize			Finger Millet			Fallow land		
				8%	12%	16%	8%	12%	16%	8%	12%	16%
03- Jul-18	57.00	46.50	AMC II	14.38	14.70	16.04	8.53	9.35	9.21	31.36	20.90	21.47
04- Jul-18	11.00	95.00	AMC III	1.41	2.00	2.34	0.00	0.37	0.59	5.80	3.68	4.05
27- Jul-18	57.00	3.40	AMC I	1.58	1.95	1.99	0.00	0.00	0.00	15.37	5.49	5.22
28- Jul-18	129.40	35.00	AMC I	29.50	29.98	30.93	16.55	17.94	17.77	68.88	42.97	43.97
29- Jul-18	35.00	189.80	AMC III	15.83	16.67	17.91	11.40	12.85	13.01	26.09	21.00	22.43
01- Aug 18	19.00	221.40	AMC III	3.98	4.52	5.25	1.95	2.52	2.73	10.58	6.98	7.99
05-Aug-18	13.00	24.40	AMC I	2.27	2.09	1.88	5.67	5.26	5.08	0.00	0.41	0.29
06-Aug-18	20.50	37.40	AMC II	0.28	0.51	0.75	0.00	0.00	0.00	5.97	2.00	2.42
12-Aug-18	7.30	10.00	AMC I	3.43	2.64	2.98	7.08	6.82	5.68	0.00	0.00	0.74
25-Aug-18	11.50	2.50	AMC I	2.52	2.43	2.44	5.59	5.73	5.53	0.00	0.07	0.65
26-Aug-18	17.20	14.00	AMC I	0.65	0.59	0.14	2.81	2.87	2.49	0.00	0.00	0.00
31-Aug-18	117.80	40.00	AMC II	55.18	56.58	59.77	42.98	44.12	45.70	85.60	69.03	70.65
02-Sep-18	29.60	122.60	AMC III	11.48	12.63	14.72	8.39	8.91	9.74	20.49	16.78	18.40
03-Sep-18	29.00	152.20	AMC III	11.81	12.18	14.04	8.29	8.99	9.74	19.98	16.11	17.17
07-Sep-18	17.20	58.60	AMC III	4.04	4.54	5.37	1.96	2.52	2.97	9.78	7.08	8.19
23-Sep-18	15.60	0.00	AMC I	2.91	2.07	2.11	5.92	5.92	5.28	0.00	0.69	0.75
24-Sep-18	43.70	15.60	AMC I	0.00	0.11	0.24	0.00	0.00	0.00	8.47	1.75	1.98
25-Sep-18	22.20	59.30	AMC III	6.94	8.36	9.23	4.39	4.93	5.83	14.59	10.81	11.93

Table G2: Computation of Runoff (Qc) using Existing SCS-CN model

Date	Rain-fall (P) (mm)	P5 (mm)	AMC	Q calculated (Existing SCS-CN) $Q = \frac{(P-Ia)^2}{(P-Ia+S)}$								
				Maize			Finger Millet			Fallow land		
				8%	12%	16%	8%	12%	16%	8%	12%	16%
03-Jul-18	57.00	46.50	AMC II	10.94	11.96	12.99	5.75	6.40	7.06	28.02	17.23	18.62
04-Jul-18	11.00	95.00	AMC III	0.24	0.44	0.70	0.00	0.01	0.07	2.89	1.18	1.71
27-Jul-18	57.00	3.40	AMC I	0.75	0.94	1.16	0.00	0.00	0.00	11.81	3.31	3.74
28-Jul-18	129.40	35.00	AMC I	24.05	25.36	26.67	12.58	13.46	14.35	61.66	36.60	38.24
29-Jul-18	35.00	189.80	AMC III	11.20	12.65	14.21	7.27	8.27	9.31	22.09	16.46	18.48
01-Aug-18	19.00	221.40	AMC III	2.51	3.16	3.90	1.01	1.35	1.73	8.46	5.08	6.21
05-Aug-18	13.00	24.40	AMC I	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
06-Aug-18	20.50	37.40	AMC II	0.02	0.07	0.15	0.00	0.00	0.00	3.30	0.68	0.92
12-Aug-18	7.30	10.00	AMC I	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25-Aug-18	11.50	2.50	AMC I	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
26-Aug-18	17.20	14.00	AMC I	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
31-Aug-18	117.80	40.00	AMC II	50.57	52.86	55.10	37.37	39.20	41.00	82.10	63.68	66.30
02-Sep-18	29.60	122.60	AMC III	7.84	9.04	10.35	4.68	5.47	6.30	17.29	12.28	14.05
03-Sep-18	29.00	152.20	AMC III	7.49	8.66	9.94	4.42	5.18	5.99	16.76	11.84	13.57
07-Sep-18	17.20	58.60	AMC III	1.83	2.38	3.02	0.62	0.89	1.19	7.09	4.04	5.05
23-Sep-18	15.60	0.00	AMC I	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24-Sep-18	43.70	15.60	AMC I	0.00	0.00	0.03	0.00	0.00	0.00	5.72	0.76	0.96
25-Sep-18	22.20	59.30	AMC III	3.90	4.72	5.65	1.88	2.36	2.88	11.01	7.07	8.42