PREDICTION OF RAINFALL VARIABILITY IMPACT ON WATER EROSION INTENSITY UNDER FOUR SOIL MANAGEMENT PRACTICES AT NSUKKA, NIGERIA

BY

IBOKO, Maduabuchi Paul

(MTech/SPS/2015/6072)

WEST AFRICAN SCIENCE SERVICE CENTER ON CLIMATE CHANGE AND ADAPTED LAND USE (WASCAL) FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA

MARCH, 2018

PREDICTION OF RAINFALL VARIABILITY IMPACT ON WATER EROSION INTENSITY UNDER FOUR SOIL MANAGEMENT PRACTICES AT NSUKKA, NIGERIA

BY

IBOKO, Maduabuchi Paul

(MTech/SPS/2015/6072)

A THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGERIA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF TECHNOLOGY (MTech) IN CLIMATE CHANGE AND ADAPTED LAND USE

MARCH, 2018

DECLARATION

I hereby declare that this thesis titled: **"Prediction of Rainfall Variability Impact on Water Erosion Intensity Under Four Soil Management Practices at Nsukka, Nigeria"** is a collection of my original research work and it has not been presented for any other qualification anywhere. Information from other sources (published or unpublished) has been duly acknowledged.

IBOKO, Maduabuchi Paul
MTech/SPS/2015/6072
FEDERAL UNIVERSITY OF TECHNOLOGY,
MINNA, NIGERIA.

SIGNATURE AND DATE

CERTIFICATION

The thesis titled: **"Prediction of Rainfall Variability Impact on Water Erosion Intensity Under Four Soil Management Practices at Nsukka, Nigeria"** by: IBOKO, Maduabuchi Paul (MTech/SPS/2015/6072) meets the regulations governing the award of the degree of Master of Technology (MTech) of the Federal University of Technology, Minna and it is approved for its contribution to scientific knowledge and literary presentation.

Prof. A. O. Osunde	…………………………
Major Supervisor	Signature & Date
Prof. A. A. Okhimamhe	…………………………
Director of WASCAL-FUT, Minna	Signature & Date
Prof. M.G.M. Kolo	…………………………
Dean of Postgraduate School	Signature & Date

DEDICATION

This work is dedicated to Almighty God who has made it possible for me to come to the end of this programme.

ACKNOWLEDGEMENT

My sincere appreciation goes to the Federal Ministry of Education and Research (BMBF) and West African Science Centre on Climate Change and Adapted Land Use (WASCAL) for providing the scholarship and financial support for this programme. I am most grateful to the Director of WASCAL Centre Minna, Prof. A.A. Okhimamhe, all the lecturers and the entire Staff of WASCAL for their support throughout the study.

My special gratitude goes to my supervisor Prof. A.O. Osunde for his sincere and scholarly guidance throughout my research. I also wish to thank Prof. A. J. Odofin for his contributions towards the successful completion of the work. I am truly grateful to my family and the following persons: Prof Mbajiorgu, Mr Vintus, Dr S. Obalum and Mr C. J. Oraegbunam for all of their help throughout the study.

I also wish to acknowledge the people of Nsukka and the entire staff of Soil Science laboratory, University of Nigeria, Nsukka for their assistance throughout my field work and laboratory analyses. I am indeed grateful.

Finally, I thank all my colleagues for their comments and contributions towards the successful completion of this work.

ABSTRACT

Anthropogenic activities and natural factors are majorly responsible for soil degradation. These degradations are bound to increase with change in climate, thereby making some of the current soil management practices unsustainable in the future. Therefore, this study was aimed at predicting the impact of rainfall variability on water erosion intensity and to identify the most sustainable soil management practices in Nsukka Local Government Area of Enugu State, Nigeria. Four soil management practices were analysed using Water Erosion Prediction Project (WEPP) model. Soil samples were collected from profile pits dug on fallow land, range land, manually cultivated land and tractorized cultivation, at 0-20, 20-40 and 40-60cm depths with two replications each. The samples were analysed for their physical and chemical properties. Climate data collected from the Nigeria Meteorological Agency, Abuja from 1981 to 2010 were used as a baseline climate scenario while projected climatic data for Representative Concentration Pathways (RCP) 4.5 and 8.5 outputs scenarios from World Climate Research Programme (WRF) model were used as future (2041 to 2070) climate scenarios. The future and historical rainfall, minimum and maximum temperatures were tested for trends and also used to simulate mean monthly and annual soil losses and runoffs for Nsukka. The trend test at 95 % confidence level for the historical data set showed a significant trend for the mean monthly rainfall and a non-significant seasonal trend with a Kendall S statistics of 119.00 and 6.00 respectively. The test also showed significant trend for future temperatures but was not significant for both historical temperatures and future rainfalls for RCP 4.5 and 8.5 although there were high variations. The soil properties and climate data for historical and projected scenarios were incorporated into the WEPP model as inputs and ran for the different soil management practices. The model predicted highest runoff and soil loss of 1097.47 mm and 32.974 Mg ha^{-1} yr^{-1} under tractorized and fallow land managements respectively while the lowest amount of runoff and soil loss of 594.92 mm and 0.005 Mg ha^{-1} yr^{-1} were recorded by rangeland. Highest runoff and soil loss were also predicted under the historical climate at 1190.92 mm and 38.294 Mg ha^{-1} yr^{-1} respectively while the projected RCP 8.5 produced the lowest amount of runoff and soil loss. The test of sustainability using Least Significant Difference (LSD) revealed that rangeland would be the most sustainable in the future. It also showed a statistically significant difference in the amount of soil losses and runoffs from the different land management practices and rainfall regimes (historical and projected climate conditions) with the historical climate posing the greatest threat to both runoffs and soil losses. The study concluded that range land would be the most sustainable land management in the future as its soil loss was less than the soil loss tolerance level (1.3 Mg/ha/yr) for Nsukka, runoffs and soil losses from the future rainfall would generally be lower than that of the baseline and as such, the various management practices with little modifications are considered sustainable.

TABLE OF CONTENTS

Content **Page**

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF ABBREVIATIONS AND ACRONYMS

ADF	Augmented Dickey-Fuller
ANOVA	Analysis of Variance
CDO	Climate Data Operation
CEC	Cation Exchange Capacity
CLIGEN	CLImate GENerator
CMIP	Coupled Model Intercomparison Project
CNTRL	Control
CORDEX	COordinated Regional Downscaling EXperiment
CREAM	Chemical, Runoff and Erosion from Agricultural Management Systems
EPIC	Erosion-Productivity Impact Calculator
ERA	European Re-Analysis
FAO	Food and Agricultural Organization of the United Nations
FUTA	Federal University of Technology Akure
GCM	Global Circulation Model
IPCC	Intergovernmental Panel on Climate Change
LGA	Local Government Area
LSD	Least Significant Difference
MDRS	Moving Downstream Rainfall Scenarios
MMF	Morgan, Morgan and Finney
MURS	Moving Upstream Rainfall Scenarios
NCDC	Cational Climatic Data Center
NiMet	Nigeria Meteorological Agency
OSM	On the Street Map

PE	Potential Energy
RCM	Regional Climate Model
RCP	Representative Concentration Pathways
RUSLE	Revised Universal Soil Loss Equation
SEP	Soil Erosion Parameter
SOC	Soil Organic Carbon
SRES	Special Report on Emissions Scenario
SWAT	Soil and Water Assessment Tool
UNESCO	United Nations Educational, Scientific and Cultural Organization
USA	United State of America
USDA-ARS	United States Department of Agriculture – Agricultural Research Service
USLE	Universal Soil Loss Equation
WEPP	Water Erosion Prediction Project
WCRP	World Climate Research Programme
WMO	World Meteorological Organization
WRF	Weather Research Forecasting model

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Study

Atmospheric scientists have generally agreed that the climate is changing with respect to precipitation and air temperature (WMO, 2001). These changes in the global environment have been identified as the consequences of man's activities, with some of the changes known to be of sufficient magnitude to have potentially catastrophic impacts on future generations. Changes such as increase in CO_2 and other greenhouse gases in the atmosphere are likely to cause variations in atmospheric variables and processes. The ecosystem being in a dynamic equilibrium, reacts with high sensitivity to any perceived adjustment in the environment, be it climate or soil (Várallyay, 2010). It is on record that most of the high temperatures recorded on the earth surface since 1960 have occurred from 1990 (WMO, 2001), with the year 1998 previously identified as having the hottest temperature in the Northern Hemisphere since the last 1000 years (IPCC, 2001), followed by the year 2001 (NCDC, 2002). However, with the recent report of WMO (2017), which showed that 2016 has been the hottest year ever recorded on the earth surface. It is obvious that global warming has continued to rise unabated, setting a new record of approximately 1.1^0C above the record previously observed in the pre-industrial era and rising to about 0.06^0C above the previous highest record that was observed in 2015 WMO (2017). The changing climate is bound to have lots of consequences on activities on the surface of the earth including soil processes. For instance, Várallyay (2010) posited that modifications in the earth atmosphere results in the alteration of soil properties and processes. Also, Pruski and Nearing (2002a) reported that if such factors as temperature, CO_2 level and solar radiation remain constant, a 1% increase in precipitation amount can almost lead to doubling of runoff and about 1.7% change in erosion. Researches have shown that although both rainfall duration and intensity are important factors influencing the magnitude and the rate of runoff, rainfall intensity plays much more important role than the amount of rainfall in changes in runoff (Várallyay, 2010). Pruski and Nearing (2002a) also observed that increasing air temperature as a result of climate change plays important role in soil erosion process, with warmer temperature leading to increased biomass production and maturation rate while excessive temperature can cause a decrease in the photosynthetic activities of plants. Temperature plays significant part in the process of organic matter decomposition in the soil by influencing microbial activities. Similarly, Stockle *et al*. (1992) observed that the amount of CO_2 contained in the atmosphere impacts the amount of biomass that plants can accumulate through photosynthesis and in turn affects the ground residue cover over the soil and the amount of canopy as well as the rate of soil detachment. According to Schulze (2000), increase in the amount of atmospheric CO_2 content can lead to stomatal resistance, consequently giving rise to a wetter soil and greater runoff-induced erosion. Additionally, changes in temperature can lead to changes in evapotranspiration from the soil, which can influence soil moisture and runoff amount (Pruski and Nearing, 2002b).

Soil, which according to Zhao *et al.* (2013) has been classified as a fixed resource is an important and intricate part and parcel of the climate system and regulates both hydrological and biological as well as geochemical cycles of the earth system. It also provides other invaluable ecosystem services to man (Berendse *et al*., 2015) but its conservation and productivity have been continuously and principally threatened by water erosion, a process majorly driven by inappropriate agricultural management practices, lack of implementation of conservation practices on lands that are not in use and construction of roads as well as wild fire which render the soil surface bare and unprotected (Cerdà *et al*., 2010; Palacio *et* al., 2014 and Panagos *et al.*,2014). Soil erosion is a physical process that causes the reconfiguration of the surface landscape, creating a major environmental problem around the world (Abdulfatai *et al*., 2014), mainly controlled by urbanisation, topography, soil properties and effects of climate change (high rainfall regime, desertification and drought) (UNESCO, 2009). Therefore, there is the need to evaluate the various soil management techniques currenlty in use in order to ascertain their level of susceptibility to erosion with reference to the predicted increase in rainfall and rainfall intensity.

1.2 Statement of Research Problem

Historically, Africa has the second highest percentage of degraded land at 27% after Asia at 31% (Oldemal, 1994). This high percentage of degradation in the soils of Africa is a product of combination of factors, mostly climatic factors. The high vulnerability of the soils of the region to climate variability amplifies the dangers ahead with a changing climate. Climate change and land use changes play significant role in runoff generation and erosion both at local and regional scales. Scientists have already predicted that climate change will lead to increased precipitation. The implication of this is that the threat of water erosion will also increase especially in erosion flash points such as the south eastern part of Nigeria. Researchers (Stone and Hilborn, 2000; Anejionu and Nwilo, 2013) identified Enugu State as the second most susceptible state in south eastern Nigeria to soil erosion, with most of the soils of the area having erodibility factor of 0.20. With the predicted increase in the amount and variability of the most important agent of erosion (water), increase in the problem of water erosion is inevitable. Therefore, there is need to determine the erosion risk of the different land management practices currently in use in Nsukka Local Government Area of Enugu State as this is key in combatting anticipated increase in soil erosion.

Many studies have been carried out on soil erosion in Enugu State, for instance (Nwakor *et al.,* 2015) and more specifically, Nsukka (Gobin, *et al.,* 1999) but none has considered erosion with respect to future climate scenarios. More so, many researchers in the area employed Revised Universal Soil Loss Equation (RUSLE) (Nwakor *et al.,* 2015) and Universal Soil Loss Equation (USLE) models in erosion prediction with little or no focus on the future impact of climate change on soil erosion. These models are empirically based prediction models and lack many physical processes that are important in erosion prediction. But in this study, I would be employing the Water Erosion Prediction Project (WEPP) model developed by United States Department of Agriculture (USDA-ARS) (Flanagan and Nearing, 1995). A physically based erosion prediction model which contains all the formerly missing physical processes necessary in soil erosion (processes such as infiltration, runoff, raindrop and flow detachment, sediment transport, deposition, plant growth, and residue decomposition) as input parameters (Demeny et al.,2010). Although some of the land use management practices have been researched on and found to be more protective in erosion control (Senjobi, 2007) but this is basically true for the present situation and therefore, insights are needed on the preventive capacities of these land uses in controlling erosion in the future. There is also the need to check if the soil loss from the presently considered less preventive management to soil erosion exceeds annual soil formation as it is only when this is true that the management can be considered inappropriate Therefore, there is need to determine the erosion risk of the different land management practices currently in use in

Nsukka Local Government Area of Enugu State as this is critical to the development of sustainable and resilient land management systems in the face of changing climate.

1.3 Justification

Natural and anthropogenic factors are the two major factors responsible for land degradation processes (Kiunsi and meadows, 2006), with unsustainable management of agricultural land as a direct cause (FAO, 1994). Also inadequate or non-availability of soil management and conservation practices together with intensive cropping systems have led to acute land degradation and erosion (Klara and Fredrik, 2014). But the more worrisome problem is rainfall variability. Change in climate will exacerbate water erosion in the tropics and the current soil management techniques may not be sustainable in the face of the changing climate. The changing climate will also produce rainfall regimes that are likely going to threaten soil productivity particularly in the south eastern part of Nigeria.

1.4 Scope

This research covered only the Nsukka Local Government Area of Enugu State and focused on water erosion and the following soil or land management practices were evaluated:

i. Fallow land

ii. Land under continuous tractorized cultivation

iii. Land under continuous manual cultivation with hoe

iv. Range or pasture land

1.5 Limitations of the Study

In order to ensure that very accurate results are produced during analysis, the standard procedures for models are usually advised to be followed strictly. However, due to non-availability of some data, some of the standard procedures as described for the model were not followed in this study. For instance, the historical data lacked wind direction and speed while the future data lacked solar radiation. And these unavailable data for the historical data were generated using the available historical parameters and those unavailable for the future scenarios were also generated with the available parameters for the future scenarios such as rainfall, minimum and maximum temperatures using the model's inbuilt CLImate GENerator (CLIGEN). Similarly, the model was used in an uncalibrated and unvalidated mode because of lack of observed historical data on soil erosion for the area. This is so because most of the previous studies in the area used Universal Soil Loss Equation (USLE) and did not capture many of the details (soil moisture content, plant and management data, topographic, soil, solar radiation, precipitation, minimum and maximum temperature data) which are necessary or required to calibrate the WEPP model. However, most researchers who have employed WEPP in an uncalibrated mode have reported a non-significant difference between results obtained when the model was applied after calibration and when it was executed without calibration. It therefore means that in the absence of the required historical data for its calibration, the model could still be used without calibration with low or no error margin in the result.

The crop management database of the WEPP model lacks some of the local crop management and crop farming mixture options currently being used by farmers in Nsukka and as such may have had little role to play in the overall accuracy of the predicted result.

1.6 Aim and Objectives

This study aimed to assess the impact of rainfall variability on water erosion intensity under four soil management techniques in Nsukka Local Government Area of Enugu State, Nigeria under varying rainfall scenarios.

The specific objectives were to:

i. Find out the past and potential future trends of rainfall and temperature in Nsukka.

ii. Determine which of the current soil management practices is most sustainable through reduction in runoff and soil loss under the changing climate.

iii. Predict the future levels of runoffs and soil losses through water erosion from the soils under the four management practices

1.7 Hypotheses

H_O: The mean runoffs and soil losses from the current soil management practices are statistically the same under the changing climate (different climatic scenarios).

H_O: There are no statistically significant differences between the predicted levels of runoffs and soil losses through water erosion from the soils under the four management practices

1.8 Research Questions

i) What are the past and potential future trends of rainfall and temperature in Nsukka?

ii) Which of the current soil management practices is most sustainable through reduction in runoff and soil loss under the changing climate.?

iii) What are the future levels of runoff and soil loss through water erosion from the soils under the four soil management practices?

1.9 Description of the Study Area

1.9.1 Location of the study site

This study was conducted in Nsukka Local Government Area (L.G.A.) of Enugu State, Nigeria. Figure 1.1 is a map showing the location of Nsukka. Nsukka L.G.A. Nsukka lies between longitudes $7^0$13'00" N and $7^0$35'30" N, latitudes $6^0$43'30" and $7^0$00'30" E and covers a land area of about 480 km^2 (Ezeh and Ugwu, 2010)

1.9.2 Soil and elevation of the study site

The soils of Nsukka consist mainly of parchments of Ultisols, Entilsols and Alfisols while the remaining mixture of soils found in the area are the red earth soils usually found at the foot slope and plateau, the hydromorphic soils found on its floodplains and the toe slope, summit and valley of a toposequence (Mbagwu, 1995). Nsukka is generally hilly with a minimum elevation of about 250 m above sea level while the maximum elevation is about 590 m with an average elevation of 400 m above sea level (Mbagwu, 1995). The soils contain low activity clays and are also well drained and of poor nutrient status due mainly to the impact of high erosion and leaching (Ezeaku, 2006). Also the soils of Nsukka are classified as Nkpologwu and Uvuru soil series. Nkpologwu soil series is derived from colluvium deposited by weathering and erosion. Uvuru series is derived from the weathered lithology of the upper coal measures formation (Shales, siltstones and mudstones) (Akamigbo and Igwe, 1990).

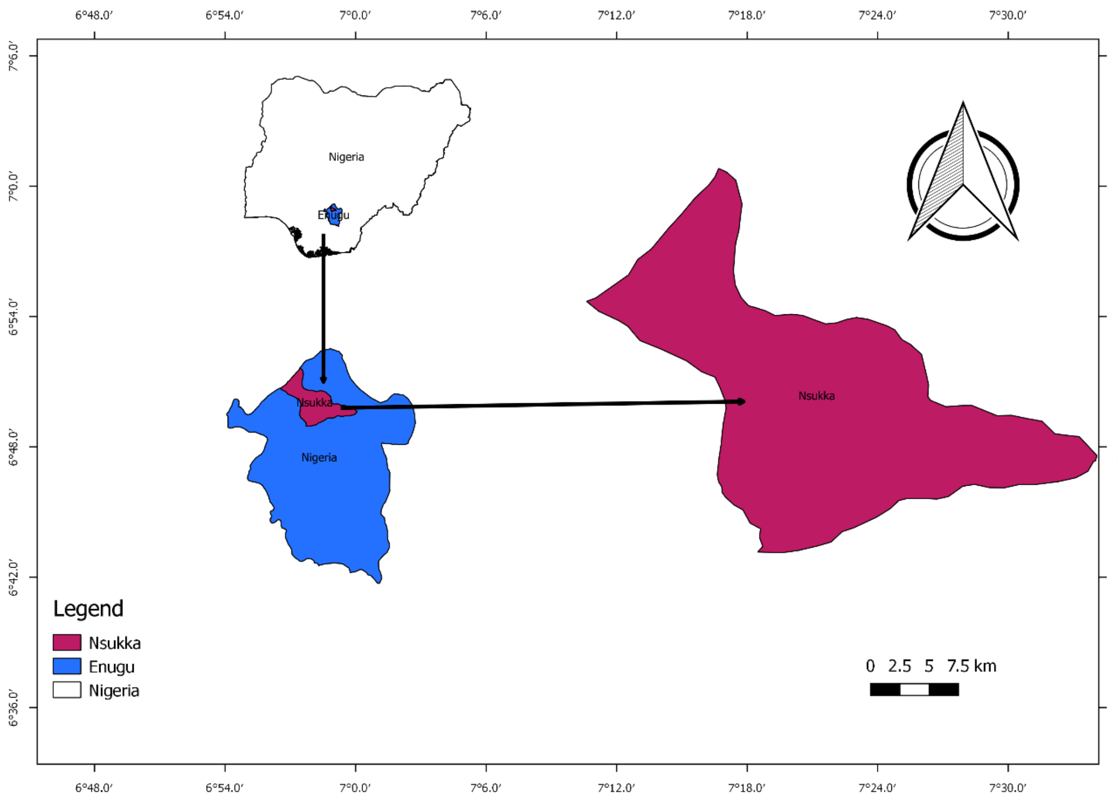


Figure 1.1: Study area map (Source: OSM with author's modification, 2017)

1.9.3 Climate and vegetation

The area falls under sub-humid tropical climate with wet and dry season and a characteristic pattern of rainfall that peaks at two different periods within a year (bimodal distribution of rainfall). It also experiences a total annual rainfall of about 1700 mm. The wet season starts in April while the dry season runs from November to March (Obi, 1982). The mean annual minimum and maximum temperatures for the area are respectively 21.8^{0}C and 27^{0}C while the relative humidity ranges between 70% and 80% (Oko-Ibom and Asiegbu, 2006) and the soil temperature at 50 cm depth is 28^{0}C (Azuka and Obi, 2012).

The vegetation is derived savannah agro-ecology with varying land uses such as pasture, cultivated lands, primary and secondary forests. The area is dominated by shrubs and grasses some of which include: African star grass, elephant grasses, Bahia grasses, para grass, setaria to mention but a few (Ezeaku *et al.*, 2015).

1.9.4 Geology

The area is made up of three geologic formations namely: Mamu, Ajali and Nsukka formations. The Mamu formation according to Reyment (1965, cited by Ezeh and Ugwu, 2010) was known formally as the lower coal measures and consists of medium-fine grains, grey sandstones, shaly sandstones, sandy shales and coal seams. Mamu is about 450 m in thickness and sits below the Ajali formation. Similarly, Reyment also described Ajali formation as false bedded sandstone, made up of friable thick and poorly sorted sandstones, whitely coloured although sometimes iron-stained with an average thickness of about 300 m usually overlain by the oxidated iron (iii) oxide formed through the process of parent material breakdown (weathering) and ferruginisation of the formation. Additionally, the Nsukka formation was formerly described as the upper coal measures by Reyment (1965, cited by Ezeh and Ugwu, 2010) and lies conformably on the Ajali sandstone with lithology very similar to that of Manu formation and is made up of alternatingly succeeding sandstones, dark shale and sandy shale with different horizons. It is highly eroded with a remaining thickness of about 250 m on the average.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Climate Change

Climate change has been variously defined, but according to IPCC (2014), climate change is any identifiable change in the state of the climate, detectable through statistical means and observable through variations in the average as well or variability in the climatic properties that lasts for a prolonged period of time ranging from decades or more. It may be as a result of internal or external forcings such as changes in the land use pattern, eruption from volcanic activities, and changes in the atmospheric gas composition as a result of human activities (IPCC, 2014). Climate change is characterized by high atmospheric carbon content (≥400 ppm); a rising air temperature (between 2 and 4^0C or more); abrupt and or statistically significant variation in the inter-annual, seasonal and daily temperatures; alteration of the long term established dry and wet season cycles; increase in the intensity of rainfall and/or heavy storms in certain areas and extended or prolonged drought periods in some other areas; a very extreme and far reaching frost condition; and increased frequency of heat waves and fire outbreaks, all of which are expected to have a pronounced impact on terrestrial systems as well as the soil properties, surface water and stream flow (Patterson, *et al.*, 2013). The changes in the climate systems will also impact significantly on the hydrologic cycle of the terrestrial ecosystems, quality of ground water as well as its supplies, environmental health and quality and most importantly, the general food security of the globe (Pangle *et al*., 2014).

In 2007, IPCC reported that the global temperature is expected to rise between 1.1 and 6.4^0 C in the 21 century (2090-2099) as against the average level of 1.8^0 C and 4.0^0 C recorded between 1980 and 1999. The global precipitation is also expected to change in the 21st century (IPCC, 2007). Soils are closely connected to the climate system through its process in the carbon sequestration, nitrogen cycle and the hydrological system. And because of this interconnectivity between the soil system and the climate system, any major change in the climatic process will also trigger changes in the soil processes and properties. Climatic elements play important roles in the carbon storage of the soil. Therefore, climate change may cause some soils to become net carbon source to the atmosphere instead of storing carbon and can also increase soil erosion by water and wind (Brevik, 2013).

Klik and Eitzinger (2010) studied the impact of climate change on soil erosion in Austria and revealed that under future climatic conditions, erosive force of runoff is likely to increase on agricultural fields together with its attendant soil loss despite lower amount of rainfall, thus producing soil loss greater than the soil loss tolerance level. This view has also been persuasively presented by Zhang (2005) who showed that substantial amount of soil loss would occur in the future as the climate changes, due to increased precipitation variability. Furthermore, Boardman and Poesen (2006) observed that climate significantly influences the rate of soil erosion, since rain properties control and determine the rate at which soil particles are detached and transported from one location to another (rainfall erosivity). It therefore, follows that gully erosion, land sliding, surface sealing, surface crusting as well as pipe and tunnel erosion, rill and interrill erosion and most importantly, the rate of soil degradation are all directly related to the rainfall characteristics. The degradation process which scientists have predicted as shown above, will increase as a result of increased rainfall variability. The cumulative effects of this, is the exacerbation of soil erosion. Also, they reported that for the past 30 years, it has been established that high or large volume of rainfall rather than intensity falling on an unprotected or non-vegetated arable land could result in soil surface crusting and /or soil saturation with the consequence of increasing soil surface runoff and erosion. Although these works were able to look into the future with regards to the sustainability of the different land management practices, the peculiarity of the environment where these researches were carried out makes it difficult for the findings to be extrapolated to Nigeria. Generally, the erosivity of rains in Europe and America and the susceptibility of soils to erosion are lower compared to Africa or in the tropics. While rainfall in Europe and America mostly come as light rains or in the form of shower, rainfall in the tropics (Africa) are usually heavy, intense and torrential. Also unlike the soils in Europe and America which are usually of high activity clay minerals with high organic matter and other soil binding materials making them more resistant to the detaching force of rain drops and the erosive force of surface runoff, the soils in Africa and particularly, Nsukka are usually very much more susceptible to the factors of erosion due to its low content of organic matter and other soil binding materials and high content of low activity clay minerals.

Many researchers have noted that some of the specific ways in which a change in climate is going to impact soil erosion is still not clearly known because of the uncertainties in the direction of temperature and precipitation on the earth surface as the climate changes (Clavo-Cases and Harvey, 1996; De Luís *et al.*,2010). Similar observation has also been adopted by Zhang and Nearing (2005) when they remarked that the likelihood of increase of soil erosion as result of the changing climate is not quite vivid yet but that the damage which will result is not in doubt. On the other hand, García-ruiz *et al*. (2013) maintained that some of the factors that required to be researched more on due to their roles or influence on the severity and location of soil erosion or materials being eroded include: splash effects, transportation of eroded materials down to the fluvial network, and behaviour of sediment sinks. The behaviour of sediment yields worthy of consideration includes: the future changes of pattern of growth of plant cover; probable future evolution in soil behaviour such as: the soil organic matter content, infiltration capacity, and soil structure; water content of the soils (which is a function of evapotranspiration and rainfall); the intensity and seasonality of heavy rainfalls; and the redistribution of runoff generation areas.

2.2 Soil Erosion

Soil erosion has been variously defined. According to Boardman and Poesen (2006) "soil erosion is the detachment, entrainment and transport (and deposition) of soil particles caused by one or more natural or anthropogenic erosive forces (rain, runoff, wind, gravity, tillage, land levelling and crop harvesting)". It involves complex processes of soil detachment, transportation and deposition of soil particles under the influence of raindrops and runoff. Different factors are responsible for the severity and importance of this process. These important factors are climate, soil properties, cropping and land management practices, the size of the area under measurement and the previously existing conditions of the area (Helming and Prasad, 2001).

Helming and Prasad (2001) studied soil erosion with highly erodible soil in the U.S.A. under different rainfall intensities using a flume and rainfall simulator as water applicators with a laser microelefmeter and tensiometric system as soil response measuring device. Their study revealed the following; that air dried soil suffers from high level of soil loss from rainstorm that decreases in intensity with time than that which increases in intensity with time and that surfaces which are smooth and uniform initially will yield less soil than those which were initially rough. This finding is in contrast with the previous works of Moldenhauer and Kemper (1969); Farres (1978); Romkens and Wang (1987) who found that surface roughness reduced water velocity and hence reduces soil loss from the surface. Similarly, Aina (1979) understudied soil changes caused by long term land management practices in Western Nigeria for their physical and chemical properties under long term pasture, bush fallow and arable cultivation under three tillage methods and two fertility levels and discovered that the percentage of water stable aggregates (a key factor of soil erosion) between 0-15 cm depth was >2.36 mm and was highest and more stable in fallow system than bush. He found that stability ranged between 95 and 80% under grass and bush and that more than 80% of this stability associated with pasture and fallowed land was destroyed under continuous cropping within 5 years.

Yao *et al*. (2016) while examining the roles of rainfall erosivity, soil erodibility and land use on soil erosion employed SWAT model in their analysis and reported that during the months with well distributed rainfall, rainfall erosivity factor increased more than soil erodibility factor, with land cover showing little sensitivity in the area. They concluded that rainfall plays a major role in erosion process with soil erodibility and land use playing a supporting role especially during the rainy season. They therefore suggested that soil conservation measures should focus on water and soil type together with land use adjustment. However, one particular gap in knowledge which most of these researches have not been able to address according to Bracken and Croke (2007); Reaney *et al*. (2007) has to do with factors influencing connectivity dynamics of soil erosion such as the relationship between storm input and connectivity or the influence of the temporal fragmentation of high-intensity rainfalls in determining the overland flow travel distances and the amount of runoff leaving the slope as discharge.

Soil erosion is one of the most problematic environmental degradation factors and often leads to the gradual washing away of plant nutrients from the topsoil, causing a decline in the overall soil fertility and crop productivity. It is a non-point source pollution that can cause river silting, water pollution and flash floods (Wilson *et al*., 2008).

2.2.1 Processes and factors affecting soil erosion

Natural and anthropogenic factors are the two major factors responsible for land degradation (Kiunsi and Meadows, 2006), with unsustainable management of agricultural land as a direct cause (FAO, 1994). Also, non-adoption of appropriate soil management and conservation practices together with intensive cropping systems can lead to accelerated erosion and land degradation (Klara and Fredrik, 2014). Depending on the agent of erosion, different types of erosion have been identified with different but interrelated factors necessary for such erosion to take place and the intensity of which depends on these factors. For water as agent of erosion; interrill erosion (splash and sheet erosion), rill erosion and gully erosion have been identified as the main types of soil erosion (Osman, 2014). Irrespective of the type of erosion, generally, from the universal soil loss equation, the main factors of erosion include: soil erodibility, rainfall erosivity, vegetation, management, slope length and gradient. The severity of erosion increases as soil erodibility, rainfall erosivity, slope length and gradient increase. Erosion severity also increases with increase in the percentage content of silt and sand, and decreases with increase in the particle binding factors such as organic matter and clay. However, the rate of erosion decreases as the amount of vegetation increases but can also either decrease depending on the type of conservation practices or management.

Ochoa *et al*. (2016) studied the effects of climate, land cover and topography on erosion risk in a semi-arid basin of the Andes with the aim of identifying the level of risk of erosion and the most important factors controlling erosion in the study area. The findings of the study revealed that rainfall distribution and erosivity, rugged topography as well as land cover were the most important factors necessary to quantify the risk of erosion. However, in the dry season, the most important factor of soil erosion was the soil erodibility factor. They concluded that even with steep slope and high rainfall, the rate of erosion was low in areas with green vegetation. This finding was further buttressed by Boardman and Poesen, (2006) who postulated that among the factors affecting soil erosion process, geomorphology, topography of the soil as well as the soil general characteristics influence the types and location of soil erosion processes.

Water erosion is a process with three steps, namely soil detachment, transportation and deposition. Because of human casualties, economic losses, infrastructural destruction, damages to sources of human livelihood and destruction of crop lands and animals associated with soil erosion, soil erosion has received considerable attention since the early 90s. For instance, Ellison (1948) studied the mechanism of soil detachment by water and observed that soil erosion process occurs as two independent events. The first stage involves the detachment and shattering of the soil particles while the second stage involves the actual transportation of the already detached soil particles. The study revealed that rainfall impacts consolidates certain soils and compacts the particles and hence make them less susceptible to detachment through this consolidation while soils with low cementing materials such as smooth grained particles are easily detached and transported. He added that the severity of erosion is directly related to the gradient of the slope of the area. This argument was expanded further by Morgan (2005) who maintained that the process of soil erosion basically consists of detachment of individual soil particles from the soil clod and their subsequent transportation by any of the agents of erosion and are deposited when the agent loses its kinetic energy and that rain splash is the most important factor in detaching soil particles. According to the finding of the work, the rain drops strike the soil surface and shatter the clod and send the particles some centimetres away from their point of origin. With the process of continuous striking of the soil weakening the soil structure, making the soil more susceptible to further breakdown by agents of weathering. These processes of continuous striking of the soil surface by rain and subsequent weathering of the soil he argued, separate the particles from each other and make them easy to be transported and that the severity of the resulting erosion depends on the ease of the particles to be detached and the carrying capacity of the transporting agents. If the transported materials are more than the carrying capacity of the transporting agent, deposition occurs. The work, identified kinetic and potential energy as the two energy sources necessary for the process of erosion and that potential energy is as a result of the height difference between a body with respect to another while kinetic energy is energy in motion which is actually used for the detachment of the soil particles and that potential energy possessed by a rain drop is converted to kinetic energy as it falls.

The two energy sources are given as: $PE = mgh$ where PE is potential energy, m is the mass of the body, g is acceleration due to gravity, h is the height from which the rain is falling. And the kinetic energy is represented as mv^2 where m is the mass and v is the velocity.

Similarly, Marie *et al*. (2011) highlighted that splash erosion marks the beginning of water erosion and occurs when raindrops on a bare soil surface causes the breakup of soil aggregates, sending some of the shattered particles vertically upward and some others laterally. Also, they showed that surface runoff has the capacity to detach soil particles from the surface of the soil as it moves, it picks up soil particles that have been detached through splashing by rain drops. These combined processes of consistent detachment by rain drops and transportation by runoff leads to the removal of reasonable amount of soil from the soil surface resulting in the development of sheet erosion. Rills and gullies develop when runoff becomes concentrated and carves out channels. Rills are small channels which can easily be closed during ploughing or tilling. However, gullies are usually larger than rills and erode large amounts of soil in larger volumes of runoff. Farm operations are usually not able to cover or close gullies.

2.3 Rainfall Characteristics in Relationship to Soil Erosion

Understanding the inherent characteristics of rainfall is a key factor in curbing the threats posed by erosion since rainfall is a driving factor for runoff generation. Generally, rainfall events in the tropics are largely heavy and intense, with large raindrops falling at high velocity. The size of individual rainfall events in this region varied from approximately zero to about 7 mm with an average of around 2 mm and increases as the intensity increases. The terminal velocity of falling rain drops varies with raindrop diameter from approximately zero to about 9 m/s (Hu, 1999). Obi and Salako (1995) while characterizing rainfall erosivity for south-eastern Nigeria, noted that for the Guinea savannah, forest and coastal belt, the highest amounts of rainfall erosivity observed were between 117 and 183 per rain event and that the maximum 6-minutes intensities were between 191 and 254 mm h^{-1} with advanced storms dominating the region. The mean erosivity values recorded using EI_{30} index ranged from 12,814 to 18,611 MJ. mm/ha.h. They concluded that the high erosivity of rains in the area is attributable to heavy storms of relatively high intensities that usually fall without stopping for an extended period (long duration). Furthermore, Ran *et al*. (2012) investigated the impact of rainfall characteristics on runoff generation and soil erosion and observed significant differences in hydrograph, infiltration depth, soil water content and sediment graph. They showed this using different laboratory experiments while considering varying intensities of rainfall, durations, directions of the rains, rainfall positions and no rainfall intervals, although the rainfall characteristics impact on runoff generation and soil erosion are still not well understood even with their importance. Some of their conclusions include the following: that surface sealing causes changes in the infiltration pattern in such a way that moving upstream rainfall scenarios (MURS) produce more accumulated runoff than moving downstream rainfall scenarios (MDRS), that rainfall duration is an important factor in soil crack occurrence and that erosion and runoff peaks rise together until a point where soil erosion peak begins to decrease even with increase in runoff peak.

2.3.1 Rain-splash erosion

When rain falls from the cloud with its kinetic energy, the impact causes the shattering of soil aggregates and detachment of soil particles leading to rain-splash erosion, with the raindrops breaking into ballistic droplets. The detached particles together with the broken rain droplets further rebound and fall some distance away (Hu, 1999). Using single drop experiments, Al-Durrah and Bradford (1982) studied the mechanism of rain-splash erosion on soil surfaces and observed that instantaneous loading as a result of the impact of rain drop hindered drainage but causes no significant variation in either the volume of soil or its bulk density. The impact causes deformation of the soil surface and the transformation of vertical force of the rain drop to lateral shear by the radial flow of the impacting drop. They also reported a correlation between splash shape, surface shear strength and splash angle with soil shear strength.

The relationship below was found between splash angle and shear strength:

$$\theta_s = 40.5.\tau^{-0.425} \qquad (1)$$

where θ_s is the splash angle in degrees and τ is the shear strength (kPa). The research concluded that the type of soil does not affect this relationship.

2.3.2 Rill erosion

It is widely agreed that rill erosion is usually developed at certain distances where the surface runoff has become concentrated or channelized (Morgan, 2005). Merritt (1984 cited by Morgan, 2005) investigated the characteristics of overland flow and reported that for a change in overland flow to be converted to rill flow, it has to pass through four stages, viz: unconcentrated overland flow, overland flow with concentrated flow path, micro channels without head cuts and micro channels with head cuts. According to the findings, a huge difference exists between unconcentrated overland flow and overland flow with concentrated flow paths, implying that flow concentrations within the overland flow should be viewed as the beginning of rill system. Rauws and Govers (1988 as cited by Morgan, 2005) suggested that critical shear velocity for rill initiation (Y_c) is linearly related to the shear strength of the soils (T_s) measured at saturation point with a torvane for soils with low clay content:

$$Y_c = 0.89 + 0.56\ T_s \qquad (2)$$

The expansion of the formed rill upslope is usually through the retreat of the head-cut at the top of the channel, the rate of which depends on the cohesive forces of the soil, the height and angle of the headwall, the discharge and the velocity of the flow (De Ploey, 1989 as cited by Morgan, 2005).

2.3.3 Interrill erosion

Runoff is usually generated when the rate of infiltration is lower than the rainfall intensity. Interrill which is an advanced stage of runoff, transports the detached soil particles to the deposition points or into the streams. It involves the uniform washing away of the soil surface without any conspicuous ditches. It occurs when the shear stress resulting from interrill exceeds that of the soil, detachments begin to occur. Empirically, interrill is normally represented as a power function as shown by Meyer (1998); Meyer and Harmon (1989); and Line and Meyer (1988, cited by Hu, 1999) in the given equation:

$$E = xY^z \quad (3)$$

where E is the rate of interrill erosion for a given rainfall duration (ton/ha-h), x and z are constants related to soil properties, y is the rainfall intensity during the rainfall duration (mm/min).

In the WEPP model, interrill is represented as:

$$Di = K_iR^2 \quad (4)$$

where Di is the interrill erosion rate, K_i is the interrill soil erodibility and R^2 is the rainfall intensity.

2.4 Soil Erosion Prediction Methods

According to Laflen and Flanagan (2013), the history of soil erosion prediction is dated back to about 70 years ago when Austin Zing published a relationship between soil erosion by water and land slope and length. Although many studies have been carried out to understand the problem of erosion and the factors affecting it, Zing in 1940 was the first to publish mathematical relationship between these factors and soil erosion. According to the work, the relationship between erosion and the factors affecting it is expressed thus:

$$Tl = KS^{m}X^{n} \tag{5}$$

where Tl is the total soil loss from a land slope of unit width (lbs), K is the constant of variation, S is land slope in percentage, X the horizontal length of field measured in feet and m and n are exponents. Zing also noted that the mean rate of soil loss for a unit area with a slope of uniform width is given as:

$$\mu = KS^{m}X^{n-1} \tag{6}$$

where μ = average or mean soil loss, K, S and X are as stated above. He gave the values of m and n as 1.4 and 1.6 as derived from his rainfall simulation experiment. Shortly afterwards, Dwight Smith expanded the equation to include soil conservation practices. Smith and Zing worked together to derive alternative equation for an average soil loss and was given as:

$$\mu = K{*}S^{1.4}X^{0.6}P \tag{7}$$

where all the other parameters are as stated earlier and P is the ratio of soil loss with a mechanical conservation practice to soil loss without conservation practice. In a similar effort, Browning *et al*. (1947) established a full erosion prediction technology with soil erodibility based on the work of Smith. In furtherance of the effort, Smith and Wischmeier (1957) observed that apart from the rainfall factor, other factors to be considered which affect erosion are: the slope gradient of the soil, the length of the slope, the vegetation or the type of crops or cropping system, soil and the type of management regime under which it is. They therefore, established an empirical formula for estimating soil loss from the field as

$$\bar{Y} = K*P*M*Z*S*L \quad (8)$$

where $\bar{Y}$ is the average annual soil loss from the field (ton/acre), Z is the mean annual soil loss from the given plot measured in ton/acre for a selected rotation with farming up and down slope, S and L are the slope and its length, P is the conservation practise in relation to up and down hill farming and M is the management factor. They suggested the following equation formed by the combination of raindrop diameter and velocity for the determination of kinetic energy of rainfall:

$$Ke = 916 + 331\log_{10} RI \quad (9)$$

where Ke is the kinetic energy (ft-ton/acre-in), RI = intensity of rainfall measured in inh^{-1} and that the product of Ke and the total amount of rainfall gives total kinetic energy. And also that KeI_{30}, kinetic energy of rainfall multiplied by the maximum 30 minutes' rainfall intensity (I_{30}) was the best single rainfall parameter for the prediction of soil loss. However, it took about 20 years before the expansion by Dwight Smith resulted in the development of the popular Universal Soil Loss Equation (USLE) which has been considered the most important achievement in soil erosion prediction in the last century. The USLE (Wischmeier and Smith, 1978) is given as:

$$X = R_e*K_s*L_s*S_g*V_c*P_r \quad (10)$$

where X is the estimated annual soil loss (ton/acre-year), R_e is the rainfall erosivity, K_s is the soil erodibility factor, L_s is the slope length, S_g the slope gradient, V_c is the vegetative cover and management factor and P_r is the supporting practice factor. The following is the elaboration on the parameters in the model:

- **Rainfall erosivity (R)**

Wischmeier and Smith employed rainfall and soil loss data from different locations of the United States to arrive at the conclusion on the most influential characteristics of rainfall with reference to erosion.

- **Soil erodibility factor (K)**

Olson and Wischmeier (1963) estimated the erodibility values using the newly established rainfall factor. Multiple regression analysis was also used to establish the other important variables to soil erodibility and concluded that very fine sand behaves more like silt than sand and this was used to establish a soil erodibility nomograph (Wischmeier *et al*., 1971) which has been shown as a good tool for estimating soil erodibility.

- **Length and steepness of slope (LS)**

Smith and Wischmeier (1957) studied the role of slope and slope length on soil erosion at different locations and hence defined slope length as the distance measured from the point of origin of overland flow to where deposition begins to occur or where runoff entered a well-defined channel. Slope effect on erosion was therefore expressed as:

$$M = (\lambda/72.6)^{g} \qquad (11)$$

where M is the slope length factor, λ slope length and g is the slope gradient.

Similarly, they also established the following equation as the relationship between soil loss and steepness of slope:

$$Z = (4.3 + 3.0s + 0.43s^2)/66.13 \qquad (12)$$

where Z is the slope factor and s is the slope gradient.

- **Cropping and management factor (C)**

  In USLE, C factor is simply the ratio of soil loss from a particular cropping system and management regime to soil loss from a continuously tilled fallow area (Laflen and Flanagan, 2013).

- **Conservation practices factor (P)**

  In USLE, the conservation practice factor which later became known as erosion control practice factor (Wischmeier and Smith, 1965) and support practice (Wischmeier and Smith,1978) is explained as the fraction of soil loss under a given management or practice to the soil loss with up and down hill practice.

  In the late 1970, a major breakthrough was recorded in the study of soil erosion through the development of a field scale model for Chemical, Runoff and Erosion from Agricultural Management Systems-CREAM (Knisel, 1980) and with more people involved in the use of computer, more efforts were then channelled towards the development of an erosion technology that is computer-based. Also with the various shortcomings associated with USLE, especially with the problem of attributing rainfall erosivity to soil detachment by natural rainfall and ignoring detachment as a result of irrigation or other forms of water detachments. This led to the development of Modified Universal Soil Loss Equation (Williams *et al*. 1971). Furthermore, in April 1985, a consensus was reached which finally led to the revision of USLE to Revised Universal Soil Loss Equation (RUSLE). The Revised Universal Soil Loss Equation was introduced by Renard *et al.,* (1994). Basically, the fundamental structures of both the USLE and RUSLE are the same, although the factors of

RULSE were further simplified for better and more accurate prediction by the model. The basic equation of RUSLE is as shown below:

$$Á = P.C.LS.K.R \tag{13}$$

where Á is the estimated soil loss in $\text{tonacre}^{-1}\text{yr}^{-1}$, P is the supporting practice factor, C is the vegetative cover and management, LS is the slope length and steepness factor, K is the soil erodibility factor and R is the rain and runoff factor.

Immediately after the change of the name, efforts were on to develop a process-based technology to replace the empirically based USLE for erosion prediction.

2.5 Water Erosion Prediction Project (WEPP) Model

In many parts of the developed world, after the development of the USLE and RUSLE, efforts towards the development of new empirical models started declining and momentum was shifted towards the development of process based simulation models (Nearing *et al.,* 1990). In August 1989, the first prototype of a process based model was developed to replace the USLE and RUSLE and was known as Water Erosion Prediction Project (WEPP). Its initiation process started in the year 1985 with the aim of developing a new type of water erosion prediction model much more adaptable in soil and water conservation study and in environmental planning and assessment (Abaci and Papanicolaou, 2009). The WEPP model, a physically based and new generation water erosion prediction technology was developed by the United States Department of Agriculture. Its complete application, documentation and validation was released in 1995 (Flanagan and Nearing,1995). WEPP model is a continuous simulation model exclusively computer based, unlike the popular RUSLE. The model employs the steady state sediment continuity equation to estimate annual runoff, soil loss and sediment yield (Mbajiorgu and Ogbu, 2011). The model basically simulates the hydrology of the surface, plant growth, the daily water balance, soil loss, as well as the rate of decomposition of residues.

The erosion model used in the WEPP technology was presented by Nearing *et al.* (1989). The model employs a steady state continuity equation shown as:

$$\frac{dL}{dX} = D_r + D_i \tag{14}$$

where L is the sediment load ($kgs^{-1}m^{-1}$), X is the distance downslope (m), D_r is the rate of rill erosion ($kgs^{-1}m^{-2}$) and D_i is the rate of interrill erosion (Foster *et al.,* 1995). They also expressed the rates of interril and rill erosion components of the above equation as:

$$D_i = K_{ad} RI_e \delta_{ir} ISR_{rr} \mathfrak{f}_{nozzle} \frac{R_x}{W} \tag{15}$$

where D_i is the rate of interrill erosion, K_{ad} is the adjusted interrill ($kgs^{-1}m^{-4}$) erodibility factor, RI_e represents the effective rainfall intensity (ms^{-1}), δ_{ir} is the rate of interrill runoff, ISR_{rr} is the ratio of interrill sediment delivery, F_{nozzle} is the factor of adjustment for sprinkler irrigation nozzle impact energy (usually taken as 1 in natural rainfall), R_x is the rill spacing (m) and W is the width of rill.

$$D_r = D_z[1 - \frac{L}{T_c}] \tag{16}$$

Dr is as stated above, D_z is the detaching capacity of the rill flow ($kgs^{-1}m^{-2}$) and T_c represents the sediment transport capacity in the rill.

But when the hydraulic shear stress of the rill flow is greater than the critical shear stress for the soil, D_z becomes

$$D_z = K_{ri}(\tau_f - \tau_c) \tag{17}$$

where D_z is as shown above, K_{ri} is the rill erodibility parameter (sm^{-1}), τ_f is the flow shear stress acting on the soil particle (Pa) and τ_c is the rill detachment threshold parameter (Pa).

Flanagan *et al.* (1995) described the sediment transport capacity of the rill flow as:

$$T_c = K_c Q_w S \tag{18}$$

where T_c is the sediment transport capacity, K_c is a constant, Q_w is the flow discharge per unit width (m^2s^{-1}) and S represents the slope in percent.

But when sediment load L, is greater than the sediment transport capacity, net deposition is calculated thus:

$$D_r = \left\lfloor \frac{V_f}{Q_w} \right\rfloor (T_C - L) \tag{19}$$

where V_f is the sediment effective fall velocity (ms^{-1}), T_c, L, D_r and Q_w are as stated above. Foster *et al* (1995) has further explained that the erosion component of the WEPP model are driven by the following hydrological variables: effective runoff duration, effective rainfall intensity and peak runoff per unit area. The hydrologic component of the model computes the runoff peak and duration while the climate generator (CLIGEN) component of the model is used to generate rainfall intensity. The computation for effective duration of runoff is by:

$$t_r = V_t P_r^{-1} \tag{20}$$

where effective runoff duration is given as t_r (s), the total volume of runoff event is V_t (m^3) and the runoff per unit area is represented as P_r.

$$I_e = \sqrt{\left(\frac{\int I^2 dt}{t_e}\right)} \tag{21}$$

where I_e is the effective rainfall intensity (mms^{-1}), I is rainfall intensity (mms^{-1}), t is time (s), t_e is the total time in which the rate of rainfall exceeded infiltration rate.

Through series of non-dimensional equation computation, erosion is computed under the WEPP model. WEPP runoff and soil loss predictions were investigated by Zhang *et al* (1996) with natural runoff plot, and reported that WEPP predicted adequately the average runoff and soil loss for different cropping and management systems. Nevertheless, the best results were obtained when the model was used to predict average annual runoff and soil loss.

Generally, WEPP has been considered a better model for runoff and soil loss prediction compared to the other previously developed erosion models because of the following: its ability to predict temporal and spatial distribution of soil losses, and wide area of application. As such, it has consequently become one of the most widely utilized models in the world today. However, its application in Africa, especially in Nigeria was hitherto lacking, until a recent work by Mbajiorgu and Ogbu (2011) that tested the model for a single event of runoff and soil loss from a single plot under a rainfall event in Nsukka.

2.6 Soil Organic Carbon Losses by Water Erosion and Climate Variability

The process of carbon sequestration involves the removal of carbon from the atmosphere by plants and its subsequent storage in the soil as soil organic matter (Lal, 2004). This process results in the overall increment in the total amount of soil organic carbon (SOC) accumulated in the soil, improves its depth of distribution and ensures its stabilization by incorporating it within the soil stable aggregates so as to protect it from microbial processes (Gaiser *et al*., 2008). Van Oost *et al*. (2007) asserted that agricultural soil erosion causes changes in the global carbon cycles. According to their study, the impact of agricultural soil erosion was estimated to range from the release of about 1 pentagram per year to a sink of the same magnitude. Their methodology involved the use of caesium-137 and carbon inventory measurement from large scale survey. They were able to establish a consistent evidence for an erosion-induced sink of atmospheric carbon of about 26% transported by erosion.

Similarly, based on this relationship, they also found that agricultural erosion leads to a global carbon sink of about 0.12 (ranging from 0.06-0.27) pentagram per year. Although the research was able to raise serious concern regarding whether agricultural erosion represents a source or sink of carbon, it was not able to present a clear-cut picture on the role of erosion to global carbon budget. Also, the implication of carbon losses by water erosion and climate variability was further studied by Velde *et al*. (2014), in their study of the future climate impacts on potential erosion and soil organic carbon in European crop lands using EPIC model driven by reference climate data and climate data with reduced variability. The study revealed that the average rates of erosion for both reference climate data and climate data with reduced variability were 14.4 and 9.1-ton ha^{-1}, and 19.1 and 9.7, for 1981 to 2010 and 2071 to 2100 respectively. From the experiment, it is obvious that soil losses due to water erosion is bound to increase in the future. They also reported a total loss of 769 Tg C carbon from European croplands resulting from erosion for the period 1981 to 2010 (from a total of 6197 Tg C without erosion) under CNTRL climate and concluded that impacts resulting from climate trend reduced the European cropland soil organic carbon by 578 Tg C without erosion, and 683 Tg C with erosion from 1981 to 2100. Furthermore, they maintained that the impacts are further exacerbated by climate variability leading to an estimated further reduction of the soil organic carbon stock by about 170 Tg C in the absence of erosion and by 314 Tg C with erosion by the end of the century and that future climate variability and erosion will enhance the rate of soil organic carbon loss from croplands. This report was also adopted by Wang *et al*. (2014) who emphasized the need for a better understanding of how water erosion causes the redistribution of soil organic carbon so as to enable the unravelling of the particular role that soil erosion plays on both local and global carbon budget.

2.7 Impact of Climate Variability on Soil Erosion

The threats of climate change on human health and other activities have been widely reported. But also worrisome is the problem of rainfall variability both in intensity and duration due to climate change. The changing climate may exacerbate the problem of water erosion in the tropics, and the current soil management techniques because of this new threat may not be sustainable. Climate change may also produce rainfall regimes that are likely going to threaten soil productivity particularly in the south eastern part of Nigeria.

Shiono *et al*. (2013) assessed the expected impact of climate change on rainfall erosivity (R) of farmlands in Japan. The study compared the R-factor values for three periods; two future periods and near past period. Using a model that estimates the maximum rainfall intensity for 30 minutes (EI_{30}) with daily rainfall data, the R-factors values of 1036 meteorological stations for three periods: 1981 to 2000, 2031 to 2050 and 2081 to 2100 were calculated. The daily rainfall data required by the model were obtained from the regional climate model RCM20 based on SRES A2 scenario. The study revealed that climate change will increase rainfall erosivity in the near future in most farmlands in Japan both in time and space. The study also concluded that in comparison to the past, the expected increase in rainfall erosivity would be more than 20% and that the changes in rainfall erosivity were mainly attributable to changes in precipitation amount and intensity. Contrastingly, Changxing *et al*. (2012) investigated the temporal and spatial changes in runoff and its relationship with some selected factors in the middle Yellow River basin and reported a decrease in the general trend of runoff for the last six decades with sharp falls in 1971 and 1991. They reported an increase in runoff from north to south and from west to east; their correlation analysis revealed that spatial variation of runoff was due to variation in the distribution of the natural conditions and that the temporal reduction in the rate of runoff was mainly as a result of climate change, hydraulic engineering and soil conservation measures. The study concluded that climate change played an insignificant role in comparison with other factors analysed in runoff reduction in semi-arid areas while causing an increase and more variation in the amount of runoff in the semi-humid areas.

Qafoku (2014) in his review of the effects of different aspects of climate change on soils, noted according to the following equation:

$$CO_{2(g)} + H_2O \leftrightarrow H_2CO_3 \leftrightarrow HCO_3^-{}_{(aq)} + H^+{}_{(aq)}$$

that dissolution of atmospheric CO_2 (gas) in soil water yields hydrogen trioxocarbonate (iv) acid which readily dissociates causing a decrease in the pH of water contained in the soil pores as a result of aqueous phase proton enrichment. The resultant acidic medium causes the disintegration of soil particles (soil weathering). When these chemical constituents of the soil are altered, the rate of weathering increases which increases soil erodibility and the resultant effect is increase in the ease of shattering and detachment of the soil particles by rain drops leading to more erosion.

More evidences on the degradation effects of changing climate on soil chemical properties were reported by Harvey *et al*. (2013) with the following equations:

$$CaCO_3 + CO_{2(g)} + H_2O \rightarrow Ca^{2+} + 2HCO_3^-$$

$$2NaAlSi_3O_8 + 11H_2O + 2CO_{2(g)} \rightarrow Al_2Si_2O_5(OH)_4 + 2Na^+ + 2HCO_3^- + 4H_4SiO_4$$

$$Al_2Si_2O_5(OH)_4 + 5H_2O + 6CO_{2(g)} \rightarrow 2Al^{3+} + 6HCO_3^- + 2H_4SiO_4$$

The equations show clearly the reaction that takes place between the soil minerals; calcite, feldspar and 1:1 phyllosilicate respectively in the presence of excess CO_2 in the atmosphere. Equally, this evidence was adopted by Gislason *et al*. (2011) who added that the rate of mineral or rock dissolution in the future would be determined by its composition, environmental temperature and crystallinity.

2.8 Plant Roots and Erosion Control

The problem of water erosion is multi-dimensional, with many different factors playing significant role in exacerbating the problem. However, the role of plant roots in ameliorating water erosion can never be over emphasized. According to Gysells *et al*. (2005), vegetation to a very large extent controls the impact of water erosion. In their review of the impact of plant roots on the resistance of soils to erosion by water, they showed that the rate at which water erosion decreases with increasing vegetation cover and root mass is exponential. As given by the equation:

$$\beta = e^{-aPR} \qquad (22)$$

where β is soil erosion parameter such as interrill or rill erosion rates relative to the rates of erosion on bare topsoil without roots, PR is root parameter, for instance, root density or root length density and "a" is a constant that indicates the effectiveness of the plant roots in erosion reduction. They found that splash erosion is usually zero, no matter the rooting parameter used, whereas "a" value is 0.1195 on the average when root density (kg m^{-3}) was used as root parameter. They also reported "a" value of 0.0022 while using root length density (km m^{-3}). Similarly, the average "a" values for rill erosion were 0.5930 and 0.0460 for root density and root length density respectively. They concluded that due to the similarity between the root effect equation and vegetation cover equation, it is hard to distinguish which of these plant elements plays more significant role in reducing the impacts of water erosion, but many researchers have attributed soil loss reduction to above-ground biomass only. However, analysis of available data suggests that vegetative cover from plants is the most significant factor or parameter necessary in containing splash and interrill erosion, but for rill and gully erosion, plant cover is just as necessary as plant root in the control of erosion. This view has also been expressed by Burylo *et al*. (2012) while studying the plant root traits affecting the resistance of soils to concentrated flow erosion. In the study, three different plants species (*Robinia pseudo acacia*, *Pinus nigra austriaca*, and *Achnatherum calamagrostis*) were used with the aim of identifying the functional plant traits that predict the species ability in controlling erosion. They showed that Robinia pseudo acacia had the lowest rate of erosion, followed by *Achnatherum calamagrostis* with *Pinus nigra austriaca* having the highest rate of erosion. They concluded that root diameter and erosion rate are inversely related and that plant species effects are necessary for long term maintenance of a degraded ecosystem.

Similarly, Vannoppen *et al*. (2015) discussed the mechanical effect of plant root on concentrated flow erosion rates. The study revealed that living plant roots play significant role in altering both the hydrological and mechanical characteristics of soil matrix. Soil characteristics such as aggregate stability, infiltration rate, soil organic matter and organic carbon and soil cohesion are strongly influenced by root density and length. They also reported using a hill curve model that as the root density increases, the rate of erodibility of soil decreases and that root length density is a better variable for estimating the rate of soil loss than root density and concluded that plant roots could be very effective in ameliorating the rate of soil loss due to concentrated flow. The research was able to show correlation between the rate of soil loss and certain root parameters.

Also Xiong *et al.* (2007) reviewed the effects and mechanisms of plant roots on slope reinforcement and soil resistance and found that plant roots increase soil shear strength and hence resist the erosion of the topsoil and shallow landslide. They also, while using Wu-Waldron model, reported that increased resistance of soil to detachment due to plants roots is directly proportional to root area ratio and root tensile strength. Furthermore, they found that root density reduces the rate of soil detachment and that the action of fibre roots > 1 mm in diameter plays significant role in strengthening the soil against erosion and also increases soil water stable aggregates, although no quantitative functional relationship was observed.

2.9 Land Use and Land Management Practices

Land use refers to the type of activities which man subjects a given site or land to (e.g., plantations or agroforestry), whereas land cover describes the status or kind of vegetation on a given land or site (e.g., forest or crop). The natural vegetation and land use types are expected to receive a considerable adjustment in terms of its distribution and size as a result of climate change. These changes in the natural vegetative distribution on the earth surface and the changes in the land use will alter the exposed surface of the earth and the natural reflectivity of the earth surface. Among the consequences will be changes in the energy balance of the near-surface atmosphere, temperature and precipitation pattern and these factors are known to have considerable influence on the field water cycle and soil formation or degradation processes (e.g. soil erosion) (Harnos and Csete, 2008; Várallyay and Farkas, 2008).

Soil erosion by water causes high losses or reduction in the soil productivity through washing away of the soil surface together with its fertile components (organic matter). This is most pronounced in areas under inappropriate agricultural management, where land had been abandoned (bad lands or lands that are exhausted); under heavy road construction or wild fires (Panagos *et al*., 2014; Cerdà *et al*., 2010; Palacio *et al*., 2014). In his study, García-Ruiz (2010), isolated the type of use to which the land is put and the type of cover on the land surface as the major key factors determining the rate and amount of soil surface flow and surface erosion. This point was amplified by Labrière *et al*. (2015) in their review where they concluded that soil erosion in the tropics is concentrated both spatially (over bare soil) and temporally (just before vegetation establishment) and that vegetative covers growing close to the ground surface are necessary in curbing the challenge of erosion. They also noted that no land use is immune to erosion but the creation of bare surface on the land through human activities should be avoided as much as possible and also the implementation of good soil conservation practices and ensuring of vegetative cover as well as general good farming practices such as contour planting, no-till farming and use of vegetative buffer strips should be encouraged as this can reduce erosion by up to 99%.

Ande *et al*. (2009) while studying soil erosion in Ekiti State using Morgan, Morgan and Finney (MMF) model (Morgan *et al*., 1984) concluded that the current land uses and soil cover in the state were sustainable for long term production. Furthermore, Blavet *et al*. (2009) researched on the role of land use and management on the early stages of soil water erosion development in the French Mediterranean vineyard under different management viz; scrub land, fallow land and several wine-growing strategies (chemical and mechanical inter-row weeding, grassing, straw mulching, rock fragment cover and clearing rock fragment), using a simulated high intensity rainfall of about 60 mm/h on dry brown calcareous soils. They reported that no soil loss occurred on fallow and scrubland but high rate of runoff and soil losses were observed in chemically weeded vineyard. However, there was a decrease in the runoff amount when prunnings were left on the soil. Also, vineyard with mulch or rock fragment cover experienced a reduced runoff and erosion. They also found that grassing hold a great future in protecting fields against water-induced erosion and equally reported that strong relationship exists between rate of initial soil crusts, crusting with the rains, aggregate stability, organic carbon content, porosity and runoff. They concluded that early stages of water erosion depend on surface soil properties which in turn depend on land use.

Similarly, Zuazo *et al*. (2009) in their review of soil erosion and runoff prevention by plant cover, observed that soil erosion has continued to pose a major challenge to the world's terrestrial ecosystems. According to their review, managed ecosystems such as crop lands, pasture, or forests as well as natural ecosystem have come under serious threats from erosion and that erosion decreases the water holding capacity of soils and increases surface runoff. They also noted that soil erosion causes a decline in soil organic matter which leads to acute reduction in soil nutrients and loss of valuable biota.

Ehigiator and Anyata, (2011) evaluated the impact of land clearing techniques and post clearing management on runoff and soil erosion under tropical rainforest in western Nigeria and observed that the highest rate of erosion occurred in mechanically cleared sub-watershed with tree-pushers/root-rake attachments. Also, high rate of erosion was reported in sub-watershed constructed with graded-channel terraces for erosion control. However, they maintained that in general, low rate of erosion was observed in manually cleared sub-watershed than on mechanically cleared sub-watershed and that application of no-tillage yielded lower erosion compared to conventionally ploughed sub-watershed. They concluded that tillage methods and management practices play important roles in soil and water conservation and in the maintenance of soil quality.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Treatments and Experimental Design

The selected land management practices constituted the treatments for this study and were at least 100 m away from each other. There were four treatments: manually cultivated land, tractorized land, fallow and range land (plate I). The manually cultivated land had been under manual cultivation for more than 20 years. The land owner believes no other type of equipment has been used on this land apart from hoe. Different crops such as cassava, maize, cocoa yam and yam are usually grown on it but at the time of sample collection, it was planted to scent leaf and *Amaranthus spp.* The tractorized land had been under this form of cultivation for the past 30 years with maize, garden eggs, cucumber and pepper being the major crops usually cultivated on it. As at the time of sampling, the area was already covered by grasses as the crops previously planted had been harvested and the next planting season was being awaited. Furthermore, the next land management practice sampled was land under fallow. The current fallow on the land has been there since 2012. The land is usually cultivated with tractor once in a while after which it is allowed to recover before the next crop is grown. The major crops usually grown on it are cassava, maize and garden egg. Similarly, the land under range has never been cultivated for the past 40 years. It has been under range with cattle, sheep and goat often grazed on it from time to time and it is dominated by carpet grass.

The experimental design was 4 by 3 factorial fitted in a randomized complete block design with two replications. There were two different factors for the experiment. The four land use or management types constituted one factor while the climatic conditions (rainfall types) or scenarios were the second factor. The climatic conditions were historical and projected climatic conditions, each spanned over a period of 30 years. There were also two types of projected climatic conditions, and they included: Representative Concentration Pathways (RCP) 4.5 and Representative Concentration Pathways (RCP) 8.5. The historical climatic condition was from 1981 to 2010 while the projected climatic conditions were from 2041 to 2070. RCP 4.5 represents what the climatic condition in Nsukka would look like if the current greenhouse gas emission level is sustained at the present level or state while RCP 8.5 represents the climatic outlook if greenhouse gas emission continues to increase unabated to the maximum level possible.

Plate Ia: Land under manual cultivation

Plate Ib: Land under tractorized cultivation

Plate Ic: Land under Fallow

Plate Id: Range land

Plate I: A view of the four soil management practices studied.

3.2 Data Collection

3.2.1 Collection of climate data

The climatic data for the study were historical climate data from the Nigeria Meteorological Agency (NiMet), Enugu station and the COordinated Regional Climate Downscaling EXperiment (CORDEX) data from the Federal University of Technology Akure (FUTA). The parameters used were daily rainfall, solar radiation, wind speed and direction, and daily minimum and maximum temperatures. The choice of Enugu station is because NiMet does not have station in Nsukka and Enugu is the closest station. The data from NiMet were used as a historical baseline for comparison while the CORDEX data were used for future scenarios. The two data sets spanned over a period of 30 years each. The NiMet data were from 1981 to 2010 and the CORDEX data from 2041 to 2070. The CORDEX data comprised the future climate conditions (downscaled output from the regional climate model: Weather Research and Forecasting model (WRF)).

The selected climate scenarios were the Representative Concentration Pathways (RCP) 4.5 and RCP 8.5, based on Inter Governmental Panel on Climate Change (IPCC) greenhouse gas emission scenarios. The RCP 4.5 known as "Business-As-Usual Scenario" assumes a world where industrial growth and greenhouse gas emission continue unabated. The industrial growth and emission are assumed to continue at the current level with no decrease or increase in the rate. RCP 8.5 (extreme case of greenhouse gas emission scenario) is known as "Worst-Case-Scenario" with the assumption that the rate of industrial growth and greenhouse gas emission double the rate which had been previously estimated. CORDEX data were for the whole of Africa, therefore, Enugu and parameters of interest as listed above were extracted using Climate Data Operate (CDO) before they were used for running the Water Erosion

Prediction Project model (WEPP). The choice of these particular climatic parameters was based on the requirement of the WEPP model and their significant role in water erosion.

3.2.2 Collection of soil data

Soil samples were collected within the study area at identified locations where land was subjected to the land uses or practices under investigation (fallow land, land under continuous tractorized cultivation, land under continuous manual cultivation with hoe, and range or pasture land). For each soil management practice, two sites were sampled to give two replicates. A profile pit was sited in each of the two replicates of the four identified soil management practices constituting a total of eight (8) profile pits. The profile pits were for the determination of the soil depth (depth before the limiting horizon). Both core and auger soil samples were collected from each of the three different depths: 0-20 cm, 20-40 cm and 40-60 cm in each pit (Plate II). The auger soil samples were air-dried for one week in preparation for laboratory analysis. The core samples were trimmed in readiness for analysis in the laboratory.

It is worth mentioning here that in building the soil layers for the WEPP model, soil samples are required to have been taken at different depths within the horizons to a maximum depth of 1.8 m. However, the sampling carried out in this study was not to that maximum depth as the focus of the study was on erosion which is basically a surface phenomenon and hardly reaches the WEPP 2 m depth except in an advanced stage (gully) which should not be allowed.

Plate IIa: A profile in the fallow land

Plate IIb: A profile pit in the range land

Plate II: A view of profile pits dug under two of the soil management practices studied

3.3 Physical and Chemical Analysis of Soil Samples

The soil components of the WEPP model include: soil organic matter, soil textural class (based on percentage composition of clay, sand and silt) for all the layers until the limiting horizon is reached, infiltration rate, hydraulic conductivity, soil erodibility, cation exchange capacity (CEC), slope and albedo. Hence, laboratory analyses of the soil samples were carried out to determine these factors required by the model. Also, soil aggregate stability was determined for the samples as this is important in determining how easily the soil aggregates would be shattered by rainfall impact.

3.3.1 Determination of soil organic carbon

Organic carbon was determined using the Walkley and Black method (1934) as modified by Allison (1965) which involves the oxidation of soil organic matter with potassium dichromate ($K_2Cr_2O_7$) and tetraoxosulphate (vi) acid (H_2SO_4). The conversion of organic carbon data to organic matter was done by multiplying organic carbon by a factor of 1.724.

3.3.2 Determination of cation exchange capacity (CEC)

Cation exchange capacity was determined using the Chapman (1965) method. This method involved leaching of the soil with neutral 1 N potassium acetate (KOAc) solution and the displacement of 5 g of soil sample with neutral I N ammonium acetate (NH_4OAc). The CEC was estimated as follows:

$$\text{CEC meq/100g of soil sample} = \text{meq K/ 100g soil} \quad (23)$$

3.3.3 Determination of particle size distribution

Particle size of air-dried soil samples was determined using Bouycous hydrometer method (Gee and Bauder, 1986). For the analysis, 50g of 2 mm sieved air-dry soil samples was dispersed with 5% sodium hexametaphosphate for 24 hours. The textural class was determined with the aid of USDA textural triangle.

3.3.4 Determination of soil bulk density

The soil bulk density was determined using the method described by Blake and Hartge (1986). Core samples of soil were collected for the depths of 0-20 cm, 20-40 cm and 40-60 cm. The samples were trimmed and oven-dried at 105^0C for 48 hours. Their bulk densities were calculated using the equation:

$$\rho\ (g/cm^3) = \frac{Ms(g)}{Vs(cm3)} \qquad (24)$$

where ρ is the bulk density, Ms is the mass of oven-dry soil and Vs is the volume of oven-dry soil (volume of the core sampler)

3.3.5 Determination of hydraulic conductivity (Ksat)

In this study, Ksat was determined based on Klute and Dirksen (1986) method. A constant water head was maintained on the core soil samples fixed in a stand and water allowed to drain through for 5 minutes. The depth of the ponded water on the reservoir on top of the core soil sample was measured and the amount of water that drained through the soil core within the time period was also determined and the calculation done using the transposed Darcy’s equation for vertical flow:

$$K = \frac{Q}{A(\Delta H/L)} \qquad (25)$$

where Q is the flow rate (cm^3/sec) through a cross sectional area A, ΔH the hydraulic head difference across a length L of porous medium.

3.3.6 Estimation of volumetric water content

Volumetric water content was determined using the relationship between the gravimetric water content and bulk density. The formula for the calculation is given below:

$$\text{Gravimetric water content}(\omega) = \frac{Mw(g)}{Ms(g)} \qquad (26)$$

where Mw is mass of wet soil and Ms is the mass of oven dry soil.

The volumetric water content is the product of bulk density and gravimetric water content.

Volumetric water content (θ) = ρ × ω; where ρ is bulk density and ω is the gravimetric water content.

3.4 Estimation of Baseline Erodibility Parameters

Erodibility parameters were calculated using the method described by Flanagan and Livingston (1995) in the WEPP user guide. The guide recommended the equations below for estimating erodibility parameters for crop land soils with more than 30% sand. Therefore, since the samples from the crop land all contained more than 30% sand, the equation was consequently used:

$$K_i = 2728000 + 192100*VF \qquad (27)$$

where VF is very fine sand and Ki is the inter rill erodibility

$$K_r = 0.00197 + 0.00030*VF + [0.03863*EXP(-1.84*O.M)] \qquad (28)$$

O.M stands for organic matter and Kr is rill erodibility.

$$T_c = 2.67 + 0.065*CLY - 0.058*VF \quad (29)$$

T_c is critical hydraulic shear and CLY is the percentage clay.

The baseline equation for estimating erodibility parameters in range land as described by Flanagan and Livingston (1995) in the WEPP user guide was used for estimating the errodibility parameters for the range land.

The baseline equation is given as follows:

$$K_i = 1810000 - 19100*SND - 63270*O.M - 846000*\Theta fc \quad (30)$$

$$K_r = [\, 0.000024*CLY - 0.000088*ORGMAT - 0.00088*BDdry - 0.00048*ROOT10] + 0.0017 \quad (31)$$

$$T_c = 3.23 - 0.056*SND - 0.244*O.M + 0.9*BDdry \quad (32)$$

where T_c, K_i, K_r and O.M are as stated above and BDdry and ϴfc are the dry bulk density and volumetric water content respectively while SND stands for percentage sand.

3.5 Albedo

Albedo which measures the reflectivity of a surface was estimated through mathematical relationship. Albedo is the portion of the solar radiation that is reflected back to the atmosphere. The parameter is important in the estimation of net solar radiation reaching the soil surface, a factor that plays significant role in evapotranspiration. Albedo in WEPP model is used to calculate evapotranspiration within the WEPP water balance routines. The soil albedo in this study was calculated mathematically with the relationship given by Baumer (1990) cited by Barfield *et al*. (1995).

The formula for albedo calculation in WEPP model is given as:

$$SALB = 0.6/\exp(0.4*O.M) \quad (33)$$

where SALB is the surface albedo, O.M is the % surface organic matter. Where a soil has zero organic matter, then the equation becomes 0.60.

3.6 Slope

In this study, the slope was determined using Abney level and ranging pole. The ranging pole was mounted on the down part of the slope and a material of conspicuous colour tied on it at eye level. After tying the material on the ranging pole, the observer moved some distance (not less than 20 m) up the slope and held the Abney level at eye level and observed the line where the material was tied. The spirit level of the Abney level was then observed and continuously adjusted until the water contained in the spirit level was just divided into two equal halves by the string connecting the two ends of the spirit level and the reading on the Abney level taken. The value on the graduated arch of the Abney level where the pointer rested was read off as the slope for that location. The slope of all the representative plots from which samples were taken were all measured.

3.7 Description of Model Input Climatic Data

The climatic data used for executing the model were solar radiation, rainfall, minimum and maximum temperatures for historical period (1981 to 2010) from NiMet and for Enugu station, and COordinated Regional Downscaling EXperiment (CORDEX) climatic data for the scenarios 4.5 and 8.5 with the same parameters as those from the station data. The choice of Enugu station is because Enugu station is the closest station to Nsukka since NiMet has no weather station in Nsukka.

CORDEX was an initiative of World Climate Research Programme (WRCP) aimed at providing projected regionally downscaled data with different regional models (Giorgi *et al*., 2009); as an alternative to the Coupled Model Inter-comparison Project (CMIP). CORDEX, according to Uppala *et al*. (2008) is a product of both statistical and dynamical downscaling at the regional level using ERA-Interim re-analysis as the boundary conditions. The output of the CORDEX project was compared with the regional data to ascertain the accuracy of the projections. Emission scenarios known as RCP 4.5 and RCP 8.5 which stood for mid-level or business as usual and high level emission scenarios respectively from the Global Circulation Model (GCM) were used for the CORDEX project and the data spanned from 1951 to 2100.

3.8 Justification for the Application of Model in an Uncalibrated and Unvalidated Mode

Ideally, in order to calibrate and validate WEPP model, historical data set for topographic, management or plant growth, runoff and soil loss data of at least 20 years are required. This comprehensive dataset is a major prerequisite for proper calibration and validation of the model. However, according to Flanagan and Frankenberger (2012), due to lack of interest in this kind of detail before now, they are not usually available and the situation is even more precarious in most developing countries as most often than not, the only historical data for erosion studies is usually the rainfall data and nothing more. A situation that was also experienced in this study. Nevertheless, the application of WEPP model without calibration and validation has yielded an acceptable result, giving a no significant difference between when it was calibrated and when it was not. The result of the uncalibrated mode application of WEPP was compared to the result of both Revised Universal Soil Loss Equation (RUSLE) and Universal Soil Loss Equation (USLE) for the same experimental plot and the result showed that the model performed quite well in that mode, meaning that in a situation where historical data set are missing, that the model can be applied successfully in uncalibrated mode (Tiwari *et al*., 2000). WEPP model can also be applied in uncalibrated mode if comparison is being made between management practices or different rainfall periods (Flanagan and Frankenberger, 2012). Therefore, the model was applied in an unclaibrated and unvalidated mode in the current study.

3.9 Application of Water Erosion Prediction Project (WEPP) Model

In this study, the Water Erosion Prediction Project (WEPP) version 2012.8 was used. In order to execute a project in WEPP model, the basic components required are as follows: land slope, soil, climate and management practices.

The measured soil properties and slope were used to build the slope and soil input components of the model while the climatic data and the land management practices which were identified in the field were used to build the climate and management components of the software. After the input of the required data set in the model, the model was run for one-year monthly simulation.

The model run was necessary for the achievement of part of objectives two and three which were to determine which of the current soil management practices is most sustainable through reduction in runoff and soil loss under the changing climate and to predict the future levels of runoff and soil loss through water erosion from the soils under the four management practices respectively. A sample of the model output (fallow land under historical climatic condition) is contained in appendix B.

3.10 Data Analysis

3.10.1 Analysis of soil data

The soil data were analysed using Excel, 2016 software. Using their formulae as described by the standard laboratory procedures through which their values were gotten, the values of interrill erodibility, rill erodibility, surface albedo, percentages of sand, clay and silt, organic matter, cation exchange capacity, critical hydraulic shear stress, baseline GreenAmpt hydraulic conductivity, bulk density and mean values of the soil samples were calculated.

3.10.2 Analysis of runoff and soil loss

Using R software, version 3.2.3 (R Core Team, 2015), the output of the WEPP model (mean annual runoff and soil) after its run under different soil management practices and climatic conditions (historical, RCP 4.5 and RCP 8.5) were tested for significance at 95% confidence level with Least Significant Difference after running the analysis of variance (ANOVA) for randomized complete block design (RCBD). The effects of the different soil management practices on the soil properties were also tested. Where F test was significant, LSD was used to separate the means for main effects and interaction where necessary.

These analysis and test were necessary in addressing part of objectives two and three which were to determine which of the current soil management practices is most sustainable through reduction in runoff and soil loss under the changing climate and to predict the future levels of runoff and soil loss through water erosion from the soils under the four management practices. Further details on the results of the analysis of the model outputs are contained in appendix A.

3.10.3 Analysis of climate data

The summary statistics were carried out on both the rainfall and temperature data for both historical (1981 to 2010) and projected climate scenarios: Representative Concentration Pathways (RCP) 4.5 and 8.5 (2041-2070) for the presence of outliers with Excel, 2016 software.

The daily data for minimum and maximum temperature and precipitation for both historical period and future scenarios were incorporated into the CLIGEN (climate generator) version 4.30 to generate other required climatic data such as wind direction, speed and dew points which were not available in the original data. This the model does using other available climatic data such as minimum and maximum temperatures and rainfall. CLIGEN is an inbuilt stochastic weather generator within the WEPP model that uses historical measurements to generate probable values for daily temperature, dew point, wind, solar radiation and precipitation for a geographic point.

3.10.3.1 Test of stationarity

To address part of objective one of the study which was to determine whether there is a trend in the data set or not. The dataset was subjected to test of stationarity with Microsoft XLSTAT version 16.08 since test of stationarity is a prerequisite for trend analysis. The Augmented Dickey-Fuller (ADF) test of stationarity approach as described by Dickey and Fuller (1981) was used. A data set is said to be stationary if the mean or the variance of the data does not vary with time. It is represented as I (0), showing that it is integrated with order zero. However, when a series is non–stationary, it is integrated with order d, written as I (d) which means that the mean or the variance is varying with time and must be differenced d times to make it stationary. These analyses were all performed on both annual rainfall and temperature to determine their order of integration

If after the ADP tests and the variable showed stationarity, the variable would be classified as having the integration of order zero – I (0). However, when stationarity is confirmed and the variable in first difference, the variable is said to be integrated in order one [1 (1)]. But when the variable is in second difference and stationarity is confirmed, the variable is said to be integrated of order two [1 (2)]. In this study, since the data are time series, unit root tests were carried out using Augmented Dickey-Fuller (ADF) (Dickey and Fuller, 1981).

The augment Dickey – Fuller (ADF) test is represented:

$\Delta Xt=\alpha+\alpha 1t+\alpha 2Xt-1+\Sigma bipi=1\Delta Xt-1+et$

where Xt is the variable under consideration, Δ is the first difference operator, $\Delta Xt-1$ is the lagged difference of Xt, t is the time or trend variable, 1981-2011, p is lag number and et is the error term.

3.10.3.2 Trend test

In order to further confirm the trend that was detected by the stationarity test and to address the first objective of the study (to find out the past and potential future trends of rainfall and temperature in Nsukka). The Mann-Kendal trend test add-on of XLSTAT, 2016 was used to test the significance of the long term annual trends of rainfall and temperature (minimum and maximum) for Nsukka for the periods 1981 to 2010 and 2041 to 2070. Mann-Kendall test is required when the number of data size (n) is higher than or equal to 10. It is a non-parametric test and has the advantage of not being affected by any form of skewness or otherwise of the data series. The null hypothesis (H0) of Mann-Kendall test states that trend does not exist in the series while the alternative (Ha) assumes that trend exists in the series. The procedure involves checking the whole data set and picking two subsets from the whole series and comparing each preceding data with its successive one in an ordered manner. If a succeeding data subset is higher than the preceding one, 1 increment is made on the data. However, if it is smaller, a decrement of the same magnitude is made. The accumulated sum of this procedure gives the final value for the Mann-Kendall S statistic (Mann, 1945; Kendall, 1975 cited by Karmesh, 2012: Onoz and Bayazit, 2003).

The Mann-Kendal S statistic is given as follows:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign(Y_j - Y_i) \tag{34}$$

The data series are Y_i and Y_j and the ranking of the series Y_i is in the order i=1, 2, 3, and stops at n-1 while Y_j starts from j=i+1, 2, 3, until n. Therefore, in order to get the value of S, the sum of the Y_j value is subtracted from the successive corresponding value of Y_i series in that order.

$$Sign\ (Y_j - Y_i) \begin{cases} 1\ when\ Y_j - Y_i > 0 \\ 0\ when\ Y_j - Y_i = 0 \\ -1\ when\ Y_j - Y_i < 0 \end{cases} \tag{35}$$

It is worth noting that the higher the number of observations, the more likely the chances of S turning to normality. For Mann-Kendall test, the mean and variance statistic (Vari(S)) is given thus:

$$Vari(S) = \left| \frac{N(N-1)(2N+5) - \sum_{i=1}^{p} q_r(q_r - 1)(2q_r + 5)}{18} \right| \tag{36}$$

where N is the total number of observations, r represents the number of ties to the p term, and q stands for the tie actual value. But the standard Mann-Kandall test statistic is calculated with the formula below:

$$z_t = \begin{cases} \frac{S-1}{\sqrt{Vari(S)}} \; when \; \mathrm{S} > 0 \\ 0 \; when \; \mathrm{S} = 0 \\ \frac{S+1}{\sqrt{Vari(S)}} \; when \; < 0 \end{cases} \tag{37}$$

The Zt is used to test for the trend significance at the chosen alpha level and to draw conclusion on whether to accept null hypothesis (H0) or to reject it and accept the alternative. The sign and magnitude of Zt also tells whether the trend is in an upward direction or otherwise. The test also provides other statistic values such as Kendall’s tau and Sen’s slope which are used to determine the level of correlation and the magnitude of trend and the direction of the trend respectively.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

This chapter presents the results obtained from the various analyses carried out on the data and also provides the discussion of the results. The results that were discussed include: the trend results, soil loss result, runoff and soil chemical properties.

4.1 Results of Unit Root and Stationarity Test

This section presents the results for objective one which sought to find out the trend of historical and future rainfall and temperatures for Nsukka.

Since the data set was a time series dataset, they were subjected to stationarity test using the Dickey-Fuller test approach. The test has the following hypothesis:

H0: There is a unit root for the series (data not stationary)

The result of the test is shown in Table 4.1 with an observed tau value of -3.383, tau critical value of -0.508 and p-value of 0.068. The table showed that the calculated p-value is greater than the significance level, and hence the null hypothesis was therefore not rejected and conclusion drawn that the dataset is not stationary.

Table 4.1: Dickey-Fuller test of stationarity for annual historical rainfall (1981 to 2010)

Parameter	Value
Tau (Observed value)	-3.383
Tau (Critical value)	-0.508
p-value (one-tailed)	0.068
Alpha	0.05

Source: Author’s computation of Dickey-Fuller test result at 5% confidence level, 2017

4.2 Results of Mann-Kendall Trend Tests

This section presents part of the results for objective one which was to find out the trend for both historical and future rainfall and temperature for Nsukka. The result presented in this part is the trend for both historical rainfall and projected rainfalls for the two scenarios. This section also partly answered the first research question: what are the past and potential future trends of rainfall and temperature in the Nsukka?

4.2.1 Result of Mann-Kendall trend test for historical rainfall (1981 to 2010)

In order to determine whether there was a trend in the rainfall pattern over the area for the period 1981 to 2010, Mann-Kendall trend test was performed on the data set. The result of the Mann-Kendall trend test is as shown in Table 4.2. Mann-Kendall’s tau value was 0.274 which implied that there was a low positive correlation between the years and rainfall, the S statistic was 119 indicating a high trend and an adjusted variance of 0.000, which also implied that there was no tie in the data set. The Sen’s slope was 11.525 and confidence interval of -136.17,152.33, the value of Sen’s slope showed high magnitude of positive trend for the data set. Both the Augmented Dickey-Fuller and Mann-Kendall trend tests indicated trends in the data. This result is not far from the recent observation of yearly flooding in most parts of the area and the ever-increasing volume of runoffs that have over the years almost defiled human knowledge in most parts of Eastern Nigeria. These yearly high volumes of runoffs resulting from the increasing trend of rainfall always come with its attendant consequences, as more and more people are usually almost on yearly basis drowned in the gullies created by these runoffs within and around Nsukka. The gullies created by the runoff have also led to destruction of roads and other infrastructural facilities within the area. If nothing is done to forestall further increase in the trend, more human casualties are bound to be recorded with other economic losses therewith. Similarly, Uguru *et al.* (2011) reported increase in the rainfall trend in Nsukka.

Table 4.2: Mann-Kendall trend test for annual rainfall (1981 to 2010)

Parameter	Value
Kendall's tau	0.274
S	119.000
Var(S)	0.000
p-value (Two-tailed)	0.035
Alpha	0.05
Sen's slope:	11.525
Confidence interval:	] -136.168, 152.327 [

Source: Author’s computation of trend analysis, 2017

The data set was also tested for seasonal trend and the result is shown in Table 4.3. The result indicated that there was no statistically significant seasonal trend in the data set since the calculated p-value was greater than the alpha level. Furthermore, the result also showed that there was a low positive correlation between rainfall and the seasons and although there was no significant trend, there were however, variations in the seasons.

Table 4.3: Seasonal Mann-Kendall test for annual rainfall (1981 to 2010)

Parameter	Value
Kendall's tau	0.500
S	6.000
p-value (Two-tailed)	0.149
Alpha	0.05

Source: Author's result of seasonal trend, 2017

The graph of the trend of the annual rainfall for the period is as shown in Figure. 4.1. From the result of the analysis, the highest annual rainfall was experienced in 1997 with the total amount of rainfall of 2284.6 mm while the lowest amount of rainfall was in the year 1983 at 917.1 mm. This is in agreement with the finding of Christian and Izuchukwu (2009) who revealed that 1997 had been the wettest year in Enugu State. Similarly, the result also showed that the mean annual rainfall for the period and the location was 1762.4 mm and that most parts of the years within the period under consideration had relatively high amount of precipitation with most of the inter-annual variations occurring in the 90s. This increasing trend in the total annual rainfall also has the tendency of increasing the probability of severe weather conditions which could lead to severe damages to both social and economic lives of the people living in the area. Correspondingly, Uguru *et al.* (2011) reported fluctuation in the rainfall pattern in Nsukka with a shift in the bi-modal rainfall pattern from September to October. The area is also experiencing a gradual increase in the total annual amount of rainfall. Contrastingly, Anyadike (1992) reported that there is a general decrease in rainfall trend for all the regions in Nigeria, Enugu inclusive.

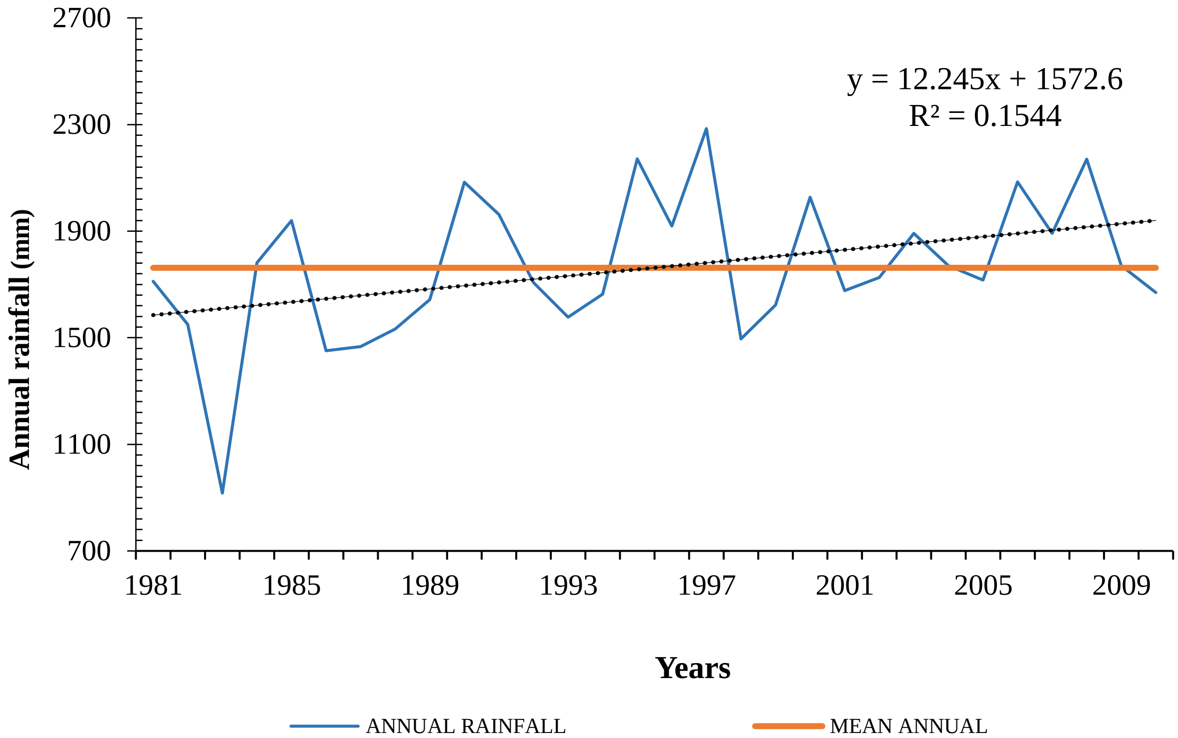


Figure 4.1: Annual rainfall series and trend lines from 1981 to 2010

4.2.2 Result of Mann-Kendall trend test for rainfall scenarios

Furthermore, Mann-Kendall trend test was also performed on the two projected rainfall scenarios: Representative Concentration Pathways (RCP) 4.5 and 8.5 and the results are shown in Tables 4 and 5 respectively. For scenario 4.5, the Kendall's tau value was - 0.094, which implied a negative correlation between the years and the total annual rainfall. The Man-Kendall statistic S, was -41 which implied a strong decline in the projected rainfall. This strong decline in the projected rainfall is in total contrast with the trend observed for the historical rainfall. Similarly, the Sen's slope also further emphasises a serious decrease in the future amount of rainfall for the projected rainfall scenario 4.5. This finding here is in line with the report of WMO (2001) which warned of a noticeable change between the historical temperature and precipitation pattern and the future weather pattern.

Table 4.4: Mann-Kendall trend test for annual rainfall for RCP 4.5

Parameter	value
Kendall's tau	-0.094
S	-41.000
Var(S)	0.000
p-value (Two-tailed)	0.479
Alpha	0.05
Sen's slope:	-4.438
Confidence interval:	] -119.473 , 149.650 [

Source: Author's result of Mann-Kendal trend test for RCP 4.5 rainfall, 2017

Figure 4.2 shows the projected rainfall from the trend analysis for RCP 4.5. From the result, the minimum total annual rainfall that would be recorded between 2041 and 2070 is 1536 mm and the maximum rainfall expected is 2647 mm with a mean of 2057 mm of rainfall. This is a clear indication that under the Business-As-Usual Scenario (RCP 4.5), the mean annual rainfall would be lower than the mean annual historical rainfall for the area. The implication of this could be disastrous, depending on the extent of the decrease in total annual precipitation. Decrease in rainfall could lead to lower amount of soil erosion but with other adverse effects on the overall agricultural productivity of the area. Decrease in rainfall could also lead to water scarcity which could result in loss of both animal and human lives. Between

2041 and 2070, the highest total annual rainfall would be in 2056 and the lowest total annual rainfall expected would be in the years 2046 and 2053, while between 2047 and 2052 the amount of total annual rainfall would be about the same.

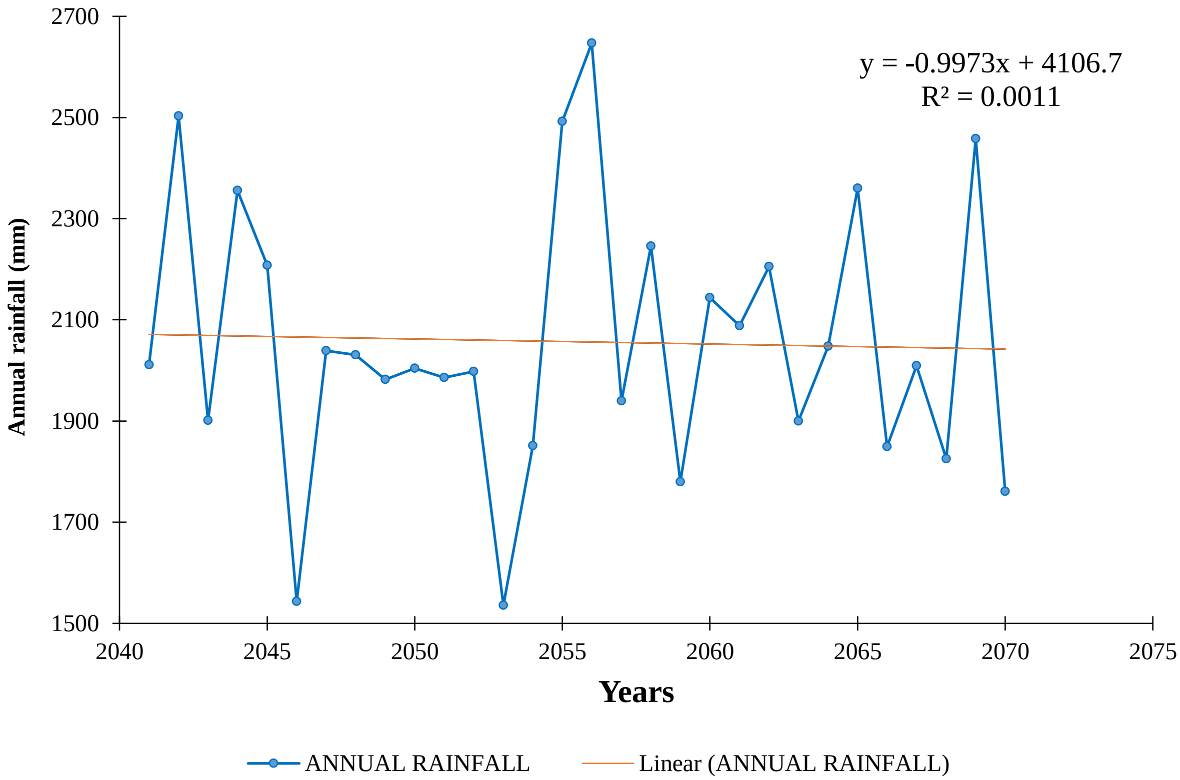


Figure 4.2: Trend of projected annual rainfall for RCP 4.5

In order to check the existence of significant trend in the total annual rainfall for the projected rainfall scenario 8.5, the scenario data were subjected to Mann-Kendall trend test and the result of the test shown in Table 4.5. The calculated p-value is greater than the alpha-level, hence the hypothesis that there is no trend in the data was accepted. The negative Kendall's tau value of -97.00 as shown in the table is an indication that there is a strong negative correlation between the years and total annual rainfall. The high negative S value as shown by the result showed that the trend is downward as was similarly confirmed by the Sen's value while the Var(S) of 0.00 showed that there was no tie in the data. The table also showed that there would be a general variability in the total annual rainfall but the variation would however not be statistically significant.

Table 4.5: Mann-Kendall trend test for annual rainfall for RCP 8.5

Parameter	Value
Kendall's tau	-0.223
S	-97.000
Var(S)	0.000
p-value (Two-tailed)	0.087
Alpha	0.05
Sen's slope:	-11.333
Confidence interval:	] -156.033, 162.950 [

Source: Author's result of Mann-Kendal trend test of rainfall for RCP 8.5, 2017

The result of the projected total annual rainfall for RCP 8.5 is as shown in Figure 4.3. The result shows that the minimum total annual rainfall is expected to be 1580 mm while the maximum total annual rainfall would be 2999 mm. The mean rainfall is expected to be 2012 mm and the highest amount of rainfall would be expected in 2050. The result further indicated that rainfall is expected to drastically reduce as the anthropogenic activities reaches its maximum level and the atmospheric concentration of greenhouse gases reaches an all-time high. The consequence of this drastic reduction in the total annual rainfall could be very catastrophic, especially to agriculture and the environment generally. A reduction in rainfall as a result of climate change could pose a different threat to Nsukka and its environs. It could lead to drought and loss of means of livelihood. This reduced total annual rainfall for the projected Scenario 8.5 however contradicted the general trend observed in the historical data. The finding of the total annual rainfall trend for RCP 8.5 is also in contradiction with the observation of Akinsanola and Ogunjobi (2014) who remarked that one of the cities in Nigeria experiencing increasing rainfall is Enugu State (Nsukka inclusive) but agreed with the work of Obasi (2013) that the general trend of rainfall in Enugu State is on the decrease based on the trend analysis of a 36-year data. It further confirmed the fear that the future with respect to the climate could be bleak and that the general trend of rainfall from historical might be different from the expected future trend. The result in Figure 4.2 is also a warning that mankind faces possible extinction in the nearest future if the rate at which greenhouse gases are released into the atmosphere is not contained. The result also revealed that from 2050 to 2070, the inter-annual variation is going to be more pronounced with most of the annual total amount of rainfall taking an unprecedented decline.

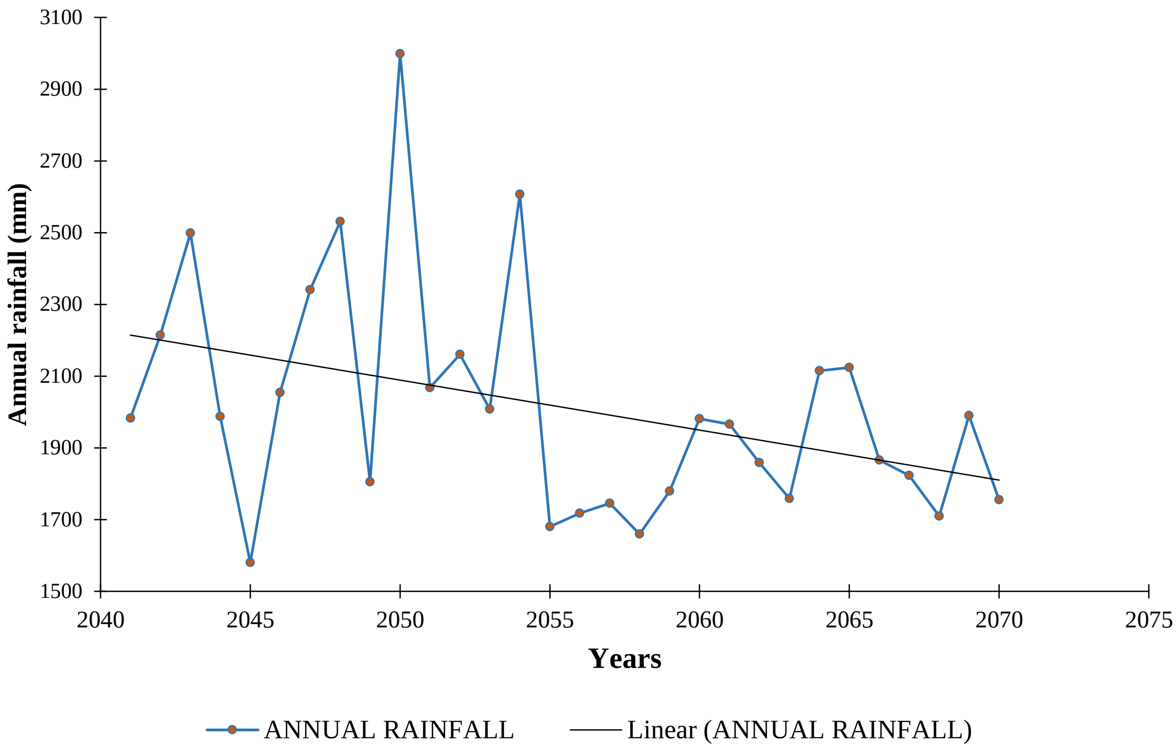


Figure 4.3: Projected annual rainfall for RCP 8.5

4.2.3 Mean historical versus projected monthly rainfall

The mean monthly rainfall for both historical and projected rainfall trends are shown in Figure 4.4. From the result, the mean monthly rainfall for the period, 1981 to 2010 varied from 8 to 279 mm with an average of 147 mm while the mean monthly rainfall for RCP 4.5 projection ranged from 25 to 369 mm with an average rainfall of 171 mm. Similarly, the mean monthly rainfall for the worst case scenario projection (RCP 8.5) for the period 2041 to 2070 had a minimum value of 21 mm and a maximum value of 360 mm with a mean value of 168 mm of rainfall. Additionally, the line graph of the mean monthly rainfall for the historical and projected rainfall scenarios (RCPs 4.5 and 8.5) showed that there is likely going to be a significant increase in the rainfall amount for the future for each month with higher rainfalls expected from January to December for both scenarios. Also, the little dry spell usually experienced in August, popularly known as “August break” is also going to deepen. With the Business-As-Usual Scenario (RCP 4.5), higher rainfall amount would be expected between September and October compared to both the historical and RCP 4.5. More so, with RCP 4.5, the highest amount of rainfall compared to historical and RCP 8.5 would be experienced in September. However, for the Worst-Case-Scenario (RCP 8.5), the highest amount of rainfall would be in July. The rainfall amount for this month and for this scenario would be higher than both for historical and RCP 4.5. The result further showed that apart from between May and June, the mean monthly rainfall for the scenarios would be higher than the historical mean monthly rainfall for all the months.

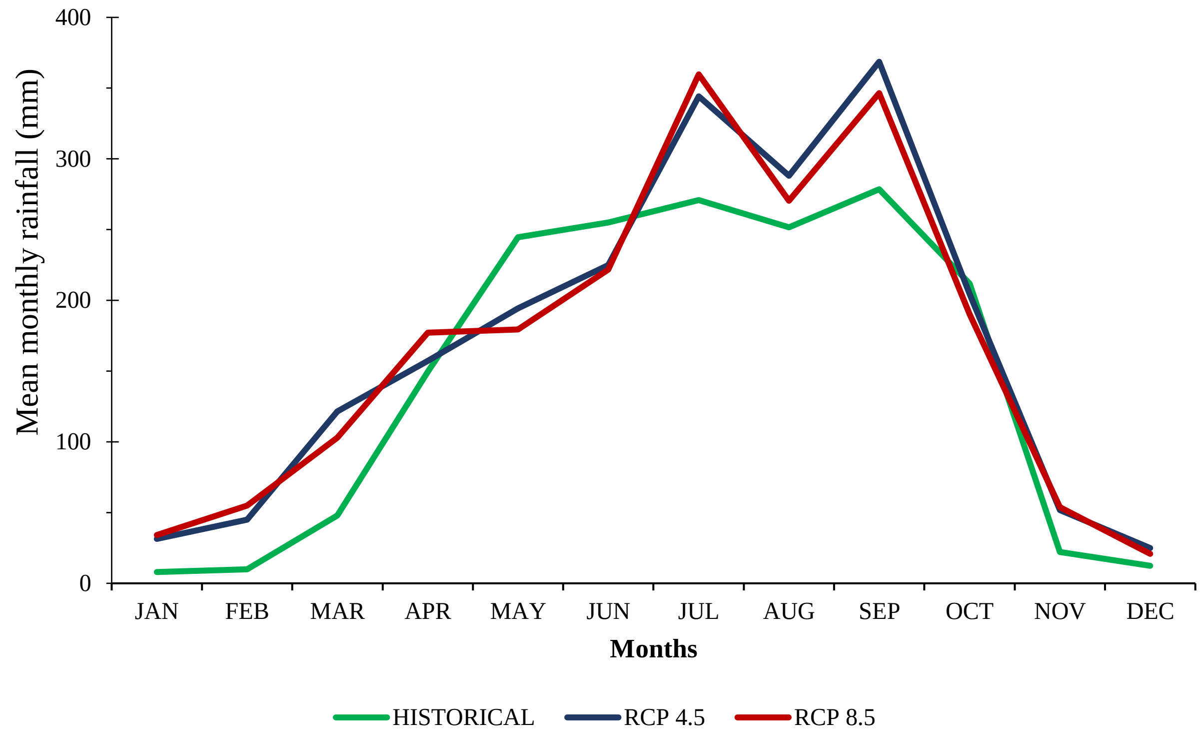


Figure 4.4: Monthly rainfall for historical versus projected rainfall

HISTORICAL=historical climate, RCP=Representative Concentration Pathway

4.3 Trend Analysis for Temperature

This section presents the results for the second part of objective one which was to find out the trend for both historical and future temperature in Nsukka.

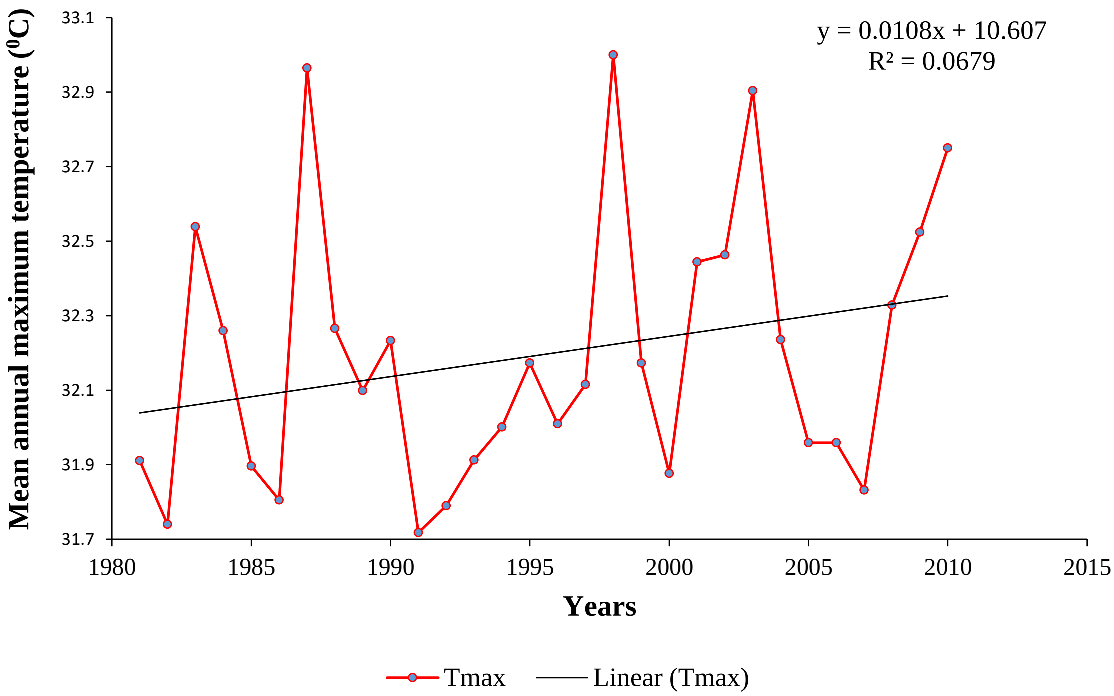
4.3.1 Result of Mann-Kendall trend analysis for historical temperatures

The result of the Mann-Kendall's trend test for historical maximum temperature is presented in Table 4.6. The result showed that the calculated p-value is greater than the set alpha level and as such there is no trend in the maximum temperature for the area and for the period 1981 to 2010. The result further revealed that the maximum temperature for Nsukka ranged from 31.72 to 33^0C with a mean of 32.2^0C and that although there is a general increment in the mean monthly temperature, this increment is not statistically significant. The slight increment is attributable to the increase in the amount of greenhouse gases in the atmosphere which causes an imbalance between the amount of heat sent into the earth and that which is leaving the earth surface. The implication of this result is that this presently non-significant increment could become significant in the future if urgent actions are not taken to reduce to the barest minimum, the anthropogenic activities responsible for the increase. According to the result, the hottest temperature was recorded in 1998 followed by 1987 and 2003. This is in line with the IPCC (2001) and WMO (2001) reports that most of the hottest years experienced in human history have all occurred in the 90s. The Kendall's tau value showed that there is a weak positive correlation between years and the projected maximum temperature for Nsukka for the period 2041 to 2070. The Kendall S statistic as shown by the result affirms that there is a strong upward increment in the mean maximum temperature although the increment is not statistically significant still. The result of this work is in total agreement with the result of Akinsanola and Ogunjobi (2014) who reported no trend in the mean annual temperature for Enugu. The finding however differs from the finding of Amadi *et al* (2014) who observed significant increment in the mean maximum temperature for Enugu. The result also contradicted the work of Mercy (2015) who found a decreasing trend in temperature in Enugu (Nsukka). However, the trend analysis for the daily data for the area and period showed that the maximum temperature is increasing.

Table 4.6: Result of trend test for mean annual maximum temperature (1981 to 2010)

Parameter	value
Kendall's tau	0.21
S	90.00
Var(S)	3140.67
p-value (Two-tailed)	0.11
Alpha	0.05
Sen's slope:	0.012
Confidence interval:	] -0.183 , 0.213 [

Source: Author's result of Mann-Kendall trend test, 2017



Tmax=maximum temperature

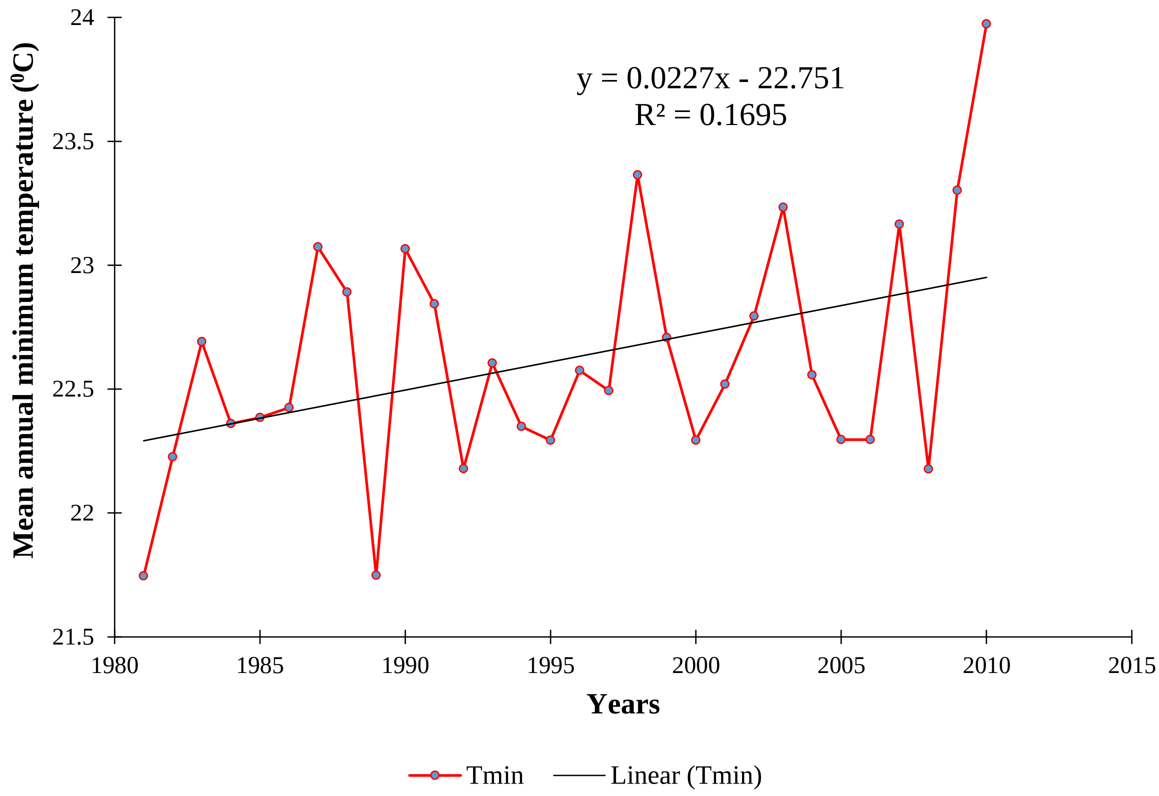
Figure 4.5: Trend of mean annual historical maximum temperature (1981 to 2010)

Furthermore, the values for the mean minimum annual temperature were between 21.75 and 23.97^{0}C, with an average minimum temperature value of 22.62^{0}C. The result showed that the average minimum monthly temperature is also on the increase, raising more concern as to what the future holds as human emission of greenhouse gases continues unabated. However, this increment is not significant at an alpha level of 0.05. This result contradicts the finding of Amadi *et al*. (2014) who obtained a significant increase in the mean monthly minimum temperature in Enugu for the period 1950-2012.

Table 4.7: Trend test result for mean annual minimum temperature (1981 to 2010)

Parameter	Value
Kendall's tau	0.212
S	92.000
Var(S)	3140.667
p-value (Two-tailed)	0.104
alpha	0.05
Sen's slope:	0.02
Confidence interval:	] -0.170 , 0.291 [

Source: Author's result of Mann-Kendall trend test for the period 1981 to 2010, 2017



Tmin=minimum temperature

Figure 4.6: Trend of mean annual historical minimum temperature

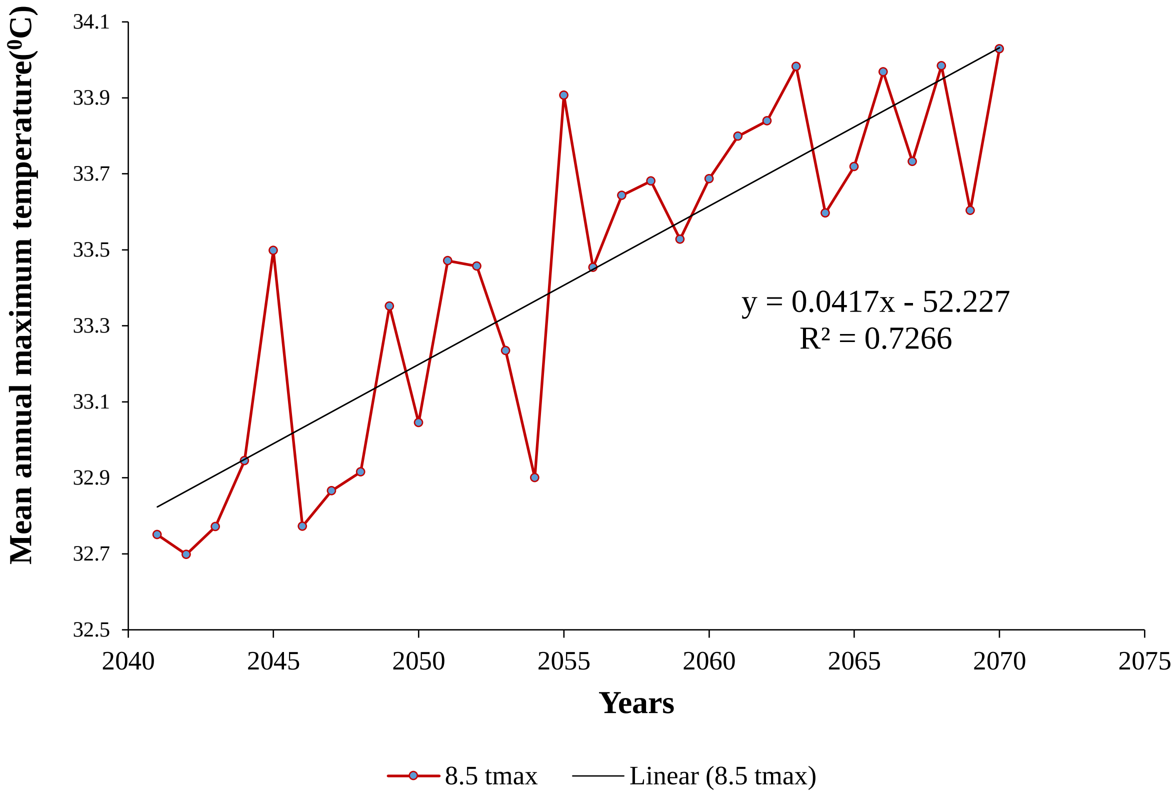
4.3.2 Trend analysis of the projected temperatures

The result of the Mann-Kendall trend test for the projected mean annual maximum temperature for RCP 8.5 scenario is contained in Table 4.8 and Figure. 4.7. The Kendall's value was 0.701, with Kendall's S statistic of 305.00 signifying strong upward trend, Var(S) 0.00 indicating no ties in the data and Sen's slope of 0.043 confirming the presence of positive trend. The test also showed a very strong significant trend in the data. Furthermore, the trend analysis result showed that the projected maximum temperature for the period between 2041 and 2070 ranged from 32.7^{0}C to 34.03^{0}C with an average of 33.43^{0}C and standard deviation of 0.430. This is similar to the result of the trend analysis obtained from the analysis of the historical temperature trend.

Table 4.8: Trend test result for mean annual maximum temperature for RCP 8.5

Parameter	Value
Kendall's tau	0.701
S	305.000
Var(S)	0.000
p-value (Two-tailed)	< 0.0001
alpha	0.05
Sen's slope:	0.043
Confidence interval:	] -0.078, 0.163 [

Source: Author’s result of trend test for RCP 8.5 mean annual maximum temperature, 2017



Tmax=maximum temperature

Figure 4.7: Trend of mean annual maximum temperature for RCP 8.5

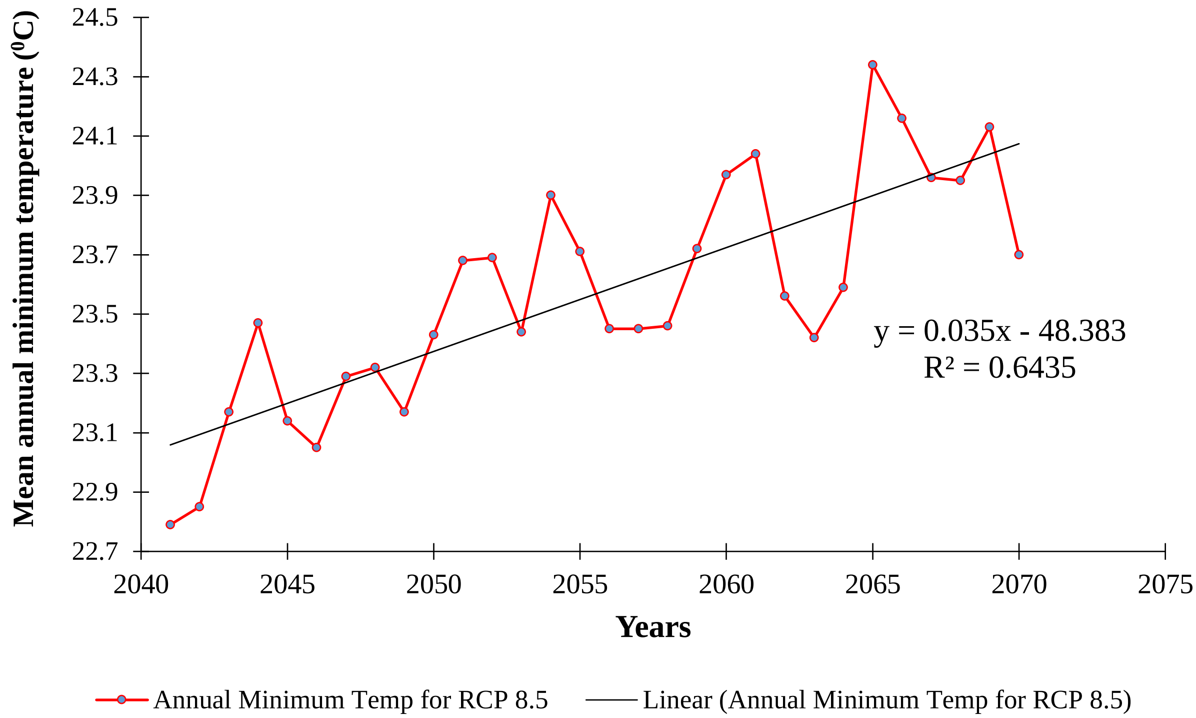
4.3.3 Result of the mean annual minimum temperature for RCP 8.5

The result of Mann-Kendall trend test for the projected mean minimum annual temperature for RCP 8.5 (2041 to 2070) is shown in Table 4.9 and Figure 4.8. According to the result, the mean minimum annual temperature varied from 22.79 to 24.34^{0}C with a mean minimum temperature value of 23.58^{0}C and standard deviation of 0.38. Similarly, the result showed that the Kendall's tau value was 0.624, the value of S was 271 and Var(S), p-value and Sen's slope values were respectively as follows: 3139.667, <0.0001 and 0.035. The test also revealed that there is a weak positive correlation between the years and the mean minimum annual temperature and a very strong positive trend in the data as shown by the high Kendall S and the calculated p value.

Table 4.9: Result of trend test for mean annual minimum temperature for RCP 8.5

Parameter	Value
Kendall's tau	0.624
S	271.000
Var(S)	3139.667
p-value (Two-tailed)	< 0.0001
Alpha	0.05
Sen's slope:	0.035
Confidence interval:	] -0.121 ,0.171 [

Source: Author’s trend test for mean annual minimum temperature for RCP 8.5, 2017



RCP=Representative Concentration Pathway

Figure 4.8: Trend of mean annual minimum temperature for RCP 8.5

4.3.4 Result of the mean annual maximum temperature for RCP 4.5

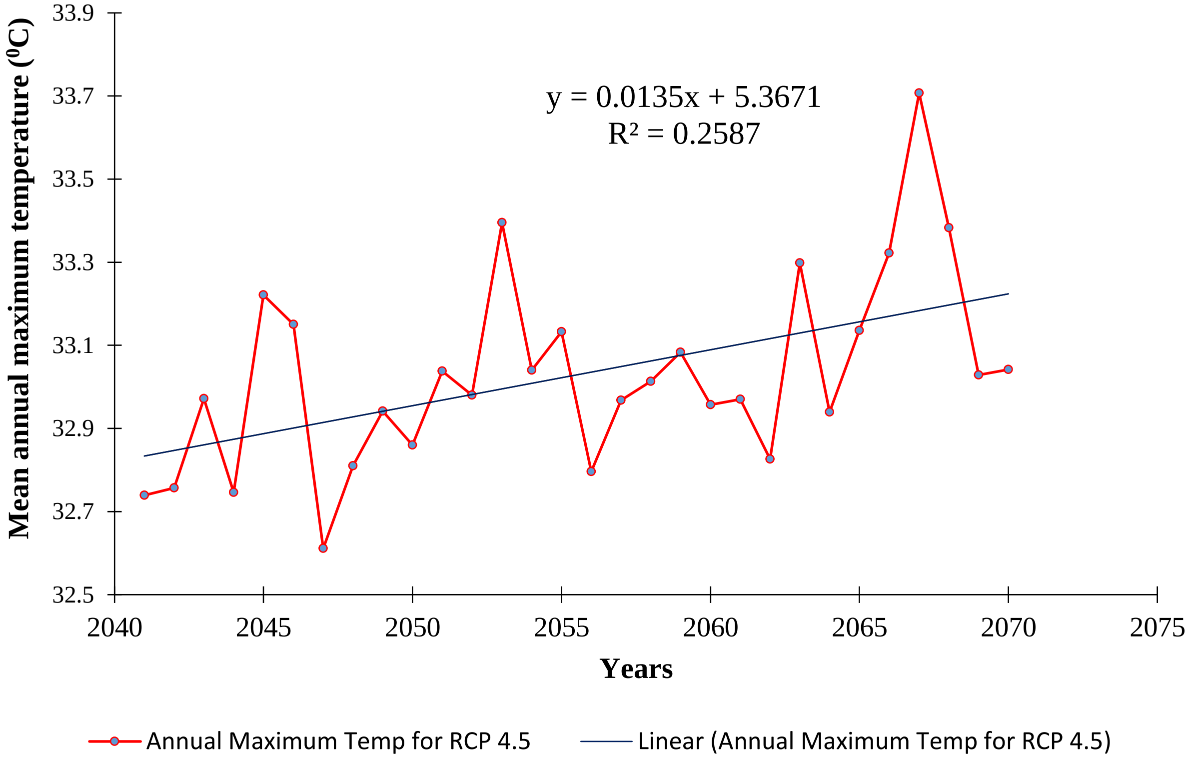
For the projected average maximum annual temperature for RCP 4.5, the result is as shown in Table 4.10 and Figure 4.9. From the result of the analysis, it could be seen that the projected maximum temperature for RCP 4. 5 had a positive trend and that the data varied from the lowest temperature of 32.61^{0}C to the maximum temperature of 33.71^{0}C with a mean maximum temperature of 33.03^{0}C and standard deviation of 0.23. The values for tau, S, Sen's slope and Var(S) were 0.356, 155, 0.012 and 0.00 in that order, showing that there is presence of weak correlation between the years and the mean maximum annual temperatures. It also showed that there is a positive and statistically significant trend in the data. The graph of the trend analysis as shown in Figure 4.9 clearly shows that there is relatively low variability in the projected annual maximum temperature with the highest temperature expected in 2067.

The result indicated that although both historical and the projected temperature are on the rise, the rate at which the temperature would increase in the late 2040s might be significantly higher than the general trend observed in the historical temperatures. This positive trend observed in the data set corroborated with the IPCC (2014) report which revealed that the global temperature is increasing more than the observed historical temperature.

Table 4.10: Trend test result for mean annual maximum temperature for RCP 4.5

Parameter	Value
Kendall's tau	0.356
S	155.000
Var(S)	0.000
p-value (Two-tailed)	0.005
Alpha	0.05
Sen's slope:	0.012
Confidence interval:	] -0.083,0.126 [

Source: Author’s result of Mann-Kendall trend test for mean annual maximum temperature for RCP 4.5, 2017



RCP=Representative Concentration Pathway

Figure 4.9: Trend of mean annual maximum temperature for RCP 4.5

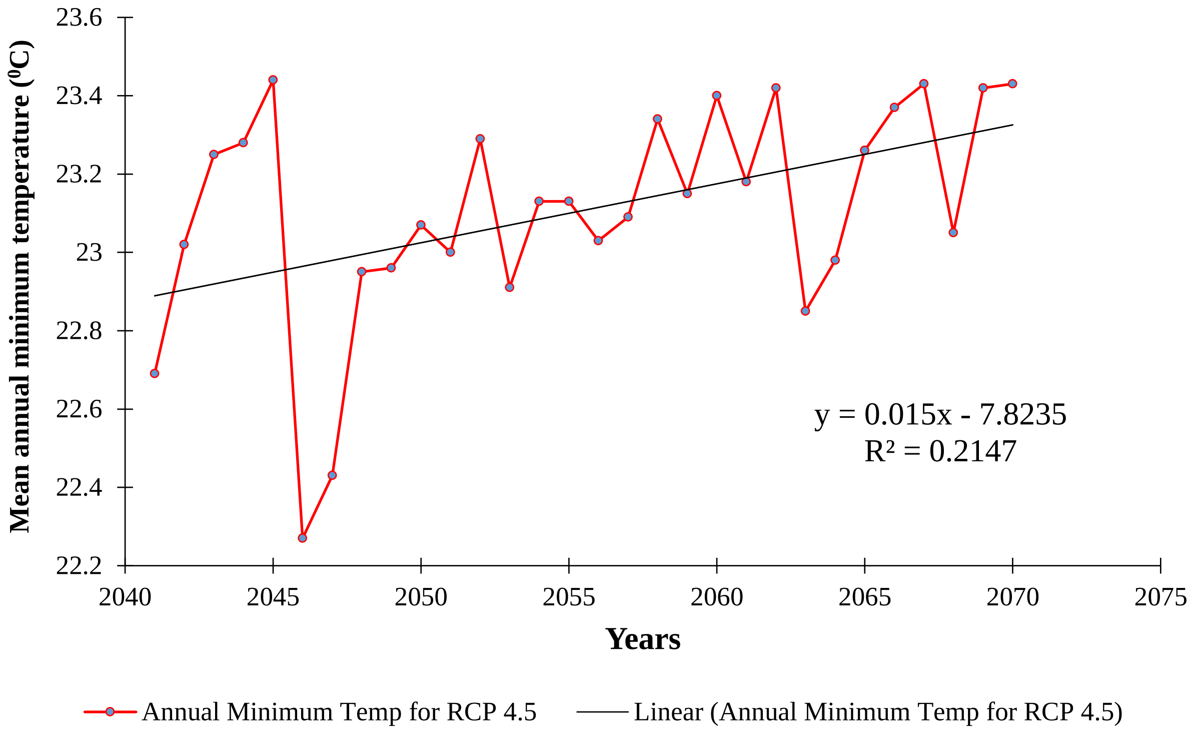
4.3.5 Result of mean annual minimum temperature for RCP 4.5

In checking whether there is trend in the projected minimum temperature for RCP 4.5 and for the period 2041 to 2070, the data set was subjected to Mann-Kendall trend test and the result and graph shown in Table 4.11 and Figure. 4.10 respectively. The result shows that the minimum annual temperature would be between 22.7 and 23.44^{0}C with an average of 23.11^{0}C. The result of the test also shows that there is positive trend and that there is also presence of tie in the data. It also showed that the trend is high as indicated by the Kendall S statistic. This increment in the mean minimum temperature is in accordance with the IPCC report of 2007 which revealed that the average annual minimum temperature is on the increase.

Table 4.11: Trend test for mean annual minimum temperature for RCP 4.5

Parameter	Value
Kendall's tau	0.374
S	162.000
Var(S)	3138.667
P-value (Two-tailed)	0.004
Alpha	0.05
Sen's slope:	0.016
Confidence interval:	] -0.088 ,0.172 [

Source: Author’s result of trend test for RCP 4.5 mean annual minimum temperature, 2017



RCP=Representative Concentration Pathway

Figure 4.10: Trend of mean annual minimum temperature for RCP 4.5

From the results, historical rainfall trended positively and significantly while historical minimum and maximum temperature all trended non-significantly but positively. On the other hand, the projected rainfall varied non-significantly in the negative direction while the projected temperatures trended positively and significantly for both RCP 4.5 and RCP 8.5.

4.4 Effects of Land Use Types on Some Selected Soil Properties

The results for objective two which was to determine which of the current soil management practices is most sustainable under the changing climate are presented here.

Tables 4.12 and 4.13 showed the effects of soil management practices on different soil properties. From the result of the analysis, the organic matter content of the soil ranged from 1. 34 (fallow land) to 2.37 gkg^{-1}, with range land having the highest amount of soil organic matter. The result of the organic matter content is in line with the work of Emadi *et al*. (2008), who revealed that conversion of land from range or forest land to crop land resulted in about 50% decrease in soil organic matter content of the soil. Similarly, cation exchange capacity (CEC) for the land uses varied from 17.47 to 32.53 cmol kg^{-1}. The range land recorded the highest amount of cation exchange capacity followed by fallow land while manually cultivated land had the lowest level of CEC. The result of the CEC is in agreement with the findings of Negasa *et al*. (2017) who showed that putting soil under different management practices leads to variation in the CEC content. Table 4.13 showed that the above surface albedo for the various soil management practices ranged from 0.24 to 0.36 with range land having the lowest albedo while manually cultivated and tractorized soil recorded 0.29 and 0.32 of albedo respectively. Range land had the lowest value for surface albedo among the various soil management practices while the mean surface albedo for the various management practices is 0.3.

Furthermore, Table 4.13 also showed that the lowest value for interrill erodibility was recorded by tractorized soil while range land had the highest value. The value for the inter rill erodibility for the different soil management practices varied from 4.16 x 10^6 to 6. 96 x 10^6 $kgs^{-1}m^{-4}$. The values for critical hydraulic shear stress ranged from 1.72 recorded by range land to 5.88 by tractorized soil. The results for baseline GreenAmpt hydraulic conductivity showed that tractorized land had the lowest value for GreenAmpt hydraulic conductivity while manually cultivated land had the highest value at 5.33 cmh^{-1} for the land uses. This low value for tractorized land is not unconnected with the compaction effect of heavy machinery being used in the field. The heavy machinery closed the pore spaces of the soil and as a result reduced the rate of infiltration. Also the table (table 4.13) showed that the soil textural classes for the various land management practices varied from clay loam, sandy clay, and clay and the percentage content of sand, silt and clay all varied in accordance with land use types. This is in accordance with the findings of Negasa *et al*. (2017) who observed a significant p-value for the sand, silt and clay contents of soils under different types of management. The bulk density varied from tractorized land with the highest bulk density of 1.59 gcm^{-3} followed by fallow land with bulk density of 1.57 gcm^{-3} and range land with the lowest mass per volume at 1.34 gcm^{-3}. The high bulk density value for the tractorized land management is attributable to the compaction effect of heavy machinery that are normally used in the cultivation of the field. Emadi *et al*. (2008) had a similar observation: that the conversion of land from range land or forest land to cultivated land leads to increase of about 16% in its bulk density.

Table 4.12: Effects of land use types on soil properties

Land use	O.M(gkg^{-1})	CEC (cmolkg-^{1})	BD (gcm^{-3})	K_b (cmh^{-1})
FL	13.45^{a}	27.73^{a}	1.57^{a}	1.33^{b}
MAN	18.27^{a}	17.47^{b}	1.51^{a}	5.33^{a}
RG	23.79^{a}	32.53^{a}	1.34^{b}	1.12^{b}
TR	15.86^{a}	20.67^{b}	1.59^{a}	0.94^{b}
S.E	4.50	4.95	0.14	2.21

Means in the same column with different letters are statistically different at $P \leq 0.05$
O.M = Organic Matter, CEC. = Cation Exchange Capacity, K_b=Baseline Green Ampt Hydraulic Conductivity, BD = Bulk Density, FL = Fallow land, MAN = Manually cultivated, RG = Range land,TR= Tractorized land.

Source: Author’s result of land use effects on soil properties, 2017

Table 4.13: Variations of WEPP parameters for the simulated soils

LU	SALB	K_i ($10^6 kgs^{-1}m^{-4}$)	K_r (sm^{-1})	T_c (Pa)	Sand (gkg^{-1})	Silt (gkg^{-1})	Fs (gkg^{-1})	Clay (gkg^{-1})	ST
FL	0.36	4.74	0.0097	5.87	392.7	21.3	104.7	586.0	CL
MAN	0.29	5.09	0.0075	4.84	519.3	38.0	122.9	442.7	SaC
RG	0.24	6.96	0.0021	1.72	382.7	28.0	117.6	589.3	Clay
TR	0.32	4.16	0.0065	5.88	419.3	21.3	74.7	559.4	Clay

K_i=Interill erodibility, LU= Land Use, SALB=Surface Albedo, ST= Soil Texture, K_r= Rill Erodibilty, T_c=Critical Hydraulic Shear Stress, CL= clay loam, SaC= sandy clay, FL= Fallow land, MAN = Manually, Fs=fine sand.

Source: Author's result of WEPP parameters, 2017

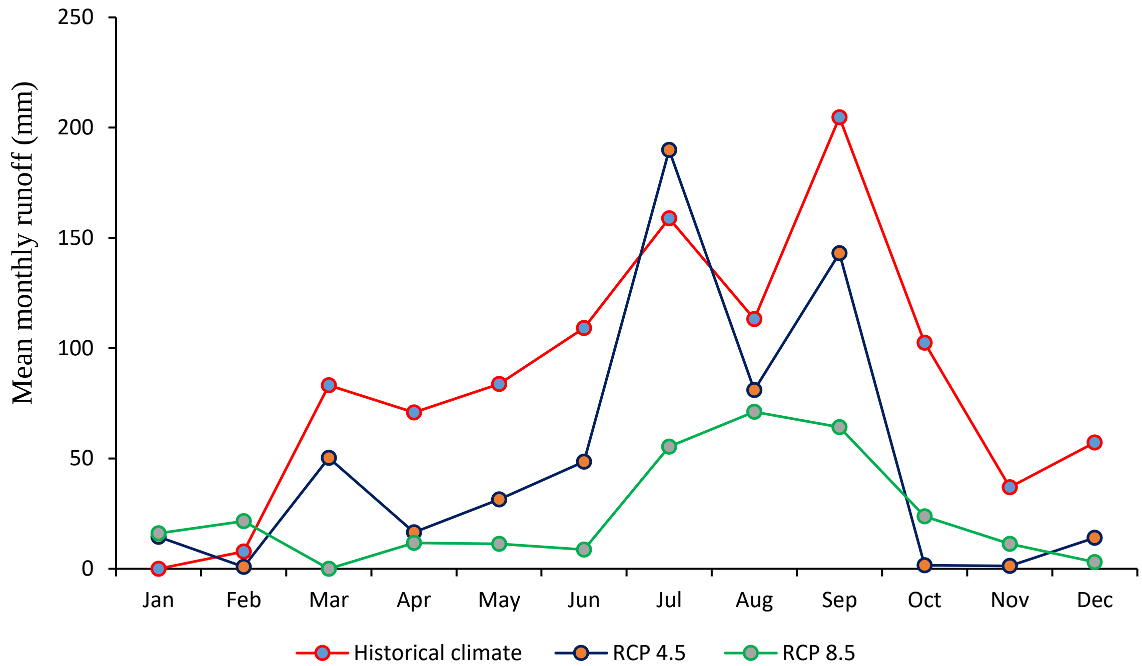
From the findings above, the use of heavy machinery on the soil degrades the soil properties more than other management practices and as such poses a greater threat to the sustainability of soils under such management. Although the range management system conserves soil properties better than the other management practices, the need to produce crops for human needs limits this system since it is basically for animal production. Hence manual cultivation could be considered a more practical conservation approach than range.

4.5 Result of Mean Monthly Runoff

The results of the mean monthly runoff to determine which of the current soil management practices is most sustainable under the changing climate were presented below to address part of objective two.

4.5.1 Mean monthly runoff for manually cultivated soil

Result of mean monthly runoff for soil under manual cultivation is presented in Figure 4.11. The result showed high variation in the mean monthly runoff which was in line with the different seasons (dry and wet) of the year usually experienced in Nsukka. From the result, high level of runoff was predicted between July and September with a little dip in August which usually marks the August break. The period of high runoff is the rainy season when rainfall is usually at its peak. Runoff under this land management generally followed that which was predicted for range land except for August in which there is a more pronounced variability in the amount of runoff under the different climatic conditions (historical, RCP 4.5 and RCP 8.5 rainfalls). Furthermore, there is a general decline in the monthly runoff for the projected climatic conditions compared to the historical condition which may be good news. However, due to the uncertainty surrounding the direction of climatic variables in the future, the result should be taken with caution. This has been emphasised by the finding of Klik and Eitzinger (2010) who noted that although the future precipitation levels are expected to reduce appreciably, soil erosion (including runoff) might not necessarily follow that same trend.

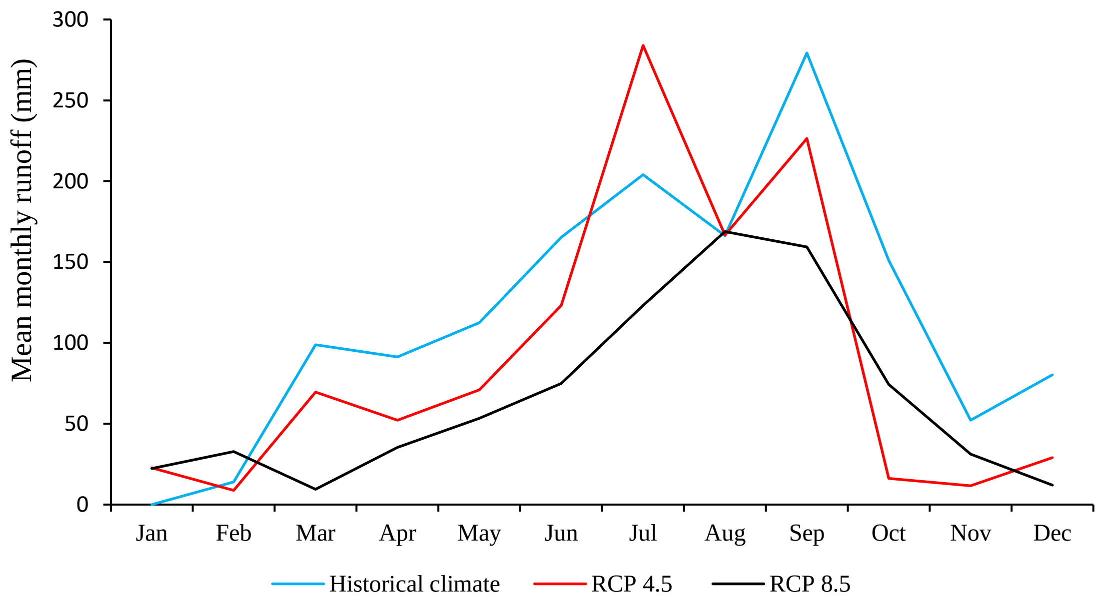


RCP=Representative Concentration Pathway

Figure 4.11: WEPP simulated mean monthly runoff under manual cultivation

4.5.2 Mean monthly runoff for tractorized soil

The result of the predicted mean monthly runoff under tractorized tillage for the different climatic scenarios is as shown in Figure 4.12. The result showed that mean monthly runoff under historical climatic condition varied from 0 to 279.31 mm with a mean of 105.63 mm. Similarly, the runoff amounts for RCP 4.5 were between 8.775 and 283.945 mm with a mean of 90.09 mm while the amounts of runoff for RCP 8.5 ranged from 9.48 to 168.82 mm with a mean of 66.41 mm. Runoff under the various climatic conditions were the same for the month of August. Apart from the month of July, the general runoff from the historical climatic condition was greater than runoff from the two other climatic conditions. The production of high runoff in July under RCP 4.5 despite a general decrease in the total annual rainfall further highlights the complication with climate change with similar finding having been reported by Klik and Eitzinger (2010). The high runoff despite decrease in the total annual runoff maybe as a result of more frequent high intense rainfall. This high runoff observed in tractorized land compared to other management practices could be as a result of soil compaction resulting from the use of heavy machinery on the field, which impeded infiltration of water into the soil compared to other management practices. On the other hand, Wang *et al*. (2017) reported a high amount of runoff in traditional plough compared to other tillage practices. Furthermore, the work of Klik (2003) showed a significant increase in the amount of runoff for soil under tractorized tillage compared to other tillage practices.



RCP=Representative Concentration Pathway
Figure 4.12: WEPP simulated mean monthly runoff under tractorized tillage

4.5.3 Mean monthly runoff for range land

Figure 4.13 shows the mean monthly runoff from rangeland. The mean monthly runoff varied from 0 to 212.155 mm under historical rainfall while under Scenario 4.5, runoff ranged from 0 mm to 205.43 mm. For range land, the lowest amount of runoff was recorded under scenario 8.5 and it was between 0 mm and 123.22 mm with a mean of 30.99 mm. The result also revealed that generally, runoff in the historical rainfall was higher than under the projected future climatic condition. This is simply so because of the predicted decline in the mean annual rainfall in the future and since runoff strongly depends on rainfall amount and intensity. It is therefore true that if the future rainfall follows the pattern that has been projected, the problem of erosion and runoff would be reduced. However, more runoff than historical is expected in July under Scenario 4.5 and the highest amount of runoff under the historical climate was predicted in September according to the model output. Contrary finding was reported by Pruski and Nearing (2002a) who predicted that soil erosion would more than double and that runoff would increase from about 6% which is currently being experienced to about 100% under climate change. The finding however corroborated the work of Klik and Eitzinger (2010) on the role of different conservation practices in Austria which suggested a decrease in the future level of runoff and soil loss under the changing climate.

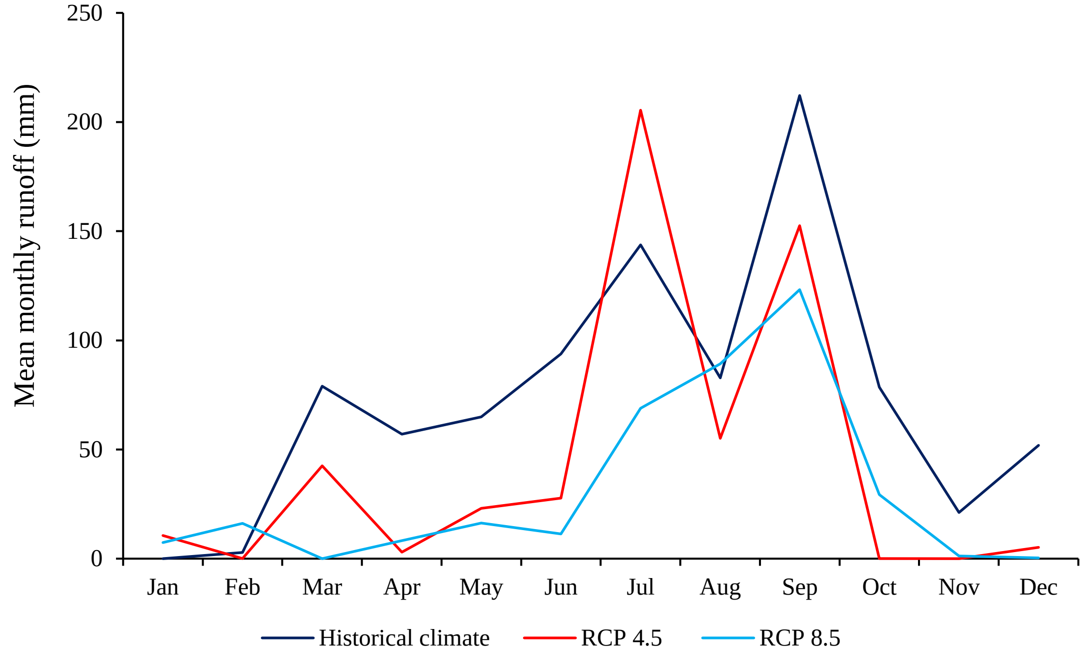


Figure 4.13: WEPP simulated mean monthly runoff under rangeland

4.5.4 Mean monthly runoff for fallow land

The result of the mean monthly runoff for different climatic conditions under fallow land management is as presented in Figure 4.14. Runoff for historical climate condition ranged from 0 to 271.13 mm. RCP 4.5 climatic condition had a predicted minimum value of runoff of 8.835 and a maximum value of 276.145 mm. The predicted runoff for RCP 8.5 varied from 9.32 to 152.065 mm. This high amount of runoff is due mainly because the area was previously under cultivation with heavy machinery and as a result might have been compacted by the machines which makes the rate of surface flow higher than the infiltration rate. Similar findings were obtained by Obi (1982) who found high runoff value for bare fallow in an Oxisol of Nsukka compared to other management practices with surface cover. This runoff is nevertheless still generally lower than that which was obtained for tractorized tillage. The mean monthly runoff is notwithstanding similar to those obtained from other land management practices, with runoff for scenario 4.5 peaking in July more than other climatic conditions. The historical climatic condition still produced a generally higher runoff especially in September than other scenarios while RCP 8.5 produced the least amount of runoff for all the months except from October to December.

Output of the model which contains information on the monthly runoff for soil under fallow land and under historical climatic condition is presented in appendix B.

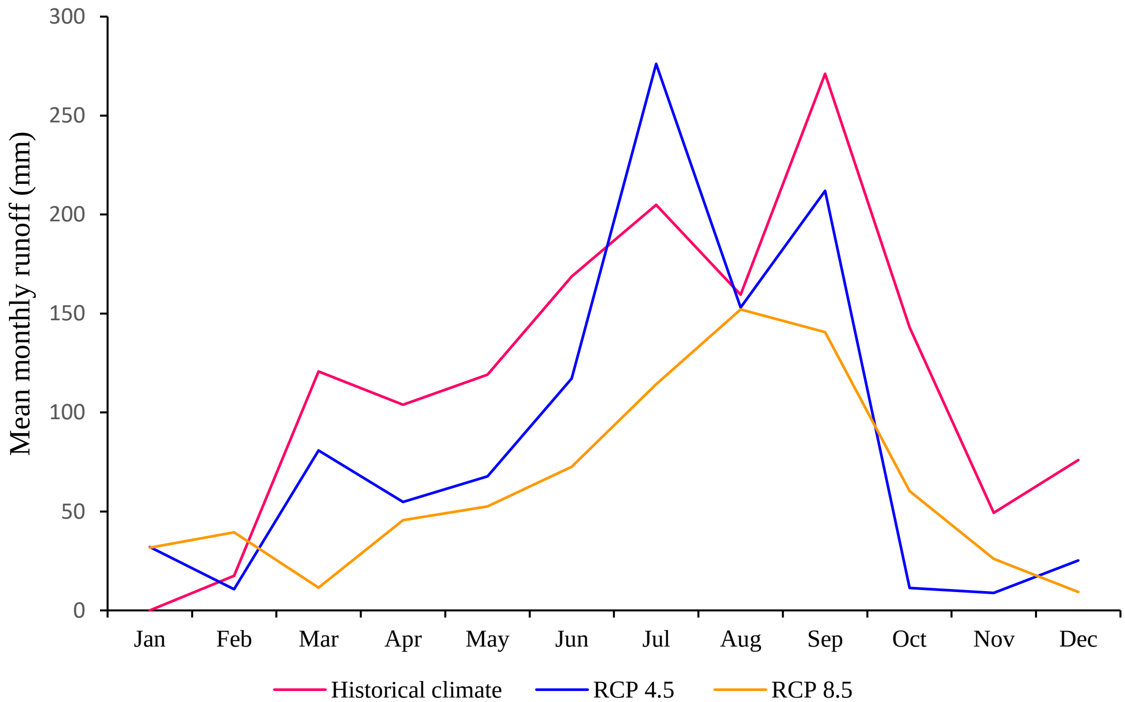


Figure 4.14: WEPP simulated mean monthly runoff under fallow land

4.6 Result of ANOVA for the Average Annual Runoffs and Soil Losses from the Different Soil Management Practices and Climatic Conditions

The results in this section address objective three (to predict the future level of runoff and soil loss through water erosion in Nsukka) and part of objective two; to determine which of the current soil management practices would be most sustainable under the changing climate. Table 4.14 is the result of the analysis of variance (ANOVA) for runoffs and soil losses from the different land management practices and different climatic regimes. The result of the runoffs from the various management practices and rainfall regimes showed that under the different climatic conditions, the predicted average annual runoff varied from 555.70 to 1190.99 mm yr^{-1} with the historical climatic condition yielding the highest amount of runoff per year while RCP 8.5 produced the lowest amount of runoff. Similarly, the average annual soil losses varied from 5.085 to 38.29 Mg ha^{-1} yr^{-1} for the various climate scenarios. The historical climate also led to the highest amount of soil loss while the projected climatic scenario of 8.5 caused the lowest amount of soil loss. Furthermore, the table showed that under the different soil management systems, the predicted mean annual runoffs ranged between 594.92 and 1097.47 mm yr^{-1} while soil losses varied from 0.01 to 29.39 Mg ha^{-1} yr^{-1} with tractorized management having both the highest amount of runoff and soil loss.

Range land recorded the lowest values for both runoff and soil loss while tractorized cultivation recorded highest value for soil loss. The high level of soil loss in the tractorized cultivation could be due to the easy concentration of runoff flow on the soil surface because of the compaction of soil particles by the heavy machinery employed in the field. Soil compaction has been noted as having significant effect on soil erosion and consequently soil loss (Liu Y *et al*., 2012). Cultivation of land destroys the soil aggregate stability and predisposes the soil to easy detachment by raindrops (Mohammad and Adam, 2010). While the low level of runoff and soil loss experienced under the range management system could be attributed to the presence of vegetative cover on the soil which generally reduces the direct impact of rainfall on the soil surface and slows the velocity at which detached soil particles are transported along the slope. Similarly, the low value of runoff in the range land could also be attributed to the special role played by vegetation in the interception of direct rainfall and bringing to minimum the kinetic energy of the flowing water (Descroix *et al*., 2001) and ensuring higher rate of infiltration as water now has more time to pond (Bochet *et al*., 1998). Similarly, Yang and Liang (2004) have reported that the problem of soil erosion was most severe in cultivated land and least under pasture or range land with surface cover.

The finding of the work further revealed a statistically significant differences in the amount of runoffs and soil losses experienced by the various soil management practices and the climatic regimes. It could also be observed that tractorized cultivation (management) had the highest amount of soil loss followed by the manually cultivated soil while fallow land and range land had the lowest amount of soil loss. The historical climate produced the highest amount of soil loss followed by scenario 4.5 while RCP 8.5 yielded the lowest amount of soil loss. The implication of this is that less efforts and resources would be needed for the conservation of soils against water erosion in the future for the area. However, low rainfall could also lead to another challenge: low availability of water for crop and animal production. Soil water content below certain critical level would be detrimental to crop production and will limit the choice of crops to be grown.

Although runoffs and soil losses from the land uses and climatic conditions were statistically different, the interaction between land management practices and climatic conditions yielded no significant difference at an alpha level of 0.05 for runoffs but yielded a significant interaction for soil losses. Contrastingly, Klik and Eitzinger (2010) while studying the impact of climate change on erosion and the efficiency of conservation practices using future rainfall scenario reported a non-significance in the amount of runoffs and soil losses for soils under different land uses. The contrary result obtained in this study could be attributed to greater amount of rainfall intensity under a changing climate.

Table 4.14: Predicted Effect of soil management practices and climatic conditions on runoff and soil loss in Nsukka, Nigeria.

Factor/level	Runoff (mm)	Soil Loss (Mg ha^{-1} yr^{-1})
SMP		
TR	1097.47[a]	29.39[a]
FL	1079.69[a]	32.97[ab]
MAN	639.66[b]	26.33[b]
RG	594.92[b]	0.01[c]
S.E	180.55	3.050
Climate conditions (R)		
Hist	1190.99[a]	38.29[a]
RCP 4.5	812.13[b]	23.14[b]
RCP 8.5	555.70[c]	5.09[c]
S.E	180.55	3.05
Interaction		
SMP x R	NS	**

Means in the same column with different letters are statistically different at P $\leq$0.05 based on LSD, SMP–soil management practices, TR-tractorized, FL-fallow, MAN-manually cultivated, RG-range, S.E-standard error, Hist-historical climate, RCP- Representative Concentration Pathways, NS – Not Significant

Source: Author's result of mean annual runoff and soil loss, 2017

4.7 Interaction of Soil Management Practices and Climatic Conditions on Soil Loss

The result of the analysis of variance showed a significant interaction between climatic condition and land use types on soil loss (Table 4. 15). The interaction occurred under the rangeland and the projected climatic condition of RCP 8.5. The interaction table showed that irrespective of the land use types that there is a general decline in soil loss from historical to RCP 8.5 climatic condition. It also showed that there is a significant variation in soil loss between the land use types except under RCP 8.5 climatic condition. There was also a significant variation in soil loss between the climatic conditions. Generally, the soil loss under range land irrespective of the climatic condition is statistically the same.

Table 4.15: Interaction effect of soil management practices and climatic conditions on soil loss in Nsukka, Nigera

	Climatic conditions		
SMP	HIST	RCP 4.5	RCP 8.5
	Soil loss (Mg ha^{-1} yr^{-1})		
Tractorized cultivation	49.7625[a]	31.5125[b]	6.8900[c]
Fallow land	45.4490[a]	27.8050[b]	5.7210[c]
Manual cultivation	57.9555[a]	33.2370[b]	7.7285[c]
Range land	0.0095[c]	0.0035[c]	0.0010[c]
S.E ±		2.1568	

Means with different letters across columns and rows are significantly different P ≤0.05 based on LSD, SMP=soil management practices, Hist=historical climate, RCP= Representative Concentration Pathways, S. E=Standard Error

Source: Author's result of interaction effect on soil loss, 2017

From the results obtained, tractorized cultivation produced the highest amount of runoff while the lowest amount of soil loss was obtained under range land management. The historical climatic condition produced the highest amount of both runoff and soil loss while the least runoff and soil loss were recorded under the future climatic condition of RCP 8.5. In answering both objective three and part of objective two, the results therefore conclude that the future levels of runoffs and soil losses through water erosion from the soils under the four management practices would be low and that range land system of management would be the most sustainable under the changing climate.

Further details on the result of the analysis of variance for the runoff and soil loss for the different soil management practices and climatic conditions can be found in appendix A.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

No nation can ever be considered developed until it is able to produce food which is not just sufficient for but also surpasses the general food need of her entire population. The environmental and agricultural sectors of South Eastern part of Nigeria has since been known to be under severe threat from soil erosion. This is mainly because of the high annual and intensive rainfall and the presence of highly erodible soils. The damages caused annually by this erosion in the area have been put into millions of naira. Erosion has become one of the greatest threats, not just to the infrastructural facilities such as roads, schools and homes but to the lives of the entire people of the area. It has also threatened agricultural productivity as soil nutrients are constantly and easily washed away. These threats have however, become more imminent with the recent observation in the general weather pattern.

The result of trend analysis for the historical rainfall indicated that there was both variability and significant trend in the mean annual rainfall for Nsukka and that there was a non-significant trend for the seasonal annual rainfall for the period 1981 to 2010. The projected rainfalls under Representative Concentration Pathways of 4.5 and 8.5 all indicated variability and decreases in the total annual rainfall with no significant trend. This is in contrast to the observed trend in the historical rainfall (1981 to 2010). It then follows that if rainfall takes the increasing trend expressed by the historical rainfall, there is bound to be some catastrophic consequences on both agriculture and human resources. Such consequences could include but not limited to astronomical rise in washing away of crops, farmlands and soil by surface runoff. More so, the high level of variability in the mean monthly rainfall in the projected monthly rainfall is also an indication that although the annual rainfall could be decreasing, the monthly or daily intensity may also pose another challenge. Nevertheless, if the rainfall pattern follows the annual pattern projected by the scenarios, soil erosion would be minimal in Nsukka, all things being equal. The research also concluded that there was no trend in the historical minimum and maximum temperatures but variation existed. However, projected minimum and maximum temperatures for both RCP 4.5 and 8.5 all varied significantly at an alpha-level of 0.05. This implies that if temperature follows the pattern that has been predicted, there could be an increase in the threat of soil erosion for both land uses that currently seem sustainable and those that are already under threat. This is so because as the temperatures (minimum and maximum) increase with no significant increase in the amount of rainfall, the rate of decomposition will also increase, leaving more areas bare for the greater part of the year. Although due to the complex interaction between plant growth and rate of decomposition, the increase in temperature could produce lower soil erosion.

Soil losses and runoffs from the different management regimes have been found to be statistically different, with tractorized land having the highest amount of runoff while range land and land under manual cultivation have the lowest amount of runoffs and soil losses. This study therefore concluded that all the soil management practices if properly carried out together with conservation practices, that the future threats of soil erosion would be significantly neutralized. The range system of management is the most sustainable form of land management in Nsukka as shown by the study. In comparison with soil loss tolerance level established by Igwe (1999) for the area, range form of management was within the 1.3Mg/ha/yr tolerance level for Nsukka and hence would be most sustainable in the future.

The study also rejected the null hypothesis and accepted the alternative that the mean annual runoff and soil losses are statistically different among the land management practices. This means that soil management practices play significant role in the determination of the susceptibility of a given soil to surface runoff and soil erosion and that given the same climatic conditions, management practice is a factor that should be put into consideration if the problem of soil degradation is to be addressed. It also implies that consideration has to always be made before a given piece of land is put into a particular usage or practices so as to reduce its susceptibility to soil degradation process. Furthermore, it also accepted the alternative of the second null hypothesis that the amount of runoffs and soil losses under the different climatic periods are statistically different. The implication of this is that the rate of soil threats coming from the future climatic condition would be different and that different approaches in conserving the soil from what used to be previously done should be adopted. But because the trend of rainfall is negative it then means that less resources should be deployed in conservation practices while more resources should be channelled towards the provision of irrigation facilities and drought resistant crops to farmers.

5.2 Recommendations

From the findings of this research, the following recommendations are made:

1. Based on soil conservation, farmers in the area should be advised to employ the use of manual cultivation (hoe and other local implements) rather than tractors to cultivate the soil, since tractorized cultivation destroys the soil properties and predisposes the soil to greater threat of soil erosion.

2. Government (federal, state and local authorities) and non-governmental organizations should assist in the provision of irrigational facilities and drought- resistant crops to the farmers as less rainfall amounts are expected in the future.
3. The expected increase in temperature also amplifies the need for additional sources of manure (for nutrient supply) as the rate of decomposition of organic matter in the soil is expected to almost double, making the traditional approach to nutrient replenishment less sustainable. The additional source of nutrients could be in form of inorganic fertilizer.
4. Climatic scenarios from different regional model outputs apart from the Weather Research Forecasting model (WRF) should also be tested for future trend of rainfall as the projection from this model seems to be at variance with the observed historical increment in future rainfall (rainfall data from 1981 to 2010).
5. Further research with rainfall intensity is recommended.

REFERENCES

Abaci, O., & Papnicolaou, A.N.T. (2009). Long-Term Effects of Management Practices on Water-Driven Soil Erosion in an Intense Agricultural Sub-Watershed: Monitoring and Modelling. *Hydrological Process,* 23, 2818–2857.

Abdulfatai, I. A., Okunlola, I. A., Akande, W. G., Momoh, L. O., & Ibrahim, K. O. (2014). Review of Gully Erosion in Nigeria: Causes, Impacts and Possible Solutions.*Journal of Geosciences and Geomatics,2*(3), 125–129. http://doi.org/10.12691/jgg-2-3-8

Allison, L.E. (1965). Organic Carbon. In: Methods of Soil Analysis, Part 2. Black, C.A. *et al*. (Eds.). *American Society of Agronomy,* Monograph No. 9. Madison, Wisconsin, 1367-1378

Al-Durrah, M. M., & Bradford, J. M. (1982). The mechanism of raindrop splash on soil surfaces. *Soil Science Society of America Journal,* 46, (5), 1086-1090.

Aina, P. O. (1979). Soil changes resulting from long-term man- agement practices in western Nigeria. *Soil Science Society of America Book Serie,* 43, 173-177.

Akamigbo, F.O.R., & Igwe, C.A. (1990). Morphology, geography, genesis and taxonomy of three soil series in eastern Nigeria. *J. Agric Res.*, 7, 33-48

Akinsanola, A. A., & Ogunjobi, O.K. (2014). Analysis of Rainfall and Temperature Variability Over Nigeria. *Global Journal of Human-Social Science: B Geography, Geo-Sciences, Environmental Disaster Management,* 14(3).

Amadi, S. O., UDO, S. O., & EWONA, I. O. (2014). Trends and Variations of Monthly Mean Minimum and Maximum Temperature Data Over Nigeria for the Period 1950-2012. *International Journal of Pure and Applied Physics,* 2(4), 1–27.

Ande, O. T., Alaga, Y., & Oluwatosin, G. A. (2009). Soil erosion prediction using MMF model on highly dissected hilly terrain of Ekiti environs in southwestern Nigeria. *International Journal of Physical Sciences,* 4(2), 53–57. Retrieved from http://www.academicjournals.org/IJPS

Anyadike, R.N.C. (1992). Regional variations in fluctuations of seasonal rainfall over Nigeria. *Theoretical and Applied Climatology,* 45, 285–292.

Ascough, J. C., Baffaut, C., Nearing, M. A., & Liu. B. Y. (1997). The WEPP watershed model: I. Hydrology and erosion. *Tran. ASAE,* 40(4), 921–933.

Azuka, C.V., & Obi, M.E. (2012). Structural Stability and hydraulic conductivity of Nkpologu Sandyloam soil under different land covers in southeastern Nigeria. *Agro-science journal of tropical Agriculture, food environment and extension*, 11 (1) 1-9

Baffaut, C., Nearing, M. A., Ascough. J. C. II., & Liu. B. (1997). The WEPP watershed model: II. Sensitivity analysis and discretization on small watersheds. *Tran. ASAE,* 40(4), 935–943.

Barfield, B., Deer-ascough, L. A., & Livingston, S. J. (1995). *WEPP user summary*. NSERL Report NO. 11, July National Soil Erosion Research Laboratory USDA-ARS-MWA 1196 SOIL Building West Lafayette, IN 47907-1196

Blake, G. R., & Hartge, K. H. (1986). Bulk density. In: methods of Soils Analysis, part 1, A. Klute (Ed.) *Agron*. No 9. USDA Maidson W. I. 370 – 373.

Blavet, D., Noni, G. De, Bissonnais, Y. Le, Leonard, M., Maillo, L., Laurent, J. Y., Roose, E. (2009). Effect of land use and management on the early stages of soil water erosion in French Mediterranean vineyards. *Soil and Tillage Researh*, 106, 124–136. http://doi.org/10.1016/j.still.2009.04.010

Berendse, F., van Ruijven, J., Jongejans, E., & Keesstra, S.D. (2015). Loss of plant species diversity reduces soil erosion resistance of embankments that are crucial for the safety of human societies in low-lying areas. *Ecosystems*, 18, 881–888.

Boardman, J., & Poesen, J. (2006). Soil Erosion in Europe: Major Processes, Causes and Consequences. *Soil Erosion in Europe*, 477–487. http://doi.org/10.1002/0470859202.ch36

Bochet, E., Rubio, J., L., & Poesen J. (1998). Relative efficiency of three representative matorral species in reducing water erosion at the microscale in a semi-arid climate (Valencia, Spain). *Geomorphology*, 23: 139–150.

Bracken, L.J., Cox, N.J., & Shannon, J. (2008). The relationship between rainfall inputs and flood generation in southeeast Spain. *Hydrological Processes*, 22, 683-696.

Brevik, E. C. (2013). Processes and Corresponding Influence on Food Security. *Agriculture,* 3, 398–417. http://doi.org/10.3390/agriculture3030398.

Browning, G.M., Parish, C. L., & Glass, J. (1947). A method for determining the use and limitations of rotation and conservation practices in the control of soil erosion in Iowa. *Journal of American Society of Agronomy*, 39, (1), 65-73.

Burylo, M., Rey, F., Mathys, N., & Dutoit, T. (2012). Plant root traits affecting the resistance of soils to concentrated flow erosion. *Earth Surface Processes and Landforms,* 37 (14), 1463–1470. http://doi.org/10.1002/esp.3248

Calvo-Cases, A., & Harvey, A.M. (1996). Morphology and development of selected badlands in southeast Spain: implications of climatic change. *Earth Surface Processes and Landforms,* 21, 725–735.

Cerdà, A., Lavee, H., Romero-Díaz, A., Hooke, J., & Montanarella, L. (2010). Soil erosion and degradation in Mediterranean type ecosystems. *Land Degradation and Development*, 21, 71–74.

Changxing, S., Yuanyuan, Z., Xiaoli, F., & Wenwei, S. (2012). A study on the annual runoff change and its relationship with water and soil conservation practices and climate change in the middle Yellow River basin. *Catena*, 100, 31–41. http://doi.org/10.1016/j.catena.2012.08.007

Chapman, H.D. (1965) Cation-exchange capacity. In: Black CA, Evans DD, White JL, Ensminger LE, Clark FE (eds) Agronomy 9, Part 2, *Am Soc Agron,* Madison, Wis, 891–901

Christian, E. I., & Izuchukwu, E. (2009). Analysis of rainfall distribution over Enugu during the little dry season (1990-2005). *Journal of Geography and Regional Planning*, 2(7), 182–189.

De Luís, M., González-Hidalgo, J.C., & Longares, L.A. (2010). Is rainfall erosivity increasing in the Iberian Peninsula. *Land Degradation and Development,* 21, 139–144.

Demény, K., Centeri, C., Jakab, G. (2010). Soil Loss Calculations with WEPP and USLE Models on Sloping Arable Land Near Isaszeg, Hungary. International Union of Soil Sciences (IUSS), c/o Institut für Bodenforschung, Universität für Bodenkultur, Wien.

Descroix, L., Viramontes, D., Vauclin, M., Gonzalez Barrios, J. L., & Esteves, M., (2001). Influence of soil surface features and vegetation on runoff and erosion in the Western Sierra Madre (Durango, Northwest Mexico). *Catena*, 43: 115–135.

Dickey, D. A., & W. A. Fuller (1981) Likelihood Ratio Statistics for Autoregressive Time Series with a Unit Root. *Econometrica*, 49, 1057-1072.

Elliot W.J., Liebenow A.M., Laflen, J.M., & Kohl K.D. (1989). *A Compendium of Soil Erodibility Data from WEPP Cropland Soil Field Erodibility Experiments 1987 and 1988.*NSERLReport No. 3. USDA-ARS National Soil Erosion Research Lab., West Lafayette, IN.

Ellison, W.D. (1948). Erosion by raindrop. *Sci. Am.*, 179 (5), 40-45

Ehigiator, O. A., & Anyata, B., U. (2011). Effects of land clearing techniques and tillage systems on runoff and soil erosion in a tropical rain forest in Nigeria. *Journal of Environmental Management*, 92(11), 2875–2880. http://doi.org/10.1016/j.jenvman.2011.06.015

Emadi, M., Mehdi, E., Baghernejad, M., Fathi, H., & Saffari, M. (2008). Effect of Land Use Change on Selected Soil Physical and Chemical Properties in North Highlands of Iran. *Journal of Applied Sciences,* 8, 496-502

Ezeaku, P. I. (2006). Estimation of crop water requirement from climate and soil data for field maize production in Southeastern Nigeria. *J. Sustain. Trop. Agric. Res.* 17, 91-96

Ezeaku, P.I., Eze, F.U., & Oke, E. (2015). Profile distribution and degradation of soil properties of an ultisol in Nsukka semi-humid area of Nigeria. *African Journal of Agricultural Research,* 10 (11), 1306-1311. Doi: 10.5897/AJAR2013.8446.

Ezeh, C.C., & Ugwu, G.Z. (2010). Geoelectrical sounding for estimating groundwater potential in Nsukka L.G.A. Enugu State, Nigeria. *International Journal of the Physical Sciences*, 5(5), 415-420

Farres, P. (1978). The role of time and aggregate size in the crusting process. *Earth Surface Proceedings*, 3, 243-254

Flanagan, D. C., & Nearing, M. A. (1995). *Water Erosion Prediction Project Hillslope Profile and Watershed Model Documentation.* NSERL Report No. 10 West Lafayette, IN: National Soil Erosion Research Laboratory.

Flanagan, D. C., & Livingston, S. J. eds. (1995). *Water Erosion Prediction Project (WEPP) Version 95.7: User Summary*. NSERL Report No. 11. West Lafayette, Ind.: USDA-ARS National Soil Erosion Research Laboratory.

Flanagan, D. C., & Frankenberger, J. R. (2012). WEPP: MODEL USE, CALIBRATION, AND VALIDATION. *Amearican society of Agricultural and Biological Engineers*, 55(4), 1463-1477.

Food and Agricultural Organization of the United Nations (FAO). (1994). Summary of the final report of the Forest Resources Assessment 1990 for the Tropical World. FAO, Rome, Italy.

Foster, G.R., Flanagan, D.C., Nearing, M.A., Lane, L.J., Risse, L.M., &Finkner, S.C. (1995). *Chapter 11: Hillslope Erosion Component: In USDA Water Erosion Prediction Project: Hillslope Profile and Watershed Model Documentation*, Vol. NSERL Report No. 10 Eds, Flanagan, D. C. and M. A.Nearing. USDA-ARS National Soil Erosion Research Laboratory

Gaiser, T., Stahr, K., Billen, N., & Mohammad, M. A. (2008). Modelling carbon sequestration under zero tillage at the regional scale. I. The effect of soil erosion. *Ecological Modelling*, 218, 110–120. http://doi.org/10.1016/j.ecolmodel.2008.06.025

García-Ruiz, J. M. (2010). The effects of land use on soil erosion in Spain: a review. *Catena*, 81, 1–11

García-ruiz, J. M., Nadal-romero, E., Lana-renault, N., & Beguería, S. (2013). Geomorphology Erosion in Mediterranean landscapes: Changes and future challenges. *Geomorphology*, http://doi.org/10.1016/j.geomorph.2013.05.023

Gee, G.W., & Bauder, J.W. (1986). Particle-size Analysis. In Methods of Soil Analysis Part 1. A. Klute (eds.), *Soil Science Society of America Book Series, 5* (PP 383-411). Madison, Wisconsin, USA.

Ghalhari, G., Dastjerdi, J., & Iran, a. (2012). Using Mann Kendal and t-test methods in identifying trends of climatic elements: A case study of northern parts of Iran.*Management Science Letters*, 2(3), 911-920.

Gíslason, S. R., Alfredsson, H. A., Eiriksdottir, E. S., Hassenkam, T., & Stipp, S. L. S. (2011). Volcanic ash from the 2010 Eyjafjallajökull eruption. *Applied Geochemistry*, 26, 188–S190.

Giorgi, F., Jones, C., & Asrar, G., R., (2009), Addressing climate information needs at the regional level: the CORDEX framework. *WMO Bulletin,* 58(3), 175-183.

Gobin, A. M., Campling, P., Deckers, J. A., Poesen, J., & Feyen, J. (1999). Soil Erosion Assessment at the Udi-Nsukka Cuesta (South Eastern Nigeria). *Land Degrad. Develop.* 10, 141–160.

Gyssels, G., Poesen, J., Bochet, E., & Li, Y. (2005). Progress in Physical Geography Impact of plant roots on the resistance of soils to erosion by water: a review. *Progress in Physical Geography*, 29, (2) 189-217. http://doi.org/10.1191/0309133305pp443ra

Harvey, O.R., Qafoku, N.P., Cantrell, K.J., Lee, G. Amonette, J.E., & Brown. C.F., (2013). Geochemical Implications of Gas Leakage Associated with Geologic Co2 Storage-a Qualitative Review. *Environmental Science & Technology,* 47:23-36

Harnos, Zs., & Csete, L. (eds.) (2008). Climate change: environment–risk–society. Research results. In Hungarian, *Szaktudás Kiadó Ház* (pp. 380). Budapest.

Helming, K., & Prasad, S. N. (2001). Soil erosion under different rainfall intensities, surface roughness, and soil water regimes.*Catena,* 46, 103–123.

Hu, L. (1999). *Bare Soil Erosion Dependence on Soil and Rainfall Properties* (Doctoral dissertation, University of Houston, United States of America). Retrived from https://www.google.com.ng/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=0ahUKEwjrqPqQgdrWAhWF1BoKHbNbAegQFggpMAA&url=http%3A%2F%2Fwww.rtfmps.com%2Fresumes%2FMyWebPapers%2Fthesis%2Fhuliu_dissertation%2Fhuliu_dissertation.pdf&usg=AOvVaw261CzDU8uSuOGBLtRbYIAm

Igwe, C.A. (1999). Land Use and Soil Conservation Strategies for Potentially Highly Erodible Soils of Central-Eastern Nigeria. *Land Degrad. Develop.* 10: 425-434

Intergovernmental Panel on Climate Change (IPCC). (2001). Working Group I: Summary for policymakers: a report of Working Group I of the Intergovernmental Panel on Climate Change. IPCC. Available online at hhttp://www.ipcc.ch/pub/spm22-01.pdfi (accessed 10, Dec. 2016).

Intergovernmental Panel on Climate Change (IPCC). (2007). Fourth Assessment Report; Cambridge University Press. London. Intergovernmental Panel on Climate Change.

Intergovernmental Panel on Climate Change (IPCC). (2014). Summary for policymakers. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability.Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B.

Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1-32.

Karmeshu, N. (2012). *Trend Detection in Annual Temperature & Precipitation using the Mann Kendall Test – A Case Study to Assess Climate Change on Select States in the Northeastern United States* (Master's thesis, University of Pennsylvania, United States of America)

Kiunsi, R.B., & Meadows M.E. (2006). Assessing land degradation in the Monduli District, northern Tanzania. *Land Degradation and Development*,17(5), 509-525. http://DOI: 10.1002/ldr.733

Klara, Å., & Fredrik F. (2014). Land cover change and its influence on soil erosion in the Mara region, Tanzania, (334). http://lup.lub.lu.se/student-papers/record/5157972

Klik, A. (2003). Conservation tillage: impacts on soil erosion, runoff and pesticide losses Figure 1: Long-term average annual runoff and soil loss from fields with conventional (CT), conservation tillage (CS) and direct seeding (DS) (1994-2015) Table 1: *Long*-, 4, 8–9.

Klik, A., & Eitzinger, J. (2010). Impact of climate change on soil erosion and the efficiency of soil conservation practices in Austria. *Journal of Agricultural Science,* 148, 529–541. http://doi.org/10.1017/S0021859610000158

Klute, A., Dirksen, J. (1986). Hydraulic conductivity and Diffusivity. Laboratory methods. In: A. Klute (ed). Methods of soil analysis part 1 2nd ed. 687-734.

Knisel, W. G. (ed). (1980). CREAMS: A Field-Scale Model for Chemicals,Runoff,and Erosion from Agricultural Management Systems. *USDA Conservation Research Report 26,* 640.

Labrière, N., Locatelli, B., Laumonier, Y., & Freycon, V. (2015). Agriculture, Ecosystems and Environment Soil erosion in the humid tropics: A systematic quantitative review. *Agriculture, Ecosystems and Environment,* 203, 127–139. http://doi.org/10.1016/j.agee.2015.01.027

Laflen, J. M., & Flanagan, D. C. (2013). The development of U. S. soil erosion prediction and modeling. International Soil and Water Conservation Research, 1(2), 1–11. http://doi.org/10.1016/S2095-6339(15)30034-4

Lal, R. (1984). Soil erosion from tropical arable lands and its control. *Advances in Agronomy,* 37, 183-188.

Lal, R. (2004). Soil carbon sequestration to mitigate climate change. Geoderma, 123, 1–22.

Liu, Y., Fu, B., L¨u Y, Wang, Z., & Gao, G. (2012). Hydrological responses and soil erosion potential of abandoned cropland in the Loess Plateau, China. *Geomorphology*, 138: 404–414.

Marie, B., Nacoulma, I., Schumann, K., & Bernhardt-ro, M. (2011). Impacts of land-use on West

African savanna vegetation: a comparison between protected and communal area in Burkina Faso, *Biodivers Conserv*, 20, 3341–3362. http://doi.org/10.1007/s10531-011-0114-0

Mbajiorgu, C.C., & Ogbu, K.N. (2011). Testing the Wepp Model for a Single Event Runoff and Soil Loss from a Plot in Nsukka, Southeast Nigeria. *Journal of Agricultural Engineering and Technology (JAET)*, 19 (2), 100-107

Mbagwu, J. S. C. (1995). Saturated hydraulic conductivity in relation to physical properties of soils in the Nsukka Plains, Southeastern Nigeria. *Geoderma,* 68, 51-66.

Mercy, I. (2015). Trend Analysis of Rainfall Pattern in Enugu State, Nigeria. *European Journal of Statistics anRetrieved from http://www.eajournals.org/wp-content/uploads/Trend-Analysis-of-Rainfall-Pattern-in-Enugu-State-Nigeria1.pdfd Probability*, 3(3), 12–18. Retrieved from http://www.eajournals.org/wp-content/uploads/Trend-Analysis-of-Rainfall-Pattern-in-Enugu-State-Nigeria1.pdf

Mohammad, A., G., & Adam, M., A., (2010). The impact of vegetative cover type on runoff and soil erosion under different land uses. *Catena*, 81: 97–103.

Moldenhauer, W.C., & Kemper, W.D. (1969). Interdependence of water drop energy and clod size on infiltration and clod stability. *Soil Sci. Soc. Am. Proc.* 33, 227–231.

Morgan, R. P. C., Morgan, D. D. V., & Finney, H. J. (1984). A predictive Model for the assessment of Soil Erosion Risk. *Journal of Agricultural Engineering Research,* 30, 245 -253

Morgan, R.P.C. (2005). *Soil Erosion and Conservation.* Oxford:Blackwell Science Ltd

National Climatic Data Center (NCDC) (2002). Climate of 2001—Annual Review. National Oceanic and Atmospheric Administration, Asheville, North Carolina, USA. Available online at hhttp://lwf.ncdc.noaa.gov/oa/climate/research/2001/ann/ann.htmli (accessed 10 Dec. 2016).

Nearing, M. A., Foster, G. R., Lane, L. J., & Finkner, S. C. (1989). A process-based soil erosion model for USDA-Water Erosion Prediction Project Technology. *Transactions of the ASAE,* 32, (5), 1587-1593.

Nearing, M. A., Lane, L. J., Alberts, E. E., & Laflen, J. M. (1990). Prediction technology for soil erosion by water: Status and research needs. *Soil Science Society of America,* 54, 1702-1711.

Negasa, T., Ketema, H., Legesse, A., Sisay, M., & Temesgen, H. (2017). Variation in soil properties under different land use types managed by smallholder farmers along the toposequence in southern Ethiopia. *Geoderma*, 290, 40–50. http://doi.org/10.1016/j.geoderma.2016.11.021

Nwakor, E.K., Ogwashi, U., & Mbajiorgu, C.C. (2015). Assessment of Soil Erosion Using Rusle2 Model and GIS in Upper Ebonyi River Watershed, Enugu State, Nigeria. *International Journal of Remote Sensing & Geoscience*, 4(4)

Obasi, R. (2013). Erosion and Flood Vulnerability of Soils: A Climatic Challenge in Southern Nigeria. *International Journal of Science and Technology*, 2(9), 675–684.

Obi, M. E. (1982). Runoff and soil loss from an oxisol in southeastern nigeria under various management practices. *Agricultural Water Management*, 5, 193–203.

Obi, M.E., & Salako, F.K. (1995). Rainfall parameters influencing erosiity in southeastern Nigeria. *Catena, 24,* 275-287.

Obinna, C.D. Anejionu, Peter C. Nwilo, & Elijah S. Ebinne (2013). Long Term Assessment and Mapping of Erosion Hotspots in South East Nigeria. Paper presented at Environment for Sustainablity Abuja, Nigeria. FIGURE working week 2013, TSO3B- Rmote Sensing for Landuse and Planning-6448.

Ochoa, P. A., Fries, A., Mejía, D., Burneo, J. I., Ruíz-sinoga, J. D., & Cerdà, A. (2016). Catena Effects of climate, land cover and topography on soil erosion risk in a semiarid basin of the Andes. *Catena*, 140, 31–42. http://doi.org/10.1016/j.catena.2016.01.011

Oko-Ibom, G.U., & Asiegbu, J.E., (2006). Growth and yield responses of rainy season field tomatoes to timing and splitting of fertilizer application. *J. Agric. Food Environ. Ext.*, 5(1), 17-25.

Oldemal, R.L. (1994). The global extent of soil degradation. In: Greenland, D.J., Szabolcs, I. (Eds.), *Soil Resilience and Sustainable Land Use,* (pp. 99–118). Wallingford, United Kingdom.

Olson, T. C., & Wischmeier, W. H. (1963). Soil-Erodibility evaluations for soils on the runoff and erosion stations. *Soil Sci. Soc. Amer. Proc,* 27,590-592.

Onoz, B., & Bayazit, M. (2003). The power of statistical tests for trend detection. *Turkish Journal of Engineering Environmental Science*, 27, 247-251.

Osman, K.T. (2014). Soil erosion by water. In: Soil degradation, conservation and remediation; *Springer:* Dordrecht, The Netherlands, 69–101.

Palacio, R.G., Bisigato, A.J., & Bouza, P.J. (2014). Soil erosion in three grazed plant communities in Northeastern Patagonia. *Land Degradation and Development*, 25, 594–603.

Panagos, P., Karydas, C., Ballabio, C., & Gitas, I. (2014). Seasonal monitoring of soil erosion at regional scale: An application of the G2 model in Crete focusing on agricultural land uses. Int. J. Appl. *Earth Observation Geoinformation,* 5, 461–487.

Pangle L.A., Gregg, J.W., & McDonnell, J.J. (2014). "Rainfall Seasonality and an Ecohydrological Feedback Offset the Potential Impact of Climate Warming on Evapotranspiration and Groundwater Recharge. *Water Resources Research,* 50,1308-21.

Patterson, L.A, Lutz, B., & Doyle, M.W. (2013). "Climate and Direct Human Contributions to Changes in Mean Annual Streamflow in the South Atlantic, USA. *Water Resources Research*, 49, 7278-91.

Pruski, F.F., & Nearing, M.A. (2002a). Climate-induced changes in erosion during the 21st century for eight U.S. locations. *Water Resources Research*, 38 (12), 1298.

Pruski, F.F., & Nearing, M.A. (2002b). Runoff and soil loss responses to changes in precipitation: a computer simulation study. *Journal of Soil and Water Conservation,* 57 (1), 7 – 16.

Qafoku, N. P. (2014). Overview of different aspects of climate change effects on soils, (August). Pacific Northwest National Laboratory Richland, Washington 99352

Ran, Q., Su, D., Li, P., & He, Z. (2012). Experimental study of the impact of rainfall characteristics on runoff generation and soil erosion. *Journal of Hydrology*, 424-425, 99–111. http://doi.org/10.1016/j.jhydrol.2011.12.035

R Core Team (2015). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Reaney, S.M., Bracken, L.J., & Kirkby, M.J. (2007). Use of the Connectivity of Runoff Model (CRUM) to investigate the influence of storm characteristics on runoff generation and connectivity in semi-arid areas. *Hydrological Processes*, 21, 894-899.

Renard, K G., Foster, G. R., Yoder, D. C., & McCool, D. K. (1994). RUSLE revisited: Status, questions, answers, and the future. *Journal of Soil & Water Conservation,* 49, 3, 213-220.

Romkens, M.J.M., & Wang, J.Y. (1987). Soil roughness changes from rainfall. *Trans. ASAE,* 31, 408–413.

Schulze, R. (2000). Transcending scales of space and time in impact studies of climate and climate change on agrohydrological responses. *Agriculture, Ecosystems and Environment,* 82, 185–212.

Senjobi, B., A. (2007). *Comparative Assessment of the Effect of Land Use and Land Type on Soil Degradation and Productivity in Ogun State, Nigeria. Published Ph.D. Thesis submitted to the Department of Agronomy, University of Ibadan, Ibadan, p. 161.*

Shiono, T., Ogawa, S., Miyamoto, T., & Kameyama, K. (2013). Expected impacts of climate change on rainfall erosivity of farmlands in Japan. *Ecological Engineering,* 61, 678-689 http://doi.org/10.1016/j.ecoleng.2013.03.002

Smith, D. D., & Wischmeier, W. H. (1957). Factors affecting sheet and rill erosion. *Trans. Am. Geophys. Union,* 38, 889-896.

Smith, D. D. (1941). Interpretation of soil conservation data for field use. *Agr. Eng.,* 22, (5), 173-175.

Stockle, C.O., Dyke, P.T., Williams, J.R., Jones, C.A., & Rosenberg, N.J. (1992). A method for estimating the direct and climatic effects of rising atmospheric carbon dioxide on growth and yield of crops: Part II. Sensitivity analysis at three sites in the Midwestern USA. *Agricultural Systems* 38, 239– 256.

Stone, R. P., & Hilborn, D. (2002). Universal Soil Loss Equation (USLE). Factsheet. Ministry of Agriculture, Food and Water Resources, Ontario.

Tiwari, A. K., Risse, L. M., & Nearing, M. A. (2000). Evaluation of WEPP and its comparison with USLE and RUSLE. *Trans.ASAE* 43(5) : 1129-1135.

Uguru, M., I., Baiyeri, K. P., & Aba, S. C. (2001). Indicators of Climate Change in the Derived Savannah Niche of Nsukka, South-Eastern Nigeria. *Agro-Science,* 10(1)

United Nations Educational, Scientific and Cultural Organization (UNESCO). (2009). The impact of global change on erosion and sediment transport by rivers: current progress and future challenges. Scientific Paper. The United Nations World Water Assessment Programme. http://unesdoc.unesco.org/images/0018/001850/185078e.pdf (accessed on 12th December, 2016).

Uppala, S., M., Simmons, A., Dee, D., Kållberg, P., & Thépaut, J.-N. (2008). Atmospheric reanalyses and climate variations. *Climate Variability and Extremes during the Past 100 Years*, S. Brönnimann et al., Eds., Vol. 33, Advances in Global Change Research: *Springer*, 103–117.

U.S. Soil Salinity Lab. Staff. (1954). Methods for soil characterization. p. 83-147. Diagnosis and improvement of saline and alkali soils. *Agricultural Handbook,* 60, USDA, Washington, D.C.

Vannoppen, W., Vanmaercke, M., De Baets, S., & Poesen, J. (2015). A review of the mechanical effects of plant roots on concentrated flow erosion rates. *Earth-Science Reviews*, 150, 666–678. http://doi.org/10.1016/j.earscirev.2015.08.011

Van Oost, K., Ritchie, J. C., Quine, T. A., McCarty, G. W., Marques da Silva, J. R., Govers, G., Heckrath, G., Merckx R., De Gryze, S., Kosmas, C., Six, J., Harden, J. W., & Giraldez, J. V. (2007). The Impact of Agricultural Soil Erosion on the Global Carbon Cycle. *Science* 318, 626 http://doi.org/10.1126/science.1145724

Várallyay, Gy., & Farkas, Cs. (2008). Impact of climate change on soils in Hungary. In: Climate change: environment–risk–society. Research results. (In Hungarian) (Eds.: Harnos, Zs. & Csete, L.) Szaktudás Kiadó Ház. Budapest. pp. 91–129.

Várallyay, G. (2010). The impact of climate change on soils and on their water management. *Agronomy Research*, 8, 385–396.

Velde, M. Van Der, Balkovi, J., Beer, C., Khabarov, N., & Kuhnert, M. (2014). Future climate variability impacts on potential erosion and soil organic carbon in European croplands, *Biogeosciences Discuss*,11, 1561–1585. http://doi.org/10.5194/bgd-11-1561-2014

Wang, X., Cammeraat, E. L. H., Romeijn, P., & Kalbitz, K. (2014). Soil Organic Carbon Redistribution by Water Erosion – The Role of CO_2 Emissions for the Carbon Budget. *PLoS ONE*, 9(5): e96299. https://doi.org/10.1371/journal.pone.0096299

Wang, L., Dalabay, N., Lu, P., & Wu, F. (2017). Effects of tillage practices and slope on runoff and erosion of soil from the Loess Plateau, China, subjected to simulated rainfall. *Soil and Tillage Research*, 166, 147–156. http://doi.org/10.1016/j.still.2016.09.007

Williams, J. R., Hiler, E., A., & Baird, R., W. (1971). Prediction of sediment yields from small watersheds. Trans. Am. Soc. *Agric. Eng.*, 14 (6), 1157-1162.

Wilson, G.V., Cullum, R.F., & Römkens, M.J.M. (2008) Ephemeral Gully Erosion by Preferential Flow through a Discontinuous Soil-Pipe. *Catena*, 73, 98-106. http://dx.doi.org/10.1016/j.catena.2007.09.008

Wischmeier, W. H., & Smith, D. D. (1965). Predicting rainfall-erosion losses from cropland east of the Rocky Mountains. *Agr. Handbook* No. 282, U.S. Dept. Agr., Washington, DC.

Wischmeier, W. H., C. B. Johnson, and B. V. Cross. 1971. soil credibility nomograph for farmland and construction sites. *Journal of Soil and Water Conservation*, 26:189-193.

Wischmeier, W. H., & Smith, D. D. (1978). Predicting rainfall-erosion losses-A guide to conservation planning. *Agriculture Handbook* No 537 U. S. Dept. of Agric.: Washington DC.58.

World Meteorological Organization. (2001). WMO statement on the status of the global climate in 2001. WMO: Geneva, Switzerland.

Available online at http://www.wmo.ch/web/Press/Press670.html (accessed 15 Dec. 2016).

World Meteorological Organization. (2017). WMO statement on the status of the global climate in 2016. WMO: Geneva, Switzerland.

Yang, Z., & Liang, L. (2004). Soil erosion under different land use types and zones of Jinsha River Basin in Yunnan Province, China. *Journal of Mountain Science*, 1 (1): 46–56.

Yao, X., Yu, J., Jiang, H., Sun, W., & Li, Z. (2016). Roles of soil erodibility, rainfall erosivity and land use in affecting soil erosion at the basin scale. *Agricultural Water Management*, *174*, 82–92. http://doi.org/10.1016/j.agwat.2016.04.001

Yoder R. E. (1936). A direct method of aggregate analysis of soils and a study of the physical nature of erosion losses. *Journal of American Society of Agronomy*, 28, 337-351.

Xiong, Y., Xia H., & Li Zhi, A. (2007). Effects and mechanisms of plant roots on slope reinforcement and soil erosion resistance: A research review. *Chinese Journal of Applied*

Ecology 18, (4) 895-904

Zhang, X. C., & Nearing, M. A. (2005). Impact of climate change on soil erosion, runoff, and wheat productivity in central Oklahoma. *Catena*, 61, 185–195. http://doi.org/10.1016/j.catena.2005.03.009

Zhang, X. C., Nearing, M. A., Risse, L. M., & McGregor, K. C. (1996). Evaluation of WEPP runoff and soil loss predictions using natural runoff plot data. *ASAE*, 39, (3), 855-863.

Zhao, G., Mu, X., Wen, Z., Wang, F., & Gao, P. (2013). Soil erosion, conservation, and ecoenvironment changes in the Loess Plateau of China. *Land Degradation and Development*, 24, 499–510**.**

Zuazo, V. H. D., & Pleguezuelo, R. R, C. (2009). Soil-Erosion and Runoff Prevention by Plant Covers: A Review. *Sustainable Agriculture*, 65–86. http://doi.org/10.1051/agro

APPENDICES

APPENDIX A: ANOVA R CODES FOR THE ANALYSES OF RUNOFF AND SOIL LOSS

```
> workie<-read.table("Runoff.csv",  sep= ",", header = TRUE, fill = TRUE)
> library(agricolae)
> attach(workie)
> str(workie)
'data.frame':    24 obs. of  7 variables:
 $ REP      : int  1 2 1 2 1 2 1 2 1 2 ...
 $ LANDUSE  : Factor w/ 4 levels "FALLOW1","MAN1",..: 2 2 4 4 3 3 1 1 2 2 ...
 $ RAINFALL : Factor w/ 3 levels "HISTORICAL","RCP4.5",..: 1 1 1 1 1 1 1 1 2 2 ...
 $ SOIL.LOSS: num  403 507 517 478 131 ...
 $ X        : num  455 NA 498 NA 110 ...
 $ RUNOFF   : num  970 1086 1526 1303 927 ...
 $ X.1      : num  1028 NA 1415 NA 882 ...
   aov(formula = RUNOFF ~ RAINFALL, data = workie)

Terms:
                RAINFALL Residuals
Sum of Squares   1551264   1186743
Deg. of Freedom        2        21

Residual standard error: 237.7216
Estimated effects may be unbalanced
> summary(lm)
            Df  Sum Sq Mean Sq F value   Pr(>F)
RAINFALL     2 1551264  775632   13.72 0.000154 ***
Residuals   21 1186743   56512
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
> anova(lm)
Analysis of Variance Table

Response: RUNOFF
          Df  Sum Sq Mean Sq F value    Pr(>F)
RAINFALL   2 1551264  775632  13.725 0.0001541 ***
Residuals 21 1186743   56512
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
> y=LSD.test(RUNOFF, RAINFALL, 21,   56512, group=TRUE )
> y
$statistics
  MSerror Df     Mean      CV  t.value      LSD
    56512  12 799.9412 29.7175 2.178813 258.9764
```

```
$parameters
        test p.ajusted   name.t ntr alpha
  Fisher-LSD      none RAINFALL   30.05
$means
             RUNOFF      std r      LCL       UCL     Min      Max      Q25      Q50
HISTORICAL  1131.4748  228.3266  8  948.3507  1314.5988  836.676  1525.778  959.1675
1102.868
RCP4.5      754.6658 251.5294 8 571.5417  937.7898 475.996 1244.346 568.3250  721.106
RCP85       513.6833 232.6686 8 330.5592  696.8073 241.808  966.978 342.5190  496.570
               Q75
HISTORICAL 1288.225
RCP4.5     861.314
RCP85      621.538

$comparison
NULL

$groups
             RUNOFF groups
HISTORICAL 1131.4748   a
RCP4.5      754.6658      b
RCP85       513.6833      b

attr(,"class")
 workie<-read.table("Runoff.csv",  sep= ",", header = TRUE, fill = TRUE)
> library(agricolae)
> attach(workie)
The following objects are masked from workie (pos = 3):

    LANDUSE, RAINFALL, REP, RUNOFF, SOIL.LOSS, X, X.1

> str(workie)
'data.frame':           24 obs. of  7 variables:
 $ REP      : int  1 2 1 2 1 2 1 2 1 2 ...
 $ LANDUSE  : Factor w/ 4 levels "FALLOW1","MAN1",..: 2 2 4 4 3 3 1 1 2 2 ...
 $ RAINFALL : Factor w/ 3 levels "HISTORICAL","RCP4.5",..: 1 1 1 1 1 1 1 1 2 2 ...
 $ SOIL.LOSS: num  403 507 517 478 131 ...
 $ X        : num  455 NA 498 NA 110 ...
 $ RUNOFF   : num  970 1086 1526 1303 927 ...
 $ X.1      : num  1028 NA 1415 NA 882 ...
   aov(formula = SOIL.LOSS ~ RAINFALL, data = workie)

Terms:
               RAINFALL Residuals
Sum of Squares  393887.1  317712.7
Deg. of Freedom        2       21
```

```
Residual standard error: 123.0007
Estimated effects may be unbalanced
> summary(lm)
            Df Sum Sq Mean Sq F value  Pr(>F)
RAINFALL     2 393887  196944   13.02 0.00021 ***
Residuals   21 317713   15129
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
> library(agricolae)
> attach(workie)
The following objects are masked from workie (pos = 3):

    LANDUSE, RAINFALL, REP, RUNOFF, SOIL.LOSS, X, X.1

The following objects are masked from workie (pos = 4):

    LANDUSE, RAINFALL, REP, RUNOFF, SOIL.LOSS, X, X.1

> str(workie)
'data.frame':	24 obs. of  7 variables:
 $ REP      : int  1 2 1 2 1 2 1 2 1 2 ...
 $ LANDUSE  : Factor w/ 4 levels "FALLOW1","MAN1",..: 2 2 4 4 3 3 1 1 2 2 ...
 $ RAINFALL : Factor w/ 3 levels "HISTORICAL","RCP4.5",..: 1 1 1 1 1 1 1 1 2 2 ...
 $ SOIL.LOSS: num  403 507 517 478 131 ...
 $ X        : num  455 NA 498 NA 110 ...
 $ RUNOFF   : num  970 1086 1526 1303 927 ...
 $ X.1      : num  1028 NA 1415 NA 882 ...
   aov(formula = RUNOFF ~ RAINFALL, data = workie)

Terms:
                RAINFALL Residuals
Sum of Squares   1551264   1186743
Deg. of Freedom        2        21

Residual standard error: 237.7216
Estimated effects may be unbalanced
> summary(lm)
            Df  Sum Sq Mean Sq F value   Pr(>F)
RAINFALL     2 1551264  775632   13.72 0.000154 ***
Residuals   21 1186743   56512
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
> anova(lm)
Analysis of Variance Table

Response: RUNOFF
```

```
          Df  Sum Sq Mean Sq F value    Pr(>F)
RAINFALL   2 1551264  775632  13.725 0.0001541 ***
Residuals 21 1186743   56512
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
> y=LSD.test(RUNOFF, RAINFALL, 21,   56512, group=TRUE )
> y
$statistics
  MSerror Df     Mean      CV  t.value      LSD
    56512 21 799.9412 29.7175 2.079614 247.1855

$parameters
        test p.ajusted   name.t ntr alpha
  Fisher-LSD      none RAINFALL   3  0.05

$means
              RUNOFF      std r      LCL       UCL     Min      Max      Q25      Q50
HISTORICAL  1131.4748  228.3266  8  956.6882  1306.2613  836.676  1525.778  959.1675
1102.868
RCP4.5      754.6658 251.5294 8 579.8792  929.4523 475.996 1244.346 568.3250  721.106
RCP85       513.6833 232.6686 8 338.8967  688.4698 241.808  966.978 342.5190  496.570
                Q75
HISTORICAL 1288.225
RCP4.5      861.314
RCP85       621.538

$comparison
NULL

$groups
              RUNOFF groups
HISTORICAL 1131.4748      a
RCP4.5      754.6658      b
RCP85       513.6833      b

attr(,"class")
[1] "group"
> lm<-aov(SOIL.LOSS~RAINFALL, data = workie)
> lm
Call:
   aov(formula = SOIL.LOSS ~ RAINFALL, data = workie)

Terms:
                RAINFALL Residuals
Sum of Squares  393887.1  317712.7
Deg. of Freedom        2        21
```

```
Residual standard error: 123.0007
Estimated effects may be unbalanced
> summary(lm)
                        Df Sum Sq Mean Sq F value  Pr(>F)
RAINFALL     2 393887  196944   13.02 0.00021 ***
Residuals   21 317713   15129
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
> anova(lm)
Analysis of Variance Table

Response: SOIL.LOSS
                      Df Sum Sq Mean Sq F value    Pr(>F)
RAINFALL   2 393887  196944  13.018 0.0002103 ***
Residuals 21 317713   15129
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
> y=LSD.test(SOIL.LOSS, RAINFALL, 21,   15129, group=TRUE )
> y
$statistics
  MSerror Df     Mean       CV  t.value      LSD
    15129 21 217.7954 56.47502 2.079614 127.8963

$parameters
        test p.ajusted   name.t ntr alpha
  Fisher-LSD      none RAINFALL   30.05

$means
           SOIL.LOSS       std r       LCL      UCL   Min    Max      Q25     Q50
HISTORICAL 367.41375 186.75015 8 276.97744 457.8501 89.13 568.56 216.8825 440.325
RCP4.5     231.46625 100.57416 8 141.02994 321.9026 80.19 337.33 138.4425 267.985
RCP85       54.50625  19.91852 8 -35.93006 144.9426 20.78  76.42  41.4150  58.755
                Q75
HISTORICAL 509.6700
RCP4.5     314.1425
RCP85       71.2050

$comparison
NULL

$groups
           SOIL.LOSS groups
HISTORICAL 367.41375      a
RCP4.5     231.46625      b
RCP85       54.50625      c

attr(,"class")
```

```
[1] "group"
> workie<-read.table("Runoff.csv",  sep= ",", header = TRUE, fill = TRUE)
> library(agricolae)
> str(workie)
'data.frame':	24 obs. of  7 variables:
 $ REP      : int  1 2 1 2 1 2 1 2 1 2 ...
 $ LANDUSE  : Factor w/ 4 levels "FALLOW1","MAN1",..: 2 2 4 4 3 3 1 1 2 2 ...
 $ RAINFALL : Factor w/ 3 levels "HISTORICAL","RCP4.5",..: 1 1 1 1 1 1 1 1 2 2 ...
 $ SOIL.LOSS: num  403 507 517 478 131 ...
 $ X        : num  455 NA 498 NA 110 ...
 $ RUNOFF   : num  970 1086 1526 1303 927 ...
 $ X.1      : num  1028 NA 1415 NA 882 ...
   aov(formula = SOIL.LOSS ~ LANDUSE + RAINFALL + LANDUSE:RAINFALL,
    data = workie)

Terms:
                 LANDUSE RAINFALL LANDUSE:RAINFALL Residuals
Sum of Squares  151769.8 393887.1          85063.4   80879.5
Deg. of Freedom        3        2                6        12

Residual standard error: 82.09725
Estimated effects may be unbalanced
> summary(lm)
                 Df Sum Sq Mean Sq F value   Pr(>F)
LANDUSE           3 151770   50590   7.506  0.00434 **
RAINFALL          2 393887  196944  29.220 2.44e-05 ***
LANDUSE:RAINFALL  6  85063   14177   2.103  0.12861
Residuals        12  80880    6740
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
> anova(lm)
Analysis of Variance Table

Response: SOIL.LOSS
                 Df Sum Sq Mean Sq F value    Pr(>F)
LANDUSE           3 151770   50590  7.5060  0.004336 **
RAINFALL          2 393887  196944 29.2203 2.444e-05 ***
LANDUSE:RAINFALL  6  85063   14177  2.1035  0.128607
Residuals        12  80880    6740
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
> y=LSD.test(workie$SOIL.LOSS, workie$LANDUSE, 12, 6740, group=TRUE )
> y
$statistics
  MSerror Df     Mean       CV  t.value      LSD
     6740 12 217.7954 37.69478 2.178813 103.2736
```

```
$parameters
       test p.ajusted        name.t ntr alpha
  Fisher-LSD      none workie$LANDUSE   4  0.05

$means
       workie$SOIL.LOSS       std r       LCL      UCL   Min    Max      Q25     Q50
FALLOW1       227.58333 199.21954 6 154.55788 300.6088 20.78 568.56  89.9475 193.985
MAN1          263.52500 182.80710 6 190.49955 336.5505 43.78 507.09 113.8550 278.330
RANGE1         86.19333  38.11082 6  13.16788 159.2188 34.32 130.94  62.1450  84.660
TRACT1        293.88000 193.40812 6 220.85455 366.9055 61.38 517.41 130.5450 315.125
            Q75
FALLOW1 298.1875
MAN1    380.5250
RANGE1  117.1200
TRACT1  442.6975

$comparison
NULL

$groups
       workie$SOIL.LOSS groups
TRACT1         293.88000      a
MAN1           263.52500      a
FALLOW1        227.58333      a
RANGE1          86.19333      b

attr(,"class")
[1] "group"
> workie<-read.table("Runoff.csv",  sep= ",", header = TRUE, fill = TRUE)
> library(agricolae)
> attach(workie)
> str(workie)
'data.frame':           24 obs. of  7 variables:
 $ REP      : int  1 2 1 2 1 2 1 2 1 2 ...
 $ LANDUSE  : Factor w/ 4 levels "FALLOW1","MAN1",..: 2 2 4 4 3 3 1 1 2 2 ...
 $ RAINFALL : Factor w/ 3 levels "HISTORICAL","RCP4.5",..: 1 1 1 1 1 1 1 1 2 2 ...
 $ SOIL.LOSS: num  403 507 517 478 131 ...
 $ X        : num  455 NA 498 NA 110 ...
 $ RUNOFF   : num  970 1086 1526 1303 927 ...
 $ X.1      : num  1028 NA 1415 NA 882 ...
   aov(formula = RUNOFF ~ LANDUSE + RAINFALL + LANDUSE:RAINFALL,
    data = workie)



Terms:
                LANDUSE  RAINFALL LANDUSE:RAINFALL Residuals
```

```
Sum of Squares   967644.5 1551263.8         28274.7  190823.9
Deg. of Freedom        3         2               6        12

Residual standard error: 126.1031
Estimated effects may be unbalanced
> summary(lm)
                  Df  Sum Sq Mean Sq F value   Pr(>F)
LANDUSE            3  967645  322548  20.284 5.43e-05 ***
RAINFALL           2 1551264  775632  48.776 1.73e-06 ***
LANDUSE:RAINFALL  6   28275    4712   0.296    0.927
Residuals         12  190824   15902
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
> anova(lm)
Analysis of Variance Table

Response: RUNOFF
                  Df  Sum Sq Mean Sq F value    Pr(>F)
LANDUSE            3  967645  322548 20.2835 5.428e-05 ***
RAINFALL           2 1551264  775632 48.7758 1.727e-06 ***
LANDUSE:RAINFALL  6   28275    4712  0.2963    0.9271
Residuals         12  190824   15902
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
> y=LSD.test(workie$RUNOFF, workie$LANDUSE, 12, 15902, group=TRUE )
> y
$statistics
  MSerror Df     Mean       CV  t.value      LSD
    15902 12 799.9412 15.76405 2.178813 158.6299

$parameters
        test p.ajusted         name.t ntr alpha
  Fisher-LSD      none workie$LANDUSE   40.05

$means
        workie$RUNOFF      std r      LCL       UCL     Min      Max      Q25      Q50
FALLOW1        868.4683  283.6966  6  756.3000   980.6366  553.974  1283.208  662.7495
817.118
MAN1       639.6567 334.3276 6 527.4884  751.8250 241.808 1086.104 399.7325  592.836
RANGE1      594.1483 241.1996 6 481.9800  706.3166 306.324  927.354 448.3735  527.685
TRACT1         1097.4917  321.9263  6  985.3234  1209.6600  626.872  1525.778  930.0210
1105.662
              Q75
FALLOW1 1050.3535
MAN1     889.9525
RANGE1   772.3505
TRACT1  1288.5420
```

```
$comparison
NULL

$groups
       workie$RUNOFF groups
TRACT1      1097.4917      a
FALLOW1      868.4683      b
MAN1         639.6567      c
RANGE1       594.1483      c

attr(,"class")
[1] "group"
```

APPENDIX B: WATER ERSOION PREDICTION PROJET (WEPP) MODEL OUTPUT FOR MONTHLY RUNOFF UNDER FALLOW LAND AND HISTORICAL CLIMATE

Monthly (Metric Units)
USDA WATER EROSION PREDICTION PROJECT

HILLSLOPE PROFILE AND WATERSHED MODEL
VERSION 2012.800
August 30, 2012
TO REPORT PROBLEMS OR TO BE PUT ON THE MAILING
LIST FOR FUTURE WEPP MODEL RELEASES, PLEASE CONTACT:
WEPP TECHNICAL SUPPORT
USDA-AGRICULTURAL RESEARCH SERVICE
NATIONAL SOIL EROSION RESEARCH LABORATORY
275 SOUTH RUSSELL STREET
WEST LAFAYETTE, IN 47907-2077 USA
PHONE: (765) 494-8673
FAX: (765) 494-5948
email: wepp@ecn.purdue.edu
URL: http://topsoil.nserl.purdue.edu

HILLSLOPE INPUT DATA FILES - VERSION 2012.800
August 30, 2012
MANAGEMENT: p0.man
MAN. PRACTICE: description 1
description 2
description 3
SLOPE: p0.slp
CLIMATE: p0.cli
Station: Man1En NGA CLIGEN VERSION 4.30
SOIL: p0.sol
PLANE 1 FALLOW1 CLAY LOAM

HILLSLOPE 1 MONTHLY SUMMARY jan 1

I. RAINFALL AND RUNOFF SUMMARY
-------- --- ------ -------
month and year: jan 1

Precipitation		Summer Runoff		Melt & Winter Runoff	
events	amount (mm)	events	amount (mm)	events	amount (mm)
0	0.00	0	0.00	0	0.00

II. ON SITE EFFECTS ON SITE EFFECTS ON SITE EFFECTS
--------------- --------------- ---------------
C. SOIL LOSS/DEPOSITION ALONG SLOPE PROFILE
Profile distances are from top to bottom of hillslope

distance (m)	soil loss (kg/m2)	flow elem	distance (m)	soil loss (kg/m2)	flow elem	distance (m)	soil loss (kg/m2)	flow elem
0.50	0.000	1	17.50	0.000	1	34.49	0.000	1
1.00	0.000	1	18.00	0.000	1	34.99	0.000	1
1.50	0.000	1	18.50	0.000	1	35.49	0.000	1
2.00	0.000	1	19.00	0.000	1	35.99	0.000	1
2.50	0.000	1	19.50	0.000	1	36.49	0.000	1
3.00	0.000	1	19.99	0.000	1	36.99	0.000	1
3.50	0.000	1	20.49	0.000	1	37.49	0.000	1
4.00	0.000	1	20.99	0.000	1	37.99	0.000	1
4.50	0.000	1	21.49	0.000	1	38.49	0.000	1
5.00	0.000	1	21.99	0.000	1	38.99	0.000	1
5.50	0.000	1	22.49	0.000	1	39.49	0.000	1
6.00	0.000	1	22.99	0.000	1	39.99	0.000	1
6.50	0.000	1	23.49	0.000	1	40.49	0.000	1
7.00	0.000	1	23.99	0.000	1	40.99	0.000	1
7.50	0.000	1	24.49	0.000	1	41.49	0.000	1
8.00	0.000	1	24.99	0.000	1	41.99	0.000	1
8.50	0.000	1	25.49	0.000	1	42.49	0.000	1
9.00	0.000	1	25.99	0.000	1	42.99	0.000	1
9.50	0.000	1	26.49	0.000	1	43.49	0.000	1
10.00	0.000	1	26.99	0.000	1	43.99	0.000	1
10.50	0.000	1	27.49	0.000	1	44.49	0.000	1
11.00	0.000	1	27.99	0.000	1	44.99	0.000	1
11.50	0.000	1	28.49	0.000	1	45.49	0.000	1
12.00	0.000	1	28.99	0.000	1	45.99	0.000	1
12.50	0.000	1	29.49	0.000	1	46.49	0.000	1
13.00	0.000	1	29.99	0.000	1	46.99	0.000	1
13.50	0.000	1	30.49	0.000	1	47.49	0.000	1
14.00	0.000	1	30.99	0.000	1	47.99	0.000	1
14.50	0.000	1	31.49	0.000	1	48.49	0.000	1
15.00	0.000	1	31.99	0.000	1	48.99	0.000	1
15.50	0.000	1	32.49	0.000	1	49.49	0.000	1
16.00	0.000	1	32.99	0.000	1	49.99	0.000	1
16.50	0.000	1	33.49	0.000	1			
17.00	0.000	1	33.99	0.000	1			

note: (+) soil loss - detachment (-) soil loss - deposition

III. OFF SITE EFFECTS OFF SITE EFFECTS OFF SITE EFFECTS

--------------- ---------------- ----------------

A. SEDIMENT LEAVING PROFILE for jan 1 0.000 kg/m

B. SEDIMENT CHARACTERISTICS AND ENRICHMENT

Sediment particle information leaving profile

Particle Composition Detached Fraction

Class	Diameter (mm)	Specific Gravity	% Sand	% Silt	% Clay	% O.M.	Sediment Fraction	In Flow Exiting
1	0.002	2.60	0.0	0.0	100.0	3.7	0.134	0.000
2	0.010	2.65	0.0	100.0	0.0	0.0	0.000	0.000
3	0.083	1.80	0.0	1.5	98.5	3.7	0.008	0.000
4	1.032	1.60	54.8	0.9	44.3	1.7	0.845	0.000
5	0.200	2.65	100.0	0.0	0.0	0.0	0.013	0.000

Weighted SSA enrichment ratio leaving profile for jan 1 = 0.00

HILLSLOPE 1 MONTHLY SUMMARY feb 1

I. RAINFALL AND RUNOFF SUMMARY

-------- --- ------ -------

month and year: feb 1

Precipitation events	Precipitation amount (mm)	Summer Runoff events	Summer Runoff amount (mm)	Melt & Winter Runoff events	Melt & Winter Runoff amount (mm)
2	27.20	2	14.52	0	0.00

II. ON SITE EFFECTS ON SITE EFFECTS ON SITE EFFECTS

--------------- --------------- ---------------

A. AREA OF NET SOIL LOSS

** Soil Loss (Avg. of Net Detachment Areas) = 0.090 kg/m2 **

** Maximum Soil Loss = 0.371 kg/m2 at 44.99 meters **

Area of Net Loss (m)	Soil Loss MEAN (kg/m2)	Soil Loss STDEV (kg/m2)	MAX Loss (kg/m2)	MAX Loss Point (m)	MIN Loss (kg/m2)	MIN Loss Point (m)
0.00- 49.99	0.090	0.123	0.371	44.99	0.000	0.50

C. SOIL LOSS/DEPOSITION ALONG SLOPE PROFILE

Profile distances are from top to bottom of hillslope

distance (m)	soil loss (kg/m2)	flow elem	distance (m)	soil loss (kg/m2)	flow elem	distance (m)	soil loss (kg/m2)	flow elem
0.50	0.000	1	17.50	0.000	1	34.49	0.168	1
1.00	0.000	1	18.00	0.000	1	34.99	0.179	1
1.50	0.000	1	18.50	0.000	1	35.49	0.189	1
2.00	0.000	1	19.00	0.000	1	35.99	0.199	1
2.50	0.000	1	19.50	0.000	1	36.49	0.209	1
3.00	0.000	1	19.99	0.000	1	36.99	0.220	1
3.50	0.000	1	20.49	0.000	1	37.49	0.230	1
4.00	0.000	1	20.99	0.000	1	37.99	0.240	1
4.50	0.000	1	21.49	0.000	1	38.49	0.249	1
5.00	0.000	1	21.99	0.000	1	38.99	0.259	1

5.50	0.000	1	22.49	0.000	1	39.49	0.269	1
6.00	0.000	1	22.99	0.000	1	39.99	0.279	1
6.50	0.000	1	23.49	0.000	1	40.49	0.288	1
7.00	0.000	1	23.99	0.000	1	40.99	0.298	1
7.50	0.000	1	24.49	0.000	1	41.49	0.307	1
8.00	0.000	1	24.99	0.000	1	41.99	0.317	1
8.50	0.000	1	25.49	0.000	1	42.49	0.326	1
9.00	0.000	1	25.99	0.000	1	42.99	0.335	1
9.50	0.000	1	26.49	0.000	1	43.49	0.344	1
10.00	0.000	1	26.99	0.003	1	43.99	0.353	1
10.50	0.000	1	27.49	0.013	1	44.49	0.362	1
11.00	0.000	1	27.99	0.025	1	44.99	0.371	1
11.50	0.000	1	28.49	0.036	1	45.49	0.358	1
12.00	0.000	1	28.99	0.048	1	45.99	0.323	1
12.50	0.000	1	29.49	0.059	1	46.49	0.286	1
13.00	0.000	1	29.99	0.070	1	46.99	0.248	1
13.50	0.000	1	30.49	0.082	1	47.49	0.208	1
14.00	0.000	1	30.99	0.093	1	47.99	0.167	1
14.50	0.000	1	31.49	0.104	1	48.49	0.125	1
15.00	0.000	1	31.99	0.115	1	48.99	0.081	1
15.50	0.000	1	32.49	0.126	1	49.49	0.035	1
16.00	0.000	1	32.99	0.136	1	49.99	0.002	1
16.50	0.000	1	33.49	0.147	1			
17.00	0.000	1	33.99	0.158	1			

note: (+) soil loss - detachment (-) soil loss - deposition

III. OFF SITE EFFECTS OFF SITE EFFECTS OFF SITE EFFECTS

---------------- ---------------- ----------------

A. SEDIMENT LEAVING PROFILE for feb 1 4.523 kg/m

B. SEDIMENT CHARACTERISTICS AND ENRICHMENT

Sediment particle information leaving profile

Class	Diameter (mm)	Specific Gravity	Particle Composition % Sand	% Silt	% Clay	% O.M.	Detached Fraction Sediment Fraction	In Flow Exiting
1	0.002	2.60	0.0	0.0	100.0	3.7	0.134	0.134
2	0.010	2.65	0.0	100.0	0.0	0.0	0.000	0.000
3	0.083	1.80	0.0	1.5	98.5	3.7	0.008	0.008
4	1.032	1.60	54.8	0.9	44.3	1.7	0.845	0.845
5	0.200	2.65	100.0	0.0	0.0	0.0	0.013	0.013

Weighted SSA enrichment ratio leaving profile for feb 1 = 1.00

HILLSLOPE 1 MONTHLY SUMMARY mar 1

I. RAINFALL AND RUNOFF SUMMARY

-------- --- ------ -------

month and year: mar 1

Precipitation		Summer Runoff		Melt & Winter Runoff	
events	amount (mm)	events	amount (mm)	events	amount (mm)
6	147.60	5	112.43	0	0.00

II. ON SITE EFFECTS ON SITE EFFECTS ON SITE EFFECTS

--------------- --------------- ---------------

A. AREA OF NET SOIL LOSS

** Soil Loss (Avg. of Net Detachment Areas) = 2.061 kg/m2 **

** Maximum Soil Loss = 4.201 kg/m2 at 44.99 meters **

Area of Net Loss (m)	Soil Loss MEAN (kg/m2)	Soil Loss STDEV (kg/m2)	MAX Loss (kg/m2)	MAX Loss Point (m)	MIN Loss (kg/m2)	MIN Loss Point (m)
0.00- 49.99	2.061	1.391	4.201	44.99	0.002	0.50

C. SOIL LOSS/DEPOSITION ALONG SLOPE PROFILE

Profile distances are from top to bottom of hillslope

distance (m)	soil loss (kg/m2)	flow elem	distance (m)	soil loss (kg/m2)	flow elem	distance (m)	soil loss (kg/m2)	flow elem
0.50	0.002	1	17.50	1.409	1	34.49	3.245	1
1.00	0.002	1	18.00	1.471	1	34.99	3.294	1
1.50	0.002	1	18.50	1.532	1	35.49	3.343	1
2.00	0.002	1	19.00	1.592	1	35.99	3.391	1
2.50	0.002	1	19.50	1.652	1	36.49	3.439	1
3.00	0.002	1	19.99	1.710	1	36.99	3.487	1
3.50	0.002	1	20.49	1.769	1	37.49	3.534	1
4.00	0.002	1	20.99	1.826	1	37.99	3.581	1
4.50	0.002	1	21.49	1.883	1	38.49	3.627	1
5.00	0.002	1	21.99	1.939	1	38.99	3.673	1
5.50	0.002	1	22.49	1.994	1	39.49	3.719	1
6.00	0.002	1	22.99	2.049	1	39.99	3.764	1
6.50	0.002	1	23.49	2.103	1	40.49	3.809	1
7.00	0.002	1	23.99	2.157	1	40.99	3.854	1
7.50	0.016	1	24.49	2.210	1	41.49	3.898	1
8.00	0.069	1	24.99	2.263	1	41.99	3.943	1
8.50	0.123	1	25.49	2.315	1	42.49	3.986	1
9.00	0.196	1	25.99	2.366	1	42.99	4.030	1
9.50	0.278	1	26.49	2.417	1	43.49	4.073	1
10.00	0.358	1	26.99	2.467	1	43.99	4.116	1
10.50	0.437	1	27.49	2.517	1	44.49	4.158	1

11.00	0.514	1	27.99	2.568	1	44.99	4.201	1
11.50	0.590	1	28.49	2.622	1	45.49	4.122	1
12.00	0.664	1	28.99	2.677	1	45.99	3.917	1
12.50	0.737	1	29.49	2.731	1	46.49	3.705	1
13.00	0.809	1	29.99	2.784	1	46.99	3.485	1
13.50	0.880	1	30.49	2.837	1	47.49	3.257	1
14.00	0.950	1	30.99	2.890	1	47.99	3.021	1
14.50	1.018	1	31.49	2.942	1	48.49	2.776	1
15.00	1.086	1	31.99	2.993	1	48.99	2.522	1
15.50	1.152	1	32.49	3.044	1	49.49	2.259	1
16.00	1.218	1	32.99	3.095	1	49.99	2.003	1
16.50	1.282	1	33.49	3.146	1			
17.00	1.346	1	33.99	3.195	1			

note: (+) soil loss - detachment (-) soil loss - deposition

III. OFF SITE EFFECTS OFF SITE EFFECTS OFF SITE EFFECTS

---------------- ---------------- ----------------

A. SEDIMENT LEAVING PROFILE for mar 1 103.042 kg/m

B. SEDIMENT CHARACTERISTICS AND ENRICHMENT

Sediment particle information leaving profile

Class	Diameter (mm)	Specific Gravity	Particle Composition % Sand	% Silt	% Clay	% O.M.	Detached Sediment Fraction	Fraction In Flow Exiting
1	0.002	2.60	0.0	0.0	100.0	3.7	0.134	0.134
2	0.010	2.65	0.0	100.0	0.0	0.0	0.000	0.000
3	0.083	1.80	0.0	1.5	98.5	3.7	0.008	0.008
4	1.032	1.60	54.8	0.9	44.3	1.7	0.845	0.845
5	0.200	2.65	100.0	0.0	0.0	0.0	0.013	0.013

Weighted SSA enrichment ratio leaving profile for mar 1 = 1.00

HILLSLOPE 1 MONTHLY SUMMARY apr 1

I. RAINFALL AND RUNOFF SUMMARY

-------- --- ------ -------

month and year: apr 1

Precipitation events	Precipitation amount (mm)	Summer Runoff events	Summer Runoff amount (mm)	Melt & Winter Runoff events	Melt & Winter Runoff amount (mm)
7	139.70	6	92.19	0	0.00

II. ON SITE EFFECTS ON SITE EFFECTS ON SITE EFFECTS

--------------- --------------- ---------------

A. AREA OF NET SOIL LOSS

** Soil Loss (Avg. of Net Detachment Areas) = 1.251 kg/m2 **

** Maximum Soil Loss = 3.147 kg/m2 at 44.99 meters **

Area of Net Loss (m)	Soil Loss MEAN (kg/m2)	Soil Loss STDEV (kg/m2)	MAX Loss (kg/m2)	MAX Loss Point (m)	MIN Loss (kg/m2)	MIN Loss Point (m)
0.00- 49.99	1.251	1.046	3.147	44.99	0.001	0.50

C. SOIL LOSS/DEPOSITION ALONG SLOPE PROFILE

Profile distances are from top to bottom of hillslope

distance (m)	soil loss (kg/m2)	flow elem	distance (m)	soil loss (kg/m2)	flow elem	distance (m)	soil loss (kg/m2)	flow elem
0.50	0.001	1	17.50	0.505	1	34.49	2.099	1
1.00	0.001	1	18.00	0.559	1	34.99	2.144	1
1.50	0.001	1	18.50	0.612	1	35.49	2.190	1
2.00	0.001	1	19.00	0.665	1	35.99	2.235	1
2.50	0.001	1	19.50	0.717	1	36.49	2.279	1
3.00	0.001	1	19.99	0.769	1	36.99	2.324	1
3.50	0.001	1	20.49	0.820	1	37.49	2.373	1
4.00	0.001	1	20.99	0.870	1	37.99	2.424	1
4.50	0.001	1	21.49	0.920	1	38.49	2.475	1
5.00	0.001	1	21.99	0.969	1	38.99	2.525	1
5.50	0.001	1	22.49	1.018	1	39.49	2.575	1
6.00	0.001	1	22.99	1.066	1	39.99	2.625	1
6.50	0.001	1	23.49	1.114	1	40.49	2.675	1
7.00	0.001	1	23.99	1.161	1	40.99	2.729	1
7.50	0.001	1	24.49	1.207	1	41.49	2.782	1
8.00	0.001	1	24.99	1.254	1	41.99	2.835	1
8.50	0.001	1	25.49	1.299	1	42.49	2.888	1
9.00	0.001	1	25.99	1.344	1	42.99	2.941	1
9.50	0.001	1	26.49	1.389	1	43.49	2.993	1
10.00	0.001	1	26.99	1.433	1	43.99	3.044	1
10.50	0.001	1	27.49	1.477	1	44.49	3.096	1
11.00	0.001	1	27.99	1.521	1	44.99	3.147	1
11.50	0.008	1	28.49	1.564	1	45.49	3.065	1
12.00	0.040	1	28.99	1.606	1	45.99	2.845	1
12.50	0.073	1	29.49	1.649	1	46.49	2.619	1
13.00	0.106	1	29.99	1.690	1	46.99	2.398	1
13.50	0.139	1	30.49	1.732	1	47.49	2.179	1
14.00	0.171	1	30.99	1.773	1	47.99	1.975	1
14.50	0.202	1	31.49	1.817	1	48.49	1.766	1
15.00	0.234	1	31.99	1.865	1	48.99	1.559	1
15.50	0.282	1	32.49	1.912	1	49.49	1.367	1
16.00	0.339	1	32.99	1.959	1	49.99	1.170	1

16.50 0.395 1 33.49 2.006 1
17.00 0.450 1 33.99 2.053 1
note: (+) soil loss - detachment (-) soil loss - deposition

III. OFF SITE EFFECTS OFF SITE EFFECTS OFF SITE EFFECTS
---------------- ---------------- ----------------
A. SEDIMENT LEAVING PROFILE for apr 1 62.545 kg/m

B. SEDIMENT CHARACTERISTICS AND ENRICHMENT
Sediment particle information leaving profile

Class	Diameter (mm)	Specific Gravity	Particle Composition % Sand	% Silt	% Clay	% O.M.	Detached Sediment Fraction	Fraction In Flow Exiting
1	0.002	2.60	0.0	0.0	100.0	3.7	0.134	0.134
2	0.010	2.65	0.0	100.0	0.0	0.0	0.000	0.000
3	0.083	1.80	0.0	1.5	98.5	3.7	0.008	0.008
4	1.032	1.60	54.8	0.9	44.3	1.7	0.845	0.845
5	0.200	2.65	100.0	0.0	0.0	0.0	0.013	0.013

Weighted SSA enrichment ratio leaving profile for apr 1 = 1.00

HILLSLOPE 1 MONTHLY SUMMARY may 1

I. RAINFALL AND RUNOFF SUMMARY
-------- --- ------ -------
month and year: may 1

Precipitation events	Precipitation amount (mm)	Summer Runoff events	Summer Runoff amount (mm)	Melt & Winter Runoff events	Melt & Winter Runoff amount (mm)
11	165.80	6	104.76	0	0.00

II. ON SITE EFFECTS ON SITE EFFECTS ON SITE EFFECTS
--------------- --------------- ---------------
A. AREA OF NET SOIL LOSS
** Soil Loss (Avg. of Net Detachment Areas) = 2.910 kg/m2 **
** Maximum Soil Loss = 7.028 kg/m2 at 44.99 meters **

Area of Net Loss (m)	Soil Loss MEAN (kg/m2)	Soil Loss STDEV (kg/m2)	MAX Loss (kg/m2)	MAX Loss Point (m)	MIN Loss (kg/m2)	MIN Loss Point (m)
0.00- 49.99	2.910	2.540	7.028	44.99	0.001	0.50

C. SOIL LOSS/DEPOSITION ALONG SLOPE PROFILE
Profile distances are from top to bottom of hillslope
distance soil flow distance soil flow distance soil flow
(m) loss elem (m) loss elem (m) loss elem

(kg/m2)				(kg/m2)				(kg/m2)	
0.50	0.001	1	17.50	0.935	1	34.49	5.579	1
1.00	0.001	1	18.00	1.086	1	34.99	5.692	1
1.50	0.001	1	18.50	1.235	1	35.49	5.799	1
2.00	0.001	1	19.00	1.380	1	35.99	5.901	1
2.50	0.001	1	19.50	1.522	1	36.49	5.998	1
3.00	0.001	1	19.99	1.660	1	36.99	6.089	1
3.50	0.001	1	20.49	1.794	1	37.49	6.176	1
4.00	0.001	1	20.99	1.925	1	37.99	6.259	1
4.50	0.001	1	21.49	2.052	1	38.49	6.337	1
5.00	0.001	1	21.99	2.174	1	38.99	6.411	1
5.50	0.001	1	22.49	2.293	1	39.49	6.480	1
6.00	0.001	1	22.99	2.408	1	39.99	6.546	1
6.50	0.001	1	23.49	2.519	1	40.49	6.608	1
7.00	0.001	1	23.99	2.626	1	40.99	6.667	1
7.50	0.001	1	24.49	2.730	1	41.49	6.722	1
8.00	0.001	1	24.99	2.830	1	41.99	6.774	1
8.50	0.001	1	25.49	2.926	1	42.49	6.823	1
9.00	0.001	1	25.99	3.019	1	42.99	6.869	1
9.50	0.009	1	26.49	3.109	1	43.49	6.912	1
10.00	0.029	1	26.99	3.226	1	43.99	6.953	1
10.50	0.050	1	27.49	3.415	1	44.49	6.992	1
11.00	0.087	1	27.99	3.605	1	44.99	7.028	1
11.50	0.126	1	28.49	3.789	1	45.49	6.682	1
12.00	0.165	1	28.99	3.969	1	45.99	5.965	1
12.50	0.203	1	29.49	4.144	1	46.49	5.267	1
13.00	0.241	1	29.99	4.313	1	46.99	4.588	1
13.50	0.278	1	30.49	4.477	1	47.49	3.931	1
14.00	0.321	1	30.99	4.635	1	47.99	3.301	1
14.50	0.386	1	31.49	4.787	1	48.49	2.705	1
15.00	0.454	1	31.99	4.933	1	48.99	2.173	1
15.50	0.521	1	32.49	5.074	1	49.49	1.796	1
16.00	0.587	1	32.99	5.209	1	49.99	1.491	1
16.50	0.654	1	33.49	5.338	1			
17.00	0.781	1	33.99	5.462	1			

note: (+) soil loss - detachment (-) soil loss - deposition

III. OFF SITE EFFECTS OFF SITE EFFECTS OFF SITE EFFECTS

A. SEDIMENT LEAVING PROFILE for may 1 145.474 kg/m

B. SEDIMENT CHARACTERISTICS AND ENRICHMENT

Sediment particle information leaving profile

Class	Diameter (mm)	Specific Gravity	Particle Composition % Sand	% Silt	% Clay	% O.M.	Detached Fraction Sediment Fraction	In Flow Exiting

1	0.002	2.60	0.0	0.0	100.0	3.7	0.134	0.134
2	0.010	2.65	0.0	100.0	0.0	0.0	0.000	0.000
3	0.083	1.80	0.0	1.5	98.5	3.7	0.008	0.008
4	1.032	1.60	54.8	0.9	44.3	1.7	0.845	0.845
5	0.200	2.65	100.0	0.0	0.0	0.0	0.013	0.013

Weighted SSA enrichment ratio leaving profile for may 1 = 1.00

HILLSLOPE 1 MONTHLY SUMMARY jun 1

I. RAINFALL AND RUNOFF SUMMARY

------ --- ------ -------

month and year: jun 1

Precipitation		Summer Runoff		Melt & Winter Runoff	
events	amount (mm)	events	amount (mm)	events	amount (mm)
17	232.30	12	148.61	0	0.00

II. ON SITE EFFECTS ON SITE EFFECTS ON SITE EFFECTS

--------------- --------------- ---------------

A. AREA OF NET SOIL LOSS

** Soil Loss (Avg. of Net Detachment Areas) = 13.807 kg/m2 **

** Maximum Soil Loss = 26.950 kg/m2 at 44.99 meters **

Area of Net Loss (m)	Soil Loss MEAN (kg/m2)	Soil Loss STDEV (kg/m2)	MAX Loss (kg/m2)	MAX Loss Point (m)	MIN Loss (kg/m2)	MIN Loss Point (m)
0.00- 49.99	13.807	9.928	26.950	44.99	0.002	0.50

C. SOIL LOSS/DEPOSITION ALONG SLOPE PROFILE

Profile distances are from top to bottom of hillslope

distance (m)	soil loss (kg/m2)	flow elem	distance (m)	soil loss (kg/m2)	flow elem	distance (m)	soil loss (kg/m2)	flow elem
0.50	0.002	1	17.50	9.899	1	34.49	24.239	1
1.00	0.002	1	18.00	10.480	1	34.99	24.463	1
1.50	0.002	1	18.50	11.157	1	35.49	24.675	1
2.00	0.002	1	19.00	11.813	1	35.99	24.876	1
2.50	0.002	1	19.50	12.445	1	36.49	25.065	1
3.00	0.002	1	19.99	13.052	1	36.99	25.244	1
3.50	0.002	1	20.49	13.635	1	37.49	25.413	1
4.00	0.002	1	20.99	14.193	1	37.99	25.571	1
4.50	0.002	1	21.49	14.728	1	38.49	25.720	1
5.00	0.002	1	21.99	15.239	1	38.99	25.860	1
5.50	0.002	1	22.49	15.727	1	39.49	25.991	1
6.00	0.002	1	22.99	16.192	1	39.99	26.114	1

6.50	0.002	1	23.49	16.635	1	40.49	26.228	1
7.00	0.002	1	23.99	17.057	1	40.99	26.335	1
7.50	0.138	1	24.49	17.457	1	41.49	26.435	1
8.00	0.582	1	24.99	17.838	1	41.99	26.527	1
8.50	1.024	1	25.49	18.199	1	42.49	26.613	1
9.00	1.451	1	25.99	18.541	1	42.99	26.692	1
9.50	1.860	1	26.49	18.865	1	43.49	26.765	1
10.00	2.253	1	26.99	19.204	1	43.99	26.832	1
10.50	2.628	1	27.49	19.619	1	44.49	26.894	1
11.00	2.987	1	27.99	20.053	1	44.99	26.950	1
11.50	3.353	1	28.49	20.469	1	45.49	25.292	1
12.00	3.896	1	28.99	20.868	1	45.99	21.943	1
12.50	4.462	1	29.49	21.251	1	46.49	18.628	1
13.00	5.007	1	29.99	21.617	1	46.99	15.355	1
13.50	5.530	1	30.49	21.967	1	47.49	12.133	1
14.00	6.031	1	30.99	22.302	1	47.99	8.977	1
14.50	6.511	1	31.49	22.621	1	48.49	5.906	1
15.00	6.987	1	31.99	22.925	1	48.99	2.951	1
15.50	7.588	1	32.49	23.215	1	49.49	0.857	1
16.00	8.200	1	32.99	23.491	1	49.99	0.035	1
16.50	8.789	1	33.49	23.754	1			
17.00	9.355	1	33.99	24.003	1			

note: (+) soil loss - detachment (-) soil loss - deposition

III. OFF SITE EFFECTS OFF SITE EFFECTS OFF SITE EFFECTS

---------------- ---------------- ----------------

A. SEDIMENT LEAVING PROFILE for jun 1 690.194 kg/m

B. SEDIMENT CHARACTERISTICS AND ENRICHMENT

Sediment particle information leaving profile

Class	Diameter (mm)	Specific Gravity	Particle Composition % Sand	% Silt	% Clay	% O.M.	Detached Sediment Fraction	Fraction In Flow Exiting
1	0.002	2.60	0.0	0.0	100.0	3.7	0.134	0.134
2	0.010	2.65	0.0	100.0	0.0	0.0	0.000	0.000
3	0.083	1.80	0.0	1.5	98.5	3.7	0.008	0.008
4	1.032	1.60	54.8	0.9	44.3	1.7	0.845	0.845
5	0.200	2.65	100.0	0.0	0.0	0.0	0.013	0.013

Weighted SSA enrichment ratio leaving profile for jun 1 = 1.00

HILLSLOPE 1 MONTHLY SUMMARY jul 1

I. RAINFALL AND RUNOFF SUMMARY

-------- --- ------ -------

month and year: jul 1

Precipitation		Summer Runoff		Melt & Winter Runoff	
events	amount (mm)	events	amount (mm)	events	amount (mm)
14	251.40	8	188.38	0	0.00

II. ON SITE EFFECTS ON SITE EFFECTS ON SITE EFFECTS
--------------- --------------- ---------------

A. AREA OF NET SOIL LOSS

** Soil Loss (Avg. of Net Detachment Areas) = 14.858 kg/m2 **

** Maximum Soil Loss = 28.380 kg/m2 at 44.99 meters **

Area of Net Loss (m)	Soil Loss MEAN (kg/m2)	Soil Loss STDEV (kg/m2)	MAX Loss (kg/m2)	MAX Loss Point (m)	MIN Loss (kg/m2)	MIN Loss Point (m)
0.00- 49.99	14.858	9.598	28.380	44.99	0.002	0.50

C. SOIL LOSS/DEPOSITION ALONG SLOPE PROFILE

Profile distances are from top to bottom of hillslope

distance (m)	soil loss (kg/m2)	flow elem	distance (m)	soil loss (kg/m2)	flow elem	distance (m)	soil loss (kg/m2)	flow elem
0.50	0.002	1	17.50	12.446	1	34.49	23.985	1
1.00	0.002	1	18.00	12.942	1	34.99	24.239	1
1.50	0.002	1	18.50	13.421	1	35.49	24.485	1
2.00	0.002	1	19.00	13.884	1	35.99	24.725	1
2.50	0.002	1	19.50	14.332	1	36.49	24.958	1
3.00	0.002	1	19.99	14.764	1	36.99	25.185	1
3.50	0.002	1	20.49	15.182	1	37.49	25.405	1
4.00	0.002	1	20.99	15.585	1	37.99	25.619	1
4.50	0.002	1	21.49	15.975	1	38.49	25.826	1
5.00	0.002	1	21.99	16.352	1	38.99	26.028	1
5.50	0.002	1	22.49	16.716	1	39.49	26.239	1
6.00	0.002	1	22.99	17.068	1	39.99	26.460	1
6.50	0.002	1	23.49	17.408	1	40.49	26.676	1
7.00	0.183	1	23.99	17.736	1	40.99	26.887	1
7.50	0.742	1	24.49	18.053	1	41.49	27.092	1
8.00	1.296	1	24.99	18.360	1	41.99	27.291	1
8.50	1.834	1	25.49	18.657	1	42.49	27.485	1
9.00	2.461	1	25.99	18.943	1	42.99	27.674	1
9.50	3.124	1	26.49	19.221	1	43.49	27.858	1
10.00	3.766	1	26.99	19.489	1	43.99	28.037	1
10.50	4.385	1	27.49	19.748	1	44.49	28.211	1
11.00	4.982	1	27.99	20.008	1	44.99	28.380	1
11.50	5.558	1	28.49	20.346	1	45.49	27.100	1
12.00	6.114	1	28.99	20.695	1	45.99	24.353	1
12.50	6.649	1	29.49	21.034	1	46.49	21.575	1

13.00	7.178	1	29.99	21.366	1	46.99	18.800	1
13.50	7.814	1	30.49	21.688	1	47.49	16.083	1
14.00	8.462	1	30.99	22.003	1	47.99	13.353	1
14.50	9.089	1	31.49	22.310	1	48.49	10.614	1
15.00	9.696	1	31.99	22.608	1	48.99	7.875	1
15.50	10.284	1	32.49	22.899	1	49.49	5.164	1
16.00	10.852	1	32.99	23.181	1	49.99	2.713	1
16.50	11.401	1	33.49	23.457	1			
17.00	11.933	1	33.99	23.725	1			

note: (+) soil loss - detachment (-) soil loss - deposition

III. OFF SITE EFFECTS OFF SITE EFFECTS OFF SITE EFFECTS

---------------- ---------------- ----------------

A. SEDIMENT LEAVING PROFILE for jul 1 742.715 kg/m

B. SEDIMENT CHARACTERISTICS AND ENRICHMENT

Sediment particle information leaving profile

Class	Diameter (mm)	Specific Gravity	Particle Composition % Sand	% Silt	% Clay	% O.M.	Detached Sediment Fraction	Fraction In Flow Exiting
1	0.002	2.60	0.0	0.0	100.0	3.7	0.134	0.134
2	0.010	2.65	0.0	100.0	0.0	0.0	0.000	0.000
3	0.083	1.80	0.0	1.5	98.5	3.7	0.008	0.008
4	1.032	1.60	54.8	0.9	44.3	1.7	0.845	0.845
5	0.200	2.65	100.0	0.0	0.0	0.0	0.013	0.013

Weighted SSA enrichment ratio leaving profile for jul 1 = 1.00

HILLSLOPE 1 MONTHLY SUMMARY aug 1

I. RAINFALL AND RUNOFF SUMMARY

-------- --- ------ -------

month and year: aug 1

Precipitation events	Precipitation amount (mm)	Summer Runoff events	Summer Runoff amount (mm)	Melt & Winter Runoff events	Melt & Winter Runoff amount (mm)
21	212.80	10	139.99	0	0.00

II. ON SITE EFFECTS ON SITE EFFECTS ON SITE EFFECTS

--------------- --------------- ---------------

A. AREA OF NET SOIL LOSS

** Soil Loss (Avg. of Net Detachment Areas) = 6.855 kg/m2 **

** Maximum Soil Loss = 16.347 kg/m2 at 44.99 meters **

Area of Net Loss (m) | Soil Loss MEAN (kg/m2) | Soil Loss STDEV (kg/m2) | MAX Loss (kg/m2) | MAX Loss Point (m) | MIN Loss (kg/m2) | MIN Loss Point (m)

0.00- 49.99 6.855 5.519 16.347 44.99 0.001 0.50

C. SOIL LOSS/DEPOSITION ALONG SLOPE PROFILE

Profile distances are from top to bottom of hillslope

distance (m)	soil loss (kg/m2)	flow elem	distance (m)	soil loss (kg/m2)	flow elem	distance (m)	soil loss (kg/m2)	flow elem
0.50	0.001	1	17.50	3.125	1	34.49	11.845	1
1.00	0.001	1	18.00	3.413	1	34.99	12.101	1
1.50	0.001	1	18.50	3.696	1	35.49	12.352	1
2.00	0.001	1	19.00	3.973	1	35.99	12.599	1
2.50	0.001	1	19.50	4.245	1	36.49	12.842	1
3.00	0.001	1	19.99	4.511	1	36.99	13.080	1
3.50	0.001	1	20.49	4.771	1	37.49	13.314	1
4.00	0.001	1	20.99	5.026	1	37.99	13.544	1
4.50	0.001	1	21.49	5.276	1	38.49	13.770	1
5.00	0.001	1	21.99	5.520	1	38.99	13.991	1
5.50	0.001	1	22.49	5.759	1	39.49	14.209	1
6.00	0.001	1	22.99	5.993	1	39.99	14.422	1
6.50	0.001	1	23.49	6.231	1	40.49	14.632	1
7.00	0.001	1	23.99	6.500	1	40.99	14.837	1
7.50	0.001	1	24.49	6.768	1	41.49	15.039	1
8.00	0.001	1	24.99	7.034	1	41.99	15.237	1
8.50	0.044	1	25.49	7.306	1	42.49	15.431	1
9.00	0.134	1	25.99	7.572	1	42.99	15.621	1
9.50	0.221	1	26.49	7.843	1	43.49	15.808	1
10.00	0.307	1	26.99	8.126	1	43.99	15.991	1
10.50	0.454	1	27.49	8.403	1	44.49	16.171	1
11.00	0.643	1	27.99	8.676	1	44.99	16.347	1
11.50	0.829	1	28.49	8.943	1	45.49	15.761	1
12.00	1.010	1	28.99	9.205	1	45.99	14.399	1
12.50	1.187	1	29.49	9.463	1	46.49	13.013	1
13.00	1.359	1	29.99	9.715	1	46.99	11.605	1
13.50	1.528	1	30.49	9.962	1	47.49	10.176	1
14.00	1.692	1	30.99	10.205	1	47.99	8.726	1
14.50	1.860	1	31.49	10.443	1	48.49	7.347	1
15.00	2.067	1	31.99	10.676	1	48.99	6.055	1
15.50	2.276	1	32.49	10.905	1	49.49	4.765	1
16.00	2.481	1	32.99	11.129	1	49.99	3.500	1
16.50	2.680	1	33.49	11.349	1			
17.00	2.876	1	33.99	11.585	1			

note: (+) soil loss - detachment (-) soil loss - deposition

III. OFF SITE EFFECTS OFF SITE EFFECTS OFF SITE EFFECTS

--------------- --------------- ---------------

A. SEDIMENT LEAVING PROFILE for aug 1 342.686 kg/m

B. SEDIMENT CHARACTERISTICS AND ENRICHMENT

Sediment particle information leaving profile

Class	Diameter (mm)	Specific Gravity	Particle Composition % Sand	% Silt	% Clay	% O.M.	Detached Sediment Fraction	Fraction In Flow Exiting
1	0.002	2.60	0.0	0.0	100.0	3.7	0.134	0.134
2	0.010	2.65	0.0	100.0	0.0	0.0	0.000	0.000
3	0.083	1.80	0.0	1.5	98.5	3.7	0.008	0.008
4	1.032	1.60	54.8	0.9	44.3	1.7	0.845	0.845
5	0.200	2.65	100.0	0.0	0.0	0.0	0.013	0.013

Weighted SSA enrichment ratio leaving profile for aug 1 = 1.00

HILLSLOPE 1 MONTHLY SUMMARY sep 1

I. RAINFALL AND RUNOFF SUMMARY

-------- --- ------ -------

month and year: sep 1

Precipitation events	Precipitation amount (mm)	Summer Runoff events	Summer Runoff amount (mm)	Melt & Winter Runoff events	Melt & Winter Runoff amount (mm)
19	349.90	14	244.14	0	0.00

II. ON SITE EFFECTS ON SITE EFFECTS ON SITE EFFECTS

--------------- --------------- ---------------

A. AREA OF NET SOIL LOSS

** Soil Loss (Avg. of Net Detachment Areas) = 9.491 kg/m2 **

** Maximum Soil Loss = 20.299 kg/m2 at 44.99 meters **

Area of Net Loss (m)	Soil Loss MEAN (kg/m2)	Soil Loss STDEV (kg/m2)	MAX Loss (kg/m2)	MAX Loss Point (m)	MIN Loss (kg/m2)	MIN Loss Point (m)
0.00- 49.99	9.491	6.881	20.299	44.99	0.003	0.50

C. SOIL LOSS/DEPOSITION ALONG SLOPE PROFILE

Profile distances are from top to bottom of hillslope

distance (m)	soil loss (kg/m2)	flow elem	distance (m)	soil loss (kg/m2)	flow elem	distance (m)	soil loss (kg/m2)	flow elem
0.50	0.003	1	17.50	6.029	1	34.49	15.669	1
1.00	0.003	1	18.00	6.361	1	34.99	15.921	1
1.50	0.003	1	18.50	6.688	1	35.49	16.169	1
2.00	0.003	1	19.00	7.008	1	35.99	16.414	1

2.50	0.003	1	19.50	7.323	1	36.49	16.656	1
3.00	0.003	1	19.99	7.631	1	36.99	16.894	1
3.50	0.003	1	20.49	7.934	1	37.49	17.130	1
4.00	0.003	1	20.99	8.232	1	37.99	17.362	1
4.50	0.003	1	21.49	8.525	1	38.49	17.590	1
5.00	0.003	1	21.99	8.812	1	38.99	17.816	1
5.50	0.003	1	22.49	9.095	1	39.49	18.039	1
6.00	0.003	1	22.99	9.378	1	39.99	18.258	1
6.50	0.003	1	23.49	9.674	1	40.49	18.475	1
7.00	0.003	1	23.99	9.966	1	40.99	18.689	1
7.50	0.003	1	24.49	10.254	1	41.49	18.900	1
8.00	0.003	1	24.99	10.537	1	41.99	19.108	1
8.50	0.003	1	25.49	10.816	1	42.49	19.313	1
9.00	0.004	1	25.99	11.090	1	42.99	19.516	1
9.50	0.130	1	26.49	11.360	1	43.49	19.716	1
10.00	0.417	1	26.99	11.626	1	43.99	19.913	1
10.50	0.772	1	27.49	11.888	1	44.49	20.107	1
11.00	1.147	1	27.99	12.149	1	44.99	20.299	1
11.50	1.516	1	28.49	12.435	1	45.49	19.751	1
12.00	1.915	1	28.99	12.724	1	45.99	18.443	1
12.50	2.326	1	29.49	13.008	1	46.49	17.100	1
13.00	2.730	1	29.99	13.288	1	46.99	15.722	1
13.50	3.126	1	30.49	13.565	1	47.49	14.311	1
14.00	3.514	1	30.99	13.837	1	47.99	12.865	1
14.50	3.895	1	31.49	14.106	1	48.49	11.390	1
15.00	4.268	1	31.99	14.370	1	48.99	9.910	1
15.50	4.634	1	32.49	14.632	1	49.49	8.412	1
16.00	4.993	1	32.99	14.892	1	49.99	6.988	1
16.50	5.345	1	33.49	15.155	1			
17.00	5.690	1	33.99	15.414	1			

note: (+) soil loss - detachment (-) soil loss - deposition

III. OFF SITE EFFECTS OFF SITE EFFECTS OFF SITE EFFECTS

---------------- ---------------- ----------------

A. SEDIMENT LEAVING PROFILE for sep 1 474.437 kg/m

B. SEDIMENT CHARACTERISTICS AND ENRICHMENT

Sediment particle information leaving profile

Class	Diameter (mm)	Specific Gravity	Particle Composition % Sand	% Silt	% Clay	% O.M.	Detached Sediment Fraction	Fraction In Flow Exiting
1	0.002	2.60	0.0	0.0	100.0	3.7	0.134	0.134
2	0.010	2.65	0.0	100.0	0.0	0.0	0.000	0.000
3	0.083	1.80	0.0	1.5	98.5	3.7	0.008	0.008
4	1.032	1.60	54.8	0.9	44.3	1.7	0.845	0.845
5	0.200	2.65	100.0	0.0	0.0	0.0	0.013	0.013

Weighted SSA enrichment ratio leaving profile for sep 1 = 1.00

HILLSLOPE 1 MONTHLY SUMMARY oct 1

I. RAINFALL AND RUNOFF SUMMARY
-------- --- ------ -------

month and year: oct 1

Precipitation events	Precipitation amount (mm)	Summer Runoff events	Summer Runoff amount (mm)	Melt & Winter Runoff events	Melt & Winter Runoff amount (mm)
15	194.90	11	125.60	0	0.00

II. ON SITE EFFECTS ON SITE EFFECTS ON SITE EFFECTS
-------------- -------------- --------------

A. AREA OF NET SOIL LOSS

** Soil Loss (Avg. of Net Detachment Areas) = 3.512 kg/m2 **
** Maximum Soil Loss = 8.396 kg/m2 at 44.99 meters **

Area of Net Loss (m)	Soil Loss MEAN (kg/m2)	Soil Loss STDEV (kg/m2)	MAX Loss (kg/m2)	MAX Loss Point (m)	MIN Loss (kg/m2)	MIN Loss Point (m)
0.00- 49.99	3.512	2.823	8.396	44.99	0.001	0.50

C. SOIL LOSS/DEPOSITION ALONG SLOPE PROFILE

Profile distances are from top to bottom of hillslope

distance (m)	soil loss (kg/m2)	flow elem	distance (m)	soil loss (kg/m2)	flow elem	distance (m)	soil loss (kg/m2)	flow elem
0.50	0.001	1	17.50	1.704	1	34.49	5.910	1
1.00	0.001	1	18.00	1.846	1	34.99	6.042	1
1.50	0.001	1	18.50	1.985	1	35.49	6.172	1
2.00	0.001	1	19.00	2.122	1	35.99	6.300	1
2.50	0.001	1	19.50	2.257	1	36.49	6.428	1
3.00	0.001	1	19.99	2.391	1	36.99	6.554	1
3.50	0.001	1	20.49	2.522	1	37.49	6.678	1
4.00	0.001	1	20.99	2.651	1	37.99	6.802	1
4.50	0.001	1	21.49	2.778	1	38.49	6.924	1
5.00	0.001	1	21.99	2.904	1	38.99	7.044	1
5.50	0.001	1	22.49	3.027	1	39.49	7.164	1
6.00	0.001	1	22.99	3.149	1	39.99	7.282	1
6.50	0.001	1	23.49	3.269	1	40.49	7.398	1
7.00	0.001	1	23.99	3.387	1	40.99	7.514	1
7.50	0.001	1	24.49	3.504	1	41.49	7.628	1
8.00	0.001	1	24.99	3.619	1	41.99	7.741	1
8.50	0.001	1	25.49	3.732	1	42.49	7.853	1

9.00	0.001	1	25.99	3.844	1	42.99	7.964	1
9.50	0.001	1	26.49	3.955	1	43.49	8.074	1
10.00	0.001	1	26.99	4.070	1	43.99	8.182	1
10.50	0.018	1	27.49	4.188	1	44.49	8.289	1
11.00	0.096	1	27.99	4.304	1	44.99	8.396	1
11.50	0.200	1	28.49	4.419	1	45.49	8.170	1
12.00	0.302	1	28.99	4.533	1	45.99	7.603	1
12.50	0.402	1	29.49	4.645	1	46.49	7.020	1
13.00	0.500	1	29.99	4.756	1	46.99	6.419	1
13.50	0.597	1	30.49	4.873	1	47.49	5.801	1
14.00	0.692	1	30.99	4.999	1	47.99	5.165	1
14.50	0.808	1	31.49	5.128	1	48.49	4.519	1
15.00	0.963	1	31.99	5.256	1	48.99	3.901	1
15.50	1.115	1	32.49	5.382	1	49.49	3.336	1
16.00	1.266	1	32.99	5.508	1	49.99	2.790	1
16.50	1.414	1	33.49	5.643	1			
17.00	1.560	1	33.99	5.777	1			

note: (+) soil loss - detachment (-) soil loss - deposition

III. OFF SITE EFFECTS OFF SITE EFFECTS OFF SITE EFFECTS

---------------- ---------------- ----------------

A. SEDIMENT LEAVING PROFILE for oct 1 175.532 kg/m

B. SEDIMENT CHARACTERISTICS AND ENRICHMENT

Sediment particle information leaving profile

Class	Diameter (mm)	Specific Gravity	Particle Composition % Sand	% Silt	% Clay	% O.M.	Detached Sediment Fraction	Fraction In Flow Exiting
1	0.002	2.60	0.0	0.0	100.0	3.7	0.134	0.134
2	0.010	2.65	0.0	100.0	0.0	0.0	0.000	0.000
3	0.083	1.80	0.0	1.5	98.5	3.7	0.008	0.008
4	1.032	1.60	54.8	0.9	44.3	1.7	0.845	0.845
5	0.200	2.65	100.0	0.0	0.0	0.0	0.013	0.013

Weighted SSA enrichment ratio leaving profile for oct 1 = 1.00

HILLSLOPE 1 MONTHLY SUMMARY nov 1

I. RAINFALL AND RUNOFF SUMMARY

-------- --- ------ -------

month and year: nov 1

Precipitation events	Precipitation amount (mm)	Summer Runoff events	Summer Runoff amount (mm)	Melt & Winter Runoff events	Melt & Winter Runoff amount (mm)
3	64.50	3	44.37	0	0.00

II. ON SITE EFFECTS ON SITE EFFECTS ON SITE EFFECTS

--------------- --------------- ---------------

A. AREA OF NET SOIL LOSS

** Soil Loss (Avg. of Net Detachment Areas) = 0.862 kg/m2 **

** Maximum Soil Loss = 1.971 kg/m2 at 44.99 meters **

Area of Net Loss (m)	Soil Loss MEAN (kg/m2)	Soil Loss STDEV (kg/m2)	MAX Loss (kg/m2)	MAX Loss Point (m)	MIN Loss (kg/m2)	MIN Loss Point (m)
0.00- 49.99	0.862	0.660	1.971	44.99	0.001	0.50

C. SOIL LOSS/DEPOSITION ALONG SLOPE PROFILE

Profile distances are from top to bottom of hillslope

distance (m)	soil loss (kg/m2)	flow elem	distance (m)	soil loss (kg/m2)	flow elem	distance (m)	soil loss (kg/m2)	flow elem
0.50	0.001	1	17.50	0.464	1	34.49	1.438	1
1.00	0.001	1	18.00	0.491	1	34.99	1.464	1
1.50	0.001	1	18.50	0.517	1	35.49	1.490	1
2.00	0.001	1	19.00	0.543	1	35.99	1.515	1
2.50	0.001	1	19.50	0.569	1	36.49	1.541	1
3.00	0.001	1	19.99	0.594	1	36.99	1.566	1
3.50	0.001	1	20.49	0.619	1	37.49	1.591	1
4.00	0.001	1	20.99	0.644	1	37.99	1.615	1
4.50	0.001	1	21.49	0.668	1	38.49	1.640	1
5.00	0.001	1	21.99	0.692	1	38.99	1.664	1
5.50	0.001	1	22.49	0.723	1	39.49	1.688	1
6.00	0.001	1	22.99	0.757	1	39.99	1.711	1
6.50	0.001	1	23.49	0.790	1	40.49	1.735	1
7.00	0.001	1	23.99	0.823	1	40.99	1.758	1
7.50	0.001	1	24.49	0.855	1	41.49	1.781	1
8.00	0.001	1	24.99	0.887	1	41.99	1.804	1
8.50	0.001	1	25.49	0.919	1	42.49	1.827	1
9.00	0.001	1	25.99	0.951	1	42.99	1.850	1
9.50	0.001	1	26.49	0.982	1	43.49	1.874	1
10.00	0.010	1	26.99	1.013	1	43.99	1.906	1
10.50	0.043	1	27.49	1.043	1	44.49	1.939	1
11.00	0.076	1	27.99	1.073	1	44.99	1.971	1
11.50	0.109	1	28.49	1.103	1	45.49	1.915	1
12.00	0.141	1	28.99	1.132	1	45.99	1.785	1
12.50	0.173	1	29.49	1.162	1	46.49	1.672	1
13.00	0.204	1	29.99	1.190	1	46.99	1.555	1
13.50	0.235	1	30.49	1.219	1	47.49	1.435	1
14.00	0.265	1	30.99	1.247	1	47.99	1.310	1
14.50	0.295	1	31.49	1.275	1	48.49	1.182	1
15.00	0.324	1	31.99	1.303	1	48.99	1.049	1

15.50	0.353	1	32.49	1.331	1	49.49	0.913	1
16.00	0.381	1	32.99	1.358	1	49.99	0.773	1
16.50	0.409	1	33.49	1.385	1			
17.00	0.437	1	33.99	1.411	1			

note: (+) soil loss - detachment (-) soil loss - deposition

III. OFF SITE EFFECTS OFF SITE EFFECTS OFF SITE EFFECTS
--------------- ---------------- ----------------

A. SEDIMENT LEAVING PROFILE for nov 1 43.066 kg/m

B. SEDIMENT CHARACTERISTICS AND ENRICHMENT

Sediment particle information leaving profile

Class	Diameter (mm)	Specific Gravity	Particle Composition % Sand	% Silt	% Clay	% O.M.	Detached Sediment Fraction	Fraction In Flow Exiting
1	0.002	2.60	0.0	0.0	100.0	3.7	0.134	0.134
2	0.010	2.65	0.0	100.0	0.0	0.0	0.000	0.000
3	0.083	1.80	0.0	1.5	98.5	3.7	0.008	0.008
4	1.032	1.60	54.8	0.9	44.3	1.7	0.845	0.845
5	0.200	2.65	100.0	0.0	0.0	0.0	0.013	0.013

Weighted SSA enrichment ratio leaving profile for nov 1 = 1.00

HILLSLOPE 1 MONTHLY SUMMARY dec 1

I. RAINFALL AND RUNOFF SUMMARY
-------- --- ------ -------

month and year: dec 1

Precipitation events	Precipitation amount (mm)	Summer Runoff events	Summer Runoff amount (mm)	Melt & Winter Runoff events	Melt & Winter Runoff amount (mm)
5	101.20	5	68.30	0	0.00

II. ON SITE EFFECTS ON SITE EFFECTS ON SITE EFFECTS
--------------- --------------- ---------------

A. AREA OF NET SOIL LOSS

** Soil Loss (Avg. of Net Detachment Areas) = 1.164 kg/m2 **

** Maximum Soil Loss = 3.013 kg/m2 at 44.99 meters **

Area of Net Loss (m)	Soil Loss MEAN (kg/m2)	Soil Loss STDEV (kg/m2)	MAX Loss (kg/m2)	MAX Loss Point (m)	MIN Loss (kg/m2)	MIN Loss Point (m)
0.00- 49.99	1.164	0.968	3.013	44.99	0.001	0.50

C. SOIL LOSS/DEPOSITION ALONG SLOPE PROFILE

Profile distances are from top to bottom of hillslope

distance (m)	soil loss (kg/m2)	flow elem	distance (m)	soil loss (kg/m2)	flow elem	distance (m)	soil loss (kg/m2)	flow elem
0.50	0.001	1	17.50	0.581	1	34.49	1.929	1
1.00	0.001	1	18.00	0.613	1	34.99	1.985	1
1.50	0.001	1	18.50	0.646	1	35.49	2.040	1
2.00	0.001	1	19.00	0.678	1	35.99	2.096	1
2.50	0.001	1	19.50	0.709	1	36.49	2.150	1
3.00	0.001	1	19.99	0.740	1	36.99	2.204	1
3.50	0.001	1	20.49	0.771	1	37.49	2.258	1
4.00	0.001	1	20.99	0.801	1	37.99	2.312	1
4.50	0.001	1	21.49	0.831	1	38.49	2.364	1
5.00	0.001	1	21.99	0.860	1	38.99	2.417	1
5.50	0.001	1	22.49	0.889	1	39.49	2.469	1
6.00	0.001	1	22.99	0.918	1	39.99	2.520	1
6.50	0.001	1	23.49	0.946	1	40.49	2.571	1
7.00	0.001	1	23.99	0.974	1	40.99	2.622	1
7.50	0.001	1	24.49	1.002	1	41.49	2.672	1
8.00	0.001	1	24.99	1.029	1	41.99	2.722	1
8.50	0.001	1	25.49	1.056	1	42.49	2.772	1
9.00	0.001	1	25.99	1.083	1	42.99	2.821	1
9.50	0.001	1	26.49	1.109	1	43.49	2.869	1
10.00	0.024	1	26.99	1.136	1	43.99	2.918	1
10.50	0.065	1	27.49	1.161	1	44.49	2.965	1
11.00	0.106	1	27.99	1.187	1	44.99	3.013	1
11.50	0.146	1	28.49	1.223	1	45.49	2.933	1
12.00	0.186	1	28.99	1.280	1	45.99	2.720	1
12.50	0.225	1	29.49	1.342	1	46.49	2.501	1
13.00	0.263	1	29.99	1.402	1	46.99	2.274	1
13.50	0.300	1	30.49	1.463	1	47.49	2.039	1
14.00	0.337	1	30.99	1.523	1	47.99	1.796	1
14.50	0.374	1	31.49	1.582	1	48.49	1.545	1
15.00	0.410	1	31.99	1.641	1	48.99	1.284	1
15.50	0.445	1	32.49	1.700	1	49.49	1.030	1
16.00	0.480	1	32.99	1.758	1	49.99	0.879	1
16.50	0.514	1	33.49	1.815	1			
17.00	0.547	1	33.99	1.872	1			

note: (+) soil loss - detachment (-) soil loss - deposition

III. OFF SITE EFFECTS OFF SITE EFFECTS OFF SITE EFFECTS

---------------- ---------------- ----------------

A. SEDIMENT LEAVING PROFILE for dec 1 58.209 kg/m

B. SEDIMENT CHARACTERISTICS AND ENRICHMENT

Sediment particle information leaving profile

Particle Composition Detached Fraction

Class	Diameter (mm)	Specific Gravity	% Sand	% Silt	% Clay	% O.M.	Sediment Fraction	In Flow Exiting
1	0.002	2.60	0.0	0.0	100.0	3.7	0.134	0.134
2	0.010	2.65	0.0	100.0	0.0	0.0	0.000	0.000
3	0.083	1.80	0.0	1.5	98.5	3.7	0.008	0.008
4	1.032	1.60	54.8	0.9	44.3	1.7	0.845	0.845
5	0.200	2.65	100.0	0.0	0.0	0.0	0.013	0.013

Weighted SSA enrichment ratio leaving profile for dec 1 = 1.00

HILLSLOPE 1 MONTHLY SUMMARY dec 1

I. RAINFALL AND RUNOFF SUMMARY

-------- --- ------ -------

month and year: dec 1

Precipitation events	Precipitation amount (mm)	Summer Runoff events	Summer Runoff amount (mm)	Melt & Winter Runoff events	Melt & Winter Runoff amount (mm)
0	0.00	0	0.00	0	0.00

II. ON SITE EFFECTS ON SITE EFFECTS ON SITE EFFECTS

--------------- --------------- ---------------

A. AREA OF NET SOIL LOSS

** Soil Loss (Avg. of Net Detachment Areas) = 56.863 kg/m2 **

** Maximum Soil Loss = 120.103 kg/m2 at 44.99 meters **

Area of Net Loss (m)	Soil Loss MEAN (kg/m2)	Soil Loss STDEV (kg/m2)	MAX Loss (kg/m2)	MAX Loss Point (m)	MIN Loss (kg/m2)	MIN Loss Point (m)
0.00- 49.99	56.863	40.817	120.103	44.99	0.015	0.50

C. SOIL LOSS/DEPOSITION ALONG SLOPE PROFILE

Profile distances are from top to bottom of hillslope

distance (m)	soil loss (kg/m2)	flow elem	distance (m)	soil loss (kg/m2)	flow elem	distance (m)	soil loss (kg/m2)	flow elem
0.50	0.015	1	17.50	37.096	1	34.49	96.106	1
1.00	0.015	1	18.00	39.262	1	34.99	97.523	1
1.50	0.015	1	18.50	41.489	1	35.49	98.904	1
2.00	0.015	1	19.00	43.659	1	35.99	100.251	1
2.50	0.015	1	19.50	45.770	1	36.49	101.565	1
3.00	0.015	1	19.99	47.822	1	36.99	102.846	1
3.50	0.015	1	20.49	49.817	1	37.49	104.101	1
4.00	0.015	1	20.99	51.754	1	37.99	105.327	1
4.50	0.015	1	21.49	53.635	1	38.49	106.522	1

5.00	0.015	1	21.99	55.462	1	38.99	107.689	1
5.50	0.015	1	22.49	57.241	1	39.49	108.841	1
6.00	0.015	1	22.99	58.977	1	39.99	109.982	1
6.50	0.015	1	23.49	60.689	1	40.49	111.097	1
7.00	0.196	1	23.99	62.388	1	40.99	112.190	1
7.50	0.906	1	24.49	64.042	1	41.49	113.257	1
8.00	1.957	1	24.99	65.651	1	41.99	114.299	1
8.50	3.034	1	25.49	67.225	1	42.49	115.317	1
9.00	4.250	1	25.99	68.755	1	42.99	116.312	1
9.50	5.627	1	26.49	70.250	1	43.49	117.285	1
10.00	7.166	1	26.99	71.792	1	43.99	118.245	1
10.50	8.853	1	27.49	73.474	1	44.49	119.184	1
11.00	10.640	1	27.99	75.169	1	44.99	120.103	1
11.50	12.435	1	28.49	76.951	1	45.49	115.148	1
12.00	14.433	1	28.99	78.737	1	45.99	104.296	1
12.50	16.438	1	29.49	80.486	1	46.49	93.384	1
13.00	18.398	1	29.99	82.193	1	46.99	82.448	1
13.50	20.427	1	30.49	83.865	1	47.49	71.552	1
14.00	22.435	1	30.99	85.506	1	47.99	60.657	1
14.50	24.439	1	31.49	87.114	1	48.49	49.875	1
15.00	26.488	1	31.99	88.686	1	48.99	39.360	1
15.50	28.650	1	32.49	90.219	1	49.49	29.935	1
16.00	30.795	1	32.99	91.718	1	49.99	22.342	1
16.50	32.884	1	33.49	93.193	1			
17.00	34.976	1	33.99	94.654	1			

note: (+) soil loss - detachment (-) soil loss - deposition

III. OFF SITE EFFECTS OFF SITE EFFECTS OFF SITE EFFECTS

---------------- ---------------- ----------------

A. SEDIMENT LEAVING PROFILE for dec 1 58.209 kg/m

B. SEDIMENT CHARACTERISTICS AND ENRICHMENT

Sediment particle information leaving profile

Class	Diameter (mm)	Specific Gravity	Particle Composition % Sand	% Silt	% Clay	% O.M.	Detached Sediment Fraction	Fraction In Flow Exiting
1	0.002	2.60	0.0	0.0	100.0	3.7	0.134	0.134
2	0.010	2.65	0.0	100.0	0.0	0.0	0.000	0.000
3	0.083	1.80	0.0	1.5	98.5	3.7	0.008	0.008
4	1.032	1.60	54.8	0.9	44.3	1.7	0.845	0.845
5	0.200	2.65	100.0	0.0	0.0	0.0	0.013	0.013

Weighted SSA enrichment ratio leaving profile for dec 1 = 1.00

ANNUAL AVERAGE SUMMARIES

I. RAINFALL AND RUNOFF SUMMARY
-------- --- ------ -------
total summary: years 1 - 1
120 storms produced 1887.30 mm of precipitation
82 rain storm runoff events produced 1283.29 mm of runoff
0 snow melts and/or
events during winter produced 0.00 mm of runoff
annual averages

Number of years 1
Mean annual precipitation 1887.30 mm
Mean annual runoff from rainfall 1283.29 mm
Mean annual runoff from snow melt
and/or rain storm during winter 0.00 mm

II. ON SITE EFFECTS ON SITE EFFECTS ON SITE EFFECTS
--------------- --------------- ---------------
A. AREA OF NET SOIL LOSS
** Soil Loss (Avg. of Net Detachment Areas) = 56.863 kg/m2 **
** Maximum Soil Loss = 120.103 kg/m2 at 44.99 meters **

Area of Net Loss (m)	Soil Loss MEAN (kg/m2)	Soil Loss STDEV (kg/m2)	MAX Loss (kg/m2)	MAX Loss Point (m)	MIN Loss (kg/m2)	MIN Loss Point (m)
0.00- 49.99	56.863	40.817	120.103	44.99	0.015	0.50

C. SOIL LOSS/DEPOSITION ALONG SLOPE PROFILE
Profile distances are from top to bottom of hillslope

distance (m)	soil loss (kg/m2)	flow elem	distance (m)	soil loss (kg/m2)	flow elem	distance (m)	soil loss (kg/m2)	flow elem
0.50	0.015	1	17.50	37.096	1	34.49	96.106	1
1.00	0.015	1	18.00	39.262	1	34.99	97.523	1
1.50	0.015	1	18.50	41.489	1	35.49	98.904	1
2.00	0.015	1	19.00	43.659	1	35.99	100.251	1
2.50	0.015	1	19.50	45.770	1	36.49	101.565	1
3.00	0.015	1	19.99	47.822	1	36.99	102.846	1
3.50	0.015	1	20.49	49.817	1	37.49	104.101	1
4.00	0.015	1	20.99	51.754	1	37.99	105.327	1
4.50	0.015	1	21.49	53.635	1	38.49	106.522	1
5.00	0.015	1	21.99	55.462	1	38.99	107.689	1
5.50	0.015	1	22.49	57.241	1	39.49	108.841	1
6.00	0.015	1	22.99	58.977	1	39.99	109.982	1
6.50	0.015	1	23.49	60.689	1	40.49	111.097	1
7.00	0.196	1	23.99	62.388	1	40.99	112.190	1
7.50	0.906	1	24.49	64.042	1	41.49	113.257	1

8.00	1.957	1	24.99	65.651	1	41.99	114.299	1
8.50	3.034	1	25.49	67.225	1	42.49	115.317	1
9.00	4.250	1	25.99	68.755	1	42.99	116.312	1
9.50	5.627	1	26.49	70.250	1	43.49	117.285	1
10.00	7.166	1	26.99	71.792	1	43.99	118.245	1
10.50	8.853	1	27.49	73.474	1	44.49	119.184	1
11.00	10.640	1	27.99	75.169	1	44.99	120.103	1
11.50	12.435	1	28.49	76.951	1	45.49	115.148	1
12.00	14.433	1	28.99	78.737	1	45.99	104.296	1
12.50	16.438	1	29.49	80.486	1	46.49	93.384	1
13.00	18.398	1	29.99	82.193	1	46.99	82.448	1
13.50	20.427	1	30.49	83.865	1	47.49	71.552	1
14.00	22.435	1	30.99	85.506	1	47.99	60.657	1
14.50	24.439	1	31.49	87.114	1	48.49	49.875	1
15.00	26.488	1	31.99	88.686	1	48.99	39.360	1
15.50	28.650	1	32.49	90.219	1	49.49	29.935	1
16.00	30.795	1	32.99	91.718	1	49.99	22.342	1
16.50	32.884	1	33.49	93.193	1			
17.00	34.976	1	33.99	94.654	1			

note: (+) soil loss - detachment (-) soil loss - deposition

III. OFF SITE EFFECTS OFF SITE EFFECTS OFF SITE EFFECTS

---------------- ---------------- ----------------

A. AVERAGE ANNUAL SEDIMENT LEAVING PROFILE

2842.423 kg/m of width

7921.834 kg (based on profile width of 2.787 m)

568.630 t/ha (assuming contributions from 0.014 ha)

B. SEDIMENT CHARACTERISTICS AND ENRICHMENT

Sediment particle information leaving profile

Class	Diameter (mm)	Specific Gravity	Particle Composition % Sand	% Silt	% Clay	% O.M.	Detached Sediment Fraction	Fraction In Flow Exiting
1	0.002	2.60	0.0	0.0	100.0	3.7	0.134	0.134
2	0.010	2.65	0.0	100.0	0.0	0.0	0.000	0.000
3	0.083	1.80	0.0	1.5	98.5	3.7	0.008	0.008
4	1.032	1.60	54.8	0.9	44.3	1.7	0.845	0.845
5	0.200	2.65	100.0	0.0	0.0	0.0	0.013	0.013

Average annual SSA enrichment ratio leaving profile = 1.00

APPENDIX C: CONFERENCE PAPER PRESENTED AT LAPAI

EFFECT OF LAND USE TYPES ON SELECTED PROPERTIES OF AN ULTISOL IN NSUKKA, NIGERIA.

Iboko, M.P.[1], Osunde, A.O.[2], Odofin, A.J.[2], Ibrahim, S.U.[1]
[1]West African Science Service Centre on Climate Change and Adapted Landuse; Federal University of Technology, Minna Nigeria
[2]Department of Soil and Land Management; Federal University of Technology, Minna Nigeria
Corresponding author e-mail address: Ibokopaul@gmail.com

Abstract

Inadequate consideration to the capacity of land to carry out specific production or provide a particular service sustainably before subjecting it to such use has resulted in preventable losses in its productivity. This study evaluated the effects of land uses and depths on the chemical and physical properties of Ultisol in Nsukka, Nigeria. Four soil land uses: range, fallow, manually cultivated land and tractorized cultivation were investigated. Soil samples were collected at the depths of 0-20, 20-40 and 40-60cm. The results showed that organic carbon (OC), phosphorus (P), Cation Exchange Capacity, pH (KCl), bulk density (BD) and exchangeable cations varied significantly across land uses while variations for particle sizes, % sTable aggregates (SA), porosity, hydraulic conductivity (Ks), silt, clay, total sand, erosivity index and exchangeable acidity varied uniformly with no significance across the land uses. The Erosivity index (Ei), % SA, TS, clay, Ks, bd, CEC, Mg^{2+} and 2-1mm particles varied significantly across the depths. The trends of SA, K^{+}, Na^{+}, clay, silt and 2-1mm with respect to depths followed as 0-20cm<20-40cm<40-60cm. while the variation of Ca^{2+}, P, pH, OC, Ei, TS, Ks and BD with depth followed as 0-20 cm>20-40 cm>40-60 cm. The finding of this research buttresses the need for proper evaluation of the capacity of soil before it is considered for a particular purpose, proper management and the need to reduce the use of heavy machinery in the soil so as to ensure sustainable production. There is also the need to always ensure that residues and vegetation are left on the soil as it improves soil quality and productivity.

Key words: Land use, soil properties, Ultisol, soil degradation

INTRODUCTION

Soil is considered an essential factor for agricultural production (Khanif, 2010). But consistent increase in human population and the consequent need to produce food sufficient enough to feed the population has put it under immense pressure. Soil, a fixed resource has been put into different uses in order to maximize its resources for man's needs. Some of these uses have been taken without due consideration to the capacity of the land to sustainably carryout such responsibilities. These inter conversions of land from one use to another have effects on both the chemical and physical properties of the soil. It has led to decline in the soil fertility, changes in the microbial population, soil properties and most importantly, the overall productivity of the soil. This fact has been aptly capture by Ezeaku *et al.* (2012) who observed that noticeable changes have been recorded in the three facets of soil properties (chemical, physical and biological) as a result of changes from one land use to another. Some of these changes are easily observable on the dynamic soil quality indicators (Sanchez-Maranon *et al.,* 2002) and may not be easily reversed or in cases where reversal is possible, it is usually at a very huge cost.

The United Nations survey of 1990 warned that more than 25% of the world's arable lands are threatened by land degradation, restricting in large proportion agricultural productivity of such lands. With about 15.6% of these lands strongly degraded that their original biotic function such as nutrient cycling, can no longer be performed optimally, leading to about 17% loss in its productivity (UN, 1990 cited by Senjobi and Ogunkunle, 2011). Agricultural intensification and rapid population growth have been identified as the major factors responsible for this degradation process (Senjobi and Ogunkunle, 2011). In Africa alone, more than 494 million hectares of lands have been degraded as a result of anthropogenic activities with only about 22 % of the total land area still producing biomass optimally (global assessment of soil degradation (GLASOD), 1998). Furthermore, in Nigeria, noticeable evidences of soil degradation abound in every part, although the types, severity, duration and the social economic impacts of this degradation vary from place to place (Aruleba, 2004; Senjobi, 2007). It is therefore pertinent to assess the level of degradation resulting from the different uses to which soil is put so as to suggest better management options and prevent further degradation.

Materials and method

Description of the study area

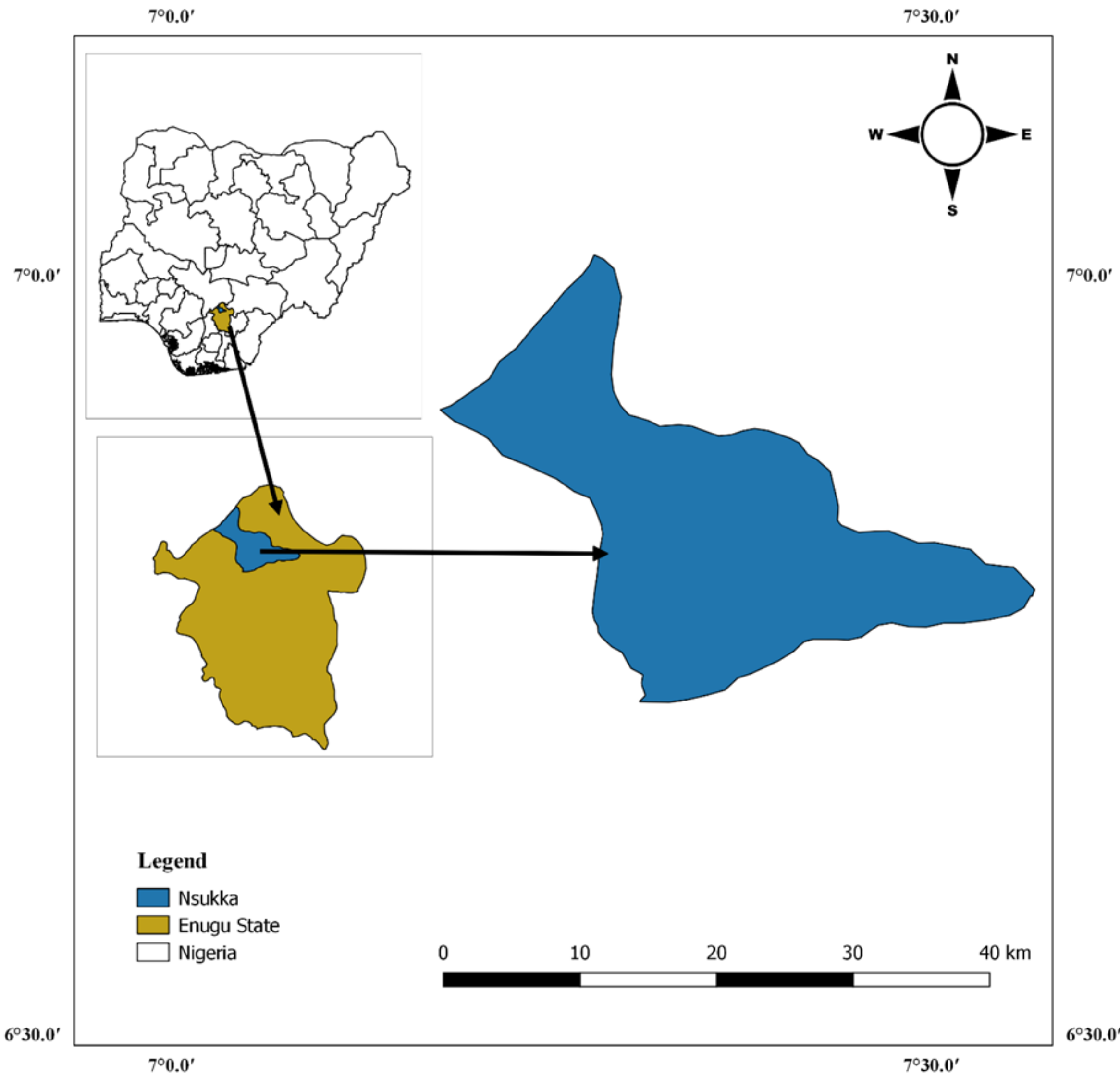


Figure 1.0: Study area map retrieved from OSM shape file

Treatments and experimental design

Four land management practices were selected which constituted the treatments for this study. The land management practices were at least 100 m away from each other. The four treatments were manually cultivated land, tractorized land, fallow and range land. The manually cultivated land had been under manual cultivation for more than 20 years. The land owner believes no other type of equipment has been used on this land apart from hoe. Different crops such as cassava, maize, cocoa yam and yam are usually grown on it but at the time of sample collection, it was planted to scent leaf and *Amaranthus spp.* The tractorized land had been under this form of cultivation for the past 30 years with maize, garden eggs, cucumber and pepper being the major crops usually cultivated on it. As at the time of sampling, the area was already covered by grasses as the crops previously planted had been harvested and the next planting season was being awaited. The fallow land has been under the current fallow since 2012. The land is usually cultivated with tractor once in a while after which it is allowed to recover before the next crop is grown. The major crops usually grown on it are cassava, maize and garden egg. Similarly, the land under range has never been cultivated for the past 40 years. It has been under range with cattle, sheep and goat often grazed on it from time to time and area is dominated by carpet grass.

The experimental design was 4x3 factorial in randomized complete block design with two replications. There were two factors for the experiment. The four land use or management types constituted one factor while the three soil depths were the second factor.

Collection of soil data

Soil samples were collected within the study area at identified locations where land was subjected to the land uses or practices under investigation. For each soil management practice, two sites were sampled to give two replicates. Both core and auger soil samples were collected from each of the three different depths: 0-20 cm, 20-40 cm and 40-60 cm. The auger soil samples were air-dried for one week in preparation for laboratory analysis. The core samples were trimmed in readiness for laboratory analyses.

Determination of soil physical properties

Erodibility Index

The erodibility index was calculated as $\frac{\text{sand+silt}}{\text{clay}}$, a method described by Hudson and Vooorees (1995).

Bulk density

Bulk density was determined according to Blake and Hartge (1986) method.

Total porosity

Total porosity was determined as a function of bulk and particle density using the following equation:

$$ƒ = 1 - \frac{\text{Bd}}{\text{Pd}} x100$$

where ƒ is the total porosity, Bd is bulk density in gcm^{-3}, Pd is particle density assumed as 2.65 gcm^{-3}

Particle size analysis

The method described by Gee and Bauder (1986) was used to determined particle size.

Aggregate analysis

The aggregate size distribution was measured by wet-sieving method as described by Kemper (1965) and the percentage stable aggregate (%SA) calculated thus:

$$\frac{(\text{weight of retained}) - (\text{weight of sand})}{(\text{total sample weight}) - (\text{weight of sand})} * 100$$

Determination of soil chemical properties

Available phosphorus

Available phosphorus was determined colorimetrically using Bray P-2 method of extraction as described by Olson and Sommers (1982).

Soil organic carbon

Soil organic carbon was determined by Walkley and Black method (1934) as modified by Allison (1965).

Exchangeable cations (Ca^{2+}, Mg^{2+}, K^{+}, Na^{+})

These cations were extracted using 1 N NH_4OAc buffered at pH 7 while EA and CEC were determined titrimetrically with 0.05 N NaOH and 0.01 N NaOH (Chapman, 196) respectively. K^+ and Na^+ were determined using flame photometer.

Hydraulic conductivity (Ksat)

Ksat was determined based on Klute and Dirksen (1986) method. The calculation was done using the transposed Darcy's equation for vertical flow:

$$K = \frac{Q}{A(\Delta H/L)}$$

where Q is the flow rate (cm^3/sec) through a cross sectional area A, ΔH the hydraulic head difference across a length L of porous medium.

pH

The pH of the soil samples was determined with pH meter using 1:2 KCl suspension of soil sample (McLean, 1982).

Statistical analysis

Analysis of variance (ANOVA) for a randomized complete block design (RCBD) was done with R-software version 3.2.3 (R Core Team, 2015) and the result used to compare the influence of land management practices and depths on soil properties. Where the F test is significant Turkey Honest Significance Difference (Turkey-HSD) was used to separate the means.

Results and discussion

The result of the effects of land use on soil chemical properties is shown in Table 1. From the Table, the soil organic carbon ranged from 7.8 to 13.8 gkg^{-1}. The values for the organic carbon varied according to the land uses. The range land had the highest amount of organic carbon while the fallow land had the lowest amount of organic carbon. The result showed a significant difference in the amount of organic carbon among the various land uses. The high organic carbon observed in range land could be as a result of the ability of the soil to sequester carbon as plants and grasses on the soil die and decompose into the soil thereby enriching the soil with high amount of organic matter. The high carbon could also be as a result of non-utilization of the organic matter that fall on the soil by crops since the area is not usually cultivated. Liu *et al* (2015) have similarly reported that land use is an important factor influencing soil organic carbon distribution. Similarly, the soil organic carbon also varied in accordance with the soil depths. However, this variation was not significant. The 0-20 cm depth recorded the highest amount of soil organic carbon while 40-60cm depth had the lowest amount of organic carbon. This decrease in organic carbon with depth could be attributed to the reduction in the biological activities in the soil especially the plants roots as the depth increases. Plants die and decay and mainly remain at the topmost part of the soil. Similar finding has been made by Assefa *et al.* (2017). The result is in total agreement with the finding of Tesfaye *et al* (2016) who showed that soil carbon distribution decreases with depth. It however differs with the finding of Ezeaku (2015) who reported an increase in soil organic carbon with depth.

The soil pH varied significantly across the different land uses (Table 1). The tractorized land was with the highest level of acidity while manually cultivated soil had the lowest level of acidity. This low alkalinity observed for tractorized land may be due to the heavy use of the area for crop production which may have resulted in the extraction of the exchangeable bases by the plants. The values for the pH were largely consistent with the values recorded for the Exchangeable Acidity (EA). The values for both pH and EA varied non-significantly across the different depths. But the CEC varied significantly across the different land uses and soil depths. The range land had the highest amount of CEC while the manually cultivated recorded the lowest amount of CEC. The high CEC also observed in fallow and range land could be connected to the high buffering capacity resulting from the effect of organic matter accumulated from the leaf fall and decay on the soil. Although the low CEC obtained in tropical soils have been attributed to the low activity clay mineral generally found in tropical soils (Sparks, 2002), the low CEC could be ameliorated or remedied through the application of organic matter. Similar finding has also been made by Nduwumuremyi *et al.* (2013).

The result of available phosphorus is shown in Table 1. From the result, there was a significant variation in available phosphorus for the different land uses. This finding differs from the finding of Ogeh and Ogwurike (2006) who found a non-significant difference in P value for different land uses but agreed with the work of Nduwumuremyi *et al.* (2013) who found a significant difference in P value for land under different uses. The tractorized land recorded the highest amount of available phosphorus while the range land had the lowest level of available phosphorus. This could be as a result of the superphosphate fertilizer constantly used in the production of garden egg and maize in the area. The manually cultivated land similarly recorded high value for the available phosphorus but low value for fallow land. This is in contrast with the finding of Ezeaku *et al.* (2015) who reported a decrease in the amount of available phosphorus due to conversion from fallow to cultivated land. But agreed with Nduwumuremyi *et al.* (2013) who observed that increase in the amount of available P under farm or cultivated lands is due to the application of P fertilizer. The result (Table 1) also showed a decreasing trend in the available phosphorus as the depth increases although this variation was not significant.

The result for the exchangeable cations (Table 1) showed a significant variation in the exchangeable cations across the land uses. Land under tractorized cultivation recorded the lowest values for magnesium and potassium. This low values for these elements is perhaps due to their high demands by plants, as they are necessary for optimum performance of crops and are hence mined by the crops. The highest value for potassium and sodium were recorded by fallow land while the highest value for magnesium was recorded by manually cultivated land. The values for the exchangeable cations all decreased with depth except for potassium which increased with depth. The increase in potassium with depth could be due to its high solubility which causes it to be easily leached into the sub-horizon. Similar results were obtained by Duguma and Hager (2010) who reported that exchangeable cations decreased with depths in all land uses except for Ca^{2+}. However, their finding on Ca^{2+} and K^{+} differs from this result.

Table 1.0: variation of soil chemical properties due to land use

	OC	pH	P	Ca^{2+}	CEC	Na^{+}	Mg^{2+}	K^{+}	EA
	(gkg^{-1})	KCL	($mgkg^{-1}$)			($cmolkg^{-1}$)			
Land use(Lu)									
MC	10.6^{ab}	5.33^{a}	11.04^{b}	2.77^{a}	17.47^{b}	0.16^{c}	1.47^{a}	1.60^{bc}	14.20^{a}
TR	9.2^{ab}	3.65^{c}	20.21^{a}	1.17^{bc}	20.67^{b}	0.28^{bc}	0.60^{b}	1.40^{c}	24.60^{a}
FL	7.8^{b}	3.78^{b}	8.08^{b}	1.23^{b}	27.73^{a}	0.50^{a}	0.87^{b}	2.54^{a}	31.47^{a}
RG	13.8^{a}	3.73^{bc}	6.68^{b}	0.73^{c}	32.53^{a}	0.42^{ab}	0.90^{b}	2.13^{ab}	18.47^{a}
S.E.	4.5	0.09	5.92	0.39	4.07	0.11	0.43	0.48	12.21
Depths(D)									
0-20 cm	11.7^{a}	4.18^{a}	15.39^{a}	1.60^{a}	21.4^{b}	0.31^{a}	0.80^{b}	1.78^{a}	20.63^{a}
20-40 cm	10.3^{a}	4.11^{a}	10.84^{a}	1.50^{a}	26.4^{a}	0.33^{a}	0.68^{c}	1.89^{a}	24.50^{a}
40-60 cm	9.0^{a}	4.09^{a}	8.28^{a}	1.33^{a}	26.0^{a}	0.37^{a}	1.40^{a}	2.09^{a}	21.43^{a}
S.E.	5.0	0.76	7.87	0.90	7.56	0.17	0.55	0.74	12.50
Interaction									
Lu x D		*							

LU=land use, DP=depth, OC=organic carbon, CEC=cation exchange capacity, P=phosphorus, Ca=Calcium, Na=Sodium, Mg=Magnesium, K=Potassium, EA= Exchangeable Acidity. Means having different letters in the same column are significantly different while those with the same letters are not* significant at $p \leq 0.05$.

Interaction effect of land use types and depth on soil pH

The interaction effect showed that soil pH in KCl were generally higher and significantly different for the manually cultivated land under different depths (Table 2.0). The 20-40 cm depth under manual cultivation recorded the highest value while range land, fallow land and tractorized land all had non-significant variation between them and for their depths. There was a decreasing trend in the pH across the depth for manually cultivated soil but the trend under range land was on the increase as the depth increases. Fallow land recorded constant value across the depths while there was no defined trend. The highest value for soil pH across the land use types and depths was observed under manually cultivated land at 0-20 cm depth.

Table 2.0: Interaction between land use types and depths on soil pH

	Depths		
Land use	0-20 cm	20-40 cm	40-60 cm
Tractorized cultivation	3.70^{b}	3.60^{b}	3.65^{b}
Fallow land	3.75^{b}	3.75^{b}	3.75^{b}
Manual cultivation	5.55^{a}	5.35^{a}	3.85^{b}
Range land	3.70^{b}	3.75^{b}	5.10^{a}
S.E ±		0.065	

Means with different letters across columns and rows are significantly different

S. E=Standard Error

Variation of soil physical properties across land use types and soil depths

Variations in soil bulk density, hydraulic conductivity, silt, total sand, erosivity index and porosity with land uses and depths are shown in Table 2. The result showed significant variation in bulk density with respect to land uses and depths. Tractorized and fallow lands had the highest values for bulk density while the lowest value for bulk density was recorded by range land. The high bulk densities obtained from tractorized and fallow land could be attributed to the compacting pressure exerted on the soil by the heavy machinery which are used for cultivating the soil. While the low value of bulk density obtained for range land could be due to the effects of the roots which pulverizes the soil and also increases the biological activities in the soil, as well as the loosening effects of high organic matter in the soil. Evidence that is further amplified by the high values for the total porosity for both range and manually cultivated lands (Table 2). The result of bulk density is also consistent with the result obtained for organic matter. Organic carbon has been found to cause a decrease in soil bulk density. The result agreed with the findings of Igwe *et al.* (1995) and Oguike *et al.* (2006) who revealed that soil organic matter causes a decrease in soil bulk density. This result disagreed with the finding of Urioste *et al.* (2006) who linked low soil bulk density to cultivation. Bulk density decreased with depth (Table 2). The decrease in bulk density with depth may have resulted due to the human activities on the soil surface. The trampling of the soil surface by animals, human beings and farm machinery may have caused the compaction of the soil particles leading to the increased bulk density. Assefa *et al.* (2017); Ezeaku *et al.*(2015); Oguike and Mbagwu (2009) have all reported a contrary finding, that soil bulk density increased with depth.

The hydraulic conductivity and porosity all varied non-significantly across the land use types (Table 2). Highest value for porosity was observed under manual cultivation while the lowest value was recorded under tractorized land. Similarly, the lowest value for hydraulic conductivity was recorded for soil under fallow. These values for both bulk density and porosity observed for both tractorized and fallow land is an indication of the high level of degradation that results when land is continuous put under cultivation with heavy machinery. The values are clear sign that the aggregate structure of the soil have been destroyed by the machinery. High values of porosity for cultivated land have been reported by Bezabih *et al.* (2014). Furthermore, the hydraulic conductivity varied significantly across the soil depths. The inverse relationship between bulk density, hydraulic conductivity and porosity were largely maintained in this result. The decrease in the hydraulic conductivity observed when bulk density increased is as a result of closure of pore spaces which reduced the rate of water movement in and out of the soil. This low amount of pore spaces was further revealed by similar variation as shown by the values for the total porosity (Table 2). The total porosity largely increased as bulk density decreased across the depths. The variability of porosity across land uses were rather minimal (Table 2). Similar result has also been obtained by Franzmeirer (1991).

The particle sizes analysis showed that the soil particles varied non-significantly across the different land uses (Table 2). This variation is rather very minimal. Fallow and manually cultivated land were highest in their clay contents while for the sand content, the manually cultivated was the highest followed by tractorized and range land. The silt content for the various land uses were generally low with fallow land recording the highest value. The various land uses generally have almost the same proportion for the various particle sizes. These similarities observed in the particle sizes could be because the land uses derive from the same parent materials. This result is consistent with the finding of Igwe *et al.* (1999) who observed that soils derived from different parent materials vary significantly. It also agreed with Igwe *et al.* (1983, cited by Oguike and Mbagwu, 2009) who noted that soil textures are related to their parent materials and are usually exhibited through the similarity in their particle sizes. Similarly, across the various depths, the particle sizes varied with significance except for the total sand. The highest value for clay was obtained at 40-60cm depth while the highest value for the total sand and silt were at the 0-20cm depth. The high value of clay at high depth perhaps could be a resultant effect of pedogenic process of translocation. Similar finding has been reported by Ezeaku *et al.* (2015).

Table 3.0: Some physical soil properties under different land use types and soil depths

LM/P	BD (gcm^{-3})	Ks (cmh^{-1})	Silt	Clay	TS	Porosity	Ei
			(%)				
MC	1.51[a]	2.17[a]	1.80[a]	53.60[a]	44.60[a]	45.61[a]	0.90[a]
TR	1.59[a]	3.27[a]	2.80[a]	52.93[a]	44.27[a]	41.51[a]	0.93[a]
FL	1.57[a]	0.31[a]	3.47[a]	58.27[a]	38.27[a]	42.14[a]	0.74[a]
RG	1.34[b]	2.97[a]	2.80[a]	52.93[a]	44.27[a]	43.71[a]	0.93[a]
S.E.	0.14	2.70	2.14	7.85	7.50	6.56	0.15
0-20	1.60[a]	4.10[a]	3.80[a]	46.1[b]	50.10[a]	40.91[a]	1.18[a]
20-40	1.47[b]	1.35[b]	2.05[a]	58.1[a]	39.85[b]	44.98[a]	0.73[b]
40-60	1.44[b]	1.09[b]	2.30[a]	59.1[a]	38.60[b]	43.83[a]	0.71[b]
S.E.	0.16	2.52	2.02	4.95	5.60	6.36	0.17

Means under the same column with different letters are statistically different at $P \leq 0.05$.
MC=Manually cultivated, TR=tractorized, FL=Fallow, RG=Range, BD=Bulk density, TS=Total sand, Ei=Erosivity index

Distribution of particle sizes across land use types and soil depths

The result of the aggregate size distribution is shown in Table 3. The different aggregate sizes and percentage aggregate stability varied non-significantly across the land uses. The highest value for >2 mm size was obtained under fallow land while the lowest value was recorded under tractorized cultivation. There was no defined trend for the variation observed for the different depths. And most of these variations were not significant except 2.0 mm-1.0 mm sizes which showed significance (Table 3). Generally, >0.25 mm aggregate size dominated for all the land uses. Although the >1 mm particle were noticeably low for the tractorized cultivation, perhaps this is a further evidence of the consequence of the use of heavy machinery in the field. It leads to degradation and destruction of soil structure and aggregate stability. High aggregate sizes of <1.2 mm has been found to be an indicator of soil degradation (Whalen and Chang, 2002). Similarly, Emadi *et al.* (2008) has noted that tillage operations cause the breakdown of large aggregate particles.

Table 4: Aggregate size distribution for the various land uses and depths

Factor/level	>2.0 (mm)	2.0 – 1.0 (mm)	1.0 – 0.50 (mm)	0.50 – 0.25 (mm)	%SA

Land use(Lu)					
MC	3.78^{a}	2.78^{a}	4.64^{a}	6.68^{a}	37.48^{a}
TR	1.66^{a}	3.01^{a}	4.78^{a}	7.46^{a}	29.37^{a}
FL	4.82^{a}	4.18^{a}	4.30^{a}	5.74^{a}	45.94^{a}
RG	4.34^{a}	3.14^{a}	4.91^{a}	6.18^{a}	41.30^{a}
S.E.	4.99	1.81	1.56	2.14	11.78
Depths(D)					
0 – 20 cm	2.45^{a}	2.33^{b}	4.79^{a}	7.30^{a}	27.39^{b}
20 – 40 cm	5.72^{a}	2.98^{b}	3.82^{a}	6.23^{a}	42.57^{ab}
40 – 60 cm	2.78^{a}	4.53^{a}	5.35^{a}	6.01^{a}	45.61^{a}
S.E.	4.79	1.57	1.38	2.05	21.23
Interaction					
NS	NS	NS	NS	**	**

Means under the same column with different letters are statistically different at P ≤0.05
MC=Manually cultivated, TR=tractorized, FL=Fallow, RG=Range, S. E=Standard Error, NS=Non-significant
** highly significant at p≤0.01.

Effects of interaction between land use types and soil depths on 0.50 – 0.25 (mm) particle
The result of the interaction effects between land use types and soil depths is shown in Table 5.0. There is no defined trend in the 0.25 mm particle sized distribution across the land use types and soil depths. However, variation was such that the highest value for the particle size was recorded under manually cultivated land at 20-40 cm depth. Similarly, high values were obtained for fallow land and land under tractorized cultivation at 0-20cm and 20-40 cm depths respectively. But range land recorded the lowest values at 20-40 cm depth.

Table 5.0: Interaction between land use types and soil depths on 0.50 – 0.25 (mm) particle

	Depths		
Land use	0-20 cm	20-40 cm	40-60 cm
Tractorized cultivation	6.42^{ab}	9.02^{b}	6.95^{a}
Fallow land	9.45^{b}	3.02^{a}	4.75^{a}

Manual cultivation	4.73[a]	9.92[b]	5.40[a]
Range land	8.6[ab]	2.98[a]	6.95[a]
S.E ±		1.09	

Means with different letters across columns and rows are significantly different, S. E=Standard Error, * significant at $p \leq 0.05$.

The interaction effects of soil depths and land use types on percentage stable aggregate

The interaction effects of soil depths and land use types on percentage stable aggregate is as presented in Figure 2.0. In all the land use types and depths, there is no defined trend for the aggregate stability. However, the highest value was observed under 20-40 cm depth and manually cultivated land. The 40-60 cm depth generally recorded low values compared to the two other depths while the 20-40 cm depth under range land recorded the lowest value among the land uses

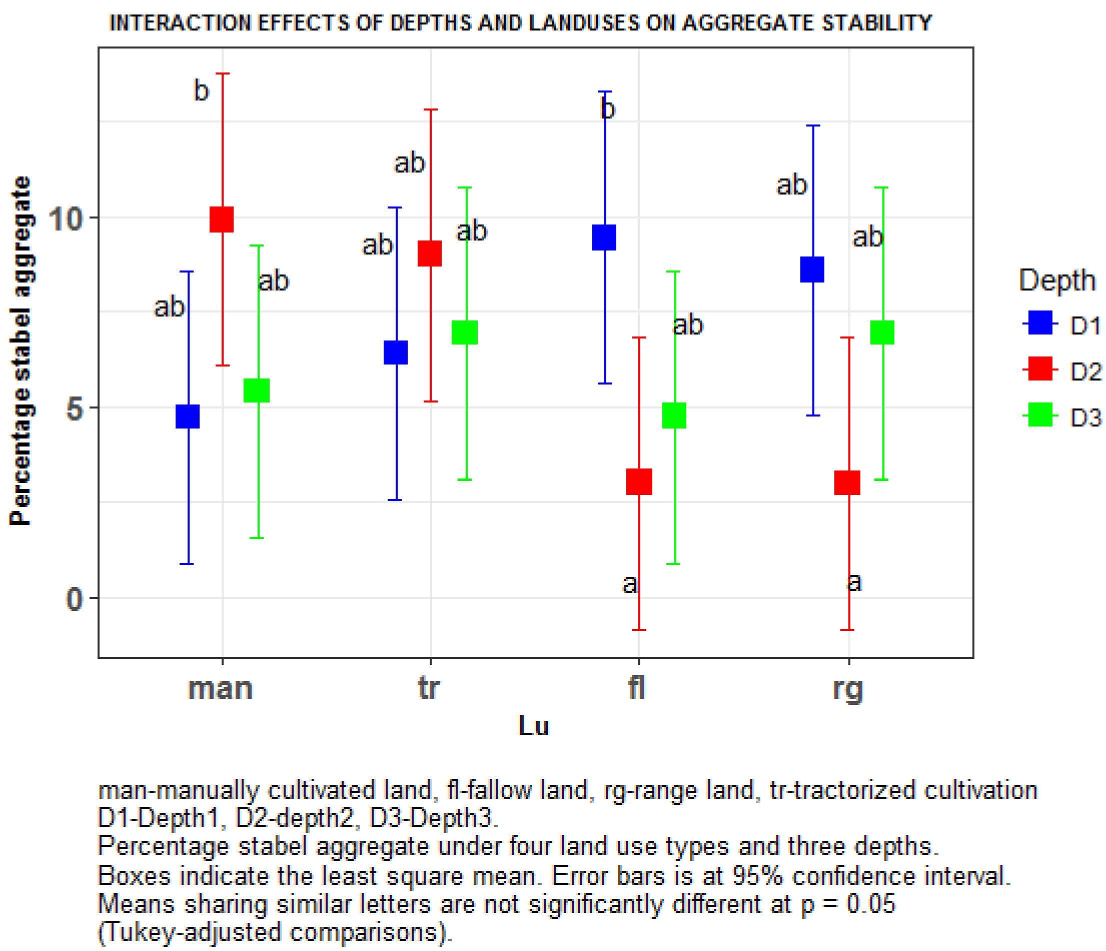


Figure 2.0: Interaction effects of soil depths and land use types on percentage stable aggregate

CONCLUSION AND RECOMMENDATION

The finding of this study showed that most of the productivity indicators decreased significantly for soil under tractorized cultivation more than other soil management practices. The study therefore concluded that the use of tractor reduces the overall productivity of soil and that ensuring substantial amount of cover on the soil surface is critical for optimum performance of soil.

The study hence recommends restoration of vegetative cover on soil surface and the use of manual cultivation in soil preparation although tractors can still be applied where it is inevitable.

References

Allison, L.E. (1965). Organic Carbon. In: Methods of Soil Analysis, Part 2. Black, C.A. *et al*. (Eds.). *American Society of Agronomy,* Monograph No. 9. Madison, Wisconsin, 1367-1378

Aruleba, J. O. (2004). *Influence of cropping systems and land types on land suitability and degradation in south western Nigeria. A Ph. D. thesis in the Dept. of Agronomy, University of Ibadan,.*

Assefa, D., Rewald, B., Sandén, H., Rosinger, C., Abiyu, A., Yitaferu, B., & Godbold, D. L. (2017). Deforestation and land use strongly effect soil organic carbon and nitrogen stock in Northwest Ethiopia. *Catena*, *153,* 89–99. http://doi.org/10.1016/j.catena.2017.02.003

Bezabih, B., Regassa, A., & Ababa, A. (2014). Soil Fertility Status as Affected by Different Land Use Types and Topographic Positions : A Case of Delta Sub-Watershed , Southwestern Ethiopia. *Journal of Biology, Agriculture and Healthcare, 4*(27), 91–106.

Bezák, P., & Lyytimäki, J. (2011). Complexity of urban ecosystem services in the context of global change. *Ekológia (Bratislava), 29*(1), 1–14. http://doi.org/10.4149/ekol

Blake, G. R., & Hartge, K. H. (1986). Bulk density. In: methods of Soils Analysis, part 1, A. Klute (Ed.) *Agron*. No 9. USDA Maidson W. I. 370 – 373.

Chapman, H.D. (1965) Cation-exchange capacity. In: Black CA, Evans DD, White JL, Ensminger LE, Clark FE (eds) Agronomy 9, Part 2, *Am Soc Agron,* Madison, Wis, 891–901

Donald L. Sparks. (2002). *Environmental Soil Chemistry*. *Soil Science* (Vol. 162). San Diego, California: Acdemic press, Inc. http://doi.org/10.1097/00010694-199703000-00009

Emadi, M., Baghernejad, M., Fathi, H., & Saffari, M. (2008). Effect of land use change on selected soil physical and chemical properties in North Highlands of Iran. *Journal of Applied Sciences, 8*(3), 496–502.

Ezeaku, P. I., Eze, F. U., & Oku, E. (2015). Profile distribution and degradation of soil properties of an ultisol in Nsukka semi-humid area of Nigeria. *African Journal of*

Agricultural Research, *10*(11), 1306–1311. http://doi.org/10.5897/AJAR2013.8446

Franzmeirer, D. P. (1991). Estimation of hydraulic conductivity from effectivity porosity data for some Indiana soils. *Soil Sci. Soc. Am. J.*, *55*, 1801–1803.

Gee, G.W., & Bauder, J.W. (1986). Particle-size Analysis. In Methods of Soil Analysis Part 1. A. Klute (eds.), *Soil Science Society of America Book Series, 5* (PP 383-411). Madison, Wisconsin, USA.

Igwe, C. A., Akamigbo, F. O. R., & Mbagwu, J. S. C. (1995). Physical properties of soils of Southeastern Nigeria and the role of some aggregating agents in their stability. *Soil Science*, *160*(6), 431–441. http://doi.org/10.1097/00010694-199512000-00009

Igwe, C. A., Akamigbo, F. O. R., & Mbagwu, J. S. C. (1999). Chemical and mineralogical properties of soils in southeastern Nigeria in relation to aggregate tability. *Geoderma*, *92:*, 111–123.

J.S Ogeh and P.C.Ogwurike. (2006). Influence of agricultural land use types on some soil properties in Mid-Western Nigeria. *Journal of Agronomy*, *5*(3), 387–390.

Khanif, Y. M. (2010). *Improvement of Soil Carrying Capacity for Better Living Department of Land Management, Faculty of Agriculture University Putra Malaysia, 43400, Serdang Selangor Malaysia.*

Klute, A., Dirksen, J. (1986). Hydraulic conductivity and Diffusivity. Laboratory methods. In: A. Klute (ed). Methods of soil analysis part 1 2nd ed. 687-734.

Liu SL , An NN , Yang JJ , Dong YH, W. C. (2015). Effects of different land-use types on soil organic carbon and its prediction in the mountainous areas in the middle reaches of Lancang River. *Journal of Applied Ecology*, *26*(4), 981–988. Retrieved from http://europepmc.org/abstract/med/26259437

Mclean, E.O. (1982). Soil pH and lime requirement. *Agron*. 9. SSSA. Madison W.I. 199-224.

Nduwumuremyi, A.; Mugwe, N. J.; Rusanganwa, C. A.; Mupenzi, J. (2013). Mapping of limestone deposits and determination of quality of locally available limestone in Rwanda. *Journal of Soil Science and Environmental Management*, *4*(5), 87–92. http://doi.org/10.5897/JSSEM12.20

Oguike, P. C., Chukwu, G. O., & Njoku, N. C. (2006). Physico-chemical properties of a Haplic Acrisol in Southeastern Nigeria amended with rice mill waste and NPK fertilizer. *African Journal of Biotechnology*, *5*(11), 1058–1061.

Oguike, P. C., & Mbagwu, J. S. C. (2009). Variations in Some Physical Properties and Organic Matter Content of Soils of Coastal Plain Sand under Different Land Use Types. *World J. Agric. Sci.*, *5*(1), 63–69.

Olson, S.R., & Sommer, L.E. (1982). Phosphorus. In: Page et al (eds). Methods of Soil

Analysis. Part 2. Agron 9. ASA, SSA. Maidson, W.I. 403-434.

Senjobi, B. A. (2007). *Comparative Assessment of the Effect of Land Use and Land Type on Soil Degradation and Productivity in Ogun State, Nigeria. Published Ph.D. Thesis submitted to the Department of Agronomy, University of Ibadan, Ibadan,.*

Senjobi, B. A., & Ogunkunle, A. O. (2011). Effect of different land use types and their implications on land degradation and productivity in Ogun State , Nigeria, *3*(January), 7–18.

Tesfaye, M. A., Bravo, F., Ruiz-Peinado, R., Pando, V., & A., B.-O. (2016). Impact of changes in land use, species and elevation on soil organic carbon and total nitrogen in Ethiopian Central Highlands. *Geoderma*, *261*, 70–79. http://doi.org/10.1016/j.geoderma.2015.06.022

Urioste, A. M., Hevia, G. G., Hepper, E. N., & Anton, L. E. (200`6). Cultivation effects on the distribution of organic carbon , total nitrogen and phosphorus in soils of the semiarid region of Argentinian Pampas. *Geoderma*, *136*, 621–630. http://doi.org/10.1016/j.geoderma.2006.02.004

Whalen, J. K., & Chang, C. (2002). Macroaggregate characteristics in cultivated soils after 25 annual manure applications. *Soil Sci. Soc. Am. J., 66*, 1637–1647