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Determination of The Physicochemical Properties and Regression of Hydraulic Conductivity on Selected Properties of Soil in Abia State, Nigeria

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ABSTRACT: Hydraulic conductivity (K) is one of the most important hydraulic properties of the soil matrix and often considered as one of the most difficult hydraulic properties to obtain. The study is situated within the broader framework of Agricultural & Bioresources Engineering, a field concerned with optimizing natural resources for sustainable Agriculture using Engineering principles. The research aims to evaluate how soil texture, physical structure, and chemical composition interact across various soil types—Ferralitic, Hydromorphic, and Alluvial and how these interactions influence hydraulic conductivity at different depths (1–15 cm, 16–25 cm, and 26–35 cm). These properties are critical for irrigation planning, fertilizer scheduling, erosion control, and the design of soil-water conservation structures. Field sampling was carried out systematically across selected Agricultural zones in Abia State. A total of 27 composite soil samples were collected and analyzed for both physical properties—sand, silt, clay, bulk density, porosity, particle density, and hydraulic conductivity—and chemical properties—nitrogen (N_2), organic carbon (OC), calcium (Ca), magnesium (Mg), potassium (K), sodium (Na), and phosphorus (P). Laboratory analysis followed standardized protocols, and data were subjected to statistical modeling, using Response Surface Methodology (RSM) to investigate multi-variable interactions and predictive capabilities. The results revealed significant spatial and vertical variability in all soil parameters. Texture analysis showed that sand dominates the topsoil (average 61.24%), while clay increases with depth, particularly in Ferralitic soils of Abia South, where values exceed 38%. Silt content remained relatively consistent but played a secondary role in determining hydraulic behavior. Bulk density ranged from 1.12 to 1.82 g/cm³, increasing with depth, while porosity showed a converse trend, reflecting classical compaction profiles. Particle density was stable (~2.34 g/cm³), suggesting mineral-dominant soils with moderate organic input. Hydraulic conductivity values were highly variable (0.02896–0.8211 cm/s), with higher values in sandy topsoils and reduced permeability in clay-rich subsoils. Alluvial and Hydromorphic soils showed moderate to high K values at surface layers, while Ferralitic subsoils in Abia Central and South recorded significantly lower K, likely due to clay accumulation and poor structure. Chemical properties also demonstrated depth-dependent variation. Organic carbon and nitrogen showed steep gradients, declining from surface to subsoil due to leaching and microbial decomposition. Calcium and magnesium were more stable but still declined with depth. Potassium, being highly mobile, showed the steepest drop, especially in sandy or coarser-textured profiles. Phosphorus levels were generally adequate but immobilized in Ferralitic soils due to fixation by aluminum and iron oxides. Sodium levels remained within acceptable limits, except in some alluvial soils where values approached thresholds that could risk structural dispersion. Response surface models were developed using second-order polynomial equations to predict hydraulic conductivity (K) as a function of texture (sand, clay), bulk density, organic carbon, and cation concentrations (Ca, Mg, Na). By integrating physical and chemical properties into a predictive framework, the study empowers stakeholders—farmers, engineers, agronomists, and policy-makers—with data-driven tools for sustainable land management in Abia State and similar agro-ecological zones. The research highlights not only the variability and complexity of tropical soils but also the opportunity to optimize productivity through informed soil management and bioresource engineering interventions.

KEYWORDS: Response surface, analysis, physicochemical, properties, hydraulic, conductivity, soil

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1.0 INTRODUCTION

1.1 Background of the Study

The importance of hydraulic conductivity cannot be over emphasized as it is an important hydraulic property frequently used in hydrological modelling and water flow related studies in soils such as irrigation, drainage system design and infiltration modelling. It is a key parameter for monitoring soil and water management (Edet *et al.*, 2024). Knowledge of the rate of water permeability through various soil types is essential for determining the type of plants to be grown, spacing, yield, managing soil–water systems and erosion control. Many methods have been developed over time for field and laboratory measurement for hydraulic conductivity (Ritzema, 2015).

In science and engineering, hydraulic conductivity (K, SI units of meters per second), is a property of porous materials, soils and rocks, that describes the ease with which a fluid (usually water) can move through the pore space, or fractures network (Edet *et al.*, 2025). It depends on the intrinsic permeability of the material, the degree of saturation, and on the density and viscosity of the fluid. Saturated hydraulic conductivity, K_{sat}, describes water movement through saturated media (Batu, 2007).

The hydraulic conductivity values of the topsoil are often subject to changes with time, which can be seasonal variations or time trends. This is due to the drying of the topsoil during a dry season or after the introduction of drainage (Dirksen, 2022). 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, 2012).

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 matter content, texture, permeability, pH and Cation exchange capacity (CEC) will influence the rate of flow of water and other pollutants (Butler, 2005). 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 (ASTM, 2016).

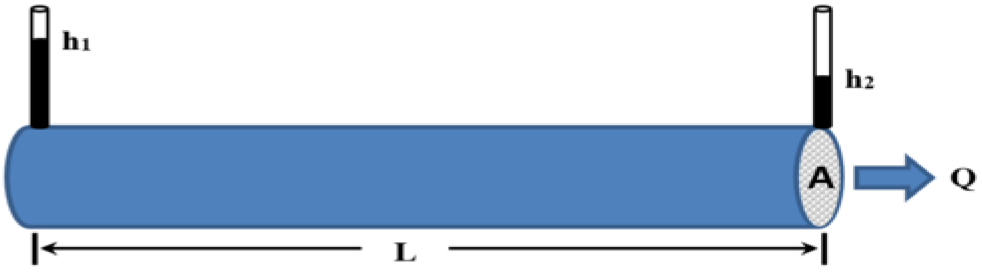
By definition, hydraulic conductivity is the ratio of volume flux to hydraulic gradient yielding; a quantitative measure of a saturated soil's ability to transmit water when subjected to a hydraulic gradient. The hydraulic conductivity proportionality constant, can be conceptualized as the relative ease of fluid passage through a porous material. It has direction and magnitude and is represented as a vector. Rearranging Darcy's law to solve for hydraulic conductivity generates Equation (**1)** (Darcy, 1999)

$$K = -Q\frac{\Delta L}{\Delta h \ A} \tag{1}$$

In this configuration, it becomes clear that the units of K are L/T because Q units are (L^3/T), A units (L^2), h units are (L), and L units are (L). The units are presented as Equation (**2**).

$$\frac{L}{T} : \frac{L^3}{T}\frac{L}{LL^2} \tag{2}$$

Thus, the constant of proportionality, K, has units of velocity (e.g., meters/seconds, meters/day). However, K is not a velocity, rather it represents the transmission properties of the porous material (Vukovic and Soro, 2010). If water easily passes through a porous material, it is described as having a high hydraulic conductivity; if water is poorly transmitted through a material, it has a low hydraulic conductivity. These conditions are also referred to as permeable or of low permeability, respectively (Darcy, 1999). Hydraulic conductivity is mathematically defined as a parameter K in Darcy's Law according to figure **1** and equation (3).



$$Q = -K \times i \times A \tag{3}$$

Where: Q = the flow rate across area A of a porous medium
K = hydraulic conductivity
I = is the hydraulic gradient which can be computed

$$i = \frac{(h_2 - h_1)}{L} \tag{4}$$

Where: h1 and h2 = the hydraulic heads at the ends of the experimental domain
L = the total length

The broad objective of the study is to mathematically analyze the properties of selected soils in Abia State, Nigeria around the soil location, soil type, depth and season. The specific objectives of the study are: To determine soil physical properties, including grain size distribution, porosity, fluid density, bulk density and particle density. To determine the chemical properties of the soils–pH, cation exchange capacity (CEC), exchangeable sodium percentage (ESP). To determine the effects of these properties on the hydraulic conductivity of soils from different locations in Abia State, Nigeria. To determine the soil properties that play more significant role with respect to hydraulic conductivity, hence, the effective factors in hydraulic conductivity prediction.

Table 1: Descriptive statistics of physical properties of different soil types at different depths in the three Senatorial Districts of Abia State

Property	Sand (%)	Silt (%)	Clay (%)	Bulk Density (g/cm³)	K (cm/s)	Particle density (g/cm3)	Porosity (%)	pH
Total count (N)	567	567	567	567	567	567	567	567
Mean	61.24	11.76	27.02	1.64	0.30	2.34	29.45	5.97
Std Dev	7.069	2.494	7.618	0.0908	0.08691	0.1360	5.448	0.4462
SE Mean	0.297	0.105	0.320	0.00381	0.00365	0.00571	0.229	0.0187
Sum	34723.00	6668.00	15322.00	931.1930	167.2917	1323.810	16696.86	3386.750
Variance	49.967	6.222	58.030	0.00825	0.00755	0.0185	29.685	0.1991
Coef Var	11.54	21.21	28.19	5.53	29.45	5.83	18.50	7.47
Minimum	43.000	4.000	7.000	1.1220	0.02896	2.0200	15.420	4.6000
Maximum	84.000	18.000	46.000	1.8200	0.8211	2.7200	48.290	6.8000
Range	41.000	14.000	39.000	0.6980	0.79214	0.7000	32.870	2.2000
Skewness	-0.01	-0.04	0.01	-1.25	0.46	0.32	0.37	-0.32
Kurtosis	0.20	-0.00	-0.31	3.55	1.72	-0.47	-0.18	-0.61
MSSD	12.1110	2.2990	17.7760	0.0013	0.0012	0.0027	4.2300	0.0291

Table 2: Descriptive statistics of chemical properties of different soil types at different depths and in the three Senatorial Districts of Abia State

Variable	N_2 (%)	Organic C (%)	Ca (cmol/kg)	Mg (cmol/kg)	K (cmol/kg)	Na (cmol/kg)	P (mg/kg)
Total Count (N)	567	567	567	567	567	567	567
Mean	0.15734	1.4514	2.4575	1.9714	0.21718	0.19474	20.679
SE Mean	0.0021	0.0184	0.0436	0.0344	0.00350	0.00303	0.172
Std Dev	0.04993	0.4380	1.0383	0.8186	0.08337	0.07205	4.103
Variance	0.00249	0.1919	1.0780	0.6701	0.00695	0.00519	16.834
Coef Var	31.73	30.18	42.25	41.52	38.39	37.00	19.84
Minimum	0.08000	0.1000	0.9400	0.0800	0.04000	0.00000	9.330
Maximum	0.60000	3.1600	9.9800	8.1200	0.42000	0.44000	32.000
Range	0.5200	3.0600	9.0400	8.0400	0.38000	0.44000	22.670
Sum	89.21000	822.9400	1393.380	1117.770	123.14000	110.42000	11725.110
Skewness	1.75	0.60	1.92	1.28	0.19	0.50	-0.16
Kurtosis	10.12	0.99	8.08	5.23	-0.72	0.00	-0.10
MSSD	0.00095	0.04100	0.12770	0.12150	0.00187	0.00136	5.14400

Table 3: Basic composition of different soil types at different depths in the three Senatorial Districts of Abia State

Location (Senatorial district)	Soil type	Soil depth (cm)	Sand (%)	Silt (%)	Clay (%)
Abia North	Ferralitic	1 – 15	$70.62^{a}\pm7.59$	$13.52^{bc}\pm2.29$	$15.86^{o}\pm6.18$
		16 – 25	$63.76^{efg}\pm4.99$	$10.86^{ghij}\pm2.44$	$25.38^{hij}\pm4.60$
		26 – 35	$61.86^{fghi}\pm6.45$	$8.86^{l}\pm2.99$	$30.71^{def}\pm4.4.3$
	Hydromorphic	1 – 15	$64.19^{def}\pm4.34$	$14.05^{abc}\pm1.50$	$21.76^{klm}\pm3.42$
		16 – 25	$60.95^{ghij}\pm4.27$	$12.00^{efg}\pm1.10$	$27.05^{ghi}\pm3.88$
		26 – 35	$57.86^{jklm}\pm3.73$	$10.24^{ijk}\pm1.14$	$31.91^{cdef}\pm3.27$
	Alluvial	1 – 15	$66.76^{cde}\pm2.76$	$13.00^{cde}\pm1.82$	$20.24^{lm}\pm3.73$
		16 – 25	$62.38^{fgh}\pm1.99$	$11.48^{fgh}\pm1.66$	$26.14^{hi}\pm3.05$
		26 – 35	$60.24^{hijk}\pm1.26$	$10.48^{hijk}\pm1.33$	$29.29^{fg}\pm1.98$
Abia Central	Ferralitic	1 – 15	$69.95^{ab}\pm3.44$	$14.00^{abc}\pm2.55$	$16.05^{o}\pm2.40$
		16 – 25	$64.29^{def}\pm3.54$	$11.38^{fghi}\pm1.66$	$24.33^{ijk}\pm2.89$
		26 – 35	$60.05^{hijk}\pm2.64$	$9.81^{jkl}\pm1.29$	$29.71^{defg}\pm3.04$
	Hydromorphic	1 – 15	$69.38^{abc}\pm8.07$	$13.38^{bcd}\pm2.67$	$17.24^{no}\pm6.37$
		16 – 25	$62.52^{fgh}\pm7.76$	$10.62^{hij}\pm2.13$	$26.86^{ghi}\pm5.87$
		26 – 35	$57.67^{klmn}\pm6.25$	$10.05^{jk}\pm3.97$	$32.29^{cde}\pm5.43$
	Alluvial	1 – 15	$63.57^{fg}\pm5.34$	$13.33^{bcd}\pm2.37$	$23.10^{jkl}\pm5.35$
		16 – 25	$56.90^{lmn}\pm6.60$	$11.43^{fgh}\pm1.78$	$31.67^{def}\pm6.54$
		26 – 35	$52.71^{op}\pm5.04$	$10.24^{ijk}\pm1.79$	$37.05^{ab}\pm5.05$
Abia South	Ferralitic	1 – 15	$57.57^{klmn}\pm4.78$	$14.71^{a}\pm1.55$	$27.57^{gh}\pm5.44$
		16 – 25	$54.71^{no}\pm4.92$	$12.33^{def}\pm0.73$	$32.48^{cd}\pm4.69$
		26 – 35	$50.95^{p}\pm5.10$	$10.43^{hijk}\pm0.81$	$38.62^{a}\pm4.65$
	Hydromorphic	1 – 15	$67.00^{bcd}\pm3.35$	$13.67^{abc}\pm1.53$	$19.33^{mn}\pm3.53$
		16 – 25	$61.86^{fghi}\pm3.25$	$11.95^{efg}\pm1.28$	$26.19^{hi}\pm3.53$
		26 – 35	$59.10^{ijkl}\pm2.86$	$9.33^{kl}\pm0.91$	$31.81^{def}\pm3.03$
	Alluvial	1 – 15	$62.86^{fgh}\pm6.94$	$14.38^{ab}\pm1.36$	$22.76^{jkl}\pm6.72$
		16 – 25	$58.57^{jkl}\pm7.29$	$12.00^{efg}\pm1.48$	$29.43^{efg}\pm7.74$
		26 – 35	$55.19^{mno}\pm6.09$	$10.00^{jkl}\pm1.58$	$34.81^{bc}\pm6.41$

Values are mean ± standard deviation of replicate determination (n = 21). Means in the same column bearing different superscripts are significantly different at $p < 0.05$.

Table 4: Physical properties of different soil types at different depths and in the three Senatorial Districts of Abia State

Location (Senatorial district)	Soil type	Soil depth (cm)	Bulk density (g/cm³)	Hydraulic conductivity, K (cm/s)	Particle density (g/cm³)	Porosity (%)	pH
Abia North	Ferralitic	1 – 15	$1.52^{n}\pm0.07$	$0.140^{k}\pm0.02$	$2.33^{efg}\pm0.11$	$34.59^{bcd}\pm4.51$	$6.24^{a}\pm0.30$
		16 – 25	$1.60^{klm}\pm0.04$	$0.232^{hi}\pm0.02$	$2.38^{cdef}\pm0.14$	$32.58^{de}\pm4.26$	$6.35^{a}\pm0.27$
		26 – 35	$1.63^{ijk}\pm0.03$	$0.246^{h}\pm0.05$	$2.35^{efg}\pm0.10$	$30.36^{fgh}\pm2.95$	$6.36^{a}\pm0.36$
	Hydromorphic	1 – 15	$1.67^{fgh}\pm0.06$	$0.278^{g}\pm0.05$	$2.37^{def}\pm0.19$	$29.26^{hi}\pm5.14$	$6.22^{ab}\pm0.40$
		16 – 25	$1.69^{cdefg}\pm0.05$	$0.301^{fg}\pm0.05$	$2.39^{cde}\pm0.18$	$28.86^{hi}\pm4.25$	$5.89^{de}\pm0.53$
		26 – 35	$1.75^{a}\pm0.04$	$0.342^{cde}\pm0.04$	$2.42b^{cd}\pm0.20$	$27.38^{ij}\pm5.67$	$5.75^{efg}\pm0.57$
	Alluvial	1 – 15	$1.61^{kl}\pm0.03$	$0.245^{h}\pm0.05$	$2.19^{i}\pm0.12$	$26.40^{jkl}\pm3.89$	$6.32^{a}\pm0.28$
		16 – 25	$1.69^{defg}\pm0.06$	$0.324^{ef}\pm0.05$	$2.22^{i}\pm0.08$	$23.89^{mn}\pm4.08$	$6.01^{bc}d\pm0.26$
		26 – 35	$1.73^{ab}\pm0.06$	$0.350^{cd}\pm0.04$	$2.25^{hi}\pm0.08$	$23.00^{n}\pm2.72$	$5.78^{efg}\pm0.24$
Abia Central	Ferralitic	1 – 15	$1.52^{n}\pm0.13$	$0.182^{j}\pm0.03$	$2.34^{efg}\pm0.07$	$35.24^{bc}\pm4.35$	$5.93^{cde}\pm0.24$
		16 – 25	$1.58^{lm}\pm0.05$	$0.207^{ij}\pm0.02$	$2.32^{fg}\pm0.08$	$31.99^{efg}\pm2.48$	$5.76^{efg}\pm0.37$
		26 – 35	$1.568^{m}\pm0.10$	$0.230^{hi}\pm0.05$	$2.35^{efg}\pm0.05$	$33.21^{de}\pm4.59$	$5.61^{ghi}\pm0.44$

	Hydromorphic	1 – 15	$1. 50^{n}\pm0.11$	$0.183^{j}\pm0.03$	$2.48^{ab}\pm0.11$	$39.59^{a}\pm3.95$	$5.91^{de}\pm0.32$
		16 – 25	$1.57^{lm}\pm0.09$	$0.233^{hi}\pm0.03$	$2.44^{abc}\pm0.09$	$35.53^{b}\pm3.18$	$5.90^{de}\pm0.39$
		26 – 35	$1.60^{klm}\pm0.03$	$0.241^{h}\pm0.02$	$2.48^{ab}\pm0.10$	$35.48^{bc}\pm2.13$	$5.88^{def}\pm0.37$
	Alluvial	1 – 15	$1.62^{jk}\pm0.03$	$0.281^{g}\pm0.04$	$2.22^{i}\pm0.05$	$27.30^{ij}\pm2.04$	$6.36^{a}\pm0.27$
		16 – 25	$1.62^{jk}\pm0.04$	$0.319^{ef}\pm0.04$	$2.24^{hi}\pm0.09$	$27.99^{ij}\pm3.00$	$6.28^{a}\pm0.29$
		26 – 35	$1.62^{jk\pm}0.05$	$0.345^{cde}\pm0.05$	$2.21^{i}\pm0.05$	$26.62^{jk}\pm2.29$	$6.20^{ab}\pm0.29$
Abia South	Ferralitic	1 – 15	$1.71^{abcde}\pm0.04$	$0.419^{b}\pm0.04$	$2.33^{efg}\pm0.12$	$26.28^{jkl}\pm3.73$	$5.96^{cde}\pm0.35$
		16 – 25	$1.73^{ab}\pm0.04$	$0.437^{ab}\pm0.03$	$2.32^{fg}\pm0.10$	$25.18^{klm}\pm2.97$	$5.78^{efg}\pm0.39$
		26 – 35	$1.74^{ab}\pm0.03$	$0.451^{a}\pm0.03$	$2.30^{gh}\pm0.04$	$24.47^{lmn}\pm1.95$	$5.67^{fgh}\pm0.38$
	Hydromorphic	1 – 15	$1.65^{hij}\pm0.3$	$0.303^{fg}\pm0.04$	$2.47^{ab}\pm0.05$	$33.48^{cde}\pm1.74$	$5.62^{ghi}\pm0.33$
		16 – 25	$1.685^{efg}\pm0.03$	$0.336^{cde}\pm0.04$	$2.49^{a}\pm0.05$	$32.21^{ef}\pm1.09$	$5.50^{hi}\pm0.34$
		26 – 35	$1.72^{abcd}\pm0.03$	$0.357^{c}\pm0.03$	$2.46^{ab}\pm0.04$	$29.99^{gh}\pm1.50$	$5.44^{i}\pm0.36$
	Alluvial	1 – 15	$1.66^{ghi}\pm0.05$	$0.330^{de}\pm0.12$	$2.25^{hi}\pm0.05$	$26.11^{jkl}\pm1.60$	$6.15^{bc}\pm0.33$
		16 – 25	$1.68^{fgh}\pm0.05$	$0.320^{ef}\pm0.03$	$2.23^{i}\pm0.07$	$24.87^{klmn}\pm1.72$	$6.18^{ab}\pm0.39$
		26 – 35	$1.70^{bcdef}\pm0.04$	$0.336^{cde}\pm0.03$	$2.22^{i}\pm0.06$	$23.28^{mn}\pm1.52$	$6.23^{a}\pm0.44$

Values are mean ± standard deviation of replicate determination (n = 21). Means in the same column bearing different superscripts are significantly different at $p < 0.05$.

Table 5: Chemical properties of different soil types at different depths in the three Senatorial Districts of Abia State

Location (Senatorial district)	Soil type	Soil depth (cm)	N_2 (%)	Organic carbon (%)	Ca (cmol/kg)	Mg (cmol/kg)	K (cmol/kg)	Na (cmol/kg)	P (mg/kg)
Abia North	Ferralitic	1 – 15	$0.158^{defgh}\pm0.04$	$1.63^{bcd}\pm0.43$	$2.71^{defghi}\pm0.49$	$2.74^{b}\pm0.44$	$0.304^{b}\pm0.05$	$0.301^{a}\pm0.04$	$22.24^{efgh}\pm4.73$
		16 –25	$0.136^{hijklm}\pm0.03$	$1.47^{cdef}\pm0.38$	$2.51^{fghijk}\pm0.48$	$2.44^{bcd}\pm0.37$	$0.259^{cde}\pm0.04$	$0.228^{bcd}\pm0.05$	$18.91^{jkl}\pm3.85$
		26 –35	$0.119^{lmn}\pm0.03$	$1.33^{efgh}\pm0.30$	$2.34^{hijklm}\pm0.40$	$2.31^{cde}\pm0.35$	$0.213^{fg}\pm0.03$	$0.204^{cdefg}\pm0.05$	$16.19^{mn}\pm3.03$
	Hydromorphic	1 – 15	$0.209^{b}\pm0.04$	$1.65^{bc}\pm0.19$	$2.86d^{efg}\pm0.50$	$3.28^{a}\pm1.28$	$0.339^{a\pm}0.06$	$0.246^{b}\pm0.06$	$26.27^{a}\pm2.90$
		16 – 25	$0.166^{defg}\pm0.03$	$1.44^{cdefg}\pm0.20$	$2.66^{efghij}\pm0.44$	$2.72^{b}\pm0.79$	$0.244^{de}\pm0.04$	$0.211^{cdef}\pm0.07$	$24.09^{cd}\pm2.40$
		26 – 35	$0.141^{hijkl}\pm0.03$	$1.25^{fghij}\pm0.23$	$2.29^{ijklmn}\pm0.44$	$2.39^{cd}\pm0.89$	$0.192^{ghi}\pm0.06$	$0.195^{efgh}\pm0.08$	$21.90^{fghi}\pm1.75$
	Alluvial	1 – 15	$0.214^{ab}\pm0.05$	$2.05^{a}\pm0.57$	$4.31^{a}\pm2.31$	$3.48^{a}\pm0.60$	$0.278^{bc}\pm0.04$	$0.324^{a}\pm0.06$	$21.66^{fghi}\pm3.81$
		16 – 25	$0.170^{cdef}\pm0.05$	$1.57^{bcd}\pm0.56$	$3.40^{bc}\pm1.64$	$2.48^{bcd}\pm0.46$	$0.211^{fgh}\pm0.04$	$0.230^{bc}\pm0.05$	$19.00^{jk}\pm3.75$
		26 – 35	$0.147^{fghij}\pm0.04$	$1.18^{hij}\pm0.39$	$2.79^{defgh}\pm1.34$	$1.68^{hij}\pm0.35$	$0.154^{jkl}\pm0.05$	$0.166^{ijkl}\pm0.03$	$16.77^{mn}\pm3.43$
Abia Central	Ferralitic	1 – 15	$0.181^{cd}\pm0.04$	$1.63^{bcd}\pm0.26$	$1.82^{nopqr}\pm0.41$	$1.39^{jkl}\pm0.25$	$0.234^{ef}\pm0.07$	$0.195^{efgh}\pm0.05$	$24.19^{cd}\pm3.15$

		16 – 25	$0.145^{ghijk} \pm 0.03$	$1.30^{efghi} \pm 0.29$	$1.60^{pqr} \pm 0.42$	$1.21^{klmn} \pm 0.18$	$0.163^{ijk} \pm 0.05$	$0.135^{mn} \pm 0.03$	$19.10^{jk} \pm 3.06$
		26 – 35	$0.116^{mn} \pm 0.03$	$1.13^{hij} \pm 0.16$	$1.35^{r} \pm 0.41$	$0.97^{n} \pm 0.39$	$0.130^{lm} \pm 0.05$	$0.108^{o} \pm 0.03$	$15.71^{mn} \pm 3.10$
	Hydromorphic	1 – 15	$0.205^{b} \pm 0.10$	$1.60^{bcd} \pm 0.68$	$2.63f^{ghij} \pm 0.43$	$1.64^{ij} \pm 0.25$	$0.300^{b} \pm 0.05$	$0.212^{cde} \pm 0.04$	$23.71^{cde} \pm 1.88$
		16 – 25	$0.151^{fghi} \pm 0.03$	$1.31^{efghi} \pm 0.56$	$2.41^{ghijkl} \pm 0.50$	$1.47^{jk} \pm 0.22$	$0.248^{cde} \pm 0.05$	$0.170^{hijk} \pm 0.05$	$20.86^{hi} \pm 1.59$
		26 – 35	$0.125^{jklmn} \pm 0.02$	$1.17^{hij} \pm 0.10$	$2.18^{jklmno} \pm 0.42$	$1.31^{klm} \pm 0.15$	$0.184^{ghij} \pm 0.04$	$0.150^{klm} \pm 0.03$	$18.67^{kl} \pm 1.43$
	Alluvial	1 – 15	$0.234^{a} \pm 0.03$	$2.06^{a} \pm 0.50$	$3.60^{b} \pm 0.54$	$2.20^{def} \pm 0.32$	$0.345^{a} \pm 0.05$	$0.298^{a} \pm 0.03$	$25.91^{ab} \pm 2.19$
		16 – 25	$0.192^{bc} \pm 0.03$	$1.78^{b} \pm 0.38$	$3.17^{bcd} \pm 0.63$	$1.95^{fgh} \pm 0.34$	$0.260^{cde} \pm 0.05$	$0.230^{bc} \pm 0.02$	$22.67^{defg} \pm 1.83$
		26 – 35	$0.170^{cdef} \pm 0.03$	$1.41^{defg} \pm 0.28$	$2.92^{cdef} \pm 0.59$	$1.81^{ghi} \pm 0.41$	$0.209^{fgh} \pm 0.05$	$0.201^{defg} \pm 0.02$	$20.86^{hi} \pm 2.08$
Abia South	Ferralitic	1 – 15	$0.178^{cde} \pm 0.05$	$1.44^{cdefg} \pm 0.35$	$2.14^{klmno} \pm 0.89$	$2.07^{efg} \pm 0.42$	$0.275^{bcd} \pm 0.09$	$0.230^{bc} \pm 0.04$	$23.19^{cdef} \pm 2.71$
		16 – 25	$0.144^{ghijk} \pm 0.04$	$1.25^{fghij} \pm 0.27$	$1.99^{lmnop} \pm 0.82$	$1.81^{ghi} \pm 0.49$	$0.180^{hij} \pm 0.05$	$0.155^{jklm} \pm 0.03$	$18.67^{kl} \pm 2.17$
		26 – 35	$0.126^{jklmn} \pm 0.04$	$1.11^{ij} \pm 0.11$	$1.75^{opqr} \pm 0.48$	$1.66^{hij} \pm 0.40$	$0.122^{mn} \pm 0.02$	$0.120^{no} \pm 0.02$	$15.14^{n} \pm 2.13$
	Hydromorphic	1 – 15	$0.156^{efgh} \pm 0.03$	$1.49^{cde} \pm 0.35$	$1.86^{mnopq} \pm 0.41$	$1.20^{klmn} \pm 0.20$	$0.184^{ghij} \pm 0.08$	$0.185^{fghi} \pm 0.08$	$24.41^{bc} \pm 2.02$
		16 – 25	$0.128^{ijklmn} \pm 0.02$	$1.26^{fghij} \pm 0.25$	$1.66^{pqr} \pm 0.35$	$1.10^{lmn} \pm 0.21$	$0.120^{mn} \pm 0.03$	$0.122^{no} \pm 0.04$	$21.21^{ghi} \pm 3.25$
		26 – 35	$0.106^{n} \pm 0.01$	$1.06^{j} \pm 0.23$	$1.40^{qr} \pm 0.23$	$1.03^{mn} \pm 0.20$	$0.094^{n} \pm 0.02$	$0.097^{o} \pm 0.03$	$16.68^{mn} \pm 2.83$
	Alluvial	1 – 15	$0.170^{cdef} \pm 0.03$	$1.74^{b} \pm 0.40$	$3.12^{bcde} \pm 0.85$	$2.58^{bc} \pm 0.61$	$0.274^{bcd} \pm 0.08$	$0.229^{bc} \pm 0.05$	$22.71^{defg} \pm 1.70$
		16 – 25	$0.142^{hijkl} \pm 0.03$	$1.58^{bcd} \pm 0.33$	$2.66^{efghij} \pm 0.81$	$2.30^{cde} \pm 0.57$	$0.203^{gh} \pm 0.05$	$0.179^{ghij} \pm 0.04$	$20.38^{ij} \pm 2.34$
		26 – 35	$0.122^{klmn} \pm 0.02$	$1.33^{efgh} \pm 0.22$	$2.23^{jklmno} \pm 0.67$	$2.03^{efg} \pm 0.59$	$0.148^{klm} \pm 0.04$	$0.141^{lmn} \pm 0.02$	$17.28^{lm} \pm 1.47$

Values are mean ± standard deviation of replicate determination (n = 21). Means in the same column bearing different superscripts are significantly different at $p < 0.05$.

2.0 DISCUSSION

Table 1 presents comprehensive summary statistics for the physical properties of soil samples collected across three senatorial districts in Abia State. These parameters are vital in understanding the textural and structural makeup of soil which directly influences crop productivity, water movement, root penetration, and general soil health.

Sand, Silt, and Clay Composition

The dominant soil textural class evident from the data is sandy loam, with an average sand content of 61.24%, followed by clay (27.02%) and silt (11.76%). Sand values span from 43% to 84%, showing wide variability in particle size distributions, likely due to parent material differences and pedogenic processes across districts. The standard deviation of 7.07% indicates moderate dispersion in sand content.

In contrast, silt showed a narrower range (4–18%) and higher coefficient of variation (21.21%), suggesting localized depositional or weathering differences. Clay, with values from 7% to 46%, showed even greater variability (CV = 28.19%) and plays a crucial role in water retention and chemical nutrient holding.

Bulk Density (g/cm³)

Bulk density, which quantifies soil compaction and porosity, averaged 1.64 g/cm³, a value bordering the upper limit for arable soils. The range from 1.12 to 1.82 g/cm³ suggests variations in organic matter content, texture, and tillage effects across sampling sites. Densities above 1.6 g/cm³ may hinder root development and water infiltration. The relatively low standard deviation (0.0908) indicates consistency across zones, but local differences especially in clay-heavy subsoils remain critical.

Hydraulic Conductivity (K, cm/s)

Hydraulic conductivity averaged 0.30 cm/s, with values ranging between 0.02896 and 0.8211 cm/s. This wide range highlights how soil texture and structure affect water movement. Areas with high clay content likely showed lower values, reflecting reduced macropores and higher water retention. The coefficient of variation (29.45%) and positive skewness (0.46) point to a subset of soils with particularly high conductivity, likely in sandy or loamy profiles.

Particle Density and Porosity

The mean particle density is 2.34 g/cm³, closely aligning with the typical value for mineral soils (~2.65 g/cm³), suggesting moderate organic matter presence. Porosity, inversely related to bulk density, averages 29.45%, with a spread from 15.42% to 48.29%. The positive skew (0.37) and significant standard deviation (5.45) suggest diverse aeration and moisture retention capabilities across zones—valuable insights for irrigation planning.

Soil pH

Soil pH, a crucial determinant of nutrient availability and microbial activity, averaged 5.97, indicating a slightly acidic reaction. The observed range (4.6–6.8) reflects zones where pH may need lime amendment to support sensitive crops. The relatively tight standard deviation (0.45) and low skew (-0.32) indicate uniform acidity across most sites, a useful trait for region-wide soil management strategies.

Table 2 presents a detailed statistical summary of the chemical characteristics of soil across various depths and zones in Abia State, Nigeria. These chemical properties—Nitrogen, Organic Carbon, and essential cations—play a critical role in crop productivity, soil fertility, and the sustainability of agricultural ecosystems. For Agricultural & Bioresources Engineering, understanding these parameters is foundational to optimizing soil management strategies, especially for modeling water movement, nutrient cycling, and plant responses in precision agriculture frameworks.

Nitrogen (N_2, %)

The nitrogen content in the soil samples had a mean of 0.157%, which is relatively low for fertile soils. Nitrogen is a crucial macronutrient involved in chlorophyll formation and plant metabolism. The range of values, from 0.08% to 0.60%, indicates significant variability across sites and depths. The coefficient of variation (CV) of 31.73% and skewness of 1.75 reflect that while most soils are nitrogen-poor, a few have high nitrogen levels—likely due to manure inputs, higher organic matter, or vegetation influence. High kurtosis (10.12) reinforces that outliers dominate the upper range. This variability makes N_2 a strong candidate for surface modeling when studying crop yield responses or fertilizer application efficiency.

Organic Carbon (OC, %)

Organic carbon averaged 1.45%, a moderate level, reflecting some degree of organic matter presence in these tropical soils. The values range between 0.1% and 3.16%, with a CV of 30.18%, showing wide fluctuation due to decomposition rates, vegetation cover, or land-use practices. High OC levels are vital as they:

- Improve soil structure and water retention
- Enhance nutrient holding capacity
- Stimulate microbial activity

Calcium (Ca, cmol/kg)

Calcium had the highest mean concentration among cations at 2.46 cmol/kg, ranging up to 9.98 cmol/kg. As an essential plant nutrient, Ca contributes to cell wall structure, enzyme activity, and soil pH buffering. The data shows high variability (CV of 42.25%) and skewness of 1.92, suggesting strong spatial heterogeneity—possibly due to parent material or liming in some regions. High Ca areas are often correlated with higher pH levels and better soil structure, potentially leading to improved hydraulic conductivity, especially in Ferralitic and Alluvial soils.

Magnesium (Mg, cmol/kg)

Magnesium, essential for chlorophyll and enzyme activation, shows a mean of 1.97 cmol/kg with a maximum of 8.12 cmol/kg. The high standard deviation (0.82) and CV (41.52%) indicate significant variability. These fluctuations may be due to differential weathering rates or fertilizer inputs. Soils low in Mg can lead to deficiencies in sensitive crops like maize and vegetables. Like Ca, Mg plays a structural role in stabilizing soil aggregates—thus impacting hydraulic conductivity indirectly.

Potassium (K, cmol/kg)

Potassium is crucial for stomatal regulation, water use efficiency, and stress tolerance in crops. The average value of 0.217 cmol/kg is low by agronomic standards, with some soils registering as low as 0.04 cmol/kg. The narrow range but high CV (38.39%) implies that while K is generally scarce, certain soils hold more due to mineral presence or amendments. The relatively low skewness (0.19) and kurtosis indicate a moderately symmetrical distribution.

Sodium (Na, cmol/kg)

Sodium, though not essential for most crops, affects soil structure, especially in high concentrations where it causes dispersion and poor infiltration. The data reveals a mean of 0.195 cmol/kg, with a maximum of 0.44 cmol/kg, and a CV of 37%. The zero minimum suggests that some samples are devoid of exchangeable sodium, which is favorable. However, areas with elevated Na warrant attention in engineering applications, especially for irrigation management and salinity control.

Phosphorus (P, mg/kg)

Phosphorus, the driver of root development and flowering, had the highest mean value at 20.68 mg/kg, with a range of 9.33 to 32 mg/kg. The low CV of 19.84% suggests moderate variability and generally sufficient P levels across the study area. The slight negative skewness (-0.16) indicates that values are evenly spread around the mean, making it a stable parameter for surface modeling. In water management contexts, higher P levels may also imply a risk of runoff pollution, which ties back to the hydraulic behavior of the soil.

Table 3: Soil Textural Composition across Soil Types and Depths in Abia State

Soil texture—the proportion of sand, silt, and clay—is one of the most permanent soil characteristics. It plays a defining role in water retention, permeability, aeration, tillage, and nutrient dynamics.

This table presents a comprehensive dataset showing how these texture components vary across three soil types (Ferralitic, Hydromorphic, Alluvial) at different depths (1–15 cm, 16–25 cm, 26–35 cm) within the three senatorial districts of Abia State: North, Central, and South.

1. Ferralitic Soils

These are highly weathered tropical soils, usually red or yellow, rich in iron and aluminum oxides, with variable textures depending on weathering intensity.

Abia North Ferralitic

At 1–15 cm, sand dominates (70.62%) with low clay (15.86%), indicating a light-textured, easily drained topsoil. By 26–35 cm, sand drops to 61.86%, and clay rises to 30.71%—a classic sign of illuviation, where fine materials leach downward and accumulate. This clay buildup can impede root growth and water infiltration.

Abia Central Ferralitic

Similar trend: sand from 69.95% to 60.05%, and clay from 16.05% to 29.71% across depths. This indicates profile development, with possible argillic (clay-rich) horizons forming at depth—crucial for understanding root zone limitations and water movement.

Abia South Ferralitic

Sand starts much lower (57.57%) and clay significantly higher (27.57%) even at 1–15 cm. At 26–35 cm, sand drops to 50.95%, and clay peaks at 38.62%, indicating deep weathering and clay enrichment—a potential issue for drainage and tillage. These Ferralitic soils require intensive organic amendments or cover cropping to improve structure and porosity.

2. Hydromorphic Soils

These are wetland or waterlogged soils, often poorly drained, and showing gleying or mottling due to seasonal saturation.

Abia North Hydromorphic

Sand reduces with depth (from 64.19% to 57.86%) while clay increases (from 21.76% to 31.91%). Indicates moderate to high water retention, but also high susceptibility to waterlogging. Moderate silt (10–14%) suggests potential for crusting on drying, impacting seedling emergence.

Abia Central Hydromorphic

Sand reduces from 69.38% to 57.67%, with clay increasing from 17.24% to 32.29%. This is a strong indication of seasonal wetting/drying cycles, with the potential to develop perched water tables.

Abia South Hydromorphic

Sand content is consistently lower (from 67% to 59.10%), and clay increases to 31.81%. Though still moderate in texture, this soil type benefits from drainage interventions, particularly for year-round cropping. Hydromorphic soils overall support paddy rice systems, but must be carefully managed to prevent iron toxicity and poor aeration.

3. Alluvial Soils

Alluvial soils form from recent riverine deposits, often stratified and fertile, though highly variable.

Abia North Alluvial

Sand decreases from 66.76% to 60.24%, and clay increases from 20.24% to 29.29%. These soils have high potential for floodplain farming, though variability in texture may require site-specific tillage.

Abia Central Alluvial

Texture ranges from 63.57% sand (topsoil) to 52.71% (subsoil), while clay grows from 23.10% to 37.05%. This pattern implies textural stratification, often typical of depositional environments.

Abia South Alluvial

Texture ranges from 62.86% sand to 55.19%, and clay from 22.76% to 34.81%. These soils are suited to crops like vegetables and cassava, with medium water-holding capacity and moderate fertility.

Table 4: Physical Soil Properties across Districts

Soil physical properties are the foundation of land productivity and dictate a wide range of agricultural and engineering outcomes—from water movement and root penetration to compaction and aeration. This table detailed breakdown of bulk density, hydraulic conductivity (K), particle density, porosity, and pH across soil type, depth, and senatorial zone offers a high-resolution look into the soil's structural and functional behavior across Abia State.

For an Agricultural & Bioresources Engineer, this data is indispensable for tasks such as irrigation design, soil amendment planning, crop suitability zoning, and structural modeling of infiltration systems.

Bulk Density (BD, g/cm³)

Bulk density is a measure of soil compaction, affecting root growth, porosity, and infiltration rates. Ideal values for plant growth typically range from 1.1 to 1.6 g/cm³, with values above 1.6 indicating potential root and water movement restriction.

Abia South Ferralitic soils exhibit the highest bulk density at depth (1.74 g/cm³ at 26–35 cm), suggesting severe compaction likely caused by clay accumulation and weathering.

Hydromorphic soils in Abia North also show increasing compaction with depth (from 1.67 to 1.75 g/cm³), confirming the presence of dense, and water-saturated layers.

In contrast, Abia Central Hydromorphic topsoil has some of the lowest bulk densities (~1.50 g/cm³), likely due to high organic matter and better aggregation in surface layers.

The trend across all zones shows that bulk density increases with depth, consistent with soil consolidation and clay enrichment, especially in Ferralitic and Hydromorphic profiles.

Hydraulic Conductivity (K, cm/s)

K is a direct indicator of soil permeability and is crucial in modeling water infiltration, drainage, and irrigation needs.

Highest K values are found in Abia South Ferralitic soils, peaking at 0.451 cm/s in the 26–35 cm layer. These high values are surprising in clay-rich layers and may result from vertical cracks or bio-pores.

Lowest values are recorded in Abia Central Hydromorphic topsoil (0.183 cm/s) and Ferralitic zones in Abia North (0.140 cm/s), reflecting poor structure or silt-clay dominance.

Alluvial soils across the state have moderate K values (0.245–0.350 cm/s), consistent with their mixed texture and relatively stable profile. Notably, while one might expect K to decrease with depth due to higher compaction and clay, some soils show the reverse trend, likely due to structural cracks or reduced root and biological interference in deeper layers.

Particle Density (PD, g/cm³)

Particle density remains relatively constant across the board (ranging from 2.19 to 2.49 g/cm³), suggesting that most soils are mineral-dominant with modest organic matter. Notable observations include:

Lowest particle density is in Alluvial soils (2.19–2.25 g/cm³), likely due to some organic residue in topsoil.

Highest PD is in Abia South Hydromorphic soils (~2.49 g/cm³), reflecting more compacted, mineral-rich subsoils. Since particle density doesn't vary as significantly as BD or K, it primarily aids in calculating porosity and assessing mineral composition consistency.

Porosity (%)

Porosity is inversely related to bulk density and directly affects water and air availability to roots.

Highest porosity (39.59%) is observed in Abia Central Hydromorphic topsoil, suggesting excellent structure and aeration. Lowest porosity (23%) occurs in Abia North Alluvial subsoil, hinting at significant compaction and potentially poor drainage capacity.

Generally, porosity declines with depth in most profiles, with Ferralitic and Alluvial soils experiencing the sharpest reductions—an indicator of horizon hardening and compaction from overburden pressure.

This pattern validates the critical role porosity plays in hydraulic modeling, where reduced porosity translates to decreased K, especially in clayey subsoils.

Soil pH

Soil pH influences nutrient availability, microbial activity, and chemical stability. Most soils in the region are slightly to moderately acidic, with pH values ranging from 5.44 to 6.36. Abia North and Central Alluvial soils maintain near-neutral values (~6.32 to 6.36), favorable for most crops. Abia South Ferralitic and Hydromorphic subsoils trend more acidic (~5.44 to 5.67), likely due to leaching of basic cations and dominance of iron/aluminum oxides.

While no strongly acidic soils are observed ($pH < 5$), the acidification trend with depth in Ferralitic soils suggests caution for deep-rooting crops and points to the potential need for lime application. pH also interacts indirectly with K—as lower pH values often correlate with higher clay and organic matter breakdown, affecting permeability.

Table 5: Chemical Properties of Soil by District, Depth, and Soil Type in Abia State

Table 5 presents a nuanced profile of key chemical soil properties—Nitrogen (N_2), Organic Carbon (OC), Calcium (Ca), Magnesium (Mg), Potassium (K), Sodium (Na), and Phosphorus (P)—measured at three depths (1–15 cm, 16–25 cm, 26–35 cm) across Ferralitic, Hydromorphic, and Alluvial soils within Abia State's three senatorial districts. Understanding these values is crucial for evaluating soil fertility and managing it through sustainable agricultural engineering practices.

These chemical properties not only influence crop yield and nutrient availability but also contribute significantly to soil structure, porosity, and thus hydraulic conductivity (K)

1. Nitrogen (N_2, %)

N_2 is consistently highest in the topsoil across all soil types and districts. For instance, values range from 0.214% in Abia North Alluvial topsoil to 0.106% in Abia South Hydromorphic subsoil. The sharp decline with depth is expected since nitrogen is strongly tied to organic matter and microbial activity, both concentrated near the surface. Hence, Low subsoil nitrogen reflects leaching and microbial degradation. Topsoil enrichment implies that surface nutrient applications (manure or urea) remain effective in root zones.

2. Organic Carbon (OC, %)

Highest OC is found in Abia Central Alluvial topsoil (2.06%), with lowest values in Ferralitic subsoils (1.11%). Decline with depth reflects oxidation of organics and reduced biological residue input. Therefore, OC governs aggregate stability, cation exchange capacity (CEC), and water retention.Soils with high OC (especially in Hydromorphic topsoil) maintain better structure and conductivity.

3. Calcium (Ca, cmol/kg)

Ca varies widely, peaking in Abia North Alluvial topsoil (4.31 cmol/kg), and dropping to 1.35 cmol/kg in some Ferralitic subsoils. It generally decreases with depth and is higher in alluvial soils.

Hence, High Ca improves soil flocculation (particle clumping), maintaining macropores necessary for drainage. Low Ca is typical of Ferralitic soils, which are leached and acidic. Ca is vital for modeling K because it affects soil dispersion or stability, especially under wet conditions.

4. Magnesium (Mg, cmol/kg)

Mg patterns mirror Ca, being highest in top Alluvial and Hydromorphic soils.

Deep Ferralitic soils record the lowest Mg (0.97–1.10 cmol/kg). Mg is critical for nutrient balance and structural integrity. In clay-dominated soils, Mg helps prevent collapse under moisture stress.

5. Potassium (K, cmol/kg)

K ranges from 0.345 cmol/kg (Abia Central Alluvial topsoil) to 0.094 cmol/kg (Abia South Hydromorphic subsoil). K declines with depth more sharply than other cations. Therefore, K supports turgor regulation in plants and is mobile in soils, making it susceptible to leaching in sandy profiles. Low K in subsoils suggests a need for split fertilizer applications. It plays a moderate role in K modeling (hydraulic conductivity), primarily through biological effects on root expansion.

6. Sodium (Na, cmol/kg)

Na levels remain below critical thresholds (most values < 0.3 cmol/kg), except slightly elevated in alluvial topsoil (e.g., Abia North: 0.324 cmol/kg). Subsoils in Ferralitic and Hydromorphic zones show much lower Na (~0.10–0.16 cmol/kg). Elevated Na can impair soil structure, causing dispersion and poor drainage.

Although most samples are safe, those nearing 0.3 cmol/kg must be monitored to prevent salinity build-up.

Na affects K (hydraulic conductivity) negatively when excessive and should be included in RSM under salinity-stress models.

7. Phosphorus (P, mg/kg)

P is consistently highest in topsoil (up to 26.27 mg/kg), especially in Alluvial and Hydromorphic soils.

Lowest values occur in Ferralitic subsoils (15.14–16.77 mg/kg). P is relatively immobile in soils, accumulating near the surface unless disturbed. It improves root proliferation, indirectly increasing K by enhancing biopore formation.

3.0 CONCLUSION

Based on the data presented, there are clear distinctions in soil properties across the three Senatorial Districts of Abia State, as well as variations related to soil type and depth. The physical properties, including parameters like bulk density, porosity, and water-holding capacity, exhibit significant differences. These variations likely influence water infiltration, aeration, and root penetration, which are critical for plant growth. For instance, the observed differences in bulk density could indicate varying degrees of compaction, with higher bulk density potentially restricting root development and water movement.

The chemical properties of the soil samples also reveal notable differences. Variations in pH levels, organic matter content, and nutrient availability (such as nitrogen, phosphorus, and potassium) suggest differing soil fertility levels across the regions. The data indicates that certain areas may require specific nutrient management strategies to optimize agricultural productivity. The observed differences in organic matter content are particularly important, as organic matter plays a vital role in soil structure, water retention, and nutrient cycling.

The basic composition analysis further supports the observed variations in soil properties. Differences in clay, silt, and sand content contribute to the unique physical and chemical characteristics of each soil type and location. The relative proportion of these components influences soil texture, drainage, and overall suitability for different types of crops.

The statistical significance ($p < 0.05$) of the differences between means in the tables underscores the reliability of the findings. These statistically significant variations highlight the need for site-specific soil management practices tailored to the unique properties of each region and soil type.

Therefore, the comprehensive assessment of soil properties across the three Senatorial Districts of Abia State reveals a complex interplay of physical, chemical, and compositional factors. These findings have important implications for agricultural planning and sustainable land management practices in the region. Further research could explore the specific relationships between soil properties, crop yields, and environmental factors to provide more targeted recommendations for optimizing agricultural productivity and minimizing environmental impacts. Understanding the spatial variability of soil properties is essential for promoting sustainable agriculture and ensuring food security in Abia State.

3.1 RECOMMENDATION

Based on the findings of this dissertation, several recommendations can be made to relevant stakeholders in Abia State, focusing on specific areas of concern to improve agricultural productivity and sustainability.

Targeted Stakeholders:

Agricultural Extension Officers: These professionals are vital for disseminating research findings to local farmers. They can use the data on soil properties to advise farmers on appropriate soil management practices, fertilization strategies, and crop selection.

Farmers: The primary beneficiaries of this research, farmers need to be educated on the specific properties of their soil and how to manage it effectively. This includes adopting practices that improve soil structure, increase organic matter content, and address nutrient deficiencies.

State Ministry of Agriculture: The ministry can use the data to inform agricultural policies and programs, ensuring that resources are allocated effectively to support sustainable farming practices.

Research Institutions: Further research is needed to explore the relationships between soil properties, crop yields, and environmental factors. This research should focus on developing innovative solutions for addressing soil-related challenges.

Environmental Protection Agencies: These agencies can use the data to monitor soil health and develop strategies for preventing soil degradation and erosion.

By addressing and implementing these recommendations, Abia State can improve Agricultural productivity, promote sustainable farming practices, and ensure food security for its citizens and the world at large.

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