DETERMINATION OF HYDROLOGIC COEFFICIENTS OF DISTURBED AND UNDISTURBED LOAMY SOIL DURING DRY SEASON (CASE STUDY OF GIDAN KWANO CAMPUS, FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGER STATE)

BY

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MATRIC No. 2006/24085EA

DEPARTMENT OF AGRICULTURAL & BIORESOURCES ENGINEERING
FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA

FEBURARY, 2012.

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BEING A FINAL YEAR PROJECT REPORT SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIRMENTS FOR THE AWARD OF BACHELOR OF ENGINEERING (B. ENG.) DEGREE IN AGRICULTURAL & BIORESOURCES ENGINEERING, FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGER STATE

FEBURARY, 2012.

DECLARATION

I hereby declare that this project work is a record of a research work that was undertaken and written by me. It has not been presented before for any degree or diploma or certificate at any university or institution. Information derived from personal communications, published and unpublished works were duly referenced in the text.

Ahmodu, Emmanuel Ocholi

29/02/2012
Date

CERTIFICATION

This is to certify that the project entitled "Determination of Hydrologic Coefficients of Disturbed and Undisturbed Loamy Soil (Case Study of Gidan Kwano Campus, Federal University of Technology, Minna, Niger State)" by Ahmodu, Emmanuel Ocholi meets the regulations governing the award of the degree of Bachelor of Engineering (B. ENG.) of the Federal University of Technology, Minna, and it is approved for its contribution to scientific knowledge and literary presentation.

Mr. John. J. Musa Supervisor	29/02/2012 Date
Engr. Dr P. A. Idah Head of Department	01/03/2012 Date
External Examiner	22-02-2012 Date

DEDICATION

This research work is dedicated to God Almighty and my lovely family which includes my parents Mr. and Mrs. John Abdullahi Ahmodu, my elder brother Mr. Nathaniel Ahmodu, and my beautiful sisters, Sister Dorcas Ahmodu, Blessing Ahmodu, Joy Ahmodu and Victoria Ahmodu.

ACKNOWLEDGEMENT

My most sincere gratitude goes to God almighty who granted me the grace, divine health and divine wisdom to undergo and complete this research work. I cannot thank him enough for his grace that was made very sufficient in my life throughout my stay in Federal University of Technology, Minna. I say may his name be forever praised.

I wish to express my profound and sincere heartfelt appreciations to my project supervisor, Mr. Musa, John Jiya, who spent his precious time, energy and resources in making sure that this project was brought to successful completion. I also want to say a big thank you to the Head of Department, Dr. Peter Idah who is tailoring the affairs of the department towards academic excellence. To the entire staffs in the department, your individual and collective efforts are highly appreciated, for without these good people, the materials used in this research work would not have been there.

My profound gratitude also goes to my parents, Mr. and Mrs. John Abdullahi Ahmodu, whose unrelenting efforts contributed so much to the success of this programme, both financially, morally, prayer wise and otherwise, may the good Lord replenish you and grant you long life to reap the fruits of your labour in Jesus name, (AMEN).

My special thanks go to my brother, Nathaniel, and sisters, Sister Dorcas, Blessing, Joy and Victoria for their immeasurable supports and contributions toward the completion of this project work. I also do appreciate your supports and contributions both financially, morally, spiritually, May the good Lord replenish you and grant you every desires of your hearts.

I shall not forget to mention my very good friends "my project mates", your tangible and intangible contributions toward the actualization of this project work would always be

remembered. I must at this point recognize my ever loving, beautiful, and wonderful course mates of Agricultural and Bioresources Engineering as well as other departments, sincerely you are all beautiful. A big thank you to the entire engineering lecturers as well as the students. And to others to numerous to mention, i appreciate you.

It is my earnest prayer that God will bless you ALL

ABSTRACT

The need to determine the hydrologic response of infiltration and surface runoff to rainfall in a watershed that would occur using a simple empirical mathematical model, led to a controlled field experiments and numerical simulations. The following parameters were determined; infiltration rate, moisture content, slope, rainfall intensity, time of concentration, soil surface condition, and also the type of soil. A rainfall simulator was used to be able to have a replicate storms event. A catchment area of $18m^2$ (6X3m) was used and ten (10) replicate of the catchment area were investigated to have an accurate result. Five of which were undisturbed and the other five were in disturbed conditions for loamy soil. The average basic infiltration rates of the undisturbed plots and disturbed plots were found to be 4.40 cm/hr and 4.20 cm/hr respectively using a double ring infiltrometer. The average slope of the undisturbed and disturbed soil plots were found to be 3.08^0 and 2.48^0 respectively, using change in height method. The average moisture content of the undisturbed and disturbed soil plots were found to be 4.32% and 4.13% respectively using gravimetric method. The intensity of the simulated rainfall was 70mm/hr and the time of simulation was 30mins. Having gathered sufficient data, an empirical mathematical model was developed using Crammer's rule. The equation developed is $T_c = 0.938L^{0.878}n^{0.324}\theta^{-0.222}S^{-0.049}i^{-0.075}$. Where T_c is the time of concentration in minutes, L is the watershed length of the study area in meters, n is Manning-Nigeria's n, θ is the antecedent soil moisture in percent, S is the watershed slope, and i is the rainfall intensity in mm/hr.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Study

The hydrologic response of infiltration and surface runoff to rainfall in a particular watershed is a pre-requisite for the development of hydrologic coefficients for that particular watershed. The proportion of total rainfall that becomes runoff during a storm event represents the runoff coefficient. In the classical 'rational method' it is considered to be a constant, depending on characteristics of the drainage basin, such as surface cover (Dooge, 1957). The rainfall–runoff transformation is a non linear process. The most important cause of non linearity is represented by the effect of antecedent conditions consequently the runoff coefficient depends on the initial conditions. It is well known that soil moisture is a major control on catchment response. Estimates of runoff flow rates and volumes for selected levels of protection provide the basis for the design of drainage facilities, irrigation structures, and channel improvement for the management of flood discharges and water quantity and quality control.

The aim of soil tillage is to create favourable conditions for the plants growth and development. As a consequence of mechanical impacts on soil, soil aggregates and pore size changes occur, influencing the water regime and air motion in the soil (Titi, 2002). It is necessary to evaluate the effects of the technologies or machine types used for soil tillage and crop covers establishing the soil hydraulic properties. The reduction of the soil permeability for water leads to the rainfall water surface runoff and soil erosion increasing. The soil wash away can affect the soil degradation particularly on inclined plots (P. Kovaříček, et.al, 2008).

When an unprotected soil surface is exposed to the direct impact of raindrops it can produce different responses such as; production of smaller aggregates, dispersed particles, particles in suspension and translocation and deposition of particles. When this has occurred, the material is reorganized at the location into a surface seal. Aggregate breakdown under rainfall depends on soil strength and a certain threshold kinetic energy is needed to start detachment (Lujan, 2003).

Studies on necessary kinetic energy to detach one kilogram of sediments by raindrop impact have shown that the minimum energy is required for particles of 0.125 mm. Particles between 0.063 to 0.250 mm are the most vulnerable to detachment. This means that soils with high content of particles into vulnerable range, for example silty loam, loamy, fine sand, and sandy loam are the most susceptible soils to detachment. So, quantitively describing the rate and path of movement of a rain droplet after it strikes the ground surface is essential for our nation's water resources (Lujan, 2003).

In order to be practical and effective, a fundamental knowledge of a method or technique is required whereby, for a known or assumed conditions within a watershed, the runoff hydrograph resulting from any real or hypothetical storm can be predicted with a high degree of reliability. Such a method must be sufficiently general to allow the determination of the change in system response that would result from proposed water management projects within the watershed. Only with this type of analysis can such projects be designed on a rational basis to produce optimum conditions for a minimum cost (Oyebode, 2010).

The concept of integrated watershed runoff coefficient has emerged as a new understanding for the interactions between the surface and subsurface pathways of water. This defines the bidirectional linkage that implies the main rationale for the unity of the two systems.

In this regard, surface flow processes such as channel and overland flow are integrated to subsurface flow process in the unsaturated and saturated ground water flow zones via the dynamic interactions at the ground surface and channel beds. Only with this kind of approach can one determine a standard coefficient for some major soils in a watershed.

1.2 Statement of the Problem

It is essential to study the relationship of rainfall, runoff and drainage basin characteristics. The establishment of a clear rainfall–runoff–drainage basin characteristics relationship is difficult due to the large number of variables which affect the process. It is more challenging to quantify the impact of vegetation change on rainfall-runoff relations for large basins where the interactions between land use, climatic characteristics and underlying hydrological process are more complex and dynamic. Hence, to study the effects of storms and to replicate the conditions, many researchers have resorted to the use of artificially simulated rainfall. Simulated rainfall provides rapid results than natural rains. It can be conducted efficiently from the stand point of time and labour. The storm characteristics can carefully be controlled and the approach is more adaptable for certain type of studies.

1.3 Objectives of the Study

1. To determine the surface runoff and infiltration rate coefficients of disturbed and undisturbed loamy soils in Gidan Kwano campus of the Federal University of Technology, Minna, Niger State, Nigeria.

2. To develop an empirical mathematical model/equation using the Crammer rule capable of determining the Manning's coefficient for the various conditions of loamy soil in Gidan Kwano area of Niger State for a small watershed..

3. To determine the relative contribution of the various components such as infiltration, surface slope and roughness and watershed shape in the generation of runoff hydrograph predicted by the model or equation.

1.4 Justification of the Study

Soil erosion, downstream flooding and siltation pose a major challenge to watershed managers, particularly in Nigeria, due to high rates of deforestation, desertification, soil types and intense rainfall in some parts of the country. Knowledge of the volume and rates of runoff generated in response to rainfall is very important, if not quintessential, to predicting soil losses and the failure of farm structures to serve their lifespan. But information concerning the extent causes, and control of water erosion in Nigeria still remains fragmentary and limited. This can be partly ascribed to the dependence upon field runoff plots under natural rainfall as the main data source (Lai, 2006; Roose, 2008). These are costly and demand long periods of observation. Because of financial limitations, measurements can be conducted only on a restricted number of sites. This failure can also be attributed to the dependent on results obtained from experiments conducted in foreign countries.

1.5 Scope of the Study

This project work shall cover the determination of hydrologic parameter such as infiltration rate, time of concentration, soil moisture content, bulk density, surface runoff and the slope of the area/catchment.

Also, a simple empirical mathematical model will be generated to show the relationship between the measured parameters and surface runoff.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Surface Runoff

This is the water flow that occurs when the void spaces in soils are fully filled or saturated to full capacity and excess water from rain, melt water, or other sources flows over the land. This is a major component of the hydrologic cycle (Keith, 2004). Runoff that occurs on surfaces before reaching a channel is also called a nonpoint source (Baven, 2004). If a nonpoint source contains man-made contaminants, the runoff is called nonpoint source pollution. A land area which produces runoff that drains to a common point is called a watershed (Nelson, 2004). When runoff flows along the ground, it can pick up soil contaminants such as petroleum, pesticides (in particular herbicides and insecticides), or fertilizers that become discharge or nonpoint source pollution (Baven, 2004).

2.1.1 Generation

Surface runoff can be generated either by rain fall or by the melting of snow, ice, or glaciers. Snow and glacier melt occur only in areas cold enough for these to form permanently. Typically snowmelt will peak in the spring and glacier melt in the summer, leading to pronounced flow maxima in rivers affected by them. The determining factor of the rate of melting of snow or glaciers is both air temperature and the duration of sunlight. In high mountain regions, streams frequently rise on sunny days and fall on cloudy ones for this reason (Keith and Nelson, 2004).

In areas where there is no snow, runoff will come from rainfall. However, not all rainfall will produce runoff because storage from soils can absorb light showers. On the extremely ancient soils of Australia and Southern Africa, proteoid roots with their extremely dense networks of root hairs can absorb so much rainwater as to prevent runoff even when substantial amounts of rain fall (South African Environmental Agency, 2001). In these regions, even on less infertile cracking clay soils, high amounts of rainfall and low potential evaporation are needed to generate any surface runoff, leading to specialized adaptations to extremely variable (usually ephemeral) streams (Spencer, 1997).

2.1.2 Infiltration Excess Overland Flow

This occurs when the rate of rainfall on a surface exceeds the rate at which water can infiltrate the ground, and any depression storage has already been filled. This is called infiltration excess overland flow, Hortonian overland flow (after Robert E. Horton), or unsaturated overland flow. This more commonly occurs in arid and semi-arid regions, where rainfall intensities are high and the soil infiltration capacity is reduced because of surface sealing, or in paved areas. This occurs largely in city areas where pavements prevent water infiltration (Susan, 2008).

2.1.3 Overland Flow

When the soil is saturated and the depression storage filled, and rain continues to fall, the rainfall will immediately produce surface runoff. The level of antecedent soil moisture is one factor affecting the time until soil becomes saturated. This runoff is saturation excess overland flow or saturated overland flow (Masten and Susan 2008).

2.1.4 Subsurface Return Flow

After water infiltrates into the soil on an up-slope portion of a hill, the water may flow laterally through the soil, and exfiltrate (flow out of the soil) closer to a channel. This is called subsurface return flow or throughflow(Spencer, 1997).

As it flows, the amount of runoff may be reduced in a number of possible ways: a small portion of it may evapotranspire; water may become temporarily stored in microtopographic depressions; and a portion of it may become run-on, which is the infiltration of runoff as it flows overland. Any remaining surface water eventually flows into a receiving water body such as a river, lake, estuary or ocean (Davis, 2008).

2.1.5 Human Impact on Surface Runoff

Urbanization increases surface runoff, by creating more impervious surfaces such as pavement and buildings, which do not allow percolation of the water down through the soil to the aquifer. It is instead forced directly into streams or storm water runoff drains, where erosion and siltation can be major problems, even when flooding is not. Increased runoff reduces groundwater recharge, thus lowering the water table and making droughts worse, especially for farmers and others who depend on the water wells (Spencer, 1997).

When anthropogenic contaminants are dissolved or suspended in runoff, the human impact is expanded to create water pollution. This pollutant load can reach various receiving waters such as streams, rivers, lakes, estuaries and oceans with resultant water chemistry changes to these water systems and their related ecosystems (Mackenzie, 2008).

2.1.6 Effects of Surface Runoff

2.1.6.1 Erosion and Deposition

Surface runoff causes erosion of the Earth's surface. There are four principal types of erosion: splash erosion, gully erosion, sheet erosion and stream bed erosion. Splash erosion is the result of mechanical collision of raindrops with the soil surface. Dislodged soil particles becoming suspended in the surface runoff and carried into streams and rivers. Gully erosion occurs when the power of runoff is strong enough that it cuts a well defined channel. These channels can be as small as one centimeter wide or as large as several meters. Sheet erosion is the overland transport of runoff without a well defined channel. In the case of gully erosion, large amounts of material can be transported in a small time period. Stream bed erosion is the attrition of stream banks or bottoms by rapidly flowing rivers or creeks (Susan, 2008).

Reduced crop productivity usually results from erosion, and these effects are studied in the field of soil conservation. The soil particles carried in runoff vary in size from about .001 millimeter to 1.0 millimeter in diameter. Larger particles settle over short transport distances, whereas small particles can be carried over long distances suspended in the water column. Erosion of silty soils that contain smaller particles generates turbidity and diminishes light transmission, which disrupts aquatic ecosystems (Susan, 2008).

Entire sections of certain countries have been rendered unproductive by erosion. On the high central plateau of Madagascar, approximately ten percent of that country's land area, virtually the entire landscape is devoid of vegetation, with erosive gully furrows typically in excess of 50 meters deep and one kilometer wide. (FAO,2002). Shifting cultivation is a farming system which sometimes incorporates the slash and burn method in some regions of the world. Erosion cause loss of the fertile top soil and reduces the fertility and quality of the agricultural produce (Baven, 2004).

Modern industrial farming is another major cause of erosion. In some areas in the American corn-belt, more than 50 percent of the original topsoil has been carried away within the last 100 years. This is a very important natural resource that forms all our mountains and valleys (American Department of Agriculture, 2006)

2.1.6.2 Environmental Impacts

The principal environmental issues associated with runoff are the impacts to surface water, groundwater and soil through transport of water pollutants to these systems. Ultimately these consequences translate into human health risk, ecosystem disturbance and aesthetic impact to water resources (USDA, 2006). Some of the contaminants that create the greatest impact to surface waters arising from runoff are petroleum substances, herbicides and fertilizers. Quantitative uptake by surface runoff of pesticides and other contaminants has been studied since the 1960s, and early on contact of pesticides with water was known to enhance phytotoxicity. In the case of surface waters, the impacts translate to water pollution, since the streams and rivers have received runoff carrying various chemicals or sediments. When surface waters are used as potable water supplies, they can be compromised regarding health risks and drinking water aesthetics (that is, odor, color and turbidity effects). Contaminated surface waters risk altering the metabolic processes of the aquatic species that they host; these alterations can lead to death, such as fish kills, or alter the balance of populations present (Spencer, 1997). Other specific impacts are on animal mating, spawning, egg and larvae viability, juvenile survival and plant productivity.

Some researches show that surface runoff of pesticides, such as DDT (Dichlorodiphenyltrichloroethane), can alter the gender of fish species genetically, which transforms male into female fish (Spencer, 1997).

In the case of groundwater, the main issue is contamination of drinking water, if the aquifer is abstracted for human use. Regarding soil contamination, runoff waters can have two important pathways of concern. Firstly, runoff water can extract soil contaminants and carry them in the form of water pollution to even more sensitive aquatic habitats. Secondly, runoff can deposit contaminants on pristine soils, creating health or ecological consequences (Spencer, 1997).

2.1.6.3 Agricultural Issues

A common context of run-off deals with agriculture. When farmland is tilled and bare soil is revealed, rainwater carries billions of tons of topsoil into waterways each year, causing loss of valuable topsoil and adding sediment to produce turbidity in surface waters (FAO, 2007). The other context of agricultural issues involves the transport of agricultural chemicals (nitrates, phosphates, pesticides, herbicides etc) via surface runoff. This result occurs when chemical use is excessive or poorly timed with respect to high precipitation. The resulting contaminated runoff represents not only a waste of agricultural chemicals, but also an environmental threat to downstream ecosystems. The alternative to conventional farming is organic farming which eliminates chemical usage (FAO, 2007).

2.2.0 Infiltration

Infiltration is the process by which water on the ground surface enters the soil. Infiltration rate in soil science is a measure of the rate at which soil is able to absorb rainfall or irrigation. It is measured in inches per hour, millimeters per hour or centimeter per hour. The rate decreases as the soil becomes saturated. If the precipitation rate exceeds the infiltration rate, runoff will usually occur unless there is some physical barrier. It is related to the saturated hydraulic conductivity of the near-surface soil. The rate of infiltration can be measured using an infiltrometer (Walker, 1997).

Infiltration is governed by two forces: gravity and capillary action. While smaller pores offer greater resistance to gravity, very small pores pull water through capillary action in addition to and even against the force of gravity (Keith and Chris, 2002).

The rate of infiltration is affected by soil characteristics including ease of entry, storage capacity, and transmission rate through the soil. The soil texture and structure, vegetation types and cover, water content of the soil, soil temperature, and rainfall intensity all play a role in controlling infiltration rate and capacity. For example, coarse-grained sandy soils have large spaces between each grain and allow water to infiltrate quickly (Skogerboe, 1997). Vegetation creates more porous soils by both protecting the soil from pounding rainfall, which can close natural gaps between soil particles, and loosening soil through root action. This is why forested areas have the highest infiltration rates of any vegetative types (Walker and Skogerboe, 1997).

The top layer of leaf litter that is not decomposed protects the soil from the pounding action of rain, without this the soil can become far less permeable. In chaparral vegetated areas, the hydrophobic oils in the succulent leaves can be spread over the soil surface with fire, creating large areas of hydrophobic soil. Other conditions that can lower infiltration rates or block them include dry plant litter that resists re-wetting, or frost. If soil is saturated at the time of an intense freezing period, the soil can become a concrete frost on which almost no infiltration would occur. Over an entire watershed, there are likely to be gaps in the concrete frost or hydrophobic soil where water can infiltrate. Once water has infiltrated the soil it remains in the soil, percolates down to the ground water table, or becomes part of the subsurface runoff process (Walker, et al., 1997).

2.2.1 Infiltration Process

The process of infiltration can continue only if there is room available for additional water at the soil surface. The available volume for additional water in the soil depends on the porosity of the soil and the rate at which previously infiltrated water can move away from the surface through the soil. The maximum rate that water can enter a soil in a given condition is the infiltration capacity. If the arrival of the water at the soil surface is less than the infiltration capacity, all of the water will infiltrate. If rainfall intensity at the soil surface occurs at a rate that exceeds the infiltration capacity, pounding begins and is followed by runoff over the ground surface, once depression storage is filled. This runoff is called Horton overland flow. The entire hydrologic system of a watershed is sometimes analyzed using hydrology transport models, mathematical models that consider infiltration, runoff and channel flow to predict river flow rates and stream water quality (Lal, 1996).

2.2.2 Factors Influencing Infiltration

A number of factors impact soil infiltration. Some of these are:

a. Texture: The type of soil (sandy, silty, clayey) can control the rate of infiltration. For example, sandy surface soils normally have a higher infiltration rate than a clayey surface soil. A soil survey is a recorded map of soil types on the landscape.

b. Crust: Soils that have many large surface connected pores which in-turn have higher intake rates than soils that have few of such pores. A crust on the soil surface can seal the pores and restrict the entry of water into the soil.

c. **Compaction:** A compacted zone (plough pan) or an impervious layer close to the surface restricts the entry of water into the soil and tends to result in ponding on the surface.

d. **Aggregation and Structure:** Soils that have stable strong aggregates as granular or blocky soil structure have a higher infiltration rate than soils that have weak, massive, or plate-like structure. Soils that have a smaller structural size have higher infiltration rates than soils that have a larger structural size.

e. **Water Content:** The content or amount of water in the soil affects the infiltration rate of the soil. The infiltration rate is generally higher when the soil is initially dry and decreases as the soil becomes wet. Pores and cracks are open in a dry soil, and many of them are filled in by water or swelled shut when the soil becomes wet. As they become wet, the infiltration rate slows to the rate of permeability of the most restrictive layer.

f. Frozen Surface: A frozen soil greatly slows or completely prevents water entry. Frozen soil is obviously a dominant factor in land surface processes because of its effects on thermal and hydrological regimes and its large area extend. Heat and moisture transfer processes in the aeration zone play an important role in the runoff generation mechanism in regions where seasonal soil freezing/thawing occurs. Seasonally, frozen soil can significantly influence the amount of runoff generated during winter and spring.

g. **Organic Matter:** An increased amount of plant material, dead or alive, generally assists the process of infiltration. Organic matter increases the entry of water by protecting the soil aggregates from breaking down during the impact of raindrops. Particles broken from aggregates can clog pores and seal the surface and decrease infiltration during a rainfall event.

h. **Pores:** Continuous pores that are connected to the surface are excellent conduits for the entry of water into the soil. Discontinuous pores may retard the flow of water because of the entrapment of air bubbles. Organisms such as earthworms increase the amount of pores and also assist the process of aggregation that enhances water infiltration.

2.3 Time of Concentration

Time of concentration is a concept used in hydrology to measure the response of a watershed to a rain event. It is defined as the time needed for water to flow from the most remote point in a watershed to the watershed outlet. It is a function of the topography, geology, and land use within the watershed (Haan, 1994).

Time of concentration is useful in predicting flow rates that would result from hypothetical storms, which are based on statistically-derived return periods. For many (often economic) reasons, it is important for engineers and hydrologists to be able to accurately predict the response of a watershed to a given rain event. This can be important for these things such as infrastructure development (design of bridges, culverts, etc.) and management, as well as to assess flood risk (Haan, 1994).

2.3.1 Travel Time

Time travel is the concept of moving between different points in time in a manner analogous to moving between different points in space. If the ground cover conditions are not homogeneous for the entire overland flow path, determine the travel time for each ground cover condition separately and add the travel times to get overland flow travel time. The average ground cover condition is not to be used. The travel time for overland flow may be determined by using the following methods as appropriate.

a. **Seelye Method**: Travel time for overland flow can be determined by using the Seelye chart. This method is perhaps the simplest and is most commonly used for small developments where a greater margin of error is acceptable (Berfield and Haan, 1994).

The length of overland flow and enter the nomograph is first determined on the left axis of the graph (Length in Feet). The intersect which is the Coefficient of Imperviousness determines the turn point on the "Pivot" line. The Intersect which is the "Percentage Slope" can be used to read the travel time for overland flow (Hayes, 1994). You need to show the graph here; it is very important.

b. **Kinematic Wave Method**: This method allows for the input of rainfall intensity values, thus allowing you to adjust the model to a selected design storm, such as the region's 2-year, 10-year, or 100-year storms (Hayes, 1994).

The equation is:

$$T_t = \frac{(0.93)L^{0.6}n^{0.6}}{i^{0.4}S^{0.3}} \tag{2.1}$$

Where:

T_t = travel time

L = length of overland flow in feet

n = Manning's roughness coefficient

i = rainfall intensity

S = slope in feet/foot

The first step is to decide on values for "L", "n", and "S". This leaves two unknown values (travel time and rainfall intensity). In order to solve the equation, find your region's I-D-F curve and choose a model storm. A trial and error process is then used to determine the overland flow time. First, assume a rainfall intensity value and solve the equation for travel time. Then compare the assumed rainfall intensity value with the rainfall intensity value that corresponds with the travel time on the I-D-F curve. The correct travel time will come from an assumed intensity which is equal to the intensity determine using the I-D-F curve (Haan, 2004).

c. **Manning's Kinematic Equation**: This is the method used in TR-55.

The equation is:

$$T_t = \frac{0.007(nL)^{0.8}}{(P_2)^{0.5} S^{0.4}} \qquad 2.2$$

Where:

T_t = travel time (hr.)

n = Manning's roughness coefficient

L = flow length (ft.)

P_2 = 2-year, 24-hour rainfall (in.)

s = slope of hydraulic grade line (feet/foot)

2.3.2 Shallow Concentrated Flow

To calculate the travel time of shallow concentrated flow, first the velocity of the flow is determined. It is then necessary to know the slope of the shallow concentrated flow and whether the flow path is paved or unpaved. Next, the travel time is calculated using the following equations:

$$T_t\,(\text{Minutes}) = \frac{L}{60V} \qquad 2.3$$

Where:

T_t = travel time (minutes)

L = length of shallow concentrated flow (feet)

V = velocity (feet per second)

2.3.3 Channel Flow

The last flow regime we need to consider is channel flow.

a. Kirpitch Chart: A simple method using a nomograph to calculate channel flow, you need to know:

1. Length of channel flow in feet
2. Height above the outlet of the most remote point in the channel
3. Whether the channel is paved

Then we simply use this data with the Kirpitch Chart to determine the travel time. (Be sure to multiply the result by 0.2 if the channel is paved.)

b. Manning's equation: Manning's equation is used to determine the velocity of channel flow. Manning's equation can either be solved mathematically or by the use nomograph.

Manning's equation is:

$$V = \frac{1.49r^{2/3}s^{1/2}}{n} \qquad 2.4$$

Where:

V = average velocity (ft./sec.)

r = hydraulic radius (ft.) and is equal to a/P_w

a = cross sectional flow area ($ft.^2$)

P_w = wetted perimeter (ft.)

s = slope of the hydraulic grade line (ft./ft.)

n = Manning's roughness coefficient for open channel flow.

Once the velocity is found, the travel time is determined using the same method used for shallow concentrated flow. The time of concentration along the hydraulic path is simply the sum of the travel times for the overland flow, shallow concentrated flow, and channel flow.

$$T_c = L_o + L_{sc} + L_c \qquad 2.5$$

2.3.4 Existing Formula for Calculating Time of Concentration

a. Izzard Formula

Based on a series of laboratory experiments by the Bureau for Public Roads, Izzard (1946) proposed a time concentration for roadways and turf surfaces. For small drainage areas without a defined channel and from which runoff behaves as a thin sheet of overland flow, the Izzard formula can be used for estimating the concentration time, t_c,

$$t_c = \frac{41L^{1/3}}{i^{2/3}}\left(\frac{0.007i + c_r}{s^{1/3}}\right) \quad 2.6$$

Where:

t_c = concentration time, min

L = length of overland flow travel, cm

i = rainfall intensity, centimeter/hour

S = slope of ground surface, cm/100 cm

K = retardance coefficient

b. Kerby Formula

Kerby (1959) defined flow length as the straight-line distance from the most distant point of a basin to its outlet, measured parallel to the surface slope. Based on this definition, time of concentration can be evaluated as

$$t_c = 0.83(Lns^{-0.5})^{0.467} \quad 2.7$$

Where t_c = time of concentration

S = surface slope

n = Manning roughness coefficient

L = flow length

c. Kirpich Formula

The Kirpich empirical equation is normally used for natural drainage basins with well-defined overland flow routes along bare soil. For overland flow on impervious surfaces, the t_c obtained should be reduced by 60%. For overland flow on grass surfaces, the computed t_c should be increased by 100%. The Upland Method is a graphical solution for finding the average overland flow velocity and can be used for overland flow in basins with a variety of land covers.

This method relates t_c to the basin slope and to the length and type of ground cover. The time of concentration, t_c, is commonly taken as the longest length of flow travel divided by the average velocity of flow.

$$t_c = 0.0078\left(\frac{L^{0.77}}{S^{0.385}}\right) \quad 2.8$$

Where:

t_c = concentration time, hrs

L = the longest length of water travel, m

S = ground surface slope = $\frac{H}{L}$

H = Difference in elevation between the most remote point on the basin and the collection point, m.

d. FAA Method

The Federal Aviation Administration (FAA, 1970) used airfield drainage data assembled by the U.S. Army Corps of Engineers to develop an estimate for time of concentration. The method has been widely used for overland flow in urban areas and is expressed as

$$t_c = \frac{0.39(1.1-C)L^{1/2}}{S^{1/3}} \quad 2.9$$

Where C = dimensionless runoff coefficient

t_c = concentration time, hrs

L = the longest length of water travel, m

S = ground surface slope

e. Bransby Williams Equation

Bransby Williams (1983) proposed the following expression for evaluation of time of concentration

$$t_c = 21.3L\frac{1}{A^{0.1}S^{0.2}} \quad (2.10)$$

Where

t_c = concentration time, hrs

L = Channel Length, m

S = Linear Profile slope

A = Watershed Area

2.4 Bulk Density

Bulk density is a property of powders, granules and other "divided" solids, especially used in reference to mineral components (soil, gravel), chemical substances, (pharmaceutical) ingredients, foodstuff or any other masses of corpuscular or particulate matter. It is defined as the mass of many particles of the material divided by the total volume they occupy. The total volume includes particle volume, inter-particle void volume and internal pore volume (Buckman, et.al., 1960).

Bulk density is not an intrinsic property of a material; it can change depending on how the material is handled. For example, a powder poured in to a cylinder will have a particular bulk density; if the cylinder is disturbed, the powder particles will move and usually settle closer together, resulting in a higher bulk density. For this reason, the bulk density of powders is usually reported both as "freely settled" (or "poured" density) and "tapped" density (where the tapped density refers to the bulk density of the powder after a specified compaction process, usually involving vibration of the container).

Bulk density is a measure of the weight of the soil per unit volume (g/cm^3), usually given on an oven-dry (110° C) basis. Variation in bulk density is attributable to the relative proportion and specific gravity of solid organic and inorganic particles and to the porosity of the soil. Most mineral soils have bulk densities between 1.0 and 2.0. Although bulk densities are seldom measured, they are important in quantitative soil studies, and measurement should be encouraged. Such data are necessary, for example, in calculating soil moisture movement within a profile and rates of clay formation and carbonate accumulation. Even when two soils are compared qualitatively on the basis of their development for purposes of stratigraphic correlation, more accurate comparisons can be made on the basis of total weight of clay formed from 100 g of parent material than one percent of clay alone. The determination usually consists of drying and weighing a soil sample, the volume of which is known (core method) or must be determined (clod method and excavation method). These methods differ in the way the soil sample is obtained and its volume determined.

2.4.1 Soil

The bulk density of soil depends greatly on the mineral make up of soil and the degree of compaction. The density of quartz is around 2.65g/cm^3 but the bulk density of a mineral soil is normally about half that density, between 1.0 and 1.6g/cm^3. Soils high in organics and some friable clay may have a bulk density well below 1g/cm^3

Bulk density of soil is usually determined on Core samples which are taken by driving a metal corer into the soil at the desired depth and horizon. The samples are then oven dried and weighed.

Bulk density = mass of oven dry soil/core volume

$$\rho_b = \frac{M_s}{V_s} \qquad 2.11$$

The bulk density of soil is inversely related to the porosity of the same soil: the more pore space in a soil the lower the value for bulk density. Bulk density of a region in the interior of the earth is also related to the seismic velocity of waves travelling through it: for P-waves, this has been quantified with Gardner's relation. The higher the density, the faster the velocity of flow of water through such medium.

2.5 Soil Moisture Content

Water or moisture content is the quantity of water contained in a material, such as soil (called soil moisture), rock, ceramics, or wood on a volumetric or gravimetric basis. The property is used in a wide range of scientific and technical areas, and is expressed as a ratio, which can range from 0 (completely dry) to the value of the materials' porosity at saturation (Dingman, 2002).

Volumetric water content, θ, is defined mathematically as:

$$\theta = \frac{V_\omega}{V_T} \qquad 2.12$$

where V_w is the volume of water and $V_T = V_s + V_v = V_s + V_w + V_a$ is the total volume (that is Soil Volume + Water Volume + Void Space). Water content may also be based on its mass or weight, thus the gravimetric water content is defined as:

$$\mu = \frac{m_\omega}{m_b} \qquad 2.13$$

Where m_w is the mass of water and m_b (or m_s for soil) is the bulk material mass. To convert gravimetric water content to volumetric water, multiply the gravimetric water content by the bulk specific gravity of the material.

2.5.1 Degree of Saturation

In soil mechanics and petroleum engineering, the term water saturation or degree of saturation, S_w is used, defined as

$$S_\omega = \frac{V_\omega}{V_v} = \frac{V_\omega}{V_{T\emptyset}} = \frac{\theta}{\emptyset} \qquad 2.14$$

where $\varphi = V_v / V_T$ is the porosity and V_v is the volume of void or pore space.

Values of S_w can range from 0 (dry) to 1 (saturated). In reality, S_w never reaches 0 or 1 - these are idealizations for engineering use (Lawrence and Honberger, 2007).

2.5.2 Normalized Volumetric Water Content

The normalized water content, (also called effective saturation or S_e) is a dimensionless value defined by van Genuchten as:

$$\Theta = \frac{\theta - \theta_r}{\theta_s - \theta_r} \qquad 2.15$$

where Θ is the volumetric water content; θ_r is the residual water content, defined as the water content for which the gradient $d\theta / dh$ becomes zero; and, θ_s is the saturated water content, which is equivalent to porosity, φ (Lawrence et.al., 2007).

2.5.3 Measurement

a. Direct Methods

Water content can be directly measured using a known volume of the material, and a drying oven. Volumetric water content, θ, is calculated using:

$$\theta = \frac{m_{wet} - m_{dry}}{\rho_w - V_b} \qquad 2.16$$

where

m_{wet} and m_{dry} are the masses of the sample before and after drying in the oven;

ρ_w is the density of water; and

V_b is the volume of the sample before drying the sample.

b. Laboratory Methods

Other methods that determine water content of a sample include chemical titrations (for example the Karl Fischer titration), determining mass loss on heating (perhaps in the presence of an inert gas), or after freeze drying. In the food industry the Dean-Stark method is also commonly used (Ozcep, 2005). From the Annual Book of ASTM (American Society for Testing and Materials, 2007) Standards, the total evaporable moisture content in Aggregate can be calculated with the formula:

$$P = \frac{W - D}{D} \qquad 2.17$$

where p is the fraction of total evaporable moisture content of sample, W is the mass of the original sample, and D is mass of dried sample.

c. Geophysical Methods

There are several geophysical methods available that can approximate in situ soil water content. These methods include: time-domain reflectometry (TDR), neutron probe, frequency domain sensor, capacitance probe, electrical resistivity tomography, ground penetrating radar (GPR), and others that are sensitive to the physical properties of water. Geophysical sensors are often used to monitor soil moisture continuously in agricultural and scientific applications (Tezel and Asei, 2005).

d. Satellite Remote Sensing Method

Satellite microwave remote sensing is used to estimate soil moisture based on the large contrast between the dielectric properties of wet and dry soil. The data from microwave remote sensing satellite such as: WindSat, AMSR-E, RADARSAT, ERS-1-2, Metop/ASCAT are used to estimate surface soil moisture (Honberger, et.al. 2007).

2.6 Mathematical Model.

A fundamental limitation of almost all of mathematical relationships that have been proposed and used to predict runoff from a known or assumed rainfall input is their dependence upon the concept of a lumped system. Thus, regardless of the number of components used in building the model, the parameters employed must represent an average or net effect of the particular component over the entire watershed. To obtain such a value requires knowledge of not only the particular component itself but of its complex interactions between all other components as well. In addition, unless all elements within the watershed are linear, a final or overall average coefficient will depend upon the magnitude and the time distribution of the system input; such an average may be determined only with previous knowledge of the system response to predict that response from which the average may be computed directly. Such method eliminates the need for the original lumped system model (Oyebode, 2010).

This hypothesis is fundamental though usually implicit, to all mathematical watershed models. This basic difference between implications for a lumped analysis and the one developed here-in-after is its use as a point relationship (Oyebode, 2010).

Considering the entire watershed to be composed of a composite group of essentially independent elements, it is apparent that the runoff water from one element is a source of supply or inflow to another element adjacent to it. On the basis of the above requirement of a uniform slope within an element, an assumption that all water flowing across an element moves parallel to the direction of the total outflow moving into each of the adjacent elements receiving this water is simply the percentage of the total area of the element. Basically, the proposed mathematical watershed empirical model requires the development of a runoff model for each element in the watershed.

(Oyebode, 2010) The time distribution of runoff from each watershed element may be determined by combining the various component relationship outlined with the equation of continuity:

$$I - O = \frac{\delta s}{\delta t} \qquad 2.18$$

Where t = time

I = Inflow

O = Outflow

S = volume of water in storage

For an effective usage of the continuity equation , the volume of water stored and rate of surface runoff are normally expressed in parametric form with the depth of water in the area as the parameter. This can further be expressed as

$$I_1 + I_2 - O_1 + \frac{2S_1}{t} = O_2 + \frac{2S_2}{t} \qquad 2.19$$

where I_1, I_2, O_1, O_2, S_1 and S_2 all stands for the initial and final rates of inflow, outflow and storage respectively. The composite runoff model for the whole area is obtained by starting at a known initial condition and applying equation 2.53? to determine conditions at all points in the system.

The conceptual model of surface runoff for a small watershed will result in a subdivision of the runoff cycle into several components. Each these components can independently be incorporated into the general mathematical model.

2.7 Types of soils

2.7.1 Loamy Soil

Loam is the soil material that is medium-textured. It feels as though it contains a relatively even mixture of sand, silt and clay because clay particles with their small size, high surface areas and high physical and chemical activities, exert a greater influence on soil properties than those of sand and silt. Loam soils are rather soft and friable. It has a slightly gritty feel, yet it is fairly smooth and slightly sticky and plastic when moist. Casts formed from this type of soils can be handled freely without breaking (Oyebode, 2010).

2.7.2 Clay Loam Soil

This consists of soil material having the most even distribution of sand, silt and clay of any of the soil textural grade. When felt, it feels as if it posses more clay than sand or silt. Sticky and plastic when wet, it forms casts that are firm when moist and hard when dry. The moist soil forms a thin ribbon that will barely sustain its own weight when squeezed carefully between the thumb and fingers (Oyebode, 2010) .

2.7.3 Sandy Loam Soil

Sandy loams consist of soil materials containing somewhat less sand and more silt and clay than loamy sands. As such, they possess characteristics, which fall between the finer-textured sandy clay loam and the coarser-textured loamy sands. Many of the individual sand grains can still be seen and felt, but there is sufficient silt and/or clay to give coherence to the soil so that casts can be formed that will bear careful handling without breaking (Oyebode, 2010)

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study Area

The Federal University of Technology permanent site is known to have a total land mass of eighteen thousand nine hundred hectares (18,900 ha) which is located along kilometer 10 Minna – Bida Road, South – East of Minna under the Bosso Local Government Area of Niger State. It has a horse – shoe shaped stretch of land, lying approximately on longitude of 06^0 28' E and latitude of 09^0 35' N. The site is bounded at Northwards by the Western rail line from Lagos to the northern part of the country and the eastern side by the Minna – Bida Road and to the North – West by the Dagga hill and river Dagga. The entire site is drained by rivers Gwakodna, Weminate, Grambuku, Legbedna, Tofa and their tributaries. They are all seasonal rivers and the most prominent among them is the river Dagga. The most prominent of the features are river Dagga, Garatu Hill and Dan Zaria dam (Musa, 2003).

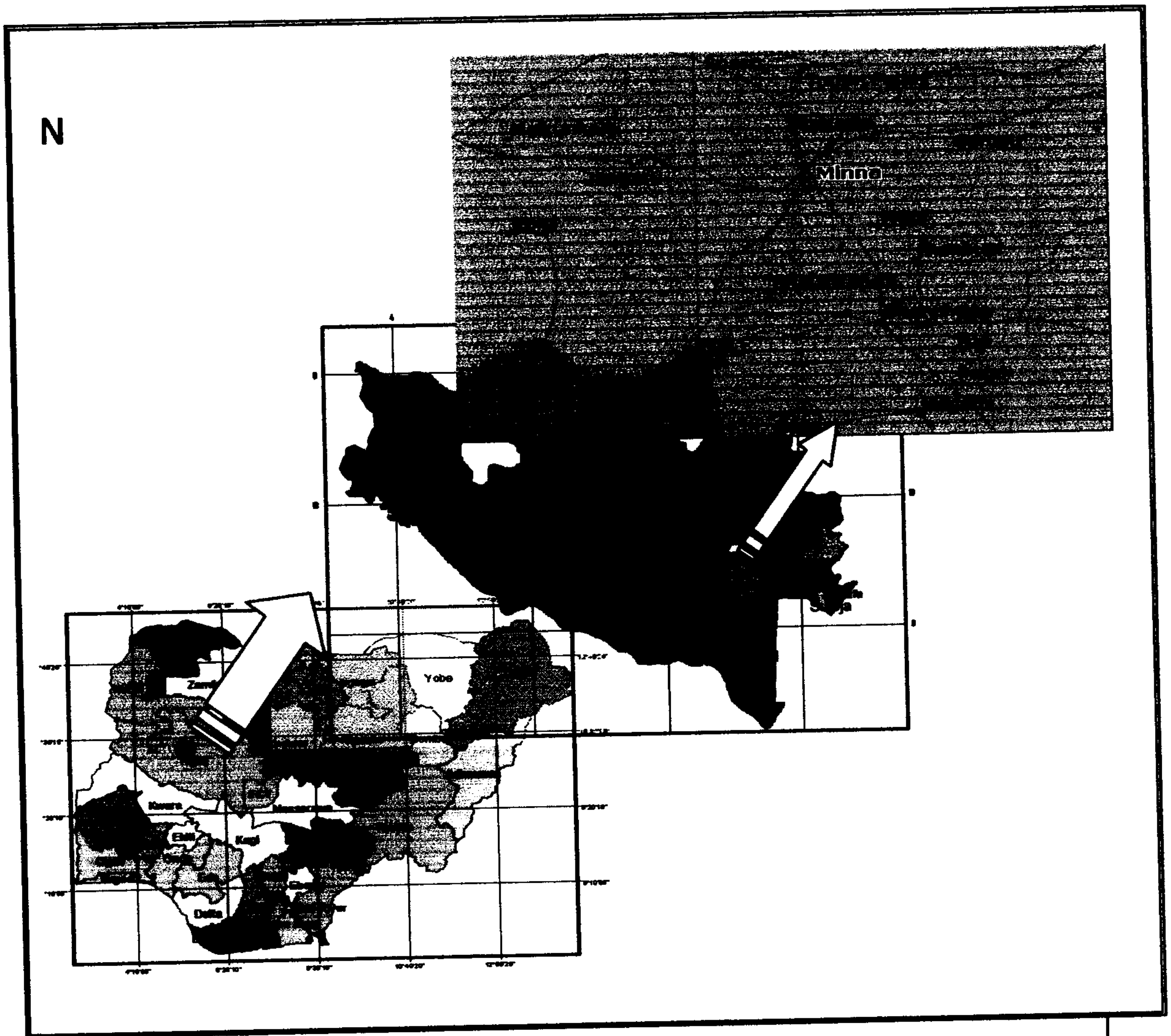
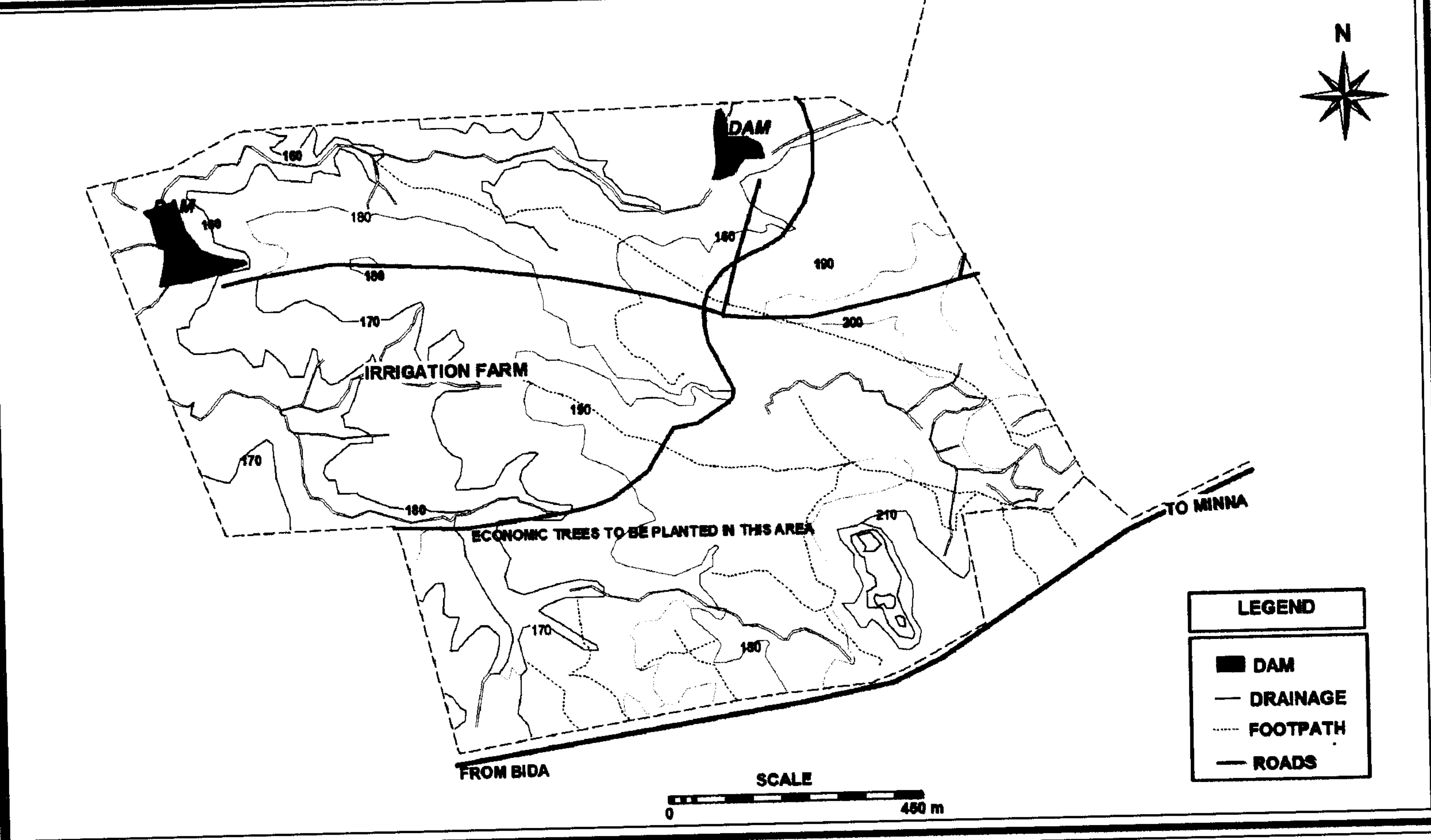


Figure 3.1: Map of Bosso Local Government Area. Niger State

FEDERAL UNIVERSITY OF TECHNOLOGY MINNA PERMANENT SITE FARM



3.1.1 Vegetation and Land Use

Minna falls within the semi-wood land or tree forest vegetation belt with derived dry grass or shrub land known as the southern guinea savannah. This is also known as the transition belt, which lies between the savannah grass/shrub land of the north and the rain forest of the south. Due to intensive fallow type of agricultural practice and grazing of the land, the area is dominated by stunted shrubs; interspersed with moderate height tree and perennial foliage. Similarly, due to human activities and land use abuse which is characteristic of most expanding urban centre in Nigeria, the site is fast losing its remaining tree species to development. Along some river course and lowland areas, the vegetation is more wooded and resembles some forest affinities. The area is still being used as farm and grazing land by the residents of Minna and her environs (Musa 2003).

3.1.2 Climate

3.1.2.1 Rainfall

Minna generally is known to experience rainfall from the month of May to the month of October and on rear occasions, to November. It is known to reach its peak between the months of July and August. Towards the end of the rainfall season, around October, it is known to be accompanied by great thunder storms (Musa, 2003).

3.1.2.2 Temperature

The maximum temperature period in this area is usually between the months of February, March and April which gives an average minimum temperature record of 33^0C and maximum temperature of 35^0C (Minna Airport Metrological Centre, 2000). During the rainfall periods, the temperature within the area drops to about 29^0C.

3.1.3 Soils of the Area

The major soil found in this area is the sandy loam type with a sparse distinction of the sandy–clay soil and sandy soils. This has so far encouraged the residents of Minna metropolis and neighboring villagers to use the land for agricultural activities such as farming and grazing by the nomadic cattle rearers (Musa, 2003).

3.2 Field Topography and Configuration

This information requires that a surveying instrument be used to measure elevations of the principal field boundaries (including dykes if present), the elevation of the water supply inlet (an invert and likely maximum water surface elevation), and the elevations of the surface and subsurface drainage system if possible. These measurements need not be comprehensive or as formalized as one would expect for a land-leveling project (Oyebode, 2010).

The field topography and geometry measurement requires placing a simple reference grid on the field, usually by staking, and then taking the elevations of the field surface at the grid points to establish slope and slope variations. Usually one to three lines of stakes placed 20-30 meters apart or such that 5-10 points are measured along the expected flow line will be sufficient. The survey establishs the distance of each grid point from the field inlet as well as the field dimensions (length of the field in the primary direction of water movement as well as field width).

3.3 Infiltration measurement

The infiltrometer rings were placed randomly from each other and the measurements were taken in centimeters per minutes. The rings were driven into the ground by hammering a wooden bar placed diametrically on the rings to prevent any blowout effects around the bottoms of the rings. In areas where ridges and furrows existed, the inner rings were always placed in the furrow. Having done that, a mat/jute sack was spread at the bottom of the inner and outer compartments of each infiltrometer to minimize soil surface disturbance when water was poured into the compartments. In grass–covered areas, they were cut as low as possible with a cutlass so that the float could have free movement and care was taken not to uproot grasses. Four sets (4) of infiltration measurements were conducted at each location of which an average was taken later.

Water was collected from the nearby storage tank using buckets. The water was therefore poured into the infiltrometer compartments simultaneously and as quickly as possible. As soon as the buckets are emptied, the water level from the inner cylinder was read from the float (rule) and the local time was noted. Repeated readings were taken at intervals of 0 minute, 1 minute, 2 minutes, 5 minutes, 10 minutes, 15 minutes, 20 minutes 30 minutes, 45 minutes, 60 minutes, 75 minutes, 90 minutes, 100 minutes and finally at 180 minutes.

3.3.1 Description of the Infiltrometer Equipment

The infiltrometer rings were rolled iron sheet of 12-guage steel and the diameters of the inner and outer rings were 300 mm and 600mm, respectively as suggested by Bambe (1995) and also by Swartzendruber and Oslo (2001). They both have a height of 250mm and the bottom ends of the ring were sharpened for easy penetration into the soil (Oyebode, 2010).

Each infiltrometer was equipped with a float consisting of a plastic rule placed perpendicularly to one face of the wooden block. This wooden block was painted to prevent it from soaking water as it floats on the water. The plastic meter rule was clamped to the inner side of the inner rings; with another sharp – edge wood placed near the rule to facilitate taking readings from the rule.

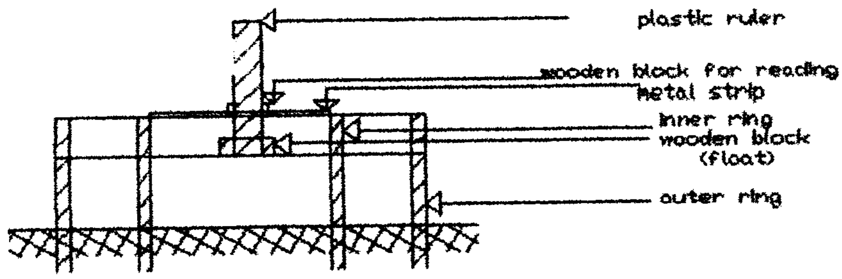


Figure 3.3: A Dissected Double Ring infiltrometer.

3. 4 Runoff Plots and Site Set-up

The exact size of each plot was the estimated size of the catchment planned for the study. Smaller dimensions were avoided, since the results obtained from very small plots are rather misleading.

Care was taken to avoid sites with special problems such as rills, cracks or gullies crossing the plot. These would drastically affect the results which would not be representative for the whole area. The gradient along the plot was regular and free of local depressions.

During construction of the plots, one out of the two plots was undisturbed and the other plot was thoroughly disturbed. A disturbed plot is one in which the structure of the soil has been changed sufficiently that test of structural properties of the soil will not be representative of in-situ conditions only properties of the grains (e.g grain size distribution, atterberg limits, and possibly the water content) can be accurately determined. An undisturbed plot is one where the condition of the soil in the plot is close enough to the condition of the soil in-situ to allow tests of structural properties of the soil to be approximate to the properties of the soil in-situ. Care was taken not to disturb or change the natural conditions of the plots such as destroying the vegetation or compacting the soil for the undisturbed soils while for the disturbed soils, every form of shrubs present on the plots were removed and the plot completely cleared of grasses.

The two project sites had a dimension of 6 X 3m each on vary slope measurements. The plots were prepared in March of 2011. Around the edge of each plot, long plywood which does not leak was placed, following the direction of the slope in a rectangular pattern to permit only runoff delivery and sediment within the experimental plot. The plywood extends 20cm above the ground surface and 10cm below the ground surface. A broad collector 1.2m long and 30cm wide was placed at the base of each of the plots to collect all the runoff and sediment produced during the simulated rain event. On the collector are spouts (15cm in diameter) through which runoff delivery empties into a collecting tank (250 litres) installed in pits just below ground level. Placed over the spout is a mesh to collect the sediment.

The plots were categorized into the disturbed and undisturbed soils for the various types of soils available within the Federal University of Technology, Minna Niger State. Records of rainfall depth for each storm were taken using a locally constructed rain-gauge.

3.5 Method of Measurement

3.5.1 Runoff Delivery and Sediment Load

After each simulated rainfall event, runoff and sediment load produced are channeled through the collector placed at the lower end of the plot. The sediment loads trapped on the collector by the mesh placed over it were scooped off into a soil bag. Sediments channeled into the tank were allowed to settle after which the runoff volume was determined. The clear water was collected with a bucket and measured with a graduated container. The sediment collected at the bottom of the tank plus the sediment collected on the collector were taken for oven drying to a constant weight. The sediment weights were determined after oven drying using a weigh balance. The sample weight divided by the area of the experimental plot gives the total soil loss from the plot. The total amounts of water collected in the container were measured and the volume was compared with the total simulated rainfall intensity within the plot area.

3.5.2.1 Soil Analysis

Soil samples were collected from each plot using a hand auger. The auger was position vertically upright on the soil surface. The handle was turned clockwise until the cylinder was full. It was lifted from the hole and the content emptied into a container. The samples were taken at a depth of 20cm. The samples were labelled before taking the next sample point.

3.5.2.2 Particle Size Analysis

The hydrometer method was used for the particle size determination. A sample (50 grams) of air dry soil was weigh into a 250ml beaker. 100ml of dispersing agent (sodium pyrophosphate solution) is added to the soil sample, mixed and allowed to soak for at least 30 minutes. The suspension is mixed for about 3 minute with a mechanical stirrer before transferring the content into a sedimentation cylinder and filled to mark with distilled water. A hand stirrer was inserted into the sedimentation cylinder to mix the content thoroughly and the time of completion of stirring was noted. A hydrometer is carefully lowered into the suspension and reading was taken after 40 seconds (R_{40}). The sands settles in about 40 seconds (silt and clay remains in suspension) and a hydrometer reading taken 40seconds determined the grams of silt and clay remaining in suspension. The hydrometer was removed and the temperature of the suspension was taken using a thermometer. The suspension was disturbed. Two hour after the final mixing of the suspension sand and silt would have settled (only clay remains in suspension). Another hydrometer and temperature reading was taken (R_{2hrs}). A blank sample containing 100ml of dispersing agent and 1 liters of distilled water was measured into a cylinder. The hydrometer was lowered into the solution carefully and readings were taken after 40 seconds (R_a) and readings after two hours (R_b). After the hydrometer readings have been obtained, the soil water mixture is poured over a screen to remove the entire sand fraction. The separated soil Percentage is calculated from

$$\% \text{ Sand} + \text{loamy} = \frac{(\text{Reading after forty seconds} - R_a) + R_c}{\text{Weight of soil}} \text{ X } 100 \qquad 3.1$$

$$\% \text{ loamy} = \frac{(R_{2hrs} - R_b) + R_d}{\text{weight of soil}} \times 100 \qquad 3.2$$

where

R_a= 40 sec, blank hydrometer reading

R_b= 2 hr, blank hydrometer reading

R_c = 40sec (Temperature × 0.360)

R_d = 2 hr correction factor (temperature × 0.36)

W = weight of soil sample used.

3.5.2.3 Soil Textural Class

The textural class was determined from the particle size analysis. After determining the distribution of sand, silt and clay from the particle size analysis, the soil was assigned a textural class based on the textural triangle. Within the textural triangle is various soil textures which depends on the relative proportion of soil particles.

3.5.3 Moisture Content

class based on the textural triangle. Within the textural triangle is various soil textures which depends on the relative proportion of soil particles.

3.5.3 Moisture Content

The weight of a clean and well labelled can was taken using a weigh balance. Soil clod was added into the can after which the weight was taken. The difference in weight between the weight of can plus clod and the weight of the can is the wet weight of the soil. The can containing the clod were taken to the laboratory for oven-drying to a constant weight at 104 ^{0}C. The can was removed from the oven, allowed to cool for several hours. After cooling the weight of the can containing the soil was taken. Weight of the dry soil is the difference in weight between the weight of the can plus soil after oven drying and the weight of the can. The moisture content was calculated as:

$$\% \text{MC} = \frac{\text{loss in weight}}{\text{weight of soil after drying}} \times 100 \qquad 3.3$$

$$\text{MC} = \frac{W_w - W_d}{W_d} \times 100 \% \qquad 3.4$$

Where

W_w= weight of wet soil (g)

W_d=weight of dry soil (g)

3.5.4 Bulk density measurement

Core sampler is commonly used to take undisturbed soil samples. The cylinder of the core sampler, which has it cutting edge, is driven into the soil and uncompacted core obtained within the tube. The samplers were carefully trimmed at both ends. Empty labelled cans were weighed, they were then filled with soil core samples and weight again and were oven dried at 110°C for about 24hrs, and samples were again weighed.

Bulk density was determined as follows;

$$\rho_b = \frac{M_s}{V_s} \qquad 3.5$$

Where;

ρ_b= bulk density (g/cm^3).

Ms = mass of dry soil (g).

Vs = volume of soil (cm^3).

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Soil

Two soil conditions were considered for this study; these conditions are undisturbed and disturbed loamy soil. A disturbed plot is one in which the structure of the soil has been changed sufficiently that test of structural properties of the soil will not be representative of in-situ conditions only properties of the grains (e.g grain size distribution, atterberg limits, and possibly the water content) can be accurately determined while an undisturbed plot is one where the condition of the soil in the plot is close enough to the condition of the soil in-situ to allow tests of structural properties of the soil to be approximate to the properties of the soil in-situ.

The disturbed soil was thoroughly disturbed even though it was dry season thus the soils were dry and hard. The soils were disturbed to depths ranging between 20 and 50cm. As a result of the thorough disturbance of the soil plots, the soils of the disturbed plots losses its structural properties and this influenced some of drainage basin characteristics. The undisturbed soil plots were left in their undisturbed state that is the properties especially the structural properties of the soil plots were not tempered with.

4.1.1 Soil Texture

Soil texture refers to the relative amounts of differently sized soil particles, or the fineness/coarseness of the mineral particles in the soil. Soil texture depends on the relative amounts of sand, silt, and clay. In each texture class, there is a range in the amount of sand, silt, and clay that class contains.

The results of the textural class of the soil in the experimental plots as determined from the department of soil science laboratory are shown in Table 4.1. which shows the different percentages of the various soil components or constituents which makes up the loamy soil. This variation in the percentages of the separate soil profile plays a significant role in influencing the hydrologic parameters. Soil properties influence the relationship between runoff and rainfall since soils are generally known to have different rates of infiltration. Based on the results obtained, they can be divided into the following horizons;

- **Horizon 0:** Soils between 0 and 20cm are having a low runoff potential due to high infiltration rates. These soils consist primarily of deep, well drained sands and gravels and little clay.
- **Horizon A:** Soils between 20 and 50cm are having a moderately low runoff potential due to moderate infiltration rates. These soils consist primarily of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures.
- **Horizon B:** Soils between 50 and 75cm are having a moderately high runoff potential due to slow infiltration rates. These soils consist primarily of soils in which a layer exists near the surface that impedes the downward movement of water or soils with moderately fine to fine texture.
- **Horizon C:** Soils between 75 and 110cm are having a high runoff potential due to very slow infiltration rates. These soils consist primarily of clays with high swelling potential, soils with permanently high water tables, soils with a clay pan or clay layer at or near the surface and shallow soils over nearly impervious parent material.

Table 4.1: Textural properties of representative soil units in Gidan Kwano and its average corresponding bulk density

Horizon	Depth (cm)	% sand	% silt	% clay	Soil type	Bulk Density (g/cm^3)
O	0-20	50	32	18	Loam	1.4528
A	20-50	58	22	20	Sandy Loam	1.45264
B	50-75	56	21	23	Sandy Clay Loam	1.42784
C	75-110	48	27	25	Sandy Clay Loam	1.39984

4.1.2 Particle Size Distribution/Analysis

The hydrometer method was used to determine the particle size. Soils generally have specific ranges of particle sizes. The smallest particles are clay particles and are classified by the USDA and FAO as having diameters of less than 0.002 mm. while the largest particles are sand particles with their diameters larger than 0.05 mm in diameter. Furthermore, large sand particles can be described as coarse, intermediate as medium, and the smaller as fine. Details of which are presented in Table 4.2 below

TABLE 4.2: Soil Classification

Name of soil separate	Diameter limits (mm) (USDA and FAO classification)
Clay	less than 0.002
Silt	0.002–0.05
Very fine sand	0.05–0.10
Fine sand	0.10–0.25
Medium sand	0.25–0.50
Coarse sand	0.50–1.00
Very coarse sand	1.00–2.00

4.2 Slope

Slope is a critical parameter controlling most translocation processes within land-scape. Its steepness is a fundamental parameter in soil erosion models. The degree of soil erosion in a particular climatic zone, with particular soils, land use and socioeconomic conditions, will always result from a combination of numbers of factors of which slope is one. The results of the slope for both disturbed and undisturbed soil plots are tabulated below.

The measured slope sizes of the various plots of loam soils around Gidan Kwano and its environs are gentle in nature. The gentility of slope may or may not encourage environmental phenomena such as soil erosion (especially accelerated soil erosion) that are highly dependent on slope. This is caused by the fact that as the slope of the drainage area increases, the velocity of overland and channel flow will increase allowing less opportunity for water to infiltrate the ground surface. Thus, more of the rainfall will become runoff from the drainage area. The maximum value of slope in degree was 3.05 which is on one of the plots (plot 6) that was undisturbed and a minimum value of 2.40 degree which is on one of the disturbed plots (plot 2) and both undisturbed and disturbed have an average slope of 3.08 and 2.48 degrees respectively.

Table 4.3: Average slope (degree) of the loamy soil type of soil areas

PLOT NUMBER	UNDISTURBED LOAM	DISTURBED LOAM
1	3.10	2.50
2	2.81	2.40
3	2.95	2.51
4	3.22	2.49
5	3.10	2.47
6	3.50	2.53
7	2.99	2.52
8	3.10	2.46
9	3.21	2.49
10	2.81	2.45
Average slope (degree)	3.08	2.48

4.3 Time of Concentration

The time of concentration is the time required for water to flow from the hydraulically most remote point of the drainage area to the point under investigation. Use of the rational formula requires the time of concentration (T_c) for each designed point within the drainage basin. T_c was computed using Federal Aviation Administration method (FAA, 1970).

The results in table 4.6 shows the average time taken for runoff within the controlled experimental plots of area 18m^2 to fill a container of volumetric capacity of 0.25m^3. The result indicates that it took approximately thrice the T_c for the 0.25m^3 container to get filled. This could be associated with the slope of the land, infiltration rate of the soil, and the characteristics of the drainage such as the surface.

It is well known that soil moisture content is a major control on catchment response; antecedent soil moisture conditions determines to extend the infiltration rate of the soil and the time of concentration which results in the prolong time required to fill a container of volumetric capacity of 0.25m^3. The result indicates that more time was required to fill the 0.25m^3 container for the disturbed soil plots than was observed for the undisturbed soil plots with an average time requirement of 41.44 minutes for the disturbed soil plots and an average time requirement of 36.80 minutes. The range of the average time requirement to fill a 0.25m^3 container for disturbed soil plots and undisturbed soil plots is 4.64 minutes which is quite an ample time.

Table 4.6: Average time for a 0.25 m^3 container to be filled up for loamy soil plots observed under various soil conditions during the dry season

PLOT NUMBER	UNDISTURBED LOAM	DISTURBED LOAM
1	33.58	37.35
2	36.42	40.10
3	37.34	41.55
4	34.27	38.48
5	39.38	43.37
6	38.15	44.26
7	38.28	42.15
8	37.49	43.35
9	35.51	41.50
10	37.56	42.25
Average Td (Mins)	36.80	41.44

4.4 Infiltration rates

The results of the average infiltration rate for loamy soil and its average cumulative values are presented in Tables 4.7 and 4.8 respectively. Infiltration is the process by which water penetrates from ground surface into the soil. Infiltration rate is governed by rainfall rate, conductivity of soil surface and vegetative cover, and ability of deeper soil profile to store and transmit incoming water.

From the Tables, it was observed that it took 180 minutes for both undisturbed and disturbed loamy soil for a steady state of infiltration to be reached. The initial infiltration rate of water into the soil was high and fast in the first fifteenth minutes and then the infiltration of water began to decrease gradually after the first twenty minutes till when there was no noticeable changes in the volume of water in the infiltrometer rings. This is due to the fact that when soil becomes saturated, rate of infiltration is observed to decrease which indicates that at that specific time (t in minutes), the soil is only taking in water which can only be transmitted down.

Once the values of the Infiltration rate are constant, the basic infiltration rate has been reached. The average infiltrations are 8.61cm/mins for the undisturbed loamy soil and 8.67cm/mins for the disturbed loamy soil and the basic infiltration rates are 4.40 cm/hr for undisturbed loamy soil and 4.20 cm/hr for disturbed loamy soil and were reached after 150 minutes. After 180 minutes their cumulative infiltration was 11.39cm. After the first 150 minutes the infiltration rate is constant: 4.40 cm/hr for undisturbed loamy soil and 4.20 cm/hr for disturbed loamy soil.

The results for the regression analysis for average infiltration and its cumulative infiltrations are shown in table 4.9 and 4.10.

Table 4.7: Average infiltration for loamy soil under the disturbed and undisturbed condition during the dry season

TIME (MINS)	UNDISTURBED LOAM	DISTURBED LOAM
0	20.00	20.00
1	17.35	18.45
2	14.25	16.28
5	13.25	14.53
10	12.10	12.59
15	10.45	9.45
20	9.10	8.18
30	8.35	8.35
45	7.55	6.55
60	6.20	5.49
75	5.00	4.59
90	4.10	4.10
100	3.10	3.57
120	2.50	2.35
150	2.20	2.10
180	2.20	2.10
Average infiltration	8.61	8.67

Table 4.8: Average Cumulative infiltration for loamy soil under the disturbed and undisturbed condition during the dry season

TIME (MINS)	UNDISTURBED LOAM	DISTURBED LOAM
0	0.00	0.00
1	2.65	2.65
2	5.75	5.75
5	6.75	6.75
10	7.90	7.90
15	9.55	9.55
20	10.90	10.90
30	11.65	11.65
45	12.45	12.45
60	13.80	13.80
75	15.00	15.00
90	15.90	15.90
100	16.90	16.90
120	17.50	17.50
150	17.80	17.80
180	17.80	17.80
Average cumulative infiltration	11.39	11.39

Table 4.9: Regression analysis of Infiltration rates for loamy soils of Gidan Kwano

Type of Soil and condition of soil		Seasonality values of R^2	Seasonality equation of the form Y = Mx +C
Soil	Condition	Dry	Dry
Loam soil	Undisturbed	0.752	$Y = -0.084X + 13.36$
	Distrubed	0.714	$Y = -0.088X + 13.64$

Table 4.10: Regression analysis of cumulative infiltration for loamy soils of Gidan Kwano

Type of Soil and condition of soil		Seasonality values of R^2	Seasonality equation of the form Y = Mx +C
Soil	Condition	Dry	Dry
Loam soil	Undisturbed	0.752	$Y = 0.084X + 6.638$
	Distrubed	0.752	$Y = 0.084X + 6.638$

4.5 Moisture Content

The results of the moisture content of undisturbed and disturbed loamy soil are presented in table 4.11. The average moisture content of the different soil conditions shows that the soil is very dry and water table had gone down due to the season (dry season). The average moisture content values for the different soil condition are 4.32% for undisturbed loamy soil condition and 4.13% for disturbed loamy soil condition. From the tabulated results, the maximum and minimum values of the moisture content are 6.94% and 1.92% which are both observed on the undisturbed loamy soil plots.

Table 4.11: Observed moisture content for dry season

PLOT NUMBER	UNDISTURBED LOAM	DISTURBED LOAM
1	4.91	3.86
2	3.52	5.22
3	4.13	3.39
4	4.32	5.54
5	4.50	6.76
6	6.94	3.44
7	5.42	2.01
8	3.01	3.72
9	4.54	4.38
10	1.92	2.96
Average MC (%)	4.32	4.13

4.6 DEVELOPING NIGERIA – MANNING COEFFICIENT

Overtimes, several numerical models have been developed by researchers to simulate the relationship between hydrologic parameters within a small watershed in different parts of the world. Based on the most recent improved numerical model which has the antecedent soil moisture variable in the model introduced by Cahill and Li (2005) but originally developed by Papadakis and Kazan (1986) from the Navier-Stroke equation, the basis was adopted to allow the simulation of sheet flow over the land surface. The overall slope of the land was fixed at 3% with a standard length of 6m to mimic the situation explored in the problem statement. The model had the following variables of;

i. length of the watershed,

ii. surface roughness (usually Manning's n),

iii. slope of the watershed, and

iv. rainfall intensity.

The model is expressed as:

$$T_c = kL^a n^b S^{-y} i^{-z} \qquad 4.1$$

where T_c is the time of concentration, L is the watershed length, n is Manning's n, S is the watershed slope, and i is the rainfall intensity. k is a constant and a, b, y, z are exponents. This equation exhibits a linear correlation of the logarithms of the variables involved.

The improved model later developed by Cahill and Li (2005) after it became obvious to them that the antecedent soil moisture of the watershed appeared to influence the runoff travel time is expressed as:

$$T_c = kL^a n^b \theta^{-x} S^{-y} i^{-z} \qquad 4.2$$

where θ is the antecedent soil moisture the new added variable, and x is an exponent of θ.

In order to develop the various exponents for Nigeria-Manning coefficient, an empirical mathematical method and Crammer's rule were employed. Details of the mathematical calculation are attached in the appendix. The model developed for this study is stated below as:

$$T_c = 0.938L^{0.878} n^{0.324} \theta^{-0.222} S^{-0.049} i^{-0.075} \qquad 4.3$$

where T_c is the time of concentration in minutes, L is the watershed length of the study area in meters, n is Manning-Nigeria's n, θ is the antecedent soil moisture in percent, S is the watershed slope, and i is the rainfall intensity in mm/hr.

From equation 4.3, making n our subject of formula we have that

$$n^{0.324} = \frac{T_c}{0.938L^{0.878}\theta^{-0.222}S^{-0.049}i^{-0.075}} \quad 4.4$$

Taking the log of both sides, we have

$$Logn^{0.324} = Log\left(\frac{T_c}{0.938L^{0.878}\theta^{-0.222}S^{-0.049}i^{-0.075}}\right) \quad 4.5$$

$$0.324Logn = Log\,T_c - 0.938\text{Log}(L^{0.878}\theta^{-0.222}S^{-0.049}i^{-0.075}) \quad 4.6$$

$$Logn = \frac{LogT_c - 0.938Log(L^{0.878}\theta^{-0.222}S^{-0.049}i^{-0.075})}{0.324} \quad 4.7$$

The equation 4.7 was used to determine the Nigeria-Manning coefficients for undisturbed and disturbed loamy soil in Gidan Kwano and environs. The values obtained were further compared with values obtained using Cahill and Li (2005), and Kerby (1959). The mathematical expressions of the above mentioned models are;

The Manning n for Cahill and Li is expressed as;

$$Logn = \frac{LogT_c - 0.951Log(L^{0.5}\theta^{-0.459}S^{-0.053}i^{-0.674})}{0.326} \quad 4.8$$

While that of Kerbys' is expressed as:

$$Logn = \left(\frac{LogT_c + 0.5LogS + 0.081}{0.467}\right) - Log\,L \quad 4.9$$

Substituting the same data obtained in the site for both undisturbed and disturbed loamy soil into equation 4.7 (equation used to determine Nigeria-Manning coefficient), equation 4.8, equation 4.9 and equation 4.10 and the results obtained were compared, it was observed that the model used to determine the Nigeria-Manning coefficients for both undisturbed loamy soils produced a better results than the others models when compared. Table 4.9 presents the developed

Nigeria-Manning coefficients for both undisturbed and disturbed loamy soils using the developed model for the soils in Gidan Kwano and those developed by Cahill and Li (2005) and Kerby (1959).

Table 4.10: Developed n values for the three models

		Manning-Nigeria model	Cahill and Li Model	Kerby's Model
Type of Soil	Condition of Soil	Dry	Dry	Dry
Loam	Undisturbed	0.09	58.88	25.53
	Disturbed	0.16	61.09	25.53

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Loamy soil within the Federal University of Technology Minna, was observed to have an average infiltration rate of 8.61cm/hr and 8.67cm/hr for disturbed and undisturbed condition of soil. This is a clear indication that the rate of movement of water into the soil is gradual and steady. This is in conformity with the works of Musa and Egherveba (2009) and Ahenaku (2010). It can therefore be concluded that the infiltration capacity for loam soils within Federal University of Technology Minna, is relatively stable over the dry season.

The developed model, $T_c = 0.938L^{0.878}n^{0.324}\theta^{-0.222}S^{-0.049}i^{-0.075}$, gave a good description of the hydrologic parameters for loam soil within the Federal University of Technology Minna. It can therefore be concluded that this model can be applied to similar loam soils with similar properties in other parts of Niger State. The FAA mothod best calculate the time of concentration for the area as it covers the entire study area of the various plots within a short period of time.

5.2 RECOMMENDATION

1. Values obtained should be tested or analyzed in different laboratories by different experts or several times, so as to make sure that the data obtained is more reliable.
2. Since the study was carried out in the dry season, more research should be done during both seasons to ascertain whether there will be significant variations in the results obtained in both seasons.

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PLATES

PLATE I: - THE RAINFALL SIMULATOR USED

PLATE II: - SITE SET-UP DISTURBED SOIL BEFORE SIMULATION

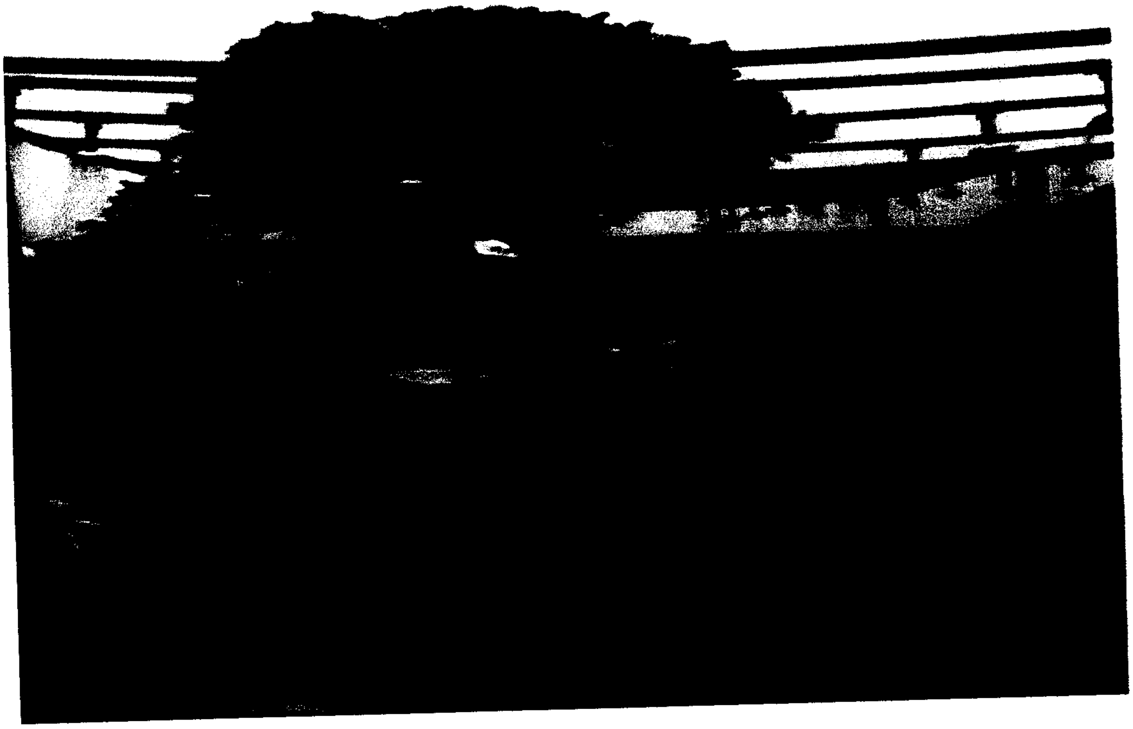

PLATE III: - SITE DURING OF SIMULATION

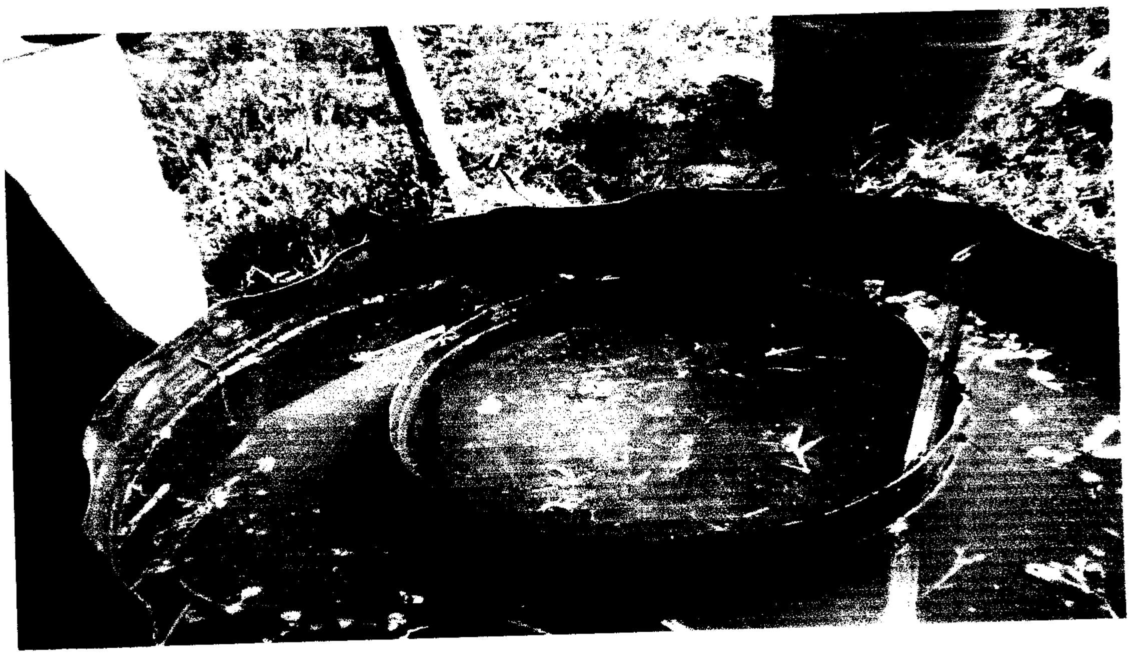

PLATE IV: - INFILTROMETER RINGS DURING INFILTRATION

LIST OF APPENDICES

MATHEMATICAL CALCULATIONS USING CRAMMER'S RULE

> $k := 0.935$

$$k := 0.935$$

> $t := \ln(9.0)$

$$t := 2.19722457$$

> $b1 := k \cdot (a \cdot \ln(22.90) + b \cdot \ln(0.0086) - y \cdot t - x \cdot \ln(142.30) - c \cdot \ln(22.90)) = \ln(13.42)$

$$b1 := 2.927613012a - 4.446853526b - 2.054404979y - 4.635671567x - 2.927613012c = 2.596746132$$

> $b2 := k \cdot (a \cdot \ln(22.90) + b \cdot \ln(0.0086) - y \cdot t - x \cdot \ln(131.67) - c \cdot \ln(22.30)) = \ln(13.51)$

$$b2 := 2.927613012a - 4.446853526b - 2.054404979y - 4.563079371x - 2.902788544c = 2.603430152$$

> $b3 := k \cdot (a \cdot \ln(22.90) + b \cdot \ln(0.0086) - y \cdot t - x \cdot \ln(165.80) - c \cdot \ln(21.10)) = \ln(12.58)$

$$b3 := 2.927613012a - 4.446853526b - 2.054404979y - 4.778581397x - 2.851070292c = 2.532108251$$

> $b4 := k \cdot (a \cdot \ln(22.90) + b \cdot \ln(0.0086) - y \cdot t - x \cdot \ln(220.30) - c \cdot \ln(45.80)) = \ln(13.26)$

$$b4 := 2.927613012a - 4.446853526b - 2.054404979y - 5.044315887x - 3.575705625c = 2.584751985$$

> $b5 := k \cdot (a \cdot \ln(22.90) + b \cdot \ln(0.0086) - y \cdot t - x \cdot \ln(235.50) - c \cdot \ln(41.10)) = \ln(13.43)$

$$b5 := 2.927613012a - 4.446853526b - 2.054404979y - 5.106699704x - 3.474467594c = 2.597491011$$

> *with*(*LinearAlgebra*) :

>

$A := [[2.927613012, -4.446853526, -2.054404979, -4.635671567, -2.927613012],$
$[2.927613012, -4.446853526, -2.054404979, -4.563079371, -2.902788544],$
$[2.927613012, -4.446853526, -2.054404979, -4.778581397, -2.851070292],$
$[2.927613012, -4.446853526, -2.054404979, -5.044315887, -3.575705625],$
$[2.927613012, -4.446853526, -2.054404979, -5.106699704, -3.474467594]]$

$A := [[2.927613012, -4.446853526, -2.054404979, -4.635671567, -2.927613012],$
$[2.927613012, -4.446853526, -2.054404979, -4.563079371, -2.902788544],$
$[2.927613012, -4.446853526, -2.054404979, -4.778581397, -2.851070292],$
$[2.927613012, -4.446853526, -2.054404979, -5.044315887, -3.575705625],$
$[2.927613012, -4.446853526, -2.054404979, -5.106699704, -3.474467594]]$

> $c1 := Determinant(A);$

$c1 := -1.171045205\,10^{-9}$

> $A1 := [[2.596746132, -4.446853526, -2.054404979, -4.635671567, -2.927613012],$
$[2.603430152, -4.446853526, -2.054404979, -4.563079371, -2.902788544],$
$[2.532108251, -4.446853526, -2.054404979, -4.778581397, -2.851070292],$
$[2.584751985, -4.446853526, -2.054404979, -5.044315887, -3.575705625],$
$[2.597491011, -4.446853526, -2.054404979, -5.106699704, -3.474467594]]$

$A1 := [[2.596746132, -4.446853526, -2.054404979, -4.635671567, -2.927613012],$
$[2.603430152, -4.446853526, -2.054404979, -4.563079371, -2.902788544],$
$[2.532108251, -4.446853526, -2.054404979, -4.778581397, -2.851070292],$
$[2.584751985, -4.446853526, -2.054404979, -5.044315887, -3.575705625],$
$[2.597491011, -4.446853526, -2.054404979, -5.106699704, -3.474467594]]$

> $c2 := Determinant(A1);$

$c2 := -1.028254250\,10^{-9}$

> $aii := \frac{c2}{c1}$

$aii := 0.878065377$

> A2 := [[2.9276130122.596746132 −2.054404979 −4.635671567
−2.927613012],
[2.9276130122.603430152 −2.054404979 −4.563079371
−2.902788544],
[2.9276130122.532108251 −2.054404979 −4.778581397
−2.851070292],
[2.9276130122.584751985 −2.054404979 −5.044315887
−3.575705625],
[2.9276130122.597491011 −2.054404979 −5.106699704
−3.474467594]]

A2 := [[2.9276130122.596746132 −2.054404979 −4.635671567
−2.927613012],
[2.9276130122.603430152 −2.054404979 −4.563079371
−2.902788544],
[2.9276130122.532108251 −2.054404979 −4.778581397
−2.851070292],
[2.9276130122.584751985 −2.054404979 −5.044315887
−3.575705625],
[2.9276130122.597491011 −2.054404979 −5.106699704
−3.474467594]]

> *c3* := *Determinant*(*A2*);

$c3 := -3.8\ 10^{-10}$

> $aiii := \frac{c3}{c1}$

$aiii := 0.3244964390$

> A3 := [[2.927613012 −4.4468535262.596746132 −4.635671567
−2.927613012],
[2.927613012 −4.446853526, 2.603430152 −4.563079371
−2.902788544],
[2.927613012 −4.446853526, 2.532108251 −4.778581397
−2.851070292],
[2.927613012 −4.4468535262.584751985 −5.044315887
−3.575705625],
[2.927613012 −4.446853526 , 2.597491011 −5.106699704
−3.474467594]]

$A3 := [[2.927613012, -4.446853526, 2.596746132, -4.635671567, -2.927613012],$
$[2.927613012, -4.446853526, 2.603430152, -4.563079371, -2.902788544],$
$[2.927613012, -4.446853526, 2.532108251, -4.778581397, -2.851070292],$
$[2.927613012, -4.446853526, 2.584751985, -5.044315887, -3.575705625],$
$[2.927613012, -4.446853526, 2.597491011, -5.106699704, -3.474467594]]$

> $c4 := Determinant(A3);$

$c4 := 2.6\ 10^{-10}$

> $aiii := \frac{c4}{c1}$

$aiii := -0.2220238790$

> $A4 := [[2.927613012, -4.446853526, -2.054404979, 2.596746132, -2.927613012],$
$[2.927613012, -4.446853526, -2.054404979, 2.603430152, -2.902788544],$
$[2.927613012, -4.446853526, -2.054404979, 2.532108251, -2.851070292],$
$[2.927613012, -4.446853526, -2.054404979, 2.584751985, -3.575705625],$
$[2.927613012, -4.446853526, -2.054404979, 2.597491011, -3.474467594]]$

$A4 := [[2.927613012, -4.446853526, -2.054404979, 2.596746132, -2.927613012],$
$[2.927613012, -4.446853526, -2.054404979, 2.603430152, -2.902788544],$
$[2.927613012, -4.446853526, -2.054404979, 2.532108251, -2.851070292],$
$[2.927613012, -4.446853526, -2.054404979, 2.584751985, -3.575705625],$
$[2.927613012, -4.446853526, -2.054404979, 2.597491011, -3.474467594]]$

> $c5 := Determinant(A4);$

$c5 := 5.85522602\ 10^{-11}$

> $aiv := \frac{c5}{c1}$

$aiv := -0.04999999990$

>

$A5 := [[2.927613012, -4.446853526, -2.054404979, -4.635671567, 2.596746132],$
$[2.927613012, -4.446853526, -2.054404979, -4.563079371, 2.603430152],$
$[2.927613012, -4.446853526, -2.054404979, -4.778581397, 2.532108251],$
$[2.927613012, -4.446853526, -2.054404979, -5.044315887, 2.584751985],$
$[2.927613012, -4.446853526, -2.054404979, -5.106699704, 2.597491011]]$

$A5 := [[2.927613012, -4.446853526, -2.054404979, -4.635671567, 2.596746132],$
$[2.927613012, -4.446853526, -2.054404979, -4.563079371, 2.603430152],$
$[2.927613012, -4.446853526, -2.054404979, -4.778581397, 2.532108251],$
$[2.927613012, -4.446853526, -2.054404979, -5.044315887, 2.584751985],$
$[2.927613012, -4.446853526, -2.054404979, -5.106699704, 2.597491011]]$

> $c6 := Determinant(A5);$

$c6 := 8.782839034\,10^{-11}$

> $av := \frac{c6}{c1}$

$av := -0.0749999999$

>