DETERMINATION OF HYDROLOGIC COEFFICIENTS OF DISTURBED CLAY SOIL

(Case study: Gidan Kwano Campus of the Federal University of Technology, Minna, Niger State)

BY

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FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA,
NIGER STATE.

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

DECEMBER, 2010

DECLARATION

I hereby declare that this project work is a record of 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 Information derived from personal communications, published and unpublished work were duly referenced in the text.

Famoriyo, Olagoke Temitope

13/12/2010.

Date

CERTIFICATION

This is to certify that the project entitled "Determination of Hydrologic Coefficeint of Disturbed Clay Soil" by Famoriyo, Olagoke Temitope 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 scientitic knowledge and literary presentation.

13/12/10

Mr John Jiya Musa
Supervisor
Date

13/12/2010

Engr. Dr A. A. Balami
Head of Department
Date

10/12/2010

External Examiner
Date

DEDICATION

Who else would I dedicate this project to if not the one who was and is and is to come, the lion of the tribe of Judah, He is the beginning and the end, the Alfa and the omega , He is the king of king , Lord of lord. He is sustainer, keeper and source of my life: JESUS CHRIST the righteous.

This journey started because you ordained it, it is ending now because you have approved it. You chose me from among the thousands just like yesterday, I graduate today. Thanks for you have never been tired with me; you love me more than anyone else. I love you lord because you are more than a father to me.

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ABSTRACT

A field portable rainfall simulator was employed to determine the surface runoff of a disturbed clay soil along with the factors that directly affected the surface runoff such as infiltration rate, moisture content, slope gradient, soil surface condition e.t.c. The rainfall simulator was used to have the replicate values of rainfall when needed. A catchment area of $18m^3$ (6m by 3m) was used on different ten (10) plot to have accurate result. The average infiltration rate of all the plot was found by using double ring infitrometer and the average slope using change in height method as well as the soil moisture content before and after the experiment was found by using gravimetric method. The time of simulation is 30 minutes. Having gotten the sufficient data, multiple linear regression was used to find the relationship between all the investigated parameters, and a simple linear mathematical model was developed to be $Y = 24.67X_1 + 213.75X_2 - 15.14X_3 + 1.61C$

Where; X_1 = Initial moisture content (%), X_2 = Infiltration rates (mm/hr), X_3 = Surface runoff (m^3) and C = Slope (Deg)

Keywords: Surface runoff ,infiltration, moisture content, slope

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CHAPTER ONE

1.0 INTRODUCTION

1.1 BACKGROUND OF THE STUDY

To understand the dynamics of surface runoff process, it constitutes one of the most important problems in hydrology, with obvious relevance for the management of agricultural and and water resources that can have both on- site and off – site detrimental effects. The impacts of surface runoff on agricultural land and water resources degradation have received the most attention; adequate knowledge of the surface runoff process is needed for among other things are (a) optimal design of water storage and drainage networks, (b) management of extreme events, such as floods and droughts, (c) determination of the rate of pollution transport, and (d) construction of roads in the farmstead. During the past few decades, a great deal of research has been devoted to the development of approaches to understand the dynamics of the surface runoff process and significant progress has been actrieved by using artificial rainfall to study the components of surface runoff such as infiltration rate, time of concentration, surface soil erosion, moisture content and sediment yield on both forest and agricultural land both in the field and in the laboratory. The major advantage of rainfall simulation research is that it is more rapid, efficient, controlled and adaptable than natural rainfall research (Meyer, 1988). In this study, a field portable rainfall simulator was employed to determine the infiltration rate, moisture content, and potential surface runoff response of disturbed sites.

1.2 STATEMENT OF THE PROBLEM

Hydrology research program requires direct measurement of erodibility, infiltration, rainfall, moisture content, dispersion, crusting and runoff at several field sites in an area. It, however, becomes difficult or rather impossible because of amount of time and labour involved in obtaining such observations from natural rainfall conditions. In addition, the natural rainstorms vary greatly in their intensity, drop size distribution and duration. It is not possible to observe replicate condition of such events. To study the effects of such 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 RESEARCH GOAL AND OBJECTIVES OF THE STUDY

(i) To determine the surface runoff co-efficient of disturbed clay soil in Gidan Kwano campus of the federal university of technology, Minna, Niger State, Nigeria. .

(ii) To develop a mathematical model or equation capable of simulating the surface hydrographs for small ungaged watershed.

(iii) To determine the relative contribution of the various components such as infiltration rate of the soil, moisture content, surface slope and roughness; and watershed slope in the generation of runoff hydrographs predicted by the model or equation.

1.4 JUSTIFICATION OF THE STUDY

Understanding the dynamics of the rainfall-runoff process constitutes one of the most important problems in hydrology, with obvious relevance for the management of water resources. Adequate knowledge of the rainfall-runoff process is needed for, among other things.

(a) Optimal design of water storage and drainage network,

(b) Management of extreme events, such as floods and droughts, and

(c) Determination of the rate pollution transport.

(d) Construction of roads in the farmstead

In Nigeria as a whole, it has been observed that we adopt other coefficient of hydrologic properties from other countries of the world to carry out design calculations for the various types of structures to construct on our various soils. Thus, such construction works end up giving way within the shortest period of time which leads to loss of lives and properties. Achieving the objectives stated above will enhance the quality of infrastructure available within the various communities, hence saving lives and properties.

1.5 SCOPE AND LIMITATION OF THE STUDY.

The scope of this research covered only Federal University of Technology, minna research farm with the view of determines:

(i) Infiltration rate of the study area and Surface runoff volume

(ii) Moisture content and slope length of the experimental plot.

The limitation of the study are the relatively short period of the data; stress of getting the necessary equipment and materials; as well as distance and accessibility of road to the site and the scope in terms of area coverage. The data were collected from a location and may be if they were to be collected over a wide area, the study will provide in sight for agricultural planning.

1.6 SIGNIFICANCE OF STUDY

The purpose of this study is to develop models that will be within Nigeria for various types of on-farm construction works, hence giving these structures a long lasting life span.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Surface Runoff

This is the water flow that occurs when soil is infiltrated 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 . 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 (Susan, 2004).

2.1.1 Meteorological Factors Affecting Runoff:

- Type of precipitation (rain, snow, sleet, etc.)
- Rainfall intensity, Rainfall duration and Amount of rainfall
- Distribution of rainfall over the watersheds
- Direction of storm movement
- Antecedent precipitation and resulting soil moisture
- Other meteorological and climatic conditions that affect evapotranspiration, such as temperature, wind, relative humidity, and season.

2.1.2 Physical Characteristics Affecting Runoff:

- Land use
- Soil type and Vegetation
- Drainage area and Basin shape
- Elevation and Slope
- Topography
- Direction of orientation

(from http://ga.water.usgs.gov/edu/runoff.html)

2.1.3 Generation:

Surface runoff can be generated either by rainfall or by 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 Beven, 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 rainfall. 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).

2.2.3.1 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 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).

2.1.3.2 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. (Susan, 2008).

2.1.3.3 Subsurface Return Flow

After water infiltrates 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 through flow (Spencer, 1997). As it flows, the amount of runoff may be reduced in a number of possible ways: a small portion of it may evapo-transpire; water may become temporarily stored in micro-topographic 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 (Nelson, 2008).

2.1.4 Effect of Surface Runoff

2.1.4.1 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. 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.

2.1.4.2 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. 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 (Spencer 1997). 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.

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.

2.1.4.3 Flooding

Flooding occurs when a water course is unable to convey the quantity of runoff flowing downstream. The frequency with which this occurs is described by a return period. Flooding is a natural process, which maintains ecosystem composition and processes, but it can also be altered by land use changes such as river engineering. Floods can be both beneficial to societies or cause damage. Agriculture along the Nile floodplain took advantage of the seasonal flooding that deposited nutrients beneficial for crops. However, as the number and susceptibility of settlements increase, flooding increasingly becomes a natural hazard. Adverse impacts span loss of life, property damage, and contamination of water supplies, loss of crops, and social dislocation and temporary homelessness. Floods are among the most devastating of natural disasters.

2.1.4.4 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. 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.

2.1.5 Measurement and Mathematical Modeling:

Runoff is analyzed by using mathematical models in combination with various water quality sampling methods. Measurements can be made using continuous automated water quality analysis instruments targeted on pollutants such as specific organic or inorganic chemicals, pH, turbidity etc. or targeted on secondary indicators such as dissolved oxygen. Measurements can also be made in batch form by extracting a single water sample and conducting any number of chemical or physical tests on that sample.

In the 1950s or earlier hydrology transport models appeared to calculate quantities of unoff, primarily for flood forecasting. Beginning in the early 1970s computer models were eveloped to analyze the transport of runoff carrying water pollutants, which considered dissolution rates of various chemicals, infiltration into soils and ultimate pollutant load delivered o receiving waters. One of the earliest models addressing chemical dissolution in runoff and resulting transport was developed in the early 1970s under contract to the United States Environmental Protection Agency (EPA)(C.M. Hogan, 1973).

2.2.0 SOIL

Soil is that thin layer of the earth made up of a mixture of mineral and organic materials, air and water formed from the underlying rocks and plant and animal material by various physical, chemical and biological process. (Areola and Mamman, 1999). The constituents of soil are minerals matter, soil organic matter, and soil air and soil water.

2.2.1 Constituents of Soil : The soil constituents comprises of mineral matter, soil organic matter, soil air and soil water

2.2.1.1 Mineral Matter

Mineral matters are solid inorganic materials in the soil include rock fragments which are undecomposed remnants of the original rock material from which the soil is formed; sand; silt and clay. In term of mineralogy, these inorganic materials comprise the remnants of undecomposed primary rock minerals such as feldspars, micas etc, clay minerals, oxide and mineral nutrient elements such as the bases, calcium, magnesium and potassium and the trace elements like sodium , iron etc.

2.1.2 Soil Organic Matter

This include the litter of fallen leaves, twigs, fruits and droppings including carcasses on e soil surface, the humus formed from the decomposition of litter mixed with the minerals articles in the soil and the population of micro-organism living in the soil which help in the reakdown of organic litter to release the nutrients stored in it to form humus.

.2.1.3 Soil Air

This acts as the "atmosphere" for roots of plants and soil micro-organisms from where ey obtain oxygen and into which they disposed unwanted gases. Soil air is replenished from ime to time from the earth's atmosphere through the process known as gaseous exchange. owever, the properties of soil air differ in some respects from those of the earth's atmosphere.

.2.1.4 Soil Water

This is the medium through which plants and many micro-organisms obtain mineral lements from the soil. Soil water is important also as a weathering and leaching agent in soils. here are different forms of soil water; the water that occupies the macro pores during or ravitational water. It is of no use to plants; rather it washes away soil materials including plant utrients.

.2.2 Soil Profile

This is the vertical section through the soil to the underlying solid rock showing layers of earth of varying colors, texture and consistency. Soil horizons are usually designated by the etters of the alphabet.

2.2.2.1 The A- Horizon

This is the layer that is in direct contact with the atmosphere and the plant and animal world. It is the zone of maximum chemical and biological activity in the soil. It is dark in nature because it contain humus and also it loses fine humus and clay and silt particles to the horizons below through the process of eluviations and referred to as an eluvia horizon.

2.2.2.2 The B- Horizon

This is the second layer of a typical soil profile. It is an alluvial horizon because most of the fine materials transferred from the A-horizon are usually deposited in it. It is generally more fined textured and compact than the A-horizon.

2.2.2.3 The C-Horizon

It is made up of the soil parent material, that is the regolith or weathered material from which the soil is formed. It has little or no organic matter and its compactness is due to precipitation of accumulated materials and water over time (Onweluzo and Omotoso, 1999).

2.3.0 SEDIMENT TRANSPORT

Sediment movement in streams and rivers takes two forms. Suspended sediment is the finer particles which are held in suspension by the eddy currents in the flowing stream, and when only settle out when the stream velocity decreases, such as when the streambed becomes flatter, or the stream discharges into a ponds or lake. Larger solid particles are rolled along the streambed and called the bedload. There is an intermediate type of movement where particles move downstream on a series of bounces or jumps, sometimes touching the bed and sometimes arried along in suspension until they fall back to the bed. This is called movement in saltation, nd is a very important part of the process of transport by wind, but in liquid flow the height of he bounces is so low that they are not readily distinguished from rolling bedload.(from AO,2002).

The relative quantities moved in suspension and as bedload vary greatly. At one extreme, where the sediment is coming from a fine grained soil such as a wind deposited losses, or an alluvial clay, the sediment may be almost entirely in suspension. On the other hand, a fast flowing clear mountain stream may have negligible amounts of suspended matter and almost all the movement by rolling gravel, pebbles and stones on the streambed. Very high concentrations of sediment, as occur in some rivers such as the Yellow River in China and the Mississippi in the USA, may cause significant changes in the rheological properties of the water. The viscosity is higher and the particle settling velocity much lower, so that the threshold between suspended sediment and bedload becomes blurred. (from FAO, 2002). There are several sources of error associated with trying to correlate the amount of sediment measured in streams with the extent of erosion within the watershed.

Firstly, there may be significant amounts of erosion taking place which do not contribute to sediment in the stream because the eroded material is deposited before it reaches the stream.

Secondly, source of error is the time factor. In larger watershed sediment may be eroded and deposited, then eroded again and redeposited, and this process could be repeated a number of times before the sediment reaches the stream. The third is that the sediment in the stream includes material which has come from several different sources with widely different delivery ratios. (from FAO,2002).

2.3.1 Estimating Suspended Load

(1) Grab Samples: The simplest way of taking a sample of suspended sediment is to dip a bucket or other container into the stream, preferably at a point where it will be well mixed, such as downstream from a weir or rock bar. The sediment contained in a measured volume of water is filtered, dried and weighted. This gives a measure of the concentration of sediment and when combined with the rate of flow gives the rate of sediment discharge. (from FAO,2002).

(2) Depth Integrating Samplers: One can allow for variation in sediment concentration at different points in the stream by using an integrating sampler that is one which gives a single sample combined from small sub-samples taken from different points. A typical sampler is illustrated in figure bellow , which consists of a glass bottle inserted in d fish shaped frame mounted on a rod when gauging small streams or suspended on a cable for larger streams.(from FAO,2002).

(3) Point Integrating Samplers: The point integrating sampler remains at a fixed point in the stream and samples continuously during the time it takes for the bottle to fill. Opening and closing the valves of the sampler are controlled from the surface electrically or by cables. Samples should be taken at a number of depths at each of several vertical sections, for the gauging of streams by the current meter method, so these two operations are often carried out at the same time.(from FAO,2002).

2.3.2 Estimating Bedload Sediment

(1) Direct Measurements: The simplest way to estimate bedload is to dig a hole in the streambed and remove; and weigh the material that drops into it. The basin upstream of a weir or flume can similarly act as a sediment trap, but it may not be known whether all the bedload has been trapped. Where heavy loads occur this process can be very time consuming and laborious.(from FAO,2002).

(2) Samplers: Estimates of bedload may be obtained from the samples caught in a device which is lowered to the streambed for a measured time then brought up for weighing the catch. Many such devices have been used, and the variety demonstrates the difficultly of taking an accurate and representative sample. The problems with bedload samplers are:

(i) The sampler disturbs the flow and changes the hydraulic conditions at the entry into the sampler.

(ii) The sampler has to be resting on the streambed and tends to dig in as scour occurs round it.

(iii) To remain stable on the bed it has to be heavy, and this restricts the use to lowering from bridges or purpose built gantries.

(iv) A sampler needs to rest on a reasonably smooth bed and not perch on large stones or boulders.

The simplest form is a wire basket with a stabilizing tail fin. The catch of such devices is low because they interfere with the flow and some material is deflected round the sampler, increasingly as the basket is fills up. This is described by saying that back pressure reduces the flow into the sampler, and this description conveys the right image without going into the mechanics of fluid flow. Some samplers have a diverging section behind the orifice, which ɪllows entry to the sampler at the surrounding stream velocity. These are called pressure difference samplers.(from FAO,2002).

(3) Radio-active Tracers: A number of studies report the use of radioactive tracers to monitor the bedload movement. The technique is to insert into the stream a radioactive tracer in a form similar to the bedload that is it should have the same shape, size and weight as the natural sediment. The movement downstream can then be monitored using portable detectors. Alternatively, the tracer can be applied to the surface of naturally occurring sediment, or it can be incorporated into artificial materials which can be made radioactive by irradiation (Tazioli 1981).

2.4.0 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 or millimeters 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. 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).

2.4.1 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, ponding 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)

2.4.2 Infiltration calculation methods

Infiltration is a component of the general mass balance hydrologic budget. There are several ways to estimate the volume and/or the rate of infiltration of water into a soil. Three excellent estimation methods are the Green-Ampt method, SCS method, Horton's method, and Darcy's law.

2.4.2.1 General hydrologic budget:

The general hydrologic budget with all the components, with respect to infiltration F, given all the other variables and infiltration is the only unknown, simple algebra solves the infiltration question.

$$F = B_I + P - E - T - ET - S - R - I_A - B_O$$

Where; F = infiltration, which can be measured as a volume or length; B_I = the boundary input, which is essentially the output watershed from adjacent, directly connected impervious areas; B_O = the boundary output, which is also related to surface runoff, R, depending on where one chooses to define the exit point or points for the boundary output; P = precipitation; E = evaporation; ET = evapotranspiration; S = the storage through either retention or detention areas;

$_A$ = the initial abstraction, which is the short term surface storage such as puddles or even possibly detention ponds depending on size; R = surface runoff.

The only note on this method is one must be wise about which variables to use and which to omit, for doubles can easily be encountered. An easy example of double counting variables is when the evaporation, E, and the transpiration, T, are placed in the equation as well as the evapotranspiration, ET. ET has included in it T as well as a portion of E.

2.4.2.2 Green-Ampt Named for two men; Green and Ampt:

The Green-Ampt method of infiltration estimation accounts for many variables that other methods, such as Darcy's law, do not. It is a function of the soil suction head, porosity, hydraulic conductivity and time.

$$\int_0^{\mathrm{F(t)}} \frac{1 - \psi\Delta\theta}{F + \psi\Delta\theta}\,\mathrm{dF} = \int_0^{t} \mathrm{Kdt}$$

Where ψ = wetting front soil suction head; θ = water content; K Hydraulic conductivity;

F = the total volume already infiltrated.

Once integrated, one can easily choose to solve for either volume of infiltration or instantaneous infiltration rate:

$$F(t) = Kt + \psi\Delta\theta \ln\left[1 + \frac{F(t)}{\psi\Delta\theta}\right]$$

Using this model one can find the volume easily by solving for F (t). However the variable being solved for is in the equation itself so when solving for this one must set the variable in question to converge on zero, or another appropriate constant. A good first guess for F is Kt. The only note on using this formula is that one must assume that h_0, the water head or the depth of ponded water above the surface, is negligible. Using the infiltration volume from this equation one may then substitute F into the corresponding infiltration rate equation below to find the instantaneous infiltration rate at the time, *t*, *F* was measured.

$$f(t) = K\left[\frac{\psi\Delta\theta}{F(t)} + 1\right]$$

(John Wiley & Sons, Inc, 2005).

2.4.2.3 Horton's equation:

Named after the same Robert E. Horton mentioned above, Horton's equation is another viable option when measuring ground infiltration rates or volumes. It is an empirical formula that says that infiltration starts at a constant rate, f_0, and is decreasing exponentially with time, *t*. After some time when the soil saturation level reaches a certain value, the rate of infiltration will level off to the rate f_c.

$$f_t = f_c + (f_0 - f_c)\, e^{-kt}$$

Where; f_t = the infiltration rate at time t; f_0 = the initial infiltration rate or maximum infiltration rate; f_c = the constant or equilibrium infiltration rate after the soil has been saturated or minimum infiltration rate; k = the decay constant specific to the soil.

The other method of using Horton's equation is as below. It can be used to find the total volume of infiltration, F, after time t.

$$F_t = f_c t + \frac{(f_0 - f_c)}{k}(1 - e^{-kt})$$

(from, Water Resources Engineering, 2005 Edition, John Wiley & Sons, Inc, 2005).

2.4.2.4 Kostiakov equation:

Named after its founder Kostiakov is an empirical equation which assumes that the intake rate declines over time according to a power function.

$$f(t) = akt^{a-1}$$

Where a and k are empirical parameters.

The major limitation of this expression is its reliance on the zero final intake rates. In most cases the infiltration rate instead approaches a finite steady value, which in some cases may occur after short periods of time. The Kostiakov-Lewis variant, also known as the "Modified Kostiakov" equation corrects for this by adding a steady intake term to the original equation.

$$f(t) = akt^{a-1} + f_0$$

in integrated form the cumulative volume is expressed as:

$$F(t) = kt^a + f_{0t}$$

Where; f_0 approximates, but does not necessarily equate to the final infiltration rate of the soil. (Walker,; Skogerboe, (1987).)

2.4.2.5 Darcy's law:

This method used for infiltration is using a simplified version of Darcy's law. In this model the ponded water is assumed to be equal to $\boldsymbol{h_0}$ and the head of dry soil that exists below the depth of the wetting front soil suction head is assumed to be equal to $-\psi - \boldsymbol{L}$.

$$f = K\left[\frac{h_0 - (-\psi - L)}{L}\right]$$

Where; h_0 = the depth of ponded water above the ground surface; K = the hydraulic conductivity; L = the total depth of subsurface ground in question. (John Wiley & Sons, Inc, 2005.).

2.4.3 Factors Influencing Infiltration: A number of factors impact soil infiltrations are;

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

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

- **Compaction:** A compacted zone (plowpan) 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.

- **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.

- **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.

- **Frozen Surface:** A frozen soil greatly slows or completely prevents water entry.

- **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.

2.5.0 RAINFALL SIMULATOR

The primary purpose of a rainfall simulator is to simulate natural rainfall accurately and precisely. Rainfall is complex, with interactions among properties (drop size, drop velocity, etc.) and large climatic variation based on topography and marine influences. Properly simulating rainfall requires several criteria:

1. Drop size distribution near to natural rainfall (Bubenzer, 1979a).

2. Drop impact velocity near natural rainfall of terminal velocity (Laws, 1941).

3. Uniform rainfall intensity and random drop size distribution (Laws and Parsons, 1943).

4. Uniform rainfall application over the entire test plot.

5. Vertical angle of impact.

6. Reproducible storm patterns of significant duration and intensity (Moore e. al., 1983)

Drop size distribution, impact velocity and reproducible storm patterns must be met to simulate the kinetic energy of rainfall. Kinetic energy (KE = mV2/2) is a single measure of the rainfall used to correlate natural storms and simulator settings. Drop size distribution depends on many storm characteristics, especially rainfall intensity. Drop size distribution varies with intensity (from less than 1 mm to about 7mm); increasing with the intensity to 2.25mm median drop size for high intensity storms (Laws and Parsons, 1943). Most design standards were based on Laws and Parson's (1943) studies. Drop velocity is important in designing a rainfall simulator. Drops from natural rainfall are at terminal velocity when they hit the soil surface (Meyer and McCune, 1958). Therefore, a rainfall simulator must create drops of adequate size and velocity to simulate the same condition, indicating the importance between an adequate and related fall distance and drop size distribution. A direct relationship exists between drop diameter and fall distance (Laws, 1941). A reproducible storm pattern is easy to simulate when a simulator can be adjusted to the desired intensities and duration. Since computers are inexpensive, a simulator can be driven by specialized software controlling the intensity and duration of the storm.

2.5.1 Desirable Characteristics of Simulated Rainfall

A rainfall simulator must be accurate and must meet all six criteria for properly simulating rainfall. Any other criteria are a matter of convenience for the user. These include weight, ease of use, reliability, accuracy and economy (Swanson et.al, 1995). The simulator and support structure should be as light as possible. Since most of the use of the simulators is in the field and on slopes, researchers should easily place them in position. Conditions in the field lead to the necessity of strong and lightweight equipment. In addition to being lightweight, the simulator should also be easy to use and setup. The support system should be adequately strong to withstand any wind and all movements of the simulator (Grierison et.al 1997). Ease of use also includes easily readable instrumentation and control systems. Proper instrumentation must be used to monitor the flow of water to the nozzles. These should be placed in such a position as to accurately measure and help regulate the inflow of water to the nozzles (Laws, 2001). Flow gages are preferred for the rainfall simulator because of the elevation differences between the points and the difficult correlation of flow rate and pressure. The control box should be built to withstand the electronic loads placed on it with a safety factor to prevent burnout. A computer-driven lab view set up is highly desirable. Reliability ties in with strength and proper instrumentation of the rainfall simulator (Hinkle, 1998). Reliability relates to the repeatability of storm events. A computer-derived storm is the most reliable because it eliminates the human error involved in altering intensities. Also, when properly monitored by the correct instrumentation, the reliability will increase or at least be as high as possible. Accuracy is achieved by creating uniform rainfall across the test plot (Meyer and Harmon,1998). When a nozzle with good drop size distribution for simulating rainfall is chosen and is placed in series with adequate spacing to allow adequate overlap lateral uniformity is achieved. When this laterally-uniform boom is swept back and forth across an area, the spray will be uniform (Thomas et.al, 1999). Properly designing and testing the boxes used for cutting off the spray is critical for creating uniform rainfall. Without question the most desirable characteristic of a rainfall simulator is its cost; it should be as low as possible. Designing a simulator must be done with cost in mind (Gunn et.al, 1999).

2.5.2 Advantages and Disadvantages of Rainfall Simulators

The main advantages are:

(i) The ability to take many measurements quickly without having to wait for natural rain.

(ii) To be able to work with constant controlled rain, thereby eliminating the erratic and unpredictable variability of natural rain.

(iii) It is usually quicker and simpler to set up a simulator over existing cropping treatments than to establish the treatments on runoff plots.

The main disadvantages are all related to scale:

(i) It is cheap and simple to use a small simulator which rains onto a test plot of only a few square meters, but simulators to cover field plots of about 100m^2 are large, expensive and cumbersome.

(ii) Measurements of runoff and erosion from simulator tests on small plots cannot be extrapolated to field conditions. They are best restricted to comparisons such as which of three cropping treatments suffers least erosion under the specific conditions of the simulator test, of the comparison of relative values of erodibility of different soil types.

(iii) Simulators are likely to be affected by wind, but having to erect windshields undermines the advantage of simplicity.

2.5.3 Applications of Rainfall Simulator

(i) In the studies of relative erodibility and studies of soil infiltration characteristics;

(iii) Erosion and surface runoff from up and down slope row crops;

(iv) The relative protection afforded at different times during the growing season.

But, some examples where rainfall simulator is not applicable are;

(i) Crops grown on a contour because the plot borders interfere with the normal water flow;

(ii) Studies of physical processes which require accurate variation of rainfall characteristics such as changes in kinetic energy or intensity;

2.5.4 Previously Developed Rainfall Simulators:

Simulators can be separated into two large groups (drop-forming simulators and pressurized nozzle simulators) (Thomas and El Swaify, 1989). Drop-forming simulators are impractical for field use since they require such a huge distance (10 meters) to reach terminal velocity (Grierson and Oades, 1977). The drop-forming simulators do not produce a distribution of drops unless a variety of drop- forming sized tubes is used. Another negative of the drop forming simulator is their limited application to small plots (Bubenzer, 1979b). Several points of raindrop production must be closely packed to create an intense enough downpour of rain. Drop forming simulators use small pieces of yarn, glass capillary tubes, hypodermic needles, polyethylene tubing, or metal tubing to form drops (Bubenzer, 1979b). Pressurized nozzle simulators are suited for a variety of uses. They can be used in the field and their intensities can be varied more than the drop forming type (Grierson and Oades, 1977). Since drops exiting the nozzles have an initial velocity greater than zero due to the pressure driving them out, a shorter fall distance is required to reach terminal velocity. Nozzle intensities vary with orifice diameter, the hydraulic pressure on the nozzle, the spacing of the nozzle and nozzle movement (Meyer, 1979). Pressurized nozzle simulators can produce variable storm intensities. A continuous spray from a nozzle creates an unnaturally intense storm. Some method of starting or stopping the spray is needed. The solution shave been a rotating disc, a rotating boom, a solenoid-controlled simulator (Miller, 1987) and an elaborate sprinkler system (Sumner et al., 1996). The simplest to use is a rotating or oscillating boom (Bubenzer, 1979b). The most popular nozzle is the Veejet 80100 nozzle run at 41 kPa (6psi). It was chosen because it most closely resembles the drop size distribution of erosive storm patterns in the Midwest (Bubenzer, 1979a). Accurate testing of nozzles must be done to ensure adequate spray coverage and uniformity in the plot.

a. The Norton Simulator: The Norton Ladder Type Rainfall Simulator is a spray boom that oscillates across a test plot at varying speeds to produce variable intensity storms. Scott McAfee and Darrel Norton designed the Norton Ladder Type Rainfall Simulator for use at the USDA National Soil Erosion Research Lab at Purdue University. Boxes around each nozzle regulate the spray for proper nozzle overlap and swath width. A clutch brake starts and stops the boom as regulated by a signal from the control box. A small gear motor drives the clutch brake and the oom. The four nozzles are supplied with water in sets of two; each set of nozzles has its own hose and pressure gauge to adjust for differences in elevation, hose orientation, etc.

The rainfall simulator uses a Spraying systems Veejet 80100 nozzle. Typical, manufacturer specified uses for this nozzle include, dust control, industrial washing applications and fire control. Its uses are high-pressure, high- velocity- high-volume water applications; all things rainfall is not. The pressure range of the nozzle is quite large, from 34 to 3400 kPa (5 to 500 psi) yielding flow rates of 13.2 to 132 Liters per minute (3.5 to35 gpm). A pressure of 41 kPa (6 psi) produces drop size and intensity similar to natural rainfall (Bubenzer, 1979a).

Most nozzles tend to produce irregular spray when used at its capacity limits due to machining differences. Thus, any differences between nozzles are amplified by the small psi used leading to a reduced uniformity. A new nozzle was needed, one with a narrower operation range, but similar drop size and intensity.

b. Non-Pressure Droppers: Many simple simulators have used the principle of drops forming and dropping from the tip of tubes connected to a water supply. The size of drop is related to the size of the tubing. Metal, glass or plastic tubing has been used or hypodermic needles which are manufactured to a high degree of accuracy. An array of tubes of different sizes may be used to produce rain of different size drops.

The advantages of this method are that the size of the drops and their fall velocity are constant, the distribution of rainfall across the test plot is uniform and can be achieved with low water pressures.

The disadvantages are that unless the device is raised up very high, the drops strike the test plot at a velocity much lower than the terminal velocity of falling rain, and therefore the values of kinetic energy are also low. A large drop of 5 mm diameter needs a height of fall of about 12 meters to reach terminal velocity and this is difficult to achieve in field conditions. To some extent this can be compensated by using larger drops than in natural rainfall. Another disadvantage is that the size of the test plot is limited by the practicalities of constructing a very large drop forming tank

c. **Pressure sprays:** The simplest possible form of spray, but which may be perfectly suitable for some simple applications, is a spray from a watering can, or the rose connected to a pressurized hosepipe (Summer et.al, 1996). Most commercial roses are drilled with all the holes of the same size, but it is easy to achieve a mixed drop distribution by drilling holes of different sizes. A basic problem with sprinklers of this type is that, like non-pressure drop formers, they only achieve a low impact velocity unless falling from a considerable height. With pressure sprays the impact velocity can be increased by pointing the spray downwards so that it leaves the nozzle with a velocity dependent on the pressure and then accelerates as it falls (Moore et.al, 1995).

Another very simple simulator using a reciprocating garden spray is. The oscillation is controlled by a simple water turbine whose rotary action is converted into simple harmonic motion. This means that the distribution is not uniform as there is a dwell at each extreme, so a test plot using this principle should be located in the central part of the spray pattern (Garierson et.al, 1997).

Many types of spraying nozzle are commercially available, some designed for other purposes and some designed especially for rainfall simulators. A major difficulty is that if the spray is to include drops of the largest size which occur in natural rain, then the nozzle opening has to be large - about 3 mm diameter. But even with low water pressures the intensity produced from nozzles of this size is higher than natural rain (Elwell and Makwanya 1980). It is therefore necessary to have some kind of interruption of the spray to reduce the intensity to that of natural rain. In Meyer's 'Rainulator' two methods were used. The spray nozzles were mounted on an overhead carriage which traversed backwards and forwards across the plot, and also the flow of water to the nozzles was switched on and off by solenoid valves. This simulator and its derivatives are very efficient, but because they were designed for operation on large plots they are complicated and expensive. Most subsequent developments have therefore been concerned with designing simpler or smaller machines. One such variation was designed by Dunne, Dietrich and Brunengo (1980) for field use in Kenya. A trolley carrying the spray nozzle is pulled backwards and forwards along an overhead track by two operators pulling on ropes.

Another approach is a machine based on a commercial rotating-boom irrigation machine. Each boom carries the water supply to a number of nozzles on each boom which rotate slowly, powered by a water turbine. The machine is set up between two test plots so that rain can be applied simulataneously to both plots. Plot lengths up to 15 m can be rained on by one machine or for longer plots two machines can be used (Swanson 1965; Hinkle 1990).

Another very popular device which has been copied and developed in many countries is the rotating disc originally designed by Morin, Goldberg and Seginer (1967). A fixed nozzle sprays continuously, but the soil is intermittently shielded from the spray. The nozzle is directed vertically downwards, and just below it is a metal disc which rotates in the horizontal plane. A radial slot is cut in the disc, and each time this passes under the nozzle a short burst of rain passes through to the plot below. The proportion of the spray which passes is determined by the angle of the slot. This design allows the use of large nozzles which give the right drop size distribution and kinetic energy but which, when spraying continuously, produce excessive intensities.

2.5.5 Practical Considerations

The main factors are power sources, water supplies and access. Most simulators need a power source for motors and pumps, the only exceptions being those using gravity. Small reliable diesel- or petrol-powered generators are available but they are not cheap, and one more thing to be carried to the site. Some small simulators can run on electricity from batteries, but lead-acid car-type batteries are heavy and awkward to carry, and dry batteries, while suitable for electronic equipment, are expensive as a power source for motors or pumps (Hinkle, 1998). Small simulators of the nozzle dropper type may need only small supplies of water because they can be targeted onto the test plot with little wastage outside the plot. Spraying systems need larger supplies, partly because they usually run at higher intensities, and also because the sprays usually cover a larger area than the test plot. It is important to calculate the amount of water which will be required, and how it is going to be delivered to the site. The spinning disc type and oscillating types can be fitted with a device to catch and recirculate the rain not going into the plot, but this has to be done without affecting the rain onto the plot. Large drops from leakages are a common problem (swanson, 1998).

Access is important. A site close to an all-weather road is so much easier to operate; indeed really large machines like the rainulator have to be able to take large trucks and trailers right to the site. But the sites to be investigated may not be easily accessible, so many simulators are designed to be carried by or operate from a four-wheel-drive vehicle (Meyer et.al, 1998).

Another practical consideration is reliability. Things never work as well in the field as when tested at the workshop. Components get dropped or bent in transit; pipes get clogged; pumps jam; motors burn out. The key is to make a field simulator as simple as possible, robust, and easy to repair and with as few moving parts as possible (Moore et.al, 1993).

2.6.0 SOIL MOISTURE CONTENT

Water content 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.

Volumetric water content, θ, is defined mathematically as:

$$\theta = \frac{V_w}{V_T}$$

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:

$$u = \frac{m_w}{m_b}$$

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. (William and Robert (1969).

2.6.1 Degree of saturation

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

$$S_w = \frac{V_w}{V_v} = \frac{V_w}{V_T \phi} = \frac{\theta}{\phi}$$

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.

2.6.2 Normalized volumetric water content

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

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

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. (Van Genuehten, (1980).

2.6.3.0 Measurement Soil Moisture Content

2.6.3.1 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:

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

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. For materials that change in volume with water content, such as coal, the water content, *u*, is expressed in terms of the mass of water per unit mass of the moist specimen:

$$u = \frac{m_{wet} - m_{dry}}{m_{wet}}$$

However, geotechnics requires the moisture content to be expressed as a percentage of the sample's dry weight i.e. % moisture content = *u* * 100, where

$$u = \frac{m_{wet} - m_{dry}}{m_{dry}}$$

(Dingman, 2002).

2.6.3.2 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. From the Annual Book of ASTM (American Society for Testing and Materials) Standards, the total evaporable moisture content in Aggregate (C 566) can be calculated with the formula:

$$p = \frac{W-D}{D}$$

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.

2.6.3.3 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. (from F. Ozcep, M. Asci, O.Tezel, T. Yas, N. Alpalan and D. Gundogdu, 2005).

2.7.0 TIME OF CONCENTRATION

The time of concentration of a watershed is often defined to be the time required for a parcel of runoff to travel from the most hydraulically distant part of a watershed to the outlet. It is not possible to point to a particular point on a watershed and say, “The time of concentration is measured from this point.” Neither is it possible to measure the time of concentration. Instead, the concept of time of concentration is useful for describing the time response of a watershed to a driving impulse, namely that of watershed runoff. In the context of the rational method then, time of concentration represents the time at which all areas of the watershed that will contribute runoff are just contributing runoff to the outlet.

That is, at time of concentration, the watershed is fully contributing. We choose to use this time to select the rainfall intensity for application of the rational method. If the chosen storm duration is larger than time of concentration, then the rainfall intensity will be less than that at time of concentration. Therefore, the peak discharge estimated using the rational method will be less than the optimal value. If the chosen storm duration is less than time of concentration, then the watershed is not fully contributing runoff to the outlet for that storm length, and the optimal value will not be realized. Therefore, we choose the storm length to be equal to time of concentration for use in estimating peak discharges using the rational method. (David, 2006).

More so, 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.

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.

2.7.1 Overland Flow - L_o

The travel time for overland flow may be determined by using the following methods as appropriate. 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. Do not use an average ground cover condition.

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.

First, determine the length of overland flow and enter the nomograph on the left axis, "Length in Feet". Intersect the "Coefficient of Imperviousness" to determine the turn point on the "Pivot" line. Intersect the "Percentage Slope" and read the travel time for overland flow.

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.

The equation is: $T_t = \frac{(0.93)L^{0.6}n^{0.6}}{i^{0.4}S^{0.3}}$

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?

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

$$The\ equation\ is\ T_t = \frac{0.007(nl)^{0.8}}{(P_2)^{0.5} s^{0.4}}$$

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). All of the values are inputted into the formula to find the travel time.

2.7.2 Shallow Concentrated Flow - L_{sc}

To calculate the travel time of shallow concentrated flow, first determine the velocity of the flow. You will need to know the slope of the shallow concentrated flow and whether the flow path is paved or unpaved. Next, calculate the travel time using the following equation:

$$T_t(minutes) = \frac{L}{60V}$$

Where: T_t = travel time (minutes); L= length of shallow concentrated flow (feet); V = velocity (feet per second)

2.7.3 Channel Flow - L_c: 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. You can either solve Manning's equation mathematically or you can use the nomograph to solve

$$\text{Manning's equation}, V = \frac{1.49r^{2/3}s^{1/2}}{n}$$

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.

2.7.4 Total Time of Concentration 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.

$T_c = L_o + L_{sc} + L_c$

2.7.5 Existing Formulas for Calculating Time of Concentration:

Izzard Formula

$$\text{time of concentration, } t_c = \frac{41L^{1/3}}{i^{2/3}}\left[\frac{0.0007i+c_r}{S^{1/3}}\right]$$

$$\text{overland flow distance, } L = \left[\frac{t_c i^{2/3} S^{1/3}}{41(0.0007i + c_r)}\right]^3$$

$$\text{retardance coefficient, } c_r = \frac{t_c i^{2/3} S^{1/3}}{41L^{1/3}} - 0.0007i$$

$$\text{slope, } S = \left[\frac{41L^{1/3}}{i^{2/3} t_c}(0.0007i + c_r)\right]^3$$

Kerby formula

$$\text{time of concentration, } t_c = 0.83[Lns^{-0.5}]^{0.467}$$

$$\text{flow length, } L = \frac{\left(\frac{t_c}{0.83}\right)^{1/0.467}}{ns^{-0.5}}$$

$$\text{retardance roughness coefficient, } n = \frac{\left(\frac{t_c}{0.83}\right)^{1/0.467}}{Ls^{-0.5}}$$

Kirpich formula

$$\text{time of concentration, } t_c = 0.0078\left(\frac{L^{0.77}}{S^{0.385}}\right)$$

$$\text{travel length, L} = \left(\frac{t_c S^{0.385}}{0.0078}\right)^{1/0.77}$$

$$\text{slope, S} = \left(\frac{0.0078L^{0.77}}{t_c}\right)^{1/0.385}$$

Kinematic wave formula

$$\text{time of concentration, } t_c = \frac{0.93L^{0.6}N^{0.6}}{i^{0.4}S^{0.3}}$$

$$\text{overland flow length, L} = \left(\frac{t_c i^{0.4} S^{0.3}}{0.93N^{0.6}}\right)^{1/0.6}$$

$$\text{Manning'soverland flow roughness coefficient, N} = \left(\frac{t_c i^{0.4} S^{0.3}}{0.93L^{0.6}}\right)^{1/0.6}$$

$$\text{rainfall, i} = \left(\frac{0.93L^{0.6}N^{0.6}}{t_c S^{0.3}}\right)^{2.5}$$

$$\text{average overland flow path slope, S} = \left(\frac{0.93L^{0.6}N^{0.6}}{t_c i^{0.4}}\right)^{1/0.3}$$

Bransby Williams Eguation

$$\text{time of concentration, } t_c = 21.3L\frac{1}{A^{0.1}S^{0.2}}$$

$$\text{channel length, L} = \frac{t_c A^{0.1} S^{0.2}}{21.3}$$

$$\text{watershed area}, A = \left(21.3L\frac{1}{t_c S^{0.2}}\right)^{10}$$

$$\text{linear profile slope}, S = \left(21.3L\frac{1}{t_c A^{0.1}}\right)^{5}$$

(Martin Wanielista, et.al, 1997).

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 kilometre 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).

3.2 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).

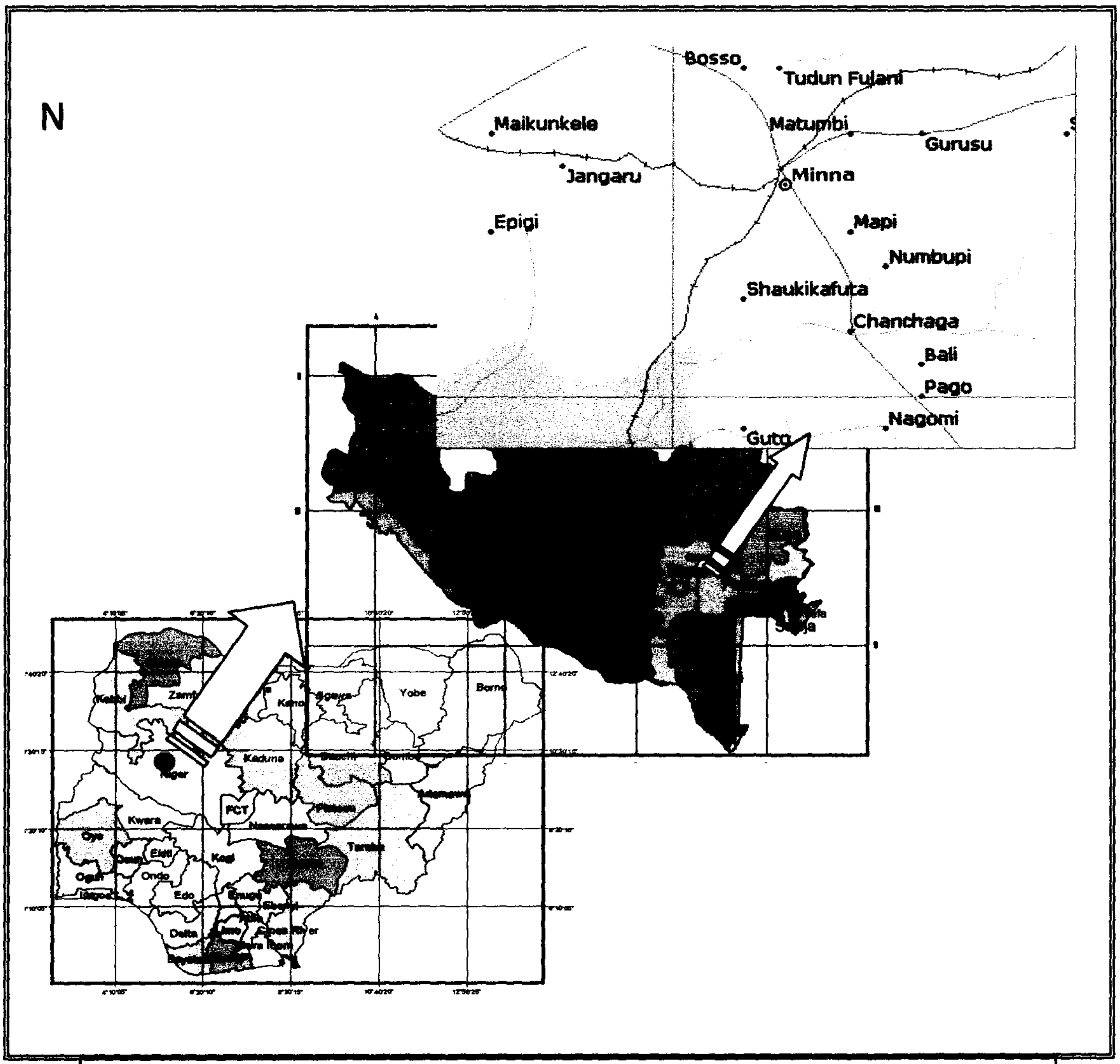

Figure 3.1: Map of Bosso Local Government Area. Niger State

3.3 Climate

3.3.1 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 f July and August. Towards the end of the rainfall season, around October, it is known to be ccompanied by great thunder storms (Musa, 2003).

.3.2 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 emperature of 35^0C (Minna Airport Metrological Centre, 2000). During the rainfall periods, the emperature within the area drops to about 29^0C.

3.4 Field Topography and Configuration

This information requires that a surveying instrument be used to measure elevations of he 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-levelling project.

The field topography and geometry should be measured. This 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. For example, a border or basin would require at most three stake lines, a furrow system as little as one, depending on the uniformity of the topography. The survey should establish 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). The important items of information that should be available from the survey are:

(1) the field slope and its uniformity in the direction of flow and normal to it;

(2) the slope and area of the field; and

(3) a reference system in the field establishing distance and elevation changes.

3.5 Area of Study

The area of study is using rainfall simulator to determine some hydrological coefficients for some soils using a surface runoff after a rainfall intensity of 30minutes within the permanent site farm of the Federal University of Technology, Minna, located along the Minna – Bida highway, Niger State Nigeria.

3.6 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 neighbouring villager to use the land for agricultural activities such as farming and grazing by the nomadic cattle rearers (Musa, 2003).

3.6.1 Types of soils

3.6.1.1 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.

3.6.1.2 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.

3.6.1.3 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.

3.6.2 Soil Sampling

Soil sampling is the only direct method for measuring soil water content. When done carefully with enough samples it is one of the most accurate methods, and is often used for calibration of other techniques. This approach requires careful sample collection and handling to minimize water loss between the times a sample is collected and processed. Replicated samples should be taken to reduce the inherent sampling variability that results from small volumes of soil. Equipment required includes a soil auger or a core sampler (with removable sleeve of known volume to obtain volumetric water content), sample collection cans or other containers, a balance accurate to at least 1 gramme and a drying oven.

Soil sampling involves taking soil samples from each of several desired depths in the root zone and temporarily storing them in water vapour-proof containers. The samples are then weighed and the opened containers oven-dried under specified time and temperature conditions (104°C for 24 hours). The dry samples are then re-weighed. Percent soil water content on a dry mass or gravimetric basis, P_w, is determined with the following formula

$$P_w = \left[\left(\frac{wet\,sample\,weight - dry\,sample\,weight}{dry\,weight\,sample}\right)\right] X 100 \qquad 3.1$$

The difference in the wet and dry weights is the weight of water removed by drying. To convert from a gravimetric basis to water content on a volumetric basis, P_v, multiply the gravimetric soil water content by the soil bulk density (BD). Soil bulk density is the weight of a unit volume of oven dry soil and usually is determined in a manner similar to gravimetric sampling by using sample collection devices which will collect a known volume of soil.

$$BD = \frac{weight\,of\,oven\,dry\,soil}{unit\,volume\,of\,dry\,soil} \qquad 3.2$$

$$P_y = P_w \; X \; BD \qquad 3.3$$

Soil water content on a volumetric percentage basis is a preferable unit for irrigation management and this is easily converted to a depth of soil water per depth of soil. Comparison of the measured volumetric soil water content with field capacity and wilting point of the soil is used to determine the available soil water and the percent of total available soil water. Either of these figures can then be used to determine if irrigation is needed.

3.6.3 Soil moisture principles

Important soil characteristics in irrigated agriculture include:

(1) The water-holding or storage capacity of the soil;

(2) The permeability of the soil to the flow of water and air;

(4) The physical features of the soil like the organic matter content, depth, texture and structure; and

(5) The soil's chemical properties such as the concentration of soluble salts, nutrients and trace elements.

The total available water, TAW, for plant use in the root zone is commonly defined as the range of soil moisture held at a negative apparent pressure of 0.1 to 0.33 bar (a soil moisture level called 'field capacity') and 15 bars (called the 'permanent wilting point'). The total available water will vary from 25 cm/m for silty loams to as low as 6 cm/m for sandy soils. Other important soil parameters include its porosity, λ, its volumetric moisture content, ω; its saturation, S; its dry weight moisture fraction, W; its bulk density, γ_b; and its specific weight, $\acute{\upsilon}_s$. The relationships among these parameters are as follows.

The porosity, λ, of the soil is the ratio of the total volume of voids or pore space, V_p, to the total soil volume V:

$$\lambda = \frac{V_P}{V} \quad 3.4$$

The volumetric water content, θ, is the ratio of water volume in the soil, V_W, to the total volume, V:

$$\theta = \frac{V_b}{V} \quad 3.5$$

The saturation, S, is the portion of the pore space filled with water:

$$S = \frac{V_w}{V_p} \quad 3.6$$

These terms are further related as follows:

$$\theta = S \; X \; \emptyset \quad 3.7$$

When a sample of field soil is collected and oven-dried, the soil moisture is reported as a dry weight fraction, W:

$$W = \frac{Wet\ Weight - Dry\ Weight}{Dry\ Weight} \quad 3.8$$

To convert a dry weight soil moisture fraction into volumetric moisture content, the dry weight fraction is multiplied by the bulk density, γ_b; and divided by specific weight of water, γ_w that can be assumed to have a value of unity. Thus:

$$\theta = \frac{\gamma_b W}{\gamma_w} \quad 3.9$$

The γ_b is defined as the specific weight of the soil particles, multiplied by the particle volume or one-minus the porosity:

$$\gamma_b = \gamma_b X (1 - \emptyset) \qquad 3.10$$

The volumetric moisture contents at field capacity, θ_{fc}, and permanent wilting point, θ_{wp}, then are defined as follows:

$$\theta_{fc} = \frac{\gamma_b W_{fc}}{\gamma_w} \qquad 3.11$$

$$\theta_{wp} = \frac{\gamma_b W_{wp}}{\gamma_w} \qquad 3.12$$

where θ_{fc} and θ_{wp} are the dry weight moisture fractions at each point.

The total available water, TAW is the difference between field capacity and wilting point moisture contents multiplied by the depth of the root zone, RD:

$$TAW = (\theta_{fc} - \theta_{wp})RD \qquad 3.13$$

3.7 Infiltration measurement

The infiltrometer rings will be placed randomly from each other and the measurement will be taken to the nearest centimetre. The rings will be 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 will always be placed in the furrow. Having done that, a mat/jute sack will be spread at the bottom of the inner and outer compartments of each infiltrometer to minimize soil surface disturbance when water will be poured into the compartments. In grass – covered areas, they will be cut as low as possible with a cutlass so that the float could have free movement and care will be taken not to uproot grasses.

Four sets (4) of infiltration measurements will be conducted at each location of which an average will be taken later.

According to Musa (2003), water will be collected from nearby canals using Jeri-cans and buckets. The water will therefore be poured into the infiltrometer compartments simultaneously and as quickly as possible. As soon as the Jeri –cans/buckets are emptied, the water level from the inner cylinder will be read from the float (rule) and the local time will be noted. Repeated readings will be taken at intervals of 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 120 minutes. The cylinder compartment will be refilled from time to time when the water level dropped half way. The water levels at both compartments (inner and outer) were constantly kept equal by adding water, as needed, into the outer compartment, which is faster. Some time will be allowed before starting another replicate measurement that no two infiltrometer will require reading the same time.

At each site, ten soil samples will be taken using the 50mm x 50mm core sampler from the surface layer (0-50cm) in the area outside the outer rings. These will be used for the determination of the initial moisture contents and bulk densities.

3.7.1 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 (1961). They both have a height of 250mm and the bottom ends of the ring were sharpened for easy penetration into the soil.

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 reading from the rule. Figure 3.2 shows a typical infiltrometer ring.

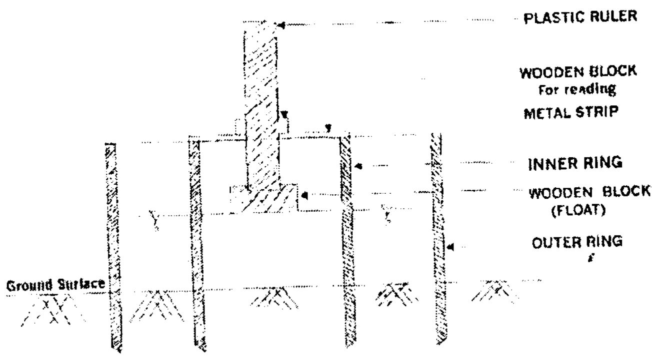

Figure 3.2: A Dissected infiltrometer Ring.

3.8 DESIGN OF A RAINFALL SIMULATOR

3.8.1 Component Parts of the Rainfall Simulator

3.8.1 Frame

The rainfall simulator frame is made of wooden planks on which the rainfall simulator rested. It is made up of a four sided frame with a dimension of 25mm. The simulator was therefore placed on top of wooden frame at a height of 1.83 m which can easily be assembled and dissembled.

Wind Shield

The wind shield which serves as a protective covering for the simulator from external wind current is made of a light transparent polythene leather. This enables system isolation which makes it possible for reproducing similar rain patterns.

3.8.2 Water Supply tank

Water supply for the simulator is supplied direct from a motorized water tanker which will feed directly to the rainfall simulator through the inlet pipe of the simulator. The quantity of water leaving the tank via the pump is regulated with the control valve attached to the pumping machine which is in-turn attached to the water tanker. The water tank capacity is 11,000,000 cm^3 which will be able to run each of the experiment for at least 4hours of continuous simulated rainfall.

3.8.3 Pump

The simulator pump that is used for this study is petrol powered one stroke engine with a rating of 2.98 KW and a volumetric flow rate of 10000 cm^3/sec which is equivalent to 0.01 m^3/sec. The pump water velocity was calculated from the formula for the mass flow rate

$$m = Q \, X \, \rho \qquad 3.14$$

where m is the mass water moving through the pump into the pipe channels which were made up of PVC within varying diameter to convey water to the simulator spray head, Q is the rate of discharge and ρ is the density of water.

Since $Q = 0.01\ m^3/sec$

$\rho = 1000kg/m^3$

Therefore, m = 0.01 X 1000

= 10 kg/sec.

From the law of mass of conservation, the mass flow rate is

$$m = \rho V A \qquad 3.15$$

Where m = mass water moving through the pipe ; ρ = density of water;

V = velocity of flow of water inside the pipe; A = area of the pipe in question.

But $A = \pi r^2$

For the first pipe with an inner diameter of 0.0381 m, the radius r of the pipe will be half the diameter

$$r = \frac{D}{2} = \frac{0.0381}{2} = 0.01905 \text{ m}$$

$$\therefore A_1 = \pi r^2$$

$= 3.142 \text{ X } 0.01905^2$

$= 3.142 \text{ X } 0.0003629025$

$= 0.001140239655 \text{ m}^2$

$= 1.1402 \text{ X } 10^{-3} \text{ m}^2$

The velocity at this point is calculated as

$$V_1 = \frac{m}{\rho A} \qquad 3.16$$

$$= \frac{10}{1000\, X\, 1.1402 X\, 10^{-3}}$$

= 8.7704 m/s

For the second pipe, a pipe diameter of 0.03175 m was used, thus $Q_1 = Q_2$.

$$\therefore A_1 V_1 = A_2 V_2$$

$$V_2 = \frac{A_1 V_1}{A_2} \qquad 3.17$$

But we know already that

$$A = \pi r^2$$

$A_2 = 3.142 X 0.015875^2$

$= 0.00079183309375\ m^2$

$= 7.9183 X 10^{-4}\ m^2$

$$V_2 = \frac{1.1402\, X\, 10^{-3}\, X\, 8.7704}{7.9183\, X\, 10^{-4}}$$

$= 12.63m^3$

At the third pipe, a diameter of 0.0254 m was used. It is worthy of note that the 10 of the 0.0254 m pipes were used which implies that the water flowing from the main and sub-main lines were further divided into ten other pipes. Thus, the quantity of water flowing through these pipes is thus reduced to 0.001 m^3/sec. Therefore, mass of flow at this point will be

$$m = Q\, X\, \rho$$

$= 1 \times 10^{-3} \times 1000$

$= 1$ kg/sec

$A_3 = \pi r^2$, where r = 0.0127 m

$= 3.142 \times 0.0127^2$

$= 5.067 \times 10^{-4}$ m^2

$$V_3 = \frac{m}{\rho A_3}$$

$$= \frac{1}{1000 \times 5.067 \times 10^{-4}}$$

$= 1.9736$ m/s

On further distribution to each of the ten pipes, a pipe diameter of 0.0127m was attached to distribute the water into the shower caps. This implies that the volume of water that will flow through each of the pipes will be 0.0002 m^3/sec.

$\therefore m = Q \times \rho$

$= 0.0002 \times 1000$

$= 0.2$ kg/sec

$A_4 = \pi r^2$

$= 3.142 \times (6.32 \times 10^{-3})^2$

$= 1.267 \times 10^{-4}$ m^2

$$V_4 = \frac{m}{\rho A_4}$$

$$= \frac{0.2}{1000\ X\ 1.267\ X\ 10^{-4}} = 1.5785\text{m/s}$$

3.8.5 Sprayer Outlet

Considering an average diameter of 2mm for the spray head area of outlet is given by

$$A_H = \pi \times r^2 \qquad 3.18$$

Where, A_H = Area of hole (m^2); r = radius of hole (m)

$= 3.142\ X\ 1\ X\ 10^6$

$= 3.142\ X\ 10^6\ m^2$

3.8.6 Number of Holes

The number of outlet holes on each of the spray head is given by dividing the pipe area of cross section by hole area of cross section

$$No\ of\ holes = \frac{Cross\ sectional\ area\ of\ pipe}{Cross\ sectional\ area\ of\ hole} \qquad 3.19$$

$$= \frac{1.267\ X\ 10^{-4}}{3.142\ X\ 10^{-6}}$$

= 40.3503184713376 holes

3.8.7 Simulator Catchments Area

Area (A_c) = $l \times b$

l = length of simulator = 6 m

b= breadth of simulator = 3 m

Area $(A_c) = 6 \times 3 = 18\ m^2$

3.8.8 Losses In The Network

In the main supply line (between pipes 1 and 2), the head loss was calculated for from

$$h_1 = \frac{kv^2}{2g} \qquad 3.20$$

Where k = a constant for a sharp inlet (o.5)

v =

g = acceleration due to gravity (9.81)

$$h_1 = \frac{0.5\ X\ 12.6263^2}{2\ X\ 9.81} = 4.06$$

In the sub main line (that is between pipes 2 and 3); the head loss is calculated as

$$h_2 = \frac{kv^2}{2g}$$

where k is a constant for tee joints is 1.8

$$h_2 = \frac{1.8\ X\ 1.9736^2}{2\ X\ 9.81} = 0.36$$

In the sub-sub-main section of the network (that is between pipes 3 and 4), we have

$$h_3 = \frac{kv^2}{2g}$$

$$h_3 = \frac{1.8\ X\ 1.5785^2}{2\ X\ 9.81} = 0.229$$

The total head loss in the network therefore is

$$H_T = \frac{4.06}{10} + \frac{0.36}{5} + 0.229$$

$= 0.406 + 0.075 + 0.229$

$= 0.71$

The final velocity at the shower caps will be

$$V = H_T V_4 \qquad 3.21$$

$= 1.5785\ X\ 0.71$

$= 1.1207$ m/s.

3.9 Runoff Plots

Runoff plots are used to measure surface runoff under controlled conditions. The plots were established directly in the project area. Their physical characteristics, such as soil type, slope and vegetation were representative of the sites where water way structures schemes are planned. The size of each plot should ideally be larger than the estimated size of the catchment planned for the study. Smaller dimensions should be avoided, since the results obtained from very small plots are rather misleading.

Care must be taken to avoid sites with special problems such as rills, cracks or gullies rossing the plot. These would drastically affect the results which would not be representative for ie whole area. The gradient along the plot should be regular and free of local depressions.)uring construction of the plot, care must be taken not to disturb or change the natural onditions of the plot such as destroying the vegetation or compacting the soil for the ndisturbed soils while for the disturbed soils, every form of shrubs present on the plots are emoved and the plot completely cleared of grasses. Several plots were constructed in series in ie project area which would permit comparison of the measured runoff volumes and to judge on ie representative character of the selected plot sites.

Around the plots wooden planks were driven into the soil with at least 15 cm of height bove ground to stop water flowing from outside into the plot and vice versa. A rain gauge was nstalled near to the plot in areas where there are no obstructions. At the lower end of the plot a utter is required to collect the runoff. The gutter should have a gradient of 1% towards the ollection tank. The soil around the gutter should be backfilled and compacted. The joint etween the gutter and the lower side of the plot may be cemented to form an apron in order to llow a smooth flow of water from the plot into the gutter. The collection tank may be onstructed from stone masonry, brick or concrete blocks, but a buried barrel will also meet the equirements. The tank should be covered and thus be protected against evaporation and rainfall. 'he storage capacity of the tank depends on the size of the plot but should be large enough to ollect water also from extreme rain storms. During the rainy season, every storm (or every day t a specific time), the volume of water collected in the rain gauge and in the runoff tank must be neasured. Thereafter the gauge and tank must be completely emptied. Any silt which may have leposited in the tank and in the gutter must be cleared.

Site Set-up

The site consists of ten plots of 6 X 3m each on vary slope measurements. The plots were prepared in April of 2010. 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 (120litres) 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. The bear/disturbed soils were carried out by treating the soil with herbicide (Glyspring). Records of rainfall depth for each storm were taken using a locally constructed rain-gauge.

3.10 Method of Measurement

3.10.1 Runoff Delivery and Sediment Load

After each simulated rainfall event, runoff and sediment load produced are channelled 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 channelled 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.

3.10.2 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.

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 ial mixing of the suspension sand and silt would have settled (only clay remains in spension). Another hydrometer and temperature reading was taken (R_{2hrs}). A blank sample ntaining 100ml of dispersing agent and 1 liter of distilled water was measured into a cylinder. ie hydrometer was lowered into the solution carefully and readings were taken after 40 seconds $_a$) and readings after two hours (R_b). After the hydrometer readings have been obtained, the il water mixture is poured over a screen to remove the entire sand fraction. The separated soil ercentage is calculated from

$$Silt + Clay = \frac{(Reading\ after\ forty\ seconds - R_a) + R_c}{Weight\ of\ soil} X\ 100 \qquad 3.22$$

$$\text{Clay} = \frac{(R_{2hrs} - R_b)\ + \text{R}_\text{d}}{\text{weight of soil}} \times 100 \qquad 3.23$$

Vhere, R_a= 40 sec, blank hydrometer reading

$_b$= 2 hr, blank hydrometer reading

$_c$ = 40sec (Temperature × 0.360)

$_d$ = 2 hr correction factor (temperature × 0.36)

V = weight of soil sample used.

.10.3 Soil Textural Class

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

.10.4 Moisture Content

The weight of a clean and well labeled can was taken using a weigh balance. Soil clod vas added into the can after which the weight was taken. The difference in weight between the veight of can plus clod and the weight of the can is the wet weight of the soil. The can ontaining the clod were taken to the laboratory for oven-drying to a constant weight at 105 C or 24 hours. The can was removed from the oven, allowed to cool for several hours. After ooling the weight of the can containing the soil was taken. Weight of the dry soil is the ifference in weight between the weight of the can plus soil after oven drying and the weight of he can. The moisture content was calculated as:

$$\% \text{ MC} = \frac{\text{loss in weight}}{\text{weight of soil after drying}} \times 100 \qquad 3.24$$

$$\text{MC} = \frac{W_w - W_d}{W_d} \times 100\,\% \qquad 3.25$$

where , W_w= weight of wet soil (g)

W_d=weight of dry soil (g)

CHAPTER FOUR

.0 RESULTS AND DISCUSSION

.1. Soil Analysis

The process of agricultural development involves identifying existing constrain to gricultural production and subsequently providing a technical or management solution to these roblems The physical observation of the area showed that the study area was discovered to be a redominately farm land which is being used by the university for research study as well as the urrounding local inhabitants of the area who are farmers and some staffs of the university. The rea is occupied also by the cattle rearers who move from one section of the land to another in earch of green pastures for their cattle.

Table 4.1 shows the various soil properties for ten different soils where surface runoff test was carried out. It was observed that the soil particles had varying percent of soil properties with plot 3, 8 and 9 have the highest clay percent of 57, sand percent of 17,24 and 15 as well silt percent of 26, 19 and 28 respectively while plot 5 had the lowest percent of clay of 46 with a sand percent of 22 and percent silt was also 32. The mean percent value of the various areas for clay was calculated to be 53.2%, sand was 23.6% and silt was23.2%. The soil water textural classification software was used to obtain the actual texture of the soil properties obtained from the field. It was also observed from the software that the soil characteristics showed that wilting point was 30.3%, a field capacity of 43.8% and soil saturation of 53.2%. When this result was compared with the other classification from for other results such as that of Adesoye and

Partners (1984), it was discovered that there was a strong correlation between the two results which implies that the soil is clay in nature.

Table 4.1: Percent distribution of the various properties of clay soil

Plot No	% Sand	%Clay	%Silt
1	33	49	18
2	25	56	19
3	17	57	26
4	17	50	33
5	22	46	32
6	39	49	12
7	32	56	12
8	24	57	19
9	15	57	28
10	12	55	33
Mean	23.6	53.2	23.2

4.2 Moisture Content

Table 4.2 shows the percent water content for the various plots of disturbed clay soil under consideration before the experiment. It was observed that percent water retained in the soil as very high because of the nature of the soil with plot 2 having the lowest percent of 30.0 and lot 8 having the highest of 34.9 percent. From Table 4.1, it was observed that plot 2 had 25% ınd content, 56% clay content while the silt content was 18%. Plot 8 is observed from Table 4.1 ı have 24% sand, 57% clay and 19% silt content. The results that were obtained were compared ıith the works of Musa (2003), Eze (2000) and Sanni (1999). They were discovered that they ıere close and highly comparable.

'able 4.2: Percent moisture content before the experiment

Plot No	Weight of Wet Soil (Kg)	Weight of Dry Soil (Kg)	Weight of Water (Kg)	Moisture Content (%)
1	0.230	0.159	0.071	30.9
2	0.250	0.175	0.075	30.0
3	0.220	0.150	0.070	31.8
4	0.250	0.171	0.079	31.6
5	0.267	0.180	0.087	32.6
6	0.258	0.173	0.085	32.9
7	0.248	0.164	0.084	33.9
8	0.235	0.153	0.082	34.9
9	0.268	0.185	0.083	31.0
10	0.256	0.172	0.084	32.8
Average	0.243	0.1655	0.078	31.8

Table 4.3 shows the percent moisture content of the various soils after the experiments had been carried out. Plot 8 showed the highest value of percent water retained to be 37.6% while plot 2 had the lowest of 31.9%. On comparing results of Table 4.3 with the soil analysis of Table 4.1, it was observed that plot 8 had 24% sand content, 57% clay content and 19% silt content. Though the area in question showed some element of water retention capability which means that water has the tendency of flowing on the surface within the shortest time. The mean value of the percent moisture content was calculated to 19.35.

Table 4.3:- Percent moisture content after the experiment

Plot No	Weight of Wet Soil (Kg)	Weigt of Dry Soil (Kg)	Weight of Water (Kg)	Moisture Content (%)
1	0.240	0.161	0.079	32.9
2	0.270	0.184	0.086	31.9
3	0.250	0.164	0.086	34.4
4	0.263	0.174	0.089	33.8
5	0.275	0.176	0.099	36.0
6	0.284	0.182	0.102	35.9
7	0.253	0.163	0.090	35.6
8	0.258	0.161	0.097	37.6
9	0.288	0.192	0.096	33.3
10	0.283	0.184	0.099	35.0
Average	0.262	0.1725	0.089	33.9

4.3 Infiltration Rate

Table 4.4 shows the average infiltration rate and the average cumulative infiltration for the various plots under consideration. It was observed that the infiltration for the various soils experienced a drop 15 minutes into its determination but picked up at 50 minutes into the process but became steady as from the 60th minute of the infiltration rate. A total cumulative infiltration of 35mm of water was used. This shows that movement of water through the soil was quite slow which has a possible implication of a different type of soil underlying the surface soil which was considered to be sandy in textural classification. Theses was compared with the works of Musa and Egharevbe (2009), who in their work stated that there are possibility of some hard pan or rocks underlying some areas of the Gidan Kwano soils of the Federal University of Technology, Minna.

Table 4.4: Average infiltration rate and cumulative infiltration.

S/No	Time (Mins)	Average Infiltration Rate (Mm/Min)	Cumulative Infiltration Rate
1	0	0.00	0.00
2	5	6.30	6.3
3	10	5.30	1.16
4	15	4.50	16.10
5	20	4.00	2.01
6	25	3.40	23.5
7	30	2.90	26.40
8	35	2.30	28.70
9	40	1.90	30.60
10	45	1.40	32.00
11	50	1.00	33.00
12	55	1.00	34.00
13	60	1.00	35.00

4.4 Slope

Various slope sizes were considered when carrying out the work which shows the rate of follow of water on the soil surface. Table 4.5 shows the various slope sizes that were considered in percentages and its conversion to degrees. It was observed that plots 5, 4 and 10 had the highest degrees, these were closely followed by plots 2 and 1.the plot that had the lowest value slope was plot 7.

Table 4.5: Slope size for the various plots

Plot	Slope (%)	Slope (Deg)
1	16.67	2.77
2	33.33	2.81
3	50.00	2.61
4	66.67	2.87
5	83.33	2.90
6	100.00	2.70
7	116.67	2.50
8	133.33	2.65
9	150.00	2.75
10	166.67	2.87

4.5 Surface Runoff

Table 4.6 shows the total amount of water collected as surface runoff within a period 30 minutes of dispense of water from the rain simulator. It was observed that the highest values of surface runoff were recorded from plot 7 while the lowest values were recorded from plots 5 and 10 while the mean value of the surface runoff was calculated as 0.1949 m^3.

Table 4.6: Surface runoff for the various plots

Plot	Surface Runoff(M^3)
1	0.2
2	0.1997
3	0.2002
4	0.2013
5	0.1899
6	0.2102
7	0.2221
8	0.2159
9	0.2
10	0.1899
Average	**0.1949**

4.6 Hydrologic Coefficient, C

The transformation of rainfall into runoff over a catchment area is a complex hydrological phenomenon, as this process is highly nonlinear, time varying and spatially distributed. To simulate this process, a number of models have been developed across the world ut not specifically for some soils in Nigeria thus making some of our water and other civil tructures fail. Depending on the complexities involved, these models are categorised as mpirical, black box, conceptual or physically based distributed models.

A model was derived using the excel Microsoft word of 2007 for clay soils(disturbed) in he Gidan Kwano area of Minna, Niger State. The parameters that were considered includes the initial moisture content of the soil of the various areas considered, infiltration rate, surface runoff and the slope of the area. Table 4.7 below shows the various parameters which was used to obtain the equation of the form $Y = MX_n + C$

From table 4.7, equation for the determination of hydrologic coefficient of Clay soils (undisturbed) in Gidan kwano and environs was determined through Multiple linear regression of the hydrologic parameters to be; $Y= 24.67X_1 + 213.75X_2 -15.14X_3 +1.61C$

Where; X_1 = Initial moisture content (%),

X_2 = Infiltration rates (mm/hr),

X_3 = Surface runoff (m^3) and

C = Slope (Deg)

This implies that when values for X_1, X_2, and X_3 are fixed into the equation a coefficient will be obtained for clay soil within the Federal University of Technology, Minna provided they have the same soil properties. It can be observed that the value of intercept of the equation obtained above is negative.

Table 4.7 Parameters for the determination of hydrologic coefficient

Initial moisture content (%)	Infiltration rates (cm/hr)	Surface runoff (m3)	Time of surface runoff (second)	slope of the plot (θ)
31	3.5	0.1998	85	2.77
30	3.4	0.1995	86	2.81
32	3.3	0.2000	83	2.61
31.5	3.6	0.1987	87	2.87
30.5	3.55	0.1807	82	2.90
33	3.7	0.2100	81	2.70
34	3.65	0.2219	88	2.50
32.8	3.5	0.2157	85	2.65
30.9	3.53	0.1998	83	2.75
33	3.49	0.1897	89	2.87

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATION

5.1 Conclusion

It is important to note from the statistical analysis obtained from the sites that there is a relative contribution of the various hydrologic parameters such as infiltration, surface slope, roughness and watershed shape in the generation of mathematical equation used to determine the coefficient for disturbed clay soil.

The research work was able to develop a mathematical model capable of simulating the surface hydrograph from small gauged watershed and the determination of the surface runoff coefficient suitable for disturbed clay soil, although the efficacy of this mathematical model and runoff coefficient could not be determined since the scope of the research work does not involve validation using natural scenario of soil in question.

5.2 Recommendation

In the application of this research work, the following research areas are recommended

Samples obtained should be tested or analyzed in different laboratories by different experts or veral times, so as to make sure that the data obtained is more reliable.

Since the study was carried out in the dry season, more research should be done during both asons to ascertain whether there will be significant variations in the obtained in both seasons.

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LIST OF PLATES

Plate 1: Construction of Rainfall Simulator

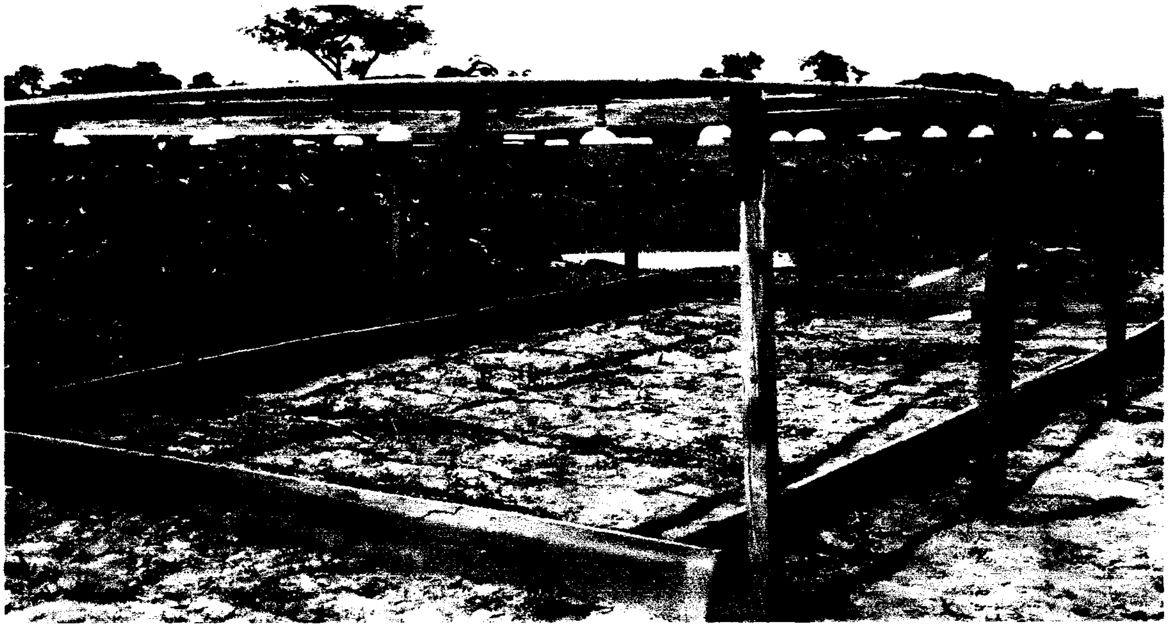

Plate 2 : Before the Experiment

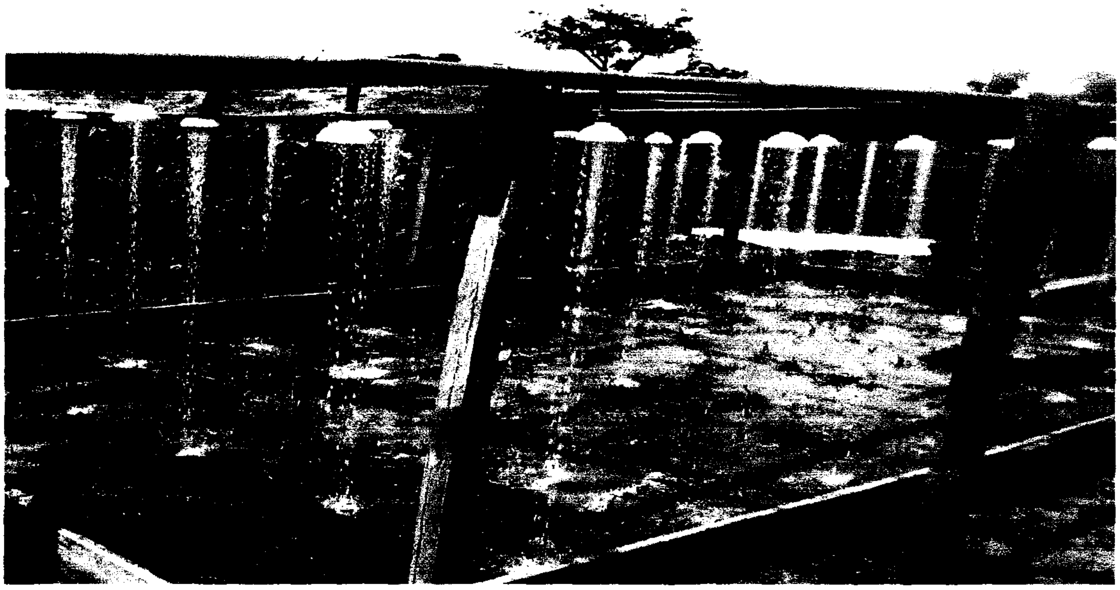

Plate 3: During the Experiment

Plate 4: After the Experiment

LISTS OF APPENDICES

Appendices I: Determination of Slope

Plot	Height 1	Height 2	H2-H1	Slope (%)	Slope (Deg)
1	1.023	1.313	0.290	4.83	2.77
2	1.016	1.310	0.294	4.90	2.81
3	1.017	1.290	0.273	4.55	2.61
4	0.987	1.288	0.301	5.02	2.87
5	0.888	1.192	0.304	5.07	2.90
6	1.046	1.329	0.283	4.72	2.70
7	0.976	1.238	0.262	4.37	2.50
8	0.934	1.212	0.278	4.63	2.65
9	1.203	1.491	0.288	4.80	2.75
10	0.644	0.945	0.301	5.02	2.87
Average				4.93	2.82

Appendices II: Infiltration Rate

Time	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8	Plot 9	Plot10
5	0.63	0.6	0.61	0.64	0.64	0.65	0.65	0.63	0.63	0.62
10	0.53	0.5	0.51	0.54	0.54	0.55	0.55	0.53	0.53	0.52
15	0.45	0.4	0.43	0.46	0.46	0.47	0.47	0.45	0.45	0.44
20	0.40	0.4	0.38	0.41	0.41	0.42	0.42	0.4	0.40	0.39
25	0.34	0.3	0.32	0.35	0.35	0.36	0.36	0.34	0.34	0.33
30	0.29	0.3	0.27	0.30	0.30	0.31	0.31	0.29	0.29	0.28
35	0.23	0.2	0.21	0.24	0.24	0.25	0.25	0.23	0.23	0.22
40	0.19	0.2	0.17	0.20	0.20	0.21	0.21	0.19	0.19	0.18
45	0.14	0.1	0.12	0.15	0.15	0.16	0.16	0.14	0.14	0.13
50	0.10	0.1	0.08	0.11	0.11	0.12	0.12	0.1	0.10	0.09
55	0.10	0.1	0.08	0.11	0.11	0.12	0.12	0.1	0.10	0.09
60	0.10	0.1	0.08	0.11	0.11	0.12	0.12	0.1	0.10	0.09
Average	3.5	3.4	3.3	3.6	3.6	3.7	3.7	3.5	3.5	3.4

ppendices III: Average and Cumulative Infiltration Rate of The Soil

S/No	Time (Mins)	Average Infiltration Rate	Cummulative Infiltration Rate
1	5	0.63	0.63
2	10	0.53	1.16
3	15	0.45	1.61
4	20	0.40	2.01
5	25	0.34	2.35
6	30	0.29	2.64
7	35	0.23	2.87
8	40	0.19	3.06
9	45	0.14	3.20
10	50	0.10	3.30
11	55	0.10	3.40
12	60	0.10	3.50

ppendices IV: Surface Runoff

Plot	Length (H) cm	Length(H)m	Surface Runoff(m^3)
1	81.16	0.8116	0.2000
2	81.03	0.8103	0.1997
3	81.24	0.8124	0.2002
4	81.71	0.8171	0.2013
5	77.05	0.7705	0.1899
6	85.3	0.8530	0.2102
7	90.13	0.9013	0.2221
8	87.61	0.8761	0.2159
9	81.15	0.8115	0.2000
10	77.05	0.7705	0.1899
Average			0.1949

ppendices V: Moisture Content Before the Experiment

Plot No	Weight of Wet Soil (Kg)	Weight of Dry Soil (Kg)	Weight of Water (Kg)	Moisture Content (%)
1	0.230	0.159	0.071	30.9
2	0.250	0.175	0.075	30.0
3	0.220	0.150	0.070	31.8
4	0.250	0.171	0.079	31.6
5	0.267	0.180	0.087	32.6
6	0.258	0.173	0.085	32.9
7	0.248	0.164	0.084	33.9
8	0.235	0.153	0.082	34.9
9	0.268	0.185	0.083	31.0
10	0.256	0.172	0.084	32.8
Average	0.243	0.1655	0.078	31.8

pendices VI: After the Experiment

Plot No	Weight of Wet Soil (Kg)	Weight of Dry Soil (Kg)	Weight of Water (Kg)	Moisture Content (%)
1	0.240	0.161	0.079	32.9
2	0.270	0.184	0.086	31.9
3	0.250	0.164	0.086	34.4
4	0.263	0.174	0.089	33.8
5	0.275	0.176	0.099	36.0
6	0.284	0.182	0.102	35.9
7	0.253	0.163	0.090	35.6
8	0.258	0.161	0.097	37.6
9	0.288	0.192	0.096	33.3
10	0.283	0.184	0.099	35.0
Average	0.262	0.1725	0.089	33.9

ppendices VII: Rainfall Data (3yrs) 2007-2009

	J	F	M	A	M	J	J	A	S	O	N	D
07	0.0	0.0	0.4	73.1	156.6	123.9	314.0	310.1	330.2	115.1	0.0	0.0
08	0.0	0.0	0.0	40.2	146.8	132.7	305.1	244.3	258.9	141.2	0.0	0.0
09	0.0	0.0	0.0	89.9	101.4	108.9	246.8	497.6	273.5	85.2	0.0	0.0

urce: Nigeria meteorological center