PERFORMANCE OF WATER CHARACTERISTICS MODEL IN SELECTED WETLAND SOILS IN ZARIA, NIGERIA

BY

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BY

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NIGERIA.

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DECLARATION

I hereby declare that this dissertation has been composed by me and that it is a record of my own research work. It has not been accepted in any previous application for a higher degree. All information derived from literatures has been duly acknowledged in the text and a list of reference provided. No part of this dissertation has been previously presented for another degree or diploma at any Institution.

Olaoluwa, Bolanle Adejumoke Oyetunde	……..…………….	……...………..
Msc/ENG/5022/2010-2011	Signature	Date

CERTIFICATION

This dissertation entitled PERFORMANCE OF WATER CHARACTERISTIC MODEL IN SELECTED WETLAND SOILS IN ZARIA, NIGERIA by Olaoluwa Bolanle Adejumoke Oyetunde meets the regulations governing the award of degree of Master of Science (Agricultural Engineering) of Ahmadu Bello University, Zaria and is approved for its contribution to scientific knowledge and literary presentation.

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DEDICATION

This work is dedicated to my husband, my children and my sweet mother Sp/M/I D.O Somolu who showed the deepest emotional and spiritual concern for the success of this program.

ACKNOWLEDGEMENT

All glory be unto the good Lord for making my master's degree another possibility, because the most highest, is the God of possibility. I am sincerely grateful to all who have helped, and contribution of many individual motivated by God, towards the completion of this dissertation.

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ABSTRACT

The performance of Soil Water Characteristic Hydraulic Properties Calculator (SWC-HPC) model to predict soil water characteristic of some wetlands in Zaria, Nigeria, was evaluated and reported herein. The objective of the study was to establish the predictability and reliability of the SWC-HPC model, and hence it use in determining water characteristic of wetland soils in the study area. Ninety soil samples collected in August, 2013 from three wetland sites were used in the evaluation. The wetland sites include Hayin Agoi in Giwa local government area along Shika Road, Rafin yerima in Basawa local government area and Kubani multipurpose Maje road in Tudunwada local government area. The soils particle size distribution (specifically percent clay and sand), organic matter contents and salinity were inputted into the model to simulate soil moisture status at saturation, field capacity, wilting point, and soil bulk density. The model outputs were statistically compared with observed parameters from laboratory tests using Root Mean square Error (RMSE), Coefficient of Variation (CV), Modeling Efficiency (EF) and Coefficient of Residual Mass (CRM). The model was able to predict the bulk densities of the soil tested and also was able to predict the soil moisture content at field capacity and wilting point. The coefficient of residual mass (CRM) revealing that the model under predicted moisture content at saturation with 0.26 (26 %), 0.26 (26 %) and 0.24 (24 %). Moisture content at field capacity under predicted at 0.01 (1 %), 0.26 (26 %), 0.24 (24 %) moisture content at wilting point was under predicted with 0.04 (4 %), 0.07 (7 %). The model under predicted bulk density at 0.2 (2 %), 0.52 (52 %) and 0.24 (24 %). The SWC-HPC may therefore be used only to simulate soil bulk densities and moisture status at field capacity and wilting point in the study locations.

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ABBREVIATIONS

CRM	-	Coefficient of Residual Mass
CV	-	Coefficient of Variation
EC	-	Electrical Conductivity
EF	-	Modelling Efficiency
NRCRI	-	National Root Crops Research Institute
OM	-	Organic Matter
PTFs	-	Pedotransfer Functions
RMSE	-	Root Means Square Erro
SOIL PAR	-	Soil Particle Analysis
SPAW	-	Soil Plant Water Atmosphere
SWC- HPC	-	Soil Water Characteristic Hydraulic Property Calculator
USDA	-	United State Department of Agriculture

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the Study

The soil water characteristic in wetland varies widely according to the soil profiles and the structural particle that constitute each of the particular region. Soil water characteristic curve describes the amount of water retained in a soil (expressed as θm (mass) or θv (volume) content under equilibrium at a given matric potential. Soil water characteristic is an important hydraulic property related to size and connectivity of pore spaces, hence strongly affected by soil texture, structure, and other constituents including organic matter. Modeling water distribution and flow in partially saturated soils requires knowledge of the soil water characteristics. The soil water characteristic curve for a soil is defined as the relationship between water content and suction of the soil (Williams, 1982).

The water content defines the amount of water contained within the pores of the soil, soil water content also governs the air content and gas exchange of the soil, this affect the respiration of roots and the activity of micro organisms and chemical state of the soil e.g. radox potential (Hillel, 1998). The degree of saturation is another term commonly used to indicate the percentage of the voids that are filled with water. Soil suction refers to soil water potential or an energy level of the soil water. Soil suction may range from zero kilos Pascal (kPa) (for moisture content at saturation when all soil pores are filled with water) to about 1,000,000 kPa at zero moisture content (when all soil pores are filled with air). (FredLund *et al*., 1994). In agriculture the variable amount of water contained in a unit mass or volume of soil are important factors affecting the growth and development of plants. In soil and water conservation information on the available water to soil are require in planning irrigation scheduling for crops, design of irrigation system, drainage system and other soil and water management strategies (Igbadun *et al.,* 2011).

1.2 Statement of the Problem

Soil water characteristic verification is important in the science and engineering of soil and water conservation. Soil water characteristics are determined through laboratory procedures carried out on collected soil samples. These procedures are slow, energy consuming and costly. As a result of these difficulties serious efforts are being made by soil scientist and engineers to develop predictive relationships between soil water characteristics and some physical properties of soil. Several general empirical equations have been proposed to describe the soil water characteristic curve. Some of these equations include the ones proposed by Brooks and Corey (1964), and those developed by Campbell (1974), Van Genuchten (1980). Most of analysis are derived by statistical correlation, although more recent analysis have explored neutral network analysis (Schaap *et al.*, 1998) or field descriptions and Pedotransfer functions (Grossman *et al*., 2001); Rawls and Pachepsky (2002). Particularly those of agricultural hydrology and water management for example SPAW model Saxton and Willey, (2004). Attempts have been made to estimate these properties indirectly from readily available soil properties, such equation are often called pedotransfer function PTFS (Rawls *et al.,* 2003). Some of these equations have been verified through several studies (Campbell, 1974; Clapp and Hornbeger, 1978; Gardner *et al.*, 1970a; Rogowski 1971; Williams *et al,* 1983 and McCuen *et al.*, 1981).

Soil water characteristics are routinely used for the estimation of unsaturated soil property function for example permeability functions, water storage function, shear strength functions and thermal property function (Fredlund and Xing, 1994). Some of these computer simulation models include SOILPAR, (Acutis and Donatella, 2003), ROSETTA, (Schaap, *et al.*, 2001) and SWC –HPC (Saxton and Willey, 2006). All have been successfully applied to a wide variety of analyses, particularly those of agricultural hydrology and water management.

The Soil Water Characteristic-Hydraulic Properties Calculator (Saxton and Willey, 2006) is a graphical computer program to readily estimate output parameter such as textural class, organic matter, Wilting point, field capacity, saturation, available water, bulk density, degree of compaction, and salinity. A better and cheaper approach to evaluate the soil water characteristic is the use of SWC-HPC model.

1.3 Justification of the Research

The wetlands are along the river banks which are ecologically and economically important to the farmers and the community at large. Farming activities are carried out round the year. Wetlands selected for this study are known for its intensive farming activities practiced through the year. However, estimating soil water hydraulic characteristics from readily available physical parameters has been a long term goal of soil physicists and engineers. (Saxton and Rawls, 1986). The importance of available water and soil water characteristic curve in the science and engineering of soil and water conservation has encouraged the continuous search for quick and easier means of quantifying their parameters. Before adoption of any simulation model for use in any locality, it is important to first evaluate the model's ability to represent the state variables it is intended to simulate for that locality (Igbadun *et al.*, 2011). Tudunwada, Basawa and Shika are Located in Zaria, Kaduna state of Northern Nigeria. One cheap and efficient way to conduct an evaluation of soil water characteristic is the use of SWC-HPC model which has not been evaluated for simulating soil water characteristic in the study area. The knowledge of their properties and classification will enable their proper use management and technological transfer. Therefore it is very important to evaluate the performance of the soil water characteristic-hydraulic property calculator model in the selected wetlands.

1.4 Aim and Objective of the Study

The aim of this study was to evaluate the performance of the soil water characteristic-Hydraulic properties calculator (SWC-HPC) model in predicting soil water characteristics of some selected wetland in Zaria and environs.

The specific objectives were to:

i. Determine from laboratory analysis the soil water characteristics and physical properties of selected wetlands in Zaria and environs

ii. Predict the soil water properties of the selected wetlands using the SWC-HPC model.

1.5 Scope and Limitations

1.5.1 Scope

This study is intended to use Soil Water Characteristics-Hydraulic Property Calculator model to predict soil water characteristic of some selected wetland and to simulate soil moisture status at saturation, field capacity, wilting point and bulk density.

1.5.2 Limitations

Saturated hydraulic conductivity could not be carried out due to mechanical problems, (malfunctioning of constant head permeameter given inaccurate and unreliable readings).

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction

Soil water characteristic curves are used for the estimation of unsaturated soil property functions (Fredlund, 1996). The soil water characteristics curves have become pivotal to the implementation of unsaturated soil mechanics into geotechnical engineering practice. Estimation procedures for unsaturated soil property functions have been proposed for virtually every physical process where soils become unsaturated (Fredlund *et al.*, 1993). However soil water characteristics curves have not proven to be a reliable means for estimating saturated soil suction and their usage for this purpose has been discouraged (Fredlund *et al.*, 1994 and Fredlund 1996).

Soil water characteristics curve can be viewed as a continuous sigmoidal function describing the water storage capacity of a soil as it is subjected to various soil suctions. Soil water characteristic curve contain important formation regarding the amount of water contained in the pores at a given soil suction and the pore size distribution corresponding the stress state in the soil (Fredlund *et al.*, 1994). Unsaturated soil behavior such as shear strength, volume change, diffusivity and adsorption are related to the soil water characteristic curve (Fredlund and Rachardjo, 1993). Regardless of the approach adopted for modeling the soil behavior, soil suction plays a major role. Therefore soil water characteristic curve is the backbone of any model for describing unsaturated soil behaviour because it describes the variation of soil suction with changes in water content.

Numerous empirical equations have been proposed to simulate the soil water characteristic curve. Among the earliest is an equation proposed by Brooks and Corey

(1964). The equation provides a good fit for sand, silt and clay soils over the entire suction range from zero to 1500 kPa.

2.2 Soil water characteristic hydraulic Properties calculator (SWC-HPC) Model

The soil water characteristic-hydraulic properties calculator (SWC-HPC) Model is a graphic computer program developed by Saxton and Willey (2006). The SWC-HPC model is a component of the soil plant water atmosphere (SPAW) hydrological model (Saxton and Willey, 2006). It is used for estimation of hydrologic water holding and transmission characteristics of an agricultural soil horizon. It is also an independent program with input and output variables. The major input variable required to run the SWC-HPC is particle size distribution, specifically percent sand and clay. Other input variable which are optional but are require to refine the output of the model and increase its predictability are organic matter, salinity, gravel and degree of compaction. The output variables of the SWC-HPC model include percent volumetric moisture content, wilting points, field capacity and saturation. Other outputs of the model are available water (AW), saturated hydraulic conductivity, bulk density and textural class of the soil. The development of SWC-HPC and the relevant equations are given in details by Saxton and Willey (2006) and Saxton *et al.,* (1986).

According to Igbadun *et al.,* (2011), research outcomes reveal that the SWC-HPC model may only be used to simulate soil bulk densities and moisture status at saturation, field capacity, wilting points of study location in Zaria (Uplands) savanna ecological zone of Nigeria. It was reported that the linear relationship between the logarithm of volumetric water content and the logarithm of suction was used by Williams *et al.,* (1983) to describe the soil water characteristic curve of many soils in Australia. It was reported that the performance of the SWC-HPC model satisfactorily simulated other parameters except saturated hydraulic conductivity of the soils tested which was poorly simulated (Igbadun *et al.*, 2011). The merit of the SWC-HPC model is that it is simple, efficient in operation and predict easily. However, the SWC-HPC has it own limitation in that it may not predict well in some locations due to the high suction range. Figure 1 shows the graphical input screen for the SWC-HPC model.

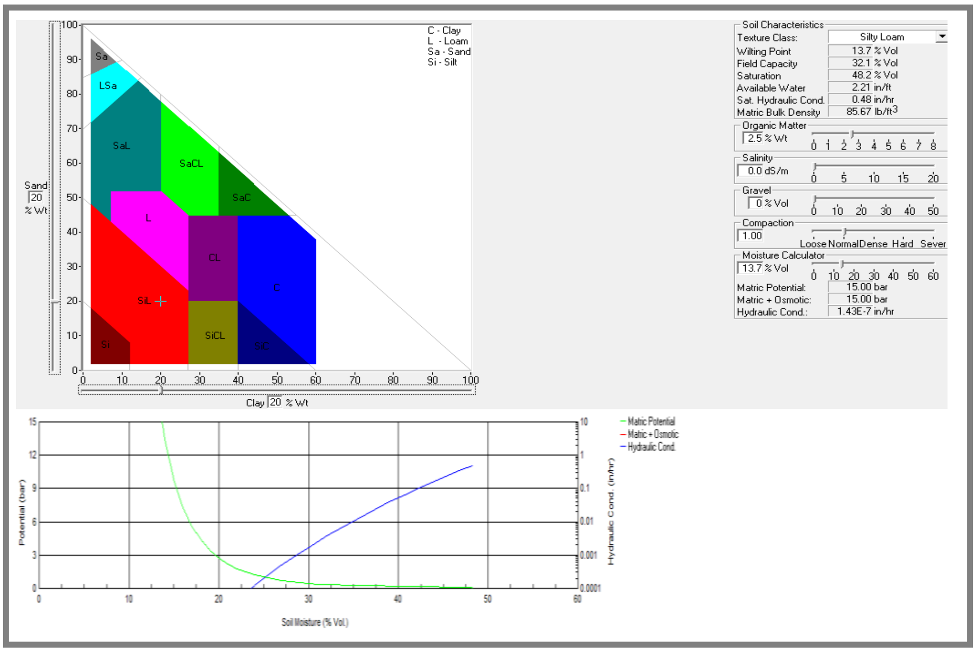


Figure 1: Graphical input screen for the SWC-HPC model (source: Saxton and Wiley 2006)

2.3 Movement of Water in the Soil

The movement of water in the soil and associated solute transport perform a role of primary importance in many applications in the field of hydrology and agriculture (Comegna *et al.*, 2012). Movement of water occurs from a higher energy state to lower energy state and the driving force for the movement is the potential difference between energy states (Turner, 2006). This potential difference is caused by gravity, osmosis and capillarity.

Water moving through the profile is either held in pore spaces within the soil particles for plant use, or percolate to underground water (Abdulkadir, 2000). When water is applied at the soil surface in the form of flood irrigation or rainfall, it enters the soil profile and changes water content distribution with depth. If irrigation continues for some time, the following zones can usually be distinguished in the water content profile (Hillel, 1980). Saturated zone, transition zone, transmission zone, wetting zone and wetting front. This phenomenon occurs under both saturated and unsaturated condition.

2.4 Soil Water Measurement

The measurement of water content is one of the most common kinds of soil analysis performed. The potential effects and influence of soil water content on the behavior and application of soil make it an important measurement in every type of soil study (Carter, 1993). Over the past years interest in the unsaturated zone of soils has been increased, The interest has been fueled by public concerns about diminishing quality of ground water and soil (Van Genuchten, 1980). As hydraulic conductivity are affected by soil physical properties such as soil texture, as soil physical property change, so does the soil water characteristics curve and hydraulic conductivity. Soil water characteristics curve shows the relationship between water content and soil suction in the unsaturated zone. Soil water content is the amount of water incorporated within the soil pores and soil suction is an energy level of soil water. Matric suction is the pore air pressure minus the pore water pressure. When an unsaturated soil becomes more saturated matric suction decreases. Gravimetric water content (ω) is calculated as:

$$\omega = M_w / M_s \qquad (2.1)$$

where M_w = mass of the water,

M_s = mass of the soil volumetric water content is calculated as:

$$\theta = (W_s - W_d)/dV_s \quad (2.2)$$

Where d is the density of water and V_s is the contained volume of the sample. The wet weight of the soil and the sample container ring is W_s and the dry weight to the soil and the container is W_d.

Gravimetric water content on dry weight

$$Ø = \frac{Ww - Wd}{Wd} \times 100 \quad (2.3)$$

Where

Ww = weight of moisture soil

Wd = weight of dry soil

2.5 Physical properties of Soil

Soil moisture is defined simple as the amount of water in a unit volume of soil. As water can only exist in the void space of soil sample, the measured soil moisture can theoretically range from a minimum value of zero (dry soil) to a maximum value of the porosity (all void space filled with water) for the given soil sample. In actual field condition this range is less as solid do not often dry completely but can reach full saturation. Soil moisture is commonly expressed as volumetric water content (θ) (Dingmans, 1994).

$$\theta = V_w / V_s \quad (2.4)$$

where V_w = Volume of water

V_s = Volume of soil

Another similar expression for soil moisture is degree of saturation which is the proportion of pore space that contains water.

$$S = V_w / (V_a+V_w) = \theta/\varphi \quad (2.5)$$

where V_a = Volume of air

$$\varphi = \text{Porosity} = \frac{Vv}{Vt} \quad (2.6)$$

Soil moisture is directly related to hydraulic Conductivity (K_h) and the soil water pressure head (ψ). As the moisture content increases, K_h increases non linearly from zero at low to moderate soil moisture up to the saturated hydraulic conductivity K_h at (θ) saturation (Dingmans, 1994). Field capacity is the amount of water in a soil column that can be held against the force of gravity (Dingmans, 1994). Water can only be removed from a soil at field capacity through evapotranspiration that is by direct evaporation or by plant uptake as part of transpiration. Although the value of field capacity varies from different soil types as low as 0.1kPa for sand and as high as 0.3 kPa for clay (Dingmans 1994).

2.6 Saturated Hydraulic conductivity (Ks)

Saturated hydraulic conductivity is one of the most critical soil hydraulic properties (Rawls *et al.,* 1998). It is influenced by the porosity of the soil, which in turn is affected by the bulk density, structure, texture, exchangeable sodium percentage, and other factors (Mbagwru, 1990; Saxton *et al.*, 1986). It is related to saturated flow where there is complete filling up of the pore spaces with water moving through the soil profile, making the soil saturated. Hydraulic conductivity of saturated soil is constant with time (Ghildyal and Tripathi, 1987). Water movements during drainage and in ground water system are obvious cases of saturated flow (Wudivira *et al.*, 2001) where only solid and liquid states of matter exist.

It has been noted that the major factors contributing to high Ks values during field surveys are abundant biosphere, texture coarser than loamy fine sand strong to medium block structure (Mbagwu, 1990).

2.7 Wetlands

Wetlands are terrestrial or semi terrestrial ecosystem characterized with low drainage quality, slow waters or seldom standing water body filled with soil. Wetland can be categorized as, marsh or swamp based on floral habitat and associated soil components (Olalekan *et al.*, 2014).

Wetlands are important aspect of the physical environment in Nigeria agriculture. In northern Nigeria, dry season vegetables (onions, Tomatoes, garden eggs and pepper) cultivation has been practiced for generations in the fadama’s or seasonally wet bottom lands (carter *et al*., 1983) using shaduf irrigation system. The awareness of dry season vegetable cultivation is growing in the southeastern agricultural zone of Nigeria National Root Crops Research Institute (NRCRI, 1993). However, the wetlands are usually utilized in planting rice, sugar cane, cocoyam and early yam in the zone. Fishery is practice along the coast. The limited studies conducted on the wetland in the zone were by Lekwa (1986) and adhoc soil surveys by the river Basin Development Authorities reported by Enwezor *et al.,* (1990).

In Nigeria wetland comprises swamp, mangrove and fresh water swamp and shallow to deep water fadama which are scattered in packets, covering over 24,009 km. Previous findings showed that all Nigerian saline wetlands occupy 59,000 acres (Ojekunle *et al.*, 2009). The wetlands of Nigeria make important contribution to the livelihood of urban and rural communities. Environmentally, they provide a range of hydrological and ecological benefits including the recharge and discharge of aquifer. The wetland soils of Africa consist of histosols, gleysols, fluvisols and temporary flooded soils (Andriesse, 1985).

In Nigeria, wetland comprises inland swamp, mangrove and fresh water swamp and shallow to deep water fadama (Ayotade and Fagade, 1980). Assessing the spatial distribution of Nigerian wetland, Kio and Ola Adams (1986) reported that the wetlands are scattered and in packets, covering over 24,009 km. The wetland resources in the sub-Saharan Africa consist of the coastal wetland inland basins, river, valley and flood plains.

2.8 Physiochemical Properties of Soils

2.8.1 Salinity

Soil salinity designates a condition in which the soil water contains a soluble salt with a concentration likely harmful to crops through the increased osmotic potential of the soil solution and the toxicity of specific ions, salts may be from those present in the original soil profile or accumulated from irrigation water. Salinity largely affects the plant water uptake through increase water potentials. However, it also can affect the hydraulic processes, infiltration and redistribution through chemical induced changes of structure and aggregate (Tanji, 1990). Salinity is a major problem for soils under continuous irrigation. A saline soil is one in which the electrical conductivity of its aqueous phase exceed 4ds/m. The metals and ligands that contribute to soil salinity are Na^+, K^+, Mg^{2+}, Co_3^{2+}, Hco^-_3, So^{2-}_4 and $B(OH)^-_4$. The soluble salts in soils refer to dissolved inorganic salts in soil solution. Measurement of these metals and ligands of dissolve salts are important in designing management and reclamation method for saline or calcareous soils. Soluble salts in soil can be determined by measuring the specific conductivity of soil water extracts or by direct determination of metals and ligands in soil water extracts (Zhou *et al.,* 2007). Soil water salinity can affect soil physical properties by causing fine particles to bind together into aggregates. This process is known as flocculation and is beneficial in term of soil aeration, root penetration and root growth. Although increasing soil solution salinity has a positive effect on soil aggregation and stability at high level, salinity can have negative and potential effect on plants. As a result salinity cannot be increased to maintain soil structure without considering potential impact on plant health. Soil dispersion causes clay particles on plug soil pores which reduces soil permeability.

2.8.2 Organic Matter

Soil organic matter is a critical component of agricultural production system because of its beneficial effects on soil productivity and fertility. Increase organic matter generally produces a soil with increased water holding capacity and conductivity largely as a result of its influence on soil aggregation associated pore space distribution (Hudson, 1994). Water content at high tensions for example 15 kPa, is determine largely by texture, thus there is minimal influence by aggregation and organic matter (Tisdall and Oades 1982). Its quantitative and qualitative distribution in a soil affects its physiochemical properties. Chemical properties such as cation exchange capacity availability of nitrogen, phosphorus and sulphur and physical properties such as bulk density, aggregation, infiltration and water retention are affected by soil organic carbon is usually determined by dichromate oxidation technique. Organic matter is the plant and animal residue in the soil at various stages of decomposition.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study Location

The study was carried out in Zaria, Nigeria. Zaria lies on longitude 7^0 35'E, latitude 11^0 11'N, and altitude 686m above mean sea level, it is located within the Northern guinea savannah ecological zone. The climate can be described as semi-arid with three distinct seasons. The hot dry season which spans from March to May, warm rainy season from June to early October, and the cool dry season which spans from November to February, the average relative humidity is 36.0% during the dry season and 78.5% during the wet season and the average minimum and maximum temperature are 15.6^0C and 38.5^0C respectively. The rainfall is monsoonal in origin averaging about 1150 mm per annum with an average of 650 mm peak in August.

. The wetland is located in Hayin Agoi off Hayin Gada along shika Road which lies on longitude 7^0 34'E and latitude 11^0 11'N at altitude of 687m above mean seal level The land area is 450 m by 210 m. The second site is along Rafin Basawa before bridge (Rafin Yerima) which lies at longitude 7^0 04'E, latitude 11^0 09', altitude of 662 m above mean sea level, area of land 300 m by 150 m. The third site is along Kubani multipurpose maje Road, Tudunwada which lies at longitude 7^0 43'E and latitude 11^0 05'N, altitude of 621m and land area of 270 m by 180 m.

3.2 Soils Condition of the Study Location

The soils of the study area are classified as alfisols based on the USDA (1975) classification. The soils are reported as mantle of residue overlain by Aeolian deposits, formed from loessial loessial-colluvial and colluvial-alluvial parent materials (Aremu, 1980). The soils are deep (1.25-2.0m) and have friable sandy clay to clay loamy textures, while the sub-horizon (20-40cm) are well structured which favour good agricultural production (Odunze, 1998).

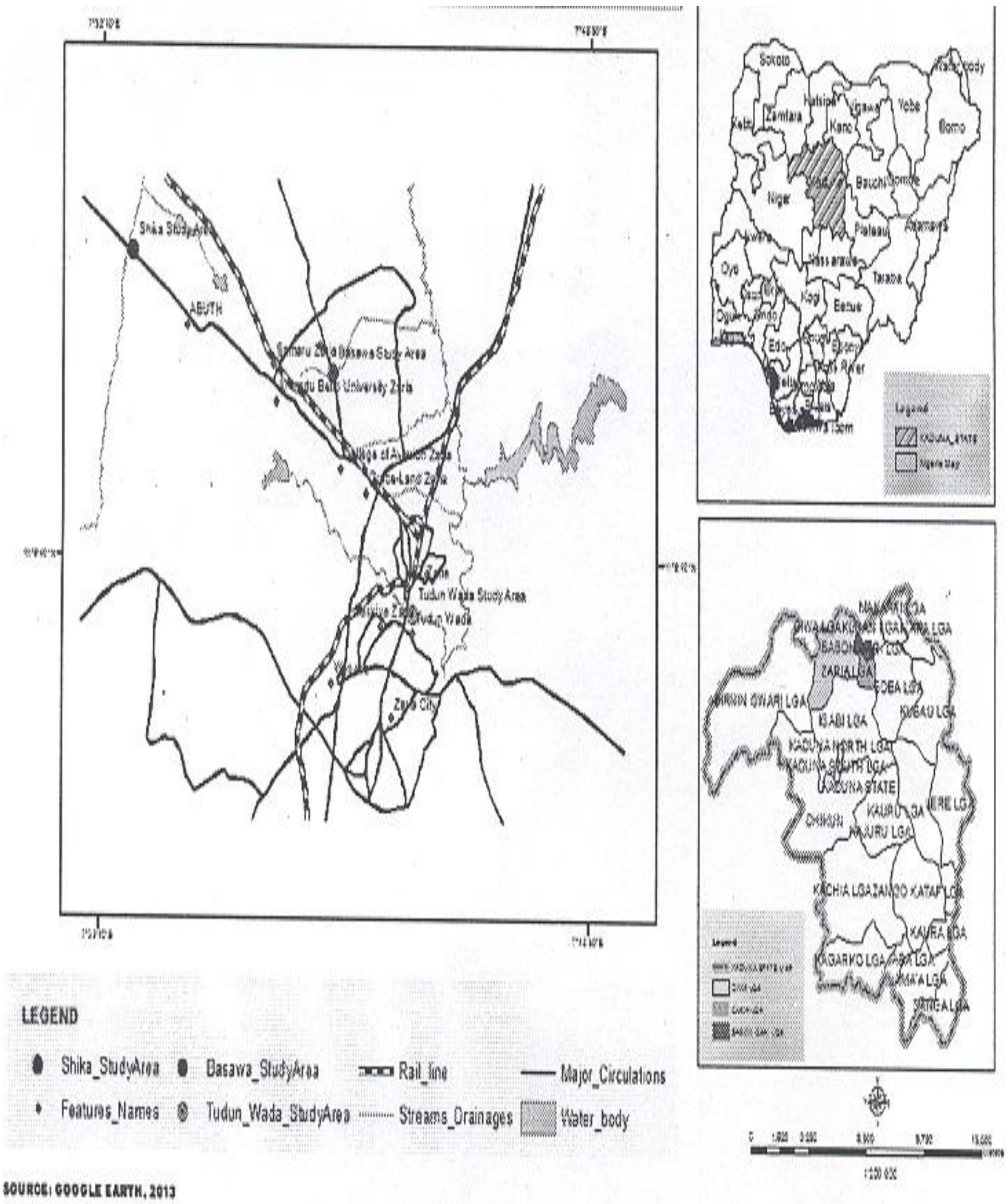


Figure 3.1 Map of the study locations

3.3 Description of Experimental Procedure

The study was carried out in three selected wetland, six profile pits was dug in each site using core samplers of 5 cm diameter. The diameter of the profile pit was 1.6 m and the depth of the pit is 50 cm. Core sampler was inserted into an anger and driven by hammer into the soil in order to collect soil samples from the identified horizon for laboratory analysis at the depth of 0 – 10 cm, 10 – 20 cm, 20 – 30 cm, 30 – 40 cm and 40 – 50 cm respectively. Each sample was placed inside the leather to preserve the moisture. Five samples were collected per pit and a total of 30 samples per site, overall total for the three sites was ninety (90) samples. The distance from one pit to another was 11.8 m apart. The soil sampling was done in August 2013.

3.4 Laboratory Analysis

The analysis of the soil samples was carried out in the Soil Physics Laboratory of the Department of Soil Science, Ahmadu Bello University Zaria. The analyses carried out include the particle size distribution, soil bulk density, organic matter content, salinity, Standard laboratory procedures for determining each of the parameters given by Klute (1965) was followed.

3.4.1 Bulk Density (BD)

Soil samples were collected using core sampler from the experimental fields and then taken to the laboratory for oven dry for 24 hours at a temperature of 105^0C until all the moisture is dried. The bulk density is then calculated

$$BD=W_d/V_t \tag{3.1}$$

Where, BD = Bulk density (g/cm^3)

W_d = Weight of dry soil (g)

V_t = total volume of soil (cm^3)

3.4.2 Organic Matter/Organic Carbon

One gramme of soil was weighed into 250ml conical flask. The weight of the soil was reduced due to the high content of organic matter. 5ml of potassium dichromate ($K_2Cr_2O_7$) was added using a pipette and the flask was swirl gently to disperse the soil. Rapidly 10ml of concentrated tetraoxosulphate (vi) acid (H_2SO_4) was added from a measuring cylinder and swirl for one minute again. The amount of soil taken was reduced to half after the colour turns greenish. The flask was allowed to stand on asbestos sheets for 30 minutes (end point is easily reached if suspension is cold). 100ml of distilled water was added to the flask and allowed to cool. Five drops of the indicator was added and titrated with ammonium Ferrous Sulphate solution with a background. $^1/_{10}$ phenonatarolien indicator, finally titrate with 0.5 normal (Fe_2 NH_4So_4)in order to obtain titre value prepare a blank also which does not contain a soil sample.

$$\% \text{ Organic Carbon} = B - T \times 0.399 \times C/_B \quad (3.2)$$

Where, B is Blank reading,T is titre or sample value, C is 5 ml of K_2 Cr_2 0_7.

Percentage organic carbon was calculated as:

$$\% \text{ OC} = \frac{Blank\ titre - actual\ titre\ x\ 0.3\ x\ M\ x\ F}{weight\ of\ soil\ taken} \quad (3.3)$$

where M = molar concentration of NH_4FeSO_4

F = Correction factors, 1.33

3.4.3 Determination of Particle Size Distribution

50 g of 2 mm sieve soil sample were poured into a polythene bottle; 25 ml calgo and 100ml distilled water was added and the bottle was shaken thoroughly at 40 to 60 revolution, using mechanical shaker for 15 minutes. The suspended soil was transfered to 1 litre (1000ml) capacity cylinder and dilutes to mark a point. This was stir for 1 minute by using plunger. Then insert the hydrometer, the reading were taken at time interval of 15 minutes. Again hydrometer was inserted for 20 seconds before the time of reading is due. First reading was taken at 4 minutes 48 seconds for silt and clay (0.02 mm). Second reading was taken at 5 hours for clay < 0.002 mm.The thermometer was inserted to take the temperature of the soil suspension after each reading by either add or subtract 0.3 units for each degree above or below 19.5^0C. Particle size ranges from gravel >2 mm, sand 0.05-2 mm, silt 0.002-0.05 mm and clay < 0.002 mm.

3.4.4 Determination of Electrical Conductivity

Distilled water and calcium chloride ($CaCl_2$) are the reagents used to determine the soil pH at the ratio of 1:2.5, 10 g of soil sample was weigh into plastic container, 25 ml of distilled water was added and stir very well and allow to settle for 30 minutes after first 30 minute, it was stir again and allow to settle for 15 minute at interval of 15 minute, pH reading was taken using pH meter after standardize the reading. To determine EC, the sample used in determining the pH is allowed to stay over night, using electric conductivity meter Bridge to obtain the reading and is given in ds/m. the remaining sample of pH is pour into cup (conductive cell) and attached to the side of conductivity meter which is calibrated with a slider bar from 0 - 500 µmhos/cm when move to and fro, where the slider bar stop the reading is taken.

3.5 Determination of Soil Suction

Soil moisture retention at different suction were determined from the soil core samples using the pressure plate apparatus. Suction points of zero kPa (maximum retention capacity), 0.1kPa, 0.3kPa, 1.0kPa (field capacity), 5kPa, 10kPa, and 15kPa (permanent wilting point) were used to extract water from the soil. Data generated were used to determine water retained at each suction and plotted as soil water characteristics curve as shown in figure 4.2. Eighteen soil samples were arranged in a ceramic plate and covered with pressure plate, compressor which is connected to electricity was turn on, to produce high pressure. It was left for two to three days so that water drains out of the orifice whenever the equilibrium is reached. Then the pressure was reduced to 0 kPa and soil sample were removed and weighed by using electronic weighing machine. The procedure was repeated again. Zero is the initial reading after saturation, water was allow to drain for 2 to 3 minutes and then reweighed.

3.6 Simulation Procedure

The predictability of the SWC – HPC model was tested by inputting the percent clay, percent sand, percent organic matter and salinity in ds/m of each soil sample into the model. The weight of the gravel was set at 0% and the degree of compaction is at normal (1.00) as no gravels were detected in the profile pits. The model output considered in this study includes moisture content at saturation, field capacity, wilting point and bulk density for the three locations. The results of simulation are found in the Appendices iv, v and vi respectively.

3.7 Soil Sample for Model Evaluation

In order to assess the performance of the SWC-HPC model in the selected wetland to predicting the soil water characteristic was first determined by obtaining soil samples in the three wetland in Zaria. The wetland include Hayin Agoi along Shika road, Rafin Yerima Basawa and Maje multipurpose road in Tudun wada. 90 soil samples are collected from the wall of six profile pits of 50 cm depth in each wetland. Five samples are taken from each pit at 0-10 cm, 10-20 cm. 20-30 cm, 30-40 cm and 40-50 cm depths using core samplers of 5cm diameter. The samples are analysed in the soil physics laboratory of the department of soil science, Ahmadu Bello university, Zaria. The analysis carried out include the particle size distribution, organic matter, soil bulk densities and moisture characteristics at suction pressures of 0, 0.1, 0.3, 1, 5, 10, 15 kPa. Standard laboratory procedures for determining each of the parameters given by Klute (1965) was carefully followed.

3.8 Model Evaluation Procedure

The comparison between the model predicted values and the laboratory measured/observed values for the three fields were carried out using selected statistical indices. The indices include root mean square error (RMSE), coefficient of variation (CV), modeling efficiency (EF) and coefficient of residual mass (CRM). The equations are express as follows

$$RMSE = \left[\frac{1}{n}\sum_{i=1}^{n}(P_1 - O_i)^2\right]^{0.5} \quad (3.4)$$

$$CV = 100 * \frac{\left[\frac{1}{n}\sum_{i=1}^{n}(P_1 - O_i)^2\right]^{0.5}}{O_m} \quad (3.5)$$

$$EF = 1 - \frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}(O_i - O_m)^2} \tag{3.6}$$

$$CRM = \frac{\sum_{i=1}^{n} O_i - \sum_{i=1}^{n} P_i}{\sum_{i=1}^{n} O_i} \tag{3.7}$$

where P_i = model predicted values

O_i = observed values

O_m = mean of observed values

n = number of data

Root mean square error is a measure of precision while coefficient of variation expressed is a measure of variability between predicted and observed data. The RMSE should tend towards zero as the measure value increases. The CV for a model aims to describe the model fit in terms of the relative sizes of the squared residuals and outcome values. This indicates that the higher the CV the greater the dispersion in the variable the lower the CV, the smaller the residuals relative to the predicted value. The modeling efficiency EF is referred to as the coefficient of Nash-Sutcliffe (Nash and Sutcliffe, 1970), is a measure of fit between predicted and measured data. Nash–Sutcliffe efficiencies can range from (-∞ to 1). An efficiency of one (E = 1) corresponds to a perfect match of predicted to the observed data. An efficiency of zero (E = 0) indicates that the model predictions are as accurate as the mean of the observed data, whereas an efficiency less than zero ($-\infty < E < 0$) occurs when the residual variance described by the numerator in Eq 3.6 is large than the data variance (describe by the denominator) and it implies that the observed mean is a better predictor than the model. Essentially, the closer the model efficiency is to 1, the more accurate the model is (Nash and Sutcliff, 1970). Coefficient of residual mass

(CRM) is an indicator of the tendency of the model to either over or under predict measured values. A positive value of CRM indicates a tendency of underestimation while a negative value indicates a tendency of overestimation (Antonopoulos, 1997). Mahdian and Gallichard, (1995) and Krause *et al*, (2005).

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Physio-Chemical Properties of the Study Locations

The averages of the results obtained from the analysis of soil physio-chemical properties at various depths of Shika, Basawa and Tudunwada locations are presented in the tables 4.1a,b,c below.

Table 4.1a Averages of physiochemical properties of Shika soil

Depth (cm)	Sand%	Silt%	Clay%	OM %	EC ds/m	Texture class
0-10	35.7	50.1	13.3	25	0.5	Sandy Loam
10-20	43.3	46.3	10.2	22	0.4	Silty loam
20-30	44.2	44.7	12.2	20	0.4	Silty loam
30-40	37.1	48.0	15.0	15	0.6	Silty loam
40-50	34.2	46.1	20.3	13	0.7	Silty loam

Based on USDA Textural Classification

Table 4.1b Averages of physiochemical properties of Basawa soil

Depth (cm)	Sand%	Silt%	Clay%	OM%	EC ds/m	Texture class
0-10	30.7	43.3	21.3	16	0.5	Silt loam
10-20	34.0	48.2	19.4	10	0.3	Silt loam
20-30	28.3	46.7	25.2	7	0.4	Sandy clay loam
30-40	27.7	45.3	33.2	4	0.5	Sandy clay loam
40-50	35.0	41.8	26.7	5	0.4	Silt loam

Based on USDA Textural Classification

Table 4.1c Averages of physiochemical properties of T/wada soil

Depth (cm)	Sand%	Silt%	Clay%	OM%	EC ds/m	Texture class
0-10	47.7	42.7	10.0	45	0.7	Sandy loam
10-20	45.3	44.0	18.7	37	0.6	Loam
20-30	40.3	47.0	12.0	49	0.4	Loam
30-40	43.7	43.0	12.7	56	0.5	Sandy loam
40-50	47.3	44.0	9.3	42	0.5	Sandy loam

Based on USDA Textural Classification

The main physio-chemical properties of the soil of the study site are present in tables 4.1a to 4.1c. The particle size distribution pattern shows that the silt loam content is high in

Shika and Basawa while it is the sandy loam content that is high at Tudun-wada. Loamy texture of Tudunwada and Shika soils is a characteristic of wetlands which gives high water table of 56 cm during the dry period of the year. High sandy soil content couples with heavy rainfall have resulted in exchangeable cation being leached out of the profile. (Fasina 2005 and Olaleye, 1998). The organic matter decreased with depth in Basawa and Tudunwada soil while organic matter increased with depth in shika soil. This is an indication of continuous decomposition of organic materials. Organic matter has been reported to have positive influence on the electrical conductivity and water holding capacity of soils (Fasina *et al.,* 2007 and Babalola *et al.,* 2011). Electrical conductivity ranged from 0.5-0.7 ds/m for Shika soil while that of Basawa soil ranged from 0.5–0.4 ds/m and that of Tudun-Wada ranged from 0.7-0.5 ds/m. This falls into two categories according to the USDA classification: 0-0.25 ds/m very low which indicates probable deficiency and 0.025-0.75 ds/m which indicates a soil that is suitable for seedling and salt sensitive plants. The percentage of clay is very low in the three sites while the sand and silt content are higher in Shika and Basawa. The sand content promotes the leaching of mineral salt in the root zone. During the experiment it was observe that organic matter was high in Tunduwada follow by Shika and least in Basawa. It implies that darker soil have high decomposition of organic materials which enable the soil to be darker and heavier. Low organic matters are lighter soil and loose in texture.

The general low clay content of all the site may probably be due to losses associated with frequent cultivation from the past histories of this site (Ogunwole and Ogunleye, 2005). The implication of having more sand content in Tunduwada site than any other fraction is that such site is expected to have an exponential increase in permeability with an increase in particle size as reported by Abdulkadir (2000). It Is also expected that such site permit rapid infiltration because of their higher permeability and effective porosity as observed in the Table 4.1 a, b, c.

4.2 Soil Water characteristic curve of the three study sites

The fields observed values of soil moisture content at the various suctions for all locations are presented in Appendices i, ii, iii respectively. The soil moisture characteristic curve for the moisture content – suction values in Appendix xi a, b, c shows a general trend of deceasing water content with increasing suction in conformity with the findings reported in literature (Hillel, 1980a: Puckett *et al.*, 1985; Ghildyal and Tripathi, 1987). Figure 4.1a-e present the graph of the moisture content against suction at the various depth of 0-10 cm, 10-20 cm, 20-30 cm, 30-40 cm and 40-50 cm in Hayin Agoi along shika road respectively. The graph shows the normal pattern as reported in Hillel, 1980a at zero kPa the moisture content is 40 %, at 10% the suction decrease gradually until the moisture content is 10 % after which increase in suction with decrease in moisture content becomes large. The suction at 10 % for all the plot is 1500 kPa, moisture content is high at zero kPa and very low at 1500 kPa which implies that as matric suction increases the moisture content decreases.

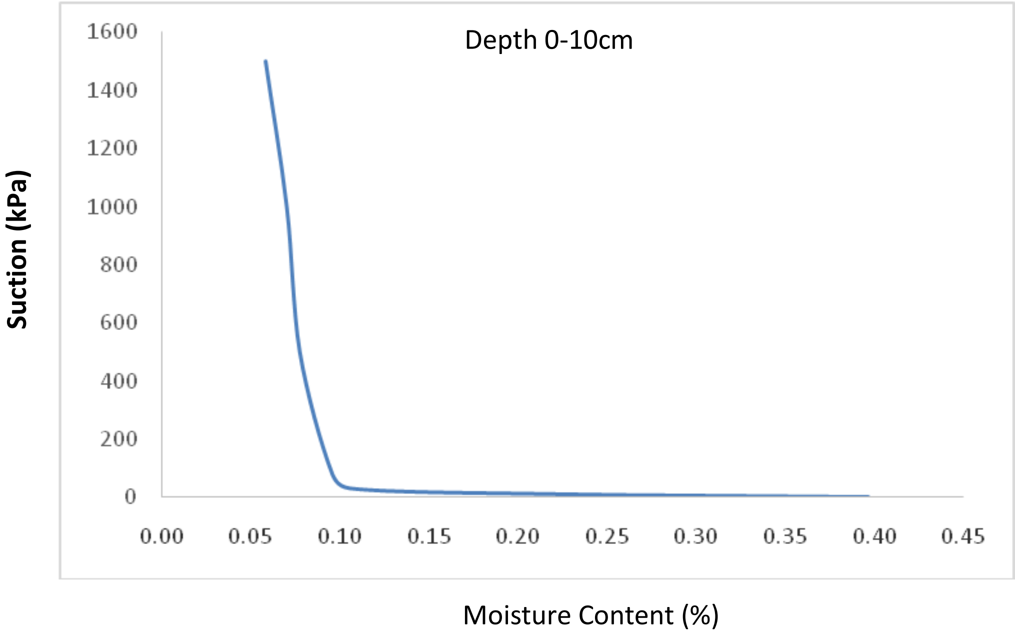


Fig 4.1a soil water characteristics curves at the depth of 0-10cm.

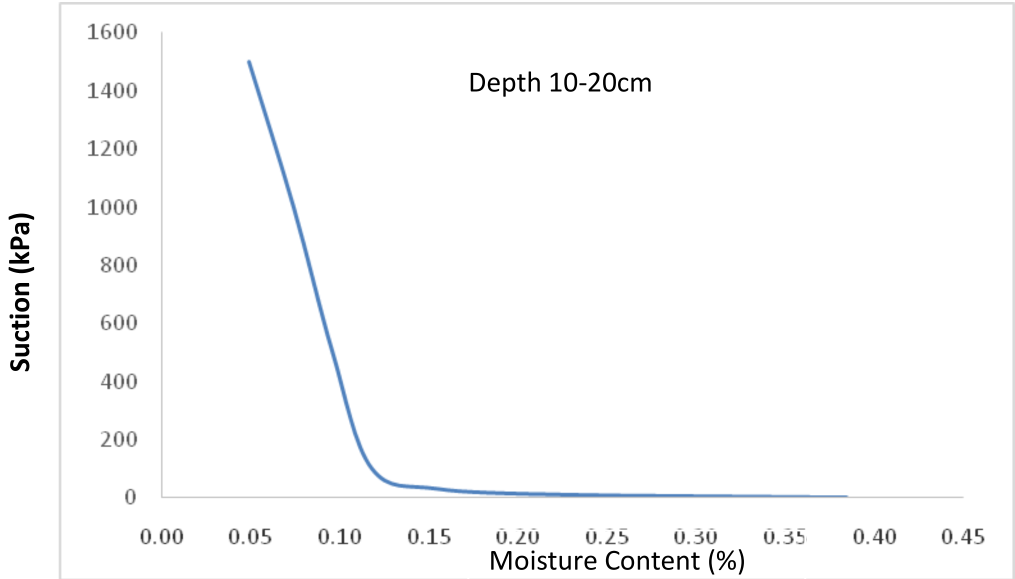
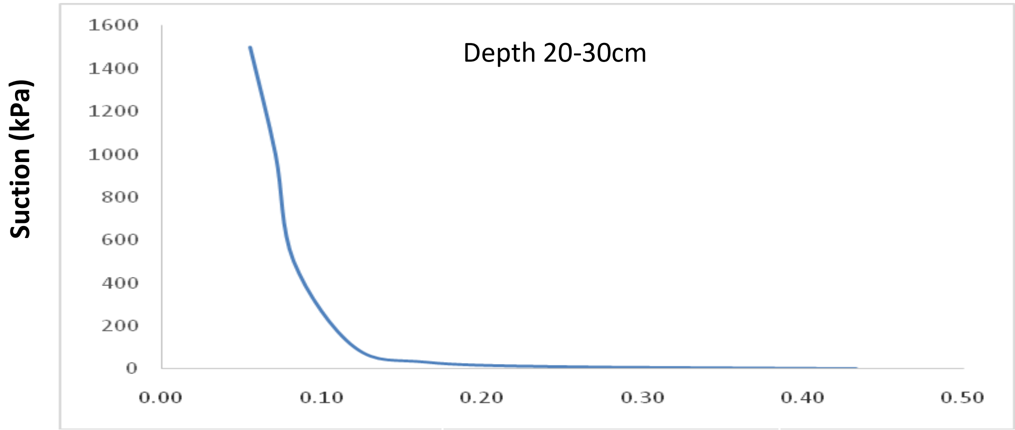


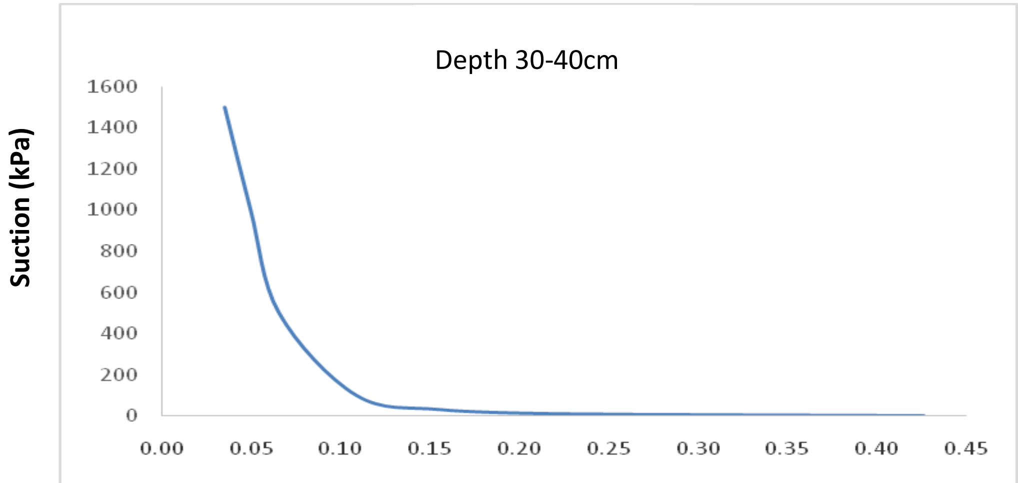
Fig 4.1b soil water characteristics curves at the depth of 10-20cm



Moisture Content (%)

Fig 4.2c

Fig 4.1c soil water characteristics curves at the depth of 20-30cm



Moisture Content (%)

Fig 4.1d soil water characteristics curves at the depth of 30-40cm

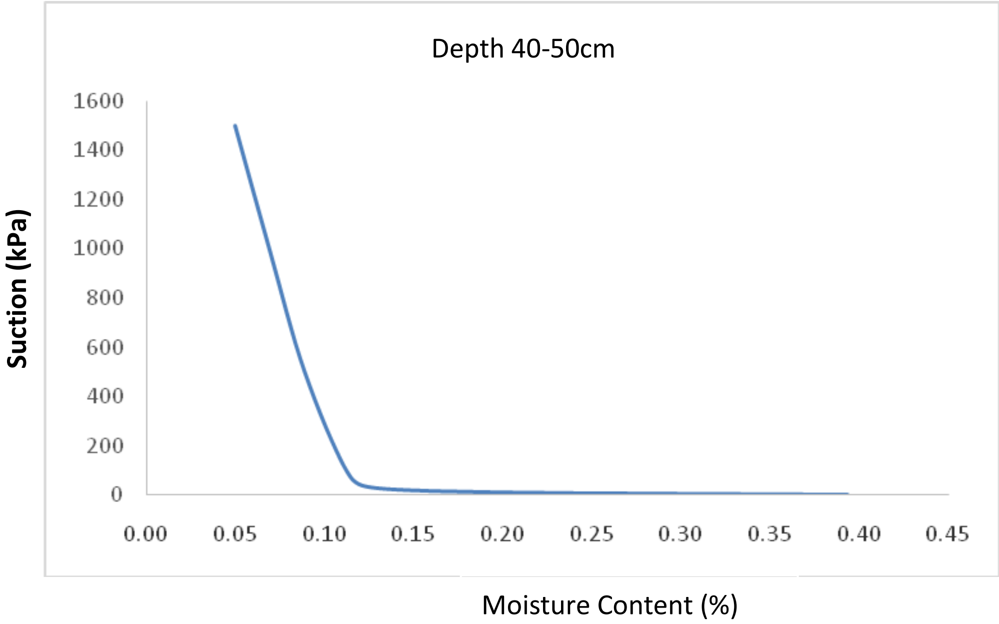
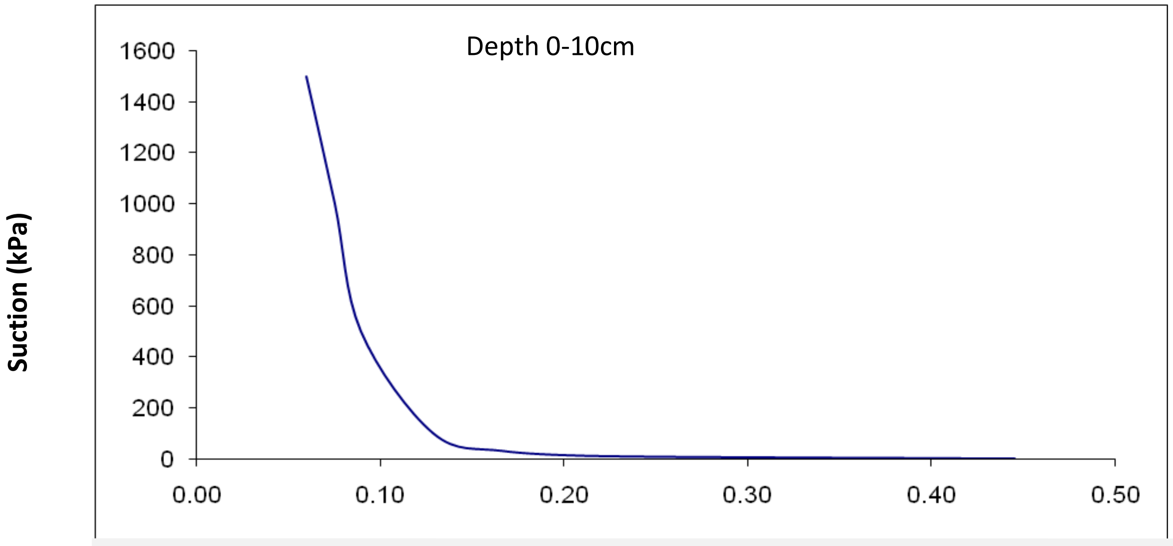


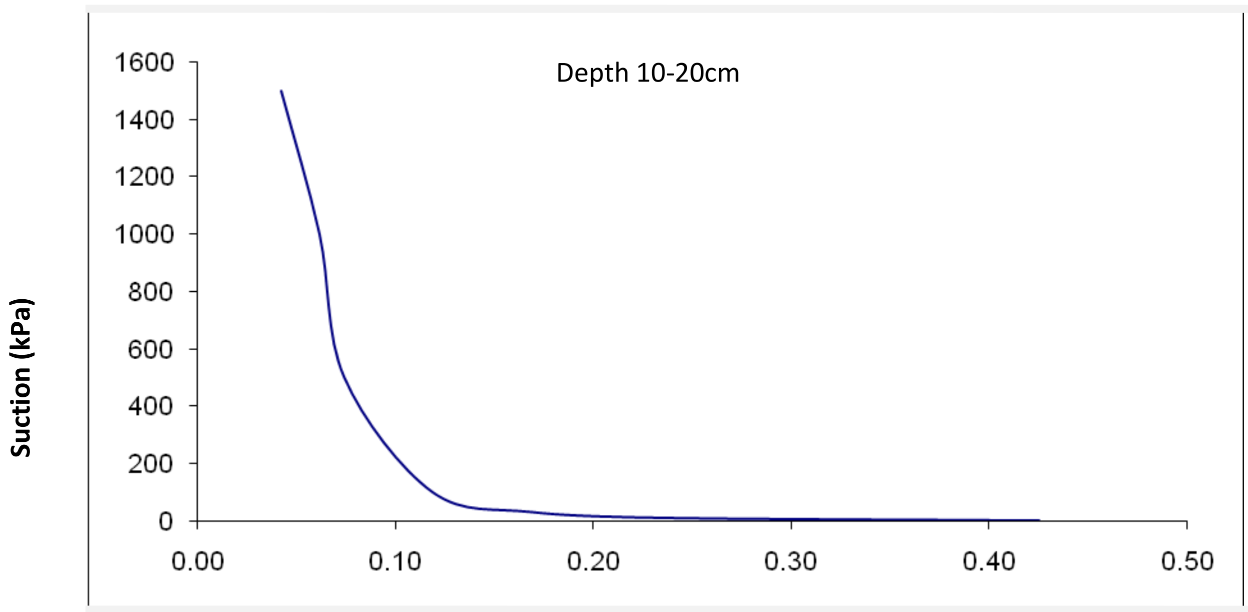
Fig 4.1e soil water characteristics curves at the depth of 40-50cm

Figure 4.2a-e present the graph of the moisture content against suction at various depth or 0-10 cm, 10-20 cm, 20-30 cm, 30-40 cm and 40-50 cm in multipurpose Maje road, Tudunwada respectively. In all the five graph at zero kPa the moisture content is above 40 %, the suction decrease gradually until the moisture content is 15 % after which increase in suction with decrease in moisture content becomes large, the suction at 5 % for all the five is 1500 kPa. Soil water characteristics curve although not perfect as gotten from other researchers (Rawls *et al.*, 1998).



Moisture Content (%)

Fig 4.2a soil water characteristics curves at the depth of 0-10cm



Moisture Content (%)

Fig 4.2b soil water characteristics curves at the depth of 10-20cm

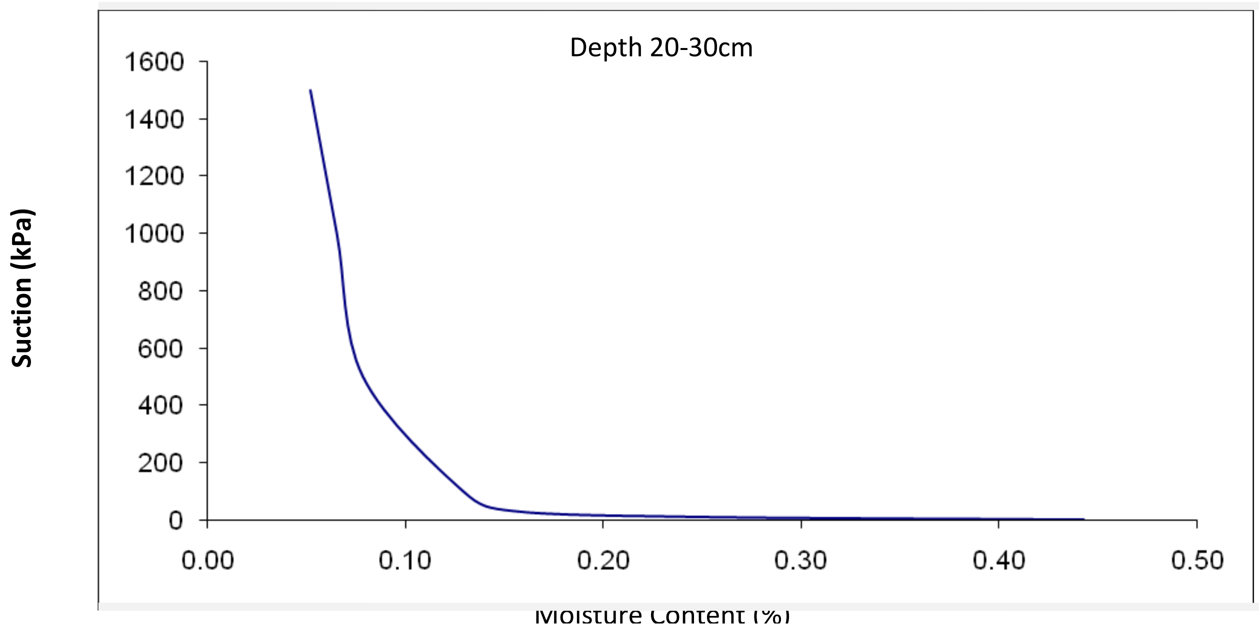


Fig 4.2c soil water characteristics curves at the depth of 20-30cm

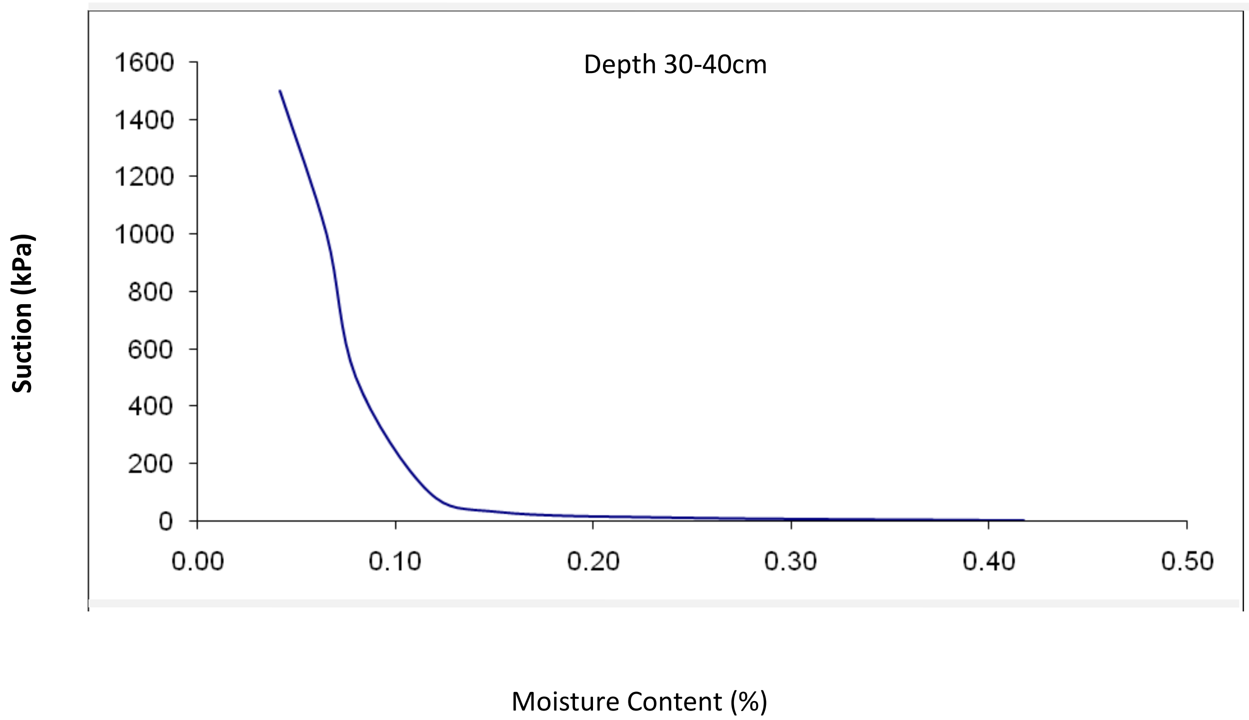


Fig 4.2d soil water characteristics curves at the depth of 30-40cm

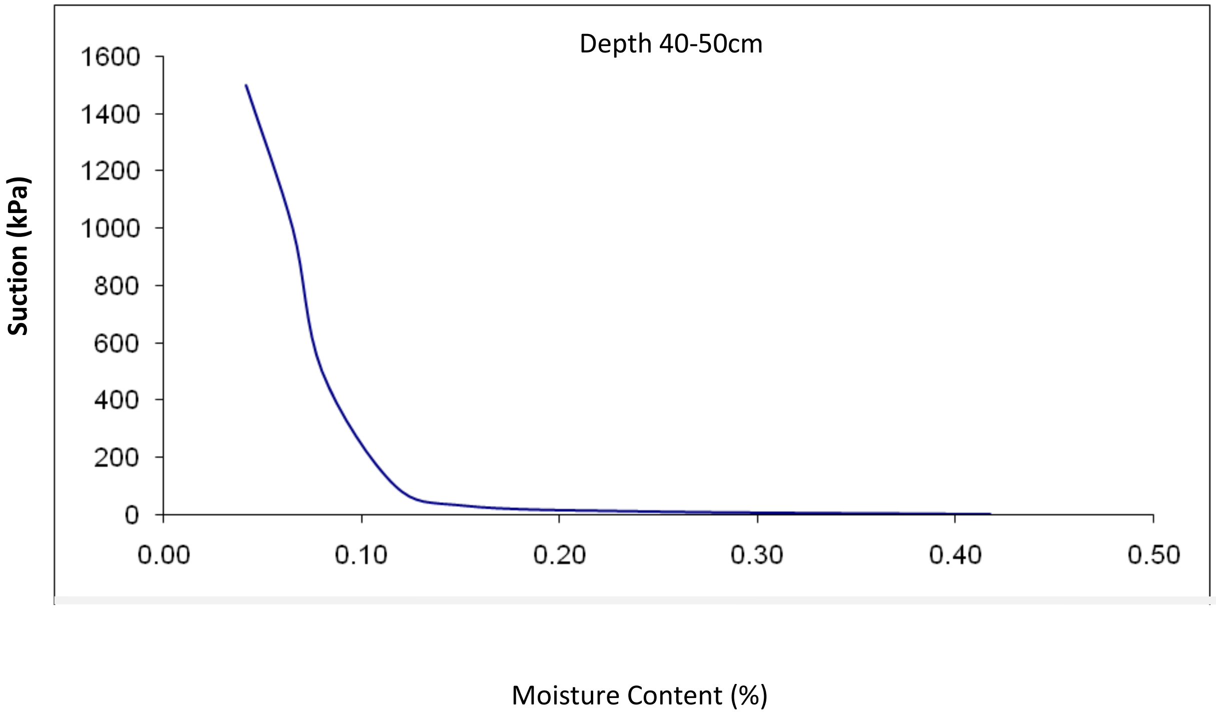


Fig 4.2e soil water characteristics curves at the depth of 40-50cm

Figure 4.3a-e present the graph of the moisture content against suction at the various depths 0-10 cm, 10-20 cm, 20-30 cm, 30-40 cm and 40-50 cm of Rafin Yerima in Basawa respectively. The suction increase gradually with decrease in moisture content up to 5 %. At field capacity (1.0 kPa) the moisture content was 30 % and at 15 kPa moisture content is 5 %. The general observation drawn from the three locations is that the soil water characteristics curves are similar in moisture trend. However, a relationship exist in the three locations according to the pattern of moisture trend. Bruard, (2004) reported that the closeness of relationship between the water retained at a given water potential and electrical conductivity increased when the water potential decreased.

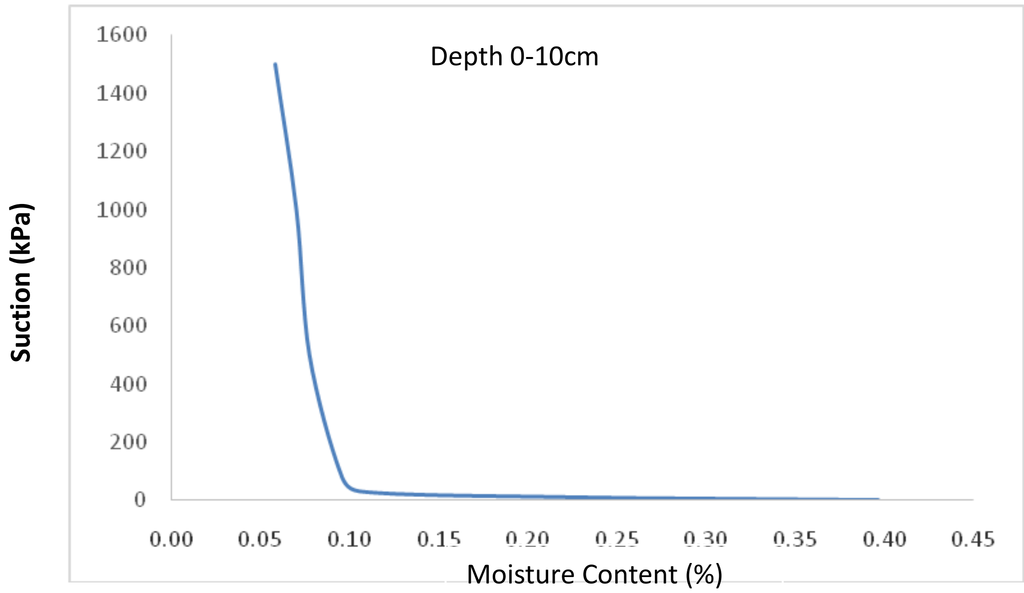


Fig 4.3a soil water characteristics curves at the depth of 0-10cm

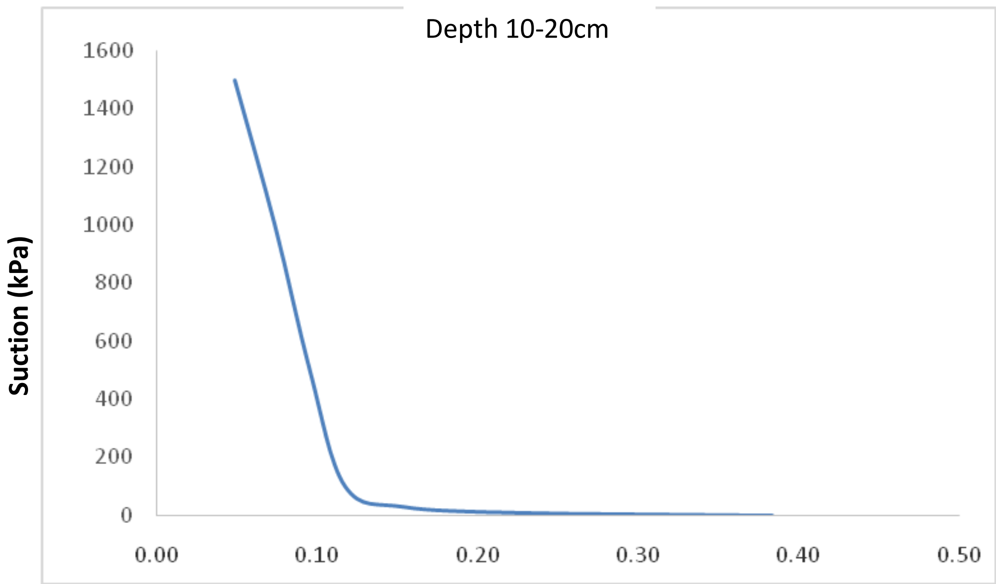


Fig 4.3b soil water characteristics curves at the depth of 10-20cm

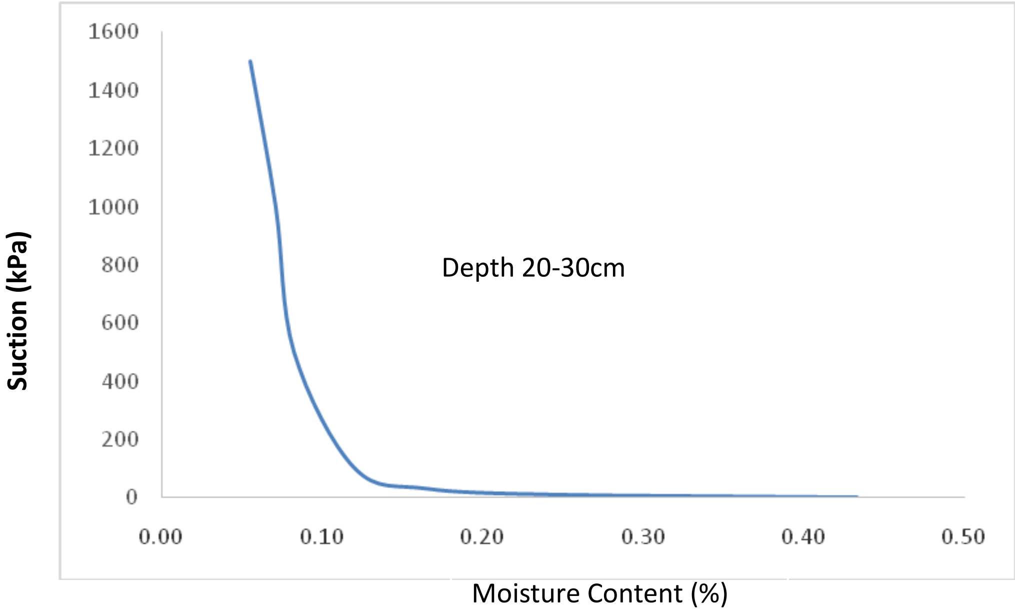


Fig 4.3c soil water characteristics curves at the depth of 20-30cm

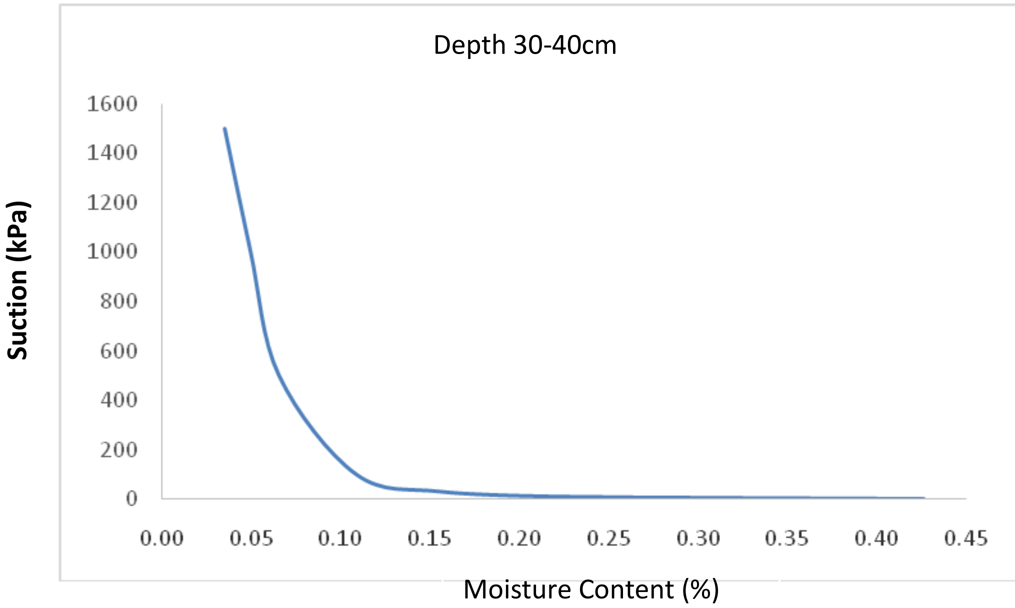


Fig 4.3d soil water characteristics curves at the depth of 30-40cm

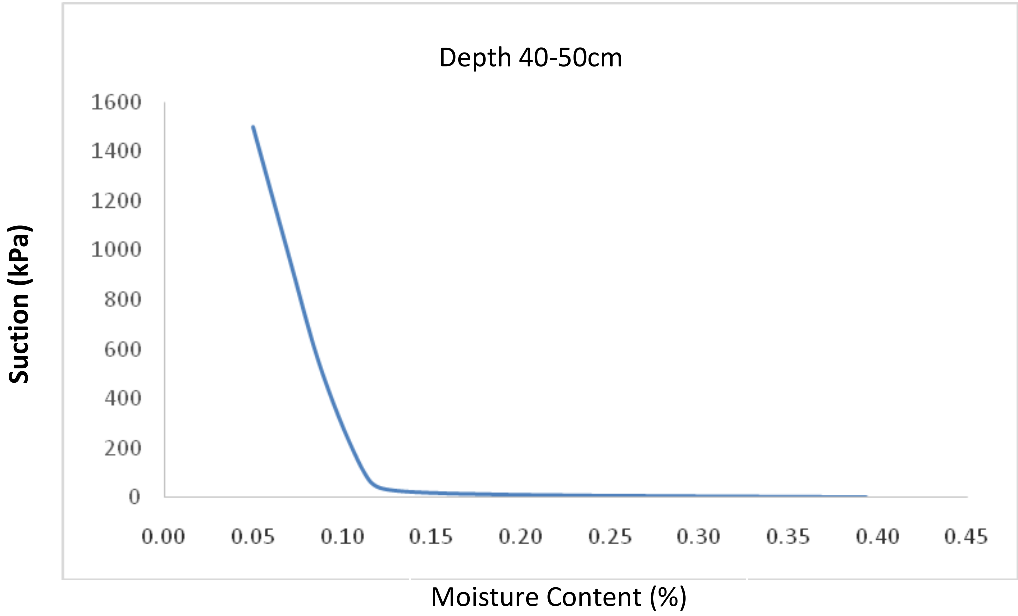


Fig 4.3e soil water characteristics curves at the depth of 40-50cm

4.3 Model Evaluation

4.3.1 Comparison of Predicted and Observed Volumetric Moisture Content at Saturation for the Three Sites.

Fig 4.4 show the predicted and observed volumetric moisture content at saturation for Shika soil. The predicted values ranged from 40.9 % to 48.2 % with a mean value of 47.55 % while the observe data ranged from 47.1 % to 74.3 % with a mean value of 61.2 %. The mean error of bias between the predicted and observed was 13.65 %. The Figure 4.4 shows great disparity between the predicted and observe thus high coefficient of variation. In shika coefficient of residual mass is 26 % which is under estimated. Similarly Fig 4.5 shows volumetric moisture content at saturation for Tudunwada soil with predicted values ranging from 41.7 % to 43.5 % with a mean value of 41.3 % while the observed Value ranged from 60.7 % to 63.7 % with a mean value of 62.2 %. The mean error of bias between the predicted and observe value was 19.6 % . There is disparity between the predicted and observed values that is observed values are higher than predicted value.

For Basawa soil, Figure 4.6 shows that predicted values ranged from 39.6 % to 40.6 % with mean value of 40.2 % while the observed range from 55.6 % to 61.6 % with a mean value of 58.6 %. The mean error of bias between predicted and the observe value was 18.4 %. However the mean error of bias between the three sites for saturation is higher in Tudunwada, 19.6 %, followed by Basawa 18.4 % and least in Shika 13.65 %. The predicted and observe values are shown in appendices viii, ix, and x for the various plots respectively. Therefore, greater disparity in the sense that the observed values are greater than predicted values.

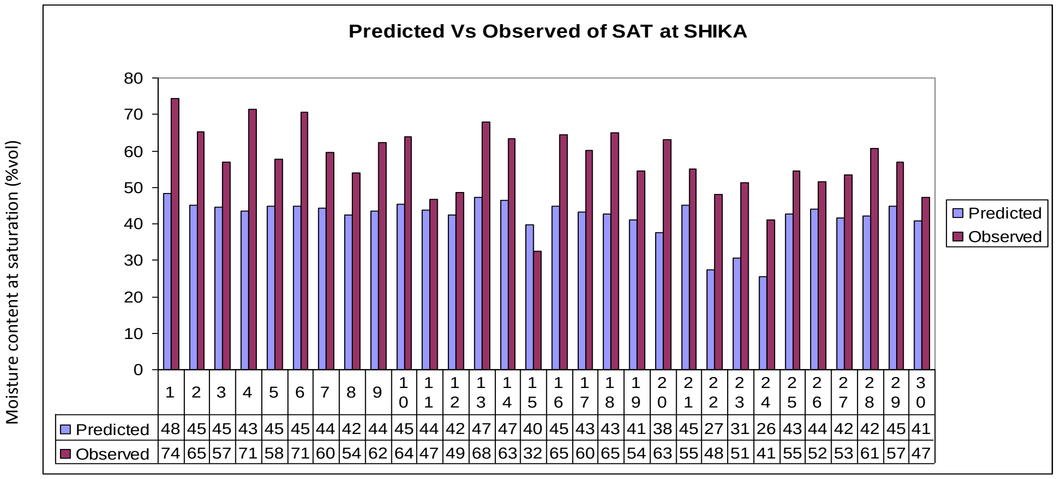


Figure 4.4. Comparison of predicted and observed volumetric soil moisture content at saturation

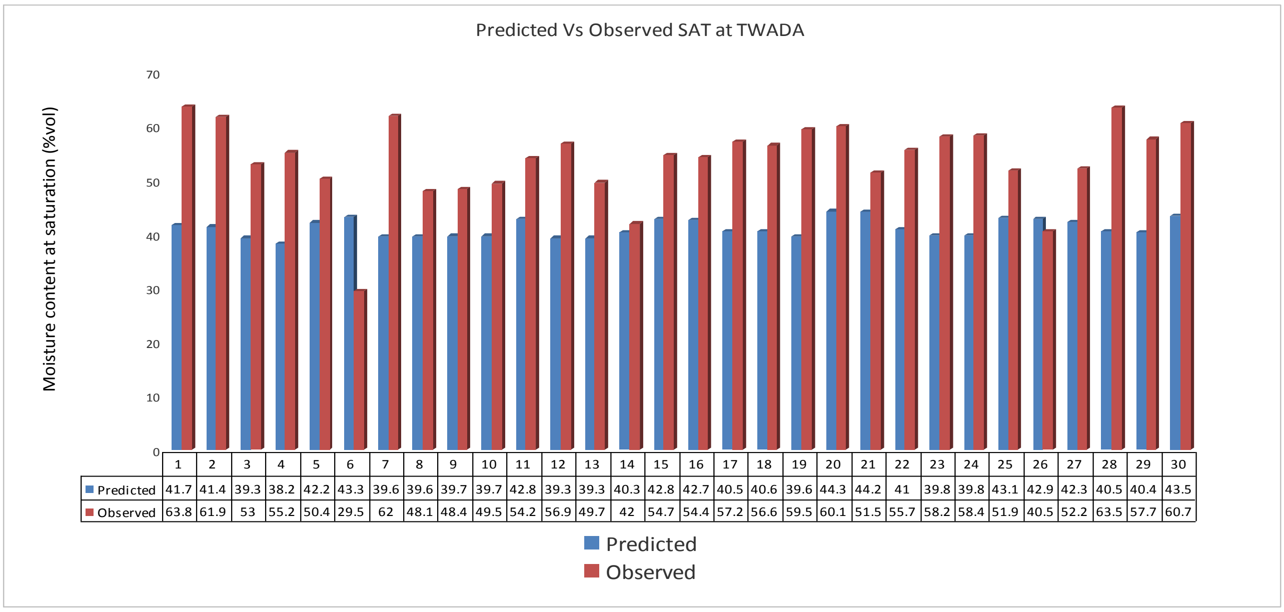


Figure 4.5: Comparison of predicted and observed volumetric soil moisture content at saturation.

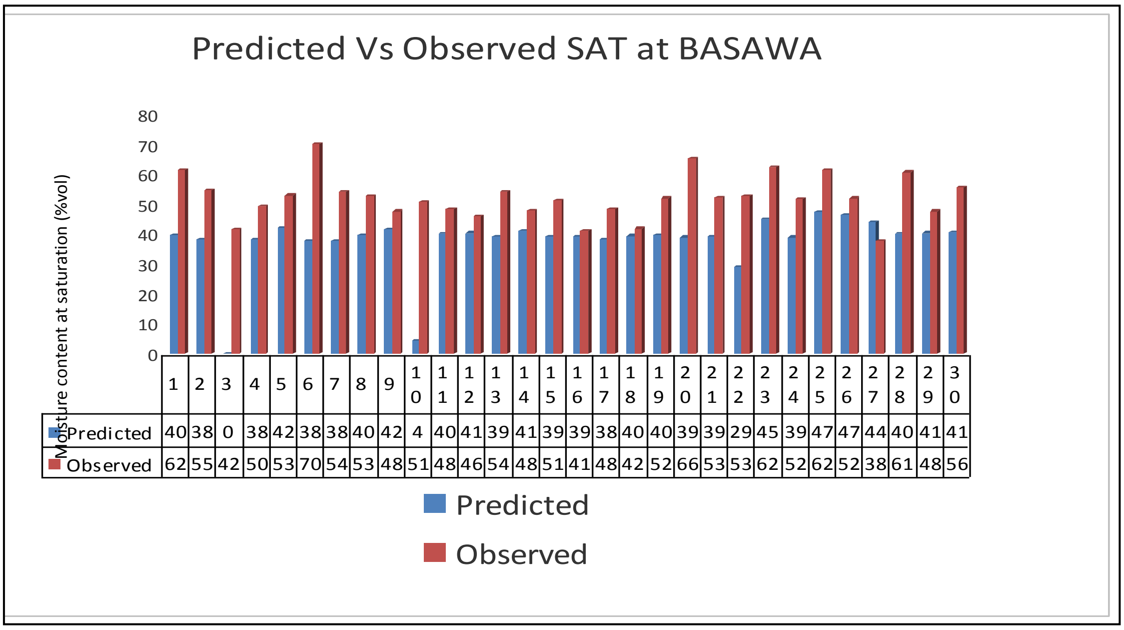


Figure 4.6.: Comparison of predicted and observed volumetric soil moisture content at saturation.

Table 4.2 Statistical indices of saturation for the study locations

Statistical indices	Shika	Basawa	Tudunwada
RMSE	17.09	16.3	14.9
CV	28.98	31.2	27.6
EF	0.81	0.41	0.72
CRM	0.26	0.26	0.24

Table 4.2 shows the statistical indices of the comparison between the model predicted and laboratory observed values for the three study locations of soil moisture at saturation. The RMSE obtained for Tudunwada, Basawa and Shika are 14.9 %, 16.3 % and 17.09 % respectively. As RMSE tend towards zero, the measure of precision between the predicted and measured data increases. This imply that the degree of precision of the

model prediction of moisture content at Shika were less than that of Basawa and Tudunwada at a lesser range. The RMSE is high and therefore the model is unreliable.

The coefficient of variation (CV) of the predicted and observed moisture content at T/wada and Shika can be said to be moderate based on Wilding (1985) Variability soil parameters of <30% as low, 15<CV <30% as moderate, and >30% as high. The result indicates that the predicted moisture status at saturation for Basawa were highly dispersed from observed data as compared to Shika and T/wada. The modeling efficiency (EF) which is a measure of the degree of fit or closeness of the predicted data to the observed values showed that soil of Shika and T/wada had higher degree of fit than that of Basawa being 0.81 %, 0.72 % and 0.41 % respectively.

However, the coefficient of residual mass (CRM) revealed that the model under predicted at the three sites. The result implies that the SWC-HPC model not accurately predicted soil moisture status of the three fields studied. In the three sites the RMSE are out of range, the data are not tending to zero means that degree of precision is lesser in the three sites. CV at Shika and Tudunwada is moderate while that of Basawa is high.

4.3.2 Comparison of model predicted and observes volumetric moisture content at field capacity for the three sites:

Figure 4.7 show the field capacity for Shika soil. The predicted moisture content at field capacity range from 26.5 % to 35.3 % with a mean value of 31.4 % while observed data ranged from 24.6 % to 29.7 % with a mean value of 22.1 %. The mean error of bias between the predicted and observed was 10.3 %. Disparity in the sense that from 1-14 predicted is higher than the observe from 15-30 observe is higher than the predicted value.

While Figure 4.8 shows field capacity for Tudunwada soil, the predicted value range from 23.8 % to 28.7 % with a mean value of 26.2 % while the observed value ranged from 16.2 % to 30.6 % with a mean value of 23.4 %. The mean error of bias between the predicted and observed value was 2.9 %. At field capacity there is great disparity between the predicted and the observe values.

Figure 4.9 shows field capacity for Basawa soil, the predicted value ranged from 18.5 % to 21.3 % with a mean value of 19.9 % while the observed value ranged from 25.1 % to 37.8 % with a mean value of 31.45 %. The mean error of bias between the predicted value and observed values was 11.6 %. It implies that the errors of bias are higher in Basawa 11.6% followed by Shika 10.3 and least in Tudunwada 2.9%. At field capacity there is great disparity between the predicted and the observe values.

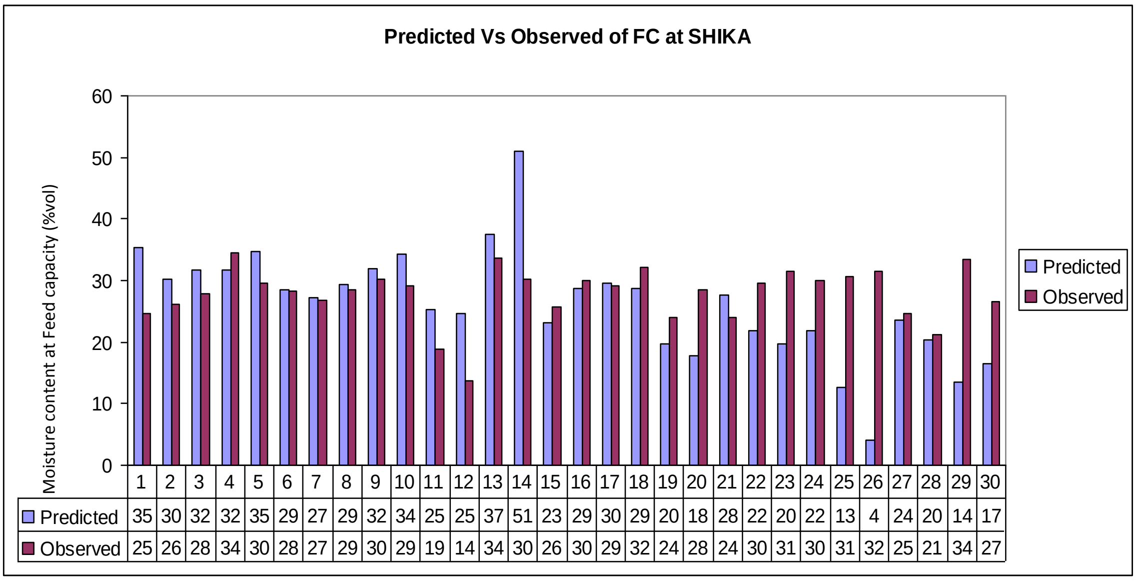
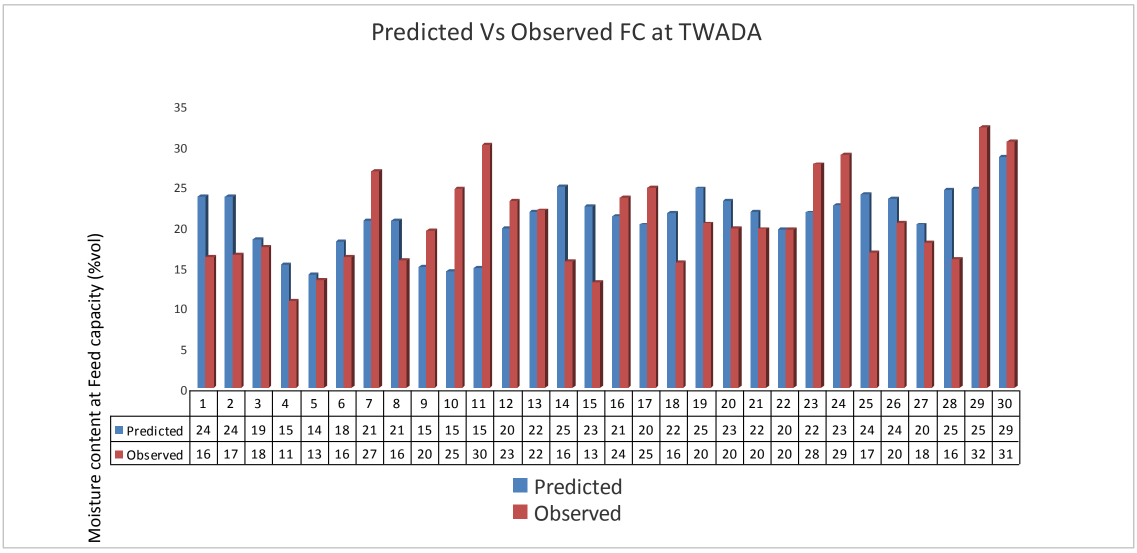
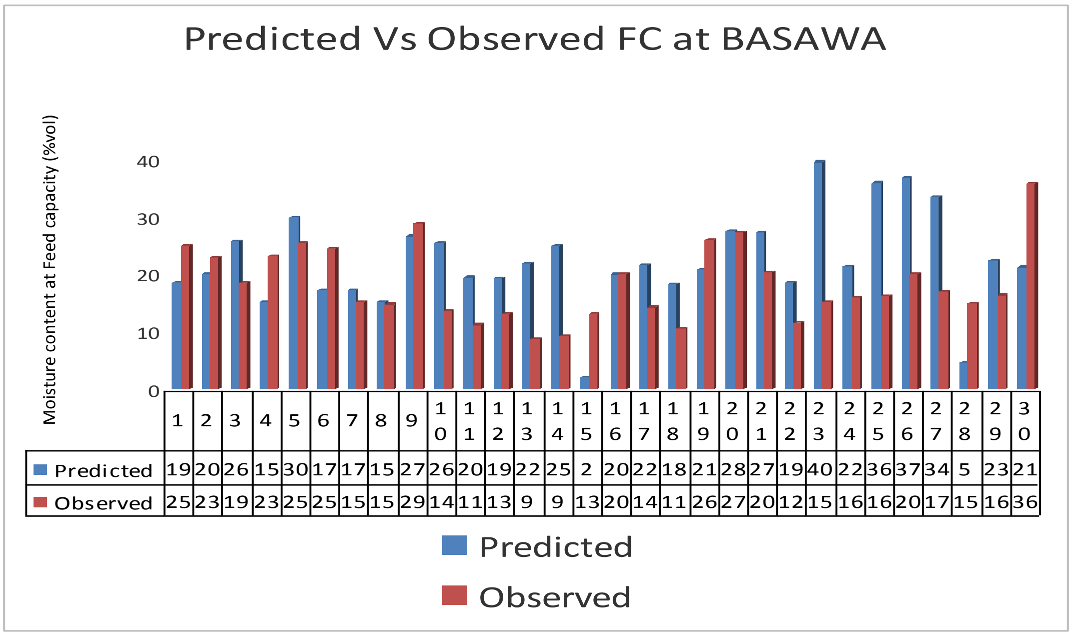


Figure 4.7: Comparison of predicted and observed volumetric soil moisture content at field capacity.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Predicted	24	24	19	15	14	18	21	21	15	15	15	20	22	25	23	21	20	22	25	23	22	20	22	23	24	24	20	25	25	29
Observed	16	17	18	11	13	16	27	16	20	25	30	23	22	16	13	24	25	16	20	20	20	20	28	29	17	20	18	16	32	31

Figure 4.8: Comparison of predicted and observed volumetric soil moisture content at field capacity.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Predicted	19	20	26	15	30	17	17	15	27	26	20	19	22	25	2	20	22	18	21	28	27	19	40	22	36	37	34	5	23	21
Observed	25	23	19	23	25	25	15	15	29	14	11	13	9	9	13	20	14	11	26	27	20	12	15	16	16	20	17	15	16	36

Figure 4.9: Comparison of predicted and observed volumetric soil moisture content at field capacity.

Table 4.3 Statistical indices of field capacity for the study locations

Statistical indices	Shika	Basawa	Tudunwada
RMSE	5.88	10.2	14.9
CV	21.45	53.8	27.6
EF	0.73	0.80	0.93
CRM	0.01	0.26	0.24

Table 4.3 show a comparison of the statistical indices of soil moisture status at field capacity, the RMSE of Shika, Basawa and T/Wada being 5.88, 10.2 and 14.9 respectively. This result show that the measure of precision of the model prediction of moisture content at T/wada were lesser than that of Shika and Basawa, the coefficient of variation (CV) for Shika and T/wada is said to be moderate based on Winding (1985) 15<CV30 %, being 21.45 % and 27.6 % and for Basawa is said to be high based on winding (1985) >30, being 53.8 %.

The modeling efficiency (EF) of T/wada had higher degree of fit than that of Basawa and Shika being 0.93, 0.80, and 0.73 respectively. The coefficient of residual mass CRM) revealed that the model under predicted at the three site being 0.01(%), 0.26(%) and 0.24(%) respectively. SWC-HPC model satisfactorily predicted soil moisture status of the three sites.

4.3.3 Comparison of model predicted and observed volumetric moisture content at wilting point for the three sites.

Figure 4.10 show the wilting point for Shika soil. The predicted moisture content at WP ranged from 13.1 % to 19.4 % with a mean value of 16.3 % while the observed value ranged from 11.6 % to 13.0 % with a mean value of 12.3 %. The mean error of bias between the predicted and observed moisture content at WP was 4 %. At wilting point there is little disparity between predicted and observed values. While Figure 4.11 for Tudunwada soil the predicted moisture content at wilting point ranged from 11.0 % to 15.9 % with a mean value of 13.14 % while the observed ranged from 9.3 % to 14.4 % with a mean value of 11.9%. The mean error of bias between the predicted and observed value was 1.24 %. In Tudunwada reverse is the case observed values is higher than the predicted values. Figure 4.12 for Basawa soil the predicted and observed volumetric moisture content at wilting point. The predicted value ranged from 6 % to 7.5 % with a mean of 6.75 % while the observed ranged from 6.9 % to 9.5 % with a mean of 8.2 %. The mean error of bias between the predicted and observed value was 12.45 %.It implies that the error of bias is higher in Shika 4 % and lower in Tudunwada and Basawa being 1.24 % and 1.45 %. In Basawa the observed value is greater than the predicted values except at some points.

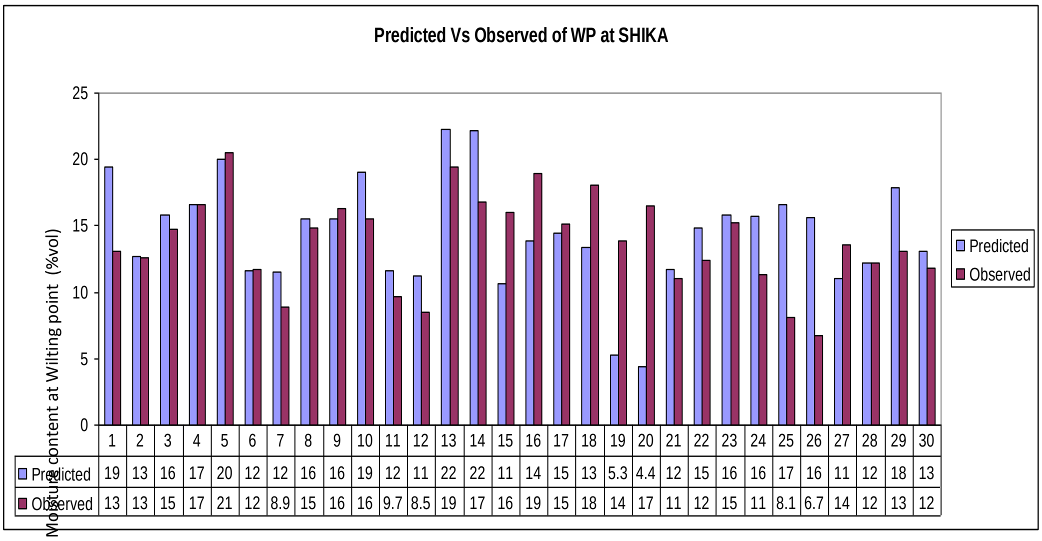


Figure 4.10: Comparison of predicted and observed volumetric soil moisture content at wilting point.

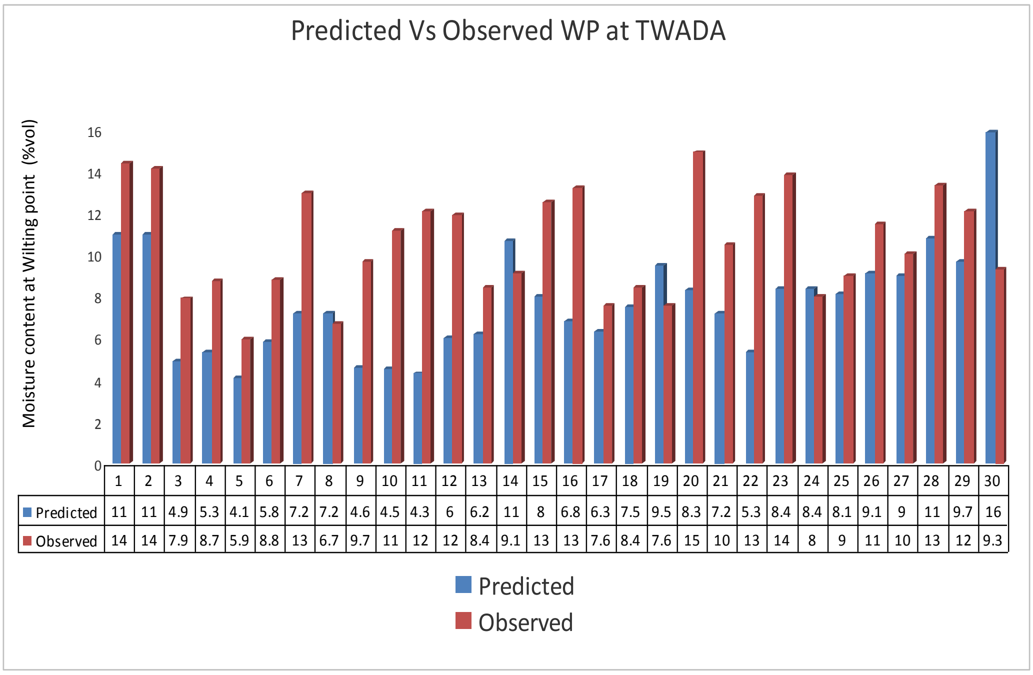


Figure 4.11: Comparison of predicted and observed volumetric soil moisture content at wilting point.

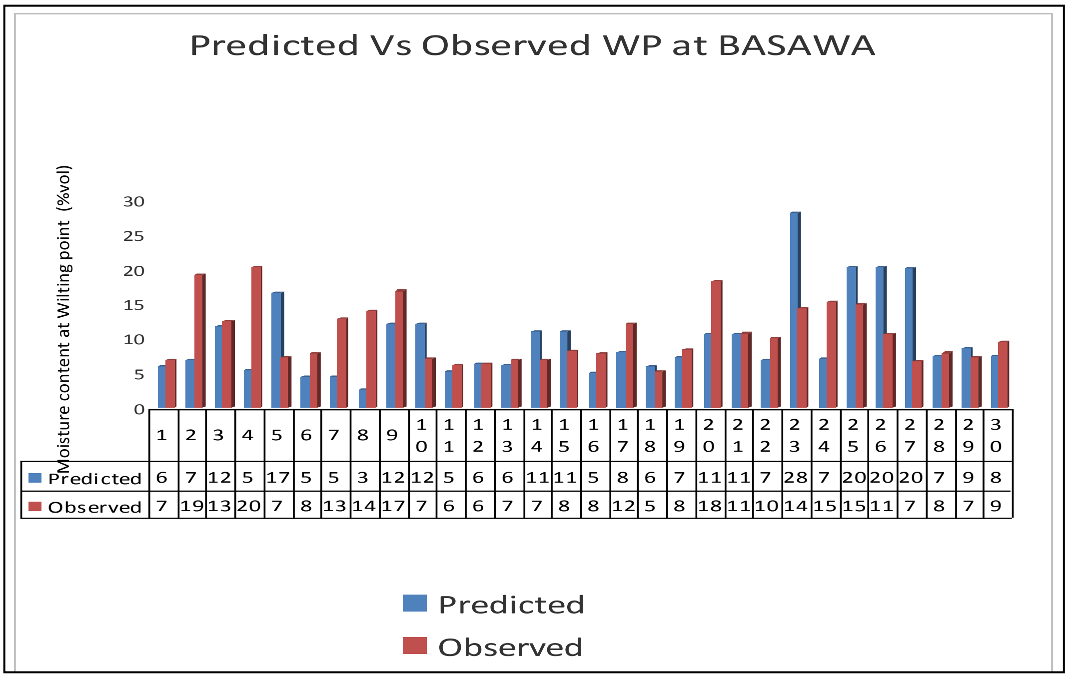


Figure 4.12: Comparison of predicted and observed volumetric soil moisture content at wilting point.

Table 4.4 Statistical indices of wilting point for the study locations

Statistical indices	**Shika**	**Basawa**	**Tudunwada**
RMSE	2.91	6.86	22.7
CV	20.14	64.8	11.4
EF	0.62	0.99	0.61
CRM	0.04	0.07	0.24

Table 4.4 show a comparison of the statistical indices of soil moisture status at wilting point. The RMSE of Shika, Basawa and T/wada being 2.91 %, 6.89 % and 22.7 % respectively. This implies that the measure of precision of the model prediction of moisture content at Tudunwada is lesser than that of Shika and Basawa. Coefficient of variation CV) for Tudunwada and Shika is said to be moderate based on Wilding (1985)

15 % <CV <30 %, being 11.4 % and 20.14 % , Basawa is said to be high according to wilding (1985)15 %<CV30 % being 64.8 %.

The modeling efficiency (EF) of Basawa had higher degree of fit than of Shika and T/wada being 0.99, 0.62 and 0.61 respectively the coefficient of residual mass (CRM) revealed that the SWC-HPC model under predicted in the three site being 0.04(4%), 0.07(7%) and 0.24(24%). SWC-HPC model satisfactorily predicted soil moisture status of the three sites.

4.3.4 Comparison of model predicted and observed volumetric moisture content at Bulk density for the three sites.

Figure 4.13 shows the predicted bulk density values for shika soil which ranged from 1.57 g/cm^3 to 1.37 g/cm^3 with a mean value of 1.47 g/cm^3 to 1.44 g/cm^3 with a mean value of 1.41 g/cm^3. The mean error of bias between the predicted and observed moisture content at bulk density was 0.06 g/cm^3. The disparity is very low between the predicted and the observed values. So the model moderately predicted BD. Predicted values are higher than the observed values. Figure 4.14 shows the predicted value for Tudunwada soil ranging from 1.3 g/cm^3 to 1.55 g/cm^3 with a mean value of 1.53 g/cm^3 while the observed ranging from 1.26 g/cm^3 to 1.32 g/cm^3 with a mean value of 1.29 g/cm^3. The mean error of bias between the predicted and observed moisture content at bulk density was 0.24 g/cm^3. Low disparity between the predicted values and the observed so predicted is greater than observed. Figure 4.15 for Basawa soil the predicted bulk density values ranging from 1.6 g/cm^3 to 1.57 g/cm^3 with a mean value of 1.59 g/cm^3 while the observed value ranged from 1.44 g/cm^3 to 1.46 g/cm^3 with a mean value of 1.45 g/cm^3. The mean error of bias between the predicted and observed value was 0.1 g/cm^3. This implies that the mean error of bias is low in the three sites as followed Tudunwada 0.21g/cm^3, Basawa 0.1g/cm^3 and Shika 0.06g/cm^3. As above the model moderately predict bulk density in the three sites.

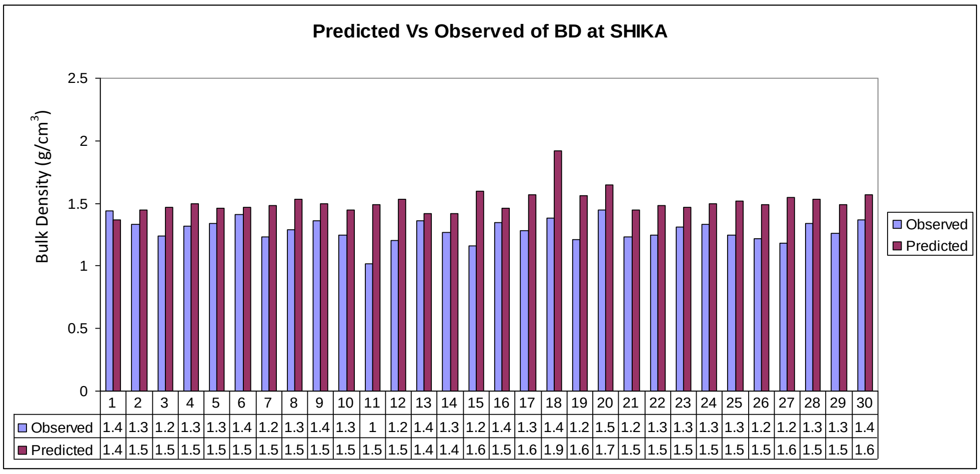


Figure 4.13: Comparison of predicted and laboratory observed soil bulk density.

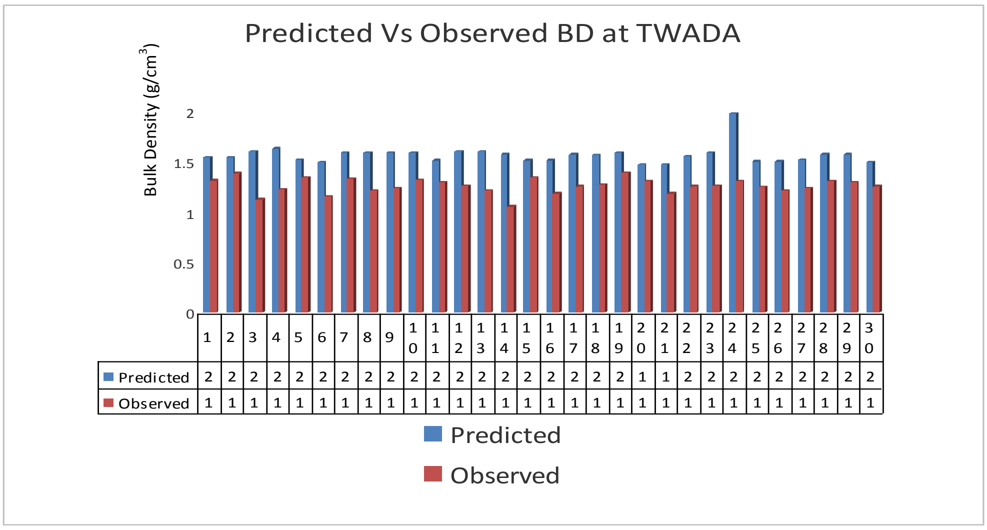


Figure 4.14: Comparison of predicted and laboratory observed soil bulk density.

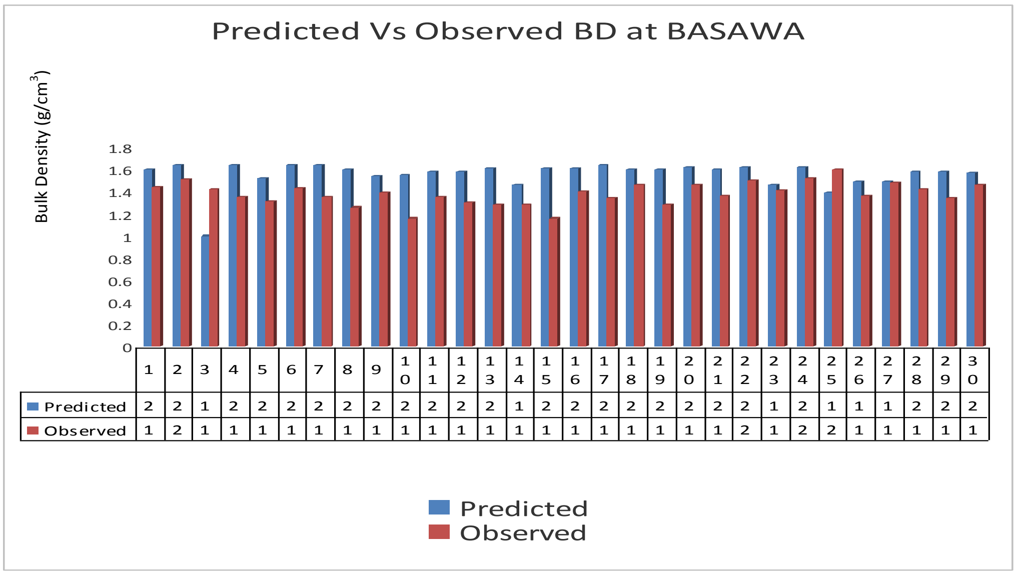


Figure 4.15: Comparison of predicted and laboratory observed soil bulk density.

Table 4.5 Statistical indices of bulk density for the three locations.

Statistical indices	Shika	Basawa	Tudunwada
RMSE	0.26	2.26	0.31
CV	19.9	63.4	25.9
EF	0.73	0.51	0.81
CRM	0.2	0.52	0.24

Table 4.5 show a comparison of the statistical indices of soil moisture status at Bulk density. The RMSE of Shika, T/wada and Bassawa being 0.26 % 0.31 % and 2.26 % respectively. However, the model was found to moderately predict the soil bulk densities in the three sites. While the level of dispersion between the three sites Shika, Tudunwada and Basawa being19.9 %, 25.9 % and 63 %. The modeling efficiency (EF) was high T/wada (81%), Shika (73%) and Basawa (51%) respectively. The magnitude of under prediction revealed that the CRM were less than 1%. The model prediction does not show

reasonable accuracy for both the result obtained in the three locations. The model prediction had some discrepancy compared to observed data. However, comparison of the result from the proposed model with laboratory method indicated its poor performances for the prediction of soil water characteristics. CV for Shika and Tudunwada being 19 %, 25 % as moderate and Basawa being 63% as high according to wilding (1985) <30 % as moderately >30 % high.

CHAPTER FIVE

5.0 SUMMARY CONCLUSION AND RECOMMENDATION

5.1 Summary

Soils of three selected wetland in Zaria, Kaduna state of Nigeria were evaluated in August, 2013. Profile pits were dug and tested, ninety soil sample were collected, using core samplers in Shika, Basawa and Tudunwada, thirty soil samples per site were used in the evaluation. The soils particle size distribution (percent clay and sand), organic matter content and salinity were inputted into the model to simulate soil moisture status at saturation, field capacity, wilting point and soil bulk density. The output of the SWC-HPC model was compared with observed data from laboratory tests using the following statistical indices RMSE. CV, EF and CRM. The study was used to determine the soil water characteristics and physical properties of soil of selected wetland in Zaria and to assess the reliability of the SWC-HPC model by comparing the predicted soil water characteristic with laboratory observed values.

5.2 Conclusion

The following conclusions are made from the result of this study.

- The Soil Water Characteristics –Hydraulic Property Calculator model to some extent predict the soil water properties of the selected wetland in shika and Tudunwada but did not satisfactorily predict wetland in Basawa due to low sandy content of the soil.
- The assessment of SWC-HPC model in predicting soil moisture characteristics of selected wetland is fairly reliable when comparing the result of the predicted with laboratory measured values. Thus an enhancement of the Saxton *et al.,* (1986) method is an appropriate extension to improve the field applications of soil

characteristics estimates with improve data basis and supplemented by recently derived relationships of conductivity and including appropriate local adjustments for organic matter, gravel and salinity.

5.3 Recommendation

The following recommendations are therefore made from the results of this study.

1. Soil Water Characteristics –Hydraulic Property Calculator model have been found to moderately predict one of the parameters (bulk density) of the selected wetland in Zaria, more information will be required including application of other models for optimal water use in the wetlands.

2. More time and information are needed, although the accuracy of Soil Water Characteristics –Hydraulic Property Calculator model is acceptable, the level of performances may be greatly improved upon if information on the degree of compaction and gravel of the soil is available.

References

Abdullkadir, A. (2000). Prediction of infiltration rate of a Typic Haplustalf in Samaru, Northern Guinea Savanna, Nigeria under Graduate Project work A.B.U Zaria pp.3 – 17

Andriesse (1985).Jp. The Tropical Lowland peat in South – East Asia. Royal Tropical Institutes, Amsterdam, Department of Agricultural research, Communication

Ayotade, K.A. and Fagade, A. A (1980). Nigeria's programme on wetland Rice Production and Rice Research. In the Wetlands and Rice in Sub – Sahara Africa, Juo, A.S.R., and owe J.A. LIITA., Ibadan.

Acutis, C. and Donatelli, M (2003). SOILPAR 2.0: Software to estimate soil hydrological parameters and functions European Journal of agronomy 18:373-377.

Antonopoulos, V.Z. (1997) Simulation of soil moisture dynamic in irrigated cotton in semi-arid climatic. Agricultural Water Management 34:233-246

Aremu J.A. (1980). Effect of different cultivation techniques on infiltration. M.Sc. Thesis of the Department of Soil Science submitted to the Postgraduate school of the Ahmadu Bello University, Zaria, Nigeria.

Aryan L.M. and Paris, J.F. (1981). A physiocoemprical model to predict soil moisture characteristics from particle - size distribution and bulk density data soil sci. soc. Am J. 45: 1023 - 1030.

Babalola T. S., Oso T. Fasina A.S. and Godnu K. (2011). Land Evaluation Studies of Two Wetland Soils in Nigeria.

Bruand, (2004) Utilizing mineralogical and chemical informations in PTFs. In: development of pedro transfer functions In soil hydrology, (Eds ya pachepsky and WJ Rawls), development in soil science. Vol 30, pp. 153-158

Brooks R.H. and Corey A.T. (1964). Hydraulic properties of porous media. Hydrology paper o. 3 Colorado state university, Fort Collins Co.

Carter, R.C., Carr M.K.V. and Kay M.G. (1983) Polices and prospects in Nigeria Irrigation, Out look on Agriculture 12(3): 73 – 76

Comegna, V., Coppola, A., Basile, A. and Comegna, A (2012). A Review of Approaches for measuring soil Hydraulic properties and Assessing the impacts of Spatial Dependence of the Results, Hydrogeology. A Global perspective, Dr. Gholam. A. Kazemi (Ed.), ISBN: 978 – 953 – 0048 5.PP71

Campbell, G. (1974) A simple method for determining unsaturated hydraulic conductivity from moisture retention data soil sci 177 : 311 – 314

Clap, R.B., and Hornberger, G.M. (1978) Empirical equations for some soil hydraulic properties. Water resources research, 14: 601 – 604.

Dingman, S.L. (1994). Physical Hydrology © by prentice hall, inc., Englewood cliffs, New Jersey, USA. 575Pp.

Enwezor, W.O., Ohiri A.C., Opuwaribo E.E. and Udo E.J (1990) A review of fertilizer use on crops in South Eastern zone of Nigeria. In: Literature review on soil Fertility investigations in Nigeria Fed.Min. Of Agric. And Nat. Res. Lagos, Nigeria 2:49 – 100.

Fasina, A.S. (2007). Irrigation Suitability evaluation of Asu River Basin Soils, South Estern Nigeria Int. Niger.J. Soil Sci. 3(1): 35 – 41.

Fasina, A.S. (2005). Properties and Classification of some selected Wetland soils in Ado Ekiti, South west Nigeria. Applied Tropical Agriculture, ID(2): 76 – 82.

Fredlund, D.G and Xing A. (1994). Equation for the soil water Characteristic Curve. Canadian Geotechnical Journal, Vol.31, No.4, 521 – 532.

Fredlund D.G., Xing A. and Huang S. (1994). Predicting the permeability function for unsaturated soils using the soil - water characteristics curve. Canadian Geo technical journal 31:533 – 546.

Fredlund, D.G and Rahadjo H. (1993). Soil mechanics for unsaturated soils, John Wiley and Sons, New York.

Fredlund, D.G and Xing A. (1994). Equation for the soil water characteristics curve. Canadian geotechnical journal, Vol.31, No.4, 521- 532.

Fredlund, M.D. (1996). Design of a knowledge - based system for unsaturated soil properties M.Sc Thesis. Department of civil engineering. University of Saskatchewan, Canada.

Gardner R.C., Davidson N.C (2011). The Ramsar Convention. In Wetlands. Springer Pp:189 – 203

Gardner, W.R., Hillel D., and Benyamini, Y. (1970a). Post Irrigation movement of Soil water. I. Redestribution. Water Resources Research, 6:851 – 861.

Gardner, W.R., Hillel D., and Benyamini, Y. (1970b). ii. Simultaneous Redistribution and evaporation. Water Resources Research , 6: 1148 – 1153

Grossman, R.B., Harms, D.S. Seybold, C.A. and Herrick J.E. (2001). Coupling use – dependent and use – invariant data for Soil quality evaluation in the United States. I. Soil water conserve. 56(1) : 63 – 68.

Ghildyal, B.P. and Tripathi R.P. (1987). Soil Physics, Wiley Eastern, New Delhi pp. 655.

Gupta, S.C and Larson W.E. (1979).Estimating soil water retention characteristics from particle size distribution organic matter percent and bulk density water Res. Research Vol. 15, No.6

Hillel, D. (1980). Fundamentals of Soil Physics Academy press New York PP 413 Journal of soil Research 2.1-5. Nigeria. Pp.110 – 115. No. 63

Hudson, B.(1994). Soil Organic Matter and Available Water Capacity. J. Soil water Conserv. 49:189 – 193.

Hillel. D (1998). Fundamentals of Soil Physics. Department of Plant and Soil Sciences University of Massachusetts. Amiherst Massachusetts. 55-59, 177- 178.

Igbadun, H.E., Oyebode M.A. and Muhammad A.S. (2011) Evaluation of a simulation Model for Predicting soil water Characteristic of selected Agricultural Fields. Nigerian journal of Technological Development Volume 8 (1) 2011.

Kio, P.R.O. and Ola – Adams, B.A. (1986). Utilization and Development of Wetlands. In Nigeria Wetlands. Akpata, V.I. and Okala D.U.U (Eds.). Man and Biosphere

Klute, A. (1965) Method of soil analysis. Part 1: Physical and mineralogical properties, including statistics of measurement and sampling. ASA SSSA, Agronomy Monograph 9:273 – 278.

Krause, P: D.P. Boyle and Base F. (2005) Comparison of different efficiency criteria for hydrological model assessment Advances in Geosciences European Geosciences union, 5:89-97.

Lekwa, G., (1986). Soils of tidal marshes in the Kono – Imo Rivers State, Nigeria. Niger J. Soil Sci. 6:47 – 56.

McCuen, R.H., Rawls W.J. and Brakensiek. D.L. (1981). Statistical Analysis of the Brooks – Corey and the Green – Ampt Parameters Across Soil Texture. Water Resources Research 17(4): 1005 – 1013 28:29 -41.

Mahdian, M.H. and Fallichard, J. (1995). Validation of the substor model for simulating soil water centred. Transaction of ASAE 38, 513 - 520.

Nash, J.E, and Sutcliffe, J.V. (1970). River flow fore casting Through conceptual models. Part I A Discussion of principles, Journal of Hydrology, 10(3), 282-290.

National Root Crops Research Institute (NRCRI) (1993) Annual Report for 1993. NRCRI Umudike, Nigeria Pp 139.

Odunze, A.C. (1998). Soil management Strategy Under continous Rainfed – Irrigation Agriculture. In Ramalan. A.A. (ed) Irrigation in Sustainable Agriculture. Book of Proceedings 12th National Irrigation And Drainage Seminar. Institute for Agricultural Research, Ahmadu Bello University Zaria. Nigeria, 14th – 16th April, Pp. 178 – 186.

Ogunwole, J.O. and Ogunleye, P.O. (2005) Influence of long-term application of organic and mineral fertilizers on quality of savanna Alfisol. Journal of sustainable agricultural, 26 (3): 5-13

Ojekunle, Z.O., Li Rouppu, Zhaolin, Tan Xin and Hamza Bangura (2009). Ameliorating water Crisis Through Sustainable waste water Reuses: Journal of America water work Association. Vol. 101. No (71 – 79).

Olalekan, E.I, Abimbola, L.M., Saheed M., Damilola, O.A, (2014) Wetland Resources of Nigeria: Case study of the Hadejia – Nguru Wetlands. Poult fish wildi Sci2:123. doi: 10,4172/2375 – 446x.

Olaleye, A.O.(1998). Characterization, Evaluation. Nutrient Dynamics and Rice yields of Selected Wetland Soils in Nigeria PhD Thesis in the Department of Agronomy, University of Ibadan. 202pp.

Puckett, W.E., Dane, J.H. and. Hajek B.F (1985). Physical and mineralogical data to determine soil hydraulic properties. Soil Sci. Soc. Am. J.44: 831 - 836

Rawls, W.J. and Pachepsky. Y.A. (2000). Using field Topographic descriptors to estimate Soil water retention. Soil Sci, 167: 423 – 435

Rawls, W.J., Pachepsky, Y.A. Ritchie, J.C. Sobeck T.M. And Blood worth, H. (2003). Effect of Soil Organic Carbon on Soil water Retention. Geoderma 116:61- 76.

Rawls, W.J.,D. Gimenez, I. and Grossman. R. (1998). Use of Soil texture, Bulk density and Slope of the water pretention curve to Predict saturated Hydraulic Conductivity Trans, ASAE 41:983 -988.

Regowski, A.S. (1971). Watershed physics: model of the soil moisture characteristic water resources research, 7: 155 – 1582.

Saxton, K.E and McGuiness, J.L. (1982). Evapotranspiration. Chapter 6 in: hydrologic modeling of small watersheds, 229 – 273. ASAE Monograph No.5.

Saxton, K.E and Willey P.H. (1999). Agricultural Wet land and pond hydrologic calculation using the SPAW -11 Model. Conf. Proc. ASAE. Toronto, ON, 18-21 July 1999. ASAE, ST Joseph, MI.

Saxton, K.E and Willey. P.H. (2004). Agricultural Wetland and pond Hydrologic analyses using the SPAW model.Conf. Proc., Self Sustaining Solutions For Streams, Water sheds and Wetlands, 12 – 15 Sept.2004, ASAE, ST. Joseph, MI.

Saxton, K.E. and Rawls, W.J. (2006). Soil water Characteristics Estimates by Texture and organic matter for Hydrological Solutions. Soil Science Society of America, 1569 – 1577.

Saxton, K.E., and Willey, P H. (2006). The SPAW model for Agricultural Field and pond Hydrologic simulation. P.401 – 435. In Singh V.P. and Frevert D.K. (ed.) water shed models . CRC Press, Boca Raton, F1.

Saxton, K.E. Rawls, W.J. Romberger J.S. and Papendick. R.I (1986). Estimating Generalized Soil water Characteristics From texture. Trans. ASAE 50:1031 – 1035.

Schaap, M.G., Leiji, F.J. and Van Genuchten. M.Th., (1998). Neural Network analysis for hierarchical Prediction of soil Hydraulic properties. Soil Sci. Soc. Am. J.62:847 – 855.

Tanji, K.K. (1990). Agricultural Salinity Assessment and Management ASCE, New York. USDA – SCS.1982. Procedures for collecting Soil Samples and Methods Of analysis for soil survey. Soil Survey Investigation Report I, Washington, DC.

Turner, E.R. (2006). Comparism of infiltration equation and their field validation with rainfall Simulation, Msc. Thesis (unpublished), Department of biology resources Engineering, University of Marry Land, U.S. A.

Tisdall, J.M., Oades, J.M. (1982). Organic matter and water stable aggregates in soils. *Journal of* Soil Science, 33 (2):141-163

United State Department of Agriculture (USDA). (1975). Soil Taxonomy: A basic System of Soil Classification For making and interpreting soil surveys. USDA Washington D.C.

Van Genuchten, M. Th. (1980). A closed – form equation For predicting the Hydraulic Conductivity of Unsaturated Soils. Soil Sci. Soc.Am. J.44: 892 – 898.

Wilding, L.P. (1985). Spatial variability: Its documentation, accommodation and implication to soil surveys P. 166 - 194. In: D.R Nielson and J. Bouma (Eds): Soil spatial variability. Pudot wageningen.

Williams J. and Prebble, R.E.; Williams, W.T. and Hignett, C.T. (1983) The Influence of Texture, Structure and clay mineralogy on the soil moisture characteristic. Aust. J. Soil Res. 21:1532.

Williams, P.J. (1982). The Surface of Earth, an Introduction to Geotechnical Science. Longman Inc., New York. Pp 158.

Wudivira, H.N., Abdulkadir, A. and Tanimu, J. (2001). Prediction of infiltration characteristics of an Alfisol In the northern Guinea Savanna of Nigeria, Nigerian *Journal of Soil Research* 2.1-5

Zhou, H., Lu., Y-Z., Yang, Z-C and Li, B-G (2007). Influence of conservation tillage on soil aggregate features in North China plain. *Agricultural Science, China 6 (9):1099- 1106*

APPENDICES

APPENDIX I: LABORATORY OBSERVED SOIL MOISTURE CONTENT AT VARIOUS SUCTION

Location: Shika

S/No	Samples/depth (cm)	Soil moisture determination MC g/g							Bulk density g/cm^3	% O.M	EC (ds/m)
		0	**0.1**	**0.3**	**1**	**5**	**10**	**15**			
1	0-10	0.516	0.318	0.171	0.158	0.130	0.126	0.091	1.44	2.10	0.010
2	10-20	0.490	0.313	0.196	0.168	0.147	0.120	0.095	1.33	1.06	0.010
3	20-30	0.460	0.314	0.225	0.196	0.129	0.121	0.119	1.24	1.26	0.010
4	30-40	0.540	0.327	0.261	0.194	0.134	0.130	0.126	1.32	0.93	0.013
5	40-50	0.431	0.326	0.221	0.186	0.169	0.169	0.153	1.34	0.79	0.011
6	0-10	0.500	0.305	0.201	0.188	0.140	0.118	0.083	1.41	1.83	0.010
7	10-20	0.485	0.296	0.218	0.180	0.148	0.108	0.072	1.23	1.76	0.010
8	20-30	0.418	0.318	0.221	0.189	0.150	0.132	0.115	1.29	0.99	0.011
9	30-40	0.457	0.323	0.222	0.186	0.136	0.131	0.120	1.36	0.76	0.014
10	40-50	0.512	0.328	0.223	0.196	0.146	0.136	0.124	1.25	1.07	0.014
11	0-10	0.458	0.333	0.184	0.156	0.102	0.098	0.095	1.02	1.72	0.070
12	10-20	0.405	0.274	0.115	0.112	0.110	0.109	0.071	1.20	1.17	0.065
13	20-30	0.580	0.349	0.247	0.168	0.155	0.150	0.143	1.36	0.86	0.029
14	30-40	0.498	0.338	0.238	0.186	0.149	0.136	0.132	1.27	0.64	0.020
15	40-50	0.279	0.249	0.221	0.206	0.194	0.156	0.138	1.16	0.36	0.090
16	0-10	0.478	0.440	0.223	0.184	0.128	0.121	0.14	1.35	1.97	0.075
17	10-20	0.469	0.414	0.227	0.188	0.137	0.130	0.118	1.28	0.99	0.029
18	20-30	0.471	0.419	0.233	0.198	0.133	0.132	0.131	1.38	0.79	0.029
19	30-40	0.450	0.404	0.198	0.178	0.136	0.124	0.115	1.21	0.71	0.032
20	40-50	0.436	0.392	0.196	0.148	0.118	0.116	0.114	1.45	0.14	0.025
21	0-10	0.448	0.413	0.195	0.138	0.109	0.106	0.090	1.23	1.99	0.080
22	10-20	0.476	0.407	0.219	0.168	0.120	0.118	0.099	1.25	1.50	0.050
23	20-30	0.514	0.414	0.234	0.188	0.124	0.119	0.116	1.31	1.26	0.028
24	30-40	0.457	0.387	0.192	0.138	0.100	0.095	0.085	1.33	1.07	0.029
25	40-50	0.437	0.387	0.179	0.129	0.075	0.073	0.065	1.25	0.79	0.028
26	0-10	0.423	0.380	0.206	0.146	0.059	0.057	0.055	1.22	1.17	0.031
27	10-20	0.453	0.409	0.216	0.187	0.144	0.126	0.115	1.18	1.03	0.021
28	20-30	0.453	0.419	0.217	0.185	0.144	0.128	0.091	1.34	1.07	0.013
29	30-40	0.452	0.393	0.246	0.196	0.118	0.109	0.104	1.26	0.99	0.050
30	40-50	0.344	0.352	0.217	0.186	0.116	0.105	0.086	1.37	0.26	0.047

APPENDIX II: LABORATORY OBSERVED SOIL MOISTURE CONTENT AT VARIOUS SUCTION

Location: Basawa

S/No	Samples/depth (cm)	Soil moisture determination MC g/g							Bulk density g/cm^3	% O.M	EC (ds/m)
		0	**0.1**	**0.3**	**1**	**5**	**10**	**15**			
1	0-10	0.428	0.269	0.174	0.061	0.048	0.042	0.037	1.44	0.53	0.035
2	10-20	0.413	0.187	0.172	0.158	0.144	0.106	0.068	1.51	0.24	0.080
3	20-30	0.336	0.275	0.150	0.126	0.101	0.076	0.033	1.42	0.41	0.080
4	30-40	0.375	0.208	0.176	0.161	0.154	0.089	0.040	1.35	0.34	0.040
5	40-50	0.396	0.253	0.190	0.149	0.054	0.048	0.029	1.31	0.81	0.056
6	0-10	0.498	0.242	0.174	0.119	0.055	0.046	0.020	1.43	0.38	0.010
7	10-20	0.442	0.163	0.124	0.118	0.104	0.096	0.084	1.35	0.14	0.056
8	20-30	0.410	0.209	0.115	0.112	0.108	0.106	0.095	1.26	0.88	0.010
9	30-40	0.351	0.221	0.212	0.158	0.124	0.088	0.035	1.39	0.81	0.012
10	40-50	0.408	0.223	0.109	0.088	0.056	0.048	0.038	1.16	0.84	0.020
11	0-10	0.475	0.209	0.110	0.089	0.060	0.045	0.022	1.35	0.72	0.020
12	10-20	0.383	0.230	0.110	0.086	0.052	0.048	0.039	1.30	0.57	0.044
13	20-30	0.399	0.256	0.065	0.061	0.050	0.047	0.043	1.28	0.57	0.050
14	30-40	0.379	0.211	0.074	0.062	0.054	0.052	0.050	1.28	0.64	0.031
15	40-50	0.443	0.207	0.114	0.098	0.070	0.055	0.040	1.16	0.84	0.029
16	0-10	0.305	0.164	0.149	0.109	0.058	0.051	0.042	1.40	0.53	0.040
17	10-20	0.378	0.186	0.112	0.108	0.094	0.056	0.029	1.34	0.17	0.040
18	20-30	0.304	0.226	0.077	0.058	0.038	0.035	0.033	1.46	0.36	0.060
19	30-40	0.431	0.278	0.215	0.108	0.069	0.061	0.046	1.28	0.45	0.070
20	40-50	0.452	0.257	0.188	0.148	0.126	0.118	0.102	1.46	2.31	0.045
21	0-10	0.427	0.226	0.165	0.138	0.087	0.058	0.046	1.36	0.28	0.040
22	10-20	0.424	0.267	0.093	0.084	0.081	0.056	0.031	1.50	0.31	0.070
23	20-30	0.477	0.184	0.116	0.112	0.109	0.103	0.095	1.41	0.03	0.050
24	30-40	0.389	0.239	0.120	0.118	0.115	0.098	0.071	1.52	0.38	0.070
25	40-50	0.492	0.222	0.130	0.121	0.119	0.096	0.070	1.60	1.62	0.665
26	0-10	0.422	0.169	0.131	0.122	0.092	0.066	0.043	1.32	0.81	0.030
27	10-20	0.321	0.164	0.145	0.118	0.057	0.051	0.047	1.48	0.78	0.035
28	20-30	0.454	0.176	0.111	0.098	0.059	0.054	0.051	1.42	0.71	0.010
29	30-40	0.379	0.183	0.130	0.099	0.058	0.055	0.051	1.34	0.71	0.010
30	40-50	0.406	0.281	0.261	0.117	0.069	0.061	0.052	1.46	0.91	0.100

APPENDIX III: LABORATORY OBSERVED SOIL MOISTURE CONTENT AT VARIOUS SUCTION

Location: T/Wada

S/No	Samples/depth (cm)	Soil moisture determination MC g/g							Bulk density g/cm^3	% O.M	EC (ds/m)
		0	**0.1**	**0.3**	**1**	**5**	**10**	**15**			
1	0-10	0.483	0.146	0.123	0.116	0.109	0.089	0.073	1.32	1.17	0.080
2	10-20	0.445	0.200	0.119	0.111	0.102	0.086	0.064	1.39	1.47	0.080
3	20-30	0.469	0.234	0.155	0.136	0.070	0.061	0.068	1.13	0.43	0.050
4	30-40	0.449	0.133	0.088	0.082	0.071	0.068	0.043	1.23	0.17	0.065
5	40-50	0.373	0.168	0.099	0.091	0.044	0.041	0.037	1.35	1.36	0.010
6	0-10	0.254	0.171	0.140	0.118	0.076	0.071	0.059	1.16	1.57	0.011
7	10-20	0.463	0.203	0.201	0.128	0.097	0.072	0.060	1.34	0.40	0.060
8	20-30	0.394	0.287	0.130	0.106	0.055	0.051	0.042	1.22	0.36	0.053
9	30-40	0.390	0.286	0.158	0.116	0.078	0.058	0.036	1.24	0.26	0.040
10	40-50	0.372	0.285	0.186	0.146	0.084	0.064	0.038	1.33	0.93	0.040
11	0-10	0.417	0.247	0.232	0.128	0.092	0.068	0.038	1.30	1.53	0.100
12	10-20	0.448	0.235	0.183	0.148	0.094	0.008	0.074	1.27	0.97	0.090
13	20-30	0.407	0.242	0.181	0.139	0.069	0.062	0.076	1.22	0.47	0.050
14	30-40	0.396	0.203	0.148	0.109	0.086	0.069	0.048	1.06	0.43	0.056
15	40-50	0.405	0.229	0.097	0.095	0.093	0.071	0.037	1.35	1.69	0.120
16	0-10	0.457	0.241	0.199	0.142	0.111	0.081	0.058	1.19	1.62	0.100
17	10-20	0.454	0.221	0.197	0.138	0.060	0.058	0.056	1.26	0.81	0.020
18	20-30	0.440	0.225	0.122	0.108	0.066	0.069	0.005	1.28	0.74	0.020
19	30-40	0.425	0.213	0.146	0.112	0.051	0.051	0.047	1.40	0.38	0.050
20	40-50	0.459	0.230	0.151	0.136	0.114	0.085	0.038	1.31	1.99	0.035
21	0-10	0.433	0.289	0.166	0.134	0.088	0.078	0.064	1.19	1.78	0.050
22	10-20	0.442	0.233	0.156	0.131	0.102	0.076	0.053	1.26	1.19	0.076
23	20-30	0.458	0.247	0.219	0.116	0.109	0.081	0.052	1.27	0.78	0.060
24	30-40	0.446	0.249	0.221	0.115	0.069	0.057	0.047	1.31	0.60	0.065
25	40-50	0.415	0.202	0.135	0.106	0.072	0.068	0.048	1,25	1.52	0.060
26	0-10	0.332	0.201	0.168	0.128	0.090	0.070	0.051	1.22	1.66	0.060
27	10-20	0.421	0.242	0.146	0.116	0.081	0.071	0.051	1.24	1.16	0.010
28	20-30	0.485	0.229	0.122	0.119	0.102	0.068	0.044	1.31	0.71	0.010
29	30-40	0.444	0.307	0.249	0.136	0.093	0.065	0.038	1.30	0.57	0.045
30	40-50	0.482	0.340	0.243	0.128	0.074	0.063	0.048	1.26	1.59	0.040

APPENDIX IV: SHIKA PREDICTED MEASURE VALUE USING MODEL

S/N	% SAND	% CLAY	ds/m EC	% OM	TEX CLASS	%Vol WP	%Vol FC	%Vol SAT	CM/CM AW	mm/hr KSAT	g/cm^3 BD	Normal DC	%Vol MC
1	21	31	10	2.1	Clay loam	19.4	35.3	48.2	0.16	5.71	1.37	1	19.5
2	23	19	0.01	1.6	Silty loam	12.7	30.3	45.2	0.18	10	1.45	1	19.5
3	25	25	0.01	1.26	"	15.8	31.7	44.5	0.16	5.91	1.47	1	20.9
4	27	27	0.013	0.93	Loam	16.6	31.7	43.4	0.15	4.4	1.5	1	20.9
5	25	33	0.011	0.79	Day loam	20	34.7	44.9	0.15	2.86	1.46	1	20.9
6	27	17	0.01	1.83	Silty loam	11.6	28.6	44.7	0.17	12.3	1.47	1	20.9
7	33	7	0.01	1.76	"	11.5	27.3	44.2	0.16	13.94	1.48	1	20.9
8	35	25	0.011	0.99	Loam	15.5	29.4	42.3	0.14	5.86	1.53	1	20.9
9	21	37	0.014	0.76	Silty loam	15.5	32	43.6	0.16	4.46	1.5	1	20.9
10	23	31	0.014	1.07	Day loam	19	34.3	45.4	0.15	3.67	1.45	1	22.3
11	43	17	0.01	1.72	Loam	11.6	25.2	43.7	0.14	17.26	1.49	1	22.3
12	43	17	0.065	1.17	Loam	11.2	24.6	42.3	0.13	15.34	1.53	1	22.3
13	17	37	0.029	0.86	Silty loam	22.3	37.4	47.2	0.15	2.17	1.42	1	23.6
14	19	37	0.02	0.64	"	22.2	51.1	46.5	0.15	2.17	1.42	1	23.6
15	45	17	0.09	0.36	Loam	10.6	23.1	39.7	0.12	12.82	1.6	1	23.6
16	35	21	0.075	1.97	Loam	13.9	28.7	44.8	0.15	11.44	1.46	1	31
17	31	23	0.029	0.99	Loam	14.5	29.5	43.1	0.15	7.03	1.57	1	16.1
18	31	21	0.029	0.76	Loam	13.4	28.7	42.8	0.15	8.1	1.92	1	19
19	43	7	0.032	0.71	Silty loam	5.3	19.7	41	0.14	31.71	1.56	1	19
20	45	7	0.025	0.14	Sandy loam	4.4	17.8	37.6	0.13	27.19	1.65	1	19
21	33	17	0.08	1.99	Silt loam	11.7	27.6	45.2	0.16	15.32	1.45	1	19
22	33	23	0.05	1.5	Loam	14.8	29.6	44.2	0.15	8.55	1.48	1	19
23	27	35	0.028	1.26	Loam	15.8	31.4	44.5	0.16	6.26	1.47	1	19
24	33	25	0.029	1.07	Loam	15.7	30.1	43.4	0.14	6.46	1.5	1	19
25	33	27	0.018	0.79	Loam	16.6	30.6	42.7	0.14	4.79	1.52	1	19
26	25	25	0.031	1.17	Silt Loam	15.6	31.5	43.9	0.16	5.37	1.49	1	19
27	41	17	0.021	1.03	Loam	11	24.6	41.5	0.14	13.47	1.55	1	19
28	33	19	0.013	1.07	Loam	12.2	21.3	42.2	0.15	9.57	1.53	1	19
	23	29	0.05	0.99	Loam	17.9	33.5	44.8	0.16	4.06	1.49	1	19
30	39	21	0.047	0.26	Loam	13.1	26.5	40.9	0.31	8.29	1.57	1	26.5

APPENDIX V: BASAWA PREDICTED MEASURED VALUE

S/N	% SAND	% CLAY	ds/m EC	% OM	TEX CLASS	%Vol WP	%Vol FC	%Vol SAT	CM/CM AW	mm/hr KSAT	g/cm^3 BD	Normal DC	%Vol MC
1	49	9	0.035	0.53	Loam	6	18.5	39.6	0.12	18.96	1.6	1	28.1
2	43	11	0.08	0.24	Loam	6.9	20.2	38.2	0.13	18.17	6.64	1	28.1
3	35	19	0.08	0.41	Loam	11.7	25.9	0.14	7.51	1.6	1	1	26.5
4	59	9	0.055	0.17	Loam	5.3	15.3	38.2	0.1	34.87	1.64	1	26.5
5	37	27	0.056	0.81	Loam	16.6	29.9	42.2	0.13	4.98	1.52	1	28.1
6	47	7	0.01	0.38	S.L	4.5	17.4	37.9	0.13	29.55	1.64	1	28.1
7	45	7	0.012	0.14	S.L	4.5	17.4	37.9	0.13	29.55	1.64	1	28.1
8	51	3	0.02	0.88	S.L	2.5	15.2	39.6	0.13	55.3	1.6	1	28.1
9	35	19	0.02	0.11	Loam	12.1	26.7	41.8	0.15	9.11	1.54	1	28.1
10	41	17	0.044	0.54	Loam	12.1	25.5	4.4	0.13	11.19	1.55	1	28.1
11	43	7	0.05	0.72	S.L	5.2	19.5	40.4	0.13	28.95	1.58	1	32.2
12	47	9	0.031	0.57	Loam	6.3	19.3	40.5	0.13	28.95	1.58	1	32.3
13	35	27	0.05	0.43	Loam	6.2	21.9	39.3	0.16	18.8	1.61	1	13.7
14	39	17	0.04	0.84	Loam	11	25	41.3	0.14	12.46	12.46	1	32.3
15	35	17	0.04	0.53	Loam	11	2	39.2	0.15	24.89	1.61	1	12.7
16	39	7	0.06	0.53	S.L	5	20	39.2	0.15	24.89	1.61	1	13.7
17	41	13	0.07	0.17	Loam	8	21.6	38.3	0.14	14.21	1.64	1	13.7
18	49	9	0.045	0.36	Loam	5.9	18.4	39.5	0.12	28.62	1.6	1	13.7
19	43	11	0.04	0.45	Loam	7.2	20.8	39.6	0.14	20.31	1.6	1	13.7
20	37	17	0.07	2.31	Loam	10.6	27.5	39	0.14	9.12	1.62	1	13.7
21	25	17	0.07	0.28	S.L	10.6	27.3	39.4	0.17	5.89	1.6	1	13.7
22	51	11	0.04	0.31	Loam	6.9	18.6	29	0.12	24.59	1.62	1	13.7
23	43	11	0.05	0.03	Loam	28.1	39.6	45	0.12	0.34	1.46	1	28.2
24	39	7	0.07	0.38	Loam	7.1	21.5	39	0.14	16.96	1.62	1	28.2
25	19	33	0.065	1.62	Loam	20.3	36	47.4	0.16	4.01	1.39	1	28.2
26	11	33	0.03	0.81	Loam	20.3	36.8	46.7	0.17	2.75	1.49	1	28.2
27	33	11	0.035	0.78	Clay	20.1	33.5	44	0.13	2.97	1.49	1	28.2
28	41	13	0.01	0.71	Loam	7.4	4.6	40.3	0.14	17.28	1.58	1	28.2
29	39	13	0.01	0.71	Loam	8.6	22.5	40.5	0.14	17.28	1.58	1	28.2
30	43	11	0.01	0.91	Loam	7.5	21.3	40.7	0.14	22.13	1.57	1	28.2

APPENDIX VI: TUDUN WADA PREDICTED MEASURED VALUE

S/N	% SAND	% CLAY	ds/m EC	% OM	TEX CLASS	%Vol WP	%Vol FC	%Vol SAT	CM/CM AW	mm/hr KSAT	g/cm^3 BD	Normal DC	%Vol MC
1	45	17	0.08	1.17	Loam	11	23.8	41.7	0.13	15.01	1.55	1	26.5
2	45	17	0.08	1.47	Loam	11	23.8	41.4	0.13	15.01	1.55	1	26.5
3	45	7	0.05	0.43	Sandy	4.9	18.5	39.3	0.14	30.24	1.61	1	26.5
4	59	9	0.055	0.17	S.L	5.3	15.3	38.2	0.1	34.87	1.64	1	26.5
5	63	5	0.01	1.36	S.L	4.1	14.1	42.2	0.1	64.96	1.53	1	26.5
6	53	7	0.011	1.57	S.L	5.8	18.2	43.3	0.12	46.45	1.5	1	26.5
7	43	11	0.06	0.4	Loam	7.2	20.8	39.6	0.14	20.31	1.6	1	13.7
8	43	11	0.053	0.36	loam	7.2	20.8	39.6	0.14	20.31	1.6	1	13.7
9	59	7	0.04	0.26	S.L	4.6	15	39.7	0.1	44.88	1.6	1	13.7
10	61	7	0.04	0.93	S.L	4.5	145	39.7	0.1	47.05	1.6	1	13.7
11	61	5	0.1	1.53	S.L	4.3	14.9	42.8	0.11	63.54	1.52	1	13.7
12	43	9	0.09	0.97	Loam	6	19.8	39.3	0.14	23.74	1.61	1	13.7
13	35	27	0.05	0.43	Loam	6.2	21.9	39.3	0.16	18.8	1.61	1	13.7
14	37	17	0.056	0.43	Loam	10.7	25	40.3	0.14	10.6	1.58	1	33.2
15	41	11	0.12	1.69	Loam	8	22.6	42.8	0.15	24.6	1.52	1	33.2
16	43	9	0.1	1.62	loam	6.8	21.3	42.7	0.14	30.31	1.52	1	33.2
17	43	9	0.02	0.81	Loam	6.3	20.3	40.5	0.14	25.78	1.58	1	33.2
18	41	11	0.02	0.74	Loam	7.5	21.7	40.6	0.14	20.75	1.57	1	33.2
19	33	15	0.05	0.38	Silt loam	9.5	24.8	39.6	0.15	10.3	1.6	1	33.2
20	41	11	0.035	1.99	Loam	8.3	23.2	44.3	0.15	27.41	1.48	1	33.2
21	43	9	0.08	1.78	Loam	7.2	21.9	44.2	0.15	33.3	1.48	1	33.2
22	43	7	0.076	1.19	Silt loam	5.3	19.7	41	0.14	31.71	1.56	1	13.7
23	43	13	0.05	0.78	Loam	8.4	21.8	39.8	0.13	19.32	1.6	1	13.7
24	39	13	0.065	0.6	Loam	8.4	22.7	39.8	0.14	15.36	1.99	1	13.7
25	35	11	0.06	1.52	Loam	8.1	24.1	43.1	0.16	21.18	1.51	1	13.7
26	41	13	0.06	1.66	Loam	9.1	23.5	42.9	0.14	21.14	1.51	1	13.7
27	55	11	0.01	1.16	Loam	9	20.3	42.3	0.11	28.52	1.53	1	13.7
28	39	17	0.01	0.71	Loam	10.8	24.6	40.5	0.14	11.52	1.58	1	13.7
29	35	15	0.045	0.57	Loam	9.7	24.7	40.4	0.15	11.91	1.58	1	28.1
30	43	11	0.04	1.59	Loam	15.9	28.7	43.5	0.13	8.38	1.5	1	28.1

APPENDIX VII: THE PERTICLE SIZE DISTRIBUTION OF SOIL SAMPLES USED AS INPUT DATA INTO THE MODEL FOR THE THREE LOCATIONS

Basawa												
Profile Depth		B1 (PIT1)				B2 (PIT2)				B3 (PIT3)		
Cm	clay	silt	Sand	tex	clay	silt	sand	tex	clay	silt	sand	tex
0-10	9	42	49	loam	7	46	47	sandyloam	7	56	43	siltloam
10-20	11	46	43	loam	7	48	45	loam	9	44	47	loam
20-30	19	46	35	loam	3	46	51	sandyloam	7	52	41	siltloam
30-40	23	46	31	loam	19	46	35	loam	17	48	35	loam
40-50	27	36	37	loam	17	42	41	loam	17	48	35	loam
Average												

Shika												
Profile Depth		B1				B2				B3		
Cm	clay	silt	Sand	tex	clay	silt	sand	tex	clay	silt	sand	tex
0-10	31	48	21	clay loam	17	56	27	silt loam	17	40	43	loam
10-20	19	58	23	silt loam	17	60	33	silt loam	17	40	43	loam
20-30	25	50	25	silt loam	25	40	35	loam	37	46	19	silt clay loam
30-40	27	46	27	loam	37	42	21	clay loam	37	44	19	silt clay loam
40-50	33	42	25	clay loam	31	46	23	clay loam	17	38	45	loam
Average												

Tudun wada												
Profile Depth		B1				B2				B3		
Cm	clay	silt	Sand	tex	clay	silt	sand	tex	clay	silt	sand	tex
0-10	17	38	45	loam	7	40	53	sandyloam	5	34	61	sandyloam
10-20	17	38	45	loam	11	46	43	loam	9	48	43	Loam
20-30	7	48	45	sandyloam	11	46	43	loam	27	38	35	Loam
30-40	9	32	59	sandyloam	7	34	59	sandyloam	17	46	37	Loam
40-50	5	32	63	sandyloam	7	32	61	sandyloam	11	48	41	Loam
Average												

	B4 (PIT4)				B5 (PIT5)				B6 (PIT6)		
clay	Silt	Sand	Tex	clay	Silt	sand	tex	clay	Silt	sand	tex
7	54	39	siltloam	17	58	25	siltloam	33	56	11	silt clay loam
13	46	41	Loam	11	38	51	loam	11	56	33	silt loam
9	42	49	Loam	11	46	43	loam	13	46	41	loam
11	46	43	Loam	7	54	39	siltloam	13	48	39	loam
17	46	37	siltloam	33	56	11	silt clay loam	11	46	43	loam

	B4				B5				B6		
clay	Silt	sand	Tex	Clay	silt	sand	tex	clay	silt	Sand	tex
21	44	35	Loam	17	50	33	silt loam	25	50	25	silt loam
23	46	31	Loam	23	44	33	loam	17	42	41	loam
21	48	31	Loam	25	48	27	loam	19	48	33	Loam
7	50	43	silt loam	25	42	33	loam	29	48	23	clay loam
7	48	45	Loam	27	40	33	loam	21	40	39	Loam

	B4				B5				B6		
clay	Silt	sand	Tex	Clay	silt	sand	tex	clay	silt	sand	Tex
9	48	43	Loam	9	48	43	loam	13	46	41	Loam
9	48	43	Loam	7	50	43	silt loam	11	34	55	Sandyloam
11	52	41	Loam	13	44	39	loam	17	44	39	Loam
15	48	33	silt loam	13	48	39	loam	15	50	35	silt loam
11	48	41	Loam	11	54	35	silt loam	11	46	43	Loam

APPENDIX VIII
Observed and Model Predicted Values for Shika Soil

SHIKA							
WP		FC		SAT		BD	
Predicted	Observed	Predicted	Observed	Predicted	Observed	Observed	Predicted
19.4	13.104	35.3	24.624	48.2	74.304	1.33	1.45
12.7	12.635	30.3	26.068	45.2	65.17	1.24	1.47
15.8	14.756	31.7	27.9	44.5	57.04	1.32	1.5
16.6	16.632	31.7	34.452	43.4	71.28	1.34	1.46
20.1	20.502	34.7	29.614	44.9	57.754	1.41	1.47
11.6	11.703	28.6	28.341	44.7	70.5	1.23	1.48
11.5	8.856	27.3	26.814	44.2	59.655	1.29	1.53
15.5	14.835	29.4	28.509	42.3	53.922	1.36	1.5
15.5	16.32	32	30.192	43.6	62.152	1.25	1.45
19.1	15.5	34.3	29.125	45.4	64	1.02	1.49
11.6	9.69	25.2	18.768	43.7	46.716	1.2	1.53
11.2	8.52	24.6	13.8	42.3	48.6	1.36	1.42
22.3	19.448	37.4	33.592	47.2	68	1.27	1.42
22.2	16.764	51.1	30.226	46.5	63.246	1.16	1.6
10.6	16.008	23.1	25.636	39.7	32.364	1.35	1.46
13.9	18.9	28.7	30.105	44.8	64.53	1.28	1.57
14.5	15.104	29.5	29.056	43.1	60.032	1.38	1.92
13.4	18.078	28.7	32.154	42.8	64.998	1.21	1.56
5.3	13.915	19.7	23.958	41	54.45	1.45	1.65
4.4	16.53	17.8	28.42	37.6	63.22	1.23	1.45
11.7	11.07	27.6	23.985	45.2	55.104	1.25	1.48
6.9	10.125	18.6	11.625	29	53	1.62	1.5
8.1	14.279	39.6	15.196	45	62.487	1.46	1.41
7.1	15.295	21.5	15.96	39	51.737	1.62	1.52
20.3	14.875	36	16.25	47.4	61.5	1.39	1.6
20.3	10.614	36.8	20.13	46.7	52.094	1.49	1.36
20.1	6.726	33.5	17.11	44	37.878	1.49	1.48
7.4	7.906	4.6	14.874	40.3	60.836	1.58	1.42
8.6	7.308	22.5	16.38	40.5	47.754	1.58	1.34
7.5	9.453	21.3	35.757	40.7	55.622	1.57	1.46

APPENDIX IX: Observed and Model Predicted Values for Basawa Soil

Wp		Fc		Sat		BD	
Predicted	Observed	Predicted	Observed	Predicted	Observed	Predicted	Observed
6.1	6.912	18.5	25.056	39.6	61.632	1.6	1.44
6.9	19.152	20.2	22.876	38.2	54.929	1.64	1.51
11.7	12.524	25.9	18.6	0.14	41.664	1	1.42
5.3	20.328	15.3	23.232	38.2	49.5	1.64	1.35
16.6	7.236	29.9	25.46	42.2	53.064	1.52	1.31
4.5	7.755	17.4	24.534	37.9	70.218	1.64	1.43
4.5	12.792	17.4	15.252	37.9	54.366	1.64	1.35
2.5	13.932	15.2	14.835	39.6	52.89	1.6	1.26
12.1	16.864	26.7	28.832	41.8	47.736	1.54	1.39
12.1	7.2	25.5	13.625	4.4	51	1.55	1.16
5.2	6.12	19.5	11.22	40.4	48.45	1.58	1.35
6.3	6.24	19.3	13.2	40.5	45.96	1.58	1.3
6.2	6.8	21.9	8.84	39.3	54.264	1.61	1.28
11.1	6.858	25	9.398	41.3	48.133	1.46	1.28
11.0	8.12	2	13.224	39.2	51.388	1.61	1.16
5.2	7.83	20	20.115	39.2	41.175	1.61	1.4
8.1	12.032	21.6	14.336	38.3	48.384	1.64	1.34
5.9	5.244	18.4	10.626	39.5	41.952	1.6	1.46
7.2	8.349	20.8	26.015	39.6	52.151	1.6	1.28
10.6	18.27	27.5	27.26	39	65.54	1.62	1.46
10.6	10.701	27.3	20.295	39.4	52.521	1.6	1.36
6.9	10.125	18.6	11.625	29	53	1.62	1.5
28.1	14.279	39.6	15.196	45	62.487	1.46	1.41
7.1	15.295	21.5	15.96	39	51.737	1.62	1.52
20.3	14.875	36	16.25	47.4	61.5	1.39	1.6
20.3	10.614	36.8	20.13	46.7	52.094	1.49	1.36
20.1	6.726	33.5	17.11	44	37.878	1.49	1.48
7.4	7.906	4.6	14.874	40.3	60.836	1.58	1.42
8.6	7.308	22.5	16.38	40.5	47.754	1.58	1.34
13.4	18.078	28.7	32.154	42.8	64.998	1.21	1.56

APPENDIX X: Observed and Model Predicted Values for T/wada Soil

TWADA							
SAT		FC		WP		BD	
Predicted	Observed	Predicted	Observed	Predicted	Observed	Predicted	Observed
41.7	63.756	23.8	16.236	11	14.388	1.55	1.32
41.4	61.855	23.8	16.541	11	14.178	1.55	1.39
39.3	52.997	18.5	17.515	4.9	7.91	1.61	1.13
38.2	55.227	15.3	10.824	5.3	8.733	1.64	1.23
42.2	50.355	14.1	13.365	4.1	5.94	1.53	1.35
43.3	29.464	18.2	16.24	5.8	8.816	1.5	1.16
39.6	62.042	20.8	26.934	7.2	12.998	1.6	1.34
39.6	48.068	20.8	15.86	7.2	6.71	1.6	1.22
39.7	48.36	15	19.592	4.6	9.672	1.6	1.24
39.7	49.476	14.5	24.738	4.5	11.172	1.6	1.33
42.8	54.21	14.9	30.16	4.3	12.09	1.52	1.3
39.3	56.896	19.8	23.241	6	11.938	1.61	1.27
39.3	49.654	21.9	22.082	6.2	8.418	1.61	1.22
40.3	41.976	25	15.688	10.7	9.116	1.58	1.06
42.8	54.675	22.6	13.095	8	12.555	1.52	1.35
42.7	54.383	21.3	23.681	6.8	13.209	1.52	1.19
40.5	57.204	20.3	24.822	6.3	7.56	1.58	1.26
40.6	56.576	21.7	15.616	7.5	8.448	1.57	1.28
39.6	59.5	24.8	20.44	9.5	7.56	1.6	1.4
44.3	60.129	23.2	19.781	8.3	14.934	1.48	1.31
44.2	51.527	21.9	19.754	7.2	10.472	1.48	1.19
40.0	55.692	19.7	19.656	5.3	12.852	1.56	1.26
39.8	58.166	21.8	27.813	8.4	13.843	1.6	1.27
39.8	58.426	22.7	28.951	8.4	7.991	1.99	1.31
43.1	51.875	24.1	16.875	8.1	9	1.51	1.25
42.9	40.504	23.5	20.496	9.1	11.468	1.51	1.22
42.3	52.204	20.3	18.104	9	10.044	1.53	1.24
40.5	63.535	24.6	15.982	10.8	13.362	1.58	1.31
40.4	57.72	24.7	32.37	9.7	12.09	1.58	1.3
43.5	60.732	28.7	30.618	15.9	9.324	1.5	1.26

Appendix XI

The averages of the result of moisture content at the increamental depths and at various suctions for the study locations.

Appendix xi a Average of soil moisture content of Shika

Suction (KPa)	Moisture 0-10cm	Moisture 10-20cm	Moisture 20-30cm	Moisture 30-40 cm	Moisture 40-50cm
0	0.47	0.46	0.47	0.48	0.41
10	0.36	0.35	0.37	0.36	0.34
30	0.20	0.20	0.23	0.23	0.21
100	0.16	0.17	0.19	0.18	0.18
500	0.11	0.13	0.14	0.13	0.14
1000	0.10	0.12	0.13	0.12	0.13
1500	0.09	0.10	0.12	0.11	0.11

Appendix xi b Average of soil moisture content of Tudunwada

Suction (KPa)	Moisture 0-10cm	Moisture 10-20cm	Moisture 20-30cm	Moisture 30-40cm	Moisture 40-50cm
0	0.40	0.45	0.44	0.43	0.42
10	0.22	0.22	0.24	0.23	0.24
30	0.18	0.17	0.15	0.17	0.15
100	0.13	0.13	0.13	0.12	0.12
500	0.10	0.09	0.08	0.07	0.08
1000	0.08	0.08	0.07	0.06	0.07
1500	0.06	0.06	0.05	0.04	0.04

Appendix xi c Average of soil moisture content of Basawa soil

Suction (KPa)	Moisture 0-10cm	Moisture 10-20cm	Moisture 20-30cm	Moisture 30-40cm	Moisture 40-50cm
0	0.43	0.39	0.40	0.38	0.43
10	0.22	0.20	0.22	0.22	0.24
30	0.16	0.13	0.11	0.15	0.17
100	0.11	0.11	0.09	0.12	0.12
500	0.07	0.09	0.08	0.10	0.08
1000	0.05	0.07	0.07	0.07	0.07
1500	0.04	0.05	0.06	0.05	0.06

Plate I: The Student on the Field Collecting Soil Samples

Plate II: The Student during the Performance of Moisture Extraction Test.