DETERMINATION OF HYDROLOGIC COEFFICIENT OF UNDISTURBED SILTY SOIL
(CASE STUDY OF GIDAN KWANO CAMPUS, FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGER STATE)

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FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA

DECEMBER, 2010.

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BEING A FINAL YEAR PROJECT SUBMITTED IN PARTIAL
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NIGER STATE

DECEMBER, 2010.

DECLARATION

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 Information derived from personal communications, published and unpublished work were duly referenced in the text.

Olanrewaju, Olalekan Sarafadeen

14/12/2010
Date

CERTIFICATION

This is to certify that the project entitled "Determination of Hydrologic Coefficient of Undisturbed Silty Soil (Case study of Gidan Kwano Campus, Federal University of Technology, Minna, Niger State)" by Olanrewaju, Olalekan Sarafadeen meets the regulations governing the award of the degree of Bachelor of Engineering (B. ENG.) of the Federal University of Technology, Minna and it is approved for its contribution to scientific knowledge and literary presentation.

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Date

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Date

External Examiner

10\12\2010
Date

DEDICATION

This project is dedicated to God Almighty for his Love and mercy over me from the first day of my life till this moment and to my loving brother, mentor and hero: Dr. O. A. Adekunle whom God has used and still using in diverse ways to build my career.

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Thanks be to God Almighty the builder of this bridge for his blessings, love and mercy upon me right from the first day of my life till this moment.

I want to thank my supervisor, Engr. John J. for His guidance, direction and good supervision during this project. I wish to appreciate all the lecturers of Agricultural and Bioresources Engineering Department and other lecturer in school of Engineering and Engineering Technology, Federal University of Technology, Minna, who impacted knowledge to me, and not to forget all my primary and secondary schools teachers. God bless you all.

The story of my life would never be completed without mentioning the name of my priceless brother, mentor, adviser, confidant and friend; the person of Alhaji, Dr. O. A. Adekunle. Sir, no word is enough to describe how valuable you are to me and the entire family, because living a successful life does not necessary mean being rich, it involves giving one's offspring and relatives a good legacy and impacting positively on the society; a feat rare in modern day Nigerians and would take and amazing glory of God for an individual to achieve. But many who have had the opportunity of crossing your path will testify to this without missing word. Sir, ay you live-long and longer to reap the fruit of your labour. Thanks a million.

My profound gratitude goes to my lovely father of blessed memory and to the best mother that would ever be; Alhaja Olanrewaju A. B. (Iyaoloorire) who serious laboured to laid this solid foundation. Mama, may you live longer in good health to enjoy the fruit of your labour.

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Adekunle F. M. Miss. Olanrewaju Sakirat, Miss. Idowu Adeola Naimat, Oyewole Jummy and to my pals: Hammed Taofeeq, Olanrele Ganiyu, Ayo Bayo, Akorede Nurudeen, Ganiyu Ismail, Hammed Olanipekun, Kazeem Ticko, Olaleye Ayodeji and host of other numerous to mention. Am indebted to you all.

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ABSTRACT

It is very obvious that the absence of our own indigenous hydrologic coefficient is one of the factors responsible for the persistent deterioration of our on – farm structures and other civil construction works. This poor state of affair can be curtailed, if a coefficient that best suites our own types of soil can be developed. To this effect, an equation was developed after a careful consideration of all factors that directly affect runoff, such as infiltration rate, moisture contents, slope, soil surface condition, surface runoff and also the type of soil. A rainfall simulator was used to obtained replicate events and a catchment area of 18m^2 was used and ten (10) replicate of the catchment area was investigated to have an accurate result. The type of soil used was found to be silty soil after a thorough analysis of the soil sample. The mean cumulative infiltration rate of the ten plots was found to be 31.5cm/hr using a double rings infiltrometer. The mean slope was found to 3.92^0 (6.86%) using the change in height method. The mean moisture contents before and after the simulation were found to be 21.98% and 29.96% respectively using the gravimetric method while the mean surface runoff was 0.196m ^{3}. And after a careful consideration of these parameters a coefficient was developed for an undisturbed silty soil in Gidan Kwano campus of Federal University of Technology, Minna.

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CHAPTER ONE

1.0 INTRODUCTION

Rainfall is the primary source of water for runoff generation over the land surface. In common course of rainfall occurrence, over the land surface, a part of it is intercepted by the vegetations, buildings and other objects, lying over the land surface and pavement to reach them on ground surface, this process is called interception. When all these losses are satisfied, then excess rainfall moves over the land surface and reaches to the smaller rills, known as overland flow. It again involves building of greater storage over the land surface and draining the same into channels or streams which is termed as runoff (Saresh, 2006).

1.1 Background to the Study

As a watershed begins to accept precipitation, surface vegetation and depressions intercept and retain a portion of that precipitation. Precipitation that does not contribute to basin recharge is direct runoff. Direct runoff consists of surface runoff (overland flow) and subsurface runoff (interflow), which flows into surface streams. The basin recharge rate is at its maximum at the beginning of a storm, and decreases as the storm progresses (Saresh, 2006).

The determination of the volume and rate of movement of surface water within watershed is the fundamental step upon which the design of reservoirs, channel improvement, erosion control structures and servers as well as agricultural, highway and various drainage systems is based. Quantitatively describing the rate and path of movement of a rain droplet after it strikes the ground surface is essential for the rational development and efficient utilization of our nation's water resources.

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

Some of the more common methods of describing the hydrologic performance of a watershed have been based upon years of rainfall records and the resulting runoff from each storm. Though, a great number of water control projects must be designed and installed on smaller watersheds where little or no past hydrologic records are available.

The concept of integrated watershed runoff coefficient has emerged as a new understanding for the interactions between the surface and subsurface pathways of water. This defines the bidirectional linkage that implies the main rationale for the unity of the two systems. In this regard, surface flow processes such as channel and overland flow are integrated to subsurface flow process in the unsaturated and saturated groundwater flow zones via the dynamic interactions at the ground surface and channel beds. Only with this kind of approach can one determine a standard coefficient for some major soils in a watershed.

1.2 Statement of Problem

To develop a coefficient that is adaptive to soils in this part of the world so as to prevent if not to eliminate the frequent problem of structure failure.

1.3 Objectives of the Study

1. To determine the surface runoff coefficient for an undisturbed silty soil on Gidan Kwano soil.

2. To develop a mathematical model or equation capable of simulating the surface hydrograph from small unguarded watershed.
3. To determine the relative contribution of various components such as infiltration, surface slope, roughness and watershed shape in the generation of runoff hydrograph 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 resource. Adequate knowledge of the rainfall-runoff process is needed for among other things,

(a) Optimal design of water storage and drainage networks.

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

(c) Determination of the rate of pollution transport

In Nigeria as a whole, it has been observed that we adopt other coefficients of hydrology properties from other countries of the world to carryout design calculations for the various types of on-farm construction works. Such construction works end up giving way within the shortest period of time resulting to loss of lives and properties.

Achieving the objectives stated earlier will enhance the quality of infrastructure available within the various communities hence saving lives and properties

1.5 Scope of the Study

The scope of this project is limited to the modeling and determination of hydrologic coefficient for an undisturbed silty soil in a small watershed, a case study of the permanent site the Federal University of Technology, Minna. This will look at standardizing a basic coefficient for silty soil used in Minna for various construction works

1.6 Significance of the Study

The purpose of this study is to develop a hydrologic coefficient that will be used within Nigeria for various types of on-farm construction works and thereby giving these structures a long lasting life span.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction

Rainfall is the primary source of water for runoff generation over the land surface. In common course of rainfall occurrence, over the land surface, a part of it is intercepted by the vegetations, buildings and other objects, lying over the land surface and pavement to reach them on ground surface, this process is called interception. When all these losses are satisfied, then excess rainfall moves over the land surface and reaches to the smaller rills, known as overland flow. It again involves building of greater storage over the land surface and draining the same into channels or streams which is termed as runoff (Saresh, 2006).

2.2 Runoff

The term runoff is a descriptive term which is used to denote that part of the hydrologic cycle which falls between the phase of precipitation and its subsequent discharge in the stream channels or direct return to the atmosphere through the process of evaporation and evapotranspiration.

Before runoff in a watershed can actually take place there must be a dry period and at the end of the dry period, there begins an intense and isolated storm. During this stage, all surface and channel storages get depleted, except in reservoirs, lakes and ponds, from the previous storms. Under this condition, the source of stream flow is only the ground water flow which decreases with time. After the beginning of rainfall and before saturation of interception is the depression storage. Here every precipitation falls directly on the land surface or on stream surface which provides an immediate increment of stream flow (Saresh, 2006).

2.2.1 Types of Runoff

Based on the time delay between rainfall and runoff, it may be classified into the following types:

a. Surface Runoff

b. Sub-surface Runoff

c. Base flow

2.2.1.1 Surface Runoff

Surface runoff is that portion of rainfall, which enters the stream immediately after the rainfall. It occurs, when all losses are satisfied and if rain is still continued, with the rate greater than infiltration rate, at this stage the excess water makes a head over the ground surface (surface detention), which tends to move from one place to another is known as overland flow. As soon as the overland flow joins to the streams, channels or ocean's, it is therefore called surface runoff (Saresh, 2006).

2.2.1.2 Sub-Surface Runoff

According Saresh (2006), sub-surface runoff is that part of rainfall which first leaches into the soil and moves laterally without joining the water table, to the streams, rivers, or oceans is thus known as sub-surface runoff.

2.2.1.3 Base Flow

This is the delayed flow, defined as that part of rainfall which after falling on the ground surface, infiltrated into the soil and meets the water table and flow to the streams, oceans, etc, the movement of this type of runoff is usually slow and that is why it is referred to as the delayed runoff (Saresh, 2006).

Thus, total Runoff = surface Runoff + Base flow (including sub-surface runoff)

2.2.2 Factors Affecting Runoff

The factors affecting runoff may be divided into those factors which are associated with the climate of the area and those associated with the watershed (physiographic factors).

2.2.2.1 Climatic Factors

Climate factors of the watershed affecting the runoff are mainly associated with the characteristics of precipitation which includes:

i) **Type of Precipitation:** The various types of precipitation within a given watershed have a great effect on the runoff. Precipitation which occurs in form of rainfall starts immediately in form of surface flow over the land surface depending upon its intensity as well as magnitude, while precipitation which takes the form of snow or hails, the flow of water on ground surface will not take place immediately, but after melting of the same. During the process of melting, the time interval of the melted water infiltrates into the soil and results in a very little surface runoff generation (Saresh, 2006).

ii) **Rainfall Intensity:** One of the most important rainfall characteristics is rainfall intensity, which is usually expressed in millimeters per hour. Very intense storms are not necessarily more frequent in areas having a high total annual rainfall. Storms of high intensity generally last for fairly short periods and cover small areas. Storms covering large areas are seldom of high intensity but may last several days. The infrequent combination of relatively high intensity and long duration gives large total amount of rainfall (Saresh, 2006).

A general expression for rainfall intensity is given by $i = \frac{KT^x}{t^n}$ where i is the rainfall intensity, K, x and n are constants for a given geographic location, t is the duration of storm in minutes and T is the return period in years.

iii) **Rainfall Distribution:** Runoffs from a watershed depends on the rainfall distribution. The rainfall distribution of this purpose can be expressed by the term distribution coefficient, which may be defined as the ratio of maximum rainfall at a point to the mean rainfall of the watershed. For a given total rainfall, if all other conditions are the same, the greater the value of distribution coefficient, greater will be the peak runoff and vice-versa. However for the same distribution coefficient, the peak runoff would be resulted from the storm, falling on the lower part of the basin i.e. near the outlet (Saresh, 2006).

iv) **Direction of Prevailing Wind:** The direction of wind affects greatly the runoff flow. If the direction of prevailing wind is same as the drainage system then it has a great influence on the resulting peak flow and also on the duration of surface flow, to reach the outlet. A storm moving in the direction of the stream slope produces a higher peak in shorter period of time, than a storm moving in opposite direction (Garg, 2005).

v) **Temperature:** The process of evaporation depends mainly on temperature. If the temperature is more, the saturation vapour pressure increases, and the evaporation increases. Thus, evaporation is more during the dry season than when compared with the rainy season (Garg, 2005).

vi) **Wind Velocity:** The process of evaporation depends upon the prevailing turbulence in the air which further affects the available water on the earth surface. If the turbulence is more or in other words if the velocity of the air in contract with water surface is more, the saturated film of air contacting the water vapour will move easily, and the diffusion and dispersion of vapour will become easier, causing more evaporation hence reducing the surface runoff (Garg, 2005).

2.2.2 Physiographic Factors

The following are the different characteristics of watershed and channel which affect runoff:

(i) Size of Watershed

Assuming the depth and intensity and all other factors remaining constant, then two watersheds irrespective of their size will produce about the same amount of runoff. However, a large watershed takes longer time for draining the runoff to the outlet, as a result the peak flow expressed as depth, is being smaller and vice-versa.

(ii) Shape of Watershed

The shape of watershed has a great effect on runoff. The watershed shape is generally expressed by the terms 'form factor' and compactness coefficient.

Form factor is defined as the ratio of average width to the axial length of the watershed, expressed as:

$$\text{Form Factor} = \frac{\textit{Average width of the watershed}}{\textit{Axial length of the watershed}} = \frac{B}{L} \qquad 2.1$$

Axial length (L) of the watershed is the distance between outlet and remotest point of the area, while the average width (B) is obtained by dividing the area (A) with the axial length (L) of the watershed.

$$\text{Thus, form factor} = \frac{B}{L} = \frac{A/L}{L} = \frac{A}{L^2} \qquad 2.2$$

The compactness coefficient of watershed is the ratio of perimeter of the watershed to the circumference of a circle, whose area is equal to the area of the watershed. This is expressed as:

$$= \frac{\textit{Perimeter of the watershed}}{\textit{Circumference of a circle whose area is equal to the watershed}} = \frac{P}{2\sqrt{\pi A}} \qquad 2.3$$

Where: P = perimeter of watershed

A = Area of watershed

Π = 3.142

In respect of the watershed shape, there are two types of watersheds shape, which are commonly assumed, in which one is fan shaped and the other is fern shape. The fan shape watershed tends to produce higher peak rate of runoff very early than the fern shape, due to the fact that in the former all parts of the watershed contribute runoff to the outlet simultaneously, a short period of time, than the fern shaped watershed.

(iii) Slope of Watershed

The slope of the watershed has an important role over runoff, but its effect is complex. It controls the time of overland flow and time of concentration of rainfall in the drainage channel, which provide a cumulative effect on resulting peak runoff. An example of which is when you have a steep slope in a watershed, the time to reach the flow at outlet is less, because of greater runoff velocity, which results into formation of peak runoff very soon and vice versa.

(ix) Drainage Density

This is the ratio of the total channel length in the watershed to the total watershed area which is expressed as:

$$Drainage\ Density = \frac{Channel\ length\ (total)}{watershed\ area} = \frac{L}{A} \qquad 2.4$$

2.2.3 Others

2.2.3.1 Infiltration

Infiltration can be described as a 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 (Horton, 1993).

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 (Horton, 1993).

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 (Horton, 1993).

2.2.3.1.1 Infiltration Calculation Methods

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

(1) 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.

$$\int_{\theta}^{F(t)} \frac{1-\psi\Delta\theta}{F+\psi\Delta\theta}\, dF = \int_{0}^{t} K\, dt \qquad 2.5$$

Where:

ψ is wetting front soil suction head

θ is water content

K is Hydraulic conductivity

F is the total volume already infiltrated

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

$$F(t) = Kt + \psi\Delta\theta ln\left[1 + \frac{F(t)}{\psi\Delta\theta}\right] \qquad 2.6$$

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.

$$f(t) = K\left[\frac{\psi\Delta\theta}{F(t)} + 1\right] \qquad 2.7$$

(2) 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.

$$f_i = f_c + (f_0 - f_c)e^{-kt} \qquad 2.8$$

Where:

f_i is the infiltration rate at time t,

f_o is the initial infiltration rate or maximum infiltration rate

f_c is the constant or equilibrium infiltration rate after the soil has been saturated or minimum infiltration rate;

k is the decay constant specific of 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.

$$F_t = f_c t + \frac{(f_o - f_c}{k}(1 - e^{-kt}) \qquad 2.9$$

(3) Kostiakov equation

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

$$f(t) = akt^{a-1} \qquad 2.10$$

Where a and k are empirical parameters

The major limitation of this expression is its reliance on the zero final intake rate. 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.

$$f(t) = akt^{a-1} + f_0 \qquad 2.11$$

In integrated form the cumulative volume is expressed as:

$$F(t) = kt^0 + f_0 t \qquad 2.12$$

Where

f_0 approximates, but does not necessarily equate to the final infiltration rate of the soil.

(4) 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 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 $-\psi$-L.

$$f = K\left[\frac{h_0-(-\psi-L)}{L}\right], \qquad 2.13$$

Where

h_0 is the depth of ponded water above the ground surface;

K is the hydraulic conductivity

L is the total depth of subsurface ground in question.

In summary all of these equations provided a relatively accurate assessment of the infiltration characteristics of the soil in question.

2.3 Methods Of Surface Runoff Estimation

A storm event is generally characterized by its size and the frequency of its occurrence. The size of the storm is the total precipitation that occurs in a specified duration. How often this size storm is likely to repeat is called the frequency. The peak discharge resulting from a given rainfall is particularly influenced by the rainfall distribution, which describes the variation of the rainfall intensity during the storm duration. A rainfall may have been evenly distributed over the 24 hours period or the majority of it may have come in just a few hours, which is typical. These two scenarios present entirely different types of rainfall distributions and peak discharges.

Several techniques have been available for the estimation of runoff volume and peak discharge. These vary from simplified procedures such as the Rational Formula for small, homogenous areas, to complicated computer programs that can handle more complex situations. Some of the common methods are:

2.3.1. Runoff Coefficients

The volume of runoff can be directly computed approximately by using the equation

$$Q = KP \qquad 2.14$$

Where

Q = Runoff

P = Precipitation

K = a constant having a value less than 1 or at the most equal to 1.

The value of K depends upon the imperviousness of the drainage area. Its value increases with the increase in imperviousness of the catchments area, and may approach unity (1.0), as the area becomes fully impervious.

Though equation 2.14 cannot be rational because the runoff does not only depend upon the precipitation but also upon the recharge of the basin. But this equation gives more and more reliable results as the imperiousness of the drainage basin area increases and the value of K tends to approach infinity (Garg, 2005).

This formula is commonly used in the design of storm water drains and small water control projects, especially for urban area, where the percentage of the impervious area is quite high. This method of computing runoff should be avoided for rural areas and for analysis of major storms. Over time runoff coefficient had been developed by many researchers. The following are some of the basic coefficients which over time had been developed upon:

a. Manning Formula

The Manning formula, known also as the Gauckler-Manning formula, or Gauckler Manning Strickler formula in Europe, is an empirical formula for open channel flow, or free surface flow driven by gravity. It was first presented by the French engineer Philippe Gauckler in 1867 and later re-developed by the Irish engineer Robert Manning in 1980.

The Gauckler- Manning formula states:

$$V = \frac{K}{n} R_h^{2/3} . S^{1/2} \qquad 2.15$$

Where:

V is the cross sectional average velocity (ft/s, m/s)

K is the conversion constant equal to 1.486 for U.S. customary units or 1.0 for SI units

n is the Gauckler Manning coefficient (independent of units)

R_h is the hydraulic radius (ft, m)

S is the slope of the water surface or the linear hydraulic head loss (ft/ft, m/m) (S = h/L)

The discharge formula, Q = AV, can be sued to *manipulate* Gauckler-Manning's equation by substitution for V. Solving for Q then allows an estimate of the volumetric flow rate (discharge) without knowing the limiting or actual flow velocity.

The Gauckler-Manning formula is used to estimate flow in open channel situations where it is not practical to construct a weir or flume to measure flow with greater accuracy. The friction coefficients across weirs and orifices are less subjective than n along a natural (earthen.

stone or vegetated) channel reach. Cross sectional area, as well as n', will likely vary along a natural channel. Accordingly, more error is expected to predicting flow by assuming a Manning's n, than by measuring flow across a constructed weirs, flumes or orifices.

The formula can be obtained by use of dimensional analysis. Recently this formula was derived theoretically using the phenomenological theory of turbulence.

b. Gauckler-Manning Coefficient

The Gauckler-Manning coefficient, often denoted as n, is an empirically derived coefficient, which is dependent on many factors, including surface roughness and sinuosity. When field inspection is not possible, the best method to determine n is to use photographs of river channels where n has been determined using Gauckler-Manning's formula.

In natural streams, n values vary greatly along its reach, and will even vary in a given reach of channel with different stages of flow. Most research shows that n will decrease with stage, at least up to bank full. Overbank n values for a given reach will vary greatly depending on the time of year and the velocity of flow. Summer vegetation will typically have a significantly higher n value due to leaves and seasonal vegetation. Research has shown, however, that n values are lower for individual shrubs with leaves than for the shrubs without leaves. This is due to the ability of the plant's leaves to streamline and flex as the flow passes them thus lowering the resistance to flow. High velocity flows will cause some vegetation (such as grasses and forbs) to lay flat, where a lower velocity of flow through the same vegetation will not.

c. Darcy's Law

In 1856 Henry-Philibert-Gaspard Darcy published a lengthy assessment of a proposed upgrading of the public water system for the French city of Dijon (Darcy 1856). His

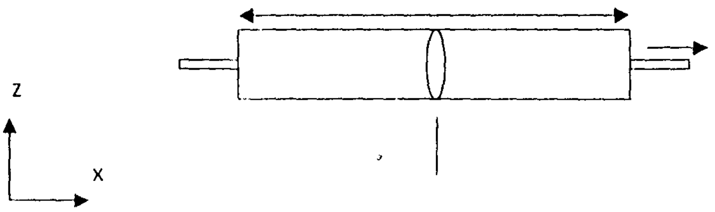

Fig. 2.1: **Diagram showing definitions and directions for Darcy's law**

Darcy assembled his conclusions in the following equation:

$$q = k\left(\frac{s}{e}\right)(h + e \pm h^{*}) \qquad 2.16$$

Where:

q = rate of water flow (volume per time)

k = a coefficient dependent on the "permeability" of the sand

s = cross sectional area of the sand filter

e = length of sand filter

h = reading of the upper manometer arm

h* = reading of the lower manometer arm

At this point, Darcy made use of the implications of his datum plane convention. Only under this convention, Darcy's law reduces to:

$$q = k\left(\frac{s}{e}\right)(h + e) \qquad 2.17$$

In modern format, using a particular sign convention, Darcy's law is usually written as:

$$Q = -KA\frac{dh}{dt} \qquad 2.18$$

Where:

Q = rate of water flow (volume per time)

K = hydraulic conductivity

A = column cross sectional area

Dh/hl - hydraulic gradient, that is, the change in head over the length of interest.

The law is often transformed by dividing through by the cross-sectional area dn is then restated as:

$$q = \frac{Q}{A} = -K\frac{dh}{dt} \qquad 2.19$$

Where q now has the dimensions of a velocity, and is referred to as the Darcy, or superficial, velocity.

d. Darcy-Weisback Equation

The Darcy-Weisbach equation has a long history of development, which started in the 18th century and continues to this day. It is named after two of the great hydraulic engineers of the middle 19th century, but others have also played a major role. Julies Weisbach (1806 1871) a native of Saxony, proposed in 1845 the equation we now use.

$$h_l = \frac{fl}{D} \times \frac{V^2}{2g} \qquad 2.20$$

Where

h_l is the head loss,

L is the pipe length

D is the pipe diameter

V is the average velocity

g is the acceleration of gravity and

f is a friction factor

However, he did not provide adequate data for the variation in f with velocity. This, his equation performed poorly compared to the empirical Prony equation (Gaspard Clair Francois Marie Riche de Prony, 1755 – 1839) in wide use at the time.

$$h_l = \frac{L}{D} \times (aV + bV^2) \qquad 2.21$$

Where a and b are empirical friction factors for the velocity and velocity squared.

While Weisbach was ahead of most other engineers, his was not the first work in the area. In about 1770 Antoine Chezy (1718 – 1798), an early graduate of l'Ecole des Ponts et Chaussees, published an equation for flow in open channels that can be reduced to the same form. Unfortunately, Chezy's work was lost until 1800 when his former student, Prony published an account describing it. Surprisingly, Prony developed his own equation, but it is believed that Weisbach was aware of Chezy's work from prony's publication. Darcy, (Prony's student) in 1857 published new relations for the Prony coefficients based on a large number of experiments. His new equation was,

$$h_l = \frac{L}{D}\left[\left(c + \frac{d}{D^2}\right)V + \left(d + \frac{e}{D}\right)V^2\right] \qquad 2.22$$

Where c, d and e are empirical coefficients for a given type of pipe. Darcy thus introduced the concept of the pipe roughness sealed by the diameter; what we now state as the relative roughness when applying the Moody diagram. Therefore, it is traditional to call f, the "Darcy f factor", even though Darcy never proposed it in that form. Fanning apparently was the first effectively together the two concepts in (1877). He published a large compilation of f values as a function pipe material, diameter and velocity. His data came from French, American, English and Germany publications, with Darcy being the single biggest source. However, it should be noted that Fanning used hydraulic radius, instead of D in the friction equation, thus "Fanning *f*" values are only ½ of "Darcy *f*" values.

e. Richard's equation

The Richards equation represents the movement of water in unsaturated soils, and was formulated by Lorenzo A. Richards in 1931. It is a non-linear partial differential equation, which is often difficult to approximate since it does not have a closed-form analytical solution.

Darcy's law was developed for saturated flow in porous media; to this Richards applied continuity requirement suggested by Buckingham, and obtained a general partial differential equation describing water movement in unsaturated non-swelling soils. The transient state form on this flow equation, known commonly as Richards's equation:

$$\frac{\partial\theta}{\partial t}\frac{\partial}{\partial z}\left[K(\theta)\left(\frac{\partial\varphi}{\partial z}+1\right)\right] \qquad 2.23$$

Where

K is the hydraulic conductivity,

φ is the pressure head,

z is the elevation above a vertical datum

θ is the water content, and

t is time.

Richards equation is equivalent to the groundwater flow equation, which is in terms of hydraulic head (h), by substituting $h=\psi+z$, and changing the storage mechanism to dewatering. The reason for writing it in the form above is for convenience with boundary conditions (often expressed in terms of pressure head, for example atmospheric conditions are $\psi = 0$).

2.3.2. Computing Runoff by using infiltration capacity curve

The infiltration capacity curve is a plot of the infiltration capacity against time. If the infiltration capacity curve is superimposed on the rainfall hyetograph, the resultant amount will represent nothing but the runoff.

This method can be used very easily, if the rainfall rate never falls below the infiltration capacity rate. But natural rains of varying intensities sometimes below and sometimes above the prevailing infiltration capacity results in a distortion of the capacity time curve. It is generally assumed that the infiltration capacity at any time is determined by the mass infiltration, which has occurred up to that time. Thus if a rain begins at low rates and the rainfall during the first hour is two-third of the infiltration, the capacity rate of infiltration at the end of the hour will be taken as the capacity that would have prevailed at t = 2/3 hr and at t = 1 hr (Grag, 2005).

2.3.3. Computing runoff Depth by using infiltration indices

The infiltration capacity curves already determined on test plots cannot be applied to large areas/basins or heterogeneous area. At any instant, in a large area, the infiltration capacity as well as the rainfall rate will vary from point to point. Moreover, subsurface flow (or interflow) will also be substantial. Since this water-flow is a part of infiltration, it will not normally be included in the runoff computed for large areas by using infiltration indices.

W_{index} and Q_{index} are the two indices which are commonly used. W_{index} is the average infiltration rate or the filtration capacity averaged over the whole storm period, and is given by

$$W_{index} = \frac{F}{t_r} = \frac{P-Q}{t_t} \qquad 2.24$$

Where:

F = Total infiltration including initial basin recharge, called potential infiltration

P Total precipitation

Q – Total runoff

t_r – Duration of rainfall in hour.

Q_{index} is defined as the average rate of loss such that the volume of rainfall in excess of t rate will be equal to the volume of direct runoff. It can also be defined as the rate of rainfall above the rainfall volume equals the runoff volume which can be expressed as:

$$Q_{index} = \frac{Total\ infiltration\ during\ period\ of\ rainfall\ excess}{Period\ of\ rainfall\ excess\ (t_e)} \qquad 2.25$$

For any uniform rainfall, Q_{index} and W_{index} will be equal but reverse will be the case where the rainfall is not uniform. The runoff coefficient K can be determined if the value of W_{index} known by using

$$K = \frac{P-W_{index}}{P}$$

Where P = rainfall rate

2.3.4. Computing Runoff Intensity by Rational Formula

For storage related design issues, it is necessary to determine total runoff volume from basin over a given period of time. For the design of most storm water conveyances, it is sufficient to determine the instantaneous peak rate of flow due to a specified storm event. The Ration method is useful to calculate the peak rate of flow at a specific collecting point of a drainage basin. This method was first employed in Ireland in urban storm sewer designs by Mulvaney, 1847. The use of this method is still recommended by many engineers for small watersheds (le than 100 acres). To calculate the peak rate of flow:

$$Q_p = CC_f iA \qquad 2.26$$

Where:

Q_p = the peak rate of flow, cfs

C = the runoff coefficient = (runoff)/(rainfall)

C_f = the frequency factor ranging from 1 to 1.25 for a return period from 1 to 100 years

i = the average rainfall intensity during the storm duration time period, mm/hr

A = the basin area, acres

The equation may also be expressed in this form.

$$Q_p = 640\ CC_f iA \tag{2.27}$$

Where:

Q_p = peak rate of flow, cfs

i = average rainfall intensity during the storm duration time period, mm/hr

A = basin area, $meters^2$

Note: Some areas may have C_f incorporated into C, in which case C_f would not appear in the above equation.

2.4 Time of Concentration, t_c

If rainfall were applied at a constant rate to an impervious surface, the runoff from the surface would eventually equal the rate of rainfall. The time required to reach that condition equilibrium is the time of concentration, t_c, the travel time of a water particle from the hydrologically most remote point in a drainage basin to a specified collection point. If the rainfall duration time is greater than or equal to t_c, then every part of the drainage area is assumed to contribute to the direct runoff at the collection point. Rainfall intensity for the Rational Method is assumed to be constant. If the duration of the storm is less than t_c, peak runoff will be less. For storms of duration longer than t_c, the runoff rate will not increase further. Therefore, the peak runoff rate is computed with the storm duration equal to t_c. Actual rainfall is not constant and the simplifying assumption is a weakness of the Rational Method. Water moves through a watershed in some combination of sheet flow, shallow concentration flow, stream flow and flow within storm drainage structures (pipes, canals, etc.) There are many ways to estimate t_c; formulas exist for predictions of overland and channel flow. Time of concentration is the total time taken for water move through each flow regime until it reaches the collection point.

2.4.1 Methods of estimating time of concentration

The time of concentration on overland flow may be estimated from the following empirical formulas:

a. Kirpich empirical equation

The Kirpich empirical equation is normally used for natural drainage basins with well defined overland flow routes along bare soil. For overland flow on impervious surfaces, the obtained should be reduced by 60%. For overland flow on grass surfaces, the computed t_c show be increased by 100%. The Upland Method is a graphical solution for finding the average overland flow velocity and can be used for overland flow in basins with a variety of land cover. This method relates t_c to the basin slope and to the length and type of ground cover. The time concentration, t_c, is commonly taken as the longest length of flow travel divided by the average velocity of flow. This is given as:

$$t_c = 0.00013L^{0.77}S^{-0.385} \qquad 2.28$$

Where

t_c = concentration time, hrs

L = the longest length of water travel, m

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

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

b. Izzard empirical equation

Based on a series of laboratory experiments by the Bureau for Public Roads, Izzard (1946) proposed a time concentration for roadways and turf surfaces. For small drainage areas without defined channel and from which runoff behaves as a thin sheet of overland flow, the Izzard formula can be used for estimating the concentration time, t_c where iL<500:

$$t_c = \frac{4iL^{1/3}}{i2/3}\left[\frac{0.0007i+K}{S^{1/3}}\right] \qquad 2.29$$

Where:

t_c = concentration time, min

L = length of overland flow travel, cm

i = rainfall intensity, centimeter/hour

S = slope of ground surface, cm/100 cm

K = retardance coefficient

For sheet flow of less than 300 feet, Manning's Kinematic solution can be used to compute Tt:

$$T_i = \frac{0.0007(nL)^{0.8}}{(P_2)0.5S^{0.4}} \qquad 2.30$$

Where:

T_t = travel time, hours

n = Manning's roughness coefficient

L = flow length, cm

P_2 = 2 years, 24 hour rainfall, mm

S = slope of hydraulic grade line (land slope), cm/100cm

Assumptions that attend this simplified form of Manning's kinematic solution are:

1. Shallow steady uniform flow
2. Constant intensity of rainfall excess (that part of a rain available for runoff)
3. Rainfall duration of 24 hours
4. Minor effect of infiltration on travel time

Rainfall depth can be obtained from IDF curves representative of the project location. The rainfall intensity in the Izzard formula may be estimated as follows:

1. Assume t_c
2. Determine the intensity from the appropriate IDF curve
3. Calculate t_c from the Izzard formula
4. Iterate steps 1 through 3 until the estimated value of t_c converges with the calculated value.

After a maximum of 90 meters, sheet flow usually becomes shallow concentrated flow. After determining average velocity, use Equation 2.48 is used to estimate travel time for the shallow concentrated flow segment. Open channel flow is that flow which is confined by sidewalls, natural or constructed, and free to travel under the influence of gravity. When runoff flows in an open channel or pipe, the length of the channel or pipe and the velocity is used to determine time of concentration, t_c, for that portion of the watershed. The following Manning equation may be used to determine the average velocity of open channel flow Manning's equation is

$$V = \frac{1.49 r^{2/3} s^{1/2}}{n} \qquad 2.31$$

Where:

V = average velocity, cm/sec

r = hydraulic radius in feet and is equal to the across section area of the flow divided by the wetted perimeter, cm^2/P_w

P_w = wetted perimeter, cm

S = slope of the hydraulic grade line (channel slope), cm/cm

n Manning's roughness coefficient for open channel flow

Then, the travel time T_t can be estimated by:

$$T_t = \frac{L}{3600V} \qquad 2.32$$

Where:

T_t = travel time, min

L = flow length, cm

V = velocity, cm/sec

c. Kerby Equation

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

$$t_c = \frac{0.83(nL)^{0.47}}{\sqrt{S}} \qquad 2.33$$

Where t_c time of concentration

S = surface slope

n = Manning roughness coefficient

L = flow length

This relationship is not commonly used and has the most limitations. It was developed based on watersheds less than 10 acres (4 ha) in size and having slopes less than one percent. It is generally applicable for flow lengths less than 300 m.

d. FAA Method

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

$$t_c = \frac{0.39(1.1-C)L^{1/2}}{S^{1/3}} \qquad 2.34$$

Where C = dimensionless runoff coefficient

e. Yen And Chow Method

Yen and Chow (1983) proposed the following expression for evaluation of time of concentration.

$$t_c = K_Y\left(\frac{NL}{S^{1/2}}\right)^{0.6} \qquad 2.35$$

Where K_Y ranges from 1.5 for light rain to 1.1. for moderate rain and 0.7 for heavy rain and N is an overland factor.

2.5 Development Of a Watershed Model

Before going into formulating mathematical expression that will describe the mathematical process of runoff, a detailed qualitative description of the process would seem desirable. The process of such a description is to delineate the parts of the process for which quantitative relations are required and hopefully, to indicate a suitable form for these expressions. This qualitative description or conceptual model, may then serve as the basis upon which to develop the fundamental form of a mathematical watershed model.

All of the models currently used to predict watershed runoff, since they consist of quantitative relationships concerning hydrologic events, represents various types of mathematical watershed models. In contrast with the lumped parameter approach, individual components of the model for specific watersheds were carefully considered.

2.6 Mathematical Model

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

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

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

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

$$I - O = \frac{\delta s}{\delta t} \qquad 2.36$$

Where:

t = time

I = Inflow

O = Outflow

S = Volume of water in storage

For an effective usage of the continuity 0f equation 2.36, the volume of water stored and rate of surface runoff are normally expressed in parametric form with the depth water in the area as the parameter. Equation 2.36 can further be expressed as

$$I_1 + I_2 - O + \frac{2S_1}{t} = O_2 + \frac{2S_2}{t} \qquad 2.37$$

Where I_1, I_2, O_1, O_2, S_1 and S_2 all stands for the initial and final rates of inflow, outflow and storage respectively. The composite runoff model for the whole area is obtained by starting at known initial condition and applying equation 2.41 to determine conditions at all points in the system.

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

2.7 Hydrologic Flow Processes and Pathways in a Watershed

The hydrology of a watershed could be analyzed in two broad categories:

i) Surface flow processes; and

ii) Subsurface flow processes.

A combination of these two major flow categories defines the overall response of the system to a hydrologic input. The surface flow processes are further classified into channel and overland flow sub-systems where the surface flow depth, velocity and width clearly proposes the presence of two distinct domains which may or may not be analyzed separately depending on the purpose of the analysis. The channel flow is usually defined as the bulk movement of water in domains with relatively well-defined boundaries. It is considered to be the major conveyance medium in terms of the quantity of water transported downstream.

The subsurface flow is generally defined by the variably-saturated flow phenomena according to the level of saturation of the porous medium (Bear, 1979). The domain could be spatially and temporally variably-saturated depending on the overall flow behavior, boundary conditions and forcing functions. In general, the variably saturated three-dimensional domain is subdivided into:

i) a saturated flow zone, and

ii) an unsaturated flow zone according to the level of saturation of the porous medium

These two sub-systems are separated from each other by the groundwater table, below which a saturated groundwater flow zone develops and above which, an unsaturated groundwater flow zone occurs. As the position of the water table is spatially and temporally variable in a watershed, the domain that is considered to be saturated varies accordingly and any modeling effort must consider the associated consequences. Although the subsurface flow processes can be modeled as a single variably-saturated medium, it is generally treated as two-separated systems linked to each other at the groundwater table. This artificial separation of variably-saturated subsurface flow phenomenon into saturated and unsaturated zones simplifies the analysis and provides a more straightforward understanding of the overall hydrologic conditions of the watershed.

The major watershed processes of concern are considered to be:

i) the channel flow

ii) the overland flow

iii) the unsaturated zone ground water flow; and

iv) the saturated zone groundwater flow

2.7.1 Channel Flow

The channel flow is characterized by small water depths when compared to other major systems such as seas, oceans and large inland lakes. While these large flow processes are described by the general three-dimensional hydrodynamic equations of fluid flow (i.e. the mass conservation equation and the Navier-Stokes equations of motion), many flow systems of interest to the hydrologic modeler, including channel flow, are characterized by small flow depths in the vertical dimension compared to their lateral and longitudinal flow dimensions. For such systems, the two-dimensional, depth averaged hydrodynamic equations are generally

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) Gunn and Kinzer, 1949).
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 and
6. Reproducible storm patterns of significant duration and intensity (Moore et al, 1983) (Meyer and Harmon, 1979).

2.9.1 Types of Rainfall Simulators

According to Thomas and El Swaify (1989), simulators can be separated into drop-forming simulators and pressurized nozzle simulators.

(a) Drop-Forming Simulator

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 are used. Another negative of the drop forming simulator is their limited application to small plots (Bubenzer, 1979b). Several point 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 needle polyethylene tubing, or metal tubing to form drops (Bubenzer, 1979b).

(b) Pressurized Nozzle Simulator

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).

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.

2.10 Soil

Soil is that thing outer 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).

2.10.1 Soil Constituents

Soil consists of the following:

(i) Minerals matter

(ii) Soil organic matter

(iii) Soil air

(iv) Soil water

3.7.4 Water Supply tank

Water supply for the simulator is supplied direct from a motorized water tanker which will feed directly 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.

3.7.5 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 $Q = 0.01 \, m^3/sec$

$\rho = 1000 kg/m^3$

therefore, $m = 0.01 \, X \, 1000$

$= 10 \, kg/sec.$

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

2.10.1.1 Mineral Matter

Mineral matters are solid inorganic materials in the soil. They include rock fragment which are undecomposed remnants of the original rock material from which the soil is formed sand; silt and clay. In terms 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.

2.10.1.2 Soil Organic Matter

This include the litter of fallen leaves, twigs, fruits and animal droppings including carcasses on the soil surface, the humus formed from the decomposition of litter mixed with the mineral particles in the soil and the population of micro-organisms living in the soil which help in the breakdown of organic litter to release the nutrients stored in it to form humus.

2.10.1.3 Soil Air

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

2.10.1.4 Soil Water

This is the medium through which plants and many micro-organisms obtain miner elements from the soil. Soil water is important also as a weathering and leaching agent to soil. There are different forms of soil water. The water that occupies the macro pores during each rainfall and drains through the soil toward the water table is called free-draining or gravitation water. It is of no use to plants; rather it washes away soil materials including plant nutrients.

The water that is normally held within the micro pores is called capillary water. It is this type that readily available to plants (Maniman, 1999).

2.11 Soil Profile

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

2.11.1 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 colour because it contains humus and also it loses fine humus and clay and silt particles to the horizon below through the process of eluviations and therefore referred to as an alluvial horizon.

2.11.2 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 fine-textured and compact than the A-horizon.

2.11.3 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 precipitation of accumulated materials and water over time (Onweluzo and Omotoso, 1999).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study Area

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

dominated by stunted shrubs; interspersed with moderate height tree and perennial foliage. Similarly, due to human activities and land use abuse which is characteristic of most expanding urban centre in Nigeria, the site is fast losing its remaining tree species to development. Along some river course and lowland areas, the vegetation is more wooded and resembles some forest affinities. The area is still being used as farm and grazing land by the residents of Minna and her environs (Musa 2003).

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

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

3.4 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.

3.5 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).

3.5.1 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

$$P_w = \left[\left(\frac{wet\ sample\ weight - dry\ sample\ weight}{dry\ weight\ sample}\right)\right] X100 \qquad 3.1$$

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.

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

$$P_v = P_w\ X\ BD \qquad 3.3$$

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.

3.5.2 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;

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

(4)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, $\acute{o}_s$.
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:

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

The volumetric water content, 0, is the ratio of water volume in the soil, V_W, to the total volume, V:

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

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

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

These terms are further related as follows:

$$\theta = S\ X\ \emptyset \qquad 3.7$$

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

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

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:

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

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:

$$TAW = (\theta_{fc} - \theta_{wp})RD \tag{3.1}$$

3.6 Infiltration measurement

The infiltrometer rings will be placed randomly from each other and the measurement will be taken to the nearest centimeter. 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.

3.6.1 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.

$m = \rho V A$ 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

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

$\therefore A_1 = \pi r^2$

$= 3.142 \times 0.01905^2$

$= 3.142 \times 0.0003629025$

$= 0.001140239655$ m^2

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

The velocity at this point is calculated as

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

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

= 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

$$A = \pi r^2$$

$A_2 = 3.142 \, X \, 0.015875^2$

$= 0.00079183309375 \, m^2$

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

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

= 12.62m/s

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

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

$= 1 \, X \, 10^{-3} \, X \, 1000$

= 1 kg/sec

where r = 0.0127 m

$A_3 = \pi r^2$

$= 3.142 \text{ X } 0.0127^2$

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

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

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

$= 1.9736 \text{ m/s}$

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.

$\therefore m = Q \text{ X } \rho$

$= 0.0002 \text{ X } 1000$

$= 0.2 \text{ kg/sec}$

$A_4 = \pi r^2$

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

$1.267 \text{ X } 10^{-4} \text{ m}^2$

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

$$= \frac{0.2}{1000 \, X \, 1.267 \, X \, 10^{-4}}$$

= 1.5785 m/s .

3.7.6 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)

$= 3.142 \, X \, 1 \, X \, 10^{6}$

$= 3.142 \, X \, 10^{6} \, m^2$

3.7.7 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 Simulator Catchments Area

$Area(A_c) = l \times b$

l = length of simulator = 6 m

b= breadth of simulator = 3 m

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

3.9 Losses in the Network

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

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

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

v = velocity

g = acceleration due to gravity (9.81)

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

In the submain 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

$$h_2 = \frac{1.8 X 1.97362^2}{2 X 9.81} = 0.36$$

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

$$V = H_T V_4 \qquad 3.21$$

$$1.5785 X 0.71$$

$$= 1.1207 \text{ m/s.}$$

3.10 Kinetic Energy

$$K.E = \frac{1}{2}MV^2 \qquad 3.22$$

at d = 1½ inches

$$K.E. = \frac{1}{2} x 10 x 8.77^2$$

$$= 384.56J$$

At d 1¼ inches

$$K.E. = \frac{1}{2} x 10 x 12.62^2$$

$$= 796.32J$$

At d = 1 inch

K.E. = $\frac{1}{2} \times 1 \times 1.97^2$

= 1.94J

At d = ½ inch

K.E. = $\frac{1}{2} \times 0.2 \times 1.58^2$

= 0.25J

3.11 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.

3.12 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.

3.13 Soil Analysis

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

3.13.1 Particle Size Analysis

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

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

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

Where; R_a= 40 sec, blank hydrometer reading

R_b= 2 hr, blank hydrometer reading

R_c = 40sec (Temperature × 0.360)

R_d = 2 hr correction factor (temperature × 0.36)

W = weight of soil sample used.

3.13.2 Soil Textural Class

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

3.13.3 Moisture Content

The weight of a clean and well labelled can was taken using a weigh balance. Soil clod was added into the can after which the weight was taken. The difference in weight between the weight of can plus clod and the weight of the can is the wet weight of the soil. The can containing the clod were taken to the laboratory for oven-drying to a constant weight at 110 C. The can was removed from the oven, allowed to cool for several hours. After cooling the weight of the can containing the soil was taken. Weight of the dry soil is the difference in weight between the weight of the can plus soil after oven drying and the weight of the can. The moisture content was calculated as:

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

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

Where

W_w weight of wet soil (g)

W_d=weight of dry soil (g)

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

Agricultural development process includes identifying existing constrain to agricultural production and subsequently providing a technical solution to these problems. From the physical observation of the area it was discovered that the study area was predominately farm lands which is being used by the surrounding local inhabitants of the area who are mostly farmers and few staffs of the university. The area is also occupied by the domestic cattle rearers who move from one section of the land to another while striving for the survival of their cattle.

Table 4.1 shows the various soil properties for ten different soils were surface runoff test was carried out. It was observed that the soil particles had varying percent of soil properties with plots 6 and 7 having the highest silty percent of 89, clay percents of 6 and 4 respectively and sand percents of 5 and 7 respectively while plot 2 had the lowest percent of silty of 80 with a clay percent of 9 and percent sand of 11. The mean percent value of the various areas for silty was find to be 84.1%, clay was 7.8% while sand was 8.1%. The soil water textural classification software was used to obtain the actual texture of the soil properties obtained from the field. Comparing this result 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 silty in nature.

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

Plot no.	% Sand	% Clay	% Silty
1	12	7	81
2	11	9	80
3	10	9	81
4	8	11	81
5	6	11	83
6	5	6	89
7	7	4	89
8	7	8	85
9	9	7	84
10	6	6	88
Mean	8.1	7.8	84.1

Table 4.2 shows the percent water content for the ten plots of silty soil before the start of the experiment. It was observed that percent water retained in each plot was extremely high because of the nature of the soil with plot 4 having the highest percent of 22.40 and plot 7 having the lowest of 21.55 percent. From Table 4.1, it was observed that plot 4 had 81% silty content, 11% clay content and 8% sand content while plot 7 was observed to have 89% silty, 4% clay and 7%

sand content. The results obtained were compared with the works of Musa (2003), Eze (2000) and Sanni (1999) and they were discovered to be highly comparable.

Table 4.:2 Percent moisture content before the experiment

Plot no	Weight of wet soil (g)	Weight of dry soil (g)	Weight water (g)	Moisture content (%)
1	249.30	204.20	45.1	22.06
2	248.70	204.00	44.70	21.90
3	247.95	203.97	43.98	21.56
4	250.20	204.40	45.80	22.40
5	249.40	204.25	45.15	22.08
6	250.10	204.35	45.75	22.38
7	247.90	203.97	43.93	21.55
8	248.60	203.99	44.61	21.86
9	249.80	204.30	45.50	22.28
10	248.30	203.98	44.32	21.74
Mean	249.03	204.14	44.78	21.98

Table 4.3 shows the percent moisture content of the ten plots of silty soils after the experiments had been carried out. And from Table 4.3, plot 5 was found to have the highest percentage of

water retained of 30.42 while plot 2 had the lowest of 29.50%. Comparing the results of Table 4.3 with the soil analysis of Table 4.1, it was observed that plot 5 had 83% silty content, 11% clay content and 6% sand content. This means that the tendency of surface flow is only for a shortest period of time because the area in question showed a very high water retention capability. The mean value of the percent moisture content after the experiment was calculated to 29.96

Table 4.3:- Percent moisture content after the experiment

Plot no	Weight of wet soil (g)	Weight of dry soil (g)	Weight of water (g)	Moisture content (%)
1	268.50	206.40	62.10	30.07
2	267.10	206.25	60.85	29.50
3	267.90	206.30	61.60	29.86
4	267.60	206.28	61.32	29.74
5	269.50	206.65	62.85	30.42
6	269.40	206.60	62.80	30.40
7	268.50	206.43	62.07	30.08
8	268.30	206.38	61.92	30.02
9	268.00	206.33	61.67	29.90
10	267.40	206.27	61.13	29.64
Mean	268.22	206.39	61.83	29.96

Table 4.4 shows the average infiltration rate and the average cumulative infiltration for the ten plots under consideration. It was observed that the rate of infiltration was high at the earlier minutes of the experiment and then tends to an approximately constant value as we approaches the final minutes of the experiment, This is because previously infiltrated water fills the available storage spaces of the soil and reduced the capillary forces drawing water into the pores. It later became steady as from the 60th minute of the infiltration rate. A total cumulative infiltration of 31.5cm of water was used, thus showing that the 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 silty in textural classification. A comparism was made between these and 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 Average Cumulative Infiltration.

S\No	Time (min)	Average infiltration (cm/min)	Average cumm. Infiltration (cm/min)
1	0	0.0	0.0
2	5	4.9	4.9
3	10	4.3	9.3
4	15	3.8	13.1
5	20	3.3	16.5
6	25	2.9	19.5
7	30	2.6	22.2
8	35	2.3	24.3
9	40	2.0	26.5
10	45	1.6	28.1

11	50	1.3	29.4
12	55	1.1	30.5
13	60	0.9	31.5

Table 4.5 shows the various sizes of slope that were considered in percentages and its conversion to degrees. It was observed that plots 6 had the highest degrees of slope of 4.14, this was closely followed by plots 7 and 1 with 4.12 and 4.10 respectively while plot 2 had the lowest degree of slope of 3.56. These various slope sizes were considered when carrying out the work which shows the rate of flow of water on the soil surface.

Table 4.5: Slope size for the ten plots

Plot	Slope (deg)	Slope (%)
1	4.10	7.17
2	3.56	6.22
3	3.72	6.50
4	3.70	6.47
5	4.09	7.15
6	4.14	7.24
7	4.12	7.20
8	4.05	7.08
9	3.89	6.79
10	3.86	6.75
Mean	3.92	6.86

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 plots 1, 3, 4, 7 and 9 these were closely followed by plots 2, 5 and 6 was the closest to the previous values. The lowest values were recorded from plots 8 and 10 while the mean value of the surface runoff was calculated as 0.196 m^3.

Table 4.6: Surface runoff for the various plots

Plot	Surface runoff(m^3)
1	0.197
2	0.196
3	0.197
4	0.197
5	0.196
6	0.196
7	0.197
8	0.195
9	0.197
10	0.195
Mean	0.196

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 but not specifically for some soils in Nigeria thus making some of our water and other civil structures fail. Depending on the complexities involved, these models are categorised as empirical, black box, conceptual or physically based distributed models.

A model was derived using the excel Microsoft word of 2007 for an undisturbed silty soils in the 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 $Y = MX_n + C$

Table 4.7: Parameters considered for the equation.

X_1	X_2	X_3	C
22.06	0.00	0.197	4.10
21.9	5.20	0.196	3.56
21.56	4.96	0.197	3.72
22.40	4.82	0.197	3.70
22.08	4.78	0.196	4.09
22.38	5.08	0.196	4.14
21.55	5.24	0.197	4.12
21.86	5.18	0.195	4.05
22.28	5.00	0.197	3.89
22.74	4.66	0.195	3.86

Where X_1 = Initial moisture content for the ten plots considered,

X_2 =Infiltration rates for the ten plots considered,

X_3 = Surface runoff for each of the plots under consideration and

C = Slope for the various plots.

On using the Microsoft excel 2007 version, the equation that best describe an undisturbed silty soils of the Federal University of Technology, Minna stated below was obtained as

$$Y = 0.35 X_1 - 234.57 X_2 - 1.51 X_3 - 0.22. \qquad 4.1$$

Substituting the values of X_1, X_2 and X_3 into equation 4.1 above a coefficient was developed for an undisturbed silty soil in Gidan Kwano campus of Federal University of Technology, Minna. And the coefficient is hereby present to the department of Agricultural and Bioresources Engineering, Federal University of Technology, Minna as -1046.48. It can be observed that the value of intercept of the equation obtained above is negative.

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 undisturbed sandy soil.

The research work was able to develop a mathematical model capable of simulating the surface hydrograph from small ungaurded watershed and the determination of the surface runoff coefficient suitable for undisturbed silty 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

1. Samples obtained should be tested or analyzed in different laboratories by different experts for several times, so as to make sure that the data obtained is more reliable.
2. Since the study was carried out in the dry season, more research should be done during both seasons to ascertain whether there will be significant variations in the obtained in both seasons.
3. All readings and values obtained regarding the soil in question should also be field or laboratory measured instead of assumed.

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APPENDIX A

OTHER HYDROLOGIC DATA RECORDED DURING THE EXPERIMENT

Infiltration Parameters For Plot 1 (Undisturbed Silt Soil)

Time (min)	Infiltration Rate (cm/min)	Cummulative Infiltration (cm/min)
0	0	0
5	5.2	5.2
10	4.6	9.8
15	4.03	13.83
20	3.51	17.34
25	3.06	20.4
30	2.67	23.07
35	2.32	25.39
40	2	27.39
45	1.7	29.09
50	1.45	30.54
55	1.21	31.75
60	0.99	32.74

Infiltration Parameters For Plot 2 (Undisturbed Silt Soil)

Time (min)	Infiltration Rate (cm/min)	Cummulative Infiltration (cm/min)
0	0	0
5	4.5	4.5
10	3.95	8.45
15	3.45	11.9
20	3.03	14.93
25	2.65	17.58
30	2.3	19.88
35	2.01	21.89
40	1.76	23.65
45	1.53	25.18
50	1.3	26.48
55	1.09	27.57
60	0.92	28.49

Infiltration Parameters For Plot 3 (Undisturbed Silt Soil)

Time (min)	Infiltration Rate (cm/min)	Cummulative Infiltration (cm/min)
0	0	0
5	5.1	5.1
10	4.28	9.38
15	3.68	13.06
20	3.32	16.38
25	2.94	19.32
30	2.62	21.94
35	2.3	24.24
40	1.96	26.2
45	1.65	27.85
50	1.29	29.14
55	1.05	30.19
60	0.68	30.87

Infiltration Parameters For Plot 4 (Undisturbed Silt Soil)

Time (min)	**Infiltration Rate (cm/min)**	**Cummulative Infiltration (cm/min)**
0	0	0
5	4.9	4.9
10	4.18	9.08
15	3.85	12.93
20	3.45	16.38
25	3	19.3
30	2.82	22.2
35	2.6	24.8
40	2.46	27.26
45	2.14	29.4
50	1.52	30.92
55	1.24	32.16
60	0.95	33.11

Infiltration Parameters For Plot 5 (Undisturbed Silt Soil)

Time (min)	Infiltration Rate (cm/min)	Cummulative Infiltration (cm/min)
0	0	0
5	5.52	5.52
10	5	10.52
15	4.5	15.02
20	4.03	19.05
25	3.57	22.62
30	3.13	25.75
35	2.72	28.47
40	2.33	30.8
45	0.98	31.78
50	0.68	32.46
55	0.56	33.02
60	0.56	33.58

Infiltration Parameters For Plot 6 (Undisturbed Silt Soil)

Time (min)	Infiltration Rate (cm/min)	Cummulative Infiltration (cm/min)
0	0	0
5	4.8	4.8
10	4.25	9.05
15	3.74	12.79
20	3.3	16.09
25	2.92	19.01
30	2.57	21.58
35	2.27	23.85
40	1.97	25.82
45	1.69	27.51
50	1.44	28.95
55	1.2	30.15
60	0.99	31.14

Infiltration Parameters For Plot 7 (Undisturbed Silt Soil)

Time (min)	Infiltration Rate (cm/min)	Cummulative Infiltration (cm/min)
0	0	0
5	5	5
10	4.42	9.42
15	3.9	13.32
20	3.44	16.76
25	3.02	19.78
30	2.64	22.42
35	2.29	24.71
40	1.98	26.69
45	1.7	28.39
50	1.44	29.83
55	1.2	31.03
60	1	32.03

Infiltration Parameters For Plot 8 (Undisturbed Silt Soil)

Time (min)	Infiltration Rate (cm/min)	Cummulative Infiltration (cm/min)
0	0	0
5	4.6	4.6
10	4.05	8.65
15	3.56	12.21
20	3.13	15.34
25	2.74	18.08
30	2.39	20.47
35	2.06	20.53
40	1.76	24.29
45	1.5	25.79
50	1.26	27.05
55	1.05	28.1
60	0.89	28.99

Infiltration Parameters For Plot 9 (Undisturbed Silt Soil)

Time (min)	Infiltration Rate (cm/min)	Cummulative Infiltration (cm/min)
0	0	0
5	4.4	4.4
10	3.86	8.26
15	3.36	11.62
20	2.92	14.54
25	2.52	17.06
30	2.17	19.23
35	1.87	21.1
40	1.61	22.71
45	1.38	24.09
50	1.19	25.28
55	1.03	26.31
60	0.94	27.25

Infiltration Parameters For Plot 10 (Undisturbed Silt Soil)

Time (min)	Infiltration Rate (cm/min)	Cummulative Infiltration (cm/min)
0	0	0
5	5.4	5.4
10	4.88	10.28
15	4.38	14.66
20	3.91	18.57
25	3.46	22.03
30	3.05	25.08
35	2.67	27.75
40	2.32	30
45	1.99	32.06
50	1.69	33.75
55	1.46	35.21
60	1.14	36.5

Surface Runoff Parameters For The Ten Plots of Undisturbed Silt Soil

Plots	Volume Of Surface Runoff, V (m^3)	Height Of Water, h (m)	Radius Of Tank, r (m)
1	0.1972	0.8016	0.28
2	0.1966	0.7992	0.28
3	0.1974	0.8024	0.28
4	0.197	0.8008	0.28
5	0.1969	0.8004	0.28
6	0.1968	0.8	0.28
7	0.1973	0.802	0.28
8	0.1959	0.7963	0.28
9	0.1971	0.8012	0.28
10	0.1954	0.7943	0.28

$$V = \pi r^2 h$$

The Slope's Parameters for The Ten plots

Plots	Slope $(\Theta)^0$	Slope (%)	Staff Reading On A, h1 (m)	Staff Reading On B, h2 (m)
1	4.1	7.168	1.05	1.0543
2	3.56	6.22	1.043	1.0467
3	3.72	6.502	1.047	1.0509
4	3.7	6.467	1.0455	1.494
5	4.09	7.1505	1.0499	1.0542
6	4.14	7.24	1.054	1.058
7	4.12	7.2032	1.052	1.0563
8	4.05	7.0804	1.048	1.523
9	3.89	6.7998	1.0478	1.0519
10	3.86	6.7472	1.0476	1.0517

$$h2 = \left[\left(\frac{V}{100}\right)LX\frac{1}{100}\right] + h1$$

Where :

$V = 100TANO$

$L = 6m$

APPENDIX B

RAINFALL DATA OF MINNA, NIGER STATE FROM 2007-2009

TEMPERATURE (3 years) 2007-2009

	J	F	M	A	M	J	J	A	S	O	N	D
2007	33.7	37.2	38.2	36.0	32.8	30.3	29.5	28.2	30.0	31.7	34.7	35.4
2008	32.7	35.6	38.6	36.4	33.2	39.1	29.5	28.6	30.3	32.2	36.0	35.6
2009	35.7	37.8	39.2	35.2	33.9	31.8	30.9	29.8	30.5	31.5	34.6	36.7

RAINFALL (3 years) 2007-2009

	J	F	M	A	M	J	J	A	S	O	N	D
2007	0.0	0.0	0.4	73.1	156.6	123.9	314.0	310.1	330.2	115.1	0.0	0.0
2008	0.0	0.0	0.0	40.2	146.8	132.7	305.1	244.3	258.9	141.2	0.0	0.0
2009	0.0	0.0	0.0	89.9	101.4	108.9	246.8	497.6	273.5	85.2	0.0	0.0

RELATIVE HUMIDITY (3 years) 2007-2009

	J	F	M	A	M	J	J	A	S	O	N	D
2007	22.0	30.0	41.0	64.0	76.0	80.0	85.0	88.0	83.0	77.0	56.0	33.0
2008	24.0	25.0	48.0	59.0	73.0	78.0	85.0	87.0	82.0	75.0	40.0	40.0
2009	40.0	43.0	37.0	70.0	73.0	77.0	81.0	85.0	80.0	76.0	44.0	26.0

WIND SPEED (3 years) 2007-2009

	J	F	M	A	M	J	J	A	S	O	N	D
2007	214.5	127.9	113.2	107.8	72.3	68.9	58.0	45.3	39.7	25.4	26.0	98.9
2008	180.8	195.9	89.5	104.8	97.5	89.2	64.5	63.5	47.4	41.9	60.3	97.8
2009	75.5	76.8	99.4	110.8	81.7	82.8	73.8	47.5	45.9	35.4	75.0	90.8