`

MODELLING OF HYDRAULIC CONDUCTIVITY BASED ON SELECTED SOIL BIOLOGICAL, CHEMICAL AND PHYSICAL PROPERTIES IN IMO AND ABIA STATES, NIGERIA

BY

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DECLARATION

I hereby declare that this thesis 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 quotations are distinguished by quotation marks and the sources of information are specifically acknowledged by means of references.

Ngwangwa, Nkechi Vivian

October, 2014.

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CERTIFICATION

We certify that this project work on **Modelling of Hydraulic Conductivity based on Selected Soil Biological, Chemical and Physical Properties in Imo and Abia States, Nigeria** by NGWANGWA, NKECHI VIVIAN with registration number: 20104757708, is a thesis submitted to the Postgraduate School, Federal University of Technology, Owerri in partial fulfillment of the requirements for the award of Master of Engineering (M.Eng.) degree in Agricultural Engineering (Soil and Water Engineering Option).

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DEDICATION

This thesis is dedicated to GOD ALMIGHTY, who has been the inspiration from the start to the completion of this work.

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ABSTRACT

Hydraulic conductivity models for different soil sub-groups (locations) were developed using dimensional analysis (DA) based on the Buckingham's π-theorem and statistical analysis (SPSS) based on stepwise method. In this research study, the independent variables: organic matter content, exchangeable sodium, soil pH, cation exchange capacity, particle density, bulk density, porosity, percentage clay, percentage silt and percentage sand and the dependent variable (hydraulic conductivity) were measured using standard experimental methods and the hydraulic conductivity values measured were compared to predicted values from the models established. High coefficients of determination R^2 = 0.9999 (SPSS) and 0.9954 (DA) for estimating hydraulic conductivity for different soil sub-groups were obtained using raw data from three locations not used in building the model. Standard errors of the models predicted fairly accurately, judging from the low residual values got from the three locations not used in building the model; (ranging from 4.4% to 18.3%) and the eight locations used in building the model (ranging from 1.69% to 18.66%). These results are clear evidence of the test of goodness of fit of the models between predicted and measured parameters for hydraulic conductivity for different soil sub-groups. The models were verified and validated by comparing the predicted with the measured Hydraulic conductivity, and shown to closely follow the experimental results. From the analysis done, it can be inferred that organic matter content and percentage silt properties of soil sub-groups affect hydraulic conductivity positively with R-values as 0.850 and 0.842 respectively whereas negative effect was observed for bulk density, soil pH, exchangeable sodium, particle density and percentage clay, with R-values as -0.539, -0.604,-0.583, -0.618 and -0.417 respectively.

Keywords: modelling, hydraulic conductivity, statistical analysis, dimensional analysis, soil properties.

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CHAPTER ONE

INTRODUCTION

1.1 Background Information

Modelling refers to the process of generating a model as a conceptual representation of some phenomenon(Zacks, 1996). Typically a model will refer only to some aspects of the phenomenon in question and two models of the same phenomenon may be essentially different, that is to say that the difference or differences between them is more than just a simple renaming of components and such differences may be due to differing requirements of the model's end user or to conceptual or aesthetic differences among the modellers. Also, Modelling can mean the process of creating abstract or conceptual model and the use of objects in the creation of a predictive statement.Modelling involves abstraction, simplification, and formalization, in light of particular methods and assumptions, in order to better understand a particular part or feature of the world, and to potentially intervene (Tom, 2012). The aim of these attempts is to construct aformal systemthat will not produce theoretical consequences that are contrary to what is found in reality. Predictions or other statements drawn from such a formal system mirror or map the real world. Aesthetic considerations that may influence the structure of a model might be the modeller's preference for a reduced ontology, preferences regardingdiscrete versus continuous time, etc. For this reason, users of a model need to understand the model's original purpose and the assumptions made that are pertinent to its validity (Fukshansky, 1992). Factors important in evaluating a model include: ability to explain past observations, ability to predict future observations, cost of use especially in combination with other models, viability, enabling estimation of the degree of confidence in the model simplicity. Generally, there are different types of modelling (Colette, 1993). Among all the types of modelling known, the one used (statistical modelling) and other ones necessary to Engineering were discussed extensively in Chapter 2 section 2.7.2.

Agricultural soil is defined as the medium for crop growth, anchorage for plants that contain nutrients, water and air on which plants depend (Ibitoye, 2008). It also refers to the top few centimetres of the land surface and soils having sufficient permeability to maintain drainage and prevent salt accumulation that cause damage to crops (Brady and Weil, 2002).Vukovic and Soro (1992) stated that restricted movement is desired to prevent losses from ponds or lakes used as water sources for domestic, agricultural, or recreational purposes.Soil physical, chemical and biological properties affect many processes in the soil that make it unsuitable for agricultural practices and other purposes. For example, texture and porosity influence the movement and retention of water, air and solutes in the soil, which subsequently affect plant growth and organism activity(Brady and Weil, 2002). The physical properties in this study include grain size distribution, soil porosity, fluid density, bulk density, particle density; chemical properties include the soil pH, cation exchange capacity (CEC), exchangeable sodium percentage (ESP) and biological effects include the macro effects of organics (Organic matter content) on the soil. The biological effects not included also involve cracks due to root penetration; insect, decayed root holes and wormburrows which allow water and air to move deep into the soil, offering greater resource movement for deep-rooted plants and adequate water drainage(Regalado and Munōz-Carpena, 2004).

All drain-spacing equations make use of these parameters to design or evaluate adrainage project where the determination of the hydraulic conductivity value is neededas accurate as possible (Boadu, 2000).The hydraulic conductivity value is subject to variation in space and time, which means that we must adequatelyassess a representative value. This is time-consuming and costly, so a balance has to be struck between budgetlimitations and desired accuracy. As yet, no optimum technique exists; much depends on the skill ofthe Soil and Water Engineer. The method categories will be briefly described later in this project. Which method to select for the survey of hydraulic conductivity depends on the practical applicability, and the choice is limited(Vukovic and Soro, 1992). Current methods of relating hydraulic conductivity to grain size distribution rely on grain size distribution parameter which are the most important characteristics of water bearing formations and their magnitude, pattern and variability significantly influence water flow patterns (Wӧsten, et al.,2001). The K-value of a saturated soil represents its average hydraulic conductivity, which depends mainly on the size and distribution of the pores (Boadu, 2000). It also depends on the soil pH and the density of the soil water.Therefore, it is indispensable to accurately determine these properties for a reliable assessment of the hydraulic conductivity. Usually however, the value of hydraulic conductivity varies with the direction of flow. The vertical permeability of

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the soil or of a soil layer is often different from its horizontal permeability because of vertical differences in texture, structure, and porosity due to a layered deposition or horizon development and biological activity (Bouman, et al., 1990).Not only can different soil layers have different hydraulic conductivities, but, even within a soil layer, the hydraulic conductivity can vary(Vukovic and Soro, 1992). In subsurface drainage systems in alluvial soils, not only the hydraulic conductivity values at drain depth are important, but also the hydraulic conductivity values of the deeper soil layers. Vertisols are characterized by a gradually decreasing hydraulic conductivity value with depth because the topsoil is made more permeable by physical and biological processes, whereas the subsoil is not (Regalado and Munōz-Carpena, 2004). If subsurface drains are to be installed, the hydraulic conductivity values must be measured during the rainy period and therefore, seasonal variability studies are important (Mausbach, 1998).

Since many soil properties are interrelated with one another, it is difficult to draw distinct lines of division where one type of property dominates the behaviour of the soil. Therefore, understanding and recognizing the important soil properties relevant in agriculture and their connections with one another is important for making sound decisions regarding soil use and management.

1.2 Statement of Problem of Study

In large farming, lack of knowledge of the rateof water movement into the soils during irrigation causes excessive water loss in form of deep percolation or flooding the entire areawith water which results in the death of some crops. Also, there are areas where recharging water to dams, embankments, etc either naturally or artificially is there only source of water during dry season during rainy season using special spreading basins or recharge pits for storage and soils having high permeability in the storage device causes inadequate storage of water for irrigation.

1.3 Objectives of the Study

The main objective of the study is:"Modelling of hydraulic conductivity based on selected soil biological, chemical and physical properties in Imo and Abia States, Nigeria"

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The specific objectives of the study are:

- To determine soil Biological (Organic matter content), Chemical {soil pH, cation exchange capacity (CEC), exchangeable sodium percentage (ESP)} and Physical properties (grain size distribution, porosity, fluid density, bulk density and particle density) that influence hydraulic conductivity from eleven locations in Imo and Abia states of Nigeria.
- To develop models to predict hydraulic conductivity based on the above selected soil physical, chemical and biological properties.
- To validate the models using actual values from soil samples from the areas.

1.4 Justification of the Study

Knowledge of current hydraulic conductivity and other soil tests from the desired areas combined with the relative understanding of water flows within the soil depths, aids in developing useful information recommended for structural maintenance in Soil and Water Engineering practices. Generally, when a soil shows a distinct layering, it is often found that the representative hydraulic conductivity values of the layers is subject to variation in location, space and time which means that we must adequately assess a representative value. This is time consuming and costly, so a balance has to be struck between budget limitations and desired accuracy in designing or evaluating a hydraulic conductivity value that is as accurate as possible. Generally, soil properties have a distinctive effect on the movement of water in the soil. The amount and rate of groundwater recharge, storage, discharge, as well as the extent ofgroundwater contamination, all depend on the soil physical, chemical and biological properties and all these properties together affect the movement of water in the soil and that is why there is need to effectively identify the relevance of the knowledge of the rate at which water flow in soils which is useful in predicting rate of water movement of soils in Imo and Abia states. The result of this work serves as a handy tool in hydraulic conductivity prediction and powerful guide to decision makers in agricultural system establishments.

1.5 Scope of the Study

This work covers the eleven soil sub-groups in Imo and Abia States at depth from 0cm to 15cm with a view to develop models that will show the effect and the

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degree of association between soil physical properties(grain size distribution, porosity, fluid density, bulk density, particle density), chemical properties (soil pH, cation exchange capacity, exchangeable sodium percentage), biological properties (organic matter content) and hydraulic conductivity so as to know the soil properties that play more significant role with respect to hydraulic conductivity and they will be termed the effective factors in hydraulic conductivity prediction. The factors will be used to develop predictive models of hydraulic conductivity which will be validated using actual field results of the several properties.

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CHAPTER TWO

LITERATURE REVIEW

2.1 Historical Background of the Study

The hydraulic conductivity values of the topsoil are often subject to changes with time, which can be seasonal variations or timetrends. This is due to the drying of the topsoil during a dry season or after the introduction of drainage (Dirksen, 1991). The seasonal variability occurs mainly in clay soils with swelling and shrinking properties which form cracks around soil masses creating peds. Cracks and channels between peds are important for water, air, and deep water drainage(Brady and Weil, 2002).

The time trend may be observed in soils with a high clay or organic fraction. The true soil component can also be defined as allmineral and naturally occurring organic materials with a particle size less than 2 mm (Barth and Flippen, 1995).The physical and chemical characteristics of the soil system influence the transformation,retention, and movement of water and pollutants through the soil. Clay content, organic mattercontent, texture, permeability, pH and Cation exchange capacity (CEC) will influence the rate of flow of water and other pollutants (Panda and Lake, 1994). These factors must be considered by the investigator when designing a soil sampling effort. Soil properties vary not only from one location to another but also among the horizons of a given profile, thus the need for sampling with the attendant sampling errors. Disturbed soils, such as those found in many sites, are reported to be more variable than virgin soils in most cases.Mausbach (1998) reported on a study conducted by the Soil Conservation Service (SCS) laboratory in Lincoln, Nebraska that matched pairs of samples were collected from areas within a soil series and the samples were stratified by a number of factors in order to reduce the variability. The samples were selected from the modal phases of the series and were collected at distances that ranged from 2 to 32 km from the other member of the pair. The author's literature indicated that up to half of the variability between similar soils may occur within a distance of one meter.Mausbach (1998) reported also that in the study of the variability within a soil type, the Cumulative Variations for physical and chemical properties ranged from 9% to 71 for different types of soils. The variation

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that seems to be inherent in data collected from any soil sampling study must be taken into consideration during the conclusion of a soil sampling plan.

2.2 Soil Propertiesfor Modelling Hydraulic Conductivity

The ability to predict Hydraulic conductivity (K) and variations in permeability (heterogeneity) of porous media such as unconsolidated soil due to soil physical, chemical and biological properties are of vital importance to many areas of geologic and geotechnical investigation and management. Hydraulic conductivity estimates are important for geotechnical problems (e.g. seepage losses, settlement computations, and stability analysis) as well for the development, management, and protection of groundwater resources (Boadu, 2000). In the field of environmental protection, prediction of likely flow paths for petroleum leakage from underground storage tanks depends primarily on the estimates of the hydraulic conductivity of the surrounding soils (Cronican and Gribb, 2004). And in coastal soils, investigation into the geochemical processes controlled by pore water circulation (e.g. remineralisation of organic matter and nutrient cycling) has required the quantification of soil hydraulic conductivity to delineate potential flow paths and make comparisons with observed flow rates.Sperry andPeirce (1995) developed a linear model to estimateKs basedon grain size, shape, and porosity. Methods of predicting hydraulic conductivity from soil properties through quantitative relations have been developed by analogy to pipe flow and flow in capillaries. Besides predictive methods, empirical relations have also been used(Boadu, 2000). Equations relating some soil properties to hydraulic conductivity are of the form of Eqn. 2.1 (Fetter, 1993).

$$K = \left\{\frac{\rho g}{\mu}\right\}. C_s. d^m \qquad 2.1$$

Where, **K =** hydraulic conductivity (L/T), **ρ =** fluid density (M/L^3), **g** = gravitational acceleration (L/T^2), **μ** = dynamic viscosity (M/LT), **c_s=** factor representing the shape and packing of grain (dimensionless), **d** = representative grain diameter (L), **m** = an exponent often equal to 2 (dimensionless).

Porosity and hydraulic conductivity in soil mixtures depend on the fractional concentration of each particle size, the diameter ratio, fluid density and particle

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packing. The effects of particle size, compaction and soil sorting can be accounted for in the Carmen-Kozeny (CK) equation Eqn. 2.2 (Bear and Bachmat, 1991).

$$K = \left\{ \frac{\left(\frac{\rho g}{\mu}\right) . d^2 . \varrho^3}{180(1-\varrho)^2} \right\} \qquad 2.2$$

Where, **K** = hydraulic conductivity (L/T), **ρ**= fluid density (M/L^3), **g** = gravitational acceleration (L/T^2), **μ** = dynamic viscosity (M/LT), **ϱ**= total porosity, accounting for compaction (dimensionless), **d** = representative grain diameter (median) (L).

Hydraulic conductivity (K) can be estimated by particle size analysis of the sediment of interest, using empirical equations relating either K to some size property of the sediment. Vukovic and Soro (1992) summarized several empirical methods from former studies and presented a general formula for estimating hydraulic conductivity in Eqn. 2.3 (Vukovic and Soro, 1992).

$$K = \left\{ \left(\frac{g}{V}\right) \times C \times \mathcal{F}(n) \times d_e^2 \right\} \qquad 2.3$$

Where,

K = Hydraulic conductivity, LT^{-1}

g = Acceleration due to gravity, LT^{-2}

v = Kinematic viscosity, $ML^{-1}T^{-1}$

C = Sorting coefficient, %

$\mathcal{F}$(n)= Porosity function, %

d_e^2 = effective grain diameter, L

The Kinematic viscosity (*v*) is related to dynamic viscosity (*μ*) and the fluid (water) density (ρ) as in Eqn. 2.4 (Vukovic and Soro, 1992).

$$V = \left(\frac{\mu}{\rho}\right) \qquad 2.4$$

The values ofC, $\mathcal{F}$(n) and d_e are dependent on the different methods used in the grain-size analysis. According to Vukovic and Soro(1992), porosity (*n*) may be

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derived from the empirical relationship with the coefficient of grain uniformity (u) as in Eqn. 2.5 (Vukovic and Soro, 1992).

$$n = 0.255(1 + 0.83^{u}) \qquad 2.5$$

Where,

$$u = \frac{d_{60}}{d_{10}}$$

Here, $\mathbf{d_{60}}$ and $\mathbf{d_{10}}$ in the formula represent the grain diameter in (mm) for which, 60% and 10% of the sample respectively, are finer than.

Former studies have presented the following formulae (Vukovic and Soro, 1992) which take the general form presented in Eqn. 2.1 above but with varying C, f(n) and $d_e$values and their domains of applicability is given in Eqn. 2.6.

$$K = \left(\frac{g}{V}\right) \times 6 \times 10^{-4}[1 + 10(n - 0.26)]d_{10}^{2} \qquad 2.6$$

Vukovic and Soro's formula in Eqn. 2.6 was originally developed for determination of hydraulic conductivity of uniformly graded sand but now it is useful for fine sand to gravel range, provided the sediment has a uniformity coefficient less than 5 and effective grain size between 0.1 and 3mm. For a subsurface system saturated with the soil fluid, the hydraulic conductivity, **k**, can be expressed as in Eqn. 2.7 (Bear and Bachmat, 1991).

$$K = \frac{ƙ\rho g}{\mu} \qquad 2.7$$

Where,

K = hydraulic conductivity, LT^{-1}.

ƙ = the intrinsic permeability of the soil which depends only on properties of the solid matrix, LT^{-1}.

g = Fluidity of the liquid which represents the properties of the percolating fluid, LT^{-2}

ρ = fluid density, ML^{-3}.

μ = dynamic viscosity, $ML^{-1}T^{-1}$.

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2.3 Soil Sampling

A sample is a part drawn from a larger whole and a sample is taken in order to learn something about the whole (the population) from which it is drawn. Several considerations impact sampling. The time of year that samples are taken impacts the results of the soil test. Generally, samples taken during the dry season demonstrate lower levels of potassium, an important nutrient governing the growth of plants in agriculture (Benjamin, 1990). Although the physical process of taking samples from surface soil is relatively simple, choosing when and where to take samples is more complicated(Schoeneberger, et al., 1998). There are different methods for choosing sampling sites, they are known as grid sampling, random sampling, soil series sampling, topographic sampling and remote sensing sampling (Franzen et al., 1998). But the method used in this work is the random sampling which will be discussed extensively.

2.3.1 Random sampling

Random sampling of the soil means that the researcher takes soil samples from areas of a given site chosen at random when there is little previous knowledge of the site (Benjamin, 1990). It can be used for agricultural purposes to determine the general levels of important nutrients like nitrogen and phosphorus, telling the researcher whether the site is suitable for crops and suggesting which crops might do best there. Uniform fields can be randomly sampled throughout the entire field. To see long-term trends in soil nutrient data, these points should be georeferenced with a global positioning system (GPS) receiver and sampled in these samelocations in subsequent years (Schoeneberger, et al., 1998). Black (1999) discussed some advantages and disadvantages of random sampling of soils.

2.4 Methods of determining Hydraulic Conductivity

Hydraulic conductivity (K) is one of the most important hydraulic properties of the soil matrix (Bagarello and Sgroi, 2007) and often considered as one of the most difficult hydraulic properties to obtain (Ünlüet al., 1990; Suleiman and Ritchie, 2001). Abroad array of methods currently exists for determining K values, both in the field and laboratory (Schaapet al., 2001). Measurements of the K values are

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laborious, time consuming and costly (Rawls et al., 1998) and the results exhibit wide variation due to experimental errors (Wessoleket al., 1993). Temporal variability also affects results from different field techniques of measuring K values (Bagarello and Sgroi, 2007) in additionto inherent soil properties that affect macro aggregates, soil fauna and tillage operations(Feunteset al., 2004). Also, both laboratory and field techniques have been found to give variable results of measured K values (Mohantyet al., 1994; Bagarello and Provenzano, 1996; Regalado and Munõz-Carpena, 2004).The different broad categories of determining hydraulic conductivity are shown in Fig. 2.1 below.

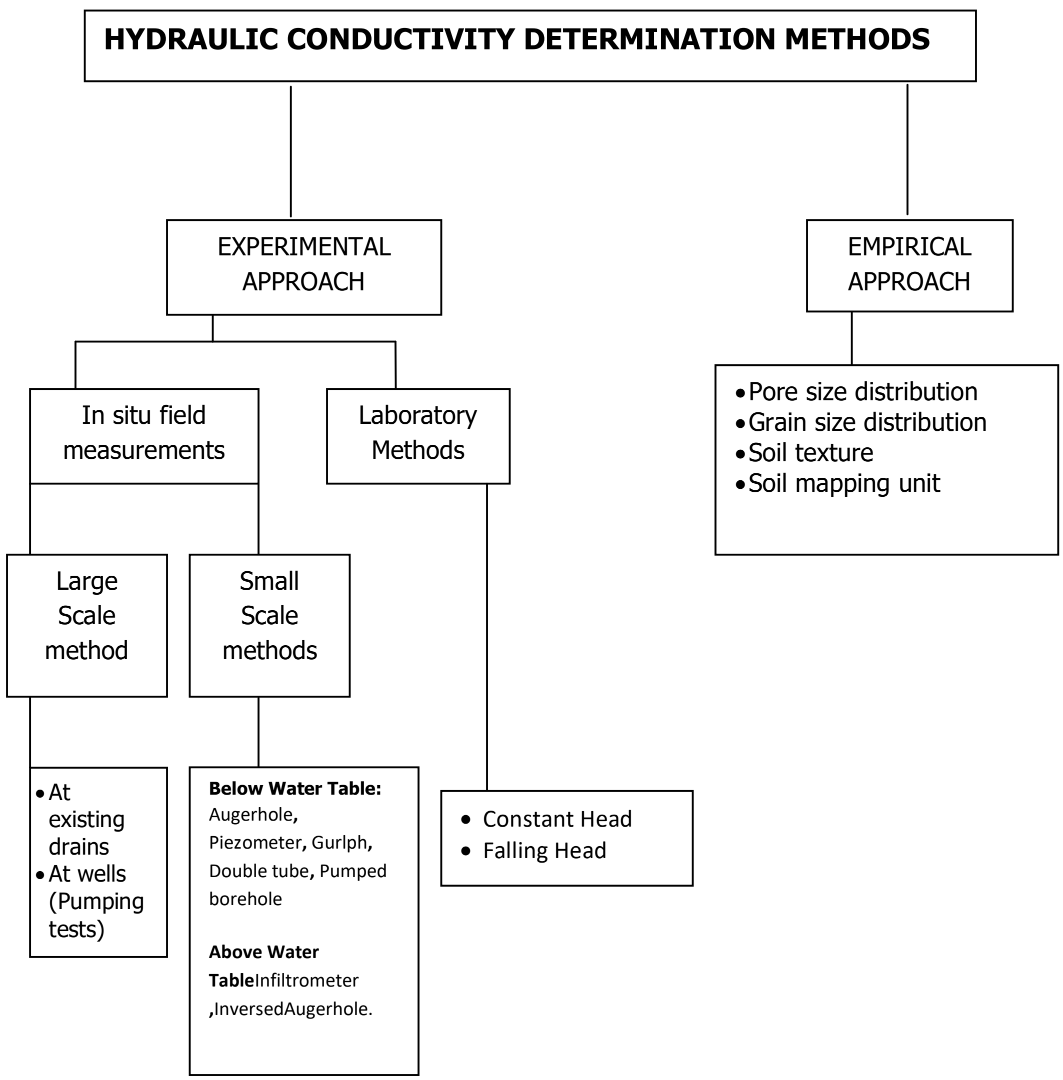

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Fig. 2.1 Overview of methods used to determine hydraulic conductivity (Ritzema, 1994)

The experimental approach used in determining the hydraulic conductivity of the soil samples from Imo and Abia states is the falling head method which is a laboratory method described explicitly by Dirksen (1991) and Bagarello and Sgroi (2007).

2.5 Factors affecting Hydraulic Conductivity of Soil

The hydraulic conductivity of soil is affected by many factors, including physical, biological, and chemical factors (Davies et al., 1992). A reconstructed soil generally has a lower water holding capacity than an undisturbed soil, which can be attributed to decreases in porosity and hydraulic conductivity (McGrath, 2001). With an increase in bulk density and decreased organic matter content, infiltration into the soil can be inhibited.Hydraulic conductivity is adversely affected in a disturbed soil (Varela et al., 1993), due to decreases in porosity, increases in bulk density, and texture changes. The main soil properties that affect the hydraulic conductivity of a soil as proposed by Davies et al., (1992)areas discussed below.

2.5.1 Biological factors

Feuntes et al., (2004)stated that organic residues from the growth process mixed with the inorganic soil fraction produces higher hydraulic conductivities by providing for stabilization of soil aggregates and reducing bulk density. Regalado and Munōz-Carpena(2004) stated that high hydraulic conductivity can be presented by use of organic matter.

Microorganisms acting on the organic material can produce either an increase or decrease in hydraulic conductivity, depending on circumstances surrounding their action. However, the action of microorganisms likewise can decrease hydraulic conductivity by clogging of soil pores with microbial cells or by-products of microbial metabolism. Also, further action by microbes on previously stable organic cemented aggregates can reduce hydraulic conductivity, as was reported by researchers (Feuntes et al. 2004). Properties such as aggregatestability, infiltration, water

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holding capacity, porosity, cation exchange capacity, and nitrogen cycling and vegetation growth will all be adversely affected by low organic matterlevels. However, organic matter accumulation can occur fairly quickly within the surface layer of a disturbed soil (Varela et al., 1993).

2.5.2 Chemical factors

The soil chemical composition plays an important role in determining the hydraulic conductivity of soils. Several efforts that were made to estimate hydraulic conductivity from soil properties such as cation exchange capacity, exchangeable sodium percentage (ESP) etc resulted in simple and complex Pedo-Transfer functions (Vereecken, 1995; Mathan et al., 1995; Rawls et al., 1998; Suleiman and Ritchie, 2001; Moustafa, 2000). The soil pH, cation exchange capacity (CEC), and exchangeable sodium percentage (ESP) are among some variables that indicate the type and amount of chemical components in the soil and how they might interact to produce changes in hydraulic conductivity (Schaap et al., 2001). For example, a soil having a high cation exchange capacity, CEC with high exchangeable sodium might have a low hydraulic conductivity relative to one having the same CEC but with high amounts of calcium salts. Also, according to Ibitoye (2008) a pH of 9.5 has 10-9.5 moles of hydrogen ions per litre of solution. A pH of 3.5 has one million times more hydrogen ions per litre than a solution with pH of 9.5 which reduces the presence of microorganisms that improves the movement water in the soil. The effect of pH on soil is to remove from the soil or to make available certain ions. Soils with high acidity tend to have toxic amounts of aluminium and manganese that kill beneficial organisms that increases the penetration of water and air into the soil (Martin et al., 2006) . Plants which need calcium need moderate alkalinity but most minerals are more soluble in acid soils (Ibitoye, 2008).

2.5.3 Physical factors

The hydraulic conductivity depends on the soil grain size, the structure of the soil matrix, the type of soil fluid and the relative amount of soil fluid (saturation) present in the soil matrix (Mbagwu, 1995). The important properties relevant to the solid matrix of the soil include particle size distribution, porosity, etc. In relation to the soil fluid, the important properties include fluid density, etc. Among other

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physical considerations of importance mentioned earlier are those of texture and structure. A sandy soil will commonly have a higher hydraulic conductivity than finer-grained soils. Franzemeier (1991) stated that compaction will reduce porosity and hydraulic conductivity by breaking the natural soil structure, fracture openings are eliminated and soil aggregates along with single grains are combined into one massive unit, greatly reducing hydraulic conductivity. The use of porosity to estimate hydraulic conductivity, as in the Kozeny-Carman equation leads to difficulties in soils, especially fine-grained, where pores may not be interconnected due to arrangement of packing or where cracks and fissures can add little to porosity but could provide large increases in hydraulic conductivity. The distribution of pore sizes in the soil would be a more effective method of characterizing hydraulic conductivity if that property could be described directly. The use of a pore-size model resulted in over-estimation of hydraulic conductivity from 2 to 70 times values found by direct measurement (Lowery and Schuler, 1994). Another physical effect on hydraulic conductivity is the method of wetting. The gravity method is a non-destructive geophysical technique that measures differences in the earth'sgravitational field at specific locations. The successful determination of the gravitational acceleration depends on the different location and earthmaterials having different bulk densities (mass) that produce variations in the measured gravitational field and can be gotten from different geological stations from different locations (Hinze, 1990).

2.5.3.1 *Soil texture (particle size distribution, bulk density)*

The particle size distribution analysis is one of the most principle determinations in Soil Science and its knowledge already allow relatively good estimations of soil hydraulic properties (Mbagwu, 1995). Grain size distribution is very important for the bulk density calculation. Hydraulic conductivity, which is affected by soil structural properties such as total porosity, pore–size distribution and pore continuity, is used as an index for field drainage. When soil become compacted, changes in total porosity, pore-size distribution, etc cause the hydraulic conductivity to decrease, and penetration resistance and bulk density to increase (Lowery and Schuler, 1994). The separation of the different particle sizes is carried out be sieving with exactly defined mesh sizes. The fine grained fraction, i.e. particle ranging from <63 μm to 2 μm, are normally separated by so called sedimentation analysis, using the different sinking properties of the grains in liquids (Stokes' law). For

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determination of the clay fractions sedimentation is speeded up by centrifugation applying several times of earth gravitational force. All these methods are time consuming. The shape of platy clay minerals has a strong influence on their sedimentation behaviour and thus influences the determined equivalent particle size. Therefore, some methods allow introduction of a shape factor (McGrath, 2001) for calculation of particle sizes.

When a soil is reconstructed after surface mining, the bulk density is often much higher than the original soil material (Davies et al., 1992; Naeth et al., 1991). The change in texture of the soil is one of the causes of the increase in bulk density (Manrique and Jones, 1991). A reconstructed soil often has low levels of organic matter which contributes to an increase in soil bulk density (Davies et al., 1992). Bulk density has a tendency in a natural soil to increase with depth due to decreases inporosity and structure changes (Manrique and Jones, 1991; Naeth et al., 1991). The bulkdensity of a soil can be lowered by natural processes such as wet-dry cycles, earthworms, other burrowing animals, and plant roots; however, these processes work very slowly (Naeth et al., 1991). When a soil is severely compacted it can affect the growth of vegetation as a result of the decrease in hydraulic conductivity of the soil. Bulk densitylimitations for root growth change with the texture of a soil which in turn changes the rate of movement of water in the soil. Bulk density that results inzero root growth varies from 1.85 gcm^{-3} to 1.80 gcm^{-3} for the textural classes of sand to sandy clay loam respectively. The water infiltration rate depend on pore structure in soil, so the quantification of pore size distribution over a wide range of pore sizes is useful in practice and theoretical modelling (Durner and Flühler, 1996; Gerke and Köhne, 2002). Relation of hydraulic conductivity to water potential or water content is a basic characteristic conditioning water movement in the environment, so theserelationships are often modeled (Pachepsky and Rawls, 2004; Slawiñski et al., 2004).

2.5.3.2 *Soil structure (porosity)*

In Franzemeier (1991), the term structure of soils generally refers to the pore geometry and the pore volume or porosity is a measure of the void spaces in the soil and is a fraction of the volume of voids over the total volume, between 0-1 or as a percentage between 0-100%. Porosity of surface soil typically decreases as particle

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size increases. The transport of water, solutes, and gases in soil is not only influenced by the absolute size of the pore volume but also on the nature of how the pores are connected which is summarized under the term tortuosity. In soil the tortuosity is closely related to soil surface area and the pore-size distribution. Small pores exhibit attractive forces strong enough to hold water in the pores. They are the water retention system of the soil which provides water storage for plant roots. During precipitation, large pores improve water movement into the soil where it fills the small pores and at field capacity, all the small pores enough to retain the water against the pull of gravity are filled (Brady and Weil, 2002). Clay soils have low hydraulic conductivity due to their numerous small pores but they hold large quantity of water and since they have few large pores, they produce very small infiltration rates(Glinski and Lipiec, 1990). The pores in the clay may be so small and hold water so tenaciously that the water is not available to plants. Sandy soils with numerous large pores but few small pores have higher rate of movement of water and percolation rates but a lower water holding capacity than other soil textures. A lower holding capacity can mean less available water for plant roots. For revegetation purposes, plants perform best in intermediate soil textures (loam) where soils contain mixture of small and large pores for effective water movement (Munshower, 1994).

The porosity of a soil is dependent on texture and structure, which often are changed ordestroyed by salvage and reconstruction procedures (Davis et al., 1992). Porosity is important to soil development because microorganisms and soilanimals need pores in which to live and move so as to enhance the rate at which water flow into the soil (Varela et al., 1993). Changes in pore size distribution oftencreate problems for soil reactions and vegetation growth. Theproportion of pores between 0.2 μm and 60 μm is also important because these poresenhance the movement of water and also hold water against gravity that is also available to plants (Naeth et al., 1991).

2.5.3.3 *Soil fluid (fluid density)*

Inrelation to the soil fluid, the important properties include fluid density and fluid viscosity (Regalado and Munōz-Carpena, 2004). Generally, ground water fluids are affected by dissolved solids, dissolved gases, compressibility and temperature.

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These conditions cause density variations in ground water and result in a heterogeneous fluid. Dissolved solids and fluid compressibility increases density, whereas dissolution of gases and thermal expansion caused by increased heat content reduce density. Viscosity is a term for the ease of a fluid to flow especially crude oil. As density increases, the ease of movement of water (viscosity) through the rock or sediment decreases which in turn increase the hydraulic conductivity of the material especially in petroleum.http://Nevada.usgs.gov/barcass/articles/Ely13.pdf. Therefore, density and viscosity can alter the hydraulic conductivity of the soil.

2.6 Soil Groups

Three major soil groups are found in Imo and Abia states. These are ferralitic soils covering about 61% of the area; the hydromorphic soils which cover about 31%; and the alluvial soils covering 8% (Madubuike, 1999). Eleven soil sub-groups were identified within these three major groups in Imo and Abia States (Appendix A).

2.6.1 Ferralitic soils

Any one of a group of soils that form in the humid areas as the result of chemical weathering (accompanied by decomposition of most of the primary minerals, except quartz, and accumulation of secondary minerals, such as kaolinite, goethite, and gibbsite) and by the accumulation of humus beneath forest vegetation is termed Ferralitic soil (Brevik, 2002). Ferralitic soils exhibit a low cation exchange capacity and high anion absorptive capacity, a soil profile that is primarily red and patchy yellow-red, and a strong acid reaction. Fulvic acids predominate in the composition of the humus. The profile of ferralitic soils reveals an upper humus horizon ranging from 1–1.5 to 8–10 percent humus; the structure of the middle section differs for different subtypes, but it generally shifts gradually from the humus horizon to parent rock. The profile also exhibits eluvial and illuvial horizons, concretions of manganese and aluminium, various forms of laterite, and gleying. They are suitable for the cultivation of rice, coffee trees, rubber trees, cacao, sugarcane, and oil palms. Ferralitic soils are sometimes called lateritic soils.

2.6.2 Hydromorphic soils

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These are soilshavingcharacteristics that are developed when there is excess water all or part of the time.They are a suborder of intrazonal soils; consisting of great soil groups all formed under conditions of poor drainage in marshes, swamps, seepage areas, or flats (Brevik, 2002). Infact, hydromorphic soils are formed in wetland conditions.There are two sub-types: Gley soils - These occur when the pore spaces between the grains become saturated with water and contain no air thereby resulting in low hydraulic conductivity of water. This lack of oxygen leads to anaerobic conditions which reduce the iron in the parent rock. This gives the soil a characteristic grey/blue colour with flecks of red. Peat soils are formed under circumstances that prevent the breakdown of vegetation completely resulting in low infiltration rate(Stanley et al., 1997). Hydromorphic soil because of the topography low-lying and poor drainage, the upper section often accumulateshumus or peat and lower gleying characteristics. Usually the peat layer thickness is less than 50 cm called Swamp soil.

2.6.3 Alluvial soils

The term "alluvium" is typically used in situations where the formation of the sediment cannot clearly be attributed to another geologic process that is well described but rather their attractive dwelling sites on river levees and higher parts in marine landscapes were recognized in prehistoric times and they are characterized by low infiltrationrate due to its flooding nature (Stanley et al., 1997). Most sedimentary material that fills a basin that is not lithified is typically lumped together in the term alluvial. Alluvial soils;Egbema soil, Eutric Fluvisol (FAO1996 classification) under natural conditions periodical flooding is fairly common, Bende soil (Dystric Cambisol) have very low conductivity due to the fine nature of the soil, etc. The soils have a clear evidence of stratification which results in varying rate of hydraulic conductivity of water within the depths and can contain many valuable ores such as gold and platinum and a wide variety of gemstones. Such concentrations of valuable ores are termed a placer deposit (Brevik, 2002). Most Fluvisols are wet in all or part of the profile due to stagnating groundwater and/or flood water from rivers or tides. Many clayey Fluvisols have few pores and low hydraulic conductivity (Stanley et al., 1997).

2.7 Modelling

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A model may be defined as a simplified version of a real-world system (here, water movement system) that approximately simulates the system. When studying models, it is helpful to identify broad categories of models and classification of individual models into these categories tells us immediately some of the essentials of their structure (Fukshansky, 1992). One division between models is based on the type of outcome they predict. Deterministic models ignore random variation, and so always predict the same outcome from a given starting point. On the other hand, the model may be more statistical in nature and may predict the distribution of possible outcomes. Such models are said to be stochastic. A second method of distinguishing between types of models is to consider the level of understanding on which the model is based. Modelling can also refer to the process of generating a model as a conceptual representation of some phenomenon. Typically a model will refer only to some aspects of the phenomenon in question and two models of the same phenomenon may be essentially different. The difference or differences between them is more than just a simple renaming of components due to the type used by the modeller. Also, Modelling can mean the process of creating abstract or conceptual model and the use of objects in the creation of a predictive statement (Scientific modelling). Modelling involves abstraction, simplification, and formalization, in light of particular methods and assumptions, in order to better understand a particular part or feature of the world, and to potentially intervene (Tom, 2012). A scientific model seeks to represent empirical objects, phenomena, and physical processes in a logical and objectiveway. All models are simplified reflections of reality but despite their inherent falsity because of some that involve making some assumptions, they are nevertheless extremely useful. Building and disputing models is fundamental to the Engineering world and in other fields of life. Predictions or other statements drawn from such a formal system mirror or map the real world. Differences in modelling may be due to differing requirements of the model's end users, or to conceptual or aesthetic differences among the modellers and to contingent decisions made during the modelling process (Fukshansky, 1992). Generally, there are different types of modelling but the ones relevant to Engineering are discussed briefly below.

2.7.1 Mathematical modelling

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A mathematical model is an abstract model that uses mathematical language to describe the behaviour of a system. Mathematical models can take many forms including but not limited todynamical systems, statistical models, differential equations, or game theoretic models. Mathematical models are used not only in the natural sciences (such as physics, biology, earth science, meteorology) and engineering disciplines (computer science, artificial intelligence), but also in the social sciences (such as economics, psychology, sociology and political science); physicists, engineers, statisticians, operations research analysts and economists use mathematical models (Colette, 1993).

2.7.2 Statistical modelling

Statistical modelling is a set of mathematical equations which describe the behaviour of an object of study in terms of random variables. Statistics generally is the study of the collection, organization, analysis, interpretation, and presentation of data. It deals with all aspects of this, including the planning of data collection in terms of the design of surveys and experiments. This method can also be called mathematical statistics which models mathematically (Breiman, 2001). A common goal for a statistical research project is to investigate causality, and in particular to draw a conclusion on the effect of changes in the values of predictors or independent variables on dependent variables or response (Dawson-Saunders and Trapp, 1994). There are two major types of causal statistical studies: experimental studies and observational studies. In both types of studies, the effect of differences of an independent variable (or variables) on the behaviour of the dependent variable are observed. The difference between the two types lies in how the study is actually conducted and each can be very effective. An experimental study involves taking measurements of the system under study, manipulating the system, and then taking additional measurements using the same procedure to determine if the manipulation has modified the values of the measurements. In contrast, an observational study does not involve experimental manipulation. Instead, data are gathered and correlations between predictors and response are investigated. Some well-known statistical tests and procedures are: Analysis of variance (ANOVA), Chi-squared test, Correlation, Factor analysis, Mann–Whitney U, Mean square weighted deviation(MSWD), Pearson product-moment correlation coefficient, Regression

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analysis, Spearman's rank correlation coefficient, Student's t-test, Time series analysis.

2.7.3 Method of statistical analysis

The "SPSS, Statistical Package for the Social Sciences" which is a Statistical software for data analysis in Statistical modelling (Breiman, 2001) used generally for correlation and regression analysis of variables because the programme is extensively documented, uses simplified data entry and transformation procedures, and allow wide flexibility in choice of analysis method. SPSS input provides for user choice of total number of variables to be used, F-levels to enter or remove variables, and tolerance levels.

Output provided by SPSS is statistically complete, providing at each step coefficients of determination and correlation, regression coefficients, analysis of variance, the F-statistics, and level of significance for the total regression and each variable entered. Significance and tolerance levels for variables not selected for entry into the regression equation are also listed. Options are available that provide for comparison of actual and predicted values with graphical plotting of the residuals, calculations and tabular presentation of 95% confidence intervals for regression coefficients, and other desired statistical information (Warne et al.,2012). A table providing a summary of the entered variables, their correlation coefficients, F-level, and significance is a standard feature of the output.

2.7.3.1 *Correlation and regression analysis*

Correlation and regression are statistical methods that are commonly used to compare two or more variables. Although frequently confused, they are quite different. Correlation measures the association between two variables and quantities the strength of their relationship. Correlation evaluates only the existing data. Regression uses the existing data to define a mathematical equation which can be used to predict the value of one variable based on the value of one or more other variables and can therefore be used to extrapolate between the existing data. The regression equation can therefore be used to predict the outcome of observations not previously seen or tested http://www.non-linear regression.com.

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- Correlation

Correlation provides a numerical measure of the linear or "straight-line" relationship between two continuous variables X and Y. The resulting correlation coefficient or "r value" is more formally known as the Pearson product moment correlation coefficient after the mathematician who first described it. X is known as the independent or predictor variable while Y is known as the dependent or criterion variable. A significant advantage of the correlation coefficient is that it does not depend on the units of X and Y and can therefore be used to compare any two variables regardless of their units (Wassertheil-Smoller, 1990). An essential first step in calculating a correlation coefficient is to plot the observations in a scattergram or scatter plot to visually evaluate the data for a potential relationship or the presence of outlying values. It is frequently possible to visualize a smooth curve through the data and thereby identify the type of relationship present. The independent variable is usually plotted on the X-axis while the dependent variable is plotted on the Y-axis. A "perfect" correlation between X and Y has an r value of 1 (or -1). If X and Y are not related at all (i.e., no correlation) their r value is 0, and we would conclude that X is responsible for none of the change in Y. The square of the r value known as the coefficient of determination or R^2 describes the proportion of change in the dependent variable Y which is said to be explained by a change in the independent variable X. If two variables have an r value of 0.40, for example, the coefficient of determination is 0.16 and we state that only 16% of the change in Y can be explained by a change in X. The larger the correlation coefficient, the larger the coefficient of determination and the more influence changes in the independent variable have on the dependent variable. The calculation of the correlation coefficient is mathematically complex, but readily performed by most computer statistics programs such as Excel, Statistical Package for Social Science, SPSS etc.

- Regression

Regression analysis mathematically describes the dependence of the Y variable on the X variable and constructs an equation which can be used to predict any value of Y for any value of X (Draper and Smith, 1998). It is more specific and provides more information than correlation does. Unlike correlation, however, regression is not scale independent and the derived regression equation depends on

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the units of each variable involved (Choy, and Taniguchi, 2001). In addition to deriving the regression equation, regression analysis also draws a line of best fit through the data points of the scattergram. These "regression lines" may be linear in which case the relationship between the variables fits a straight line or nonlinear in which case a polynomial equation is used to describe the relationship. Regression (also known as simple regression, linear regression, or least squares regression) fits a straight line equation of the following form to the data as shown in Eqn. 2.8.

$$Y = a + bX \qquad 2.8$$

Where Y is the dependent variable, X is the single independent variable, 'a' is the Y-intercept of the regression line, and b is the slope of the line also known as the regression coefficient. Once the equation has been derived, it can be used to predict the change in Y for any change in X. It can therefore be used to extrapolate between the existing data points as well as predict results which have not been previously observed or tested.

Simple linear regression and correlation

Brown (1990) stated that for the simple linear regression to be applicable, the following conditions must hold: There is only one independent variable Q affecting the dependent variable P and the relationship between P and Q is known, or can be assumed as shownbelow in Eqn. 2.9.

$$P = a + bQ \qquad 2.9$$

Multiple linear regression and correlation

Multiple linear regressions are used as in the case of this study when there is more than one independent variable to explain changes in the dependent variable in a linear form (Brown, 1990). If not in linear form, it is called multiple nonlinear regression. The equation for multiple linear regression takes the form as shown in Eqn. 2.10.

$$Y = a + b_1X_1 + b_2X_2 + ... + b_nX_n \qquad 2.10$$

Where a = the Y intercept, and b_1 through b_n are the regression coefficients for each of the independent variables X_1 through X_n.

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Once the multiple regression analysis is completed, the regression coefficients can be ordered from smallest to largest to determine which independent variable contributes the most to changes in Y. Multiple linear regression is thus most appropriate for continuous variables where we wish to identify which variable or variables is most responsible for changes in the dependent variable. A computerized multiple regression analysis results in the regression coefficients (or "regression weights"), the standard error of each regression coefficient, the intercept of the regression line, the variance of the residuals, and a statistic known as the coefficient of multiple determination or "multiple R" which is analogous to the Pearson product moment correlation coefficient "r". It is utilized in the same manner as the coefficient of determination (R^2) to measure the proportion of change in Y which can be attributed to changes in the independent variables (X_1...X_n) (Brown, 1990). Multiple regression analysis is readily performed by computer programs due to its complicated and tedious computations and can be performed in several ways.

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CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of the study area

The study was conducted in Imo and Abia States. Imo and Abia States are bounded by the west by River State, on the north by Anambra states and on the south by Cross River state as shown in Appendix A. Imo state is located between latitude 4°45′N and 7°15′N and longitude 6°50′E and 7°25′E with an area of about 5,100km^2. Imo State of the southern Nigeria lies within the humid tropics and generally characterized by a high surface air temperature regime all year-round. Current mean maximum temperature is 32.1^{O}C while the current minimum temperature is 23.5^{O}C (Nnaji, 2009). Two seasons, wet and dry are observed in the year. The rainy seasons begins in April and lasts till October. Double maxima, with the first in June and the second in September also characterized the climate. There is thus a little dry season in between known as "August break" brought about by the seasonal north and southward movement of the inter-tropical convergence zone.Imo State has 27 Local Government Council with 3 major political zones namely, Okigwe (Imo North), Orlu (Imo West) and Owerri (Imo East) where as Abia state has 17 local government areas as shown in Appendix A. Abia state is dominated by flat and low-lying land generally less than 120m above sea level. The central part of Abia state is characterised by undulating land with many hills and soils having moderate to low hydraulic conductivity (Nnaji, 2009).

Generally, three major soil groups are found in Imo and Abia states: ferralitic soils covering about 61% of the area; the hydromorphic soils which cover about 31%; and the alluvial soils covering 8% (Madubuike, 1999). Eleven soil sub-groups were identified within these three major groups in Imo and Abia States (Madubuike, 1999). These eleven soil sub-groups (FAO classification) and their locations are Abia state; Akwete (Dystric Nitosol), Isuochi (Dystric Nitosol), Igbere (Rhodic Ferralsol), Bende (Dystric Cambisol), IsiekeIbeku (Dystric Gleysol), Aba (Dystric Ferralsol) and Imo State; Egbema (Eutric Fluvisol), Owerri (Dystric Ferralsol), Okwelle (Orthic Acrisol), Umuna (Eutric Gleysol), Orlu (Eutric Nitosol) as indicated in Appendix B.

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Vereecken (1995) stated thatNitosols are acid soils with a very thick layer of fine particles of clay accumulation which makes it to have low hydraulic conductivity. They are one of the best and most fertile soils in Africa. They can suffer acidity and sodium fixation, and when organic carbon from organic matter content decreases, they become very erodible. But erosion has only slight effect on crops planted on it. Majority of Ferralsol soils such as Dystric Ferralsol and Rhodic Ferralsol are highly weathered soils rich in sesquioxide clays and with low cation exchange capacities and high hydraulic conductivity.Ferralsols are the classic red soils of the groups because of high iron. They have low supply of plant nutrients and are not therefore impacted greatly by erosion and they have strong acidity. With very few reserves of available minerals and easily lost topsoil organic matter, Ferralsols have low resilience and moderate sensitivity.Acrisols are fairly acidic soils with a layer of clay accumulation (Vereecken 1995). They are also characterized by low cation exchange capacity. Gleysols are fairly water saturated soils that are not salty that have moderate infiltration rate.Cambisols are soils with slight profile development comprising more of finer particles that is not dark in colour with a very low infiltration rate.

3.2 Sampling Procedure

Materials used include: core sampler, matchet, hoe, polyethylene bags, masking tape and permanent marker. Sampling was done in all the eleven (11) locations of the soil subgroups (Appendix B) within Imo and Abia states from the month of February to March. After clearing the desired site with matchet, separate soil samples of about 3kg by weightwere taken randomly from seven different pits in each location not less than 10meters distance apart from each other by driving a cylindrical iron core sampler into the soil to a depth of 15cm. No special technique was taken in collecting the samples rather, soils from the same pit were mixed very well so as to get a representative sample and areas close to roads, houses, farm lands, rocks etc were avoided. The soil samples were properly bagged withpolyethylene bags of size 26cm by 19cm, labelled with masking tape using a permanent ink marker and taken to the laboratory for the required analyses as shown in Plate 3.1. Distilled water was used in conducting the hydraulic conductivity for the soil subgroups (locations). All the soil samples were air dried

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Plate 3.1: Soil samples bagged

Plate 3.2:Air drying the soilsamples

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for six days in the laboratory as shown in Plate 3.2 by spreading them on flat forms except for the parts utilized for the determination of hydraulic conductivity of soils, which were air dried for 24hours only (about 1kg of soil from each location).

3.3 Data generation for the model

Soil sampling, being a very important step of the analytical procedure, was given adequate precautions so as to avoid wrongly taken results that will not reflect the real conditions. The required experiments for the generation of the raw data for all the soil properties were done as stated below.

3.3.1 Hydraulic conductivity

One kilogram of air dried (24hours drying) soil samples from each pit were taken to the laboratory mixed with about 500g of water and left to stand for 24hours and using the falling head permeameter; the individual parameters for determining the hydraulic conductivities were got (Appendix C), hydraulic conductivities calculated using the formula Eqn. 3.1 (Dirksen, 1991)below and results recorded appropriately.

$$K = \left(\frac{aL}{At}\right)\ln\left(\frac{H_1}{H_2}\right) \quad 3.1$$

A= Cross-sectional area of the cylindrical soil column, cm^2

L=length of soil column, cm

a=cross-sectional area of the burette through which the percolating fluid is introduced into the system, cm^2

H_1 = initial head of water in the burette, cm

H_2=final height of water, cm

t = time taken to get a head loss, seconds.

The values of A, a,H_1, H_2, L and t are tabulated in Appendix C.

3.3.2 Soil pH

The materials and reagents used include: 2mm sieve, mechanical sieve shaker, 100ml beaker, digital electronic pH meter, distilled water, air dried soil

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samples, electronic weighing balance and stirrer. 20 grams of air dried soil sample was collected and used in conducting the soil pH afterusing a mechanical sieve (bore size: 2mm) shaker to sift the soil samples.The 20grams of air dried soil sample was put into 100ml beaker and 20grams of distilled water was added making the soil-water ratio to be 1:1 and thewhole solution is stirred for about 3minutes. The solution is left to stand and settle for about 6hrs before the glass electrode of the pH meter is immersed deep enough in the clear solution on top of the suspension so as to read and record the result shown on the pH meter. Theexperiments (Plate 3.3) for the seventy seven samples for the soil sub-groupswere conducted and results were recorded appropriately.

Plate 3.3: Experimental approach for the electronic pH determination method

3.3.3 Organic matter content

Organic carbon was determined using Walkley-Black wet oxidation method procedure (Nelson and Sommers, 1996). Materials and reagents used include: Electronic weighing balance, 250ml conical flask, asbestos sheet, air dried soil samples, potassium dichromate vii ($K_2C_{r2}O_7$), concentrated hydrogen tetraoxosulphate vi (conc. H_2SO_4), distilled water, ferroin indicator, Iron (11) tetraoxosulphate vi(fe^{2+}) and ferrous sulphate.

Half grams of soil was crushed to a fine material and put in duplicate into 250ml conical flask. Ten millilitres of 0.167 mole of $K_2C_{r2}O_7$ and 20ml of conc. H_2SO_4

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was added rapidly and immediately the flask was gently swirled until the soil and reagents are mixed. The flask was rotated again gently and allowed to stand on a sheet of asbestos for about 30minutes after adding 100ml of distilled water. Four drops of ferroin indicator was added, titrated with 0.5mole of fe^{2+} and immediately the solution takes a greenish cast and then changes to dark green. Then, the ferrous sulphate was added drop by drop until colour changes sharply from green to brownish red. The procedure was repeated for the blank titration without soil sample. The $K_2C_{r2}O_7$ oxidizes the carbon and the excess $K_2C_{r2}O_7$ is titrated with the Iron (11) solution. In wet oxidation method, all the organic carbon is oxidized. Some resistant group such as ring-compounds (compounds in which their ring itself contain just carbon atoms) are only slightly attacked. Assume that an average of 75% of the total organic carbon is attacked and the amount calculated from the titration is multiplied by 100/75 (1.33) to give % organic carbon corrected. It is also assumed that soil organic matters contain 58% of carbon and can be expressed as % organic carbon multiplied by 100/58 (1.724). The percentage organic carbon is calculated using Eqn. 3.2 (Ibitoye, 2008), where 1ml 0.167 mole of $K_2C_{r2}O_7$ is equal to 0.003grams of carbon (Ibitoye, 2008).

$$\% \text{ Organic Carbon} = (B - T) \times M \times 0.003 \times 1.33 \times 100/wt \qquad 3.2$$

Where; wt = Weight of soil sample, 0.5g

B = Blank titre value, 21ml

T = Sample titre value, 14.67ml

M = Molarity of $(NH_4)2fe\ (SO_4)6H_20$, 0.48M

= ie actual concentration of fe^{2+}

The results were recorded (Appendix D) after the experiments were donefor the seventy seven samples from the soil sub-groups.

3.3.4 Particle size

Particle size distribution of less than 2mm fractions was determined using hydrometer method (Ibitoye, 2008). The following materials and reagents were used; 250ml beaker, sieve, weighing balance, standard hydrometer with scale in gram/l, stirrer, sedimentation cylinder, thermometer, distilled water and calgon $(N_aPO_3)_6$.

Hundred millilitre of calgon solution was added into a 250ml beaker containing 50grams of 2mm sieved air dried soil sample and stirred for about 3minutes. The whole suspension was transferred into a sedimentation cylinder and filled to the maximum mark with distilled water having the hydrometer immersed in it. After stirring again thoroughly, the hydrometer is lowered carefully into the suspension and hydrometer reading taken after 40seconds as R_{40s} and the temperature, R_e of the suspension read using a thermometer. The R_{40s} reading was taken simultaneously by two attendants and the readings are taken to ensure that a reliable reading has been obtained. After 2hours, the hydrometer reading was taken again as R_{2hrs} as well as the temperature, R_d and all were recorded appropriately. After 40seconds, all the sand would have settled and silt and clay remaining in suspension. The hydrometer stem reads directly in grams of soil/litre of suspension. The procedure was repeated for the blank solution without soil sample and readings taken as R_a for 40seconds and R_b for 2hours. To correct the hydrometer reading for temperature, add 0.36g/l for every 1°c above 20 °c and subtract 0.36g/l for every 1°c below 20°c (Ibitoye, 2008).

Finally, the formulas below Eqns. 3.4 - 3.6 (Ibitoye, 2008) were used to calculate the %clay, %silt and %sand respectively.

$$\%\,Clay + Silt = \left[\frac{(R_{40s} - R_a) + R_e}{wt}\right] \times 1003.4$$

$$\%\,Clay = \left[\frac{(R_{2hrs} - R_b) + R_d}{wt}\right] \times 100 \qquad 3.5$$

$$\%\,Sand = 100 - \%(Clay + Silt) \qquad 3.6$$

Where,

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R_{40s} and R_{2hrs} = hydrometer reading after 40 seconds and 2hours, grams

R_a and R_b= 40seconds and 2hours blank hydrometer reading, grams

R_e and R_d = Temperature readings of the suspension, °c for 40seconds and 2hours

wt = weight of soil sample, grams

Finally with the results (Appendix D), the textural classes were determined using textural triangleshown in Appendix E.

3.3.5 Particle density

Particle density was determined using specific gravity bottle, pycnometer (Ibitoye, 2008): Materials used include: specific gravity bottle, weighing balance, stirrer, thermometer, distilled water. An empty, clean dry 50ml specific gravity bottle was weighed as W_a; known quantity of air dried soil was poured inside it and weighed as W_s. Distilled water previously boiled and cooled in other to remove gas was used to fill the bottle containing the soil gently so as to remove air between the particles and weighed as W_{sw}. The temperature of the contents was determined after thorough stirring. Finally, the content of the bottle was removed; the bottle filled with boiled, cooled distilled water at the same temperature with that obtained previously and weighed as W_w. The procedure was taken for all the seventy seven samples involved and recorded appropriately. Equations 3.7 and 3.8(Ibitoye, 2008) were used to obtain density of water and soil particle density respectively.

Density of water, $d_w = \frac{W_w - W_a}{50}$ 3.7

Particle density, $D_p = \frac{d_w(W_s - W_a)}{(W_s - W_a) - (W_{sw} - W_w)}$ 3.8

3.3.6 Exchangeable calcium and magnesium

Exchangeable calcium and magnesium determinationwas determined using EDTA titration method (Ibitoye, 2008). Materials and reagents used include: 250ml conical flask, pipette, deionized water, conc. ammonia (Buffer), potassium cyanide (KCN) as masking agent, Hydroxyl ammonium chloride ($OHNH_3CL$), eriochrome black T indicator, 0.01 mole EDTA. Soil sample of about 10ml was pipette into 250ml

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conical flask as V_2, 100ml of deionized water added and 15ml of conc. ammonia solution included. Ten drops of 2g KCN with 100ml deionized water was added as a masking agent (It is a reagent that decreases the concentration of a free metal ion to a level where it can no longer react with the titrant. That is, one or more of the cations in the mixture is masked so that no reaction occurs with either EDTA or the indicator. For example, cyanide ions in KCN forms stable complexes with such cations as Cu^{2+}, Co^{2+} and that is why it is possible to estimate quantitatively calcium in the presence of other metal ions) and 10 drops of 5g of Hydroxyl ammonium chloride ($OHNH_3CL$) is also added together with 5 drops of Eriochrome black T indicator. The solution was titrated with 0.01 mole EDTA from wine red to deep blue point. The titration was repeated and the mean value, T calculated.

*Determination of only Calcium:*Ten millilitre of sample was pipette into a 250ml conical flask as V_2, 100ml of deionized water added together with 100ml of 20g of KOH. Also, 10 drops of 2g of KCN was added to the solution followed by 10 drops of 5g hydroxyl ammine hydrochloride ($OHNH_2HCL$). A pinch of calcine indicator was added into the solution and then the solution was titrated with 0.01 mole EDTA from wine red to deep blue. The titration was repeated and the mean value, T calculated. Equation 3.9 (Ibitoye, 2008) gives the calcium ion content, C_a while Eqn. 3.10(Ibitoye, 2008) gives the magnesium ion content, M_a. Sum of them gives the total cation in the soil.

Calcium, $^{Mg}/_{100g} = T \times mol\ of\ EDTA \times \frac{V_1}{V_2} \times \frac{100}{w}$ 3.9

$\mathrm{M_g} = (C_a + \mathrm{M_g}) - C_a$ 3.10

3.3.7 Bulk density

Bulk density, D_b was determined using the core method (Grossman and Reinsch, 2002). Materials used include: core sampler, knife, weighing balance. The core sampler was driven vertically into the soil to 15cm depth so as to fill the sampler with soil and later, it was removed carefully from the hole so as to get an undisturbed soil sample insitu. After trimming the soil extending from both ends of the sampler with a knife, the weight of the sampler when empty and its weight with the soil sample was recorded as W_1 and W_2. The volume of the soil sample which is the same as the

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volume of the core sampler was calculated using the formula, $V = \pi r^2 h$. Where, h and r are the height and radius of the core sampler. Bulk density is calculated using Eqn. 3.11(Ibitoye, 2008).

$$\text{Bulk density, } D_b = \frac{\text{Mass of soil}}{Volume\ of\ soil}\ {}^{g}/_{cm^3} \qquad 3.11$$

3.3.8 Porosity

Porosity is determined using Eqn. 3.12(Ibitoye, 2008)

$$\left[\left(1 - {}^{D_b}/_{D_p}\right) \times 100\right] \% \qquad 3.12$$

D_p = particle density,g/cm^3 (Eqn. 3.8)

D_b = bulk density, g/cm^3 (Eqn. 3.11)

3.3.9 Fluid density

Fluid density was determined using the following materials; Electronic weighing balance, graduated cylinder, 1.5litre plastic cans. The weight of an empty graduated cylinder and its weight when 250cm^3 volume, V of water from the sampling sites is poured inside it was read and recorded as W_a and W_w. The densities, D_f of the water were determined using the formula Eqn. 3.13(Ibitoye, 2008).

$$D_f = W_w - W_a/V \qquad 3.13$$

3.4 Experimental Design

The experiment was designed using the Randomized Complete Block Design (RCBD).The design is intended for experiments where there is significant variation in the area or environment (for example, laboratory or greenhouse experiments). The variation in the condition of the experimental area in the RCBDmay be due to the soil itself (for example soil type, fertility), slope or gradient, wind direction, water direction, etc. The blocking utilized in this research work was based on the soil sub-groups whereas the major treatments considered are:-Hydraulic conductivity, Soil

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pH, Particle density, Bulk density, Organic matter content, Exchangeable sodium, Cation exchange capacity, % Clay, % sand, % silt and Porosity.

In each block, each treatment was investigated seven (7) times and the average value was taken as the representative mean for each treatment. The design experiment in the form of RCBD is as shown in Table 3.1.

Table 3.1 Experimental Design/Planning

TREATMENT / BLOCKS	K	%Cl	%Si	%S	P	D_b	D_p	CEC	pH	ESP	OMC
Egbema	T_1B_1	T_2B_1	T_3B_1	T_4B_1	T_5B_1	T_6B_1	T_7B_1	T_8B_1	T_9B_1	$T_{10}B_1$	$T_{11}B_1$
Owerri	T_1B_2	T_2B_2	T_3B_2	T_4B_2	T_5B_2	T_6B_2	T_7B_2	T_8B_2	T_9B_2	$T_{10}B_2$	$T_{11}B_2$
Okwele	T_1B_3	T_2B_3	T_3B_3	T_4B_3	T_5B_3	T_6B_3	T_7B_3	T_8B_3	T_9B_3	$T_{10}B_3$	$T_{11}B_3$
Umuna	T_1B_4	T_2B_4	T_3B_4	T_4B_4	T_5B_4	T_6B_4	T_7B_4	T_8B_4	T_9B_4	$T_{10}B_4$	$T_{11}B_4$
Orlu	T_1B_5	T_2B_5	T_3B_5	T_4B_5	T_5B_5	T_6B_5	T_7B_5	T_8B_5	T_9B_5	$T_{10}B_5$	$T_{11}B_5$
Akwete	T_1B_6	T_2B_6	T_3B_6	T_4B_6	T_5B_6	T_6B_6	T_7B_6	T_8B_6	T_9B_6	$T_{10}B_6$	$T_{11}B_6$
Bende	T_1B_7	T_2B_7	T_3B_7	T_4B_7	T_5B_7	T_6B_7	T_7B_7	T_8B_7	T_9B_7	$T_{10}B_7$	$T_{11}B_7$
Isieke Ibeku	T_1B_8	T_2B_8	T_3B_8	T_4B_8	T_5B_8	T_6B_8	T_7B_8	T_8B_8	T_9B_8	$T_{10}B_8$	$T_{11}B_8$
Aba	T_1B_9	T_2B_9	T_3B_9	T_4B_9	T_5B_9	T_6B_9	T_7B_9	T_8B_9	T_9B_9	$T_{10}B_9$	$T_{11}B_9$
Isuochi	T_1B_{10}	T_2B_{10}	T_3B_{10}	T_4B_{10}	T_5B_{10}	T_6B_{10}	T_7B_{10}	T_8B_{10}	T_9B_{10}	$T_{10}B_{10}$	$T_{11}B_{10}$
Igbere	T_1B_{11}	T_2B_{11}	T_3B_{11}	T_4B_{11}	T_5B_{11}	T_6B_{11}	T_7B_{11}	T_8B_{11}	T_9B_{11}	$T_{10}B_{11}$	$T_{11}B_{11}$

3.5 Model building and validation

Each soil property was related to the measured hydraulic conductivity by simple correlation and multiple correlation analyses. The correlation coefficients were checked for significance usingIBM SPSS software (version 20)in order to determine the order of inclusion of the variables during model building. The soil properties were also checked for multicolinearity because it describes the situation where a high correlation exist between two or more independent variables and such high correlations cause problems when trying to draw inferences about the relative contribution of each independent variables to the success of the model.

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The models were then developed using dimensional analysis and the stepwise regression method in the statistical package. In stepwise regression method, each variable is entered in sequence and assessedusing the observed coefficient of determination (R^2) and adj. R^2. If adding a variable increases the $R^2$and adj. R^2values of the model, then it is retained but all other variables in the model are re-tested to see if they are still contributing to the success of the model. If they no longer contribute significantly, they are removed. This method ended up in giving the smallest possible set of soil properties one needed to measure so as to predict hydraulic conductivity within the studied soil subgroups. Note that out of the eleven (11) soil subgroups, only eight (8) were used in model building comprising of seven replications for each soil subgroup and the remaining three (3) were used in testing the model by using the models to predict them.

Validating was done by using the actual values of the soil properties from the remaining three locations (soil sub-groups) to predict their hydraulic conductivity, K values.Their predicted k-values were compared with the actual k-values so as to ascertain the percentage of error in the values.

3.6 Dimensional Analysis of the Model

Dimensional analysis was utilized in the model after choosing the major properties of importance influencing hydraulic conductivity of agricultural soils and using them to predict the kind of relationship between them and hydraulic conductivity based on the fundamental dimensions of mass (M), length (l) and time (T).

The influencing factors were considered for the model:

i. Physical factors/properties: grain size distribution, particle density, bulk density, porosity, fluid density, acceleration due to gravity and soil depth.
ii. Biological factor/property: organic matter content.
iii. Chemical factor/properties: cation exchange capacity, exchangeable sodium percentage and soil pH.

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Table 3.2 shows the variables and their dimensions that would be used to develop the models.

Table 3.2Dimensions of the selected variables influencing soil hydraulicconductivity

S/N	Variables	Symbols	Unit	Dimensions
1.	Hydraulic conductivity	K	cm/sec	$M^0L^1T^{-1}$
2.	Soil pH	pH	%	$M^0L^0T^0$
3.	Acceleration due to gravity	G	cm/sec^2	$M^0L^1T^{-2}$
4.	Organic matter content	OMC	%	$M^0L^0T^0$
5.	Exchangeable sodium	ESP	%	$M^0L^0T^0$
6.	Cation exchange capacity	CEC	%	$M^0L^0T^0$
7.	Porosity	P	%	$M^0L^0T^0$
8.	Bulk density	D_b	g/cm^3	$M^1L^{-3}T^0$
9.	Particle density	D_p	g/cm^3	$M^1L^{-3}T^0$
10.	Fluid density	D_f	g/cm^3	$M^1L^{-3}T^0$
11.	Percentage sand	%S	%	$M^0L^0T^0$
12.	Percentage clay	%Cl	%	$M^0L^0T^0$
13.	Percentage silt	%Si	%	$M^0L^0T^0$
14.	Soil depth	H	cm	$M^0L^1T^0$

Before developing the model, the following assumptions were made:-

- The gravitational force is constant throughout the locations of the soil subgroups.
- Soil depth of 15cm remained constant throughout the sampling process.
- The ambient air temperature remains constant throughout the experimental area.

Based on the aforementioned assumptions, the dimensional analysis was determined using Burkingham pi theorem.

The hydraulic conductivity can be expressed in the form of Eqn. 3.14 as:-

$K = (pH, OMC, ESP, CEC, P, D_f, D_p, D_b, g, H, \%S, \%Cl, \%Si)$ 3.14

Or it can be expressed in Eqn. 3.15 as:-

$f_1(K, pH, OMC, ESP, CEC, P, D_f, D_p, D_b, g, H, \%S, \%Cl, \%Si) = 0$ 3.15

The total number of variables, n = 14 and number of fundamental dimensions,m = 3 is obtained by writing the dimensions of each variables as shown in Table 3.3 above.

Then, the number of dimensionless π–terms = n – m = 14 – 3 = 11.

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The dimensionlessπ–terms as deduced from Buckingham'sπ– theorem are shown in Eqn. 3.16:-

$$f_1\,(\pi_1,\ \pi_2,\ \pi_3,\ \pi_4,\ \pi_5,\ \pi_6,\ \pi_7,\ \pi_8,\ \pi_9,\ \pi_{10},\ \pi_{11}) = 0 \qquad 3.16$$

In the dimensional analysis, the eight dimensionless terms already observed from Table 3.2 are excluded but has to be added when the other dimensionless terms had been determined (Ndukwu and Asoegwu, 2011). These already observed dimensionless terms are: - pH, OMC, ESP, CEC, P, %S, %Cl, and %Si.

Determination of π_1, π_2, π_3, ..., and$\pi_{11}$is as shown in Appendix F.

Substituting the values ofπ_1, π_2, π_3, ..., andπ_{11} in Eqn. 3.16 gives Eqns. 17a – 17c:-

$$f_1\left[\frac{K}{\sqrt{gH}};\ \frac{D_b}{D_f};\ \frac{D_p}{D_f}; pH; OMC; ESP; CEC; P; \%S; \%Cl; \%Si\right] \quad 3.17a$$

Or

$$\frac{K}{\sqrt{gH}} = f\left[\frac{D_b}{D_f};\ \frac{D_p}{D_f}; pH; OMC; ESP; CEC; P; \%S; \%Cl; \%Si\right] \quad 3.17b$$

$$\Rightarrow \pi_1 = f(\pi_2;\ \pi_3;\ \pi_4;\ \pi_5;\ \pi_6;\ \pi_7;\ \pi_8;\ \pi_9;\ \pi_{10};\ \pi_{11}) \qquad 3.17c$$

Applying the rule of combination of dimensionless π terms to reduce it to a manageable level (Shefii et al., 1996; Ndukwu and Asoegwu, 2011) by multiplication and division gives the following Eqns. 3.18, 3.19 and 3.20:-

Combining $\pi_2 and\ \pi_3$by division gives Eqn. 3.18:

$$\pi_{23} = \pi_2^{-1} \times \pi_3 = \frac{D_f}{D_b} \times \frac{D_p}{D_f} = \frac{D_p}{D_b} \qquad 3.18$$

Dividing $\pi_4 by\ \pi_5$ gives Eqn. 3.19:

$$\pi_{45} = \pi_4 \times \pi_5^{-1} = \frac{pH}{OMC} \qquad 3.19$$

Dividing $\pi_6 by\ \pi_7$ gives Eqn. 3.20:

$$\pi_{67} = \pi_6 \times \pi_7^{-1} = \frac{ESP}{CEC} \qquad 3.20$$

Multiplying Eqns. 3.18, 3.19 and 3.20 gives Eqn. 3.21:

$$\Rightarrow \boldsymbol{\pi_2^a} = \pi_{23} \times \pi_{45} \times \pi_{67} = \frac{\boldsymbol{D_p \times pH \times ESP}}{\boldsymbol{D_b \times OMC \times CEC}} \qquad 3.21$$

Similarly,

Dividing $\pi_8 by\ \pi_9$ gives Eqn. 3.22:

$$\Rightarrow \pi_{89} = \pi_8 \times \pi_9^{-1} = \left(\frac{P}{\%S}\right) \qquad 3.22$$

`

Dividing $\pi_{11} by\ \pi_{10}$ gives Eqn. 3.23:

$$\Longrightarrow \pi_{10} = \pi_{10}^{-1} \times \pi_{11} = \left(\frac{\%Si}{\%Cl}\right) \qquad 3.23$$

Multiplying Eqns. 3.22 and 3.23 gives Eqn. 3.24:

$$\Longrightarrow \boldsymbol{\pi_3^a} = \pi_{89} \times \pi_{10} = \left(\frac{\boldsymbol{P\times\%Si}}{\boldsymbol{\%Cl\times\%S}}\right) \qquad 3.24$$

Reducing Eqn (3.17c) using the rule of combination, givesEqn. 3.25:

$$\Longrightarrow \boldsymbol{\pi_1} = f(\pi_2^a; \pi_3^a) \qquad 3.25$$

Where,

$$\boldsymbol{\pi_1} = \frac{\boldsymbol{K}}{\sqrt{\boldsymbol{gH}}};\ \boldsymbol{\pi_2^a} = \frac{\boldsymbol{D_p \times pH\times ESP}}{\boldsymbol{D_b\times OMC\times CEC}};\ \boldsymbol{\pi_3^a} = \left(\frac{\boldsymbol{P\times\%Si}}{\boldsymbol{\%Cl\times\%S}}\right)$$

Substituting in Eqn. 3.25, givesEqn. 3.26

$$\Longrightarrow \frac{\boldsymbol{K}}{\sqrt{\boldsymbol{gH}}} = \left\{\left[\frac{\boldsymbol{D_p\times pH\times ESP}}{\boldsymbol{D_b\times OMC\times CEC}}\right]; \left[\frac{\boldsymbol{P\times\%Si}}{\boldsymbol{\%Cl\times\%S}}\right]\right\} \qquad 3.26$$

And when K is made the subject, Eqn. 3.27 is got:

$$\boldsymbol{K} = \sqrt{\boldsymbol{gH}}\left\{\left[\frac{\boldsymbol{D_p\times pH\times ESP}}{\boldsymbol{D_b\times OMC\times CEC}}\right]; \left[\frac{\boldsymbol{P\times\%Si}}{\boldsymbol{\%Cl\times\%S}}\right]\right\} \qquad 3.27$$

Eqn. 3.27 is the developed model using dimensional analysis.

3.6.1 Prediction equation

The equation predicting hydraulic conductivity was established by allowing one term to vary at a time while keeping the other constant and observing the resulting changes in the function (Ndukwu and Asoegwu, 2011). This was established by plotting the values of π_1 against π_2^a; keeping π_3^a constant at an average value of 0.5151 and also plotting the values of π_1 against π_3^a; keeping π_2^a constant at an average value of 2.1104 as shown in Figs. 3.1 and 3.2 respectively. The table of values is presented in Appendix G.

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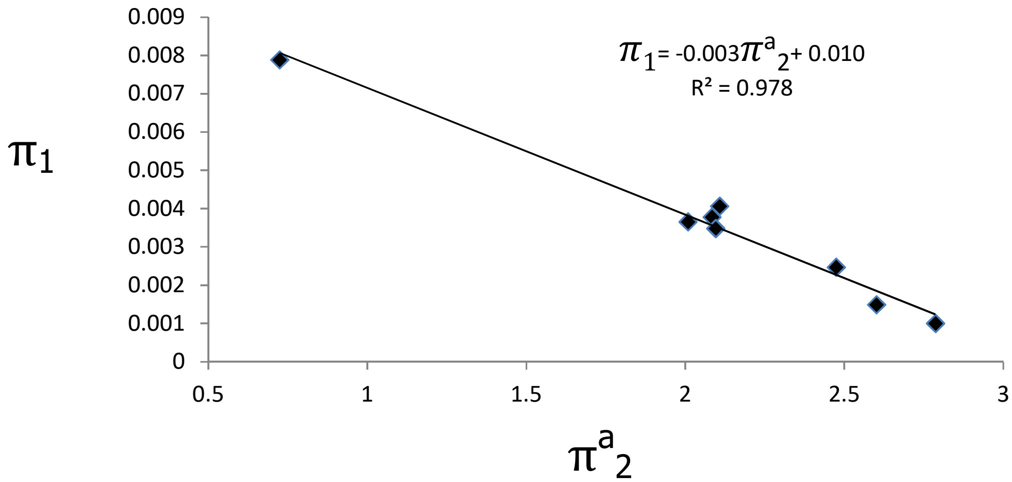

Fig. 3.1. Plot of π_1 against dimensionless π_2^a with π_3^a constant at average value of 0.5151

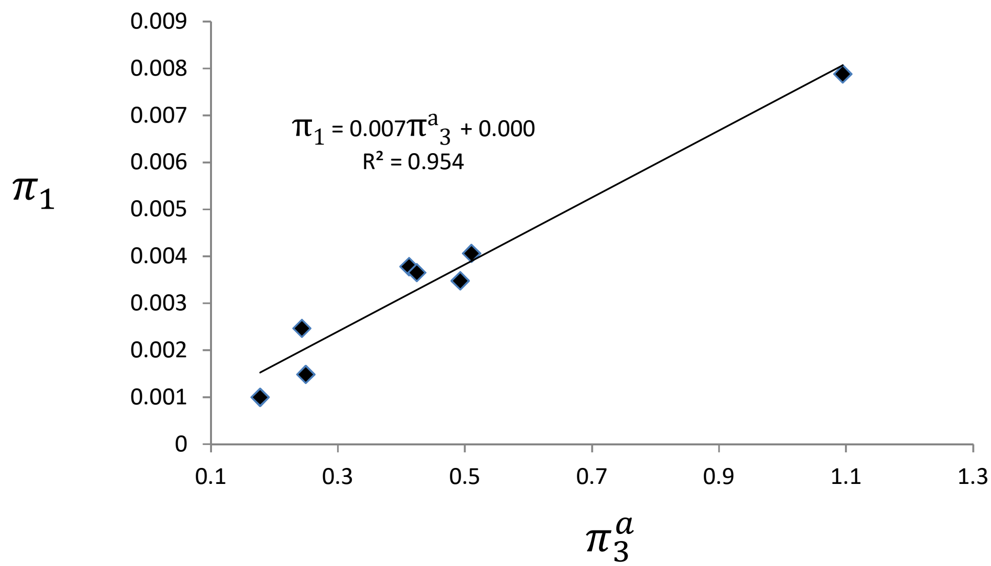

Fig. 3.2. Plot of π_1 against dimensionless π_3^a with π_2^a constant at average value of 2.1104

The linear equations are presented as shown in Eqns. 3.28 and 3.29 below with coefficient of determination, R^2 = 0.978 and 0.954 respectively.

$$\pi_1 = -0.003\pi_2^a + 0.010 \quad 3.28$$

$$\pi_1 = 0.007\pi_3^a + 0.000 \quad 3.29$$

`

Thus, from Figs. 3.1 and 3.2, the plot of the π terms forms a plane surface in linear space and according to Ndukwu and Asoegwu, 2011; it implies that their combination favours summation or subtraction. Therefore, the component Eqn. 3.30 is formed by the combination of Eqns. 3.28 and 3.29.

$$\Rightarrow \pi_1 = \frac{K}{\sqrt{gH}} = f_1(\pi_2^a; \pi_3^a) \pm f_2(\pi_2^a; \pi_3^a) + K \quad 3.30$$

Note;

At f_1; π_3^a was kept constant (0.5151) while π_2^a varies,

At f_2; π_2^a was kept constant (2.1104) while π_3^a varies.

The component Eqn. 3.30 formed gives Eqn. 3.31 below.

$$\frac{K}{\sqrt{gH}} = (-0.003\pi_2^a + 0.01) \pm (0.007\pi_3^a + 0.000) \quad 3.31$$

Subtraction combination gives Eqns. 3.32a

$$\boldsymbol{K_1} = (\boldsymbol{-0.003\pi_2^a - 0.007\pi_3^a + 0.01}) \times \left(\sqrt{\boldsymbol{gH}}\right) \quad 3.32a$$

Whereas addition combination gives Eqn. 3.32b

$$\boldsymbol{K_2} = (\boldsymbol{-0.003\pi_2^a + 0.007\pi_3^a + 0.01}) \times \left(\sqrt{\boldsymbol{gH}}\right) \quad 3.32b$$

Substituting the values of the dimensionless π terms from Eqns. 3.21 and 3.24 into Eqns.3.32a and 3.32b gives the general equations for hydraulic conductivity prediction using dimensional analysis:

Hence, the predicting equation using dimensional analysis gives Eqns. 3.33a and b:

$$\boldsymbol{K_1} = \left[\boldsymbol{-0.003}\left(\frac{\boldsymbol{D_p \times pH \times ESP}}{\boldsymbol{D_b \times OMC \times CEC}}\right) - \boldsymbol{0.007}\left(\frac{\boldsymbol{P \times \%Si}}{\boldsymbol{\%Cl \times \%S}}\right) + \boldsymbol{0.01}\right]\left[\sqrt{\boldsymbol{gH}}\right] \quad 3.33a$$

$$\boldsymbol{K_2} = \left[\boldsymbol{-0.003}\left(\frac{\boldsymbol{D_p \times pH \times ESP}}{\boldsymbol{D_b \times OMC \times CEC}}\right) + \boldsymbol{0.007}\left(\frac{\boldsymbol{P \times \%Si}}{\boldsymbol{\%Cl \times \%S}}\right) + \boldsymbol{0.01}\right]\left[\sqrt{\boldsymbol{gH}}\right] \quad 3.33b$$

Where,

$$\boldsymbol{\pi_2^a} = \frac{\boldsymbol{D_p \times pH \times ESP}}{\boldsymbol{D_b \times OMC \times CEC}}\ ;\ \boldsymbol{\pi_3^a} = \frac{\boldsymbol{P \times \%Si}}{\boldsymbol{\%Cl \times \%S}}$$

Eqns.3.33a and 3.33b give the prediction equation for hydraulic conductivity involving 12 parameters in different combinations using dimensional analysis.

3.7 Statistical Analysis of the Model

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The statistical method of analysis was done using a statistical software package called IBM Statistical Package for Social Sciences (SPSS). From the software, each soil property was related to the measured hydraulic conductivity by simple correlation and multiple correlation analyses. Correlation coefficients were checked for significance in order to determine the order of inclusion of the variables during model building. Also multicolinearity test was done for the soil properties.

Stepwise regression method was adopted in the software as each variable is entered in sequence and assessed using the observed coefficient of determination R^2 and adj. R^2. If adding a variable increases the R^2 and adj. R^2 values of the model, then it is retained but all other variables in the model are re-tested to see if they are still contributing to the success of the model. If they no longer contribute significantly, they are removed. This method would end up in giving the smallest possible set of soil properties needed for predicting hydraulic conductivity within the studied soil subgroups. Also,homogeneity of variance,Analysis of Variance (ANOVA) and Duncan's Multiple Range Tests were executed in the software and the test results were subjected to the hypothesis presented below prior decision making.

HYPOTHESIS ASSUMPTIONS FOR THE STUDY

H_o: Each property exhibits the same population mean and are not different from one another in the soil sub-groups of the study.

H_A: Each property exhibits at least a different population mean and are different from one another in the soil sub-groups of the study.

Zeger (1991) expressed a more generalizable form of the null and alternative hypothesis as:

$$H_o : \mu_{Between} \leq \mu_{Within}$$

$$H_1 : \mu_{Between} > \mu_{Within}$$

Where, $\mu_{Between}$ represents the mean between groups in the population and μ_{Within} represents the mean within groups. Thus when the mean between groups is significantly greater than the mean within groups, the null hypothesis is rejected.

`

The statistical methods used in developing SPSS software according to Wacker, 2011 are:-

- *Sample Mean, Ẍ.* This is the average value of all observations in a sample. Eqn. 3.8 gives the formula as:-

$$\ddot{X} = \frac{\sum X_i}{n} \qquad 3.34$$

Where, $\sum X_i$ is the sum of X_i where 'i' go from 1 to n

n = number of observations in a population.

- *Degree of freedom (df).* The degree of freedom (df) are the number of "free choices" one has in given "n" size of materials, observation, things, treatments, classes, etc. In the study for example, one is required to choose or arrange for eleven soil subgroups, one has only {11-1=10} "free choices" in the matter. The portion of the eleventh soil subgroup is fixed. Likewise for, 77 observations in 11 soil subgroups there will be only (77-11=66) "free choices" of arrangement.

- *Derivation.* This is the difference between an observation and the mean. It comprises of the variance (S^2) and the standard deviation (SD). Where variance is the average of the squared deviation from the mean and the standard deviation is square root of the variance. Thus, mathematically Eqns. 3.35 and 3.36 gives the formula for computing the variance and standard deviation respectively using SPSS software.

$$S^2 = \frac{\sum(X-\ddot{X})^2}{n-1} = \frac{\sum X_i^2 - \frac{[\sum X_i]^2}{n}}{n-1} \qquad 3.35$$

$$S.D = \sqrt{\left(\frac{\sum(X-\ddot{X})^2}{n-1}\right)} = \sqrt{\left(\frac{\sum X_i^2 - \frac{(\sum X_i)^2}{n}}{n-1}\right)} \qquad 3.36$$

- *Sum of squares (SS).* This is the sum of squared deviation of the observations from the mean. It is represented as SS_{Within} and $SS_{Between}$. Eqns. 3.37 and 3.38 gives the mathematical expressions for sum of squares respectively as:-

$$SS_{Within} = SS_1 + SS_2 + SS_3 + \ldots + SS_n \qquad 3.37$$

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$$SS_{Between} = \sum n\left[\ddot{X}_{Group} - \ddot{X}_{Total}\right]^2 \quad 3.38$$

❖ *Mean squares, MS.* The mean squares are estimates of the variance for each source of variation. Eqns. 3.39 and 3.40 gives the mean squares for between and within source of variation as:-

$$MS_{Between} = \frac{SS_{Between}}{df_{Between}} \quad 3.39$$

$$MS_{Within} = \frac{SS_{Within}}{df_{Within}} \quad 3.40$$

Where, df is the degree of freedom.

❖ *The 'F' statistic.* This is a ratio of the between and within group variance estimates. Eqn. 3.41 gives the formula for computing it as:-

$$F = \frac{MS_{Between}}{MS_{Within}} \quad 3.41$$

SPSS software calculates the significance (one or two tailed probability level) of the F-statistic with the two degrees of freedom such as $df_{Between}$and df_{Within}.

❖ *Correlation analysis.* This is a measure of the degree of association between the variables under study. It is also the goodness of fit of a prescribed relationship to the data at hand. Simple linear correlation designated as 'r' which is the correlation coefficient and computed using SPSS software as in Eqns. 3.42, 3.43 and 3.44 below.

Pearson correlation coefficient, $r = \frac{COV}{(SD_x)(SD_y)}$ 3.42

Where, COV (Covariance) $= \frac{Sum of Cross Products}{n-1} = \frac{SCP}{n-1}$ 3.43

SD is the standard deviation for x and y variables.

T-statistic, $t_{observed} = \frac{r}{\sqrt{(1-r^2)/(n-2)}}$ 3.44

`

SPSS computesthe significant or probability level using the degree of freedom, df = (n – 2) and $t_{observed}$

❖ *Regression*

Stepwise Multiple regression estimates the coefficients of the linear equation when there is more than one independent variable that best predicts the value of the dependent variable. The regression equation relating to the soil properties (X_1, …,X_n) to yield hydraulic conductivity (Y) is as shown in Eqn. 3.45 below:-

$$Y = a + b_1X_1 + b_2X_2 \ldots + b_nX_n \quad 3.45$$

i. Sum of squares due to regression (SSR), is calculated as in Eqn. 3.46

$$SSR = \sum(b_1)(\sum X_1 Y) \quad 3.46$$

ii. Residual sum of squares (SSE),is computed as in Eqn. 3.47

$$SSE = \sum y^2 - SSR \qquad 3.47$$

Where, $\sum y^2 = \sum(Y)^2 - \frac{(\sum Y)^2}{n}$

iii. Coefficient of determination (R^2), is computed as in Eqn. 3.48

$$R^2 = \frac{SSR}{\sum y^2} \qquad 3.48$$

The coefficient of determination R^2, measures the contribution of the linear function of k independent variables to the variation in Y. It is usually expressed in percentage.

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CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Test results for soil properties

The mean result of the raw data of the experiments done on the selected soil properties is shown in Table 4.1.

Table 4.1: Mean values of the raw data for the soil properties

Location and (Soil type; FAO 1996 Classification)	K cm/s	Grain size distribution			P %	D_b g/cm^3	D_p g/cm^3	CEC %	pH	ESP %	OMC g/kg
		%clay	%silt	%sand							
Egdema (Eutric Fluvisol)	0.2922	8.0	4.8	87.2	35.4	1.56	2.41	3.03	6.23	3.35	4.30
Owerri (Dystric Ferralsol)	0.9556	21.6	28.2	50.2	42.1	1.22	2.12	3.93	5.37	2.17	7.11
Okwele (Orthic Acrisol)	0.4433	36.6	16.3	47.1	44.9	1.45	2.62	4.70	6.08	3.85	4.48
Umuna (Eutric Gleysol)	0.4219	21.7	16.1	62.2	41.3	1.27	2.17	3.37	6.52	2.91	4.59
Orlu (Eutric Nitisol)	0.4926	24.3	18.3	57.4	38.9	1.26	2.07	5.45	7.45	3.98	4.24
Akwete (Dystric Nitosol)	0.4585	20.2	12.7	67.1	44.0	1.29	2.32	3.79	6.25	3.97	5.65
Bende (Dystric Cambisol)	0.1216	52.5	8.1	39.4	45.4	1.36	2.64	4.89	6.77	4.22	4.07
IsiekeIbeku (DystricGleysol)	0.1802	37.2	12.3	50.5	38.1	1.62	2.62	3.99	7.26	3.35	3.79
Aba (Dystric Ferralsol)	0.3011	21.5	8.0	70.5	45.3	1.40	2.56	3.16	5.55	2.59	4.14
Isuochi (Dystric Nitisol)	0.3796	21.2	13.1	65.7	40.7	1.24	2.09	3.06	5.28	2.11	3.90
Igbere (Rhodic Ferralsol)	0.9889	12.6	1.3	86.1	21.9	1.60	2.05	9.40	2.33	1.90	9.29

N/B:

K = Hydraulic conductivity
pH = Soil pH
ESP = Exchangeable sodium percentage
CEC = Cation exchange capacity
OMC = Organic matter content
P = Porosity
D_b = Bulk density
D_p = Particle density
FAO = Food and Agriculture Organization of the United Nations, 1996.

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4.2 Test of Homogeneity of Variance

The test of homogeneity of variance showed how the variability of dependent variable and the independent variables are statistically significantly different or the same across the soil sub-groups of study.

Table 4.2 shows the test of homogeneity of variance of the experimental design for the model.

Table 4.2: Test of Homogeneity of Variances

PROPERTY	LEVENE STATISTIC	DF_1	DF_2	P-value
Hydraulic Conductivity	3.101	10	66	0.003
Organic Matter Content	1.307	10	66	0.245
Bulk Density	1.182	10	66	0.319
Particle density	2.160	10	66	0.031
Exchangeable Sodium Percentage	1.625	10	66	0.119
Soil pH	6.887	10	66	0.000
Porosity	0.839	10	66	0.593
Percentage Sand	1.755	10	66	0.087
Percentage Silt	2.837	10	66	0.005
Percentage Clay	1.307	10	66	0.245
Cation Exchange Capacity	4.619	10	66	0.000

The Levene Statistical test helps in decision making for the homogeneity of variance of the soil properties across the soil sub-groups of the study. It showed that the variability of hydraulic conductivity, particle density, soil pH, percentage silt and cation exchange capacity were statistically significantly different across the soil sub-groups of study as p-value<0.05, thus the hypothesis H_o is rejected and H_A accepted. This attribute might be that the soil sub-groups are classified differently which is in agreement with FAO 1996 classification. Conversely, it also showedthat the variance of organic matter content, bulk density, Exchangeable sodium percentage, porosity, percentage sand and percentage clay across soil sub-groups (Locations) is not significantly different statistically as $p \geq 0.05$, thus the H_o is accepted. This might be attributed to close similarity of soil texture in each soil sub-groups. Generally, since the hydraulic conductivity varied across the soil subgroups (locations) for the study, hypothesis H_o is rejected and H_A accepted.

4.2 Analysis Of Variance (ANOVA)

ANOVA is a procedure for decomposing or partitioning the total source of variation in a set of data from a designed experiment. It isolates or quantifies the variances

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associated with each source of variation. Table 4.3 shows the Analysis of Variance (ANOVA) for the study.

Table 4.3: Summary of Analysis of variance table (ANOVA) for all properties under study

PROPERTY	SOURCE OF VARIATION	D.F	SUM OF SQUARES	MEAN SQUARE	F-CAL	F-TAB	P-value
HYDRAULIC CONDUCTIVITY	Between Groups	10	5.466	.547	109.257**	2.616	.000
	Within Groups	66	.330	.005			
	Total	76	5.796				
ORGANIC MATTER CONTENT	Between Groups	10	203.736	20.374	4093.139**	2.616	.000
	Within Groups	66	.329	.005			
	Total	76	204.064				
BULK DENSITY	Between Groups	10	1.538	.154	67.574**	2.616	.000
	Within Groups	66	.150	.002			
	Total	76	1.688				
PARTICLE DENSITY	Between Groups	10	4.160	.416	43.264**	2.616	.000
	Within Groups	66	.635	.010			
	Total	76	4.794				
EXCHANGEABLE SODIUM PERCENTAGE	Between Groups	10	49.300	4.930	94.362**	2.616	.000
	Within Groups	66	3.448	.052			
	Total	76	52.748				
SOIL PH	Between Groups	10	130.875	13.088	141.444**	2.616	.000
	Within Groups	66	6.107	.093			
	Total	76	136.982				
POROSITY	Between Groups	10	3492.182	349.218	42.950**	2.616	.000
	Within Groups	66	536.629	8.131			
	Total	76	4028.811				
PERCENTAGE SAND	Between Groups	10	16479.797	1647.980	1909.623**	2.616	.000
	Within Groups	66	56.957	.863			
	Total	76	16536.755				
PERCENTAGE SILT	Between Groups	10	3723.540	372.354	624.828**	2.616	.000
	Within Groups	66	39.331	.596			
	Total	76	3762.872				
PERCENTAGE CLAY	Between Groups	10	10874.199	1087.420	1910.802**	2.616	.000
	Within Groups	66	37.560	.569			
	Total	76	10911.759				
CATION EXCHANGE CAPACITY	Between Groups	10	234.034	23.403	146.839**	2.616	.000
	Within Groups	66	10.519	.159			
	Total	76	244.554				

** Highly significantly different from their means ($p < 0.01$).

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Testing the null hypothesis (H_o) from Table 4.3, it showed that all the soil properties considered for the study are highly statistically significantly different from their means between soil sub-groups as p-value<0.01, thus the H_o is rejected and H_A is accepted. This means that the hydraulic conductivity observed at (say Igbere for instance) is statistically different from that observed at Aba, Orlu, Owerri, Isuochi, Umuna, Egbema, Okwele, Akwete, Bende, Isieke Ibeku.Likewise that observed at Owerri is different from that observed at Aba and other locations. This might be as a result of different soil sub-groups (locations) according to FAO 1996 soil classification.

Similarly, it showed from Table 4.3, that organic matter content, bulk density, particle density, exchangeable sodium, soil pH, porosity, percentage sand, percentage clay, percentage silt and cation exchange capacity are highly statistically significantly different from their means between soil sub-groups as p-value<0.01. This also means that the individual soil properties considered for the study is statistically significantly different from each other across and between the soil sub-groups or locations of study. Thus, the different observed from each soil property across soil sub-groups might be as a result of the difference in the soil sub-groups according to FAO 1996 classification of soils in Nigeria. With these in mind, modelling hydraulic conductivity in relation to other properties across or between the soil sub-groups is unavoidable and practically acceptable.

From Table 4.4, based on the mean comparison technique using the Duncan's Multiple Range Test method to discover which of the soil sub-groups is significantly similar to the other. It was confirmed from Table 4.4 that Owerri and Igbere has same hydraulic conductivity values(0.9550 and 0.9889 respectively) as p>0.01. This might be as a result of the similarity in their soil physical property (bulk density); closeness in their biological property (organic matter content) and chemical properties (soil pH and exchangeable sodium percentage) and comparatively greater than the hydraulic conductivity at Bende, Isieke Ibeku, Egbema, Aba, Isuochi, Umuna, Okwele, Akwete and Orlu due to the differences in the soil characteristics or locations of the soils according to FAO 1996 soil classification. Similarly, it is confirmed from Table 4.4 that the hydraulic conductivity of Okwele, Umuna and Akwete (0.4432, 0.4112 and 0.4585 respectively) are the same statistically and the reason for this might be the closeness in value of their soil physical properties

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(porosity, bulk density, percentage silt and particle density); closeness in their biological property (organic matter content) and chemical properties (soil pH and exchangeable sodium percentage).

Likewise in Egbema and Aba, their hydraulic conductivity is same, which might be caused by close values in their soil physical properties (percentage silt, bulk density and particle density), similar chemical property (cation exchange capacity) and biological property (organic matter content). In Bende and Isieke Ibeku, hydraulic conductivity is the same and the reason behind this similarity might have been that their soil physical properties (particle density) are same.

Thus the other soil properties where explained in the same manner and summarized in the mean comparison table as shown in Table 4.4.

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4.4 MEAN COMPARISON

Table 4.4 illustrate the mean comparison for the soil properties in the soil sub-groups.

Table 4.4 Mean comparison table using Duncan's Multiple Range Test (DMRT) for the model

BLOCKS (Locations)	TREATMENTS (Soil properties)										
	K	%Cl	%Si	%S	P	D_b	D_p	CEC	pH	ESP	OMC
Egbema	*0.2922^{b} (0.062)	8.0^{a} (0.606)	4.8^{b} (0.629)	87.2^{j} (0.496)	35.4^{b} (2.482)	1.56^{e} (0.038)	2.41^{b} (0.039)	3.03^{a} (0.240)	6.23^{cd} (0.095)	3.35^{e} (0.051)	4.30^{d} (0.083)
Owerri	0.9550^{e} (0.135)	21.6^{d} (0.170)	28.2^{g} (0.437)	50.2^{c} (0.474)	42.1^{def} (3.376)	1.21^{a} (0.049)	2.12^{a} (0.061)	3.93^{c} (0.364)	5.37^{b} (0.179)	2.17^{b} (0.103)	7.11^{h} (0.032)
Okwele	0.4432^{cd} (0.156)	36.6^{f} (0.499)	16.3^{e} (0.577)	47.1^{b} (0.250)	44.9^{f} (1.324)	1.45^{d} (0.031)	2.62^{c} (0.028)	4.70^{d} (0.133)	6.08^{c} (0.460)	3.85^{f} (0.250)	4.48^{e} (0.073)
Umuna	0.4112^{cd} (0.049)	21.7^{d} (0.457)	16.1^{e} (0.258)	62.2^{e} (0.449)	41.3^{cde} (2.216)	1.27^{ab} (0.032)	2.17^{a} (0.054)	3.37^{ab} (0.184)	6.52^{de} (0.091)	2.91^{d} (0.110)	4.59^{f} (0.063)
Orlu	0.4929^{d} (0.024)	24.3^{e} (0.939)	18.3^{f} (1.437)	57.4^{d} (1.315)	38.9^{cd} (1.947)	1.26^{ab} (0.045)	2.07^{a} (0.058)	5.45^{e} (0.262)	7.45^{f} (0.261)	3.98^{fg} (0.355)	4.24^{d} (0.078)
Akwete	0.4585^{cd} (0.042)	20.2^{c} (1.174)	12.7^{d} (1.049)	67.1^{g} (1.011)	44.0^{ef} (4.658)	1.29^{b} (0.039)	2.32^{b} (0.221)	3.79^{bc} (0.395)	6.25^{cd} (0.054)	3.97^{fg} (0.253)	5.65^{g} (0.103)
Bende	0.1220^{a} (0.021)	52.5^{g} (0.993)	8.1^{c} (0.397)	39.4^{a} (0.972)	45.4^{g} (3.161)	1.36^{c} (0.069)	2.64^{c} (0.048)	4.89^{d} (0.242)	6.77^{e} (0.298)	4.22^{f} (0.290)	4.07^{c} (0.053)
IsiekeIbeku	0.1800^{a} (0.028)	37.2^{f} (0.888)	12.3^{d} (0.814)	50.5^{c} (1.033)	38.1^{bc} (2.617)	1.62^{f} (0.064)	2.62^{c} (0.112)	3.99^{c} (0.975)	7.26^{f} (0.651)	3.35^{e} (0.133)	3.79^{a} (0.095)
Aba	0.3011^{b} (0.035)	21.5^{d} (0.921)	10.9^{c} (0.269)	67.6^{h} (0.877)	45.3^{f} (2.836)	1.40^{cd} (0.053)	2.56^{c} (0.139)	3.16^{a} (0.240)	6.55^{b} (0.258)	3.72^{c} (0.309)	4.14^{c} (0.051)
Isuochi	0.3796^{c} (0.026)	21.2^{d} (0.335)	13.1^{d} (0.639)	65.7^{f} (0.852)	40.7^{cd} (2.751)	1.24^{ab} (0.036)	2.09^{a} (0.058)	3.06^{a} (0.301)	5.28^{b} (0.150)	2.11^{ab} (0.236)	3.90^{b} (0.059)
Igbere	0.9889^{e} (0.023)	12.6^{b} (0.639)	1.3^{a} (1.048)	86.1^{i} (1.581)	21.9^{a} (2.698)	1.60^{ef} (0.051)	2.05^{a} (0.082)	9.40^{f} (0.361)	2.33^{a} (0.290)	1.90^{a} (0.209)	9.29^{i} (0.056)

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* Group means with different superscript(s) in same column are significantly different from each other.
Values in parenthesis"()" represent the standard deviation for each mean value.

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4.5 Correlation between hydraulic conductivity, K and selected soil properties

Table 4.5 shows the result of the correlation analysis (Appendix H) of the measured hydraulic conductivity value against the soil properties.

Table 4.5: Correlation coefficients of between hydraulic conductivity and the selected soil properties

Soil properties	Correlation, r	P-value	Remark
K and Bulk density	-0.539**	0.000	Significant
K and Porosity	0.001	0.497	Not Significant
K and Cation Exchange Capacity	-0.032	0.408	Not Significant
K and Soil pH	-0.604**	0.000	Significant
K and Exchangeable Sodium Percentage	-0.583**	0.000	Significant
K and Organic matter content	0.850**	0.000	Significant
K and Particle density	-0.618**	0.000	Significant
K and % Clay	-0.417**	0.001	Significant
K and % Silt	0.842**	0.000	Significant
K and % Sand	-0.019	0.444	Not Significant

N/B ** = Correlation is significant at 0.01 level (2-tailed)
K = Hydraulic conductivity

From Table 4.5, the r-value computed for the correlation between hydraulic conductivity and organic matter content exceeds both tabular r-values at 5% and 1% probability levels. It was concluded that the simple linear correlation coefficient is significantly different from zero at 1% probability level. This significantly high r-value indicates that there is strong evidence that the hydraulic conductivity and organic matter content in the different soil sub-groups are highly associated with one another in a linear function. This linear association shows that soil sub-groups with high hydraulic conductivity will have a high organic matter content or vice versa. Also with an r-value of 0.850, the implication is that 72.25% ($100r^2 = 100(0.850)^2 = 72.25\%$) of the variation in the hydraulic conductivity can be accounted for by the linear function of the organic matter content in the soil sub-groups of the study.

Also, observed from Table 4.5 is the significantly high positive r-value between hydraulic conductivity and percentage silt association, which indicates that there is strong evidence that the hydraulic conductivity and percentage silt in the

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different soil sub-groups are highly associated with one another in a linear function. This shows that soil sub-groups with high K-value will have a high %Silt value and/or vice versa. With an r-value of 0.842, it implies that 70.9% of the variation in the hydraulic conductivity can be explained by the linear function of the %Silt in the soil sub-groups.Also, since the r-value computed for the correlation between k and soil pH exceeds both tabular r-values at 5% and 1% probability levels, it is concluded that the simple linear correlation coefficient is significantly different from zero at the 1% probability. This significant, high negative r-value indicates that there is strong evidence that the hydraulic conductivity and soil pH in the different soil sub-groups are highly associated with one another in a linear way. This linear association shows that the soil sub-groups with high hydraulic conductivity will have a lower soil pH or soil sub-groups with high soil pH will have a low hydraulic conductivity. With an r-value of -0.604, the implication is that $100r^2 = 100 \times (-0.604)^2 = 36.48\%$) 36.48% of the variation in the hydraulic conductivity can be accounted for by the linear function of the soil pH in the soil sub-groups of the study. Similarly, hydraulic conductivity is significantly high and negatively correlated with individual soil properties as bulk density, exchangeable sodium, particle density and percentage clay since r-value computed exceeds tabular r-value at both 5% and 1% probability level. This indicated that there is strong evidence that the hydraulic conductivity and these soil properties in the different soil sub-groups are highly associated with one another in alinear way. This linear association shows that soil sub-groups with high hydraulic conductivity will have a low bulk density, low exchangeable sodium; low particle density and low percentage clay respectively or low hydraulic conductivity is associated with high bulk density, high exchangeable sodium, high particle density and high percentage clay.

Inferentially, an agronomist or a farmer who wants to irrigate a farmland without over flooding the land can be advised to increase the hydraulic conductivity of the agro land mass using organic manure which thereby increases the burrowing aerating and other activities of micro- organisms thereby reducing bulk density and increasing soil pH.

4.6 Stepwise Regression

Table 4.6 listed the best fit equations of the stepwise regression for the different number of model variables including their test characteristics; correlation coefficient,

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R, coefficient of determination, R^2, adjusted coefficient of determination, R^2_{adj}, F test and standard error of estimate, S.E.

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Table 4.6: Stepwise regression Equation for Different Numbers of Model Variables

S/N	Equation	R	R^2	R^2_{adj}	F	SE	Remarks
1.	**-0.575 + 0.208OMC**	0.850	0.723	0.717	140.623	0.1344	Best of 10 one-variable equation. Sig. at 0.01
2.	**-0.437 +0.1240OMC + 0.018Si**	0.915	0.837	0.830	135.728	0.1041	Best of 9 two-variable equation. Sig. at 0.01
3.	**-0.645 + 0.091OMC + 0.025%Si + 0.005%S**	0.938	0.880	0.873	127.592	0.0899	Best of 8 three-variable equation. Sig. at 0.01
4.	**-0.128 + 0.055OMC + 0.027%Si + 0.005%S – 0.057pH**	0.944	0.892	0.883	105.133	0.0863	Best of 7 four-variable equation. Sig. at 0.01
5.	**-0.240 + 0.053OMC + 0.026Si + 0.006%S - 0.094pH + 0.063CEC**	0.956	0.914	0.905	105.979	0.0779	Best of 6 five-variable equation. Significant at 0.01
6.	**-0.240 + 0.053OMC + 0.026Si + 0.006%S - 0.094pH + 0.063CEC + 0.000D_p**	0.956	0.914	0.905	105.979	0.0779	Best of 5 six-variable equation. Not significant at 0.05
7.	**-0.240 + 0.053OMC + 0.026Si + 0.006%S - 0.094pH + 0.063CEC + 0.000D_p + 0.000D_b**	0.956	0.914	0.905	105.979	0.0779	Best of 4 seven-variable equation. Not significant at 0.05

N/B: OMC = Organic Matter Content; Si = % Silt; Cl = %Clay; CEC = Cation Exchange Capacity; pH = Soil pH

From Table 4.6, Eqn. 4.1 seems to be the optimum of the best fit using statistical analysis in serial number five (S/N 5) equations as shown in Table 4.6.

$$K = -0.240 + 0.053OMC + 0.026S_i + 0.006S - 0.094pH + 0.063CEC \qquad 4.1$$

Where; K = Hydraulic conductivity

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OMC = Organic matter content

Si = % Silt
S = % Sand
CEC = Cation exchange capacity
pH = Soil pH

Using SPSS software, multiple linear regression was run to predict hydraulic conductivity from soil pH, exchangeable sodium percentage, cation exchange capacity, organic matter content, fluid density, porosity, bulk density, particle density, % clay, % silt and % sand but the effective variables that influence hydraulic conductivity and was retained in the model include: organic matter content of soil, %silt, soil pH, %Sand and Cation exchange capacity of the soil. These variables generally were statistically significant and predicted hydraulic conductivity as stated the Table 4.6 above. Since p values (sig.) are 0.000 and they are less than 0.05, it implies that the entire variables in the model are statistically significantly different from one another. This model has variables (for example: cation exchange capacity and %sand) not originally well correlated with measured soil hydraulic conductivity retained in the model while those variables originally well correlated was eventually excluded (for example: bulk density, exchangeable sodium percentage, particle density and % clay) from the model. Based on Table 4.5, particle density, exchangeable sodium percentage, %clay and bulk density were to appear in the final hydraulic conductivity model for being highly correlated with the measured hydraulic conductivity but rather they were excluded. What this suggests is that though a variable may not on its own be well correlated with another factor but its interaction with other variables may enhance its relationship with that variable with which it was not originally well correlated as a single variable.

The coefficient of determination, R^2 increased gradually (Table 4.6) until it gets to a point where R^2 remained unchanged which shows that the best model fit has been achieved.

Finally, the number of variables retained in the SPSS model is five. Generally, less number of variables reduced the fit of the model thereby rendering predicted hydraulic conductivity values unreliable whereas no change was observed in the values of coefficient of determination R^2 and adj. R^2 when more variables were added (Table 4.6). Thus, the optimum number of the variables in SPSS equation is five which conforms to the statement by Madubuike (1999) that the optimum

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number of variables in any model should be 30 to 40 percent of the number of observations. These models can therefore be said to conform to standard requirements.

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4.7 Dimensional Analysis

The general prediction equations from dimensional analysis are given in Eqns. 4.2a and b:

$$K_1 = \left[-0.003\left(\frac{D_p \times pH \times ESP}{D_b \times OMC \times CEC}\right) - 0.007\left(\frac{P \times \%Si}{\%Cl \times \%S}\right) + 0.01\right]\left[\sqrt{gH}\right] \qquad 4.2a$$

$$K_2 = \left[-0.003\left(\frac{D_p \times pH \times ESP}{D_b \times OMC \times CEC}\right) + 0.007\left(\frac{P \times \%Si}{\%Cl \times \%S}\right) + 0.01\right]\left[\sqrt{gH}\right] \qquad 4.2b$$

Where,

K = Hydraulic conductivity, cm/sec
D_p = Particle density of soil, g/cm^3
pH = Soil pH, %
ESP = Exchangeable sodium percentage of soil, %
D_b = Bulk density of soil, g/cm^3
OMC = Organic matter content of soil, %
CEC = Cation exchange capacity of soil, %
P = Porosity, %
%Si = Percentage silt, %
%Cl = Percentage clay, %
%S = percentage sand, %
g = Acceleration due to gravity, cm/sec^2
H = Sampled soil depth, cm

4.8 Validation and Comparison of Models

Tables 4.7shows the difference between the measured, spss predicted and predicted dimensional analysis (for both combinations) with subtraction combination predicting better in dimensional analysis when compared to measured and spss prediction whereas Table 4.8 shows the difference between the measured and the predicted hydraulic conductivity values for the three location used not used in developing the model and the three locations used in developing the models used in testing the models using both statistical and dimensional analysis while Figs. 4.2a, b and c, are the plots for the SPSS predicted and dimensionally predicted hydraulic conductivity (K-values) against measured hydraulic conductivity values.Figure 4.3 shows the Bar chart for measured, SPSS predicted and dimensionally predicted hydraulic conductivity (K-values) against locations (soil sub-groups)

Example: Aba (Dystric Ferralsol): OMC = 4.14; S_i = 8.0; %S =70.5; CEC = 3.16; pH = 5.55; P = 45.3; D_b = 1.40; D_p = 2.56; %S = 70.5; %C_l = 21.5; g = 981cm/s^2; H = 15

Substituting in Eqn. 4.1, we have:

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K_1 =-0.240 + 0.053OMC + 0.026S_i + 0.006S – 0.094pH + 0.063CEC 4.1

=-0.240 + 0.053(4.14) + 0.026(8.0) + 0.006(70.5) – 0.094(5.55) + 0.063(3.16)

K= 0.2878

Also, from Eqn. 4.2, we have

$$K = \left[-0.003\left(\frac{D_p \times pH \times ESP}{D_b \times OMC \times CEC}\right) - 0.007\left(\frac{P \times \%Si}{\%Cl \times \%S}\right) + 0.01\right]\left[\sqrt{gH}\right] \quad 4.2$$

$$K = \left[-0.003\left(\frac{2.56 \times 5.55 \times 2.59}{1.40 \times 4.14 \times 3.16}\right) - 0.007\left(\frac{45.3 \times 8.0}{21.5 \times 70.5}\right) + 0.01\right]\left[\sqrt{981 \times 15}\right]$$

K = 0.2788

The others were done in the same manner using Eqns. 4.1 and 4.2, results recorded below.

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Table 4.7: Measured and predicted hydraulic conductivity values from the three locations not used in building the model for both dimensional and statistical analysis

Location (soil group)	Measured	Predicted, Spss	Residual (%)	Predicted K_1, Dimensional analysis	Residual (%)	Predicted K_2, Dimensional analysis	Residual (%)
Aba (Dystric Ferralsol)	0.3011	0.2878	4.4	0.2788	7.4	0.6849	127
Isuochi (Dystric Nitisol)	0.3796	0.3980	4.8	0.3154	16.9	0.9655	154
Igbere (Rhodic Ferralsol)	0.9889	1.1700	18.3	1.1671	18	1.2117	22.5

From Table 4.7, the predicted K_2 (which is additive) is much higher than the measured K and K_1 (which is subtractive). Thus, the K_1 is accepted as the model from dimensional analysis. Also, the residual % from K_1 is less than 20% which is acceptable from experiments.

Table 4.8: Measured and predicted hydraulic conductivity values from the eight locations used in building the model for both dimensional and statistical analysis

Location (soil group)	Measured	Predicted, Spss	Residual (%)	Predicted, K_1 Dimensional analysis	Residual (%)
Egbema (Eutric Fluvisol)	0.2922	0.2412	5.1	0.1056	18.66
Owerri (Dystric Ferralsol)	0.9556	0.914	4.16	0.8962	5.94
Okwele (Orthic Acrisol)	0.4433	0.4329	1.04	0.4215	2.18
Umuna (Eutric Gleysol)	0.4219	0.3945	2.74	0.3207	10.12
Orlu (Eutric Nitisol)	0.4926	0.4478	4.48	0.4252	6.74
Akwete (Dystric Nitisol)	0.4585	0.4416	1.69	0.4046	5.39
Bende (Dystric Cambisol)	0.1216	0.0944	2.72	0.048	7.36
Isieke Ibeku (Dystric Gleysol)	0.1802	0.1526	2.76	0.0546	12.56

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Table 4.7 showed that the Measured, K and predicted, K_1 (which is subtractive) hydraulic conductivity values from the eight locations used in building the model for both dimensional and statistical analysis is accepted as their residual % is less than 20% which is acceptable from experiments.

Tables 4.7 and 4.8 shows that the models predicted fairly accurately, judging from the low residual values got from the three locations not used in building the model; (SPSS: 4.4%, 4.8%, 18.3% and dimensional analysis: 7.4%, 16.9%, 18%) and the eight locations used in building the model (SPSS: 5.1%, 4.16%, 1.04%, 2.74%, 4.48%, 1.69%, 2.72%, 2.76% and dimensional analysis: 18.66%, 5.94%, 2.18%, 10.12%, 6.74%, 5.39%, 7.36%, 12.56%) and their plots against the locations showed a uniform trend of line as shown in Fig. 4.2 which indicates that the developed equations are good. These agree with the findings of Nkakini and Akor, (2012) which states that the smaller the percentage error values between measured and predicted results, the better the models.

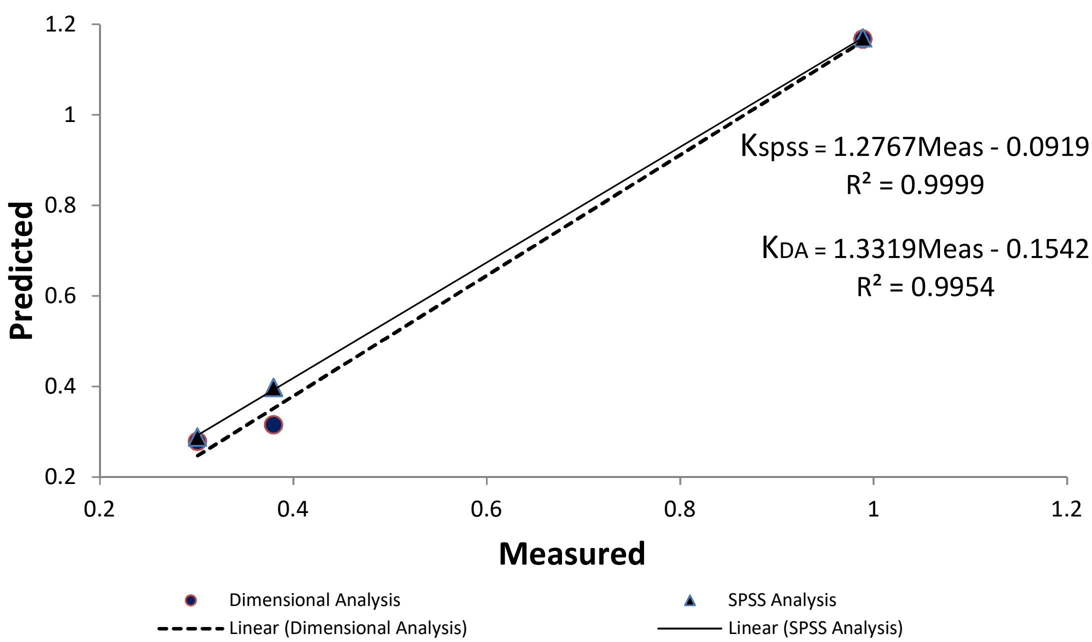

Fig. 4.1a: Plot showing the trend of line for the three locations not used in building the models.

Fig 4.1a showed the trend of line for the three locations not used in building the models. It is verified from Fig. 4.1a that both models using DA and stepwise SPSS

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analysis following same trend line such that their coefficient of determination, R^2 is higher is greater than 0.9. Thus, Eqns. 4.3 and 4.4 showed the relationships between predicted and measured K-values as:-

$$K_{spss} = 1.2767\text{Meas} - 0.0919 \qquad R^2 = 0.9999 \qquad 4.3$$

$$K_{DA} = 1.3319\text{Meas} - 0.1542 \qquad R^2 = 0.9954 \qquad 4.4$$

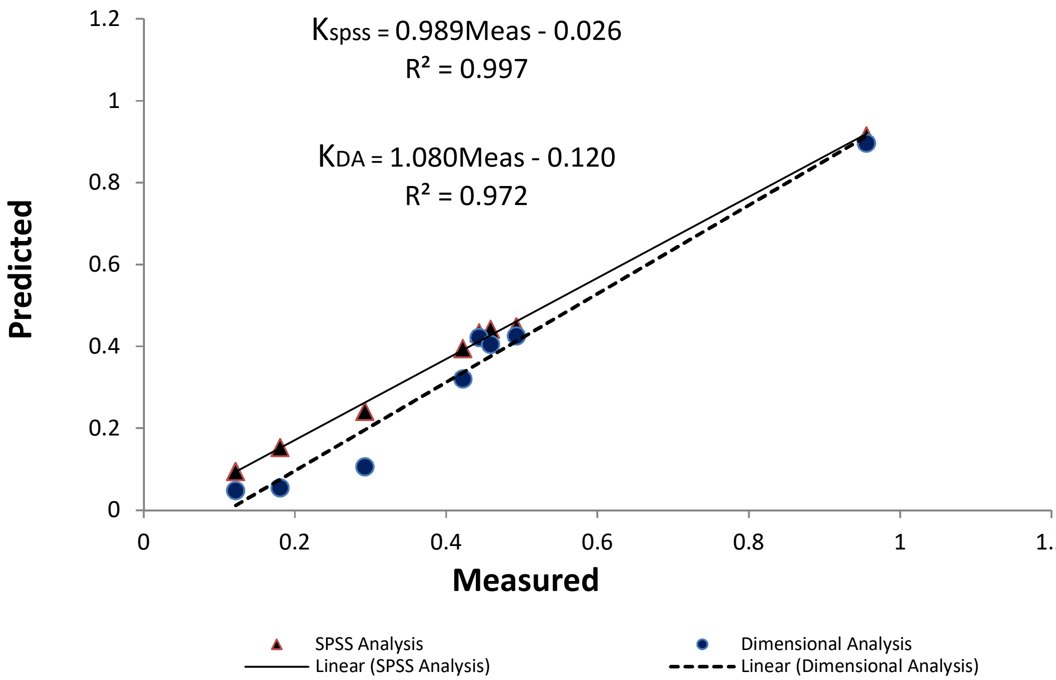

Fig. 4.1b: Plot showing the trend of line for the eight locations used in building the models.

It is observed from Fig. 4.1b that the trend line showing the relationship between predicted and measured K-value using dimensional and SPSS analysis is similar with R^2-value which depicts a good model validation. The Eqns. 4.5 and 4.6 showed the trends expressions between predicted and measured K-values for the eight locations used in building the models as:-

$$K_{SPSS} = 0.989\text{Meas} - 0.026 \qquad R^2 = 0.997 \qquad 4.5$$

$$K_{DA} = 1.080\text{Meas} - 0.120 \qquad R^2 = 0.972 \qquad 4.6$$

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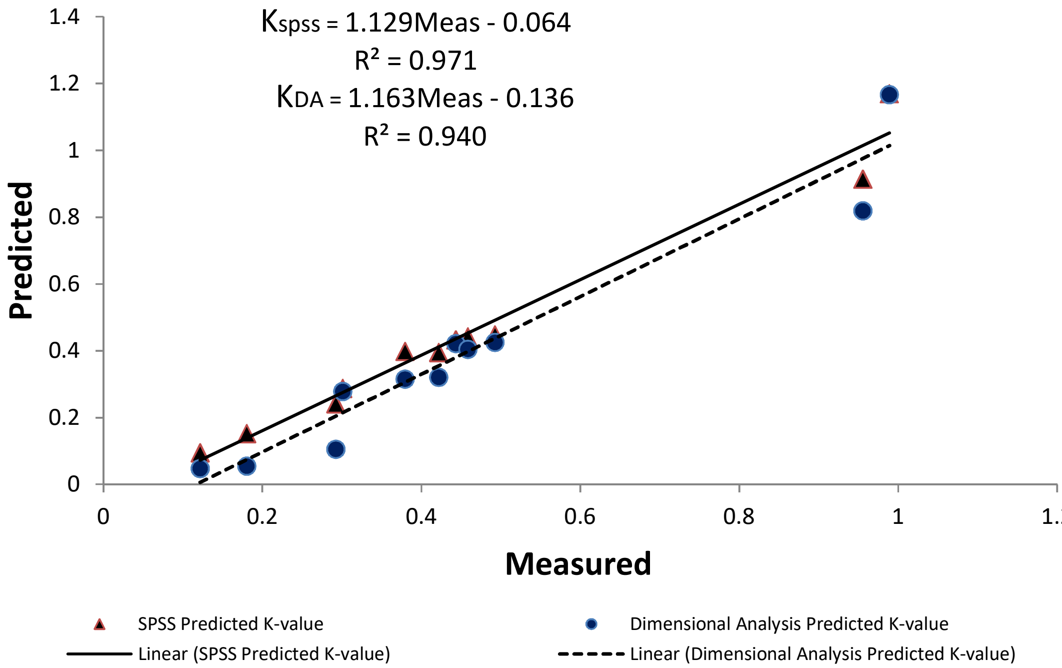

Fig. 4.1c: Plot showing the trend of line for all the locations.

Similarly, Fig. 4.1c showed the trend of line for all the locations. It showed similar trend line for the relationships between predicted and measured K-value using dimensional (DA) and SPSS analyses with R^2>0.9. Hence, Eqns. 4.7 and 4.8 below showed the relationship.

$$K_{spss} = 1.129\text{Meas} - 0.064 \qquad R^2 = 0.971 \qquad 4.7$$

$$K_{DA} = 1.163\text{Meas} - 0.136 \qquad R^2 = 0.940 \qquad 4.8$$

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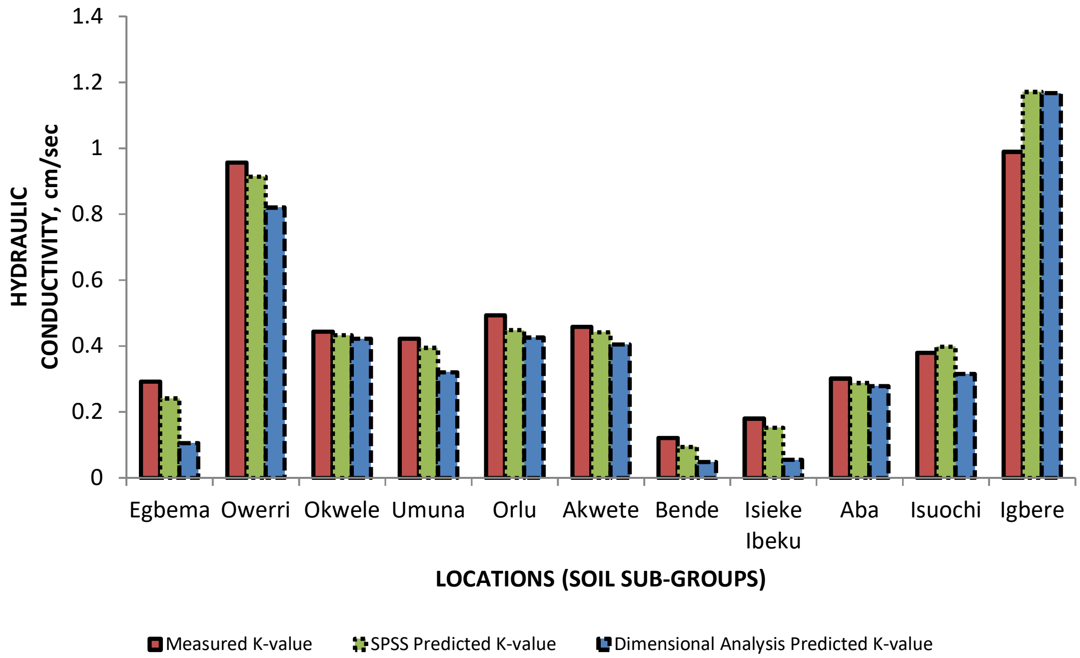

Fig. 4.2:Bar chart for measured, SPSS predicted and dimensionally predicted hydraulic conductivity (K-values) against locations (soil sub-groups)

A bar chart for measured, SPSS predicted and dimensionally predicted hydraulic conductivity (K-values) against locations (soil sub-groups) as presented in Fig. 4.2 above showed vividly the location with the highest or lowest hydraulic conductivity compared with other locations. For instance, it showed that Owerri and Igbere have the highest hydraulic conductivity values (0.9550 and 0.9889 respectively). This might be as a result of similar soil physical properties (bulk density); closeness in their biological properties (organic matter content) and chemical properties (soil pH and exchangeable sodium percentage) and comparatively greater than the hydraulic conductivity at Bende, Isieke Ibeku, Egbema, Aba, Isuochi, Umuna, Okwele, Akwete and Orlu due to the differences in the soil characteristics or locations of the soils according to FAO 1996 soil classification. Also it is confirmed from Fig. 4.2 that the hydraulic conductivity of Okwele, Umuna and Akwete (0.4432, 0.4112 and 0.4585 respectively) are the same and the reason for this might be the closeness in value of their soil physical properties (porosity, bulk density, percentage silt and particle density); closeness in their biological properties (organic matter content) and chemical properties (soil pH

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and exchangeable sodium percentage) but higher than the K-values for Bende and Isieke Ibeku whose K- values are the least compared with others.

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CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.2 Conclusions

Mathematical models were established for determination of the hydraulic conductivity of Imo and Abia States using dimensional analysis and SPSS stepwise method. The developed models using the two methods were verified and validated. These equations gave sufficiently accurate results for predicting the hydraulic conductivity of the soil sub-groups of the region.

The following conclusions were drawn from the study:

5.2.1 Conclusions based on Dimensional Analysis

1. A mathematical model was established using dimensional analysis based on the Buckingham's π theorem and the results obtained showed no significant difference between the measured and predicted hydraulic conductivity values at 5% level of significance.
2. Theresults showed the relationship between hydraulic conductivity and all the soil properties for this studyand high coefficient of determination (R^2 = 0.9954) was obtained in the relationship. With this observation, a good model was established for estimating hydraulic conductivity for different soil subgroups.
3. The standard errors of the model predicted fairly accurate results, judging from low residual (percentage error) values ranging from 7.4% - 18% obtained from the three locations (Aba, Isuochi and Igbere) not used in building the model and 2.18% - 18.66% for the eight locations (Orlu, Owerri, Umuna, Egbema, Okwele, Akwete, Bende and Isieke Ibeku) used in building the model.
4. From Dimensional Analysis method, the model developed gave Eqn. 5.1 below as:

$$\mathbf{K_{DA}} = \left[-\mathbf{0.003}\left(\frac{\boldsymbol{D_p \times pH \times ESP}}{\boldsymbol{D_b \times OMC \times CEC}}\right) - \mathbf{0.007}\left(\frac{\boldsymbol{P} \times \%\boldsymbol{Si}}{\%\boldsymbol{Cl} \times \%\boldsymbol{S}}\right) + \mathbf{0.01}\right]\left[\sqrt{\boldsymbol{gH}}\right] \quad 5.1$$

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5.2.2 Conclusions based on SPSS Stepwise Analysis

1. A mathematical model was established using statistical analysis based on the SPSS stepwise method.

2. The result showed very high coefficient of determination (R^2 = 0.9999) and the difference between the actual (measured) and the predicted hydraulic conductivity values were below 20% which implies a better model in estimating hydraulic conductivity for different soil subgroups compared with Dimensional Analysis model.

3. The Low standard errors of the model predicted hydraulic conductivity better, judging from the low percentage error values ranging from 4.4% - 18.3% obtained from the three locations (Aba, Isuochi and Igbere) not used in building the model and 1.04% - 5.10% residual values obtained from the eight locations (Orlu, Owerri, Umuna, Egbema, Okwele, Akwete, Bende and Isieke Ibeku) used in developing the model.

4. From the analysis done, it can be inferred that organic matter content and percentage silt properties of soil sub-groups affect hydraulic conductivity positively with R-values as 0.850 and 0.842 respectively whereas negative effect was observed for bulk density, soil pH, exchangeable sodium, particle density and percentage clay, with R-values as -0.539, -0.604, -0.583, -0.618 and -0.417 respectively.

5. Therefore, using SPSS stepwise method, the model gave Eqn. 5.2 below, which is better:

$$\mathbf{K_{spss} = -0.240 + 0.053OMC + 0.026S_i + 0.006S - 0.094pH + 0.063CEC} \quad 5.2$$

Any of these models may be used for the determination of hydraulic conductivity of the soils in the region.

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5.2 Contributions to Knowledge

The following are the contributions to knowledge of this study:

- ✓ This research work on hydraulic conductivity models based on selected soil biological, chemical and physical properties in Imo and Abia States is the first of its kind in South Eastern Nigeria.

- ✓ Mathematical modelling of hydraulic conductivity based on selected soil biological, chemical and physical properties in Imo and Abia States using dimensional and statistical methods would serve as useful tool for designing farm irrigation system during wet and dry season of crop cultivation.

5.3 Recommendations

The following recommendations were drawn from the study to further bridge the knowledge gap.

1) Properties like dynamic viscosity, kinematic viscosity, aggregate stability, water holding capacity, anion exchange capacity, et cetera, should be added for further studies in modelling hydraulic conductivity.

2) The study area for modelling hydraulic conductivity should be expanded to cover the other geographical regions of Nigeria.

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APPENDIX A

MAP OF IMO AND ABIA STATES SHOWING SAMPLE LOCATIONS

APPENDIX B

Table B1: Representative soil groups and their locations in the study area (Imo and Abia States)

S/N	USDA	FAO	Parent Material	Location	State
1	Eutric Tropofluents	**Eutric Fluvisol**	**Sandy Alluvium**	Egbema	Imo
2	Orthoxic Tropodult	**Dystric Ferralsol**	**Coastal Plain Sands**	Owerri	Imo
3	Typic Hapuldult	**Orthic Acrisol**	**Shale and Sandstone**	Okwele	Imo
4	Typic Tropaquepts	**Eutric Gleysol**	**Shales and Siltstone**	Umuna	Imo
5	Typic Tropudalis	**Eutric Nitosol**	**Siltstone**	Orlu	Imo
6	Arenic Paleudult	**Dystric Nitosol**	**Sandy Alluvium**	Akwete	Abia
7	Typic Dystropepts	**Dystric Cambisol**	**Shale**	Bende	Abia
8	Typic Tropaquepts	**Dystric Gleysol**	**Shale and Sandstone**	IsiekeIbeku	Abia
9	Typic Tropudult	**Dystric Ferralsol**	**Coastal Plain Sands**	Aba	Abia
10	Gross Arenic Paleudult	**Dystric Nitosol**	**Sandstone**	Isuochi	Abia
11	Orthoxic Tropodult	**Rhodic Ferralsol**	**Sandstone**	Igbere	Abia

(Federal Department of Agricultural Land Resources, 1985)

USDA: United States Department of Agriculture.

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**FAO : **Food and Agriculture Organization of the United Nations.

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APPENDIX C

The raw data for computing hydraulic conductivity in each locations

Table C1: Egbema(Eutric Fluvisol)

Hydraulic conductivity parameters / Pits	A (cm^2)	a (cm^2)	H_1 (cm)	H_2 (cm)	L (cm)	t (secs)
P_1	411.29	597.14	100	42	12.83	54.21
P_2	411.29	597.14	100	51	12.83	31.90
P_3	411.29	597.14	100	59	12.83	34.00
P_4	411.29	597.14	100	74.1	12.83	30.02
P_5	411.29	597.14	100	40	12.83	66.05
P_6	411.29	597.14	100	55	12.83	35.00
P_7	411.29	597.14	100	54	12.83	37.99

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Table C2: Owerri(Dystric Ferralsol)

Hydraulic conductivity parameters / Pits	A (cm^2)	a (cm^2)	H_1 (cm)	H_2 (cm)	L (cm)	t (secs)
P_1	411.29	597.14	100	15	12.83	48.50
P_2	411.29	597.14	100	2	12.83	62.86
P_3	411.29	597.14	100	1.3	12.83	79.98
P_4	411.29	597.14	100	12	12.83	39.31
P_5	411.29	597.14	100	9	12.83	44.91
P_6	411.29	597.14	100	5	12.83	60.39
P_7	411.29	597.14	100	6	12.83	60.79

Table C3: Okwele(Orthic Acrisol)

Hydraulic conductivity parameters / Pits	A (cm^2)	a (cm^2)	H_1 (cm)	H_2 (cm)	L (cm)	t (secs)
P_1	411.29	597.14	100	64.1	12.83	42.83
P_2	411.29	597.14	100	67	12.83	17.47
P_3	411.29	597.14	100	29	12.83	32.00
P_4	411.29	597.14	100	50	12.83	25.73
P_5	411.29	597.14	100	55	12.83	24.65
P_6	411.29	597.14	100	35	12.83	48.60
P_7	411.29	597.14	100	60	12.83	23.43

Table C4: Umuna(Eutric Gleysol)

Hydraulic conductivity parameters / Pits	A (cm^2)	a (cm^2)	H_1 (cm)	H_2 (cm)	L (cm)	t (secs)
P_1	411.29	597.14	100	64	12.83	17.28
P_2	411.29	597.14	100	54.5	12.83	31.28
P_3	411.29	597.14	100	54.5	12.83	31.00
P_4	411.29	597.14	100	54.9	12.83	28.05

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P_5	411.29	597.14	100	65.2	12.83	17.99
P_6	411.29	597.14	100	65	12.83	18.75
P_7	411.29	597.14	100	62	12.83	18.67

Table C5: Orlu(Eutric Nitosol)

Hydraulic conductivity parameters / **Pits**	A (cm^2)	a (cm^2)	H_1 (cm)	H_2 (cm)	L (cm)	t (secs)
P_1	411.29	597.14	100	18	12.83	70.79
P_2	411.29	597.14	100	25.4	12.83	51.97
P_3	411.29	597.14	100	39.0	12.83	34.40
P_4	411.29	597.14	100	15.0	12.83	72.00
P_5	411.29	597.14	100	15.1	12.83	73.98
P_6	411.29	597.14	100	13.1	12.83	72.00
P_7	411.29	597.14	100	41	12.83	33.00

Table C6:Akwete(Dystric Nitosol)

Hydraulic conductivity parameters / **Pits**	A (cm^2)	a (cm^2)	H_1 (cm)	H_2 (cm)	L (cm)	t (secs)
P_1	411.29	597.14	100	12	12.83	90.90
P_2	411.29	597.14	100	8.9	12.83	91.00
P_3	411.29	597.14	100	19.1	12.83	80.33
P_4	411.29	597.14	100	40.3	12.83	35.04
P_5	411.29	597.14	100	21	12.83	67.03
P_6	411.29	597.14	100	15	12.83	71.05
P_7	411.29	597.14	100	11.1	12.83	85

TableC7: Bende (Dystric Cambisol)

Hydraulic conductivity parameters / **Pits**	A (cm^2)	a (cm^2)	H_1 (cm)	H_2 (cm)	L (cm)	t (secs)

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P_1	411.29	597.14	100	52.8	12.83	94.04
P_2	411.29	597.14	100	50	12.83	121.69
P_3	411.29	597.14	100	48	12.83	84.19
P_4	411.29	597.14	100	42.8	12.83	128.31
P_5	411.29	597.14	100	51.9	12.83	109.86
P_6	411.29	597.14	100	49.5	12.83	132.58
P_7	411.29	597.14	100	38	12.83	146.77

Table C8: Isieke Ibeku(Dystric Gleysol)

Hydraulic conductivity parameters / **Pits**	A (cm^2)	a (cm^2)	H_1 (cm)	H_2 (cm)	L (cm)	t (secs)
P_1	411.29	597.14	100	44.8	12.83	73.79
P_2	411.29	597.14	100	40.8	12.83	116.37
P_3	411.29	597.14	100	30.1	12.83	106.50
P_4	411.29	597.14	100	49	12.83	71.75
P_5	411.29	597.14	100	35.2	12.83	95.06
P_6	411.29	597.14	100	42	12.83	110.30
P_7	411.29	597.14	100	38.6	12.83	104.98

Table C9: Aba (Dystric Ferralsol)

Hydraulic conductivity parameters / **Pits**	A (cm^2)	a (cm^2)	H_1 (cm)	H_2 (cm)	L (cm)	t (secs)
P_1	411.29	597.14	100	26	12.83	103.39
P_2	411.29	597.14	100	22	12.83	96.86
P_3	411.29	597.14	100	18.2	12.83	98.89
P_4	411.29	597.14	100	26.4	12.83	79.49
P_5	411.29	597.14	100	12.9	12.83	109.78
P_6	411.29	597.14	100	24.5	12.83	81.85
P_7	411.29	597.14	100	19.2	12.83	112.64

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Table C10: Isuochi(Dystric Nitosol)

Hydraulic conductivity parameters / **Pits**	A (cm^2)	a (cm^2)	H_1 (cm)	H_2 (cm)	L (cm)	t (secs)
P_1	411.29	597.14	100	28.5	12.83	69.22
P_2	411.29	597.14	100	16	12.83	82.50
P_3	411.29	597.14	100	22.7	12.83	70.03
P_4	411.29	597.14	100	25.1	12.83	65.72
P_5	411.29	597.14	100	36.2	12.83	54.17
P_6	411.29	597.14	100	34.9	12.83	52.19
P_7	411.29	597.14	100	21.3	12.83	70.74

Table C11: Igbere (Rhodic Ferralsol)

Hydraulic conductivity parameters / Pits	A (cm^2)	a (cm^2)	H_1 (cm)	H_2 (cm)	L (cm)	t (secs)
P_1	411.29	597.14	100	2.7	12.83	69.75
P_2	411.29	597.14	100	2.7	12.83	69.74
P_3	411.29	597.14	100	1.9	12.83	75.47
P_4	411.29	597.14	100	0.5	12.83	97.73
P_5	411.29	597.14	100	1.2	12.83	80.27
P_6	411.29	597.14	100	11	12.83	41.26
P_7	411.29	597.14	100	5.3	12.83	55.69

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APPENDIX D

Replicates for the treatments (Soil properties) in the blocks (Soil sub-groups)

Table D1: Block A – Egbema (Eutric Fluvisol)

TREATMENT / REPLICATION	K	%Cl	%Si	%S	P	D_b	D_p	CEC	pH	ESP	OMC
R_1	0.2981	8.4	5.2	86.4	35.83	1.54	2.40	2.85	6.20	3.44	4.18
R_2	0.3931	7.9	5.1	87.0	37.10	1.56	2.45	3.27	6.36	3.34	4.26
R_3	0.2891	7.1	5.4	87.5	35.54	1.56	2.42	2.90	6.14	3.33	4.31
R_4	0.1860	8.4	3.9	87.7	37.70	1.52	2.44	3.27	6.33	3.34	4.42
R_5	0.2584	8.9	3.9	87.2	37.71	1.52	2.43	2.90	6.23	3.38	4.35
R_6	0.3182	7.7	5.1	87.2	32.77	1.60	2.38	3.30	6.10	3.32	4.22
R_7	0.3022	7.6	4.5	87.9	31.36	1.62	2.36	2.73	6.26	3.28	4.34
Average value	**0.2922**	**8.0**	**4.8**	**87.2**	**35.4**	**1.56**	**2.41**	**3.03**	**6.23**	**3.35**	**4.30**

Table D2: Block B – Owerri (Dystric Ferralsol)

TREATMENT / REPLICATION	K	%Cl	%Si	%S	P	D_b	D_p	CEC	pH	ESP	OMC
R_1	0.7286	21.4	28.3	50.3	39.62	1.28	2.12	3.60	5.12	2.40	7.10
R_2	1.1593	21.7	28.2	50.1	44.03	1.22	2.18	4.00	5.18	2.11	7.12
R_3	1.0114	21.8	28.0	50.2	38.61	1.24	2.02	4.57	5.32	2.18	7.11
R_4	1.0048	21.4	28.4	50.2	44.86	1.18	2.14	3.88	5.56	2.16	7.14
R_5	0.9987	21.7	28.5	49.8	42.13	1.25	2.16	4.10	5.60	2.10	7.06
R_6	0.9241	21.8	28.6	49.6	38.24	1.26	2.04	3.95	5.42	2.14	7.16
R_7	0.8621	21.6	27.3	51.1	46.98	1.14	2.15	3.44	5.37	2.13	7.10
Average value	**0.9556**	**21.6**	**28.2**	**50.2**	**42.1**	**1.22**	**2.12**	**3.93**	**5.37**	**2.17**	**7.11**

Table D3: Block C – Okwele (Orthic Acrisol)

TREATMENT / REPLICATION	K	%Cl	%Si	%S	P	D_b	D_p	CEC	pH	ESP	OMC
R_1	0.1934	35.8	17.2	47.0	43.08	1.48	2.60	4.68	6.93	3.30	4.42
R_2	0.4270	36.2	16.8	47.0	45.67	1.44	2.65	4.80	6.14	3.99	4.40

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R_3	0.7206	36.5	16.0	47.5	45.66	1.46	2.61	4.42	5.65	3.96	4.44
R_4	0.5018	36.6	16.2	47.2	43.72	1.48	2.63	4.72	5.70	3.92	4.46
R_5	0.4518	36.8	16.4	46.8	43.89	1.47	2.62	4.80	5.69	3.91	4.50
R_6	0.4024	36.7	16.5	46.8	45.74	1.40	2.58	4.78	6.33	4.02	4.55
R_7	0.4062	37.4	15.4	47.2	46.61	1.42	2.66	4.70	6.10	3.91	4.60
Average value	**0.4433**	**36.6**	**16.3**	**47.1**	**44.9**	**1.45**	**2.62**	**4.70**	**6.08**	**3.85**	**4.48**

Table D4: Block D – Umuna (Eutric Gleysol)

TREATMENT / REPLICATON	K	%Cl	%Si	%S	P	D_b	D_p	CEC	pH	ESP	OMC
R_1	0.4811	4.42	16.5	62.2	43.26	1.22	43.26	3.20	6.42	2.82	4.61
R_2	0.3614	4.40	16.3	61.9	41.01	1.28	41.01	3.18	6.64	2.90	4.70
R_3	0.3647	4.44	15.9	62.7	43.24	1.26	43.24	3.62	6.40	2.82	4.60
R_4	0.3982	4.46	16.1	61.9	41.96	1.30	41.96	3.44	6.61	3.04	4.56
R_5	0.4428	4.50	15.7	62.1	42.66	1.25	42.66	3.56	6.56	2.92	4.53
R_6	0.4280	4.55	16.1	62.1	39.23	1.27	39.23	3.42	6.52	2.81	4.63
R_7	0.4770	4.60	16.1	63.1	37.4	1.32	37.4	3.19	6.48	3.08	4.52
Average value	**0.4219**	**21.7**	**16.1**	**62.2**	**41.3**	**1.27**	**2.17**	**3.37**	**6.52**	**2.91**	**4.59**

Table D5: Block E – Orlu (Eutric Nitosol)

TREATMENT / REPLICATION	K	%Cl	%Si	%S	P	D_b	D_p	CEC	pH	ESP	OMC
R_1	0.4512	24.2	16.2	59.6	42.31	1.20	2.08	5.24	8.02	4.12	4.32
R_2	0.4912	24.8	16.8	58.4	36.63	1.28	2.02	5.46	7.40	3.25	4.24
R_3	0.5099	25.7	18.2	56.1	39.22	1.24	2.04	5.80	7.44	4.00	4.22
R_4	0.4908	22.6	20.2	57.2	37.38	1.29	2.06	5.74	7.28	4.32	4.20
R_5	0.4760	24.0	18.0	58.0	37.44	1.32	2.11	5.08	7.32	4.26	4.30
R_6	0.5258	24.6	19.2	56.2	40.09	1.30	2.17	5.32	7.48	3.88	4.14
R_7	0.5032	24.2	19.4	56.4	39.00	1.22	2.00	5.54	7.26	4.00	4.28
Average	**0.4926**	**24.3**	**18.3**	**57.4**	**38.9**	**1.26**	**2.07**	**5.45**	**7.45**	**3.98**	**4.24**

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value											

Table D6: Block F – Akwete (Dystric Nitosol)

TREATMENT / REPLICATION	K	%Cl	%Si	%S	P	D_b	D_p	CEC	pH	ESP	OMC
R_1	0.4344	18.0	13.2	68.8	41.28	1.28	2.18	4.12	6.20	3.88	5.57
R_2	0.4952	21.4	12.2	66.4	42.59	1.24	2.16	4.16	6.32	3.64	5.72
R_3	0.3839	20.6	12.7	66.7	40.91	1.30	2.20	3.82	6.19	3.98	5.68
R_4	0.4832	20.2	12.4	67.4	43.10	1.32	2.32	3.06	6.24	4.40	5.70
R_5	0.4337	20.0	14.4	65.6	41.88	1.36	2.34	3.66	6.32	3.88	5.62
R_6	0.4974	19.6	13.2	67.2	44.24	1.26	2.26	3.58	6.22	3.82	5.79
R_7	0.4817	21.4	11.0	67.6	54.29	1.28	2.80	4.10	6.27	4.20	5.48
Average value	**0.4585**	**20.2**	**12.7**	**67.1**	**44.0**	**1.29**	**2.32**	**3.79**	**6.25**	**3.97**	**5.65**

Table D7: Block F – Bende (Dystric Cambisol)

TREATMENT / REPLICATION	K	%Cl	%Si	%S	P	D_b	D_p	CEC	pH	ESP	OMC
R_1	0.1265	52.5	8.2	39.3	47.72	1.38	2.64	5.00	6.87	4.22	4.14
R_2	0.1061	54.2	7.6	38.0	47.01	1.42	2.68	5.11	6.29	4.13	4.09
R_3	0.1624	50.8	7.8	41.4	53.68	1.26	2.72	4.78	6.61	4.07	4.12
R_4	0.1232	52.7	8.0	39.3	47.29	1.36	2.58	4.56	6.75	4.44	4.08
R_5	0.1112	52.4	8.4	39.2	46.15	1.40	2.60	5.10	7.23	4.04	4.06
R_6	0.0988	52.2	8.8	39.0	45.04	1.44	2.62	5.12	6.89	3.90	3.98
R_7	0.1228	52.5	8.0	39.5	51.88	1.28	2.66	4.62	6.67	4.76	4.04
Average value	**0.1216**	**52.5**	**8.1**	**39.4**	**45.4**	**1.36**	**2.64**	**4.89**	**6.77**	**4.22**	**4.07**

Table D8: Block G – Isieke Ibeku (Dystric Gleysol)

TREATMENT / REPLICATION	K	%Cl	%Si	%S	P	D_b	D_p	CEC	pH	ESP	OMC
R_1	0.2027	37.0	14.0	49.0	36.36	1.68	2.64	2.18	6.20	3.12	3.80
R_2	0.1435	36.2	12.0	51.8	35.44	1.70	2.62	3.17	6.75	3.42	3.85
R_3	0.2100	38.4	11.5	50.1	35.83	1.54	2.40	4.22	7.72	3.52	3.90
R_4	0.1852	38.2	11.8	50.0	37.21	1.62	2.58	4.80	7.70	3.28	3.73

R_5	0.2046	36.1	12.0	51.9	38.97	1.66	2.72	4.66	6.86	3.30	3.61
R_6	0.1465	37.4	12.4	50.2	42.34	1.58	2.74	4.17	7.80	3.46	3.80
R_7	0.1689	37.2	12.2	50.6	40.61	1.55	2.61	4.74	7.81	3.36	3.84
Average value	**0.1802**	**37.2**	**12.3**	**50.5**	**38.1**	**1.62**	**2.62**	**3.99**	**7.26**	**3.35**	**3.79**

Table D9: Block H – Aba (Dystric Ferralsol)

TREATMENT / REPLICATION	K	%Cl	%Si	%S	P	D_b	D_p	CEC	pH	ESP	OMC
R_1	0.2427	22.4	11.1	66.5	44.31	1.42	2.55	2.80	6.34	3.75	4.19
R_2	0.2912	20.2	10.9	68.9	49.61	1.32	2.62	3.00	6.28	4.05	4.12
R_3	0.3209	21.0	11.3	67.7	44.35	1.38	2.48	3.50	6.68	3.94	4.08
R_4	0.3121	21.4	10.9	67.7	41.38	1.36	2.32	3.18	6.88	3.15	4.10
R_5	0.3475	22.7	10.7	66.5	47.06	1.44	2.72	3.00	6.25	3.93	4.11
R_6	0.3201	21.4	10.5	68.1	47.40	1.42	2.70	3.25	6.61	3.51	4.15
R_7	0.2729	20.5	11.1	68.1	43.08	1.48	2.50	3.36	6.80	3.73	4.22
Average value	**0.3011**	**21.5**	**8.0**	**70.5**	**45.3**	**1.40**	**2.56**	**3.16**	**5.55**	**2.59**	**4.14**

Table D10: Block I – Isuochi (Dystric Nitosol)

TREATMENT / REPLICATION	K	%Cl	%Si	%S	P	D_b	D_p	CEC	pH	ESP	OMC
R_1	0.3378	21.4	14.2	64.4	38.46	1.28	3.92	2.62	5.56	1.90	2.08
R_2	0.4014	20.8	12.8	66.4	41.90	1.22	3.84	3.44	5.12	2.02	2.10
R_3	0.3944	21.0	12.2	66.8	44.08	1.18	3.95	3.28	5.32	1.82	2.11
R_4	0.3918	21.4	13.4	65.2	44.59	1.23	3.97	2.88	5.34	2.42	2.22
R_5	0.3620	21.0	13.2	65.8	38.73	1.25	3.82	2.96	5.14	1.98	2.04
R_6	0.3627	21.2	13.0	65.8	38.46	1.28	3.88	2.90	5.28	2.36	2.08
R_7	0.4072	21.8	12.6	65.6	38.83	1.26	3.95	3.36	5.20	2.26	2.06
Average value	**0.3796**	**21.2**	**13.1**	**65.7**	**40.7**	**1.24**	**2.09**	**3.06**	**5.28**	**2.11**	**3.90**

Table D11: Block J – Igbere (Rhodic Ferralsol)

TREATMENT / REPLICATION	K	%Cl	%Si	%S	P	D_b	D_p	CEC	pH	ESP	OMC
R_1	0.9646	12.0	1.0	86.0	21.97	1.58	2.03	8.88	2.82	2.35	9.28

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R_2	0.9647	12.4	1.3	86.1	22.52	1.62	2.12	9.12	2.46	1.89	9.23
R_3	0.9782	13.2	2.0	84.6	23.14	1.64	2.18	9.26	2.12	1.75	9.36
R_4	1.0099	11.8	0.1	88.9	24.78	1.52	2.04	9.9	2.08	1.89	9.33
R_5	1.0264	12.5	1.0	86.1	21.37	1.60	1.94	9.64	2.32	1.91	9.30
R_6	0.9964	12.8	3.0	84.0	16.29	1.68	1.98	9.70	2.01	1.78	9.22
R_7	0.9824	13.6	0.1	86.8	23.21	1.58	2.08	9.28	2.52	1.75	9.35
Average value	**0.9889**	**12.6**	**1.3**	**86.1**	**21.9**	**1.60**	**2.05**	**9.40**	**2.33**	**1.90**	**9.29**

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APPENDIX E

Table E1: Soil classification

Location	Grain size distribution classification			Soil classification
	%clay	%silt	%sand	
Egdema	8.0	4.8	87.2	Loamy sand
Owerri	21.6	28.2	50.2	Sandy clay loam
Okwele	36.6	16.3	47.1	Sandy clay
Umuna	21.7	16.1	62.2	Sandy clay loam
Orlu	24.3	18.3	57.4	Sandy clay loam
Akwete	20.2	12.7	67.1	Sandy clay loam
Bende	52.5	8.1	39.4	Clay
IsiekeIbeku	37.2	12.3	50.5	Sandy clay
Aba	21.5	8.0	70.5	Sandy clay loam
Isuochi	21.2	13.1	65.7	Sandy clay loam
Igbere	12.6	1.3	86.1	Loamy sand

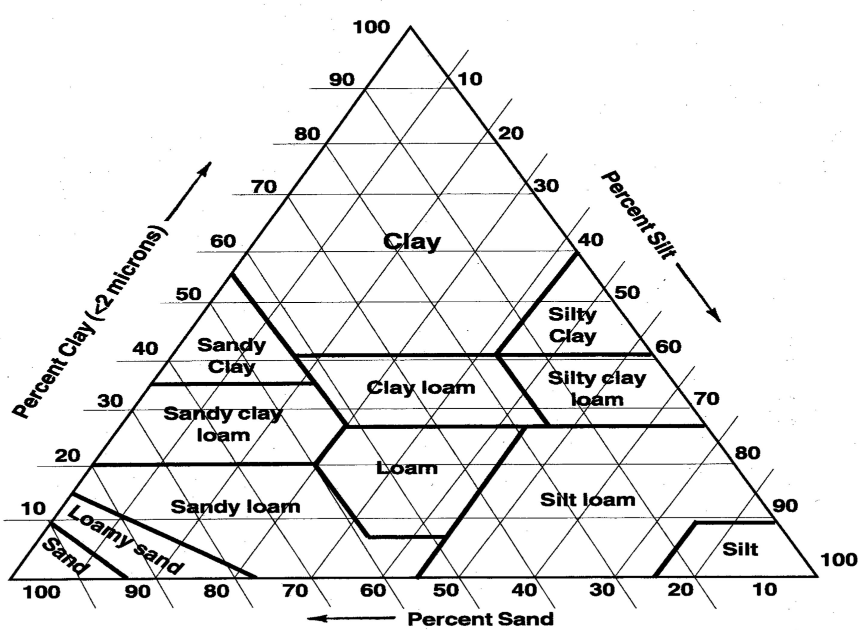

Fig. E1:Soil textural triangle (Ibitoye, 2008)

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APPENDIX F

Calculation of the eleven dimensionless π-terms

Out of fourteen (14) variables, three variables (as m = 3) are to be selected as repeating variables. Since K is a dependent variable; it should not be selected as repeating variable. Therefore, the selected repeating variables are:-

(i) In terms of geometric property, select "H" as $M^o L^1 T^o$

(ii) In terms of flow property, select "g" as $M^o L^1 T^{-2}$

(iii) In terms of fluid property, select "D_f" as $M^1 L^{-3} T^o$

Hence, each π-term (m + 1 variables) is written as shown below.

$$\pi_1 = D_f^{a_1} * g^{b_1} * H^{c_1} * K \quad 1$$

$$\pi_2 = D_f^{a_2} * g^{b_2} * H^{c_2} * D_b \quad 2$$

$$\pi_3 = D_f^{a_3} * g^{b_3} * H^{c_3} * D_p \quad 3$$

The others where done in the same manner to get the remaining 11 π-terms.

For π_1-term:

$$\mathrm{M}^0 * \mathrm{L}^0 * \mathrm{T}^0 = (\mathrm{M}^1\mathrm{L}^{-3}\mathrm{T}^0)^{a_1} \times (\mathrm{M}^0\mathrm{L}^1\mathrm{T}^{-2})^{b_1} \times (\mathrm{M}^0\mathrm{L}^1\mathrm{T}^0)^{C_1} \times \mathrm{M}^0\mathrm{L}^1\mathrm{T}^{-1}$$

$$= \mathrm{M}^{(a_1)} \times \mathrm{L}^{(-3\ _1+b_1+C_1+1)} \times \mathrm{T}^{(-2b_1-1)}$$

Equating the exponents of M, L and T respectively gives:-

For M: $0 = a_1$

L: $0 = -3a_1 + b_1 + c_1 + 1$

T: $0 = -2b_1 - 1$

$a_1 = 0$; $b_1 = -1/2$; $c_1 = -1/2$

Substituting the values of a_1, b_1 and c_1 in Eqn. 1 gives Eqn. 4

$$\pi_1 = D_f^0 * g^{-1/2} * H^{-1/2} * K$$

$$\pi_1 \Longrightarrow \frac{K}{\sqrt{gH}} \quad 4$$

For π_2-term:

$$M^0 * L^0 * T^0 = (M^1L^{-3}T^0)^{a_2} * (M^0L^1T^{-2})^{b_2} * (M^0L^1T^0)^{C_2} * (M^1L^{-3}T^0)$$

$$= M^{(a_2+1)} * L^{(-3a_2+b_2+C_2-3)} * T^{(-2b_2)}$$

For M: $0 = a_2 + 1$; $a_2 = -1$

For L: $0 = -3a_2 + b_2 + c_2 - 3$

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For T: 0 = -2b_2

a_2 = -1; b_2 = 0; c_2 = 0

By substituting the values of a_2, b_2 and c_2 in Eqn. 2 gives Eqn. 5:-

$$\pi_2 = D_f^{-1} * g^0 * H^0 * D_b \Longrightarrow \frac{D_b}{D_f} \quad 5$$

For π_3-term:

$$M^0L^0T^0 = (M^1L^{-3}T^0)^{a_3} * (M^0L^1T^{-2})^{b_3} * (M^0L^1T^0)^{C_3} * (M^1L^{-3}T^0)$$

$$= M^{(a_3+1)} * L^{(-3_3+b_3+c_3-3)} * T^{(-2\ \ _3)}$$

By equating the exponents on both sides gives:-

For M :$0 = a_3 + 1 \rightarrow a_3 = -1$

L :$0 = -3a_3 + b_3 + C_3 - 3$

T :$0 = -2b_3$

$\Longrightarrow a_3 = -1;\ b_3 = 0;\ C_3 = 0$

Thus, substituting the values of a_3, b_3 and c_3 in Eqn. 3 givesEqn. 6

$$\pi_3 = D_f^{-1} * g^0 * H^0 * D_p \Longrightarrow \frac{D_p}{D_f} \quad 6$$

In this dimensional terms determination exercise, the eight dimensionless terms already observed from Table 3.2 were excluded but will be added now the other three dimensionless π-terms has been determined because solving them dimensionally gives back the individual variables.

Therefore, the total eleven dimensionless π-terms are as:-

$$\pi_1 = \frac{K}{\sqrt{gH}};\ \pi_2 = \frac{D_b}{D_f};\ \pi_3 = \frac{D_p}{D_f};\ \pi_4 = pH;\ \pi_5 = OMC;\ \pi_6 = ESP;$$

$$\pi_7 = CEC;\ \pi_8 = P;\ \pi_9 = \%S;\ \pi_{10} = \%Cl;\ \pi_{11} = \%Si$$

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APPENDIX G

Table of values for $\pi_1, \pi^a{}_2$ and $\pi^a{}_3$

S/N	Location	π_1	$\pi^a{}_2$	$\pi^a{}_3$
1	Egbema	0.002467	2.4747	0.2436
2	Owerri	0.007878	0.7247	1.0948
3	Okwele	0.003654	2.0087	0.4246
4	Umuna	0.003478	2.0958	0.4926
5	Orlu	0.004061	2.1080	0.5104
6	Akwete	0.003779	2.0839	0.4123
7	Bende	0.001002	2.7865	0.1778
8	IsiekeIbeku	0.001486	2.6011	0.2495

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APPENDIX H

CORRELATION COEFFICIENT AMONG THE VARIABLES

Correlations												
		Hydraulic conductivity	**% Clay**	**% Silt**	**% Sand**	**Bulk density**	**Soil porosity**	**Cation exchange capacity**	**Soil pH**	**Exchangeable sodium**	**Soil particle density**	**Organic matter content**
Pearson Correlation	Hydraulic conductivity	1.000	-.417	.842	-.019	-.539	.001	-.032	-.604	-.583	-.618	.850
	% Clay	-.417	1.000	-.094	-.878	.123	.575	.552	.297	.391	.591	-.360
	% Silt	.842	-.094	1.000	-.393	-.542	.065	.186	-.360	-.561	-.562	.712
	% Sand	-.019	-.878	-.393	1.000	.147	-.562	-.600	-.101	-.092	-.276	-.010
	Bulk density	-.539	.123	-.542	.147	1.000	-.390	-.204	.132	.169	.650	-.563
	Soil porosity	.001	.575	.065	-.562	-.390	1.000	.331	-.129	.290	.397	.138
	Cation exchange capacity	-.032	.552	.186	-.600	-.204	.331	1.000	.452	.440	.050	-.203
	Soil pH	-.604	.297	-.360	-.101	.132	-.129	.452	1.000	.471	.099	-.711
	Exchangeable sodium	-.583	.391	-.561	-.092	.169	.290	.440	.471	1.000	.422	-.588
	Soil particle density	-.618	.591	-.562	-.276	.650	.397	.050	.099	.422	1.000	-.501
	Organic matter content	.850	-.360	.712	-.010	-.563	.138	-.203	-.711	-.588	-.501	1.000
Sig. (1-tailed)	Hydraulic conductivity	.	.001	.000	.444	.000	.497	.408	.000	.000	.000	.000
	% Clay	.001	.	.245	.000	.184	.000	.000	.013	.001	.000	.003

	% Silt	.000	.245	.	.001	.000	.317	.085	.003	.000	.000	.000
	% Sand	.444	.000	.001	.	.141	.000	.000	.228	.250	.020	.472
	Bulk density	.000	.184	.000	.141	.	.001	.066	.166	.107	.000	.000
	Soil porosity	.497	.000	.317	.000	.001	.	.006	.171	.015	.001	.156
	Cation exchange capacity	.408	.000	.085	.000	.066	.006	.	.000	.000	.357	.067
	Soil pH	.000	.013	.003	.228	.166	.171	.000	.	.000	.233	.000
	Exchangeable sodium	.000	.001	.000	.250	.107	.015	.000	.000	.	.001	.000
	Soil particle density	.000	.000	.000	.020	.000	.001	.357	.233	.001	.	.000
	Organic matter content	.000	.003	.000	.472	.000	.156	.067	.000	.000	.000	.
N	Hydraulic conductivity	56	56	56	56	56	56	56	56	56	56	56
	% Clay	56	56	56	56	56	56	56	56	56	56	56
	% Silt	56	56	56	56	56	56	56	56	56	56	56
	% Sand	56	56	56	56	56	56	56	56	56	56	56
	Bulk density	56	56	56	56	56	56	56	56	56	56	56
	Soil porosity	56	56	56	56	56	56	56	56	56	56	56
	Cation exchange capacity	56	56	56	56	56	56	56	56	56	56	56
	Soil pH	56	56	56	56	56	56	56	56	56	56	56
	Exchangeable sodium	56	56	56	56	56	56	56	56	56	56	56

	Soil particle density	56	56	56	56	56	56	56	56	56	56	56
	Organic matter content	56	56	56	56	56	56	56	56	56	56	56

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