MODELLING OF SURFACE RUNOFF AND SEDIMENT YIELD IN NUMU FARM CENTRE, BOSSO, NIGER STATE, NIGERIA.

BY

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(MENG/SEET/2001/0790)

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MAY, 2005

DECLARATION

I, IBRAHIM HASSANA, hereby declare that this project is an original work of mine, and has never been presented elsewhere for the award of any degree. Information derived from published work has been duly acknowledged in the references.

______________________ ______________________

Ibrahim Hassana Date

CERTIFICATION

This thesis titled "Modelling Surface Runoff and Sediment Yield in Numu Farm Centre, Bosso, Niger State, Nigeria by Ibrahim Hassana (M.ENG/SEET/2001/790) meets the regulations governing the award of the Degree of Masters in Engineering (M.ENG) of the Federal University of Technology, Minna and is approved for its contribution to scientific knowledge and literary presentation.

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DEDICATION

This project is dedicated to my family.

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ABSTRACT

The aim of this project was to develop mathematical model for predicting the quantity of soil eroded from land during natural rainfall runoff event. Numu Farm Centre, Minna, Niger State was used as the erosion test site. Three replicates of Natural–cover and Bare-treatment plots were used. Runoff and sediment yield were analyzed for the storm events. The highest runoff and sediment yield were observed from the Bare–treatment plot in the month of August, 2003. The soil eroded was approximately eight times higher than that from the month of May which had the least sediment yield. A 2 by 3 (2^3) Factorial Experimental design was used to develop a mathematical model relating sediment yield ($\hat{y}$) to temperature (x_1), rainfall intensity (x_2) and runoff depths (x_3). The developed predictive equation is given as $\hat{y} = 0.4685 + 0.2202x_1 - 0.0691x_3 + 0.3898x_{23} + 0.2130x_{123}$. Statistical analyses were carried out using software Statigraph and Mathcard 2000 Professional on the generated results and the regression coefficient was found to be equal to 0.96. This equation, therefore may be useful in predicting soil loss in an adjacent (or other) watershed of interest in the same physiographic zones.

TABLE OF CONTENTS

	Page
Title	i
Declaration	ii
Certification	iii
Dedication	iv
Acknowledgement	v
Abstract	vii
Table of Contents	viii
List of Tables	xi
List of Figures	xii
List of Plates	xiii
List of Abbreviations	xiv
CHAPTER ONE: INTRODUCTION	
1.1 Background Study	1
1.2 Problem Definition	1
1.3 Project Objectives	2
1.4 Justification	2
1.5 Scope of the Study	3
CHAPTER TWO: LITERATURE REVIEW	
2.1 Surface Runoff	4
2.2 Sediment Yield	5
2.2.1 Sediment Delivery Ratio (SDR)	7
2.2.2 Sediment Enrichment Rati (SER)	8
2.3The Evolution of Soil Loss Estimation Prediction	9
2.4. The Universal Soil Loss Equation	12

	Page
2.4.1 Modification of USLE and Sediment Yield Predictive Equations	14
2.5 The Revised Universal Soil Loss Equation (RUSLE)	15
2.5.1 The RUSLE Model	15
2.5.2 Application of RUSLE	18
2.6 Sedimentation in Storage Reservoirs	20
2.6.1 Estimation of Sediment Yield	22
2.6.2 Reducing Sediment in Reservoir	25
2.7.3 Sediment Exclusion Measures	26
2.8 Other Studies on Erosion Control Practices	27
CHAPTER THREE: MATERIALS AND METHOD	
3.1 Description of the Study Area	29
3.1.1 Soils	29
3.1.2 Vegetation	29
3.2 The Experimental Design	30
3.3 Experimental Procedure	31
3.3.1 Determination of soil properties of the study area	31
3.3.2 Rain gauge Installation and measurement of Rainfall depth	32
3.3.3 Runoff collection system set up and Runoff depth measurement	33
3.3.4 Sediment Yield Determination	34
3.3.5 Piezometer Installation and Measurement of Depth to Water Table	34
3.3.6 Full Factorial Experimental design	38
CHAPTER FOUR: RESULTS AND DISCUSSION	
4.1 Soil Analysis	36
4.2 Vegetation	36
4.3 Rainfall depth	37

	Page
4.4 Runoff	39
4.5 Drainage	41
4.6 Sediment Yield	41
4.7 Sediment Size Characteristics	44
4.8 Regression Model	49
4.8.1 Statistical Analysis of data	49
4.8.2 Statistical Analysis and Model Stimulation	50
4.8.3 Confidence Interval	52
4.8.4 Determination of Model Adequacy	54
4.8.5 Diagnostic Checking	56
4.8.6 Interpretation of the model	58
4.9 Correlation Coefficient, R^2	60
CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS	
5.1 Conclusions	64
5.2 Recommendations	65
REFERENCES	66
APPENDICES	

LIST OF TABLES

Table Page

2.1: Sediment Yield Data From Reservoir Surveys 23

2.2: LOIS Results on Sediment Yield 23

2.3: Average Annual Area – Specific Capacity Loss and Sediment Yield rates for Reservoirs in Britain 26

2.4: Environmental Aspect of Sediment removal from reservoir 26

3.1: Annual Rainfall Amount (mm) of Experimental Site 30

3.2: 2003 Monthly Temp, Evaporation and Relative humidity for Bosso Area 30

3.3: Sediment Yield and Runoff Depths at 10-days interval 38

4.1: Soil Profile showing textural composition and bulk density of Study Area 39

4.2: Rainfall characteristic and Corresponding Sediment Yield 40

4.3: Correlation Matrix 43

4.4: Cumulative Rainfall amount, duration, intensity, runoff rates, Drainage and sediment yield April – October for the period of 2003 44

4.5: Experimental Data Table for a 2^3 full factorial experiment 48

4.6: Summary of Estimated effects, confidence interval and t-value 54

4.7: Analysis of variance table for replicated 2^3 factorial experiment 56

4.8: The Observed values (y_u), fitted values ($\hat{y}_u$), Residuals (e_u) and squares of residual (e_u^2) 57

LIST OF FIGURES

Figure	Page
2.1: A general flowchart of RUSLE Software for soil loss Estimation	17
3.1: Typical Non-Recording gauge	32
3.2: Field set-up for runoff measurement	33
3.3: Hand driven Auger used to drill out well	35
3.4: Cross section of pipe in well	35
4.1: Runoff Rate for grass and bare surface condition	37
4.2: Sediment yield for grass and bare surface condition	37
4.3: Effects of rainfall on study area – Numu Farm – Niger State	38
4.4: Scattergram illustrating the relationship between Runoff depth (Natural cover) and Rainfall depth	40
4.5: Runoff Amount for grass and bare surface condition	41
4.6: Scattergram illustrating the relationship between sediment yield (Natural cover) and Runoff depth (Natural cover)	47
4.7: Scattergram illustrating the relationship between sediment yield Natural cover and Rainfall depth	48
4.8: Scattergram illustrating the relationship between sediment yield (Bareplot) and Runoff depth (Bare plot)	48
4.9: Scattergram illustrating the relationship between Runoff depth (Bare plot) and Rainfall depth	49
4.10: Scattergram illustrating the relationship between sediment yield (Bare plot) and Rainfall depth	49

LIST OF PLATES

Plate	Page
1: Runoff Collection System set – up for Natural-cover plot	34
2: Runoff Collection System Set –up for Bare – treatment plot	34
3: Bare – treatment plot showing the spout where discharged run off is funneled into the tank.	35
4: The Vegetation had tripped towards the end of the growing season	35

LIST OF ABBREVIATIONS AND NOTATIONS

LOIS:	Land – Ocean Interaction Study
USLE:	Universal Soil Loss Equation
RUSLE:	Revised Universal Soil Loss Equation
USDA:	United State Department of Agriculture
US-EPA:	United State – Environmental Protection Agency
FAO:	Food and Agriculture Organisation
X:	Height of water in the well
Y:	Depth of Pipe the ground surface
Z:	Depth of water below the ground surface
S_{AV}:	Average Sediment Yield
R_{AV}:	Average Runoff Depth
$\hat{y}$:	Sediment Yield
x_0:	Constant
x_1:	Temperature, 0_C (main effect)
x_2:	Rainfall Intensity, mm/hr
x_3:	Rainfall Depth, mm
x_{23}:	Rainfall Intensity – Runoff depth (two factor interaction)
x_{123}:	Temperature – Rainfall Intensity – Runoff depth (three factor interaction)

CHAPTER ONE

INTRODUCTION

1.1 Background

Erosion is one of the most important agricultural problems in the World. It is a primary source of sediment that pollutes streams and fills reservoirs. Erosion is the process of detachment and transportation of soil particles by natural process such as wind and water (Schwab et al., 1993). Soil loss is the soil moved off a particular slope or the field, while sediment yield is the soil delivered to a point under evaluation (Mitchell and Bubenzer, 1980).

Erosion by water and sediment yield has become a tremendous problem since the beginning of cultural practices and it has an adverse effect on agricultural productivity and on the environment. Eroded sediment can carry nutrients, particularly phosphates, to waterways, and contribute to eutrophication of lakes and streams; adsorbed pesticides are also carried with eroded sediments, adversely affecting surface water quality (FAO, 1996).

1.2 Problem Definition

Soil erosion problems have been widely reported in various parts of Nigeria. The Federal and State Governments have spent millions of Naira to combat erosion and associated problems. There is need therefore for a mathematical model that can estimate how much erosion might occur at a location and what land management can be used to try and control soil loss where necessary.

Thus, this project will be a step towards the developing of a surface runoff-sediment yield model for environmental conditions found in the guinea savannah zone of Nigeria.

1.3 **Project Objectives**

The objectives of the work reported herein are:

(i) Developing mathematical model of sedimentation load that would predict soil loss under the environmental conditions found in the moist guinea savannah zone of Nigeria.

(ii) Investigating the relationship between:

- Rainfall amount and Sediment yield.
- Rainfall amount and Runoff depth
- Sediment yield and Runoff depth at Numu Agricultural field, (Bosso Local Government Area) Niger State.

(iii) And also to observe the impact of Rainfall – Runoff on sediment yield.

1.4 **Justification**

There has been a growing need to study, understand and quantify the impact of major land use changes on hydrologic regime, both water quantity and quality. This is necessary to anticipate and minimize potential environmental detriment and satisfy water resources requirement.

Many advantages can be derived from this project, which aims at providing a better understanding of the relationship between surface runoff and sediment yield of a farmland in the Guinea Savannah zone of Nigeria.

This would also reduce to a barest minimum the cost expended in combating the problems of surface runoff and sediment yield since a better understanding of the parameter affecting soil erosion will provide better management techniques / methods to tackle the problems. In addition recent environmental concerns require that soil loss and sediment predictions be made to evaluate the extent of non-point pollution sources.

Mathematical modelling of surface runoff and sediment yield models will be useful tools of hydrologic investigation system for both research hydrologists and soil and water engineers involved in the planning and development of integrated approach for management of land and water resources.

1.5 Scope of the Study

This study will focus on:

(i) Soil erosion by water

(ii) The impact of rainfall – runoff on sediment yield using natural cover (vegetative surface) and bare treatment plots.

(iii) One rainfall season and

(iv) Numu Farm Centre, Bosso, Niger State as the research site.

CHAPTER TWO

LITERATURE REVIEW

2.1 Surface Runoff

The term runoff usually means surface flow (Schwab et al.,1993) or overland flow (Briggs and Courtney, 1991). For runoff to occur precipitation must satisfy the demands of evaporation, interception, infiltration, surface storage, surface detension and channel detension (Schwab, et al.,1993). Runoff therefore means the drainage or flowing off of precipitation from a catchment area through a surface channel after satisfying all surface and subsurface losses (Kulkarni et al. 2004).

Soil erosion by water results from the surface runoff of rainfall in excess of the amount that the soil can absorb. Obviously where runoff occurs part of the rainfall fails to infiltrate into the soil where it can be stored in the profile for use by plants, or may gradually drain away to maintain the perennial flow of streams or accumulate in subsurface aquifers (Webster and Wilson, 1980).

As erosion and runoff increases, a progressive process of desertification sets in, streams and wells become dry for long periods, the water table lowered, for want of water, the vegetation becomes sparser or changes its course and semi-desert conditions are eventually reached. The floodwater of streams resulting from excessive runoff may cause damage to water supplies, communications and property over a considerable distance. Dams and reservoirs built to conserve water, or to operate hydroelectric schemes, may be silted up. The deposition of silt in rivers and harbours may impede navigation. Scouring and undercutting of riverbanks may destroy good agricultural land or property, rivers may jump their banks and change their courses and floods may damage crops, buildings or wash away sections of road and railway embankments.

The methods of land use, or agronomic and mechanical measures suitable for the control of water erosion, aim principally at reducing runoff by increasing the proportion of the rainfall percolating into the soil and are consequently beneficial in conserving water (Webster and Wilson, 1980).

Runoff rate is highly important for the planning of municipal and industrial water supply, flood control, stream flow forecasting, reservoir design, navigation, irrigation and drainage (Kulkarni et al. 2004).

2.2 **Sediment Yield**

Sediment yield, usually expressed as tonnes per unit area of the basin per year, is the amount of sediment measured at some point in the basin divided by the basin area (FAO, 1996). It is always less than the total erosion due to sediment storage during transport (Mitchell and Bubenzer,1980), and is highly variable because of measurement difficulty, the temporal variability of hydrological processes, and changes in land management practices in the basin from one year to the next.

The major consequences of erosion of land surfaces by water is that it can destroy the productivity of the land from which sediment originates and the sediment becomes a problem in the area in which it is deposited. These depositions of sediment reduce water reservoir capacities, clog navigational channels or seaports and hinder other water supply requirements (Webster and Wilson, 1980).

For soil erosion to be controlled, tools are needed to estimate how much erosion might occur at a location and what land management can be used to try and control soil loss where necessary. Since it is very often impractical or impossible to directly measure soil loss on every piece of land, the tools used are usually mathematical equations and / or computer simulation models (Laflen et al., 2004). In order to estimate sediment yield, there are general categories of procedures to consider; (1) predictive equations, (2) gross erosion and sediment delivery ratio computations, and (3) suspended sediment load or reservoir, sediment deposition measurements.

Sediment yield predictions are empirical because as one continues to follow the erosion process to deposition or sediment yields only few verified theoretical relationships are available to describe soil loss. The watershed variables often used in predictive equations are amount or intensity of rainfall, amount or peak rate of runoff, temperature, drainage area size, slope or relief parameter, soil descriptions and land use descriptions. Additionally, several geologic and time parameters are found in some equations. Onstad et al. (1976) and Williams (1975) modified the erosivity term of the Universal Soil Loss Equation (USLE) by using volume and peak rate of runoff.

Estimates of sediment yield have important economic consequences. In many developing countries the database with which to estimate reservoir life is very limited. According to White (1988) examples of predicted sediment yield in Asia tend to be between two to sixteen times lower than actual measured rates, with the consequence that actual reservoir life is greatly reduced. This arises partly from the use of unreliable prediction techniques and the use of short-term data, which usually fail to account for occasional but severe episodes of erosion such as major storm events and from increased land pressure after construction of the reservoir.

2.2 **Sediment Delivery Ratio (SDR)**

Sediment delivery ratio is commonly used in erosion and transport studies to describe the extent to which eroded soil (sediment) is stored within the basin. The SDR is defined as:

$SDR = S_m/G_{eb}$ ---2.1

where S_m = measured sediment yield

G_{eb} = gross erosion in the basin

Where yield is determined from reservoir sedimentation or from sediment monitoring station, and gross erosion is estimated using estimation techniques such as the Universal Soil Loss Equation. The SDR is always less than 1.0 indicating that the soil which is eroded at the field level tends not to travel far before it is deposited (FAO, 1996). Indeed, sediment storage in rills on fields, at field margins and at the foot of slopes is large. Storage also occurs in river channels (bed and overbank deposition), in wetlands, and in reservoirs and lakes. The SDR is highly variable, however, the concept is one of the most important in the understanding of erosion and sedimentation processes and how these operate in time and space (Walling, 1983).

Sediment yield is obtained by multiplying the gross erosion by the delivery ratio. Sediment delivery ratio equations have been developed from studies of watersheds in particular regions. As with predictive equations, most sediment delivery ratio equations have limited regional applicability. The sediment delivery ratio is dependent upon drainage area size and watershed characteristics as described by relief and stream length (Mitchell and Bubenzer, 1980). Sediment delivery ratio is also influenced by the sediment source and its proximity to the stream, the transport system, and the texture of the eroded material (Renfro, 1975). The gross erosion and sediment delivery ratio computation method of sediment yield estimation is in some respects similar to the predictive equation method. The similarity is most evident in the case of the modified Universal Soil Loss Equation (USLE) and for other watershed parameter equations that include gross erosion.

2.2.2 **Sediment Enrichment Ratio (SER)**

The concept of the sediment enrichment ratio (SER) is quite important in understanding the impact and economic cost of chemical loss from fields. The process of surface erosion tends to be selective towards fine particles. Consequently, the particle size characteristics of material eroded at source (at the plot level) are progressively changed towards finer particles through deposition of the coarser fraction such as sand–size material. The chemically enriched clay-size sediment are associated with sediment with concentration of chemicals such as phosphorous, metals, organic nitrogen, hydrophobic pesticides which increases as the impoverished sand-size fraction is lost during down–field transport resulting in an increasing proportion of the chemically enriched fine (silt-clay) fraction.

The Sediment Enrichment Ratio (SER) is defined as:

$$SER = [X]_{TS} / [X]_S \qquad \text{--} \; 2.2$$

where:

$[X]_{TS}$ = concentration of chemical "X" in transport sediment and

$[X]_S$ = Concentration of the chemical "X" in the soil

Sediment chemistry is measured at some point down slope, for example at the edge of a field or in adjacent streams.

The importance of the sediment enrichment ratio lies in the fact that there is proportionally more fine-grained sediment transported than coarse-grained sediment during surface erosion. Therefore, the sediment being transported has a finer texture than the source material. Soil nutrients have greater affinity for nutrients for finer sediments, this proportionally larger loss of fine materials means that there is net impoverishment of the soil which may never be replaced by the addition of fertilizers. The cost to the farmer is therefore twofold; loss of productivity due to loss of natural nutrition in the soil; and economic cost of fertilizer which is added in the attempt to compensate for this loss.

2.3 The Evolution of Soil Loss Estimation Prediction

Soil conservationist and agriculturalists World – wide have spent much time and resources attempting to find reliable methods of predicting erosion and sediment – associated chemical (fertilizer / pesticides) runoff under different conditions of crop type, tillage practices and so on. Consequently, there are a large number of models that have been developed for the prediction of agricultural non-point source, runoff of sediment, nutrients and pesticides. Many of the models permit using alternative choices of land management, crop type, fertilizer and pesticide application rates.

The evolution began as far back as in the nineteenth century. Wollny was thought to have carried out the first scientific study of erosion effects (Hudson, 1971). The forest service in 1915 in America began the first quantitative experiment. Miller in 1917 began a plot study of the effect of crops and rotations on runoff and erosion. (Mitchell and Bubenzer, 1980) in the 1920s, and early 1930s there was an increase in scientific erosion research because of the wide spread concern of the dangers of soil erosion. The results of this early work were of necessity, qualitative in nature. However, a basic understanding of the factors affecting erosion was developed during that year (Ayres, 1936). The importance of raindrop impact in the erosion process was not fully appreciated until the natural rainfall studies of Laws (1940) and the analysis of the mechanical action of raindrops by Ellison (1947). Several Scientists began to develop empirical equations for soil erosion prediction as data were accumulated and exchanged.

Zingg (1940) was the first to relate soil loss to steepness and length of slope. Zingg used plots under simulated rainfall and field conditions to demonstrate the effects of doubling the degree of slope and horizontal slope length, this resulted into an increased soil loss of 2.61 to 2.80 times as well as 3.09times in runoff. The relationship was expressed as:

$$A = CS^m L^{n-1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.3$$

where, A = average soil loss per unit area of land slope of unit width (t/ha/yr)

C = a constant of variation

S = degree of slope, percent

L = horizontal slope length, m

m, n = exponents of degree and horizontal length of land slope, m and n are 1.4 and 1.6 respectively.

Musgrave (1947) introduced the relationship of rainfall characteristics to the amount of soil eroded and the equation proposed was;

$$E = (0.00527)\, IRS^{1.35} L^{0.35} P_{30}^{1.175} \text{-----------------------------------} 2.4$$

where R = the soil loss, mm per year

I = the inherent erodibility of soil at 10percent slope

S = degree of slope, percent

L = Length of slope, metres and

P_{30}= maximum 30 – minute rainfall, mm

Equation 2.4 was used extensively for estimating gross erosion from watersheds.

A disadvantage of this Zingg's steepness of slope evaluation was that the soil loss from slopes less than four percent was under predicted and zero soil loss was computed for zero percent slope.

Smith and Whitt (1948) proposed an equation of the form:

$$A = a + bS^m \text{---} 2.5$$

Using the effects of slope steepness, length of slope, crop rotations, conservation practices, and soil groups, Smith and Whitt (1947) also presented a method of estimating soil loss for the clay pan of Missouri. The equation presented was:

$$A = CSLKP \text{ ---2.6}$$

where, A = the average annual soil loss, mm per year

C = the average annual rotation soil loss from plots, and

S, L, K and P = are multipliers to adjust the plot soil loss C for slope steepness, length, soil group and supporting conservation practice respectively.

It is interesting to note that Eq. 2.6 is similar in form to the Universal Soil Loss Equation introduced eleven years later, however, the equation did not have a separate rainfall factor.

In order to overcome many of the disadvantages inherent in local or regionalized research projects, soil erosion prediction research was consolidated in a co-operative effort in 1954. This led to the compilation of more than 8000 plot-years of erosion research data from 36 locations in 21 States of America. A re-evaluation of the various factors affecting soil loss (Smith and Wischmeier, 1957) was made which led to development of the widely used soil loss prediction method called the Universal Soil Loss Equation (USLE).

Hudson (1961) concurrently presented an erosion equation, which is identical in concept to the Universal Soil Loss Equation, he reported an extensive research on the erosivity of rainfall in the sub-tropic of Africa. Hudson's equation is presented as:

$$E = TSLPMR \text{ ---2.7}$$

Where E = erosion and the remaining factors are functions of soil type, slope gradient, and length, agronomic or agricultural practice, mechanical protection and rainfall amount respectively.

Elwell (1978) developed a Soil Loss Estimation System for Southern Africa. He argued that the USLE was not suitable for Southern Africa (McKyes, 1989). His equation is presented as:

$$Z = KCX \quad \text{-----} \quad 2.8$$

where, Z = predicted mean annual soil loss (t/ha/yr)

K = mean annual soil loss, from a standard field plot 30m x 10m at 4.5 percent slope for a soil of known erodibility under bare fallow.

C = the ratio of soil loss from a cropped plot to that from standard plot and

X = the ratio of soil from a plot of length L and slope S to that lost from the standard plot.

The consolidation of data from many stations enabled researchers to develop prediction equations applicable to a given region or a number of regions. Each of the predictive technique was limited in its applicability by the limits of data from which it was developed. Hence, it is usually useful only for a local area, specific soil type, or perhaps a region. As more data sources became available, more conditions could be estimated and the area of applicability expanded.

2.4 The Universal Soil Loss Equation

The Universal Soil Loss Equation (USLE) is an empirical erosion equation developed by Smith and Wischmeier (1978) to estimate the average annual soil loss from an area (usually agricultural lands). The equation is based on plot data collected mainly from cropland areas in eastern United States. The Cropland rainfall simulation erosion research used relatively large plots, a standard plot tilled up-down slope, in fallow condition with 9% slope and standard sequences of rainfall input (Wischmeier and Mannering, 1969). It is the most widely used method of soil loss prediction by conservationists in the United States. It is also being adapted for soil loss estimation in other countries. The equation is given as:

$$A = (0.224)\ RKLSCP \qquad (2.9)$$

Where A = the soil loss, kg/m^{2}S

R = the rainfall erosivity factor

K = the soil erodibility factor

L = the slope length factor

S = the slope gradient, per cent

C = the cropping management factor, and

P = the erosion control practice factor.

The USLE was developed as a method to predict average annual soil loss from interill and rill erosion. With the parameter values available, cropping and management alternatives can be determined to reduce the estimated soil loss to suggested tolerance values for the soil types. The USLE may also be a useful research tool provided one is more precise in evaluating the equation factors than for conservation planning. The equation was developed to estimate long-term average annual soil loss. Therefore, its application to a specific year or storm may not be appropriate. When used with a specific storm it will estimate the average soil loss for numerous recurrences of that event and, as with any average, the soil loss from anyone of these events may vary considerably. Applying the equation to situations for which factor values are not yet determined is especially dangerous. Although expedient and often necessary for conservation planning purposes, extrapolation is always hazardous.

Foster and Wischmeier (1974), have identified USLE's short coming as (1) it lumps rill and interrill erosion together; (2) it does not account for deposition within the watershed and (3) it does not estimate soil loss from single storms.

2.4.1 Modification of USLE and Sediment Yield Predictive Equations

There are different modifications of the USLE and they have been suggested for several applications. Modifications to improve the estimation of R-values for a region, an effort to apply the USLE to sediment yield estimates from small watersheds by describing sediment yield as (Mitchell and Bubenzer, 1980).

$$A = (0.224)\,(RKLSCP)\,E_C \quad \text{------------ } 2.10$$

where, E_C = the channel erosion factor and the other terms previously designed.

Williams and Berndt (1977) modified the USLE for predicting yield from watersheds as:

$$Y = 11800\,(Qq_p)^{0.50}\,KCPLS \quad \text{------------ } 2.11$$

where Y = Sediment yield from an individual storm, kg

Q = storm runoff volume, m^3

q_p = peak runoff rate, m^3/sec and

KLSCP are defined in the USLE

Onstad et al (1976) used the modification of the USLE by Foster et al (1973), as the major component in sediment yield model for small watersheds, that is;

$$A = (0.224)\,WKCPSL \quad \text{------------ } 2.12$$

In which, W is a hydrologic term and the other terms are defined in the USLE and $W = aRSt + (1 - a)\,0.40Qq_p^{1/2}$

Where, Rst = storm rainfall factor

Q = runoff volume

Q_p = peak runoff rate, mm/hr and

a = coefficient (0□ a □1) that represent the relative importance of rainfall energy compared with runoff energy for detaching soil and a = 0.5.

All three modifications are preliminary and limited to regions where they are developed because limited data verification has been accomplished.

2.5 The Revised Universal Soil Loss Equation (RUSLE)

The Revised Universal Soil Loss Equation is a technology for estimating soil loss from most undisturbed lands experiencing overland flow, from lands under-going disturbance, or from newly or established reclaimed lands.

2.5.1 The RUSLE Model

RUSLE is a set of mathematical equations that estimate average annual soil loss and sediment yield resulting from interrill and rill erosion. It is derived from the theory of erosion processes of more than 10,000 plot – years of data from natural rainfall plots, and numerous rainfall-simulation plots. RUSLE is an exceptionally well-validated and documented equation. The strength of RUSLE is that it was developed by a group of nationally recognised scientists and soil conservationists who had considerable experience with erosional processes (Soil and Water Conservation Society, 1993).

RUSLE retains the structure of its predecessor, the Universal Soil Loss Equation (USLE) as given by Wischmeier and Smith (1978) namely:

$$A = RKLSCP$$

Where, A = Rainfall / runoff erosivity

K = soil erodibility

LS = Hillslope length and steepness

C = cover management

P = support practice.

The R factor is an expression of the erosivity of rainfall and runoff at a particular location. The value of "R" increases as the amount and intensity of rainfall increases. Figure 2.1 shows a general flowchart of the RUSLE software.

The K factor is an expression of the inherent erodibility of the soil or surface material at a particular site under standard experimental conditions. The value of "K" is a function of the particle size distribution, organic matter content, structure and permeability of the soil or surface material. For undisturbed soils, values of "K" are often available from soil surveys conducted by the Natural Resources Conservation Society (NRCS). For disturbed soils, the nomograph equations embedded within the RUSLE programme are used to compute appropriate erodibility values.

The LS factor is an expression of the effect of topography, especially hillslope length and steepness, rates of soil loss at a particular site. The value of "LS" increase as hillslope length and steepness increases, under the assumption that runoff accumulates and accelerates in the downslope direction. This assumption is usually valid for lands experiencing overland flow but may not be valid for forest and other densely vegetated areas.

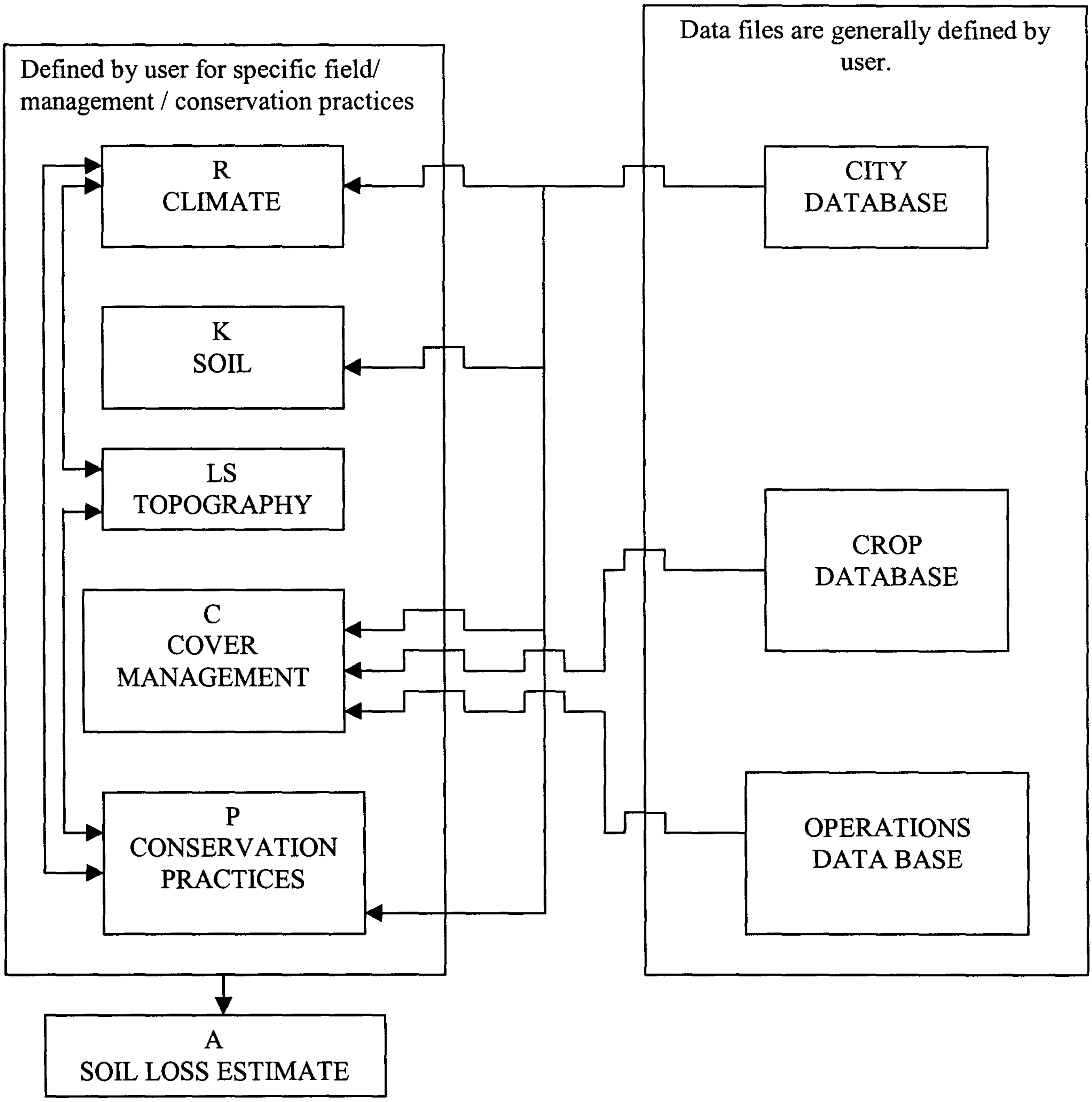

Figure 2.1: A general Flowchart of the RUSLE Software for Soil Loss Estimation

The C factor is an expression of the effects of surface covers and roughness, soil biomass, and soil disturbing activities as rates of soil loss at a particular site. The value of "C" decreases as surface cover and biomass increase, thus protecting the soil from rain splash and runoff. The RUSLE programme uses a sub-factor method to compute the value of "C". The subfactors that influence "C" change through time resulting in concomitant changes in soil protection. For user convenience, a vegetation database file is contained within the computer programme that characterizes numerous plant types. In some cases, the plants used for reclamation may be included in these files. In other cases, files may be customized to include the desired plants and plant combinations. Likewise, the files include other types of surface treatments such as temporary covers for erosion control.

The P factor is an expression of the effects of supporting conservation practices, such as contouring, buffer strips of close-growing vegetation and terracing on soil loss of a particular site. The value of "P" decreases with the installation of these practices because they reduce runoff volume and velocity and encourage the deposition of sediment on the hill slope surface. The effectiveness of certain erosion –control practices varies substantially due to local conditions. For example, contouring is far more effective in low rainfall areas than in high –rainfall areas.

The Revised Universal Soil Loss Equation (RUSLE) is a tool to estimate the rate of soil loss based on site–specific environmental conditions and a guide for the selection and design of sediment and erosion control systems for a site. The RUSLE does not determine when soil loss is excessive at a site or when erosion control systems have failed. The RUSLE user makes decisions based upon numerous criteria, of which soil loss and sediment yield estimates are important components.

2.5.2 **Application of RUSLE**

Numerous erosion-control and reclamation activities are integral parts of a thoroughly planned design that collectively contribute to the reduction of soil loss, but are not accounted for in the Original Universal Soil Loss Equation (USLE). For years, erosion – control and reclamation specialists have encouraged concurrent reclamation, leaving the soil/spoil surface in a roughened state, using mulch of a temporary cover crop, contouring, and terracing, and establishing sustainable vegetation. These erosion – control measures have become standard operating procedures on many mined lands and construction sites resulting in long-term stabilized areas, reduced sediment basin clean-out costs, and reduced potential off-site impacts. With the RUSLE the benefits of these and other erosion-control measures can be estimated and alternative reclamation plans can be readily compared. Other advantages of using the RUSLE include: (1) assessment of alternative hillslope configurations (convex, uniform, concave and complex), (2) obtaining erosion-control or erosion –reduction credit for the surface rock fragment covers that exists on many mine sites, and (3) analyses of the effects of straw mulch, random roughness, soil consolidation, sediment deposition, and changes through time due to mulch decomposition and deterioration of surface roughness due to rainfall.

Soil loss can be estimated with respect to the influence of plant growth, canopy development, residue cover, and below–ground root development as a function of time and geographical region. Decreases in random roughness through time, which decrease the resistance of disturbed soils to erosion, and increases in soil consolidation through time, which increase the resistance of disturbed soils to erosion, can be estimated using the RUSLE programme.

The RUSLE is a powerful programme that is capable of predicting soil loss from fields or hillslopes that have been subjected to a full spectrum of land manipulation and reclamation activities. In addition, the RUSLE can accommodate undisturbed soil, spoil and soil–substitute (growth medium) material, percent rock cover, random surface roughness, mulches, vegetation types, and mechanical equipment effects on soil roughness, hillslope shape, and surface manipulation including contour furrows, terraces, and strips of close – growing vegetation and buffers.

2.6 Sedimentation in Storage Reservoirs

Sediment yield can be considered as the portion of the gross erosion within a catchment area that is not deposited before being transported from the area. Given that erosion is a two stage process comprising both detachment and the transport of material (by water or wind) two distinct conditions can be recognised (Morgan, 1995):

(i) Supply limited conditions whereby less material is detached than can be transported.

(ii) Transport limited conditions whereby more material is available than can be transported.

The behaviour of sediment in small reservoirs under dam failure conditions has been found to be strongly dependent on the rate of flow into the reservoir (Water, 2001). If the dam fails under "Sunny day" conditions when the flow into the reservoir is small, then only a small proportion of even the very low strength deposits found in small reservoirs can be expected to 'flow' with the escaping contents of the reservoir. If there is a large flow into the reservoir when a breach occurs then more sediment is entrained. It would be expected that more sediment would subsequently be suspended by the action of the stream, which may have environmental impacts on the river system but would not constitute part of the 'escapable contents' of the reservoir under dam failure conditions.

The sediment control measures includes residuum lodges (silt traps) and bypass channels, these are shown to be effective in prolonging the life of a reservoir although improvements to allow mechanical removal of the sediment may be required. Disposal of accumulated material may pose difficulties. A private company in pennine area of Britain has developed a potting compost that successfully utilizes the sediment collected in residuum lodges (Water, 2001).

For the future there are concerns that changes in the climate may increase sedimentation rates due to more intense rainfall and more frequent storms but this has not as yet become apparent from reservoir surveys. (Water, 2001).

The operational life of the reservoir is normally determined by the point in time at which sediment accumulations reduce the reservoir yield below supply requirements. This 'useful' life of a reservoir is often defined as the time taken for 90% of the live reservoir storage to be depleted, although in practice measures normally have to be taken well before this occurs to ensure reliability of supply. This is dependent not only on the magnitude and nature of the incoming sediment yield but also on any physical or operational measures that are in place to reduce the rate at which the remaining storage is depleted. Such measures might include upstream sediment traps (residuum lodges) and managed diversion of water around the reservoir by means of by-wash channels. For example, in Britain, many reservoirs which have surpassed their useful life have been supplemented by larger reservoirs downstream and then effectively act as gravel traps. However, even when the useful life has been reached, the reservoir will often continue to provide supplementary benefits such as recreational usage or wetland development. provided that such benefits outweigh the operational costs involved in maintaining the reservoir, the life of the reservoir can be extended at least until such time as the reservoir is completely filled with sediment. However, with the increasing problems associated with the location of suitable sites for replacement reservoirs, it is expected that reservoir owners will increasingly consider extending their life through the removal of sediment from reservoirs, for example by dredging (Mahmood, 1987).

As flow enters a newly-formed reservoir, the channel cross-sectional area increases and this is accompanied by a decrease in flow velocity and a dampening of water turbulence such that particles begin to deposit. The pattern of sediment distribution is dependent on many factors including the size and texture of the sediment particles, the physical characteristics of the reservoir and reservoir operation. Sedimentation patterns are such that the usable capacity starts to diminish before the entire non-usable component is filled with sediment. Generally, deposition commences with the coarser particles, creating a delta formation at the reservoir headwaters. These form the 'top set' bed and the point at which coarse sediments are deposited moves gradually towards the reservoir. Fine sediment particles are carried further into the reservoir and settle on the floor of the reservoir areas forming 'bottom set' beds.

2.6.1 Estimation of Sediment Yield

Mahmood (1987) gave the global average total sediment yield as 190t/km^2/yr. Walling (1987) gave 50t/km^2/yr as a typical value of suspended sediment yield for Britain and cities site specific yield measurements between land as 488t/km^2/yr. For Yorkshire's peat dominated upland reservoirs, White et al (1996) obtained an average yield of 124.5t/km^2/yr. In Austria, tropical figures for sediment loads are:

- Urban catchments in Sydney, 270 – 890 kg /ha/yr (Water, 1996).
- Rural catchments in NSW of Sydney, 5kg/ha/yr (Water, 1996).

It should be noted that these are average quantities. Actual values may deviate substantially from these. For urban catchments, runoff concentrations of suspended solids tend to range between 150 and 650mg/l.

Table 2.1: Sediment Yield Data from Reservoir Surveys.

REGION	SEDIMENT YIELD ($t/km^2/yr$)
America	1104
Africa	259
Asia	293

Source: White (1993)

Care is required in interpreting the data in Table 2.1, which are all higher than the global average values given by Mahmood (190t/km^2/yr). The data are dominated by reservoirs from North America, with very poor representation from other parts of the world. Many of the data consist of individual studies in reservoirs where a severe sedimentation problem has been identified and these sediment yield data may misrepresent the general situation for the region from which they originate.

Table 2.2 shows the results of the work with consideration of land use and sediment yield. Land – Ocean Interaction Study (LOIS) was launched by the Natural Environmental Research Council in 1992 and was completed in 1998. The analysis of reservoir and lake sediments carried out within the Land-Ocean Interaction study provided a significant new data set of significance to reservoir sedimentation (Foster and Lee, 1999). Table 2.3 shows a significant variation in both variables between reservoir age groupings and capacity loss.

Table 2.2: LOIS Results on Sediment Yield

Catchment Land use	*Reservoir*	*Trap Efficiency % calculated*	*Catchment Area (Km^2)*	*Reservoir Area (Km^2)*	*Sediment Yield ($t/km^2/yr$)*
Pasture	Silsden	91	8.15	0.1036	18
	Elleron lake	63	2.56	0.0299	8
Mixed	Newburgh Priory Pond	46	5.88	0/0396	52
Arable	Filling ham bike	87	2.90	0.0699	16
	Yetholm Loch	63	12.21	0.144	25

Forested	Bolt by Reservoir	83	3.25	0.0224	16
	Fontbum Reservoir	91	27.74	0.32	9
Moorland	Bames Loch	80	1.78	0.058	23
	March Ghyll	85	4.04	0.057	34

Source: Foster and Lee (1999)

Results of the work with consideration of land use and sediment yield (Table 2.2). LOIS is Land – Ocean Interaction study. It was launched by the Natural Environmental Research Council in 1992 and was completed in 1998. The analysis of reservoir and lake sediments carried out within the Land – Ocean Interaction Study (LOIS) studies was launched provided a significant new data set of significance to reservoir sedimentation (Foster and Lee, 1999). Table 2.3 shows a result of the work with consideration of land use and sediment yield.

Table 2.3 :Average annual Area-Specific Capacity Loss and Sediment Yield rates for Reservoirs in Britain

Age at survey	*Sediment*	*Yield*	*Capacity loss*	
	No. of cases	*(t/km²/yr)*	*No. of cases*	*(m²/km²/yr)*
< 50	5	442.2	6	391.1
50 – 75	12	76.9	16	161.5
75 – 100	27	139.4	29	174.9
100 – 125	33	65.3	34	138.5
>125	16	128.3	17	226.1

Source: Water (2001)

Significant variation in both variables between reservoir age groupings, and there is a general downward trend in yield/loss rate as older reservoirs are considered. This could suggest that actual sediment yield or sediment delivery is decreasing with time or that there is a decrease in the amount of sediment trapped by the reservoir.

The proportion of this sediment actually deposited with the reservoir must be amended using the calculated trapping efficiency and the percentage loss in volumetric capacity of a reservoir can then be calculated as follows (Water, 2001).

$$ANNPEC = \left(\frac{SY * CATCHMENT * TRAP}{MEANBD * (1000 * ORIGCAP)} \right) \text{-----------------------------------} 2.13$$

where,

ANNEPC = annual loss of capacity (% / year)

SY = Sediment yield to reservoir (t/km^2/year)

CATCHMENT = Catchment area (km^2)

MEANDBD = Mean dry bulk density of sediment (t/m^3)

ORIGCAP = Original reservoir capacity (ml)

And TRAP = Reservoir trapping efficiency (%).

TRAP may be determined from an empirical relationship and reservoir characteristics.

2.6.2 **Reducing Sediment in Reservoir**

The methods for reducing reservoir sediment can be divided into four main options:

(i) Minimise sediment loads entering reservoir

(ii) Minimise deposition of sediment within the reservoir basin

(iii) Remove previously accumulated sediment

(iv) Replace lost reservoir capacity.

Bruk (1985) summarised the views of an international panel of expert contributors and concluded that, in the long run, watershed management is the best way to reduce the yield of sediment and its entry into reservoir. For large basins, however, this many be a slow and prohibitively expensive process but protecting the existing regime to prevent deterioration is also important. The construction of auxillary check dams or silt traps may have a quicker effect but these will in turn be filled with sediment and so may not last long unless actively managed, which again increases the costs.

By- passing of sediment-laden flows is another effective method recommended for consideration in the design stages of any project, but these should be maintained.

Flood flushing and venting of turbid currents can prove to be an effective means of reducing deposition in reservoir but this depends on provision of suitable bottom outlets and an excess of water.

Removal of sediment deposits by dredging or excavation is a costly operation, which may be justified in certain circumstances by the economic value of the water and the impossibility of replacing lost reservoir capacity. Disposal of the excavated silt may also cause difficulties unless it can be used for the improvement of surrounding agricultural land.

2.7.3 **Sediment Exclusion Measures**

There are a range of options for exclusion of sediment from reservoirs, these includes (Water,2001)

(i) Setting Basins, Boulder and Gravel Traps, Settling Areas

(ii) Bypass channels with sediment excluding /splitting structures

(iii) Use of catch water channels.

(iv) Use of off stream Reservoirs.

Settling Basins, Boulder and Gravel Traps are known by a number of different titles such as 'silt pond' or 'residuum lodge' and in a number of cases, smaller upstream reservoir are left to act as silt traps to a larger downstream reservoir chain and no longer used for normal releases. The removal and disposal of sediment trapped may be problematic and more expensive than raising the main reservoir, where fine sediments are the main concern then to be effective, a large settling area may be needed for removal of the material a suitable bypass will be needed and access for sediment removal provided.

Table 2.4: Environmental aspect of sediment removal from reservoir

Category	*Examples of possible issues*
Removal of sediment	♦ Loss of habitat – dredging reservoirs, particularly at the shallow headwaters and reservoir margins can destroy habitat and affect wetland birds etc. ♦ Loss of land for containment areas to drain / treat sediment ♦ Possible reduction in downstream river water quality during dredging.
Transportation	♦ Reservoirs are often in remote areas – transportation on minor roads can place pressure on local communities (noise /air pollution and physical damage to road).
Disposal	♦ Contamination of groundwater by leaching ♦ Viability of disposal to land depends on level of contaminants.
Re – use	♦ Examples of re-use include sand/gravel/bricks for construction, industry and fertilizer. ♦ Can be used to fill in disused quarry areas or mines ♦ Can be used to cap landfill sites.

Source: Water (2001)

2.8 **Other Studies on Erosion Control Practices**

Benik et al., 2003 evaluated five different erosion control product using two years of natural rainfall events (1997 and 1998) on the slopes of a newly constructed highway sedimentation basin to determine their impact on vegetative growth, runoff and soil erosion. The five tested treatments were a wood fiber blanket, a straw/coconut blanket, straw blanket, a bonded–fiber matrix (hydraulically applied) and disk–anchored straw mulch. Three replicates of each treatment were used. The site was seeded with native prairie seeds and the establishment of vegetation was monitored over time.

For under consideration, the study showed that the straw mulch plots had the greatest biomass, and the bare treatment had the least. There was no difference among treatments after the second growing season. The highest runoff and sediment yields were observed from bare treatment. The soil erosion was approximately ten times greater than that from the straw-mulch plots. The blanket treatments had less erosion than straw-mulch plots. There was, however, little difference between blanket types.

Egharevba (2004) tested three erosion control practices under Tudun Fulani soil conditions during the 2001-cropping season under natural rainfall events. The three tested treatments were zero tillage with straw mulch, disc tillage with straw mulch and disc tillage without mulch. Three replicates of each treatment were used. The impact of these treatment / practices on surface runoff and sedimentation load were measured. Observed runoff depths and sediment yield varied substantially by storm and by erosion control treatment. The soil loss on the average was 33.6kg/ha/day, 27.5kg/ha/day and 194.2kg/ha/day for the zero tillage with straw mulch; disc tillage with straw mulch and disc tillage without mulch plots respectively. Predictive equations relating the sediment yield and rainfall amount as well as sediment and runoff depths for each treatment were developed, and it took a linear form.

Odofin et. al., (2001) also worked on three different types of erosion control practices with three replicates each to determine their effects on moisture condition and maize (zeamays) performance. Although these recent studies provide useful information, very limited field research has been done in the guinea savannah zone of Nigeria.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of the Study Area

The research site, Numu is located in Tudun Fulani, Bosso Local Government Area of Niger State in the Guinea Savannah Zone of Nigeria (latitude 9^0 41`N and Longitude $6^0$ 31`E) considering an area of about 0.3ha. The climate of Nigeria is characterized by distinct wet and dry seasons, the wet (rainy) season starts in April and ends in October with a maximum rainfall occurring in August. The annual rainfall of Minna range from 1,153 to 1,790mm (Table 3.1), the number of rain days varies from 2 to 25days from month to month. Mean monthly temperatures range from 28^0C in January to 26.0^0C in August with the maximum mean temperature being recorded in March and relative humidity highest in August but lowest in December (Table 3.2).

3.1.1 Soils

The soils are typical Durorthid (shallow, mixed thermic) loamy with randomly dispersed clay pockets and formed in a material weathered from limestone and quartz (Gelderman,1970). The soils are well drained with medium to rapid runoff, and have moderate permeability. It is classified as an Alfisol soil using the United State Department of Agriculture (USDA) classification with sandy loam texture at the surface (Odofin et. al, 2001).

3.1.2 Vegetation

The major vegetation at the experimental site includes: *Urena lobata* (Urena), *sida acuta* (Brown weed), *Indigofera hirsuta* (rough hairy indigo), *Panicum maximum* (Guinea grass), *corymbosa* (Freesia) *and Hyptis Suaveolens Poit* (pignut).

Table 3.1: Annual Rainfall Amount (mm) of Experimental Site

				Month						
Year	J – M	A	M	J	J	A	S	O	N-D	Total
2000	Nil	3.5	159.7	244.2	294.4	445.9	360.8	281.3	Nil	1,789.8
2001	Nil	94.6	152.0	305.7	433.0	248.6	148.7	31.4	Nil	1,414.0
2002	Nil	98.8	42.6	201.0	143.2	226.5	260.6	180.3	Nil	1,153.0
2003	Nil	17.4	114.6	405.6	123.0	416.20	345.9	192.4	Nil	1,390.5
Long term average (1960 – 1999)	160	56.9	135.7	163.3	214.3	272.9	244.7	107.1	4.0	1,214.8

Sources:(i)Metrological Station, Nigeria Airport Authority, Minna, Niger State 2000–2003 data
(ii) Odofin et al (2003)–long-term average

Table 3.2: 2003 Monthly Temperature, Evaporation and Relative humidity for Bosso Area.

Month	*Temperature (^0C)*	*Relative humidity*
January	28.10	36.0
February	31.10	39.0
March	32.50	36.0
April	31.40	63.0
May	30.60	67.0
June	26.85	81.0
July	26.25	85.0
August	26.00	87.0
September	25.95	82.0
October	27.50	77.0
November	28.35	46.0
December	27.25	27.0

Source: Metrological station, Nigeria Airport Authority Minna, Niger State

3.2 **The Experimental Design**

The erosion control treatment plots examined in this study was natural cover (close-growing grass and shrub vegetation) replicated three times and matched with bare plot condition (litter and rock fragments greater than 5mm removed). The natural cover was intended to determine vegetative effects on erosion and the bare plot served as the experimental control.

Each of the research plots had a natural uniform slope of approximately 3%. The lengths of the plots were set at 2.5m and the breadth (width) 2.0m.

The runoff collection systems and the piezometers were also installed. The rain gauge was installed at the upper part of the plot.

Full factorial design experiment was used for this study. It allowed for the investigation of the impact of surface runoff and sediment yield using natural rainfall event on natural cover and bare treatment plots.

3.3 **Experimental Procedure**

3.3.1 **Determination of soil properties of the study area.**

For soil depth of 0 – 20cm, the cutting edge of the core sampler was driven into the soil to obtain undisturbed soil sample into the tube of the cylinder, this was gently removed by placing a cutlass under the core sampler, the soil was then transferred into a moisture can and covered immediately in order to avoid loss or gain of moisture by evaporation. The same procedure was repeated for soil depths; 20 -40cm, 40 – 60cm, 60 – 80cm and 80 – 100cm respectively.

The cans were clearly labeled to distinguish the samples. These samples were then conveyed to the laboratory where they were weighed using an electronic weighing balance and dried in an oven at 105^0C for about 24hrs until all the moistures was driven off and the samples were weighed again. The initial and final weights were taken. The particle size distribution of the soil in the profile was determined by soil coil method and bulk density calculated.

3.3.2 **Raingauge installation and measurement of Rainfall depth.**

The non-recording gauge was made such that a funnel was mounted on a receiving bottle and the whole placed in a cylinder (fig.3.1). The Funnel has a diameter of 12.5cm and the bottle was placed in casing (glass). These were placed in a conical cylinder, which was buried into the ground. Whenever the bottle was filled up, the excess rain goes into the cylinder provided and this was measured. There was a graduated dipstick placed between the bottle and the cylinder for the purpose of measuring the rainfall depth. This raingauge used is similar to the one described by Mustafa and Yusuf (1999). The conical collector shape minimized splash and funneled water into a receiving bottle where measurements were carried out after every rain event to the nearest 0.25mm with a graduated dipstick placed between the bottle and the cylinder.

A couple of times, the bottle was filled up and the spill went into the cylinder, this was also measured in mm. In addition, rainfall amount and the corresponding duration were obtained from River Basin, and Minna Airport Meteorological Stations.

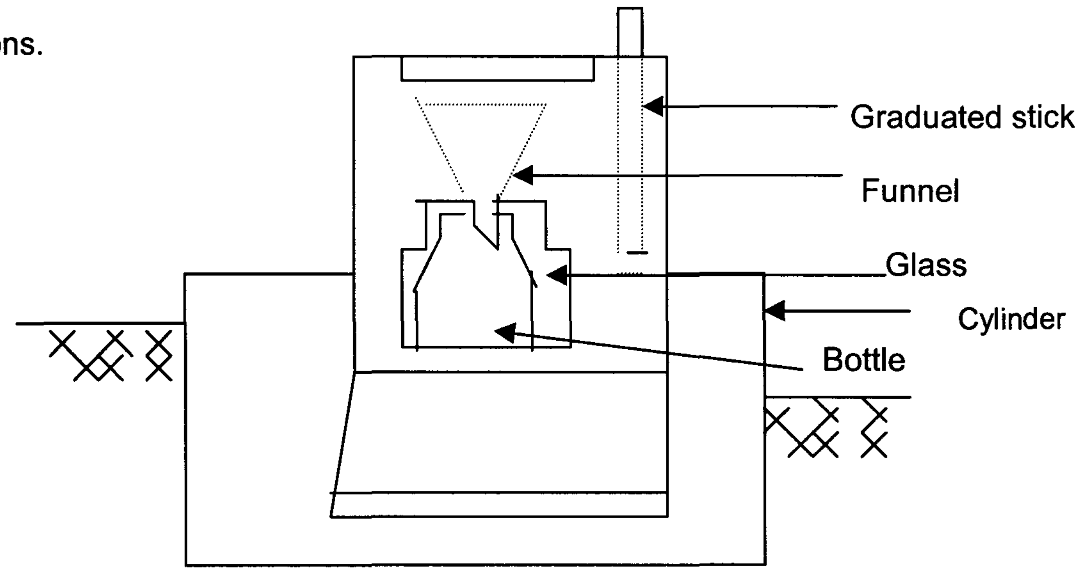

Fig.3.1: Typical Non-Recording gauge

3.3.3 **Runoff collection system set up and Runoff depth measurement**

Three (3) replicates of natural cover and bare plots were constructed. Plot size of 2.5m by 2m were marked out using a measuring tape, the marked out plots were dug 20cm below the ground surface and the 60cm high asbestos sheets were inserted into the dug ditch to prevent run-on while permitting runoff collection. A collector drain bordering the lower side of each runoff plot discharge runoff water through a spout into a 320litre tank installed in a pit 70cm below the ground level.

The discharged runoff was funneled into a 320litre tank installed in a pit below the ground level through a spout (Fig.3.2). Rain was prevented from falling directly into the runoff collectors (water tanks) by metal shields (metal covers)(Pictorial View).The discharged runoff water was measured manually using a 1000ml measuring cylinder as well as calibrated plastic buckets. Measurements were taken after every rainfall event. The readings were recorded immediately against their corresponding plots.

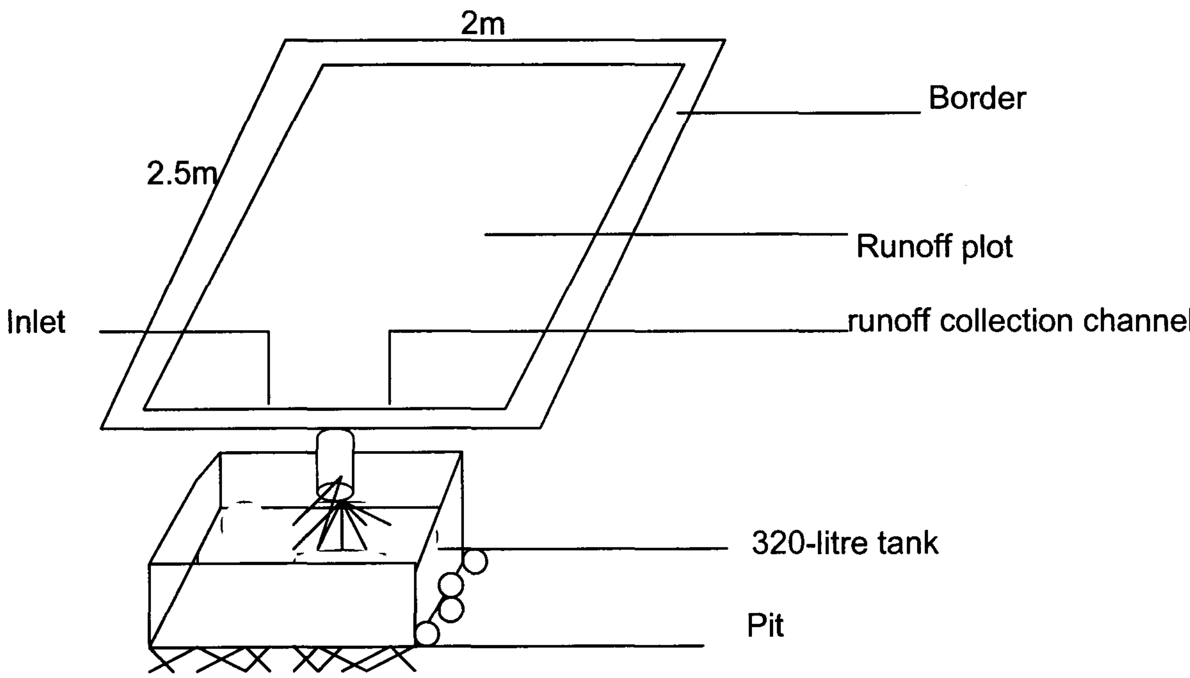

Figure 3.2: Field Set – up for runoff measurement

Plate 1: Runoff Collection System set – up for Natural – cover plot

Plate 2: Runoff Collection System set-up for Bare –treatment plot.

Plate 3: Bare – treatment plot showing the spout where discharged run-off is funneled into the tank

Plate 4: The Vegetation had trippbed towards the end of the growing season

3.3.4 **Sediment Yield Determination**

The sediment yield was determined by adding a flocculent of aluminum ammonium sulphate to the tank to settle out clay and fine particles. The total runoff volume in the tank was recorded and the clean runoff was removed. The settled sediment was then collected using a spatula into polyethylene bags with a known weight, which were labelled, to avoid mix up. They were tied up immediately to avoid loss of moisture. After most of the sediments were removed, the tanks were flushed with a known volume of water and the remaining sediment in the tanks were collected. These samples were then taken to the laboratory to weigh using an electronic weighing balance. The wet weight was then recorded after which they were dried in the oven at 105^{0}C for 24hours. The samples were then weighed again (dry weight). The sediment particle size distributions were also determined using gravimetric method.

3.3.5 **Piezometer Installation and Measurement of Depth to Water Table**

Three wells were dug using a hand driven auger of length 4.2m and screw diameter of 50mm at specified locations P_1, P_2, and P_3 to the depth of about 2m. These pipes were perforated at one end. The perforated ends were placed into the soil vertically and the other ends of the pipes were opened to the atmosphere. At the neck of the pipe on the ground surface, the clearance between the well and the pipe was sealed up using envelope materials made up of gravel materials of diameter greater than 5mm, these were to allow the vertical flow of water in the well (Fig.3.3). The depth to water table was measured by means of calibrated dipstick. The reading on the dipstick was the height of water in the well (x). To determine the depth of the water below the ground surface (z), the height of water in the well (x)

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 **Soil Analysis**

The mechanical analyses of the soil samples collected at different depths are given in table 4.1. Using the textural triangle, it was discovered that samples fitted into sandy loam at the depth of 0-20cm and 20–40cm, sandy clay loam at the depth of 40–60cm and 60–80cm and at the depth of 80–100cm was sandy clay class. The soil of the experimental site was thus classified as an Alfisol (USDA)

Table 4.1: Soil profile showing textural composition and bulk density of study area

Soil depth at 20cm interval	*Sand %*	*Silt %*	*Clay %*	*Textural class (Soil identification)*	*Bulk density (g/cm)*
0 – 20	76	14	10	Sandy loam	1.52
20 – 40	70	14	16	Sandy loam	1.54
40 – 60	66	14	20	Clay	1.59
60 – 80	60	14	26	Sandy clay loam	1.65
80 – 100	52	16	32	Sandy clay	1.65

4.2 **Vegetation**

The vegetation covering the Research Project location was assessed by visual inspection. The average percent – cover of the vegetation was about 90% and the height ranged from 20 to 86cm above the ground surface. The most striking physical observation on plant variety and diversity was the prevalence of weedy species. *Urena lobata lin* (Urena), *sida acuta* (Brown weed), and *Indigofera hisuta* (rough hairy indigo) were dominant weedy species. In addition, *Panicum* maximum (Guinea grass) was the dominant grass species. *Conymbosa* (Freesia) and *Hyptis suaveolens poit* (Mint weed) were also observed on the site.

Vegetative cover during the first two months of the rainy season did not appreciably affect runoff or sediment as such (figs 4.1 and 4.2). However, as month of September generated the second highest record of rainfall amount / intensity and runoff depth. The bare–treatment plot had an average depth of 4.6mm and 139mm accumulated amount, which was approximately two times greater than for the Natural–cover plot. The average runoff depth had a steady decline in rainfall amount, which is normal as the rainy season was coming to an end. The bare-treatment plot for the month of October, was almost two times greater than for the Natural –cover plot. This comparison is shown in Fig.4.5. The differences are statistically significant at 5% level. This is shown on the correlation matrix (Table 4.3).

Table 4.2: Rainfall Characteristics and the Corresponding Sediment Yield

Month	*Rainfall depth (mm) I*	*Rainfall duration (hr) II*	*Rainfall intensity (mm/hr) III*	*Runoff depth (mm) IV*		*Runoff rate (mm/hr) V*		*Drainage (%) $\frac{I-IV}{I} \cdot 100$*		*Sediment yield (kg/m^2)*	
				Natural cover	*Bare plot*	*Natural cover*	*Bare plot*	*Natural cover*	*Bare plot*	*Natural cover*	*Bare plot*
April	0.57	0.36	1.37	0.0	0.0	0.0	0.0	100	100	0.0	0.0
May	3.70	0.22	6.27	0.26	0.76	0.84	2.08	92.97	79.46	0.02	0.04
June	13.47	1.46	4.36	1.17	3.44	0.38	1.12	91.24	73.87	0.06	0.21
July	3.65	1.47	1.21	0.43	1.02	0.14	0.28	88.22	72.14	0.002	0.14
Aug.	13.42	1.65	6.77	3.79	6.11	1.97	3.58	68.63	47.99	0.18	0.46
Sept.	11.69	2.14	6.00	2.58	4.61	2.49	2.85	70.49	60.57	0.03	0.04
Oct.	10.72	0.86	5.31	2.00	3.60	0.89	1.71	81.25	66.32	0.02	0.05

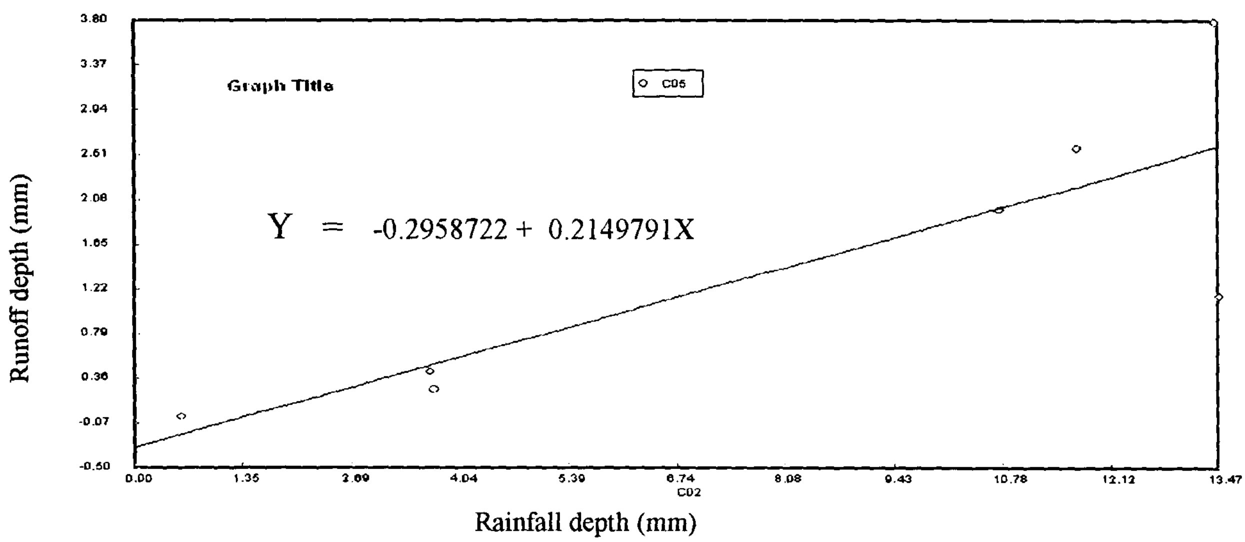

Fig. 4.4: Scattergram illustrating the relationship between runoff depth (natural cover) and rainfall depth ($R^2 = 0.68$)

Table 4.3: Correlation Matrix

	Minimum Temperature (°c)	Maximum Temperature (°c)	Evaporation	Rainfall Duration (hr)	Rainfall Amount (mm)	Rainfall Intensity (mm/hr)	Runoff Vol.1 (mm) (Grassed)	Runoff Vol.2 (mm) (Bare)	Drainage 1 (mm) (Grassed)	Drainage 2 (mm) (Bare)	Sediment Yield 1 (kg/m^2)	Sediment Yield 2 (kg/m^2) (Bare)
Minimum Temperature (°c)	1.00											
Maximum Temperature (°c)	0.73*	1.00										
Evaporation	0.35*	0.50*	1.00									
Rainfall /duration (hr)	-0.20*	-0.27*	-0.28*	1.00								
Rainfall Amount (mm)	0-20*	-0.24*	-0.29*	0.42*	1.00							
Rainfall Intensity (mm/hr)	-0.07	-0.14	-0.32*	0.57*	0.13	1.00						
Runoff Vol.1 (mm) (Grassed)	-0.21*	-0.23*	-0.21*	0.81*	0.33*	0.56*	1.00					
Runoff Vol,2 (mm) (Bare)	-0.21*	-0.24*	-0.24*	0.09*	0.38*	0.60*	0.94*	1.00				
Drainage 1 (mm) (Grassed)	-0.81*	-0.23*	-0.29*	0.98*	0.43*	0.51*	0.70*	0.82*	1.00			
Drainage 2 (mm) (Bare)	-0.17	-0.22*	-0.30*	-0.97*	0.42*	0.51*	0.65*	0.79*	0.99*	1.00		
Sediment Yield 1 (Kg/m^2) (Grassed)	-0.11	-0.15	-0.09	0.69*	0.22*	0.39*	0.73*	0.70*	0.65*	0.61*	1.00	
Sediment Yield 2 (kg/m^2 (Bare)	-0.11	-0.17	-0.11	0.79*	0.22*	0.41*	0.69*	0.75*	0.78*	0.75*	0.93*	1.00

*Significant at 5% * ($P<0.05$)

Table 4.6 : Experimental Data Table For 2^3 Full Factorial Experiment

No Of Runs	Coded factors (Factorial Effect)								Replicate										
	$X_.$	X_1	X_2	X_3	X_{12}	X_{13}	X_{23}	X_{123}	y_{u1}	y_{u2}	y_{u3}	y_u	$y_{u1} - u$	$y_{u2} - y_u$	$y_{u3} - y_u$	$(y_{u1} - y_u)^2$	$(y_{u2} - y_u)^2$	$(y_{u3} - y_u)^2$	S_u^2
1.	+	-	-	-	+	+	+	-	0.41	0.45	0.83	0.563333	-0.153333	-0.113333	0.266667	0.023511008	0.012844368	0.071111288	0.0537333
2.	+	+	-	-	-	-	+	+	1.27	1.49	1.32	1.36	-0.09	0.13	-0.04	0.0081	0.0169	0.0016	0.0133
3.	+	-	+	-	-	+	-	+	0.068	0.041	0.052	0.053666	0.014334	-0.012666	0.001666	$2.05463X10^{-4}$	1.60427×10^{4}	2.775×10^{-6}	1.34332×10^{-4}
4	+	+	-	-	-	-	+	+	0.18	0.18	0.16	0.173333	0.006667	0.006667	-0.013333	4.4448×10^{-5}	4.4448×10^{-5}	1.77768×10^{-4}	1.3332×10^{-4}
5.	+	-	-	+	+	-	-	+	0.099	0.094	0.064	0.085666	3.334×10^{-3}	-2.1666×10^{2}	1.77735×10^{-4}	6.9455×10^{-5}	4.69455×10^{-5}	4.69415×10^{-4}	3.58332×10^{-4}
6.	+	+	-	+	-	+	-	-	0.002	0.0026	0.0018	0.002133	-1.33×10^{-4}	4.67×10^{-4}	-3.333×10^{-4}	1.7×10^{-3}	2.18×10^{-7}	1.11×10^{-7}	1.73×10^{-7}
7.	+	-	+	+	-	-	+	-	0.36	0.18	0.31	0.283333	0.076667	-0.103333	0.026667	5877828×10^{-3}	1.06777×10^{-2}	7.111128×10^{-4}	8.633328×10^{-3}
8.	+	+	+	+	+	+	+	+	1.02	1.16	1.50	1.226667	-0.206667	-0.0666667	0.273333	0.0427112480	0.0044445	0.07477109	0.0609333

The model for a 2^3 Experiment is given as follows:

$$Y = b_0 x_0 + b_1 X_1 + b_2 x_2 + b_3 X_3 + b_{12} X_{12} + b_{13} X_{13} + b_{23} X_{23} + b_{123} X_{123} + e_i$$

Where; Y = Dependent Variable

b_0, b_1, b_2,---------b_{23}, b_{123} = Regression Coefficient

x_0, x_1, x_2,---------x_{23}, x_{123} =Coded Variables

e_i = Random error with zero(0) mean and constant variance$(0, \sigma^2)$

4.8. **Statistical Analysis of Data**

(i) The sample mean, $\bar{y}u$

$$\bar{y}u = \frac{i}{r}\sum_{v=1}^{r} y_{uv}$$

$$= \frac{1}{8}\sum^{8}\begin{pmatrix}0.05633 + 1.36 + 0.053666 + 0.173333 + 0.085666 + 0.002133 + \\ 0.2833 + 0.283333 + 1.226662\end{pmatrix}$$

$$= \frac{1}{8}(4.012125) = 0.501515625$$

(ii) Dispersion, Su^2

$$Su^2 = S^2 = \frac{1}{r}\sum_{r=1}\left(y_{uv} - \overset{u}{\bar{y}}u\right)^2$$

$$= \sum_{i=1}^{n} \frac{\left(Yi - \bar{Y}\right)}{r - 1} \text{ ------------------------------(2)}$$

$\sum Su^2$ = 0.0533733 + 0.0133 + 1.845332 x 10^{-4} + 1.3332 x 10^{-4} + 3.58332 x 10^{-4} + 1.73 x 10^{-7} + 8.633328 x 10^{-3} + 0.0609333 = 0.137275785

(iii) Su_{max} = 0.0609333 from table 4.5

(iv) To test for condition for Homogeneity:

The G-criteria test (Cochran G-criteria) is used to test the homogeneity of the dispersion of the replicate experiment. The calculated G-value is given as:

$$G_{cal} = \frac{Su^2 \max}{\sum_{u=1}^{n} Su^2} \text{ ----------------------(3)}$$

$$G_{cal} = \frac{0.0609333}{0.137275785} = 0.443875079$$

The condition of Homogeneity is given as

$G_{cal} \leq G^{tab}{}_{(f_1, f_{2,\alpha})} = G^{tab}{}_{(2,8,0.05)}$

G_{cal} = 0.443875079 from equation (3)

G_{tab} = 0.516 from Monograph (Table value/Appendix) .

Since $G_{cal} < G_{tab}$ (0.444 < 0.516), the condition of homogeneity is fulfilled.

Therefore, we can proceed with regression analysis.

4.8.2 STATISTICAL ANALYSIS AND MODEL SIMULATION

(i) Determination of Error mean square, S^2 (y):

$$S^2(y) = \frac{\sum_{u=1}^{N} Su^2}{N} \text{ ------------------ (4)}$$

$$S^2(y) = \frac{0.137275785}{8} = 0.017.59473$$

(ii) Determination of Experimental Error , S (y):

$$S(y) = \sqrt{S(y)^2} \text{ ------------------ (5)}$$

$$= \sqrt{0.017159473} = 0.130994172$$

(iii) Determination of Model Regression coefficients:

The mean effect is estimated by

$$b_0 = \frac{1}{N}\sum_{u=1}^{N} (x_0 \bar{y} u) \text{ ------------------ (6)}$$

$$b_o = \frac{1}{8} \times \begin{pmatrix} 0.563333 + 1.36 + 0.053666 + 0.173333 + 0.085666 + \\ 0.002133 + 0.283333 + 1.226667 \end{pmatrix}$$

$$= \frac{1}{8} \times (3.748131) = 0.468516375$$

Main effect:

$$b_i = \frac{1}{N}\sum_{u=1}^{N} (x_i \bar{y} u)$$

$$b_1 = \frac{1}{8}(- 0.563333 + 1.36 - 0.053666 + 0.173333 - 0.085666 + 0.002133 - 0.283333 + 1.226667)$$

$$= \frac{1}{8}(1.776135) = 0.222016875$$

$$b_2 = \frac{1}{8}\begin{pmatrix} -0563333 & -1.36 + 0.053666 & +0.173333 & -0.085666 & - \\ 0.002133 & +0.283333 & +1.226667 \end{pmatrix}$$

$$= \frac{1}{8}(-0.274133) = -0.034266625$$

$$b_3 = \frac{1}{8}\begin{pmatrix} -0.563333 & -1.36 + 0.053666 & +0.173333 & -0.085666 \\ +0.002133 & -0.283333 & +1.226667 \end{pmatrix}$$

$$= \frac{1}{8}(-0.5525227) = -0.069065337$$

Two factor interactions:

$$b_{ij} = \frac{1}{N}\sum_{u=1}^{N}\left(x_{ij}\,\dot{\bar{y}}\,u\right)$$

$$b_{12} = \frac{1}{8}\begin{pmatrix} +0.563333 & -1.36 - 0.053666 & +0.173333 & -0.085666 & -0.002133 \\ -0.283333 & +1.226667 \end{pmatrix}$$

$$= \frac{1}{8} \times (0.3498703) = 0.043733787$$

$$b_{13} = \frac{1}{8}\begin{pmatrix} +0.563333 & -1.36 - 0.053666 & -0.173333 & -0.085666 & +0.002133 \\ -0.28333 & +1.226667 \end{pmatrix}$$

$$= \frac{1}{8}(-0.05653) = -0.00706625$$

$$b_{23} = \frac{1}{8}\begin{pmatrix} +0.563333 & +1.36 - 0.053666 & -0.173333 & -0.085666 & -0.002133 \\ +0.28333 & +1.226667 \end{pmatrix}$$

$$= \frac{1}{8} \times (3.118532) = 0.3898165$$

Three factor interactions

$$b_{ijk} = \frac{1}{N}\sum_{u=1}^{N}\left(X_{ijk}\,\bar{y}_u\right)$$

$$= \frac{1}{8}\begin{pmatrix} -0.563333 & +1.36 + 0.053666 & -0.173333 & +0.085666 & -0.002133 \\ -0.28333 & +1.226667 \end{pmatrix}$$

$$= \frac{1}{8} \times (1.70387) = 0.21298375$$

The Regression Model

$$\hat{y} = 0.4685 + 0.220x_1 - 0.0343x_2 - 0.0690x_3 + 0.0437x_{12} - 0.0071x_{13} + 0.3898x_{23} + 0.2130\, x_{123} \quad \text{-----} (7)$$

4.8.3 **Confidence Interval**

To test the statistical significant of an individual regression coefficient in a regression model, we must construct confidence interval and carryout test of hypothesis.

Confidence intervals for regression coefficient with a confidence level, α are of the general term:

$b's \pm t\,(\alpha, N(r-1), S\,b's$

i.e. $b's \pm \Delta\, b's$

Where, $S\,b's$ = the estimated standard error in regression coefficient (b's)

$t\,(\alpha N(r-1))$ = an appropriate tabulated t-criteria with N(r-1) degree of freedom.

For a full Factorial Experiment (FFE), errors in each coefficient is the same and is determined by:

$$S_{bo} = S\,(_{bi}) = \text{------} = S\,(_{bij\,k}) = \frac{S(y)}{\sqrt{N.r}} \quad \text{------}(8)$$

But S(y) = 0.130994172 from equation (5)

and $\sqrt{N.r} = \sqrt{8x3} = \sqrt{24} = 4.898979486$

The statistical significance of the regression coefficients are tested by

$$t_o = \frac{b_o}{Sb_o}$$

but $S_{bo} = S_{(bi)} = S_{(bij)} = S_{(bijk)} = \dfrac{0.130994172}{4.898979486} = 0.026739073$

$$t_0 = \frac{b_o}{S_{(bo)}} = \frac{0.468516375}{0.0267390737} = 17.52178825$$

$$t_1 = \frac{|b_1|}{S_{(b1)}} = \frac{0.22016875}{0.0267379073} = 8.233970938$$

$$t_2 = \frac{|b_2|}{S_{(b2)}} = \frac{0.034266625}{0.26739073} = 1.28151881$$

$$t_3 = \frac{|b_3|}{S_{(b3)}} = \frac{0.069065337}{0.006739093} = 2.582936851$$

$$t_{12} = \frac{|b_{12}|}{S_{(b12)}} = \frac{0.043733787}{0.026739073} = 1.635576035$$

$$t_{13} = \frac{|b_{13}|}{S_{(b13)}} = \frac{0.007006625}{0.026739073} = 0.264266827$$

$$t_{23} = \frac{|b_{23}|}{S_{(b123)}} = \frac{0.3898165}{0.026739073} = 14.57853457$$

$$t_{123} = \frac{|b_{123}|}{S_{(b123)}} = \frac{0.21298375}{0.026739073} = 7.965263044$$

$t_{cal} > t_{[\alpha,N(r-1)]}$

$t^{table}\ f_E, \alpha$; where $F_E = N(r-1) = 8(3-1) = 16$, $\alpha = 0.05$

$\therefore\ t^{table}_{16,0.05} = 2.12$ from table (Appendix)

Therefore, from the t_{cal}, coefficients b_2, b_{12} and b_{13} are statistically insignificant since they are less than t^{table}

Determination of Confidence interval, Δb_i

Confidence interval for regression coefficient are of the general form: $b_i \pm \Delta b_i$

Where, $\Delta b_i = t(\alpha, N(n-1)\ Sb_i$

$\therefore \Delta b_i = t^{table} \times Sb_i$ -- (9)

$= 2.12 \times 0.026739073 = 0.056686834$

Table 4.7: Summary of Estimated effects, Confidence interval and t-value

Regression Coefficient	*Estimated effect*	*Confidence interval*	*t-value*
b_0	0.468516375	±0.0566834	17.52178825
b_1	0.22016875	± 0.0566834	8.233970938
*b_2	-0.034266625	±0.0566834	1.28151881
b_3	-0.069065337	±0.0566834	2.582936851
*b_{12}	0.043733787	±0.0566834	1.635576035
•b_{13}	- 0.00706625	± 0.0566834	0.264266827
b_{23}	0.3898165	±0.0566834	14.57853457
b_{123}	0.21298375	±0.0566834	7.965263044

* Insignificant at 5% level of confidence

$$\hat{y} = 0.4685 + 0.2220x_1 - 0.0690x_3 + 0.3898x_{23} + 0.2130x_{123} \text{ ------------------- } (10)$$

Coefficients b_2, b_{12} and b_{13} are insignificant at 5% level of confidence therefore they are eliminated from the regression model.

4.8.4 **Determination of Model Adequacy**

In order the magnitude or significance of the effects, we have to carry out an analysis of variance (ANOVA).

(I) **Determination of sum of squares for each component of the model**: In the 2^k Factorial Design with replicates, the regression sum of squares for any effect is = $SS_R = \frac{r}{N}$ (contrast)^2 --(ii)

For the main effect:

$$SS_{bi} \frac{r}{N}\Sigma\left(x_i \bar{y}_u\right)^2$$

$$= \frac{3}{8}(1.776135)^2 = 1.182995827$$

$$SS_{b2} = \frac{3}{8}(-0.274133)^2 = 0.028180838$$

$$SS_{b3} = \frac{3}{8}(-0.5525227)^2 = 0.1144805$$

For the two factor interaction:

$$SS_{bij} = \frac{r}{N}\sum_{u=1}^{w}\left(x_{ij}\bar{y}_u\right)^2$$

$$SS_{b12} = \frac{3}{8}(0.3498703)^2 = 0.04590346$$

$$SS_{b13} = \frac{3}{8}(-0.05653)^2 = 0.001198365$$

$$SS_{b23} = \frac{3}{8}(3.118532)^2 = 3.646965688$$

For the three factor interaction.

$$SS_{bijk} = \frac{r}{N}\sum_{u=1}^{w}\left(x_{ijk}\bar{y}_u\right)^2$$

$$SS_{b123} = \frac{3}{8}(1.70387)^2 = 1.088689866$$

The total sum of sum of square, SS_T is given as

$$SS_T = \sum_{u=1}^{N-r} y^2_{uv} - \frac{\left(\sum_{u=1}^{N-r} y_{uv}\right)^2}{N.r} \text{ ---------------- } (12)$$

$$SS_T = 11.651156 - \frac{126.4365314}{8x3} = 6.382968193$$

Error sum of squares, SS_E is given as

$$SS_E = SS_T - \sum SS_R \text{ --- } (13)$$

$= 6.382967193 - 6.108414736$

$= 0.274552457$

In multiple linear regression, testing the significance or contribution of the individual coefficients is accomplished by testing the null hypothesis.

$H_0 : b_1 = 0$

The appropriate statistical test is the F-test, and is given as:

$$F_{cal} = \frac{MS_R}{MS_E} = \frac{\text{Mean Square Residual}}{\text{Mean Square Error}} = \frac{SS_R / df_R}{SS_E / N(r-1)} \text{ ---------- } (14)$$

Condition : $F_{cal} > F_{[\alpha, d.f, N(r-1)]}$

Table 4.6: Analysis of Variance table for Replicated 2^3 factorial Experiment

Source of variance	*Effect*	*Sum of square (ss)*	*Degree of freedom (d.f)*	*Mean Squares (ms)*	*F-ratio (F_0)*
Main effect					
b_1	0.22016875	1.182995827	1	1.182995827	68.94104704[a]
b_2	-0.034266625	0.028180838	1	0.028180838	1.642285149[8]
b_3	-0.0690665337	0. 1144805	1	0.1144805	6.671541315[b]
Two factor interaction					
b_{12}	0.043733787	0.04590346	1	0.04590346	2.675100387
b_{13}	-0.00706625	0.001198365	1	0.001198365	0.069836711
b_{23}	0.3898165	3.646965688	1	3.64695688	212.5324706[a]
Three factor interaction					
b_{123}	0.21298375	1.088689866	1	1.08869866	63.44572298[a]
Error		0.274552457	16	1.08869866	63.44572298[a]
Total		6.382967193	23		

[a] Significant at 1 percent
[b] Significant at 5 percent

4.8.5 **Diagnostic Checking**

Diagnostic checks are applied to the residuals of a 2^k design

The analysis indicates that the only significant effects are

$X_1 = 0.2220$, $X_3 = -0.0690$, $X_{23} = 0.3898$ and $X_{123} = 0.2130$

If this is true, then the estimated sediment yield at the vertices of the design are given by:

$$= 0.4685 + \left(\frac{0.2202}{2}\right) X_1 - \left(\frac{0.0691}{2}\right) X_3 + \left(\frac{0.3898}{2}\right) X_2X_3 + \left(\frac{0.2130}{2}\right) X_1X_2X_3$$

Where 0.4685 is the average response and the coded variables x_1, x_3, x_2 take on the values +1 or – 1. The predicted sediment yield at run (1) is

$$= 0.4685 + \left(\frac{0.2202}{2}\right)(-1) - \left(\frac{0.0691}{2}\right)(-1) + \left(\frac{0.3898}{2}\right)(+1) + \left(\frac{0.2130}{2}\right)(-1) = 0.48135$$

At run (2)

$$= 0.4685 + \left(\frac{0.2202}{2}\right)(+1) - \left(\frac{0.0691}{2}\right)(-1) + \left(\frac{0.3898}{2}\right)(+1) + \left(\frac{0.2130}{2}\right)(+1) = 0.91455$$

At run (3)

$$= 0.4685+\left(\frac{0.2202}{2}\right)(-1) - \left(\frac{0.0691}{2}\right)(-1) + \left(\frac{0.3898}{2}\right)(-1)+ \left(\frac{0.2130}{2}\right)(+1)=0.30455$$

At run (4)

$$= 0.4685 + \left(\frac{0.2202}{2}\right)(+1) - \left(\frac{0.0691}{2}\right)(-1) + \left(\frac{0.3898}{2}\right)(-1)+ \left(\frac{0.2130}{2}\right)(-1) =0.31175$$

At run (5)

$$= 0.4685 + \left(\frac{0.2202}{2}\right)(-1) - \left(\frac{0.0691}{2}\right)(+1) + \left(\frac{0.3898}{2}\right)(-1)+ \left(\frac{0.2130}{2}\right)(+1) =0.23545$$

At run (6)

$$= 0.4685 + \left(\frac{0.2202}{2}\right)(+1) - \left(\frac{0.0691}{2}\right)(+1)+\left(\frac{0.3898}{2}\right)(-1)+ \left(\frac{0.2130}{2}\right)(-1) =0.02245$$

At run (7)

$$= 0.4685 + \left(\frac{0.2202}{2}\right)(-1) - \left(\frac{0.0691}{2}\right)(+1)+ \left(\frac{0.3898}{2}\right)(+1)+\left(\frac{0.2130}{2}\right)(-1) =0.41225$$

At run (8)

$$= 0.4685 + \left(\frac{0.2202}{2}\right)(+1) - \left(\frac{0.0691}{2}\right)(+1)+\left(\frac{0.3898}{2}\right)(+1)+\left(\frac{0.2130}{2}\right)(+1) =0.84545$$

The values of y_u, $\overset{\Delta}{y}$ ε_n and ε_u^2 for all 8 observations follows:

Table 4.9: The Observed values (y_u), fitted values ($\hat{y}_u$), Residuals (e_u) and squares of residual (e_u^2)

Run	Y_u	y_1	$e_u y_1 - y_u$	[illegible]
1.	0.5633	0.4804	0.0859	0.007379
1.	0.5633	0.48135	-0.08195	0.0067158
2.	1.36	0.91455	-0.44545	0.1984257
3.	0.05366	0.30455	0.25089	0.0629457
4.	0.1733	0.31175	0.13845	0.0629457
5.	0.08566	0.23545	0.14979	0.022437
6.	0.00213	0.02245	0.02032	0.0004129
7.	0.2833	0.41225	0.12895	0.0166281
8.	1.2266	0.84545	-0.38115	0.1452753

The analysis of variance for this model is summarised in Table 4.8 the model sum of square is:

SS_{model} = □SS_R = 6.108414736

And $R^2 = \frac{SS_{mod\,el}}{SS_T}$ ---------------------------(16)

$R^2 = \frac{6.108414736}{6.382967193} = 0.956986704$

□ R^2 = 0.96, so that the model explains about 96 percent of the variability in the sediment yield (soil loss).

4.8.6 **Interpretation of the Model**

The analysis of variance is summarised in Table 4.8,and it confirms the significance of the main effects (temperature,b_i and Runoff depth, b_3), two factor interaction (Rainfall intensity-Runoff depth,b_{23}) and three factors interaction (Temperature–Rainfall intensity–Runoff depth, b_{123}).

The main effect b_1, b_{23} interaction and b_{123} interaction are significant at 1 percent level while main effect b_3 at 5 percent; thus there is a great interaction between Temperature, Rainfall intensity and Runoff depth (b_{123} = 0.2130) and a greater interaction between Rainfall intensity and Runoff depth (0.3898) with the largest effect. Runoff depth (x_3 = -0.0690) alone does not appear to have as large an impact on the soil loss as the interaction effects.

In conclusion, b_i, b_3, b_{23} and b_{123} are the only significant effects and that the underlying assumptions of the analysis are satisfied. Furthermore, the correlation coefficient, R^2 was obtained as 0.96. Thus, the model variability in the sediment yield (soil loss).

Increasing temperature (x_1) and rainfall intensity–runoff depth (X_{23}) the soil loss (sediment yield ($\hat{y}$) from the erosion test site increases. This is because the coefficients b_1 and b_{23} have great impact on erosion control. Reducing rainfall intensity-runoff depth reduces the soil loss from the site.

Along side, linear effect significantly also proved effect of factors in interaction, these factors have more impact on the system than the main effect. In order to reduce sediment yield from the erosion test site, it is necessary to reduce rainfall intensity and runoff depth by applying the most suitable cropping and land management practice.

There are no unique solutions to erosion control problems. However control measures depend very much on the economic status of the farmer, the degree of importance placed on sediment erosion by environmental authorities, availability of capital, and the state of development of the country. Control measures as well as classification as recommended by US–EPA (1993) are outlined in Appendix IV. Control measure techniques have beneficial effects for conservation of nitrogen and phosphorus in the soil (FAO, 1996).

Diagnostic check was also applied to the residuals to further check the significant effects of the model. All the residuals were close to zero (0). The R^2 is equal to 0.96 which implies that about 96percent of the variability of the sediment yield is explained in the model.

4.9 Correlation Coefficient, R^2

Natural –cover plot. There was a high positive correlation between Runoff/ Rainfall amount and sediment yield /Rainfall amount on the Natural –cover plot, representing an increase in variable (x) with (Y). The R^2 values are 0.68 and 0.62 respectively (Figs. 4.4 and 4.7), however, there was a linear correlation between

Sediment yield / Runoff depth (Fig.4.6) but weak, which implies that there are other factors affecting sediment yield hence the value 0.4.

The bare-treatment plot, likewise, gave positive correlation between Runoff / Rainfall, Sediment yield/Runoff and sediment yield/ Rainfall amount (depth). The degrees of relationship were not as high as that for the Natural–cover plot. However, the correlation between sediment yield/Runoff (fig.4.8) had a very high positive correlation coefficient (R^2 = 0.0.87). The R^2 -values for Runoff depth / Rainfall amount (depth) and sediment yield / Rainfall depth are 0.44 and 0.48 respectively (Figs. 4.9 and 4.10).

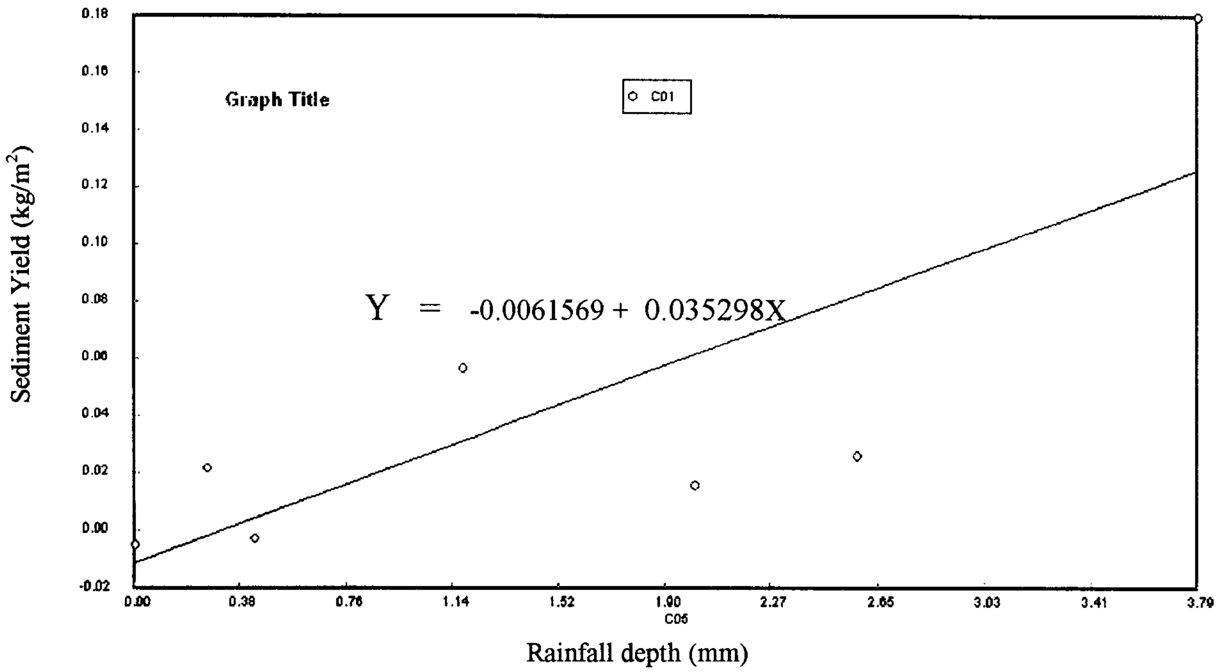

Fig. 4.7: Scattergram illustrating the relationship between sediment yield (natural cover) and rainfall depth ($R^2 = 0.62$)

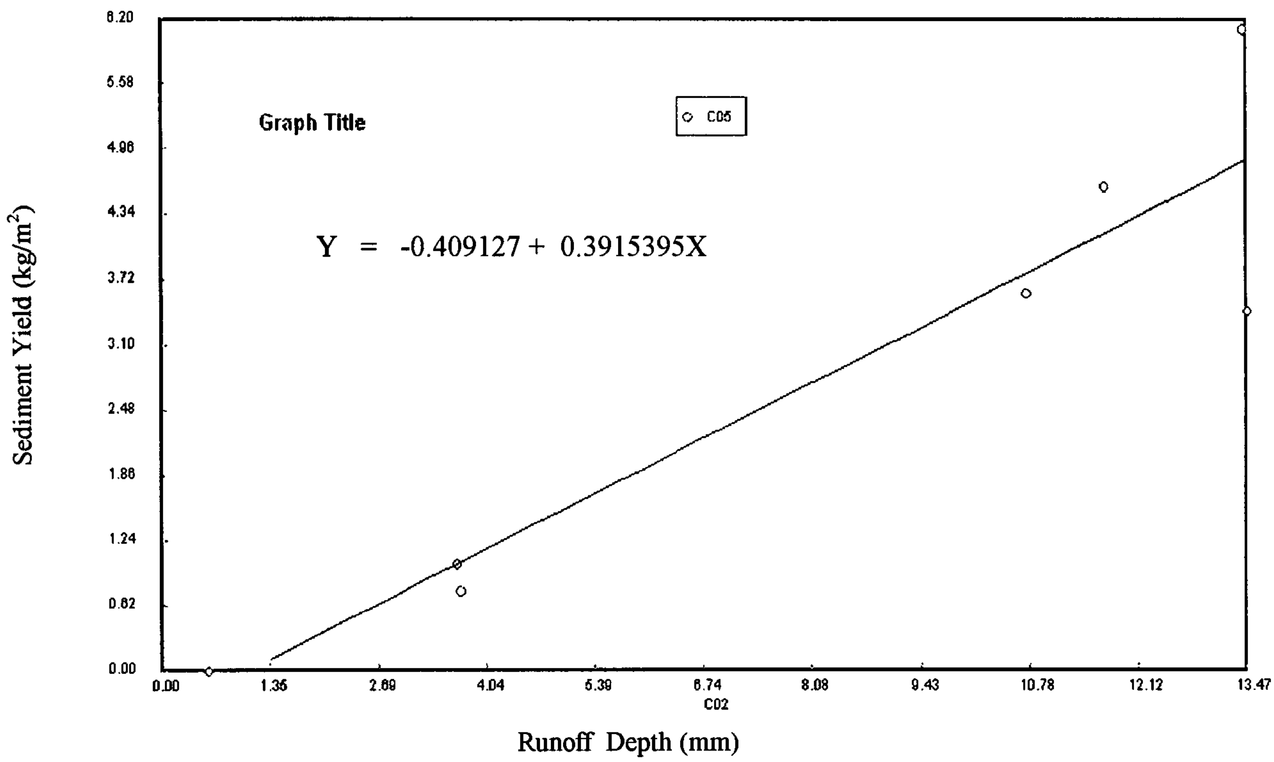

Fig. 4.8: Scattergram illustrating the relationship between sediment yield (bare plot) and runoff depth (bare plot) ($R^2 = 0.87$)

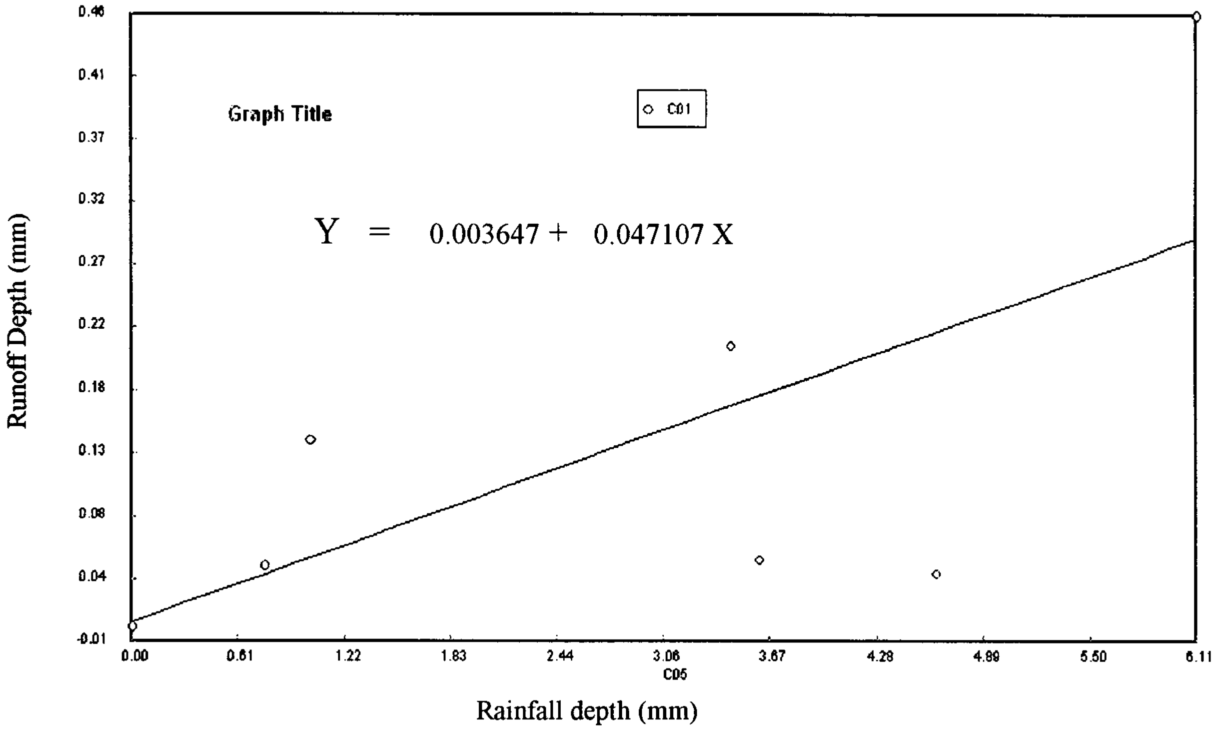

Fig. 4.9: Scattergram illustrating the relationship between runoff depth (bare plot) and rainfall depth ($R^2 = 0.44$)

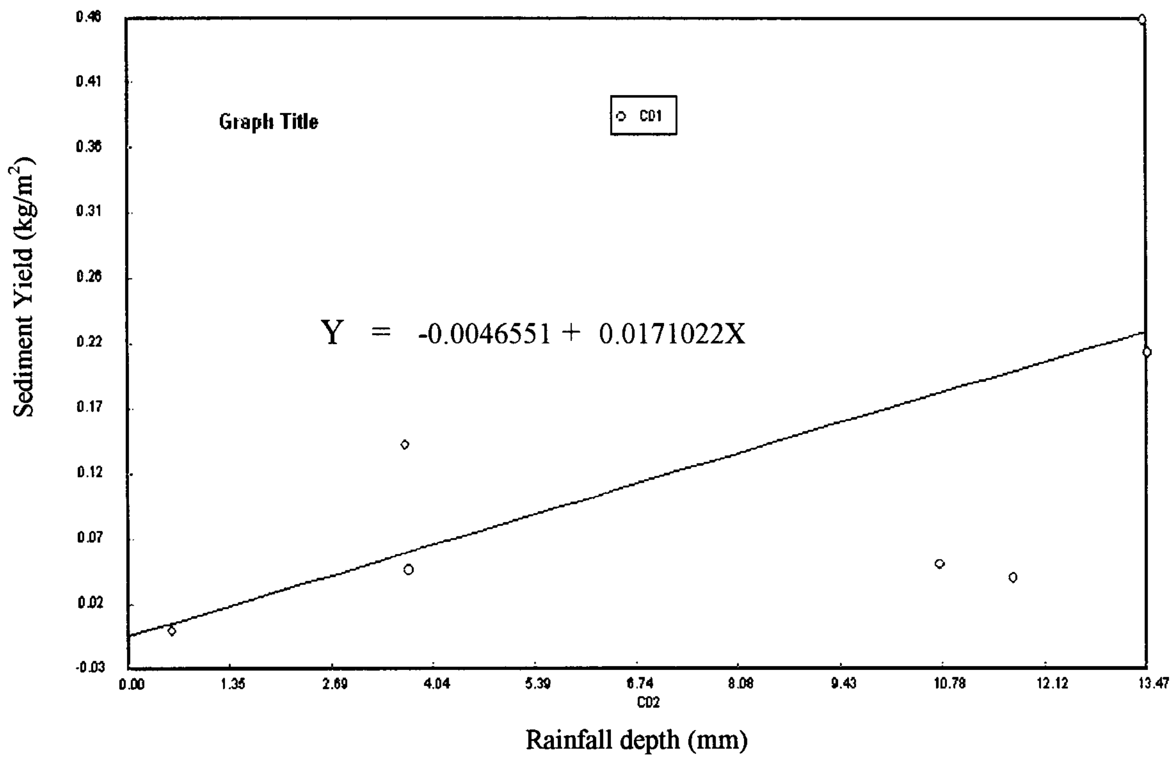

Fig. 4.10: Scattergram illustrating the relationship between sediment yield (bare plot) and rainfall depth ($R^2 = 0.33$)

Comparing this result (R^2=0.41) to a previous work (Egharevba, 2004), Y = 60x +71 with R^2 = 0.5, the previous work has a higher correlation between Sediment yield and Runoff depth. However, the correlation coefficient between Sediment yield and Rainfall depth represent an increase in variable (x) with (y). Comparing this relationship to a previous work (Egharevba, 2004), the previous work has 46% correlation, while this work has 62% correlation which gives a better relationship. The relationship between runoff depth and rainfall depth gave the best correlation (68%) when compared with the other two equations (present work).

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Natural-cover plot and Bare–treatment plot were examined under the conditions of guinea savannah zone of Nigeria during the wet season of 2003. The impact of these treatments on surface runoff and sediment yield was examined. Surface runoff and sediment yields were measured for rainfall events in 2003.

From the investigation carried out, it is concluded that:

1. Even though the Natural – cover plot was lightly vegetated during the first few months (April – May) of the wet season, the erosion rate changed very little with time, suggesting that the erosion –reducing effect of vegetation was not as significant as the effect of surface rock fragments, as shown by Simanton et al (1984). The vegetative cover nearly tripled towards the end of the growing season in (August), the increase was undoubtedly as a result of the increased rainfall, thus simulating the vegetative growth.
2. Observed surface runoff depths and sediment yields varied substantially by storm and by treatment. The largest surface runoff was from the bare-treatment, and the smallest surface runoff was from the natural-cover. Runoff trends appeared to be related to vegetative cover.
3. The bare-soil treatment produced the largest erosion and the rate increased with time. The increase in erosion rate for the Bare–soil treatment closely emulated runoff changes which may be attributed to the decrease in root

and residue material in the soil which, in turn, decreased the soil macropore structure (Dixon and Simanton, 1979). Another reason for an erosion could be attributed to the formation of a rill network that developed after the vegetation and rock fragments were removed. Also, removing rock fragments would cause a decrease in surface roughness and a corresponding increase in runoff, erosion and runoff response-time to the rainfall.

4. The soil loss from the bare plot was approximately three times greater than the Natural–cover plot.
5. Predictive equation relating sediment yield to runoff took a linear form. Although the correlation coefficients were generally low. This tends to suggest that more factors or parameters are at play to determine sediment yield.
6. The multiple regressions (sediment yield model) is designed to be used to estimate the quantity of soil eroded from land by rainfall runoff. It should be used primarily for planning purposes as a first estimate of soil losses on the field. Then, based on what is judged as an allowable annual soil loss rate, different cropping systems or conservation practices could be recommended.

5.2 RECOMMENDATIONS

1. Future research should focus on runoff response – time, and evaluation of transport mechanism of sediment.

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APPENDIX A

Table A1: Daily Rainfall amount, Runoff depth and Rates, drainage and sediment yield data collected at Numu Farm Centre during natural rainfall event from April – October, 2003.

PERIOD: APRIL, 2003

Day	I Rainfall depth (mm)	II Rainfall Duration (hr)	III Rainfall intensity (mm/hr)	IV Runoff depth (mm) Natural cover plot					V Runoff depth (mm) $V = IV / II$ Natural cover plot					VI Drainage (%) = $(I - IV)/I \times 100$ Natural – cover plot					Sediment Yield (kg/m^2) $VII = \frac{\text{Dry weight of Eroded Soil}}{\text{Plot area}}$ Natural cover plot				
				R_1	R_2	R_3	R_{Av}	R_{Bare}	R_1	R_2	R_3	R_{Av}	R_{Bare}	D_1	D_2	D_3	D_{AV}	D_{Bare}	S_1	S_2	S_3	S_{AV}	S_{Bare}
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.00	100.00	100.00	100.00	100.00	0.0	0.0	0.0	0.0	0.0
5	5.7	0.43	13.26	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0.0
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.3	0.50	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table A1: Contd

Day	I Rainfall depth (mm)	II Rainfall Duration (hr)	III Rainfall intensity (mm/hr)	IV Runoff depth (mm) Natural cover plot					V Runoff depth (mm) V = IV / II Natural cover plot					VI Drainage (%) = (I – IV)/I x 100 Natural – cover plot					Sediment Yield (kg/m²) $VII = \frac{\text{Dry weight of Eroded Soil}}{\text{Plot area}}$ Natural cover plot				
				R_1	R_2	R_3	R_{Av}	R_{Bare}	R_1	R_2	R_3	R_{Av}	R_{Bare}	D_1	D_2	D_3	D_{AV}	D_{Bare}	S_1	S_2	S_3	S_{AV}	S_{Bare}
22	9.5	0.40	23.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.00	100.0	100.00	100.00	0.0	0.0	0.0		0.0	0.0
23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26	1.7	0.47	3.62	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.00	100.00	100.00	100.00	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sum	17.20	1.80	41.23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0						0.0	0.0	0.0	0.0	0.0
Mean	0.57	0.06	0.57	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0						0.0	0.0	0.0	0.0	0.0

Table A2: Daily Rainfall amount, Runoff depth and Rates, drainage and sediment yield data collected at Numu Farm Centre during natural rainfall event from April – October, 2003

PERIOD: MAY, 2003

Day	I Rainfall depth (mm)	II Rainfall Duration (hr)	III Rainfall intensity (mm/hr)	IV Runoff depth (mm) Natural cover plot					V Runoff depth (mm) V = IV / II Natural cover plot					VI Drainage (%) = (I – IV)/I x 100 Natural – cover plot					Sediment Yield (kg/m²) VII = Dry weight of Eroded Soil / Plot area Natural cover plot				
				R_1	R_2	R_3	R_{Av}	R_{Bare}	R_1	R_2	R_3	R_{Av}	R_{Bare}	D_1	D_2	D_3	D_{AV}	D_{Bare}	S_1	S_2	S_3	S_{AV}	S_{Bare}
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0..0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	1.57	1.37	4.17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.00	100.00	100.00	100.00	100.00	0.0	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	3.6	0.25	15.43	0.23	0.41	0.33	0.52	1.04	1.00	1.78	1.45	1.39	4.52	93.61	88.61	90.83	91.11	70.11	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0,0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table A2: Contd

Day	I Rainfall depth (mm)	II Rainfall Duration (hr)	III Rainfall intensity (mm/hr)	IV Runoff depth (mm) Natural cover plot					V Runoff depth (mm) V = IV / II Natural cover plot					VI Drainage (%) = (I – IV)/I x 100 Natural – cover plot					Sediment Yield (kg/m²) VII = Dry weight of Eroded Soil / Plot area Natural cover plot				
				R_1	R_2	R_3	R_{Av}	R_{Bare}	R_1	R_2	R_3	R_{Av}	R_{Bare}	D_1	D_2	D_3	D_{AV}	D_{Bare}	S_1	S_2	S_3	S_{AV}	S_{Bare}
23	0.0	0.0	0.0	0.0	[illegible]	0.0	0.0	0.0	0.0	0.0	0.0		0.0		0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0
24	12.60	0.92	13.75	0.53	0,58	0.52	0.54	1.98	0.58	0.65	0.57	0.59	2.15	95.79	95.40	95.87	95.71	84.29	0.0	0.0	0.0	0.0	0.0
25	22.10	1.03	22.39	0.71	0.68	0.62	0.67	2.01	0.69	0.66	0.60	0.65	1.95	96.79	96.92	97.20	96.97	90.50	0.0	0.0	0.0	0.0	0.0
26	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27	21.30	0.92	23.24	1.04	0.97	1.10	1.03	4.13	1.13	1.05	1.20	1.12	4.49	95.12	95.45	94.84	95.16	80.61	0.0	0.0	0.0	0.0	0.0
28	32.60	2.12	15.12	1.66	1.93	2.00	1.86	6.04	0.78	0.91	0.94	0.88	2.85	94.91	94.08	93.87	94.30	81.47	0.12	0.15	0.26	0.18	0.45
29	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31	16.7	0.17	98.24	3.20	3.67	4.11	3.66	8.23	8.23	18.82	21.59	24.18	48.41	81.82	78.82	75.39	78.08	50.72	0.29	0,30	0.57	0.39	0.74
Sum	114.6	6.76	194.3	7.37	8.24	8.68	8.08	23.43	23.00	26.62	28.94	26.16	64.37						0.41	0.45	0.85	0.57	1.19
Mean	3.70	0.22	6.27	0.24	0.27	0.28	0.26	0.76	0.74	0.86	0.93	0.84	2.08						0.013	0.015	0.03	0.02	0.04

Table A3: Daily Rainfall amount, Runoff depth and Rates, drainage and sediment yield data collected at Numu Farm Centre during natural rainfall event from April – October, 2003

PERIOD: JUNE, 2003

Day	I Rainfall Depth (mm)	II Rainfall Duration (hr)	III Rainfall intensity (mm/hr)	IV Runoff depth (mm) Natural cover plot R_1	R_2	R_3	R_{Av}	R_{Bare}	V Runoff depth (mm) V = IV / II Natural cover plot R_1	R_2	R_3	R_{Av}	R_{Bare}	VI Drainage (%) = (I – IV)/I x 100 Natural – cover plot D_1	D_2	D_3	D_{AV}	D_{Bare}	Sediment Yield (kg/m²) $VII = \frac{\text{Dry weight of Eroded Soil}}{\text{Plot area}}$ Natural cover plot S_1	S_2	S_3	S_{AV}	S_{Bare}
1	2.25	5.45	41.28	19.24	20.11	19.56	19.64	56.1	3.53	3.69	3.59	3.60	10.29	91.45	91.06	91.31	91.27	75.07	1.17	1.39	1.23	1.26	5.432
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	2.0	1.55	1.29	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.00	100.00	100.00	100.00	100.00	0.0	0.0	0.0	0.0	0.0
4	0.1	0.12	0.86	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.00	100.00	100.00	100.00	100.00	0.0	0.0	0.0	0.0	0.0
5	12.4	3.93	3.15	0.16	0.27	0.14	0.19	2.61	0.04	0.07	0.04	0.05	0.66	98.71	97.82	98.87	98.49	78.95	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	19.0	2.45	7.76	1.32	1.61	2.46	1.80	5.04	0.54	0.66	1.00	0.74	2.06	93.05	91.53	87.05	90.53	73.47	0.096	0.10	0.091	0.096	0.136
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	12.6	2.57	4.91	0.29	0.46	0.23	0.33	3.12	0.11	0.18	0.09	0.13	1.21	97.70	93.18	98.18	97.38	75.24	0.0	0.0	0.0	0.0	0.0
13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	11.9	1.18	10.06	0,31	0.41	0.38	0.37	3.43	0.26	0.35	0.32	0.31	2.91	97.40	96.56	96.81	96.89	71.18	0.0	0.0	0.0	0.0	0.0
15	12.0	2.23	4.24	1.11	1.32	1.18	1.90	1.20	2.47	0.39	0.47	0.42	0.87	90.75	89.00	90.17	90.00	79.42	0.0	0.0	0.0	0.0	0.0
16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	20.1	1.2	16.75	3.38	2.70	3.26	3.11	7.52	2.82	2.25	2.72	2.59	6.27	83.18	86.57	83.78	84.53	62.59	0.068	0.041	0.052	0.161	0.128
18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	6.5	3.35	1.94	0.0	0.0	0.0	0.0	1.24	0.0	0.0	0.0	0.0	0.34	100.00	100.00	100.00	100.00	80.92	0.0	0.0	0.0	0.0	0.0
20	1.6	0.2	8.00	0.0	0.0	0.0	0.0	0.35	0.0	0.0	0.0	0.0	1.75	100.00	100.00	100.00	100.00	78.13	0.0	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	40.7	1.82	22.40	4.00	6.31	4.25	4.85	13.68	2.20	3.47	2.34	2.67	7.52	90.17	84.50	89.56	88.16	66.39	0.13	0.11	0.096	0.112	0.440
24	0.25	7.5	0.03	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.00	100.00	100.00	100.00	100.00	0.0	0.0	0.0	0.0	0.0

Table A3: Contd

Day	I Rainfall Depth (mm)	II Rainfall Duration (hr)	III Rainfall intensity (mm/hr)	IV Runoff depth (mm) Natural cover plot					V Runoff depth (mm) V = IV / II Natural cover plot					VI Drainage (%) = (I – IV)/I x 100 Natural – cover plot					Sediment Yield (kg/m²) VII = Dry weight of Eroded Soil / Plot area Natural cover plot				
				R_1	R_2	R_3	R_{Av}	R_{Bare}	R_1	R_2	R_3	R_{Av}	R_{Bare}	D_1	D_2	D_3	D_{AV}	D_{Bare}	S_1	S_2	S_3	S_{AV}	S_{Bare}
25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28	30.3	5.17	5.88	3.66	2.17	2.48	2.77	7.2	0.71	0.42	0.48	0.54	1.39	87.92	92.84	91.82	90.85	76.24	0.045	0.071	0.066	0.0607	0.208
29	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30	9.9	4.19	2.33	0.69	1.2	0.88	0.92	2.30	0.16	0.29	0.21	0.22	0.55	93.09	87.63	90.93	90.52	76.29	0.0	0.0	0.0	0.0	0.0
Sum	40.41	43.49	130.88	34.14	36.56	34.82	35.18	105.06	10.96	11.85	11.21	11.27	35.85						1.509	1.712	1.535	1.690	6.344
Mean	13.47	1.45	4.36	1.14	1.22	1.16	1.17	3.50	0.36	0.40	0.37	0.33	1.20						0.0503	0.057	0.051	0.056	0.212

Table A4: Daily Rainfall amount, Runoff depth and Rates, drainage and sediment yield data collected at Numu Farm Centre during natural rainfall event from April – October, 2003

PERIOD: JULY, 2003

Day	I Rainfall depth (mm)	II Rainfall Duration (hr)	III Rainfall intensity (mm/hr)	IV Runoff depth (mm) Natural cover plot					V Runoff depth (mm) V = IV / II Natural cover plot					VI Drainage (%) VI (I – IV)/I x 100 Natural – cover plot					Sediment Yield (kg/m²) VII = Dry weight of Eroded Soil / Plot area Natural cover plot				
				R_1	R_2	R_3	R_{Av}	R_{Bare}	R_1	R_2	R_3	R_{Av}	R_{Bare}	D_1	D_2	D_3	D_{AV}	D_{Bare}	S_1	S_2	S_3	S_{AV}	S_{Bare}
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	15.8	1.92	8.24	3.12	3.56	4.02	3.57	5.81	1.63	1.85	2.09	1.86	3.03	80.25	77.47	74.56	77.41	63.23	0.023	0.026	0.031	0.027	1.24
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	1.10	1.03	0.40	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.00	100.00	100.00	100.00	0.00	0.0	0.0	0.0	0.0
8	2.50	1.70	1.47	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.00	100.00	100.00	100.00	0.00	0.0	0.0	0.0	0.0
9	3.00	6.52	0.48	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	53.50	4.03	3.25	8.01	7.32	5.48	6.94	15.10	1.99	1.82	1.36	1.72	3.75	85.03	89.75	87.56	87.56	71.78	0.076	0.068	0.036	0.060	2.464
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	0.2	0.15	1.33	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.00	100.00	100.00	100.00	0.00	0.0	0.0	0.0	0.0
13	0.5	0.32	1.58	0,0	0.0	0.0	0.0	0.0	0:0	0.0	0.0	0.0	0.0	0.0	100.00	100.00	100.00	100.00	0.00	0.0	0.0	0.0	0.0
z14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	14.0	3.32	4.22	2.66	3.78	2.24	2.89	6.57	0.80	1.14	0.68	0.87	1.98	81.00	73.00	84.00	79.36	53.07	0.002	0.0026	0.0018	0.0021	0.78
16	6.80	5.53	1.23	0.0	0.0	0.0	0.0	2.21	0.0	0.0	0.0	0.0	0.40	100.00	100.00	100.00	100.00	67.5	0.0	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	0.50	1.10	0.46	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.00	100.00	100.00	100.00	100.00	0.0	0.0	0.0	0.0	0.0
19	0.40	0.55	0.92	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.00	100.00	100.00	100.00	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	0.30	0,87	0.35	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.00	100.00	100.00	100.00	100.00	0.0	0.0	0.0	0.0	0.0
22	0.40	0.68	0.59	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.00	100.00	100.00	100.00	100.00	0.0	0.0	0.0	0.0	0.0
23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	0.40	1.43	0.28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.00	100.00	100.00	100.00	100.00	0.0	0.0	0.0	0.0	0.0

Table A4: Contd

Day	I Rainfall depth (mm)	II Rainfall Duration (hr)	III Rainfall intensity (mm/hr)	IV Runoff depth (mm) Natural cover plot					V Runoff depth (mm) V = IV / II Natural cover plot					VI Drainage (%) VI (I – IV)/I x 100 Natural – cover plot					Sediment Yield (kg/m²) VII = Dry weight of Eroded Soil / Plot area Natural cover plot				
				R_1	R_2	R_3	R_{Av}	R_{Bare}	R_1	R_2	R_3	R_{Av}	R_{Bare}	D_1	D_2	D_3	D_{AV}	D_{Bare}	S_1	S_2	S_3	S_{AV}	S_{Bare}
25	4.40	5.80	0.76	0.0	0.0	0.0	0.0	0.51	0.0	0.0	0.0	0.0	0.09	100.00	100.00	100.00	100.00	88,41	0.0	0.0	0.0	0.0	0.0
26	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28	2.90	2.70	1.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.00	100.00	100.00	100.00	100.00	0.0	0.0	0.0	0.0	0.0
29	0.10	0.47	0.21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.00	100.00	100.00	100.00	100.00	0.0	0.0	0.0	0.0	0.0
30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31	6.30	7.48	0.84	0.0	0.0	0.0	0.0	1.50	0.0	0.0	0.0	0.0	0.20	100.00	100.00	100.00	100.00	76.19	0.0	0.0	0.0	0.0	0.0
Sum	113.1	45.60	37.41	13.79	14.68	11.74	13.4	31.7	4.42	4.81	4.13	4.45	9.45						0.308	0.0966	0.0688	0.0891	4.412
Mean	3.148	1.471	1.209	0.444	0.474	0.379	0.432	1.023	0.143	0.155	0.133	0.144	0.31						0.010	0.003	0.0022	0.003	0.142

Table A5: Daily Rainfall amount, Runoff depth and Rates, drainage and sediment yield data collected at Numu Farm Centre during natural rainfall event from April – October, 2003

PERIOD: AUGUST, 2003

Day	I Rainfall depth (mm)	II Rainfall Duration (hr)	III Rainfall intensity (mm/hr)	IV Runoff depth (mm) Natural cover plot					V Runoff depth (mm) V = IV / II Natural cover plot					VI Drainage (%) = (I – IV)/I x 100 Natural – cover plot					Sediment Yield (kg/m²) VII = $\frac{\text{Dry weight of Eroded Soil}}{\text{Plot area}}$ Natural cover plot				
				R_1	R_2	R_3	R_{Av}	R_{Bare}	R_1	R_2	R_3	R_{Av}	R_{Bare}	D_1	D_2	D_3	D_{AV}	D_{Bare}	S_1	S_2	S_3	S_{AV}	S_{Bare}
1	0.3	4.02	0.074	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.00	100.00	100.00	100.00	100.00	0.0	0.0	0.0	0.0	0.0
2	0.3	2.37	0.11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.00	100.00	100.00	100.00	100.00	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	11.2	0.40	28.0	3.22	2.86	3.04	3.04	7.11	8.05	7.15	7.60	7.60	17.78	71.25	74.46	72.86	72.86	36.52	0.36	0.18	0.31	0.28	1.23
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	0.3	0.63	0.47	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.00	100.00	100.00	100.00	100.00	0.0	0.0	0.0	0.0	0.0
8	1.4	3.92	0.36	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.00	100.00	100.00	100.00	100.00	0.0	0.0	0.0	0.0	0.0
9	3.1	1.85	1.68	0.58	0.61	0.72	0.64	1.66	0.31	0.33	0.39	0.35	0.90	81.29	80.32	76.77	79.39	40.45	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	2.1	0.22	9.55	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.00	100.00	100.00	100.00	100.00	0.0	0.0	0.0	0.0	0.0
12	11.0	3.63	3.03	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.00	100.00	100.00	100.00	100.00	0.0	0.0	0.0	0.0	0.0
13	23.1	2.72	8.15	0.61	0.56	0.71	0.63	10.23	0.22	0.21	0.26	0.23	3.76	97.36	97.58	96.93	97.27	55.71	55.76^{-3}	5.35^{-3}	6.88^{-3}	5.97^{-3}	1.02
14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	18.3	3.65	5.01	3.05	4.48	5.16	4.23	9.11	0.84	1.23	1.41	1.16	2.50	83.22	75.52	71.80	76.89	50.22	0.012	0.023	0.039	0.025	0.86
17	3.3	4.20	0.79	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.00	100.00	100.00	100.00	100.00	0.0	0.0	0.0	0.0	0.0
18	128.0	4.32	29.63	25.87	56.65	26.13	36.22	61.52	5.99	13.11	6.05	8.38	14.24	79.79	55.74	7959	71.70	51.94	1.64	5.50	2.19	3.11	7.00
19	19.9	1.12	17.77	1.70	2.77	3.63	2.70	5.31	1.52	2.47.	3.24	2.41	4.77	91.46	86.08	81.76	86.43	73.17	0.048	0.29	0.35	0.22	0.81
20	47.3	2.55	18.55	10.34	23.62	15.46	16.47	29.66	4.06	9.26	6.06	6.46	11.63	78.18	50.06	67.32	65.18	37.29	0.82	1.34	0.91	1.023	1.42
21	19.9	4.50	4.42	5.71	2.87	4.29	4.29	6.01	1.27	0.64	0.95	0.95	1.34	71.31	50.06	67.32	65.18	37.29	0.82	1.34	0.91	1.003	1.42

Table A5: Contd

Day	I Rainfall depth (mm)	II Rainfall Duration (hr)	III Rainfall intensity (mm/hr)	IV Runoff depth (mm) Natural cover plot					V Runoff depth (mm) V = IV / II Natural cover plot					VI Drainage (%) = (I – IV)/I x 100 Natural – cover plot					Sediment Yield (kg/m²) VII = Dry weight of Eroded Soil / Plot area Natural cover plot				
				R_1	R_2	R_3	R_{Av}	R_{Bare}	R_1	R_2	R_3	R_{Av}	R_{Bare}	D_1	D_2	D_3	D_{AV}	D_{Bare}	S_1	S_2	S_3	S_{AV}	S_{Bare}
22	8.6	1.69	5.15	1.96	3.32	2.78	2.67	4.36	1.17	1.99	1.67	1.60	2.61	77.21	61.40	85.59	68.72	49.30	0.0	0.0	0.0	0.0	0.0
23	10.0	0.45	22.22	2.66	3.07	5.48	3.74	5.78	5.91	6.82	12.18	8.31	12.84	73.40	69.30	42.20	62.60	42.2	0.086	0.128	0.229	0.149	0.259
24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	54.9	1.32	41.59	23.78	30.40	22.79	25.66	40.11	18.02	23.03	17.27	19.44	30.39	56.69	44.63	58.49	53.26	26.94	0.170	0.423	0.298	0.297	0.76
26	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30	4/40	4.30	10.23	20.32	14.65	14.98	16.65	23.22	4.73	3.41	3.48	3.87	5.40	53.82	66.71	65.96	62.16	47.23	0.285	0.232	0.246	0.254	0.325
31	9.1	2.80	3.25	0.27	0.31	1.41	0.66	7.69	0.10	0.11	0.50	0.24	2.75	97.03	96.59	84.51	92.75	15.50	0.0	0.0	0.0	0.0	0.0
Sum	416.2	81.66	209.88	100.07	146.17	106.58	117.6	211.80	52.18	69.76	61.06	61.00	110.01								4.660	5.467	14.33
Mean	13.43	2.63	6.77	3.23	4.72	3.44	3.79	6.83	1.68	2.25	1.97	1.97	3.58								0.150	0.176	0.462

Table A6: Daily Rainfall amount, Runoff depth and Rates, drainage and sediment yield data collected at Numu Farm Centre during natural rainfall event from April – October, 2003

PERIOD: SEPTEMBER, 2003

Day	I Rainfall depth (mm)	II Rainfall Duration (hr)	III Rainfall intensity (mm/hr)	IV Runoff depth (mm) Natural cover plot					V Runoff depth (mm) V = IV / II Natural cover plot					VI Drainage (%) = (I – IV)/I x 100 Natural – cover plot					Sediment Yield (kg/m²) VII = Dry weight of Eroded Soil / Plot area Natural cover plot				
				R_1	R_2	R_3	R_{Av}	R_{Bare}	R_1	R_2	R_3	R_{Av}	R_{Bare}	D_1	D_2	D_3	D_{AV}	D_{Bare}	S_1	S_2	S_3	S_{AV}	S_{Bare}
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	10.0	2.27	4.45	1.38	0.72	1.34	1.15	2.01	0.61	0.32	0.59	0.51	0.89	86.34	92.87	86.93	88.61	80.10	0.0	0.0	0.0	0.0	0.0
3	1.9	1.40	1.36	0.11	0.04	0.13	0.11	0.44	0.08	0.03	0.09	0.08	0.31	94.21	95.26	95.26	94.21	76.84	0.0	0.0	0.0	0.0	0.0
4	0.4	0.27	1.48	0.0	0.0	0.25	0.25	0.33	0.0	0.0	0.93	0.93	0.22	0.0	0.0	37.50	37.50	17.50	0.0	0.0	0.0	0.0	0.0
5	21.9	4.28	5.12	5.32	9.11	4.3	6.24	10.6	1.24	2.13	1.00	1.46	2.48	75.71	58.40	80.37	71.51	51.60	0.0	0.0	0.0	0.0	0.0
6	30.1	7.18	4.19	6.51	9.3	8.97	8.26	11.16	0.91	1.30	1.25	1.15	1.55	78.37	69.10	70.20	72.56	62.92	0.202	0.280	0.270	0.251	0.460
7	32.0	6.55	4.89	6.62	10.4	8.6	8.54	10.34	1.01	1.55	1.31	1.30	1.88	79.31	69.50	73.13	73.31	61.44	0.0	0.0	0.0	0.0	0.0
8	22.8	5.00	4.56	1.33	3.39	2.46	2.39	4.00	0.27	0.68	0.50	0.48	0.8	94.17	85.13	89.21	89.52	82.46	0.069	0.056	0.078	0.068	0.120
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	38.3	2.45	15.63	1.96	0.6	14.05	5.54	14.46	0.80	0.25	5.74	2.26	5.90	94.88	98.43	63.32	85.51	62.25	0.112	0.120	0.136	0.123	0.173
13	16.3	1.08	15.09	3.03	5.25	6.18	4.82	6.71	2.31	4.86	5.72	4.46	6.21	81.41	67.79	62.09	70.43	58.83	0.0	0.0	0.0	0.0	0.0
14	4.5	1.98	2.2	1.76	3.03	1.25	2.01	3.18	0.89	1.53	0.63	1.02	1.61	60.89	32.67	72.22	55.33	29.33	0.0	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	8.2	0.30	27.33	3.19	5.32	4.85	4.45	6.38	10.63	17.73	16.17	14.83	21.27	61.10	35.12	40.85	45.73	22.20	0.0	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	24.4	1.3	18.77	2.06	1.31	2.66	2.01	3.19	1.59	1.01	2.05	1.55	2.45	91.56	94.68	89.10	91.76	86.93	0.0	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	39.1	13.83	2.83	1.73	2.46	6.18	3.46	13.22	0.13	0.18	0.45	0.25	0.96	95.58	93.71	84.19	91.15	66.19	0.084	0.214	0.268	0.188	0.330
24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	16.3	13.08	1.25	1.13	1.53	3.39	2.02	5.25	0.09	0.12	0.26	0.15	0.40	93.07	90.61	79.20	87.61	67.79	0.0	0.0	0.0	0.0	0.0
26	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table A6: Contd

Day	I Rainfall depth (mm)	II Rainfall Duration (hr)	III Rainfall intensity (mm/hr)	IV Runoff depth (mm) Natural cover plot					V Runoff depth (mm) V = IV / II Natural cover plot					VI Drainage (%) = (I – IV)/I x 100 Natural – cover plot					Sediment Yield (kg/m²) VII = Dry weight of Eroded Soil / Plot area Natural cover plot				
				R_1	R_2	R_3	R_{Av}	R_{Bare}	R_1	R_2	R_3	R_{Av}	R_{Bare}	D_1	D_2	D_3	D_{AV}	D_{Bare}	S_1	S_2	S_3	S_{AV}	S_{Bare}
27	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28	28.2	1.78	15.84	10.95	10.93	11.06	10.97	12.46	6.15	6.14	6.21	6.16	7.00	61.17	61.2f4	60.78	61.10	55.82	0.0	0.0	0.0	0.0	0.0
29	55.2	1.08	51.11	4.12	23.25	17.87	15.08	32.28	3.82	21.53	16.55	13.96	29.89	92.54	57.88	67.63	72.68	41.52	0.0	0.0	0.0	0.0	0.0
30	0.9	0.23	5.91	0.11	0.11	0.12	0.2	0.79	0.48	0.48	0.52	0.87	3.44	87.78	87.78	86.67	87.78	87.78	0.0	0.0	0.0	0.0	0.0
Sum	350.60	64.06	180.08	51.31	86.48	93.47	77.22	138.80	31.51	59.84	59.97	51.42	88.26						0.467	0.670	0.752	0.630	1.083
Mean	11.69	2.14	6.00	1.71	2.88	3.12	2.57	4.63	1.05	2.00	2.00	1.71	2.94						0.016	0.022	0.025	0.021	0.036

Table A7: Daily Rainfall amount, Runoff depth and Rates, drainage and sediment yield data collected at Numu Farm Centre during natural rainfall event from April – October, 2003

PERIOD: OCTOBER

Day	I Rainfall depth (mm)	II Rainfall Duration (hr)	III Rainfall intensity (mm/hr)	IV Runoff depth (mm) Natural cover plot					V Runoff depth (mm) V = IV / II Natural cover plot					VI Drainage (%) = (I – IV)/I x 100 Natural – cover plot					Sediment Yield (kg/m²) VII = Dry weight of Eroded Soil / Plot area Natural cover plot				
				R_1	R_2	R_3	R_{Av}	R_{Bare}	R_1	R_2	R_3	R_{Av}	R_{Bare}	D_1	D_2	D_3	D_{AV}	D_{Bare}	S_1	S_2	S_3	S_{AV}	S_{Bare}
1	27.7	2.5	11.08	1.86	2.18	2.26	2.10	2.46	0.74	0.87	0.90	0.84	0.98	93.29	92.13	91.84	92.42	91.12	0.0477	0.1097	0.1437	0.1004	0.1557
2	24.4	1.5	16.27	2.46	2.86	3.79	3.04	5.65	1.64	1.91	2.53	2.03	3.77	86.93	88.28	84.47	87.54	77.48	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	65.2	4.17	15.64	13.42	23.85	17.87	18.38	32.28	3.22	5.92	4.29	4.41	7.74	79.42	63.42	72.59	71.81	50.49	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0737	0.0757	0.0937	0.0810	0.1877
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	11.9	1.97	5.97	0.93	2.99	3.92	2.55	4.85	0.47	1.52	1.89	1.29	2.46	92.05	74.44	67.44	73.93	54.27	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	54.6	3.42	5.97	9.70	23.61	20.76	18.02	28.80	2.84	6.90	6.07	5.27	8.42	82.23	56.76	61.98	67.00	47.25	0.0	0.0	0.0	0.0	0.0
10	12.0	1.00	12.0	0.39	1.40	0.60	0.80	2.39	0.39	1.40	0.60	0.80	2.39	96.75	88.33	95.00	98.33	80.08	0.0	0.0	0.0	0.0	0.0
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	10.0	1.52	6.58	0.20	1.13	0.80	1.04	3.01	0.13	0.74	0.53	1.98	1.98	98.00	88.70	92.00	89.60	69.90	0.0	0.0	0.0	0.0	0.0
13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	15.3	1.52	10.09	0.56	1.01	0.74	0.77	1.27	0.37	0.67	0.49	0.51	0.84	96.34	93.40	95.16	94.97	91.70	0.0	0.5425	0.03	0.2898	0.6054
15	45.0	3.70	12.16	0.23	0.23	0.08	018	1.09	0.06	0.06	0.02	0.05	0.30	99.49	99.49	99.82	99.60	97.58	0.0	0.0	0.0	0.0	0.0
16	38.2	2.00	19.10	6.25	15.3	8.41	9.99	19.08	3.13	7.65	4.21	5.00	9.54	83.64	59.95	77.98	73.85	50.05	0.0	0.36	0.04	0.200	0.540
17	14.7	0.75	18.77	2.25	2.13	4.41	2.93	6.01	2.89	2.73	5.65	3.76	7.71	84.69	85.51	70.00	80.07	59.12	0.0	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	010	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table A7: Contd

Day	I Rainfall depth (mm)	II Rainfall Duration (hr)	III Rainfall intensity (mm/hr)	IV Runoff depth (mm) Natural cover plot					V Runoff depth (mm) V = IV / II Natural cover plot					VI Drainage (%) = (I – IV)/I x 100 Natural – cover plot					Sediment Yield (kg/m^2) $VII = \frac{\text{Dry weight of Eroded Soil}}{\text{Plot area}}$ Natural cover plot				
				R_1	R_2	R_3	R_{Av}	R_{Bare}	R_1	R_2	R_3	R_{Av}	R_{Bare}	D_1	D_2	D_3	D_{AV}	D_{Bare}	S_1	S_2	S_3	S_{AV}	S_{Bare}
19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	01.0	0.0	0.0	0.0	0.0	0.0	0.0
23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	10.1	0.68	14.85	2.01	2.13	2.06	2.09	4.63	2.956	3.132	3.029	3.044	6.81	80.10	78.91	79.60	79.51	54.16	0.0	0.0	0.0	0.0	0.0
26	0.6	1.12	0.54	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.00	100.00	100.00	100.00	100.00	0.0	0.0	0.0	0.0	0.0
27	2.6	0.58	4.46	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.00	100.00	100.00	100.0000	100.00	0.0	0.0	0.0	0.0	0.0
28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	01.0
30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31	0.3	0.3	1.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.00	100.00	100.00	100.00	100.00	0.0	0.0	0.0	0.0	0.0
Sum	332.4	26.76	164.48	40.76	78.82	65.50	61.87	111.52	18.84	33.30	30.21	28.89	46.59						0.1214	1.0949	0.3004	0.6712	1.4888
Mean	10.72	0.86	5.31	130	2.54	2.11	2.00	3.60	0.61	1.07	0.98	0.93	1.505						0.0607	0.0353	0.0010	0.027	0.048

APPENDIX B

Table B1: Sample Correlations (Matrix)

	Min - temp	*Max- temp*	*Evaporation*	*Rainfall duration*	*Rainfall amount*	*Rainfall intensity*	*Runoff depth (N.C)*	*Runoff depth (Bare)*	*Drainage (N.C)*	*Drainage (Bare)*	*Sediment (N.C)*	*Sediment (Bare)*
Min temp	1.0000	.7323	.3458	-.2039	-.1967	-.0679	-.2102	-.2129	-.1768	-.1732	-.1076	-.1026
	(212)	(212)	(212)	(212)	(212)	(212)	(212)	(212)	(212)	(212)	(212)	(212)
	.0000	.0000	.0000	.0029	.0040	.3252	.0021	.0018	.0099	.0115	.1183	.1365
Max Temp	.7323	1.0000	.5035	-.2728	-.2409	-.1368	-.2315	-.2419	-.2259	-.2188	-.1485	-.1670
	(212)	(212)	(212)	(212)	(212)	(212)	(212)	(212)	(212)	(212)	(212)	(212)
	.0000	.0000	.0000	.0001	.0004	.0467	.0007	.0004	.0009	.0013	.0307	.0149
Evapo	.3458	.5035	1.0000	-.2788	-.2913	-.3170	-.2128	-.2421	-.2882	-.2983	-.0876	-.1108
	(212)	(212)	(212)	(212)	(212)	(212)	(212)	(212)	(212)	(212)	(212)	(212)
	.0000	.0000	.0000	.0000	.0000	.0000	.0018	.0004	.0000	.0000	.2037	.1077
Rainfall duration	-.2039	-.2728	-.2788	1.0000	.4236	.1310	.3290	.3761	.4225	.4152	.2159	.2222
	(212)	(212)	(212)	(212)	(212)	(212)	(212)	(212)	(212)	(212)	(212)	(212)
	.0029	.0001	.0000	.0000	.0000	.0569	.0000	.0000	.0000	.0000	.0016	.0011
Rainfall amount	-.1967	-.2409	-.2913	.4236	1.0000	.5707	.8078	.9019	.9812	.9712	.6923	.7937
	(212)	(212)	(212)	(212)	(212)	(212)	(212)	(212)	(212)	(212)	(212)	(212)
	.0040	.0004	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000

Table B1: Sample Correlations (Matrix)

	Min - temp	*Max-temp*	*Evaporation*	*Rainfall duration*	*Rainfall amount*	*Rainfall intensity*	*Runoff depth (N.C)*	*Runoff depth (Bare)*	*Drainage (N.C)*	*Drainage (Bare)*	*Sediment (N.C)*	*Sediment (Bare)*
Rainfall intensity	-.0679	-.1368	-.3170	.1310	.5707	1.0000	.5603	.5957	.5131	.5065	.3906	.4078
	(212)	(212)	(212)	(212)	(212)	(212)	(212)	(212)	(212)	(212)	(212)	(212)
	.3252	.0467	.0000	.0569	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
Runoff (N.C)	-.2102	-.2315	-.2128	.3290	.8078	.5603	1.0000	.9356	.6985	.6530	.7256	.6902
	(212)	(212)	(212)	(212)	(212)	(212)	(212)	(212)	(212)	(212)	(212)	(212)
	.0021	.0007	.0018	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
Runoff (Bare)	-.2129	-.2419	-.2429	.3761	.9019	.5957	.9356	1.0000	.8214	.7883	.6949	.7511
	(212)	(212)	(212)	(212)	(212)	(212)	(212)	(212)	(212)	(212)	(212)	(212)
	.0018	.0004	.0004	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
Drainage (N.C)	-.1768	-.2259	-.2882	.4225	.9812	.5131	.6985	.8214	1.0000	.9919	.6508	.7807
	(212)	(212)	(212)	(212)	(212)	(212)	(212)	(212)	(212)	(212)	(212)	(212)
	.0099	.0009	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
Drainage (Bare)	-.1732	-.2188	-.2983	.4152	.9712	.5065	.6530	.7883	.9919	1.0000	.6095	.7463
	(212)	(212)	(212)	(212)	(212)	(212)	(212)	(212)	(212)	(212)	(212)	(212)
	.0115	.0013	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000

TABLE B1: Sample Correlations (Matrix)

	Min - temp	*Max-temp*	*Evaporation*	*Rainfall duration*	*Rainfall amount*	*Rainfall intensity*	*Runoff depth (N.C)*	*Runoff depth (Bare)*	*Drainage (N.C)*	*Drainage (Bare)*	*Sediment (N.C)*	*Sediment (Bare)*
Sediment (N.C)	-.1076	-.1485	-.0876	.2159	.6923	.3906	.7256	.6949	.6508	.6095	1.0000	.9293
	(212)	(212)	(212)	(212)	(212)	(212)	(212)	(212)	(212)	(212)	(212)	(212)
	.1183	.0307	.2037	.0016	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
Sediment (Bare)	-.1026	-.1670	-.1108	.2222	.7937	.4078	.6902	.7511	.7807	.7463	.9293	1.0000
	(212)	(212)	(212)	(212)	(212)	(212)	(212)	(212)	(212)	(212)	(212)	(212)
	.1365	.0149	.1077	.0011	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000

APPENDIX C

One – way Analysis of Variance

Range test : Tukey

Confidence level: 95

C1: Analysis of variance for Minimum temperature

Source of variation	Sum of squares	d.f	Mean square	F – ratio	Sig. Level
Between groups	392.47728	6	65.412880	40.942	0.0000
Within groups	330.72366	207	1.597699		
Total	723.20093	213			

C2: Analysis of variance for Maximum temperature

Source of variation	Sum of squares	d.f	Mean square	F – ratio	Sig. Level
Between groups	1731.7200	6	288.61999	88.577	0.0000
Within groups	674.4903	207	3.25841		
Total	2406.2103	213			

C3: Analysis of variance for Rainfall depth (amount)

Source of variation	Sum of squares	d.f	Mean square	F – ratio	Sig. Level
Between groups	5256.348	6	876.05807	1.991	0.0684
Within groups	91092.292	207	440.05938		
Total	96348.640	213			

C4: Analysis of variance for Rainfall duration

Source of variation	Sum of squares	d.f	Mean square	F – ratio	Sig. Level
Between groups	91.5565	6	15.192608	3.616	0.0020
Within groups	869.79211	207	4.201894		
Total	960.94776	213			

C5: Analysis of variance for Runoff depth (Natural – cover)

Source of variation	Sum of squares	d.f	Mean square	F – ratio	Sig. Level
Between groups	359.1181	6	59.853011	3.325	0.0038
Within groups	3726.4613	209	18.002228		
Total	4085.5793	213			

C6: Analysis of variance for Runoff depth (Bare – plot)

Source of variation	Sum of squares	d.f	Mean square	F – ratio	Sig. Level
Between groups	12286.284	6	2047.7139	10.566	0.0000
Within groups	39729.580	205	193.8028		
Total	52015.863	211			

C7: Analysis of variance for Evaporation

Source of variation	Sum of squares	d.f	Mean square	F – ratio	Sig. Level
Between groups	932.609	6	155.43490	2.639	0.0173
Within groups	12191.306	207	58.89520		
Total	13123.915	213			

C8: Analysis of variance for Drainage, mm (Natural – cover)

Source of variation	Sum of squares	d.f	Mean square	F – ratio	Sig. Level
Between groups	3152.129	6	525.35491	1.694	0.1239
Within groups	64193.131	207	310.11174		
Total	67345.260	213			

C9: Analysis of variance for Drainage, mm (Bare – treatment)

Source of variation	Sum of squares	d.f	Mean square	F – ratio	Sig. Level
Between groups	1960.392	6	326.73207	1.615	0.1444
Within groups	41877.127	207	202.30496		
Total	43837.519				

C10: Analysis of variance for Sediment Yield (Natural – cover)

Source of variation	Sum of squares	d.f	Mean square	F – ratio	Sig. Level
Between groups	0.699078	6	0.1165130	1.989	0.0687
Within groups	12.125672	207	0.0585781		
Total	12.824750	213			

C11: Analysis of variance for Sediment Yield (Bare – treatment)

Source of variation	Sum of squares	d.f	Mean square	F – ratio	Sig. Level
Between groups	4.858489	6	0.8097482	1.930	0.774
Within groups	86.844113	207	0.4195368		
Total	91.702602	213			

APPENDIX D

Control measures classified and recommended by US – EPA (1993).

▪ *CONSERVATION COVER*	*Establish and maintain perennial vegetative cover to protect soil and water resources on land retired from agricultural production.*
▪ *CONSERVATION CROPPING*	*A sequence of crops designed to provide adequate organic residues erosion by increasing organic matter. It may also disrupt disease, insect and weed production cycles hereby reducing the need for pesticides. This may include grasses and legumes planted in rotation.*
▪ *CONSERVATION TILLAGE*	*Also known as reduced tillage, this is a planting system that maintains at least 30% of the soil surface covered by residue after planting. Providing soil cover reduces erosion. Runoff is reduced and infiltration into groundwater is increased.*
▪ *CONTOUR FARMING*	Ploughing, planting, and other management practices that are carried out along land contours, thereby reducing erosion and runoff.
▪ *COVER AND GREEN MANURE CROP*	*A crop of close-growing grasses, legumes, or small grain grown primarily for seasonal protection and soil improvement. Usually it is grown for one year or less.*
▪ *CRITICAL AREA PLANTING*	*Planting vegetation, such as trees, shrubs,vines, grasses or legumes, On highly erodible or eroding areas.*
▪ *CROP RESIDUE USE*	*Using plant residues to protect cultivated fields during critical erosion periods.*
▪ *DELAYED SEEDBED PREPARATION*	*Any cropping system in which all crop residue is maintained on the soil surface until shortly before the succeeding crop is planted. This reduces the period that the soil is susceptible to erosion.*
▪ *DIVERSIONS*	*Channels constructed across the slope with a supporting ridge on the lower side. By controlling downslope runoff, erosion is reducedand infiltration into the ground water is enhanced.*
▪ *FIELD BORDERS AND FILTER STRIPS*	*A strip of perennial herbaceous vegetation along the edge of fields. This slows runoff and traps coarser sediment. This is not generally effective, however, for fine sediment and associated pollutants.*
▪ *GRASSED WATERWAYS*	*A natural or constructed channel that is vegetated and is graded and shaped so as to inhibit channel erosion. The vegetation will also serve to trap sediment that is washed in from adjacent fields.*

▪ *SEDIMENT BASINS*	*Basins constructed to collect and store sediment during runoff events. Also known as detention parts sediment is deposited from runoff during impoundment in the sediment basin.*
▪ *STRIP CROPPING*	*Growing crops in a systematic arrangement of strips or bands across the general slope (not on the contour) to reduce water erosion. Crops are arranged to that a strip of grass or close-growing crop is alternated with a clean-tilled crop or follow.*
▪ *TERRACING*	*Terraces are constructed earthen embankments that retard runoff and reduce erosion by breaking the slope into numerous flat surfaces separated by slopes that are protected with permanent vegetation or which are constructed from stone, etc. Terracing is carried out on very steep slopes, and on long gentle slopes where terraces are very broad.*

Source: FAO (1996)

APPENDIX E

MULTIPLE LINEAR REGRESSION

This sheet demonstrates Mathcad statistical functions for multiple linear regression of n-tuple data. The first column of the data is assumed to be the y-variable and the remai columns the x variables.

NATURAL COVER

Below is the matrix of n-tuple data:

E1: Matrix Of N-Tuple Data (Natural Cover)

data :=

0	0.57	0.36	1.37	0	0	100
0.026	3.7	0.22	6.27	0.26	0.84	92.97
0.06	13.47	1.46	4.36	1.17	0.38	91.31
0.002	3.65	1.47	1.21	0.43	0.14	88.22
0.18	13.42	1.65	6.77	3.79	1.97	71.76
0.03	11.69	2.14	6	2.58	2.49	77.93
0.02	10.72	0.86	5.31	2	0.89	81.34

N := rows(data)   n := cols(data)

Degree of fitting polynomial: k := 1

$Y := data^{\langle 0 \rangle}$ X := submatrix(data, 0, N − 1, 1, n − 1)

Number of data points: N = 7

Number of coordinates: n = 7

z := regress(X, Y, k)   i := 0.. N − 1

Polynomial fitting function:

fit(x) := interp(z, X, Y, x)

$predY_i := fit\left[\left(X^T\right)^{\langle i \rangle}\right]$

Coefficients for regression equation $= a_0 + a_1x_1 + \ldots + a_nx_n$

coeffs := submatrix(z, 3, length(z) − 1, 0, 0)

$coeffs^T$ = (−0.029672 0.185905 0.071572 0.178825 −0.19278 0.012854 −1.433467)

$$Y_m = -1.433467 - 0.029672 \cdot x_1 + 0.185905 \cdot x_2 + 0.071572 \cdot x_3 + 0.178825 x_4 - 0.19278 \cdot x_5 + 0.012854 \cdot x_6$$

Residuals: $resid := predY - Y$

Original Y data **Predicted Y values**

$$Y = \begin{pmatrix} 0 \\ 0.026 \\ 0.06 \\ 0.002 \\ 0.18 \\ 0.03 \\ 0.02 \end{pmatrix} \qquad predY = \begin{pmatrix} -0 \\ 0.026 \\ 0.06 \\ 0.002 \\ 0.18 \\ 0.03 \\ 0.02 \end{pmatrix}$$

R^2:

$$\frac{\sum \overrightarrow{(predY - mean(Y))^2}}{\sum \overrightarrow{(Y - mean(Y))^2}} = 1$$

BARE

Below is the matrix of n-tuple data:

data :=

E2: Matrix Of N-Tuple Data (Bare)

0	0.57	0.36	1.37	0	0	100
0.046	3.7	0.22	6.27	0.76	2.08	79.46
0.21	13.47	1.46	4.36	3.44	1.12	74.46
0.14	3.65	1.47	1.21	1.02	0.28	72.06
0.46	13.42	1.65	6.77	6.11	3.58	54.47
0.04	11.69	2.14	6	4.61	2.85	60.57
0.05	10.72	0.86	5.31	3.6	1.71	66.42

$N := rows(data)$ $n := cols(data)$

Degree of fitting polynomial: $k := 1$

$Y := data^{\langle 0 \rangle}$ $X := submatrix(data, 0, N-1, 1, n-1)$

Number of data points: $N = 7$

APPENDIX F

(1) Correlation Coefficient, r for Runoff depth (Natural – cover) and Rainfall depth. The scattergram is presented in figure 6.

TABLE F1: Matrix Plan For Runoff Depth And Rainfall Depth

Month	*Runoff*	*Rainfall*	*Runoff Ranking*	*Rainfall Ranking*	*D*	*D^2*
April	0.0	0.57	1	1	0	0
May	0.26	3.70	2	3	-1	1
June	1.17	13.47	4	7	-3	9
July	0.43	3.65	3	2	1	1
August	3.79	13.42	7	6	1	1
September	2.59	11.69	6	5	1	1
October	2.00	10.72	5	4	1	1

$\Sigma D^2 = 14$

Calculation:

$$r_s = 1 - \frac{6\Sigma D^2}{N(N^2-1)} = 1 - \frac{6 \times 14}{7 \times 48}$$

$$= 1 - \frac{84}{336}$$

$$= 1 - 0.25$$

$$\therefore r_s = 0.75$$

(2) Correlation Coefficient, r for sediment yield (Natural – cover) and Rainfall depth. The scattergram is presented in figure 7.

TABLE F2: Matrix Plan For Sediment Yield And Rainfall Depth

Month	*Sediment yield*	*Rainfall depth*	*Sediment ranking*	*Rainfall Ranking*	*D*	*D^2*
April	0.0	0.57	1	1	0	0
May	0.02	3.70	3 ½	3	½	¼
June	0.06	13.47	6	7	-1	1
July	0.002	3.65	2	2	0	0
August	0.18	13.42	7	6	1	1
September	0.003	11.69	5	5	0	0
October	0.02	10.72	3 ½	4	- ½	¼

$\Sigma D^2 = 2\frac{1}{2}$

Calculation:

$$r_S = 1 - \frac{6\sum D^2}{N(N^2-1)} = 1 - \frac{6 \times 2\frac{1}{2}}{7 \times 48}$$

$$= 1 - \frac{15}{336}$$

$$= 1 - 0.04464 = 0.9554$$

$$\therefore r_S = 0.96$$

(3) Correlation coefficient, r for sediment yield (Natural – cover) and Runoff depth. The Scattergram is presented in figure 8.

TABLE F3: Matrix Plan For Sediment Yield And Runoff Depth

Month	*Sediment yield (Natural Cover)*	*Runoff Natural (Natural cover)*	*Sediment Ranking*	*Runoff Ranking*	*D*	*D^2*
April	0.0	0.0	1	1	0	0
May	0.02	0.26	3 ½	2	1 ½	2 ¼
June	0.06	1.17	6	4	2	4
July	0.002	0.43	2	3	-1	1
August	0.18	3.79	7	7	0	0
September	0.03	2.59	5	6	-1	1
October	0.02	2.00	3 ½	5	-1 ½	2 ¼

$\Sigma D^2 = 11\ 1/16$

Calculation:

$$r_S = 1 - \frac{6\sum D^2}{N(N^2-1)} = 1 - \frac{6 \times 11\frac{1}{16}}{7 \times 48}$$

$$= 1 - \frac{66\frac{3}{8}}{336}$$

$$= 1 - \frac{66.375}{336}$$

$$= 1.019755$$

$$\therefore r_S = 0.80$$

(4) Correlation Coefficient, r for Runoff depth (Bare-treatment) and Rainfall depth. The Scattergram is presented in figure 9

TABLE F4: Matrix Plan For Runoff Depth And Rainfall Depth

Month	*Runoff (Bare)*	*Rainfall depth*	*Runoff Ranking*	*Rainfall Ranking*	*D*	*D^2*
April	0.0	0.57	1	1	0	0
May	2.08	3.70	5	3	2	4
June	1.12	13.47	3	7	-4	16
July	0.28	3.65	2	2	0	0
August	3.58	13.42	7	6	1	1
September	2.58	11.69	6	5	1	1
October	1.17	10.72	4	4	0	0

$\Sigma D^2 = 22$

Calculation:

$$r_S = 1 - \frac{6\Sigma D^2}{N(N^2-1)} = 1 - \frac{6 \times 22}{7 \times 48}$$

$$= 1 - \frac{132}{336}$$

$$= 1 - 0.3928571$$

$$= 0.607142857$$

$$\therefore r_S = 0.61$$

(5) Correlation coefficient, r for sediment yield and Runoff for Bare treatment.

The Scattergram is presented in Figure 10

TABLE F5: Matrix Plan For Sediment Yield And Runoff Depth

Month	*Sediment (Bare)*	*Runoff (Bare)*	*Sediment Ranking*	*Runoff Ranking*	*D*	*D^2*
April	0.0	0.0	1	1	0	0
May	0.04	2.08	2 ½	5	2 ½	6 ¼
June	0.21	1.12	6	3	3	9
July	0.14	0.28	5	2	3	9
August	0.46	3.58	7	7	0	0
September	0.04	2.85	2 ½	6	- 3 ½	12 ¼
October	0.05	1.17	4	4	0	0

$\Sigma D^2 = 36 \frac{1}{2}$

Calculation:

$$r_S = 1 - \frac{6\Sigma D^2}{N(N^2-1)} = 1 - \frac{6 \times 36\frac{1}{2}}{7 \times 48}$$

$$= 1 - \frac{219}{336}$$

$$= 1 - 0.65178571$$

$$r_S = 0.3482$$

$$\therefore r_S = 0.35$$

(6) Correlation coefficient, r for sediment (Bare –treatment) Rainfall depth. The scattergram is presented in figure 11

TABLE F6: Matrix Plan For Sediment Yield And Rainfall Depth

Month	*Sediment (Bare)*	*Rainfall depth*	*Sediment Ranking*	*Rainfall Ranking*	*D*	*D^2*
April	0.0	0.57	1	1	0	0
May	0.04	3.70	2 ½	3	- ½	¼
June	0.21	13.47	6	7	-1	1
July	0.14	3.65	5	2	3	9
August	0.46	12.42	7	6	1	1
September	0.04	11.69	2 ½	5	- 2 ½	6 ½
October	0.05	10.72	4	4	0	0

$\Sigma D^2 = 17\ ½$

Calculation:

$$r_s = 1 - \frac{6\Sigma D^2}{N(N^2-1)} = 1 - \frac{6 \times 17.5}{336}$$

$$= 1 - \frac{105}{336}$$

$$= 1 - 0.3125$$

$$\therefore r_s = 0.69$$

G – CRITERIA TABLE

ПРИЛОЖЕНИЕ VI

Критические значения G-критерия при уровне значимости α = 0,05

288

Число опытов N	Число степеней свободы													
	1	2	3	4	5	6	7	8	9	10	16	36	144	∞
2	0,999	0,975	0,939	0,906	0,858	0,853	0,833	0,816	0,801	0,788	0,734	0,660	0,581	0,500
3	0,967	0,871	0,798	0,746	0,707	0,677	0,653	0,633	0,617	0,603	0,547	0,476	0,403	0,333
4	0,907	0,768	0,684	0,629	0,590	0,560	0,537	0,518	0,502	0,488	0,437	0,372	0,303	0,250
5	0,841	0,684	0,598	0,544	0,506	0,478	0,456	0,439	0,424	0,412	0,365	0,307	0,251	0,200
6	0,781	0,616	0,532	0,480	0,446	0,418	0,398	0,382	0,368	0,357	0,314	0,261	0,212	0,167
7	0,727	0,561	0,480	0,431	0,391	0,373	0,356	0,338	0,325	0,316	0,276	0,228	0,183	0,143
8	0,680	0,516	0,438	0,391	0,360	0,336	0,319	0,301	0,293	0,283	0,246	0,202	0,162	0,125
9	0,640	0,478	0,403	0,358	0,329	0,307	0,290	0,277	0,266	0,257	0,223	0,182	0,145	0,111
10	0,602	0,445	0,373	0,331	0,303	0,282	0,267	0,254	0,244	0,235	0,203	0,166	0,131	0,100
12	0,541	0,392	0,326	0,288	0,262	0,244	0,230	0,219	0,210	0,202	0,174	0,140	0,110	0,083
15	0,471	0,335	0,276	0,242	0,220	0,203	0,191	0,182	0,174	0,167	0,143	0,114	0,089	0,067
20	0,389	0,271	0,221	0,192	0,174	0,160	0,150	0,142	0,136	0,130	0,111	0,088	0,065	0,050
24	0,343	0,235	0,191	0,166	0,149	0,137	0,129	0,121	0,116	0,111	0,094	0,074	0,057	0,042
30	0,293	0,198	0,159	0,138	0,124	0,114	0,106	0,100	0,096	0,092	0,077	0,060	0,046	0,033
40	0,237	0,158	0,126	0,108	0,097	0,089	0,083	0,078	0,075	0,071	0,060	0,046	0,035	0,025
60	0,174	0,113	0,090	0,077	0,068	0,062	0,058	0,055	0,052	0,050	0,041	0,032	0,023	0,017
120	0,100	0,063	0,050	0,042	0,037	0,034	0,031	0,029	0,028	0,027	0,022	0,017	0,012	0,008
∞	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000

ПРИЛОЖЕНИЕ VII

КАТАЛОГ ФАКТОРНЫХ ПЛАНОВ

1. Вспомогательные матрицы

D/4

D/8

D/5

D/12

D/16

D/18

D/20

[illegible]

287

$F_{.01,\nu_1,\nu_2}$

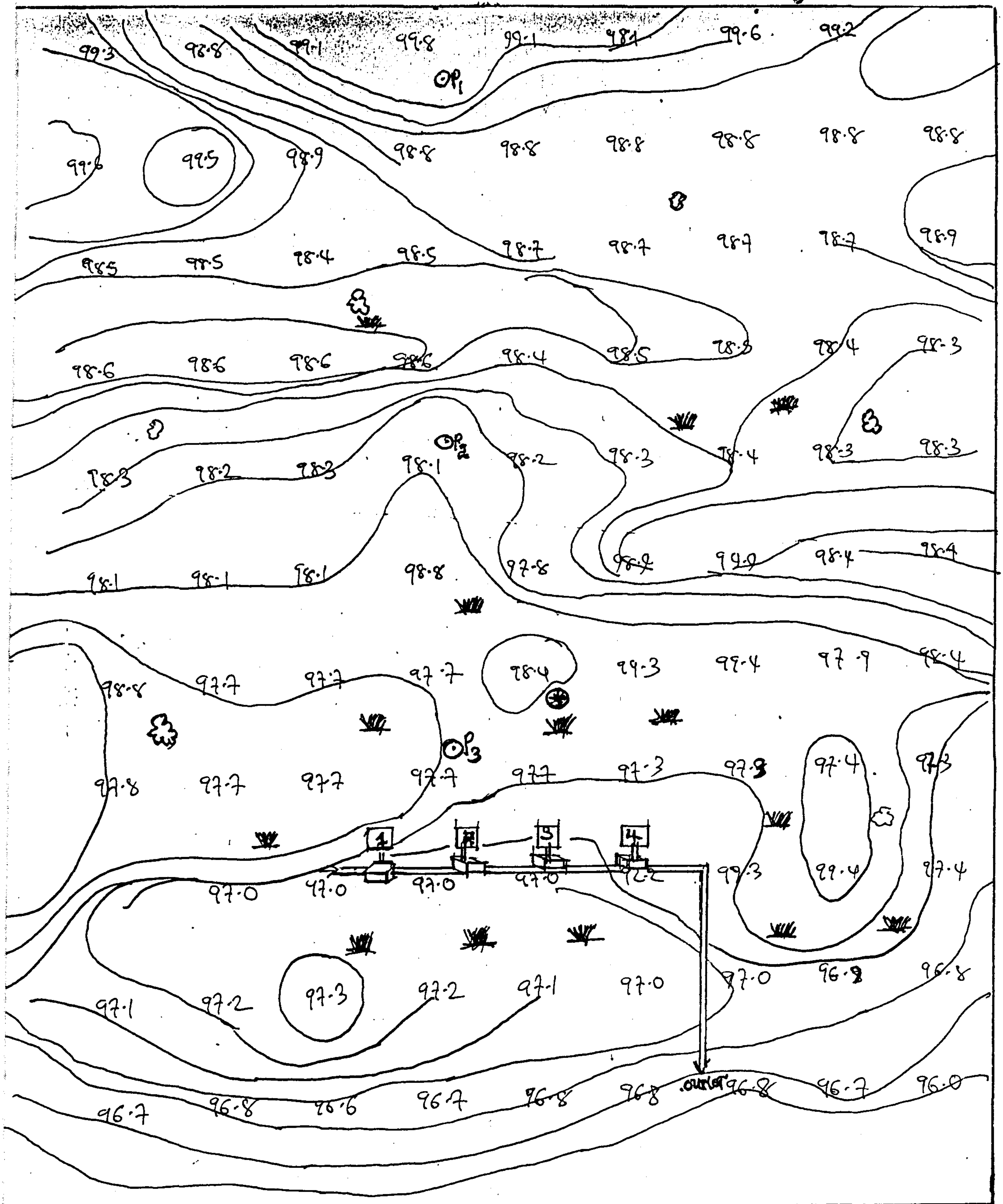
ν_2 \ ν_1	1	2	3	4	5	6	7	8	9	10	12	15	20	24	30	40	60	120	∞
	Degrees of Freedom for the Numerator (ν_1)																		
1	4052	4999.5	5403	5625	5764	5859	5928	5982	6022	6056	6106	6157	6209	6235	6261	6287	6313	6339	6366
2	98.50	99.00	99.17	99.25	99.30	99.33	99.36	99.37	99.39	99.40	99.42	99.43	99.45	99.46	99.47	99.47	99.48	99.49	99.50
3	34.12	30.82	29.46	28.71	28.24	27.91	27.67	27.49	27.35	27.23	27.05	26.87	26.69	26.60	26.50	26.41	26.32	26.22	26.13
4	21.20	18.00	16.69	15.98	15.52	15.21	14.98	14.80	14.66	14.55	14.37	14.20	14.02	13.93	13.84	13.75	13.65	13.56	13.46
5	16.26	13.27	12.06	11.39	10.97	10.67	10.46	10.29	10.16	10.05	9.89	9.72	9.55	9.47	9.38	9.29	9.20	9.11	9.02
6	13.75	10.92	9.78	9.15	8.75	8.47	8.26	8.10	7.98	7.87	7.72	7.56	7.40	7.31	7.23	7.14	7.06	6.97	6.88
7	12.25	9.55	8.45	7.85	7.46	7.19	6.99	6.84	6.72	6.62	6.47	6.31	6.16	6.07	5.99	5.91	5.82	5.74	5.65
8	11.26	8.65	7.59	7.01	6.63	6.37	6.18	6.03	5.91	5.81	5.67	5.52	5.36	5.28	5.20	5.12	5.03	4.95	4.86
9	10.56	8.02	6.99	6.42	6.06	5.80	5.61	5.47	5.35	5.26	5.11	4.96	4.81	4.73	4.65	4.57	4.48	4.40	4.31
10	10.04	7.56	6.55	5.99	5.64	5.39	5.20	5.06	4.94	4.85	4.71	4.56	4.41	4.33	4.25	4.17	4.08	4.00	3.91
11	9.65	7.21	6.22	5.67	5.32	5.07	4.89	4.74	4.63	4.54	4.40	4.25	4.10	4.02	3.94	3.86	3.78	3.69	3.60
12	9.33	6.93	5.95	5.41	5.06	4.82	4.64	4.50	4.39	4.30	4.16	4.01	3.86	3.78	3.70	3.62	3.54	3.45	3.36
13	9.07	6.70	5.74	5.21	4.86	4.62	4.44	4.30	4.19	4.10	3.96	3.82	3.66	3.59	3.51	3.43	3.34	3.25	3.17
14	8.86	6.51	5.56	5.04	4.69	4.46	4.28	4.14	4.03	3.94	3.80	3.66	3.51	3.43	3.35	3.27	3.18	3.09	3.00
15	8.68	6.36	5.42	4.89	4.36	4.32	4.14	4.00	3.89	3.80	3.67	3.52	3.37	3.29	3.21	3.13	3.05	2.96	2.87
16	8.53	6.23	5.29	4.77	4.44	4.20	4.03	3.89	3.78	3.69	3.55	3.41	3.26	3.18	3.10	3.02	2.93	2.84	2.75
17	8.40	6.11	5.18	4.67	4.34	4.10	3.93	3.79	3.68	3.59	3.46	3.31	3.16	3.08	3.00	2.92	2.83	2.75	2.65
18	8.29	6.01	5.09	4.58	4.25	4.01	3.84	3.71	3.60	3.51	3.37	3.23	3.08	3.00	2.92	2.84	2.75	2.66	2.57
19	8.18	5.93	5.01	4.50	4.17	3.94	3.77	3.63	3.52	3.43	3.30	3.15	3.00	2.92	2.84	2.76	2.67	2.58	2.49
20	8.10	5.85	4.94	4.43	4.10	3.87	3.70	3.56	3.46	3.37	3.23	3.09	2.94	2.86	2.78	2.69	2.61	2.52	2.42
21	8.02	5.78	4.87	4.37	4.04	3.81	3.64	3.51	3.40	3.31	3.17	3.03	2.88	2.80	2.72	2.64	2.55	2.46	2.36
22	7.95	5.72	4.82	4.31	3.99	3.76	3.59	3.45	3.35	3.26	3.12	2.98	2.83	2.75	2.67	2.58	2.50	2.40	2.31
23	7.88	5.66	4.76	4.26	3.94	3.71	3.54	3.41	3.30	3.21	3.07	2.93	2.78	2.70	2.62	2.54	2.45	2.35	2.26
24	7.82	5.61	4.72	4.22	3.90	3.67	3.50	3.36	3.26	3.17	3.03	2.89	2.74	2.66	2.58	2.49	2.40	2.31	2.21
25	7.77	5.57	4.68	4.18	3.85	3.63	3.46	3.32	3.22	3.13	2.99	2.85	2.70	2.62	2.54	2.45	2.36	2.27	2.17
26	7.72	5.53	4.64	4.14	3.82	3.59	3.42	3.29	3.18	3.09	2.96	2.81	2.66	2.58	2.50	2.42	2.33	2.23	2.13
27	7.68	5.49	4.60	4.11	3.78	3.56	3.39	3.26	3.15	3.06	2.93	2.78	2.63	2.55	2.47	2.38	2.29	2.20	2.10
28	7.64	5.45	4.57	4.07	3.75	3.53	3.36	3.23	3.12	3.03	2.90	2.75	2.60	2.52	2.44	2.35	2.26	2.17	2.06
29	7.60	5.42	4.54	4.04	3.73	3.50	3.33	3.20	3.09	3.00	2.87	2.73	2.57	2.49	2.41	2.33	2.23	2.14	2.03
30	7.56	5.39	4.51	4.02	3.70	3.47	3.30	3.17	3.07	2.98	2.84	2.70	2.55	2.47	2.39	2.30	2.21	2.11	2.01
40	7.31	5.18	4.31	3.83	3.51	3.29	3.12	2.99	2.89	2.80	2.66	2.52	2.37	2.29	2.20	2.11	2.02	1.92	1.80
60	7.08	4.98	4.13	3.65	3.34	3.12	2.95	2.82	2.72	2.63	2.50	2.35	2.20	2.12	2.03	1.94	1.84	1.73	1.60
120	6.85	4.79	3.95	3.48	3.17	2.96	2.79	2.66	2.56	2.47	2.34	2.19	2.03	1.95	1.86	1.76	1.66	1.53	1.38
∞	6.63	4.61	3.78	3.32	3.02	2.80	2.64	2.51	2.41	2.32	2.18	2.04	1.88	1.79	1.70	1.59	1.47	1.32	1.00

$F_{.05,\nu_1,\nu_2}$

ν_2 \ ν_1	1	2	3	4	5	6	7	8	9	10	12	15	20	24	30	40	60	120	∞
	Degrees of Freedom for the Numerator (ν_1)																		
1	161.4	199.5	215.7	224.6	230.2	234.0	236.8	238.9	240.5	241.9	243.9	245.9	248.0	249.1	250.1	251.1	252.2	253.3	254.3
2	18.51	19.00	19.16	19.25	19.30	19.33	19.35	19.37	19.38	19.40	19.41	19.43	19.45	19.45	19.46	19.47	19.48	19.49	19.50
3	10.13	9.55	9.28	9.12	9.01	8.94	8.89	8.85	8.81	8.79	8.74	8.70	8.66	8.64	8.62	8.59	8.57	8.55	8.53
4	7.71	6.94	6.59	6.39	6.26	6.16	6.09	6.04	6.00	5.96	5.91	5.86	5.80	5.77	5.75	5.72	5.69	5.66	5.63
5	6.61	5.79	5.41	5.19	5.05	4.95	4.88	4.82	4.77	4.74	4.68	4.62	4.56	4.53	4.50	4.46	4.43	4.40	4.36
6	5.99	5.14	4.76	4.53	4.39	4.28	4.21	4.15	4.10	4.06	4.00	3.94	3.87	3.84	3.81	3.77	3.74	3.70	3.67
7	5.59	4.74	4.35	4.12	3.97	3.87	3.79	3.73	3.68	3.64	3.57	3.51	3.44	3.41	3.38	3.34	3.30	3.27	3.23
8	5.32	4.46	4.07	3.84	3.69	3.58	3.50	3.44	3.39	3.35	3.28	3.22	3.15	3.12	3.08	3.04	3.01	2.97	2.93
9	5.12	4.26	3.86	3.63	3.48	3.37	3.29	3.23	3.18	3.14	3.07	3.01	2.94	2.90	2.86	2.83	2.79	2.75	2.71
10	4.96	4.10	3.71	3.48	3.33	3.22	3.14	3.07	3.02	2.98	2.91	2.85	2.77	2.74	2.70	2.66	2.62	2.58	2.54
11	4.84	3.98	3.59	3.36	3.20	3.09	3.01	2.95	2.90	2.85	2.79	2.72	2.65	2.61	2.57	2.53	2.49	2.45	2.40
12	4.75	3.89	3.49	3.26	3.11	3.00	2.91	2.85	2.80	2.75	2.69	2.62	2.54	2.51	2.47	2.43	2.38	2.34	2.30
13	4.67	3.81	3.41	3.18	3.03	2.92	2.83	2.77	2.71	2.67	2.60	2.53	2.46	2.42	2.38	2.34	2.30	2.25	2.21
14	4.60	3.74	3.34	3.11	2.96	2.85	2.76	2.70	2.65	2.60	2.53	2.46	2.39	2.35	2.31	2.27	2.22	2.18	2.13
15	4.54	3.68	3.29	3.06	2.90	2.79	2.71	2.64	2.59	2.54	2.48	2.40	2.33	2.29	2.25	2.20	2.16	2.11	2.07
16	4.49	3.63	3.24	3.01	2.85	2.74	2.66	2.59	2.54	2.49	2.42	2.35	2.28	2.24	2.19	2.15	2.11	2.06	2.01
17	4.45	3.59	3.20	2.96	2.81	2.70	2.61	2.55	2.49	2.45	2.38	2.31	2.23	2.19	2.15	2.10	2.06	2.01	1.96
18	4.41	3.55	3.16	2.93	2.77	2.66	2.58	2.51	2.46	2.41	2.34	2.27	2.19	2.15	2.11	2.06	2.02	1.97	1.92
19	4.38	3.52	3.13	2.90	2.74	2.63	2.54	2.48	2.42	2.38	2.31	2.23	2.16	2.11	2.07	2.03	1.98	1.93	1.88
20	4.35	3.49	3.10	2.87	2.71	2.60	2.51	2.45	2.39	2.35	2.28	2.20	2.12	2.08	2.04	1.99	1.95	1.90	1.84
21	4.32	3.47	3.07	2.84	2.68	2.57	2.49	2.42	2.37	2.32	2.25	2.18	2.10	2.05	2.01	1.96	1.92	1.87	1.81
22	4.30	3.44	3.05	2.82	2.66	2.55	2.46	2.40	2.34	2.30	2.23	2.15	2.07	2.03	1.98	1.94	1.89	1.84	1.78
23	4.28	3.42	3.03	2.80	2.64	2.53	2.44	2.37	2.32	2.27	2.20	2.13	2.05	2.01	1.96	1.91	1.86	1.81	1.76
24	4.26	3.40	3.01	2.78	2.62	2.51	2.42	2.36	2.30	2.25	2.18	2.11	2.03	1.98	1.94	1.89	1.84	1.79	1.73
25	4.24	3.39	2.99	2.76	2.60	2.49	2.40	2.34	2.28	2.24	2.16	2.09	2.01	1.96	1.92	1.87	1.82	1.77	1.71
26	4.23	3.37	2.98	2.74	2.59	2.47	2.39	2.32	2.27	2.22	2.15	2.07	1.99	1.95	1.90	1.85	1.80	1.75	1.69
27	4.21	3.35	2.96	2.73	2.57	2.46	2.37	2.31	2.25	2.20	2.13	2.06	1.97	1.93	1.88	1.84	1.79	1.73	1.67
28	4.20	3.34	2.95	2.71	2.56	2.45	2.36	2.29	2.24	2.19	2.12	2.04	1.96	1.91	1.87	1.82	1.77	1.71	1.65
29	4.18	3.33	2.93	2.70	2.55	2.43	2.35	2.28	2.22	2.18	2.10	2.03	1.94	1.90	1.85	1.81	1.75	1.70	1.64
30	4.17	3.32	2.92	2.69	2.53	2.42	2.33	2.27	2.21	2.16	2.09	2.01	1.93	1.89	1.84	1.79	1.74	1.68	1.62
40	4.08	3.23	2.84	2.61	2.45	2.34	2.25	2.18	2.12	2.08	2.00	1.92	1.84	1.79	1.74	1.69	1.64	1.58	1.51
60	4.00	3.15	2.76	2.53	2.37	2.25	2.17	2.10	2.04	1.99	1.92	1.84	1.75	1.70	1.65	1.59	1.53	1.47	1.39
120	3.92	3.07	2.68	2.45	2.29	2.17	2.09	2.02	1.96	1.91	1.83	1.75	1.66	1.61	1.55	1.55	1.43	1.35	1.25
∞	3.84	3.00	2.60	2.37	2.21	2.10	2.01	1.94	1.88	1.83	1.75	1.67	1.57	1.52	1.46	1.39	1.32	1.22	1.00

Appendix I : Perched Water table for Experimental Site

DAY	PIEZOMETRIC DATA (cm)								
	AUGUST			SEPTEMBER			OCTOBER		
	1	2	3	1	2	3	1	2	3
01	0.0	0.0	0.0	0.0	0.0	0.0	98.0	120.0	118.0
02	0.0	0.0	0.0	131.0	136.0	132.0	129.0	140.0	137.0
03	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
04	0.0	0.0	0.0	113.9	128.0	129.0	0.0	0.0	0.0
05	0.0	0.0	0.0	0.0	0.0	0.0	143.0	157.0	153.0
06	0.0	0.0	0.0	128.0	143.0	143.0	0.0	0.0	0.0
07	0.0	0.0	0.0	0.0	0.0	0.0	108.0	124.0	118.0
08	0.0	0.0	0.0	124.0	149.0	143.0	0.0	0.0	0.0
09	0.0	0.0	0.0	0.0	0.0	0.0	140.0	154.0	150.0
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	147.7	180.7	166	125.0	148.0	140.0	105.0	124.0	124.0
13	19.3	33.5	33.5	128.0	142.0	140.0	0.0	0.0	0.0
14	0.0	0.0	0.0	128.0	142.0	140.0	89.0	114.0	111.0
15	16.1	30.3	26.6	0.0	0.0	0.0	135.0	149.0	145.0
16	18.4	35.3	31.6	0.0	0.0	0.0	109.0	134.0	133.0
17	43.0	28.0	42.0	0.0	0.0	0.0	86.0	111.0	108.0
18	103.0	102.5	98.0	0.0	0.0	0.0	0.0	0.0	0.0
19	97.4	109.0	105.3	0.0	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	138.0	134.7	131.0	128.0	147.0	143.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	90.0	113.0	109.0	121.0	135.0	123.0	0.0	0.0	0.0
24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	127.0	140.0	135.0	115.0	139.0	133.0	83.0	117.0	114.5
26	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0	78.0	116.8	118.0
28	0.0	0.0	0.0	123.0	137.0	131.0	0.0	0.0	0.0
29	0.0	0.0	0.0	143.0	157.0	153.0	0.0	0.0	0.0
30	145.0	149.0	139.5	0.0	0.0	0.0	0.0	0.0	0.0
31	142.0	147.4	136.9	0.0	0.0	0.0	0.0	0.0	0.0



I	RUNOFF PLOT 1
II	RUNOFF PLOT 2
III	RUNOFF PLOT 3
IV	CONTROL PLOT
=	CHANNEL
	VEGETATION
⊙	PIEZOMETER
	RAINGAUGE

KEY

CONTOUR INTERVAL: 0.1M = 10CM

FIG I1: TOPOGRAPHIC MAP OF NUMU FARM PLOT