

**EVALUATION OF PEDOTRANSFER FUNCTIONS IN
PREDICTING SOIL WATER CHARACTERISTICS OF
SOILS IN ZAMBIA**

BY

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- Soil Classification

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ABSTRACT

Development of models that simulate water flow and solute transport has progress rapidly in recent years. These models require input parameters that can be obtained directly in the field or in the laboratory. However, because of the large spatial and temporal variability of soil hydraulic properties, their direct measurement is both time consuming and expensive. Indirect method e.g pedotransfer functions (PTFs) are therefore increasing being used to provide these estimates. PTFs are functions that estimate soil hydraulic properties from easily measurable soil properties like soil texture and organic matter. Soil exhibit high spatial and temporal variability and this can cause PTFs to fail to predict soil hydraulic properties accurately. A study was undertaken to evaluate the performance of three PTFs (Saxton *et al.* 2006; Campbell, 1974 and Rawls-Brakensiek, 1985) in predicting soil moisture content at field capacity and wilting point as well as the saturated hydraulic conductivity from four sites at the UNZA. Soils were collected in each soil mapping unit and soil characterization was done as well as the measurement of the soil hydraulic properties like the moisture content at field capacity and wilting point as well as saturated hydraulic conductivity. The coefficient of correlation(R^2), Mean Deviation (MD) and the Root mean square error were used compare the measured and predicted values by the three different PTFs and to evaluate the performance of the three different PTFs. From the results obtained, the Saxton *et al.* (2006) model was the better predictor of moisture content at field capacity with the lowest MD and RMDE of 0.0004 and 0.0359 respectively while having a coefficient of correlation of 0.684. At wilting point, the Rawls-Brakensiek (1985) was a better predictor with the highest coefficient of correlation (0.8636) while having the lowest MD and RMSD of -0.0140 and 0.0249 respectively. For hydraulic conductivity, both Saxton *et al.*, 2006 and Campbell ,1974 proved to be poor predictors of soil saturated hydraulic conductivity with low coefficients of correlation of 0.185 and 0.227 and very high MD of -11.446 and 5.852 respectively. The RMSE was 20.537 and 6.404 respectively. The study showed that in the absence of measured data of the moisture content in the study area, the Saxton *et al.* (2006) and the Rawls-Brakensiek (1985) models can be used to predict soil moisture content at field capacity and wilting point respectively provided a local calibration factor for the study area is used to take into account any systematic under or over estimations. This cannot be done for saturated soil hydraulic conductivity.

DEDICATION

I dedicate this report to all members of my family. It because of you that I have made it this far. I will forever be grateful to my mother Mrs. Diana Miti and my father Mr. Damiano Miti for their relentless love, prayers, encouragement and motivation.

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LIST OF ACRONYMS

AWC	-	Available Water Content
cm	-	Centimeter
FC	-	Field Capacity
g.	-	grams
hr.	-	Hour
H ₂ O	-	Water
Kg	-	kilograms
KPa	-	Kilopascals
Ksat	-	Saturated Hydraulic Conductivity
M	-	Meter
MD	-	Mean Deviation
ml.	-	milliliter
mm	-	millimeter
N	-	Normality
PDF	-	Pedotransfer Functions
pF	-	-log Pressure
pH	-	Potential Hydrogen
RMSE	-	Root Mean Square Error
SOILPAR	-	Soil Parameter Estimator
SPAW	-	Soil Plant Air and Water
UNZA	-	University Of Zambia
WP	-	Wilting Point
°C	-	Degree Celcius

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CHAPTER ONE

1.0 INTRODUCTION

The development of models for simulating water flow and solute transport in soils has progressed rapidly in recent years. These models usually require many input parameters to describe the soil processes. These parameters can be obtained directly in the field or laboratory (Dirksen, 2000). Because soil hydraulic properties have large spatial and temporal variability, their direct measurement is both time consuming and expensive, hence indirect methods are increasingly used to provide estimates. To this end, pedotransfer functions (PTFs) have been developed to predict soil hydraulic properties (e.g. Vereecken *et al.*, 1989; Bell and van Keulen, 1995; Wosten, 1997; Pachepsky *et al.*, 1998; Jarvis *et al.*, 2002; Tomasella *et al.*, 2003; Saxton *et al.*, 2006).

Pedotransfer functions are predictive functions which predict soil hydraulic parameters such as the water content at field capacity and wilting point and hydraulic conductivity from more easily measurable soil properties such as soil texture (sand, silt and clay), bulk density, organic matter (or organic carbon) content and other data from routinely measured soil properties registered in soil surveys (van den Berg *et al.*, 1997). However, the most basic input parameter in the PTFs is the soil texture (sand, silt and sand).

PTFs can be classified into four levels (level 1, level 2, level 3 and level 4) according to the number of input parameters used. Level 1 PTFs use only the particle size fractions of sand, silt and clay as inputs e.g. Saxton (1986). Level 2 PTF, in addition to particle size fraction, use either organic matter or soil bulk density e.g. the Rawls (1982) and Salter (1969). Level 3 PTFs use particle size fractions, organic matter content and soil bulk density e.g. Gupta (1979), De Jong (1980), Vereecken (1989) and Simota (1996). Level 4 is a more complex PTF. The variables necessary for level 4 are one or more particle size fractions, organic matter (or organic carbon) content, soil bulk density and volumetric water content at -33 and -1500 kPa e.g. Rawls (1982) and the van Genuchten (1980).

Pedotransfer functions can also be classified as single point regressions or parametric functions. Single point PTFs predict water content at a particular point on the water

retention curve. The parametric PTFs are used to predict the parameters of a model, e.g. the van Genuchten (1980) model, as dependent variables and readily obtainable soil properties are used as independent variables.

Pedotransfer functions have been developed from different regions of the world, by different people using different methods and on different soils. Therefore different PTFs may give different results for the same type of soil depending on the level of validation and assessment for fine tuning the model. To assess and validate the performance of different PTFs, various statistical analysis methods are routinely used and these include comparison of mean deviation, root mean square deviation and the coefficient of variation. Many studies have been conducted to ascertain their accuracy and reliability.

1.1 STATEMENT OF THE PROBLEM

Soils exhibit very high spatial and temporal variability and this can cause PTFs to fail to predict soil hydraulic properties with high accuracy. Attempts to use PTFs developed elsewhere have not as been successful. Results from other studies agrees well with the concept that PTFs perform better on soils which are similar to those in which it was developed (Givi *et al.*, 2004).

A study was undertaken to evaluate the performance of three PTFs in predicting soil hydraulic properties (soil water content at field capacity and wilting point, and saturated hydraulic conductivity) from four sites at UNZA Field Station based on the described soil mapping units.

1.3 OBJECTIVES

1.3.1 GENERAL OBJECTIVE

- To evaluate the performance of three PTFs (Saxton *et al.*, 2006; Campbell, 1974 and Rawls-Brakensiek, 1985) in predicting soil hydraulic properties.

1.3.2 SPECIFIC OBJECTIVE

- Determine soil hydraulic properties of soil at UNZA using three different pedotransfer function
- To compare the performance of the three PTFs in predicting soil moisture content at field capacity and wilting point and

- To compare the performance of the three PTFs in predicting saturated hydraulic conductivity

1.3.3 HYPOTHESIS

There are no significant differences in the soil hydraulic properties obtained by laboratory method and the predicted values from of the pedotransfer functions.

1.3.4 JUSTIFICATION

The use of pedotransfer functions in the simulation and generation of soil hydraulic properties worldwide and Zambia in particular is becoming a common tool. This is due to the unavailability of data, high cost of measurement, time consuming process of laboratory analysis, few laboratory facilities and equipment. According to documentation available, there are few studies that have been done to compare the performance of the PTFs in predicting soil hydraulic properties based on available database on Zambian soils.

This study will help us select the best performing PTF for predicting soil hydraulic properties in Zambia.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 DEVELOPMENT OF PEDOTRANSFER FUNCTION

Pedotransfer functions (PTFs) are defined as predictive functions of certain soil properties derived from other easily measured properties (Bouma, 1989). These functions were not formally recognized and named until 1989, but the concept of the pedotransfer function has long been applied to estimate soil properties that are difficult to determine. Parameters like soil texture, organic matter and bulk density are variables that are used to predict soil hydraulic properties.

Habib *et al* (2010) reports that to this end many PTFs have been developed to predict soil hydraulic properties and these include Vereecken *et al.*, (1989); Bell and van Keulen, (1995); Wosten, (1997); Pachepsky *et al.*, (1998); Mayer and Jarvis, (1999); Minasny and McCartney, (2000); Jarvis *et al.*, (2002); Tomasella *et al.*, (2003) and Saxton *et al.*, (2006).

However, several equations commonly applied to hydrologic analyses were summarized by Rawls *et al.*, (1992) and Hillel (1998). These included equations developed by Campbell (1974), Brooks and Corey (1964), Van Genuchten (1980) and others. Many early trials were sufficiently successful with limited data sets to suggest that there were significant underlying relationships between soil water characteristics and parameters such as soil texture (Gupta and Larson, 1979; Rawls *et al.*, 1998; Ahuja *et al.*, 1999). More recent studies have evaluated additional variables and relationships (Gijssman *et al.*, 2002 and Pachepsky and Rawls, 2005).

Several estimating methods developed in recent years have shown that generalized predictions can be made with variable accuracy (Habib *et al.*, 2010). Nearly all of these methods involve multiple soil descriptors, some of which are often not available for practical applications. Most were derived by statistical correlations, although more recent analyses have explored neural network analysis (Schaap *et al.*, 1998) or field descriptions and PTFs (Rawls and Pachepsky, 2002).

2.2 ACCURACY AND RELIABILITY OF PEDOTRANSFER FUNCTIONS

As predictive functions, PTFs are routinely evaluated in terms of correspondence between measured and predicted values. When measured values are those used to develop the equation, the accuracy is evaluated but if the measured values are from another soil not the one used to develop the equation, reliability is evaluated (Wosten *et.al* 2001). The same statistics are used to evaluate both accuracy and reliability. Some of the commonly used statistics are spearman correlation coefficient, multiple determination coefficient, root mean square error and mean error.

Reliability of the PTFs is very important and this can be achieved by cross validation. Many studies have been conducted to assess the reliability by using them to independent and regional data set. Although no general conclusion could be derived from the review of these studies, some observations were made. These observations are that PTFs developed from regional database gives good results when applied to regions with similar soil and landscape history (Wosten *et al.* 2001). For example PTFs developed in Belgium (Vereecken *et al* 1989) gave accurate predictions in northern Germany as compared to other 13 PTFs and functions developed in Austria were more accurate for Mississippi delta when compared with other regional PTFs (Timlin *et al.*, 1996). It remains to be seen whether this observation holds for other cases and which soil and land scape features have to be similar in two regions to assure the mutual reliability of the developed PTFs (Wosten *et al.*, 2001).

There are many indications that the larger the differences in soil and climate conditions the larger the difference in the PTFs that may be expected (Wosten *et al.* 2001). Kay *et al.*, (1997) found that changes in structural characteristics, which were derived from database from different geographical regions of the world exhibit considerable variation. These authors remarked that the impact of soil and climatic conditions on these PTFs have received little attention and merit more research. MacLean and Yager (1972) and Tomasella and Hodnett(1998) clearly proved the point of regional specificity of PTFs by pointing out that PTFs developed in temperate regions may not perform well in tropical soils. van den Berg *et al.* (1997) also argued that physical and chemical differences between temperate and humid tropical soils might be the causes of the poor performance of

temperate PTFs when applied to tropical soils, sub-tropical and semi-arid regions. These differences may originate from marked differences in mineralogical properties (Tomasella and Hodnett, 2004).

2.3 DIFFERENCES IN TEMPERATE AND TROPICS SOIL PROPERTIES

Most of the PTFs available in the literature have been derived and tested using extensive databases of soils of temperate regions. The lack of data for tropical, sub-tropical and semi-arid soils has been pointed out as a major constraint for the development of PTFs for tropical soils (Hodnett and Tomasella, 2002).

Kaolinitic tropical soils have usually clay contents ranging from 60 to 90%. In temperate climates, soils with more than 60% of clay are considered as low permeability heavy clays and are regarded as non-agricultural soils (Habib *et al.*, 2010). Hodnett and Tomasella, (2002) clearly showed that kaolinitic tropical soils show unusual properties when compared with typical temperate clayey soils. They have low bulk density (0.7–1.2 kg/ m³), high permeability (usually 10–1000 mm /hr), have low available water capacity (AWC), and almost 80% of the plant available water between 210 and 2100 kPa (Schaap *et al.*, 2001).

The pronounced differences between temperate and tropical clayey soils are usually explained by the micro-aggregated structure of oxisols. In kaolinitic tropical soils, major cations such as Ca²⁺, Mg²⁺, K⁺ and silica are eliminated from the soil profile as a result of the high rainfall and continuous leaching (Hodnett and Tomasella, 2002). The removal of alkali elements, added to the transport of oxides from the upper horizon, increase the concentration of sesquioxides in the B horizon (Schaap *et al.* 2001). In oxisols and Nitisols, Fe and Al oxides play an important role as binding agents of negatively charged clay minerals, creating stable micro-aggregates within the size range of silt to fine sand. This explains why their field texture is loamy rather than clayey as determined by laboratory analysis (Hodnett and Tomasella, 2002). Since oxisols are very permeable, most of the soil water is released between saturation and water potentials above 210 kPa. This behavior resembles that of sandy soils, although the water contents are comparatively higher because of the clayey character of oxisols (Habib *et al.*, 2010). At lower potentials a significant proportion of water is held within the micro-aggregates. Therefore, the water retention curve is almost flat from 2100 kPa up to water potentials as low as 24000 kPa (van den

Berg *et al.* 1997) , where a sudden drop of soil water content occurs, which probably coincides with the air-entry value of the aggregates. Since water below 1500 kPa is no longer available for the majority of plants, the plant available water in oxisols is lower compared to temperate clays.

Although the mineralogical composition and the characteristic chemical processes cause oxisols and related soils to be characterized by uniform texture, high friability, and the presence of extremely stable micro-aggregates (Tinsdale *et al.*, 1982), this observation cannot be generalized to other soils of the tropics and subtropics, particularly those under intensive land use. Surface horizons of many soils of the tropics and sub tropics, with relatively less clay and organic matter, are less aggregated than soils of temperate zones (Habib *et al.*, 2010).

Physical and chemical differences between temperate and tropical soils might explain why the PTFs derived for soils of temperate climate origin appeared to be inadequate for oxisols and related soils (van den Berg *et al.*, 1997). It may also be argued that the poor performance of temperate soil PTFs arises because the clay content of oxisols frequently exceeds 60%, while PTFs developed for temperate soils often do not cover that range. As an example, the PTF by Rawls and Brakensiek (1985) is only valid for soils with clay contents between 5% and 60%. Tomasella *et al.* (2000) compared the performance of a PTF derived for Brazilian soils with a range of temperate soil PTFs and concluded that the former performed substantially better, even within the range of validity of latter. This result implies that there must be a marked difference in the hydraulic properties of tropical, sub-tropical, semi-arid and temperate soils (Hodnett and Tomasella, 2002). It is not surprising then that the PTF proposed by Tomasella *et al.* (2000) performed better in Cuban oxisols (Medina *et al.*, 2002) compared to temperate soil PTFs.

More recently, Sobieraj *et al.* (2001) argued that the hydrological behavior of tropical and sub-tropical soils cannot be attributed to the mineralogical factors as it had been suggested by Tomasella and Hodnett (1996). Based on data from kaolinitic soils with hydrated vermiculite interlayers from western Amazonia (which are similar to ultisols found everywhere in the world, according to the authors), they concluded that the poor performance of temperate PTFs in predicting saturated hydraulic conductivity resulted

from the lack of ability to reproduce the effects of macro porosity in tropical and sub-tropical soils. This may indeed be the case, but it is likely that tropical and sub-tropical soils typically have a greater macro porosity than temperate soils, and there is no reason why this should not be linked to their different mineralogy (Hodnett and Tomasella, 2002).

2.4 VALIDATION OF PTFs IN DIFFERENT REGIONS OF THE WORLD

There are many factors that lead to the variability of predicted and measured hydraulic soil properties by PTFs. These variations include climatic, topographical and soil differences. The effect of these factors on pedotransfer measurements have been evaluated in several parts of the world.

In china, Vandose region, Donhao Ma *et al.*, (2010) evaluated the validation of the use of pedotransfer function in this region which has soils that contain a lot of rock fragments. The use of pedotransfer function was adopted because of the lack of simple methods of determining unsaturated soil hydraulic conductivity. The relationship between saturated hydraulic conductivity and rock fragment content was not accurately estimated by different equations relating saturated hydraulic conductivity of stony soils to that of non-stony soils. These findings imply that other factors other than the reduction of cross sectional area for water flow influence the hydraulic properties of stony soils.

In Iran, there are areas which contain calcareous soils and the derivation of pedotransfer functions did not consider the effect of calcium compounds of the hydraulic conductivity. It was for this reason that Habib *et al* 2010 evaluated the use of pedotransfer function in Iran calcareous soils. No significant difference in accuracy was found between the PTFs with and without CaCO₃ in terms of estimating specific soil water retention values or the van Genuchten soil hydraulic parameters. Compared with the Rosetta PTFs of Schaap *et al.* (2001), the derived point and parametric PTFs provided better accuracy with average RMSE values of 0.028 and 0.107, respectively. A similar conclusion was reached by Homae and Farrakhan Firouzi (2008) regarding the use of Rosetta to predict water retention data of gypsiferous soils of Iran.

In Zimbabwe, Mugabe (2005). evaluated the validity of the pedotransfer function developed by Rawls (1982) on Zimbabwean soils. Mugabe (2005), in the study of Romwe

catmint stated that PTFs developed from different locations have not been used in other locations because of difference in particle size analysis, classification, and difference in pedology and in clay size minerals of the clay fraction. A significant difference between the measured and predicted values was realized. The Rawls (1982) equation was used to predict catchment soil moisture content at two potentials of -1500 and -60 kPa. The study shows that, in the absence of measured data of moisture characteristic curve, the Rawls (1982) empirical equation could be used to predict soil moisture content at given potentials provided a local calibration factor is used to take account of any systematic under or over estimation.

In the humid regions of the Congo, The point PTF of Dijkerman (1988) performed best at -33 kPa, while those of Arruda *et al.* (1987) and Pidgeon (1972) were best at -1500 kPa. Regarding the parametric PTFs which predicted the Van Genuchten, 1980 parameters, the tropical PTFs of Hodnett and Tomasella (2002) and the temperate PTFs of Schaap *et al.* (2001) gave the best results. Preliminary results of this evaluation studies in the suggest that estimates of water content by several existing temperate as well as tropical PTFs may induce errors in the outputs of watershed models used in various agricultural studies under the humid tropics (Buccigrossi *et al.*, 2010). Large discrepancies in the derived soil hydraulic data can substantially reduce the quality of the modelling results particularly in regions where soils may have been formed and evolved in similar climatological and pedological conditions as soils from the Lower Congo.

In Germany, Espino *et al.*, (1995) studied the influence of temperate PTFs of Vereecken *et al.* (1989) on the outcomes of the SWATRER model in the simulation of the hydraulic response of a multi-layered soil profile under natural climatic boundary conditions for a period of 1 year. They recommended that in further studies, many other PTFs should be included in a testing procedure prior to their application in more advanced models. To do this, a limited number of measured water retention data from the site of interest can be used to evaluate the PTFs. Most studies have evaluated PTFs that have been developed in temperate regions by using independent datasets (e.g. Tietje and Tapkenhinrichs, 1993; Kern, 1995; Cornelis *et al.*, 2001; Buccigrossi *et al.*, 2010). However, only a limited

number of studies have been conducted with databases of soils from the tropics and sub tropics (e.g. Tomasella and Hodnett, 2004; Reichert *et al.*, 2009; Nebel *et al.*, 2010).

CHAPTER THREE

3.0 MATERIALS AND METHOD

3.1 LOCATION

The study was conducted at the Field station of School of Agricultural Sciences at the University of Zambia in Lusaka. This site is at latitude 15° South and Longitude 28° 15' East and is 1140 m above sea level. It is in Agro-ecological Region II of Zambia which receives 800mm to 1200mm of rainfall per annum and average temperature of 24 °C.

3.2 SAMPLING

Soil samples were collected using core rings from four different soils based on soil mapping units for measurement of both basic and soil hydraulic properties. Ten replicate samples were collected for each type of soil. Another bulk sample was collected from each soil for soil characterization. The soil samples were collected to a depth of 0 – 20 cm. The collected undisturbed soil samples using the coring were subjected to analysis of selected hydraulic properties in the Laboratory at the University of Zambia. Additional disturbed samples were collected, air dried and sieved to less than 2 mm particle size diameter for further laboratory analysis. The hydraulic properties measured included saturated hydraulic conductivity, moisture content at wilting point and field capacity. Other parameters measured include organic matter content, particle size distribution and bulk density.

3.3 DETERMINATION OF SOIL BULK DENSITY

The soil bulk density was determined by the Core Method (Blake & Hartge, 1986). Using a pre-weighed core ring of known diameter and a hummer, one core was pushed into the ground and another on top was hammered into the ground. Using a spade, the cores were removed from the ground. A knife was used to cut the edges so that the soil fits into the cores and covered using lids. Once this was done for the four soil types, the samples were taken for laboratory analysis.

Each of the samples in the core was dried at a constant temperature of 105 °C for 24 hours in an oven. The oven dried soil was weighed and the bulk density of the soil was found by

dividing the mass of the dry soil by the volume of the core from each soil map unit. The porosity was then calculated from the bulk density.

$$\rho_b = \frac{M_s}{V_s} \quad \text{Equation 1}$$

Where ρ_b is the soil bulk density, and M_s is the mass of dry soil and V_s is volume of dry soil.

$$TPV = 1 - \frac{\rho_b}{\rho_s} \quad \text{Equation 2}$$

Where TPV is Total Pore Volume and ρ_s is particle density

3.4 PARTICLE SIZE ANALYSIS

The Hydrometer Method (Head, 1980) was used to evaluate the particle size distribution of the soil. An air dry sample was sieved through a 2 mm sieve to provide 50 g weight on an oven dry basis. The sample was placed in a dispersing cup and 50 mm of dispersing agent (5% calgon) was added and the cup was filled up to half with distilled water and stirred for 5 minutes.

The suspension was transferred to the sedimentation cylinder. Using a stream of distilled water, the transfer was completed. The level of the liquid was brought to 1 litre mark with distilled water. The temperature of the suspension was measured using a thermometer.

A plunger was inserted while holding the cylinder firmly, it was moved up and down to mix the content thoroughly. After 20 seconds, the hydrometer was lowered carefully and a reading was taken after 40 seconds. The mixing of the soil suspension was repeated and each time a reading was taken until a constant 40 second reading was obtained. This measurement measured the silt and clay content of the soil.

To get the clay content reading, the suspension was left standing for 16 hours and a hydrometer reading was obtained. The temperature was measured again after the hydrometer reading.

The hydrometer readings obtained were corrected for temperature and density of the dispersing agent. To find the correction factor of the dispersing agent, a clean sedimentation cylinder was filled with 50 mm of the dispersing agent (5% calgon) and was made to one litre with distilled water. The suspension was mixed with a plunger and the hydrometer was used to measure the density. To correct for temperature, 0.4 was added for temperature above 20⁰c while 0.4 was subtracted for temperature below 20⁰c.

3.5 DETERMINATION OF SOIL ORGANIC MATTER

Soil organic matter was determined using the Walkley and Black method (1934). One gram of air dry soil for each soil replicated three times was weighed into 250 ml conical flasks. 10 ml of 1N potassium chromate was pipetted and 20 ml of the concentrated sulphuric acid was added rapidly using an automatic pipette in the fume hood. It was stirred until there was complete mixture of the soil and the solution. The sample was swirled vigorously for 1-2 minutes and left to settle in the fume hood for thirty minutes. 150 ml of distilled water and 10 ml of concentrated phosphoric acid was added.

10 drops of the diphenylamine indicator was added and the sample was titrated with iron (II) sulphate. The colour changed from yellow brown to blue to violet then changed abruptly to green. The volume of the end point was recorded.

A blank sample was also done without soil to standardise the potassium chromate using the same procedure.

3.5.1 PREPARATION OF POTASSIUM CHROMATE (1N K₂CR₂O₇)

55 grams of potassium chromate (1N K₂Cr₂O₇) was dried at 200⁰C for two hours. From this amount, 49.04 grams was weighed into a one litre beaker and 300ml of distilled water was added. This was heated while stirring with a glass rod until all the potassium chromate was dissolved. The solution was poured into a volumetric flask of one litre. The flask was cooled and filled to the mark with distilled water.

3.5.2 PREPARATION OF IRON SULPHATE (Fe (II) SO₄7H₂O)

278 grams of Powder iron sulphate (Fe (II) SO₄7H₂O) was weighed into a one litre beaker. 700 ml of distilled water was added after which, 5 mls of concentrated sulphuric acid was added. To completely dissolve it, heat was applied while stirring. This solution was then transferred into a one litre volumetric flask, cooled and made to volume with distilled water.

3.5.3 DIPHENYLAMINE INDICATOR

0.5 grams of diphenylamine was weighed and dissolved in a mixture of 20ml distilled water and 100ml concentrated sulphuric acid (H₂SO₄) in a 500ml beaker. This was stirred vigorously and left to cool at room temperature.

3.6 DETERMINATION OF PLANT AVAILABLE WATER

Moisture content at field capacity and wilting point were measured using Pressure Chamber Apparatus. Undisturbed soil Samples were collected from the field using cylindrical core rings. Using an insert which fits exactly in the core, the sample was pushed out of the core for 1cm and a rubber ring was fitted around it. Using a knife, 1cm slice was cut. Another 1cm slice was pushed out and cut. One was used to measure moisture at field capacity and the other wilting point .This was done for all the ten replicate samples for each soil type.

For each of the replicate samples, the slice samples were placed on a plate inside two pressure chambers. The porous plates with the soil samples was wetted with distilled water and the pressure cell were closed. After 24 hours, the samples on the plate were saturated with water.

A pressure of 0.1 bars was applied (pF value 2) to one pressure chamber and the other a pressure of 15 bars was applied (pF value 4.2). The samples were removed after reaching equilibrium (48 hours) indicated by no water flowing out through the outlet. Before releasing the air pressure from the vessel of the apparatus, a pinch was put on the outflow tube for each plate. This prevented the back flow of moisture into the sample.

The soil samples were transferred into the pre-weighed moisture canes. The moist samples were weighed and then they were oven dried at 105⁰c for 24 hours. The oven dry sample were weighed and recorded.

The gravimetric moisture content was calculated at both 0.1 bars (field capacity) and 15 bars (wilting point) as H₂O (g)/100g soil. Volumetric moisture content was calculated from gravimetric moisture by multiplying with bulk density. The available moisture was then calculated as the difference between water content at Field Capacity and Wilting Point.

3.7 DETERMINATION OF PF VALUE AT LOW WATER CONTENT

This was done using potential meter (Decagon, 1998). Using potential meter plastic canes, 10 grams of soil was weighed and 3 ml of water was added. The soil and water was mixed uniformly and cover placed on the soil. This was left to equilibrate overnight.

Using a potential meter, the pF value was measured and the temperature was noted. The samples were oven dried at 105⁰C for 24 hours and the mass of the air dry soil samples was measured. The gravimetric moisture content was measured and converted to volumetric moisture content.

3.8 DETERMINATION SATURATED HYDRAULIC CONDUCTIVITY

Soil hydraulic conductivity was determined indirectly from infiltration measurements. Using a mini disc infiltrometer method, undisturbed soil samples in core rings were first oven dried in an oven at 105⁰C. A disc infiltrometer was filled with water and volume adjusted to zero. The infiltrometer fitted to a clamp stand was placed on top of the soil surface of the core ring and the stop watch was started. The volume of water in the infiltrometer was noted at 0.25,0.5,1,2,3,5,7,10,15,20,25,30,40,50,60,70,80,90,100 and 120 minutes.

Infiltration rate was calculated using the Modified Horton (1940) and the fitting parameters obtained using nonlinear method defined in Mathcad model (2000). Hydraulic conductivity was estimated from the basic infiltration rate from the Modified Horton equation.

$$I(t) = \frac{(q_i - q_0)}{k} [1 - e^{(-k*t)}] + q_0.t$$

Equation 3

Where q_i is initial flux, q_0 is final flux at equilibrium, k is a constant, t is time in minutes and $I(t)$ is the infiltration rate at time t .

3.8 DESCRIPTION OF THE PTFS USED

3.8.1 SAXTON et al., (2006)

This function was developed from original Brooks and Corey function (1964). It uses particle size analysis, organic matter, bulk density and salinity as parameter inputs to predict water content at field capacity and wilting point as well as hydraulic conductivity.

3.8.2 CAMPBELL (1974)

This function was developed by Campbell (1974) based on Brooks and Corey (1964). It predicts wilting point, field capacity moisture content and saturated hydraulic conductivity from soil texture and bulk density data.

3.8.3 RAWLS-BRAKENSIEK (1985)

This PTF is based on the original van Genuchten function (1980) and it allows estimation of different variables such as the air entry potential, pore size distribution index, residual water content. These variables are used to estimate the van Genuchten function parameters (n , m , θ_s and θ_r). To determine these parameters, sand (Sa) and clay (Cl) percentages and the porosity are requested.

3.9 VALIDATION ANALYSIS

The statistical analysis of the measured and predicted values was compared through the Coefficient of variation (R^2), Root Mean Squared Error (RMSE) and Mean Deviation (MD), also called bias, to evaluate the performance of models.

CHAPTER FOUR

4.0 RESULTS

4.1 SOIL CHARACTERIZATION

Results on selected basic soil and hydraulic properties are presented in *Table 1* and *Table 2*. Soil 2 had the highest organic matter content of 3.4 % while soil 1 had the lowest organic matter content of 1.04 %. The high organic matter content of soil 2 also corresponded with the lower bulk density while soil 1 had the highest bulk density. Soil 1 was found to be loam, soil 2 clay loam and soil 3 and 4 despite having different particle size distribution fell in the same textural class of Sand loam. These properties were used as inputs in the pedotransfer functions.

The van Genuchten parameters of the different soil represented in table 2 show that all the four soils had different parameters. These parameters were used to develop moisture characteristic curves to check how the measured moisture content at different potentials fitted into the soil moisture characteristic curves.

The results on the fitted water retention data are presented in *Figure 1*. The results showed that the measured values fitted well with the fitted equation.

Table 1: Selected soil properties

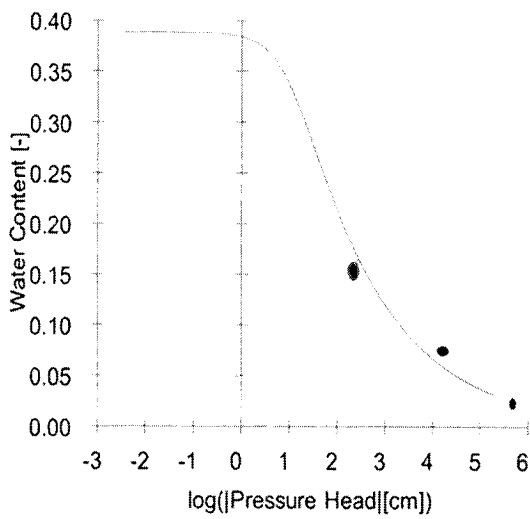
	O.M (%)	pd(g/cm ³)	Clay (%)	Silt (%)	Sand (%)	USDA class
Soil 1	1.04	1.62	21.6	36.5	41.9	Loam
Soil 2	3.44	1.47	31.6	39.4	29.0	Clay loam
Soil 3	1.10	1.61	8.6	38.0	53.4	Sand loam
Soil 4	1.75	1.58	2.6	47.0	50.4	Sand loam

OM=Organic matter, pd=bulk density

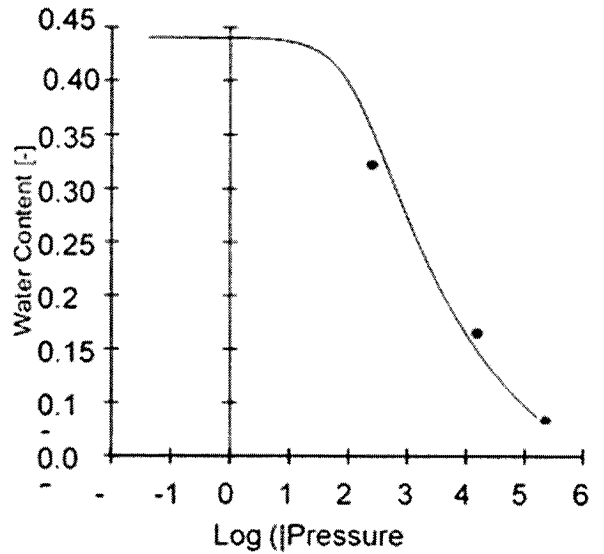
Table 2: Soil hydraulic properties according to the van Genuchten (1980) parameters

	θ_r	θ_s	α	n
Soil 1	0.044	0.357	0.0140	1.3306
Soil 2	0.069	0.435	0.0097	1.2818
Soil 3	0.030	0.331	0.0374	1.3643
Soil 4	0.034	0.336	0.0082	1.4528

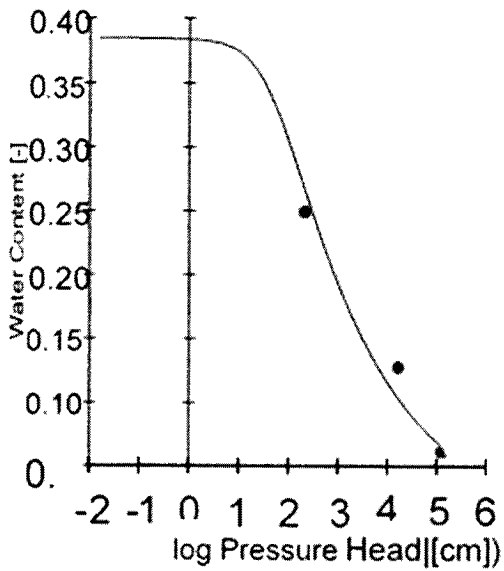
θ_s = Water content at saturation, θ_r = residual water content, α and n = curve fitting coefficients



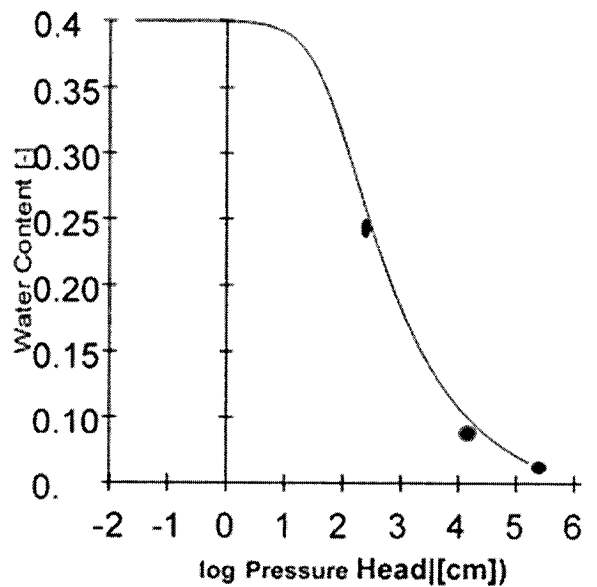
Soil 1



Soil 2



Soil 3

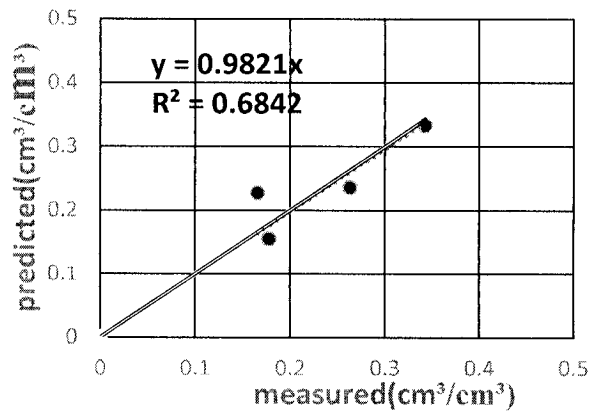


Soil 4

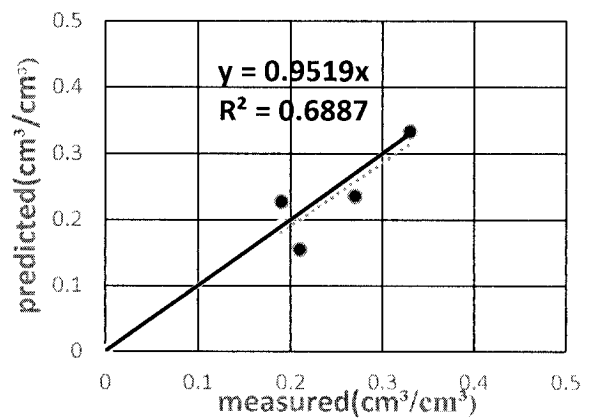
Figure 1: Soil moisture retention curves according to van Genuchten (1980) for the four types of soil.

Results of the comparison of the predicted and measured values at field capacity are presented in

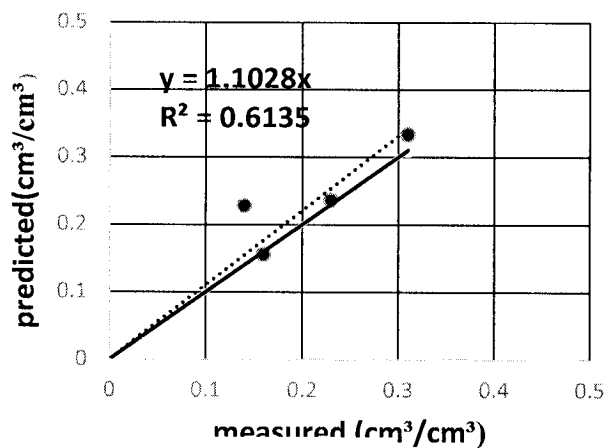
Figure 2. From the results, all the PTFs had a moderately high correlation of above 60%. The Campbell (1974) had the highest correlation of 0.6887 while the Rawls-Brakensiek (1985) had the lowest. However, the Saxton et al (2006) and Campbell (1974) models had a slope of less than zero (0.98 and 0.95 respectively) hence underestimated water content at field capacity. The Rawls-Brakensiek (1985) overestimated the value as indicated by the slope of above one (1.10). Generally, all the models predicted equally the water content at field capacity ($R^2 > 60\%$).



Saxton et al 2006



Campbell 1974



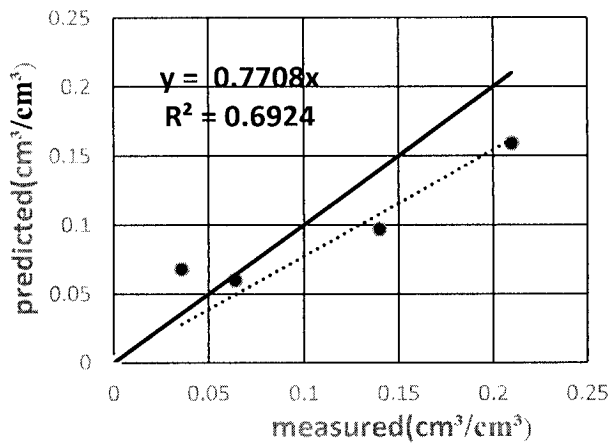
Rawls-Brakensiek 1985

- Measured moisture content
- 1:1 line (predicted= measured)
- trend line for measured moisture content

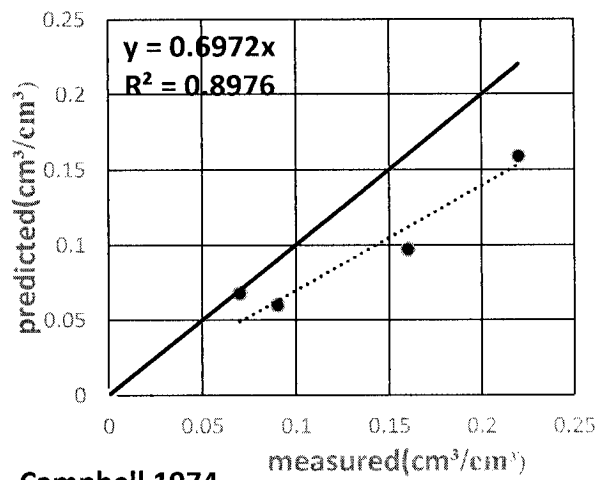
Figure 2: Comparison of measured and predicted Soil water content at field capacity by the three pedotransfer functions

4.2.2 COMPARISON OF MEASURED AND PREDICTED SOIL WATER CONTENT AT WILTING POINT

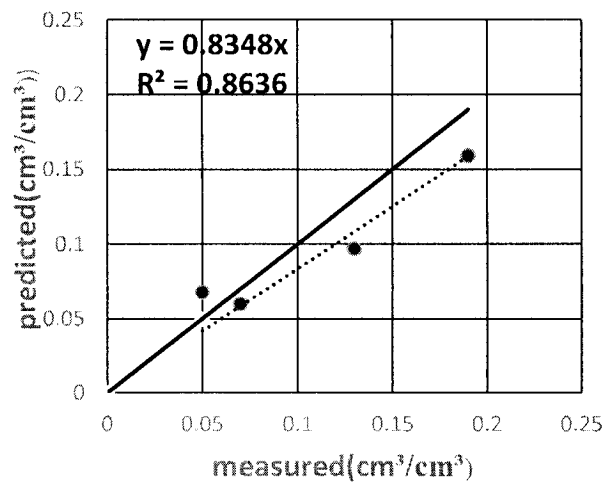
The results of the comparison of the predicted and measured values at wilting point are presented in Figure 3. The Campbell (1974) had the highest correlation coefficient of 0.8976 while the Saxton et al. (2006) had the lowest 0.6924. All the PTFs underestimated the moisture content as indicated by the slope less than one. The Rawls- Brakensiek (1985) had a slope closest to one, followed by the Saxton *et al.* (2006), then the Campbell (1974) which were 0.8348, 0.7708 and 0.6972 respectively.



Saxton et al 2006



Campbell 1974



Rawls-Brakensiek 1985

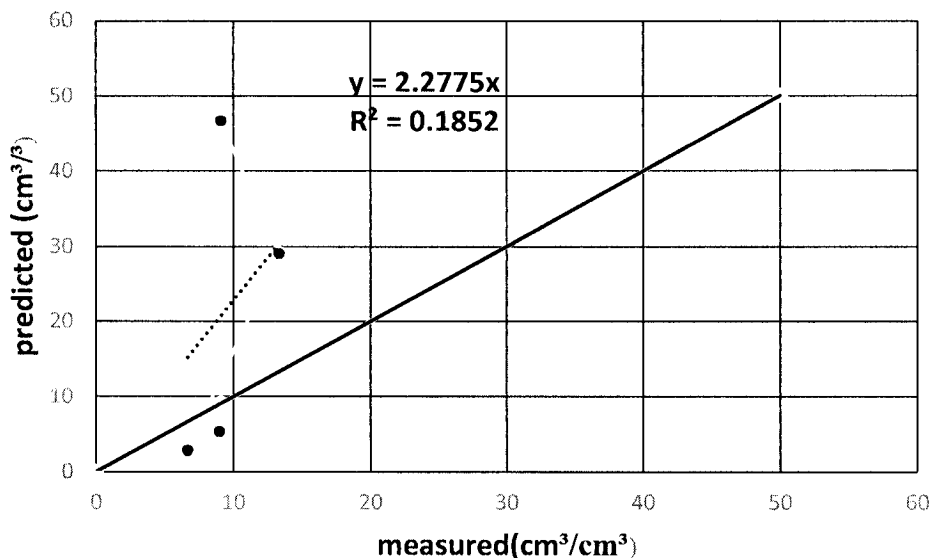
- Measured moisture content
- 1:1 line (predicted= measured)
-trend line for measured moisture content

Figure 3: Comparison of measured and predicted Soil water content at wilting point by the three pedotransfer functions.

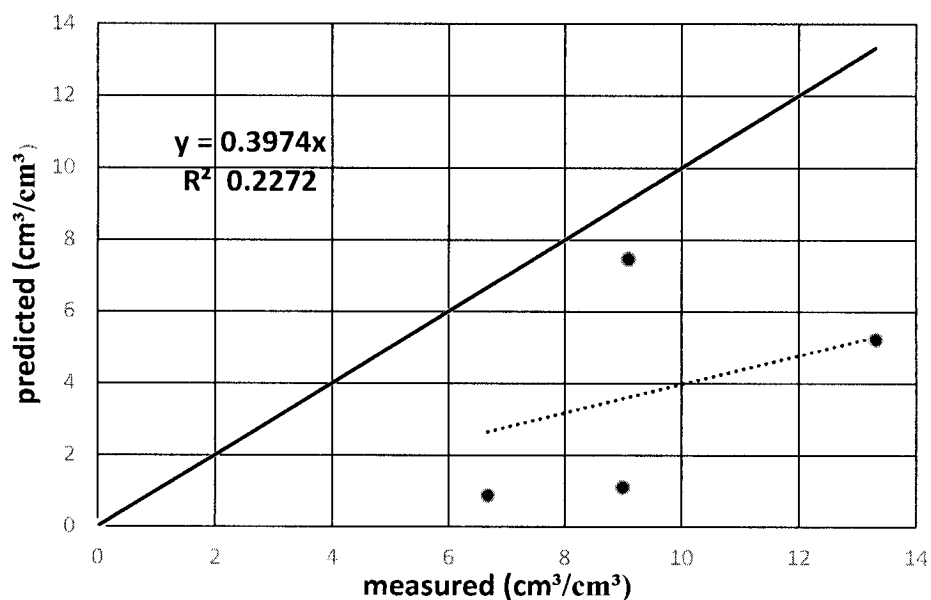
4.2.3 COMPARISON OF MEASURED AND PREDICTED SATURATED HYDRAULIC CONDUCTIVITY

Results of the comparison of the predicted and measured values of hydraulic conductivity are presented in *Figure 4*. The two PTFs showed a poor correlation coefficient between the measured and predicted moisture content of 0.1852 and 0.2272 for the Saxton et al. (2006) and the Campbell (1974) respectively. The Saxton et al. (2006) with a slope of

2.2775 overestimated the hydraulic conductivity while the Cambell (1974) with a slope of 0.3974 underestimated the value.



Saxton et al 2006



Campbell 1974

- Measured moisture content
- 1:1 line (predicted= measured)
- trend line for measured moisture content

Figure 4: Comparison of measured and predicted saturated hydraulic conductivity by the two pedotransfer functions.

4.2.4 COMPARISON OF MEAN DEVIATION (MD), ROOT MEAN SQUARE DEVIATION (RMSE) AND CORRELATION COEFFICIENT (R^2) FOR THE FITTED PTFs FOR THE DIFFERENT HYDRAULIC MEASUREMENTS.

The results of the comparison of the Mean Deviation (MD), Root Mean square deviation (RMSE) and Correlation coefficient (R^2) for the fitted PTFs for the different hydraulic measurements are presented in *Table 3*. At field capacity, the Saxton *et al* 2006 had the lowest mean deviation and root mean square error of 0.0004 and 0.0359 respectively. The cambell (1974) had the second lowest mean deviation and root mean square error of -0.0121 and 0.0374 respectively while the Rawls- Brakensiek (1985) had the lowest mean deviation and root mean square error of -0.2100 and 0.2203 respectively. This means it prediction was the closest to the measured value.

At wilting point, the Rawls-Brakensiek (1985) has the lowest mean deviation and root mean square error of -0.0140 and 0.0249 respectively and the Campbell (1974) had the lowest mean deviation and root mean square error of -0.039 and 0.0464 respectively. This means it predicted values were closest to the measured values.

For hydraulic conductivity, both the PTFs had a very high mean deviation and root mean square error. The Saxton *et al.*, (2006) had a mean deviation and root mean square error of -11.4455 and 20.5374 respectively while the Campbell (1974) had a mean deviation and root mean square error of 5.8520 and 6.4044 respectively. The two PTFs had high mean deviation and root mean square error implying that both the PTFs predictions were not close to the measured value.

Table 3: Mean Deviation (MD), Root Mean square deviation (RMSE) and Correlation coefficient (R^2) for the fitted PTFs for the different hydraulic measurement.

	Saxton et al (2006)	Campbell (1974)	Rawls-Brakensiek (1985)
Field capacity	MD = 0.0004 RMSE = 0.0359 R ² = 0.684	MD = -0.0121 RMSE = 0.0374 R ² = 0.6887	MD = -0.2100 RMSE = 0.2203 R ² = 0.6135
Wilting point	MD = -0.0165 RMSE = 0.0371 R ² = 0.6924	MD = -0.039 RMSE = 0.0464 R ² = 0.8976	MD = -0.0140 RMSE = 0.0249 R ² = 0.8636
Saturated hydraulic conductivity	MD = -11.4455 RMSE = 20.5374 R ² = 0.1852	MD = 5.8520 RMSE = 6.4044 R ² = 0.2272	

CHAPTER FIVE

5.0 DISCUSSION

The three pedotransfer functions were evaluated using the Mean deviation (MD), the Root mean square deviation (RMSD) and the coefficient of correlation. The use of the RMSD was to consolidate or confirm the mean deviation result. A lower MD value could be attributed to the low values of the differences between estimated and measured soil water contents or from more or less soil moisture differences which assigned positive or negative notation that opposite sign that, on summation cancel out each other. To avoid this uncertainty, use of the RMSD means squaring of the values of the differences between estimated and measured soil water contents. This eliminates the effect of the notation, and therefore it shows a real view of the values error.

At field capacity, the MD of the Saxton *et al.*, (2006), Campbell (1974) and the Rawls-Brakensiek (1985) are 0.0004,-0.0121 and -0.2100 while the RMSD are 0.0359, 0.0374 and 0.2203 respectively. These results implied that Saxton *et al.*, (2006) was able to predict the field capacity with the smallest degree of deviation from the measured as compared to the other two PTFs followed by the Campbell and lastly the Rawls-Brakensiek (1985). The high suitability of the Saxton *et al.*, (2006) at field capacity was also clear from the graphical presentation. The slope of the Saxton *et al.*, (2006) is the closest to 1(0.98) while the Rawls-Brakensiek (1985) has a slope of 1.1 which is the furthest from 1. The slope value can be seen as the ratio of the predicted to the measured value. This implies that the predicted value of the Saxton *et al.*, (2006) was the closest to the measured value.

In cases where these PTFs are to be used, the predicted value should be divided by 0.98, 0.95 and 1.1 for the Saxton *et al.*, (2006), Campbell (1974) and the Rawls-Brakensiek (1985) in order to get the actual value of the field capacity. This is because the Saxton *et al.* (2006) and the Campbell (1974) under predicted field capacity measured as indicated by the slope line less than one while the Rawls-Brakensiek (1985) over predicted the field capacity as indicated by the slope line greater than one (1.1028).

Although the Saxton *et al.*, (2006) has the closest slope to one, the three PTFs did not show very good correlation between the measured and predicted results. The coefficient of

correlation of the PTFs are 0.6842, 0.6887 and 0.6135 for the Saxton *et al* (2006), Campbell (1974) and the Rawls-Brakensiek (1985) respectively. Therefore there is need to evaluate other PTFs which can give a higher correlation.

The good prediction of the Saxton *et al.*, (2006) can be attributed to the fact that it has a high number of input parameters used to estimate the hydraulic properties than the other two PTFs. In addition to the soil texture and bulk density used as inputs in the Campbell (1974) and the Rawls-Brakensiek (1985), the Saxton *et al.*, (2006) includes organic matter content and salinity parameters as inputs.

At wilting point, the MD of the Saxton *et al.*, (2006), Campbell (1974) and the Rawls-Brakensiek (1985) are -0.0165,-0.039 and -0.014 while the RMSD is 0.0371, 0.0464 and 0.0249 respectively. This implies the Rawls-Brakensiek 1985 is a better predictor at wilting point than the other two functions. This is because it has a lower degree of deviation from the measured values.

The ability of the Rawls-Brakensiek 1985 to predict water content at wilting point is also proved using graphical analysis. The slope of the Saxton *et al.*, (2006), Campbell (1974) and the Rawls-Brakensiek (1985) are 0.7708, 0.6972 and 0.8348 respectively. The slope of the Rawls-Brakensiek (1985) is the closest to 1 hence more accurate. In cases where these PTFs are used to predict moisture content in the area of study, the predicted value should be divided by the above slope values to get the actual value of the moisture content.

The Coefficient of correlation (R^2) between the predicted and measured of all the three PTFs was favorable (above 90%). R^2 is highest for the Rawls-Brakensiek (1985) which is 0.9217. The Saxton *et al.*, (2006) and Campbell (1974) have R^2 of 0.9119 and 0.9055 respectively. There was better correlation of the measured and predicted values at wilting point than at field capacity for all the three PTFs. This was because at high potentials, moisture retention was strongly affected by texture unlike at lower potential where organic matter and other factors also strongly influence the water content. Therefore there was good correlation as only one factor was strongly variable.

At wilting point, all the three PTFs under predicted the moisture content. As indicted by the slope line less than one. These were 0.7708, 0.6972 and 0.8348 for the Saxton *et al.*,

(2006), Campbell (1974) and the Rawls-Brakensiek (1985) respectively. This could be attributed to the difference in mineralogy. The soils from which the PTFs were developed might have had a higher proportion of clay minerals that do not hold a lot of water like the 2:1 non expandable clays than the soils on which it was used to predict. Hence giving a lower prediction of water content for the same overall clay content. In addition to this, for the Campbell (1974) and Rawls-Brakensiek (1985), the under prediction could have arisen from the fact that they do not incorporate organic matter content as an input. Organic matter tends to hold water thereby increasing the water content at a given potential.

For hydraulic conductivity, Saxton *et al.* (2006) and Campbell (1974) were evaluated. Although the Campbell (1974) showed a less degree of deviation from the measured values (5.852) and graphical slope closest to 1(0.3974) than the Saxton *et al.*, (2006), both these functions indicated a poor correlation between the measured and predicted results. The R² was 0.2114 and 0.2565 for the Saxton *et al* (2006) and Campbell (1974) respectively. In general, the deviation from the measured value for both is very high. The Saxton *et al.*, (2006) over estimate the hydraulic conductivity as indicated by a slope value of 2.2775 while Campbell 1974 under estimated the measured values as indicated by the slope value of value 0.3974.

Because of the poor correlations, both these function were not favorable for use in the study area. This inaccuracy of the two functions could be attributed to climate, structure of soil and methodological used to measure hydraulic conductivity.

The under estimation of hydraulic conductivity by the Campbell (1974) can be attributed to presence of sesquioxides and carbonates in the studied soils (subtropical soils). These act as cementing agents in the soil and improve the soil structure. This means that for the same texture and organic matter content, tropical and semi-arid soils could have a better soil structure than temperate soils. The better soil structure means the hydraulic conductivity will be higher for subtropical and semi-arid climate soil like studied soils. The laboratory determination of the hydraulic conductivity may differ from that used in this research and this could be the source of the deviation. The values differ if disturbed and undisturbed samples are used. Some European laboratories where these functions were

developed, used disturbed samples to measure hydraulic conductivity (Schaap *et al.*, 2001) while in this research, undisturbed samples were used.

The over estimation by the Saxton *et al.*, (2006) could be attributed to the fact that saturated hydraulic conductivity of a soil depends on many factors. The main factor that affected the value of hydraulic conductivity was the average size of the pores between particles in the soil, which in turn was related to the distribution of particle sizes, particle shape and roughness, pore continuity, and soil structure. In general, the bigger the average size of the pores, the higher the value of hydraulic conductivity. The soils on which this PTF was developed could have different properties than the one on which it was used to measure the saturated hydraulic conductivity. Hence it predicted a higher saturated hydraulic conductivity.

Secondly, the hydraulic conductivity is also dependent on viscosity and density of water in which both are affected by temperature. Therefore, value of hydraulic conductivity would then be affected by changes in temperature. Theoretically, it can be shown that for laminar flow and saturated soil condition, there is an inverse relationship between temperature and hydraulic conductivity. The difference in the temperature between the temperate and tropical climate could have caused the variations.

In general, the mineralogical and climatic differences between the temperate and tropical climates might be the cause of the poor performance of the temperate pedotransfer functions.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATION

6.1 CONCLUSION

The Saxton *et al.*, (2006) with the lowest values of MD and RMSD (0.0004 and 0.03585 respectively) was a better predictor of moisture content at field capacity while the Rawls-Brakensiek (1985) with the lowest values of MD and RMSD (-0.014 and 0.0464) was the better predictor of moisture content at wilting point.

Both the Saxton *et al.*, (2006) and the Campbell (1974) with MD values of -11.44 and 5.852 respectively are poor predictors of saturated hydraulic conductivity.

6.2 RECOMMENDATIONS

The research was successfully conducted but with a few challenges which could have affected the quality of the results. The following recommendations can be made to improve on the quality of this research.

Firstly, the study area for future research should be increased so that more soil types with varied texture, bulk density and organic matter content are studied. Secondly, there is room to compare more available PTFs.

With these recommendations, the results of this study can be improved.

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APPENDICES

APPENDIX 1: Evaluation analysis at field capacity for Campbell 1974

Measured	Predicted	(x-y)	$\sum(x-y)$	$\sum(x-y)/n$	(x-y) ²	$\sum(x-y)^2$	$\sum(x-y)^2/n$	$\sqrt{\sum(x-y)^2/n}$
0.236	0.27	-0.034	-0.048	-0.0121	0.00115	0.0056	0.0014	0.0374
0.333	0.33	0.003			9E-06			
0.155	0.21	-0.055			0.0030			
0.2275	0.19	0.0375			0.0014			

APPENDIX 2: Evaluation analysis at wilting point for Campbell 1974

Measured	Predicted	(x-y)	$\sum(x-y)$	$\sum(x-y)/n$	(x-y) ²	$\sum(x-y)^2$	$\sum(x-y)^2/n$	$\sqrt{\sum(x-y)^2/n}$
0.097	0.16	-0.063	-0.156	-0.039	0.0040	0.0086	0.0021	0.0464
0.159	0.22	-0.061			0.00372			
0.06	0.09	-0.03			0.0009			
0.068	0.07	-0.002			4E-06			

APPENDIX 3: Evaluation analysis for hydraulic conductivity of the Campbell 1974

Measured	Predicted	(x-y)	$\sum(x-y)$	$\sum(x-y)/n$	(x-y) ²	$\sum(x-y)^2$	$\sum(x-y)^2/n$	$\sqrt{\sum(x-y)^2/n}$
8.989	1.1	7.889	23.4080	5.852	62.2363	164.0670	41.0167	6.4044
6.676	0.87	5.806			33.7096			
13.313	5.22	8.093			65.4966			
9.09	7.47	1.62			2.6244			

APPENDIX 4: Evaluation analysis at field capacity for saxton et al 2006

Measured	Predicted	(x-y)	$\sum(x-y)$	$\sum(x-y)/n$	(x-y) ²	$\sum(x-y)^2$	$\sum(x-y)^2/n$	$\sqrt{\sum(x-y)^2/n}$
0.236	0.263	-0.027	0.0015	0.00038	0.00073	0.00514	0.00128	0.03585
0.333	0.343	-0.01			0.0001			
0.155	0.178	-0.023			0.00053			
0.2275	0.166	0.0615			0.00378			

APPENDIX 5: Evaluation analysis at wilting point for saxton et al 2006

Measured	Predicted	(x-y)	$\sum(x-y)$	$\sum(x-y)/n$	(x-y) ²	$\sum(x-y)^2$	$\sum(x-y)^2/n$	$\sqrt{\sum(x-y)^2/n}$
0.097	0.14	-0.043	-0.066	-0.0165	0.001849	0.00549	0.0013725	0.03705
0.159	0.21	-0.051			0.002601			
0.06	0.064	-0.004			0.000016			
0.068	0.036	0.032			0.001024			

APPENDIX 6: Evaluation analysis for saturated hydraulic conductivity for saxton et al 2006

Measured	Predicted	(x-y)	$\sum(x-y)$	$\sum(x-y)/n$	(x-y) ²	$\sum(x-y)^2$	$\sum(x-y)^2/n$	$\sqrt{\sum(x-y)^2/n}$
8.989	5.33	3.659	-45.782	-11.4455	13.388281	1687.1462	421.7865	20.5374
6.676	2.83	3.846			14.7917			
13.313	29.02	-15.707			246.7098			
9.09	46.67	-37.58			1412.2564			

APPENDIX 7: Evaluation analysis for field capacity of the Rawls- Brakensiek 1985

Measured	Predicted	(x-y)	$\sum(x-y)$	$\sum(x-y)/n$	$(x-y)^2$	$\sum(x-y)^2$	$\sum(x-y)^2/n$	$\sqrt{\sum(x-y)^2/n}$
0.236	0.23	-0.23	-0.8400	-0.2100	0.0529	0.1942	0.0486	0.2203
0.333	0.31	-0.31			0.0961			
0.155	0.16	-0.16			0.0256			
0.2275	0.14	-0.14			0.0196			

APPENDIX 8: Evaluation analysis for wilting point of the Rawls- Brakensiek 1985

Measured	Predicted		(x-y)	$\sum(x-y)$	$\sum(x-y)/n$	$(x-y)^2$	$\sum(x-y)^2$	$\sum(x-y)^2/n$	$\sqrt{\sum(x-y)^2/n}$
0.097	0.13	0.097	-0.033	-0.0560	-0.0140	0.0011	0.0025	0.0006	0.0249
0.159	0.19	0.159	-0.031			0.0010			
0.06	0.07	0.06	-0.01			0.0001			
0.068	0.05	0.068	0.018			0.0003			