# CHARACTERIZATION OF AQUACULTURE EARTHEN POND SOILS IN UMUDIKE AND MAKURDI METROPOLIS

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**ABSTRACT**
*Bottom soils were collected from selected earthen ponds with 5cm$^{-3}$ diameter core tubes at a depth of 10cm$^{-3}$ of the pond bottom. The study investigated the physical, chemical, soil profile, mechanical, aquaculture pond soil texture, and water quality characteristics of selected fish ponds in Umudike and Makurdi Metropolis. In the results obtained, Umudike had higher sand content than Makurdi, regardless of season. In the dry season, Umudike had 72.00% compared to 54.50% in Makurdi, and in the Wet Season, Umudike had 69.90% compared to 63.80% in Makurdi. Makurdi had higher clay content (28.20% in the dry season and 25.60% in the wet season) than Umudike (18.20% in the dry season and 18.30% in the wet season). Makurdi had a substantially higher particle density than Umudike. Both locations had similar moisture levels (Makurdi:18%, Umudike:17.7%) during the dry season. Organic matter values were also consistent across seasons and locations, ranging from 1.50% to 1.54%. The results obtained from water quality parameters showed that there were significant effects in dissolved oxygen for both seasons and locations ($p<0.001$) but no significant interaction ($p=0.318$). Values of biological oxygen demand were similar across both locations and seasons, ranging from 0.07 to 0.15mg/L. Both locations had similar temperatures (~29.6 - 29.7°C) during the dry season, while temperatures were lower, ranging from 27.7°C to 28. 6°C.during the wet season.Turbidity values varied across seasons, with Makurdi showing higher turbidity in the dry season (12.80 NTU) compared to the wet season (6.37 NTU).The results obtained from this work proved that there was a significant difference, $p<0.01$, in the soil and water quality parameters of the two locations and seasons. The soil types in the two locations are similar and suitable for aquaculture.*

**Keywords**: Pond soils, Water quality, Characteristics, Soil texture, Interaction, and Correlation.

## INTRODUCTION

The soil on the bottom of a pond acts as a source of nutrients and also buffers water in aquaculture. The soil also acts as a biological filter, adsorbing organic remains of feed, fish excrement and algal products (Saberina *et al*., 2023). The soil quality is an important factor in fish pond productivity as it controls pond bottom stability, pH of overlying water and concentrations of plant nutrients required for the growth of phytoplanktons. Pond soil plays an important role in the balance of an aquaculture system and consequently on the growth and survival of aquatic organisms (Siddique *et al*.,2012). Soils are formed by the weathering of rock or materials deposited by river or storm. Soil is a product of transformations of organic substances and minerals found on the earth's surface (Hatfield *et al*., 2017). It is a fundamental element for the maintenance of life because it provides support and nutrition for the development of phytoplanktons and zooplanktons and balance of the environment (Hena *et al*., 2018).

Pond soil can be a source of toxic metabolites that can enter the water and harm aquatic animals. Suspended soil particles reduce light transmission through the water, adversely impacting light reception by plants, plant productivity, and photosynthetic oxygen production. Sedimentation can smother aquatic organisms and destroy fish nesting sites. Suboptimal soil texture and pH may limit the production of benthos, the food of many aquatic animals (Boyd *et al.,* 2010, Shafi *et al.,* 2022)

Desirable ranges of most water-quality variables have been established, but less is known about optimal anges of pond soil condition factors. It is generally assumed that acidic soils, anaerobic conditions at the soil-water interface, high concentrations of soil organic matter, high rates of sedimentation, erosion of pond soils, and infestations of macrophytes in the pond bottom are detrimental factors in aquaculture ponds (Bansode *et al*., 2020). Aquaculture pond managers measure water quality variables and attempt to maintain them within optimal ranges for shrimp and fish, but surprisingly little attention is paid to pond soil conditions(Hena *et al*.,2018).

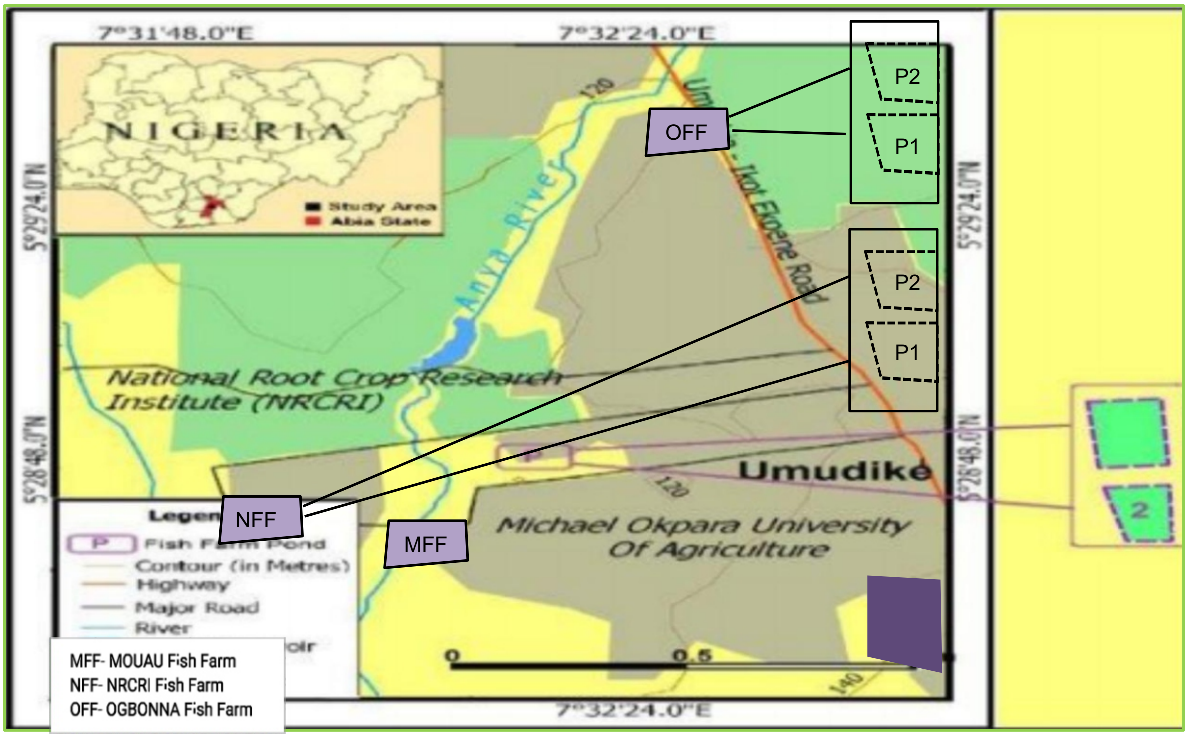
The physical properties of pond soil include colour, texture, porosity, composition consistency, permeability, and mineral content. The soil texture refers to the soil's comparative quantity of sand, silt, and clay (Pantjara *et* *al*.,2020). It is a significant soil parameter since it determines the appropriateness of a location for fish civilization (Mobilan *et al*.,2021). The alkalinity shows the buffering capacity of the water body expressed as mg/L and it's concentration of the pond water indicates it's capacity to neutralize the acid or to buffer the changes in pH(Pantjara *et al*.,2020). Porosity is the proportion of the volume of the void to the total volume of the soil aggregate; the volume of voids refers to that segment of the volumes of soil engaged by mineral grains. (Wang *et al*., 2021). Permeability is the rate at which water or gases pass through a cylindrical centre segment (Elhakim, 2016) Water Quality management has been considered one of the most important aspects of pond aquaculture for many years. Still, less attention has been given to pond bottom soil quality management in Africa, especially in Nigeria. The condition of pond bottoms and the exchange of substances between soil and water can strongly influence water quality (Boyd,2015).

## MATERIALS AND METHODS

### Study Areas and Selection of Ponds.

#### Umudike

Umudike is located in a rainforest agro ecological zone. It is a semi-urban settlement in Oboro, Ikwuano Local Government Area in Abia State, Nigeria. It is about 11 kilometers south east of Umuahia, the state capital. It lies on the geographical coordinates of $5^{\circ}28'$ N and $7^{\circ}33'0"$E Latitude and Longitude, respectively, and 122m above sea level. Umudike experiences a significant amount of rainfall throughout the year.




Note

MOUAU -\ Michael Okpara University of Agriculture, Umudike

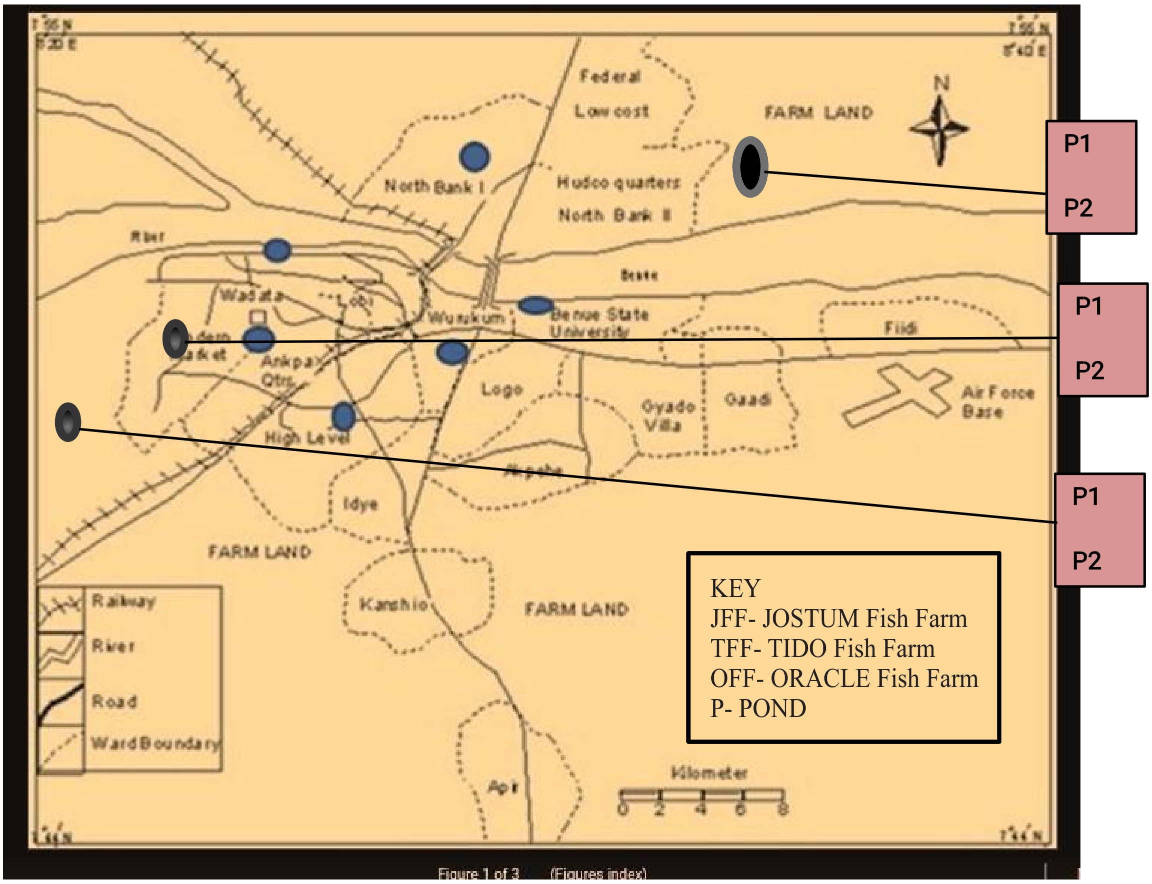
NRCRI -\National Root Crops Research Institute

*Source*: *Wikipedia, 2025*

**Figure 1a:** Map of study area showing location of the selected earthen fish ponds in Umudike

#### Makurdi

Makurdi is the capital of Benue State and is located in the southern Guinea agro-ecological zone, east of Central Nigeria. It lies on the South bank of the Benue River. It lies on the geographical coordinates of $7^{0}44'0$ North, $8^{0}32'0"$ East. Makurdi records an average rainfall of around 1,100mm,with the rainy season typically lasting from April to October.




NOTE
JOSTUM- Joseph Sarwuan Tarka University, Makurdi
*Source*: *Wikipedia, 2025*

**Figure 1b:** Map of study area showing location of the selected earthen fish ponds in Makurdi

**Sampling Stations**

A total of six samplying stations were selected with three sampling stations from each location inorder to have unbias and equal data representation of the two locations.The presence of few earthen ponds in Umudike unlike Makurdi coupled with the favourable vegetations, rainfall , natural ecosystem, proximity and good climate were reasons or factors considered for choosing the samplying stations with the view to compare and investigate the soil and water quality parameters of the two agroecological zones inorder to get findings and make recommendations to fish farmers and fish scientists. A total of twelve(12) fish earthen ponds were selected, comprising six earthen ponds from umudike and six earthen ponds from Makurdi metropolis.

**Collection of Samples during the Wet and Dry seasons.**

Bottom soils were collected from eleven(11) out of the twelve selected earthen ponds in Umudike ,Abia State and Makurdi,Benue State due to the fact that the second selected pond of NRCRI ,Umudike became unfit during the collection of bottom soil and water samples. The samples were collected within one week in the two locations during the wet season and one week during the dry season respectively.

The bottom soils were collected using a 5cm diameter core tube at a depth of 10cm of the pond bottom. Approximately 1kg of samples were collected from each pond at a 10m distance for every replication. Furthermore, the soil samples were held in plastic bags labelled.The wet samples from Umudike fish ponds were labelled A to E with a suffix of 1, while samples from Makurdi fish ponds were labelled F to K with a suffix of 1, respectively. Similarly,the samples collected during the dry season from Umudike were labelled A to D with a suffix of 2, due to the fact the third selected fish farm ponds got dried during the dry season, while the samples from Makurdi were labelled F to K with a suffix of 2.All samples were collected in triplicates. The samples were transported to the Fish Nutrition Laboratory of Joseph Sarwuan Tarka University, Makurdi, for documentation and assessment. They were later taken to the Advanced Analytical Soil Science Laboratory of Joseph Sarwuan Tarka University for analysis.

**Laboratory Analysis of the Collected Samples.**

**Determination of Soil profile and Textural Characteristics of the Selected Ponds.**

The hydrometer method was used to determine particle size and texture(sand,silt and clay).

Sand: The soil sample was air dried and crushed to pass through a 2mm sieve. 50g of the soil sample that passed through a 2.00mm sieve was weighed and transferred into a measuring cylinder. 50 ml of prepared sodium hexametasulphate and sodium carbonate were added to the soil sample. The solution was vigorously stirred for 15 minutes.

1000 ml of distilled water was added to the soil sample and stir thoroughly and then transferred into a 1000 ml cylinder.The hydrometer bulb was immediately inserted and fully submerged inside the solution, a watch was set up, and the hydrometer initial reading(R1) was taken at 1-2 minutes .The suspension was allowed to Settle for 40 seconds (for sand particles to settle). A Second hydrometer reading (R2) was taken and the percentage sand was calculated using the following formula below.

Sand(%)=(R1-R2)-(1000/1650)

Where R1= First reading of the hydrometer .

R2=Second reading of the hydrometer.

Silt : The soil sample was air dried and crushed and passed through a 2mm sieve.50 g of the sieved soil samples was weighed and 50 ml of sodium hexameta phosphate was added to the soil sample and mixed thoroughly. 1000 ml of distilled water was added to the soil sample and stirred vigorously and immediately poured into 1000 ml cylinder.The hydrometer was inserted into the cylinder and fully submerged and the initial reading of the hydrometer(R1) was recorded at 1-2 minutes after insertion.

The suspension was allowed to settle for 40 seconds (for sand particles to settle) and the sencond hydrometer reading(R2) was recorded after the 40 seconds. Furthermore, the suspension was allowed to settle for additional 4 hours (for silt particles to settle) and the third hydrometer reading(R3) was recorded immediately after the 4 hours. Finally, the percentage of silt was calculated using the below formula.

Silt(%) = (R2-R3) x (1000/1650).

Clay: The soil sample was air dried and crushed to pass through a 2mm sieve .50 g of the sample was weighed and 50 ml of hexameta phosphate was added to the sample and mixed for about 15 minutes.1000 ml of distilled water was added to the soil sample and stirred thoroughly and it was immediately poured into the 1000 ml cylinder.

The hydrometer was carefully inserted into the cylinder and fully submerged. The initial reading of the hydrometer(R1) at 1-2 minutes was recorded after the insertion and the suspension was allowed to settle for 2 hours ( for clay particles to settle at the bottom of the cylinder).The second hydrometer reading (R2) was recorded after the 2 hours . The percentage of clay was determined using the following formula.

Clay (%) = (R2-0) x (1000/1650).

**Determination of the Physical and Chemical Characteristics of the Soils:**

**Electrical conductivity:** An Electrical conductivity meter was used to measure soil electrical conductivity. The soil conductivity was measured by the 2-AC bipolar method.

The soil sample was air dried and 20g of the dried sample was weighed and kept in a non conductive plastic container. The Electrical conductivity meter was however set to conductivity mode and the readings of the conductivity between the two electrodes were taken and recorded.

**Soil moisture content:** In the determination of the moisture content of the soil samples, 10g of each soil sample was weighed. The weight of 11 aluminum dishes was recorded. The soil samples were oven-dried at 105°C for 24 hours. After 24 hours, they were removed from the oven, placed in the desiccators, and allowed to cool for 30 minutes. The weight of the dishes with the soil samples was taken immediately after they were removed from the desiccators. Finally, the moisture content was computed using the following formula.

$$\text{Moisture (\%)} = \left[\frac{Weight of wet soil}{Weight of dry soil} - 1\right] \times 100$$

**Organic matter:** The tare weight of each crucible was taken, after which 2g of each dried soil sample was added to each and oven-dried for 24 hours at a temperature of 105ºC. The samples were removed from the oven and placed in the desiccators to cool for 30 minutes. The samples were further weighed and placed in a muffle furnace at 350ºC for 8 hours, after which they were removed and cooled in the desiccators for 30 minutes. The samples were finally weighed, and the organic matter content was computed using the following formula.

$$OM = 100 - \frac{W_F - W_T}{W_{TS} - W_T}$$

Where OM=Organic Matter Concentration %

$W_F$= Weight of crucibles and Soil after Ashing (g)

$W_T$=Tare Weight of crucibles and oven-dried soil(g)

$W_{TS}$=Tare Weight of crucibles and oven-dried Soil (g).

**Particle density:** The particle density was determined using the following procedure. First, the weight of a volumetric flask and its cap was measured. Then, 10 grams of air-dried soil were added to the flask. Distilled water was added until the flask was half full, ensuring no soil adhered to the sides of the flask. The contents (soil and water) were then boiled in an oven for 15 minutes and gently stirred to prevent spilling. After boiling, the flask and its contents were cooled to room temperature, and freshly cooled distilled water was added to bring the contents up to the required volume. The flask was gently dried with a towel, and the combined weight of the flask, contents, and cover was recorded. Next, the temperature of the contents was measured, and they were disposed of. Finally, the flask was refilled to volume with freshly boiled and cooled distilled water at the same temperature as the previously disposed contents. The flask was again dried with a towel and weighed. The particle density was calculated following Boyd (1995):

$$Particle\ density(gcm^{-3}) = \frac{\rho_w(W_{FS}-W_{FA})}{(W_{FS}-W_{FA})-(W_{FSW}-W_{FW})}$$

Where; pw = density of water at observed temperature ($gcm^{-3}$)
$W_{FA}$ = Weight of flask filled with air(g)
$W_{FW}$ = Weight of flask filled with water at observed temperature (g)
$W_{FA}$ = Weight of flask +oven dried weight of soil (g)
$W_{FSW}$ = Weight of flask containing soil and filled with water(g).

**Bulk density:** The wet soil samples collected were transferred into a measuring cylinder at a 10cm level and then transferred to tare aluminum dishes on a weighing scale. The weight of each aluminum dish was recorded before being tarred. All the soil samples were oven-dried for 24 hours at 105°C. The samples were later removed and kept in the desiccator to cool for 30 minutes, after which the dry soil samples were weighed and recorded. Finally, the volume of the soil was calculated using the following formula.
$V=0.785D^2L$.
Where, V=Volume ($cm^3$)
D =Diameter of soil core (cm)
L=Length of soil core segment (cm)

$$\text{Bulk Density} = \frac{\text{Final Weight} - \text{Tare Weight}}{\text{Volume}}$$

**Porosity:** The volume of pore space in the soil samples (porosity) was estimated from bulk density and particle density using the following formula.

$$\text{Porosity (\%)} = 100 - \frac{\text{Bulk density}}{\text{Particle Density}}$$

**Soil pH:** The hydrogen ion activity (pH) was measured by direct potentiometer.
A pH meter with glass electrode standard pH buffer solutions was used to determine the soil pH.

**Organic carbon:** To determine the organic carbon content of the soil, 1 gram of each wet soil sample was sieved to pass through a 0.5 mm sieve. It was weighed and placed in a 500 ml conical flask. Then, 10 ml of potassium dichromate and 20 ml of sulfuric acid ($H_2SO_4$) were added to the sample. The solution was left to stand for 30 minutes, after which 100 ml of distilled water was added. Next, 3-4 drops of the o-phenanthroline indicator were introduced to the solution. The mixture was then titrated with 0.5N ferrous sulphate, and adding it drop by drop until the endpoint was reached.

Calculation:

$$\%\ Organic\ Carbon = \frac{0.5\ (B-T) \times 0.003 \times 1.33 \times 100}{\text{1 gram of soil sample (weight of air dry soil taken)}}$$

Where B= blank titre, T =Actual titre.

**Permeability**
Permeability of soil samples from the selected ponds was measured in the laboratory with the aid of an instrument called Permeameter through a hydraulic method also known as the constant head method .

**Stiffness and Strength of the Selected Fish Pond Soils**
Soil stiffness was determined using a modified version of the FAO (2003) field test method and classification was done using the BSI (2007) international standard Eurocode 7 for geotechnical design to obtain numerical values. Testing was conducted when the soil was moist but not wet. A small amount of moist soil was crushed by being pressed between the thumb and forefinger or squeezed in the palm.

**Water Quality Analysis**
Water samples were collected from the selected ponds in Umudike and Makurdi Metropolis. They were drawn in sterile 500ml bottles and filtered through 0.4-um filters to remove particulate matter to slow down sample degradation. The fish pond water samples were transported to the Fish Nutrition Laboratory of the Fisheries Department of Joseph Sarwuan Tarka University, Makurdi, for physiochemical analysis as described by Eaton (2005)

**pH**
The pH of the water samples was measured using the Hanna Multi Parameter Water Tester Model HI 98129.

**Alkalinity**
The alkalinity of the water samples was measured using the Lovibond Tintometer Model MD 600.

**Hardness:**
The hardness of the water samples was determined using the Lovibond Tintometer Model MD600.

**Dissolved oxygen**
Dissolved Oxygen (DO) was measured using the Sper Dissolved Oxygen Meter Model L933246.

**Biological oxygen demand**
Biological Oxygen Demand (BOD) was measured using the Sper Dissolved Oxygen Meter Model L933246, first on Day 1 and again after a five-day incubation period. Mathematically, BOD is calculated as the difference between the Dissolved Oxygen (DO) levels on Day 1 and Day 5, expressed as:
$BOD = DO_1 - DO_5$.

**Temperature**
The temperature of the water sample was measured using the Hanna Multi Parameter Water Tester Model HI 98129.

**Total dissolved solids**
The Hanna Multi Parameters Water Tester Model HI 98129 was used to measure Total Dissolved Solids of the water sample.

**Turbidity**
Turbidity in the water samples was measured using a Sper Turbidimeter Model 860040.

**Statistical Analysis**
The results obtained were analyzed by two -way Analysis of Variance (ANOVA) and Tukey Test. ANOVA and Turkey Test were used to analyze and compare the means of multiple data obtained from the two locations and seasons respectively.

## RESULTS

**Soil Profile and Texture of Makurdi and Umudike.**
The results in Table 1 showed that Umudike had 72.00% sand content compared to 54.50% in Makurdi during the dry season. In the wet season, Umudike had 69.90% sand content compared to 63.80% in Makurdi. The interaction effect shows that the difference in sand content between locations varies significantly between seasons with the biggest difference seen in the dry season. Makurdi had higher clay content (28.20% in the dry season and 25.66% in the wet season) compared to Umudike (18.20% in the dry season and 18.30% in the wet season).

Clay content was significantly influenced by location,but season and the interaction were not significant. Makurdi had higher silt content than Umudike in the dry season (17.30%Vs.9.78%), but in the wet season, Umudike 's silt Content (11.70%) slightly surpassed Makurdi's (10.60%).There was a significant difference in silt content.

**Table 1:** Aquaculture Earthen Ponds Soil Profile and Texture of Makurdi and Umudike

| Variable | Dry | | Wet | | *P*-value | | |
|---|---|---|---|---|---|---|---|
| | Makurdi *(n = 18)* | Umudike *(n = 12)* | Makurdi *(n = 18)* | Umudike *(n = 15)* | Season | Location | S×L[1] |
| Sand (%) | $54.50 \pm 3.37^b$ | $72.00 \pm 2.87^a$ | $63.80 \pm 0.48^a$ | $69.90 \pm 0.56^a$ | 0.03 | <0.001 | 0.015 |
| Clay (%) | $28.20 \pm 2.29^a$ | $18.20 \pm 2.65^b$ | $25.60 \pm 0.39^a$ | $18.30 \pm 0.80^b$ | 0.272 | <0.001 | 0.44 |
| Silt (%) | $17.30 \pm 1.12^a$ | $9.78 \pm 0.27^b$ | $10.60 \pm 0.12^b$ | $11.70 \pm 0.28^b$ | <0.001 | <0.001 | <0.001 |

Values are means ± SEM. $^{a-b}$Means in a row without a common superscript letter differ ($P < 0.05$) as analyzed by two-way ANOVA and the TUKEY test.
[1]S × L = Season × Location interaction effect

**Aquaculture Pond Soil Texture of Makurdi and Umudike during Wet Season (2023/2024).**

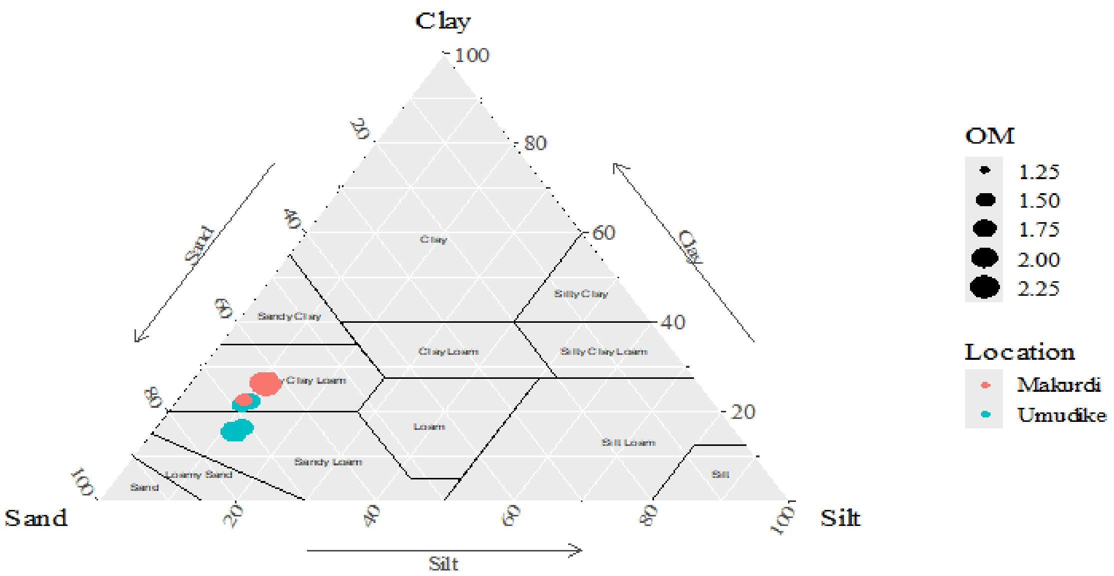



**Figure 1**: Aquaculture pond soil texture of Makurdi and Umudike during the wet season (2023)

Figure 1 showed that the triangular plot classified soil based on the proportions of sand, silt and clay. The majority of samples from both locations fall within the sandy loam and sand clay,with moderate levels of clay and silt. The size of each circle represents the organic matter (OM) content in the soil, with larger circles indicating higher OM levels. The Organic Matter levels range from 1.25 to 2.25. The Makurdi samples generally show slightly larger sizes indicating higher organic matter content than the Umudike samples.

**Aquaculture Pond Soil Texture of Makurdi and Umudike during Dry Season (2023/2024).**
Figure 2 showed that the triangular plot represents soil

texture classes based on the percentages of sand, silt, and clay. Samples from two locations, Makurdi and Umudike, are plotted on this diagram, each represented by circles of different sizes and colours. The size of the circles represents the organic matter content in the soil, with larger circles indicating higher organic matter levels. Larger circles (closer to 2.0 organic matter) indicate higher organic matter content.

Small circles (closer to 0.8 Organic matter) indicate lower organic matter content. For the Makurdi samples, organic matter content ranges between 1.2 and 1.6. For the Umudike samples, organic matter content ranges between 0.8 and 1.2.

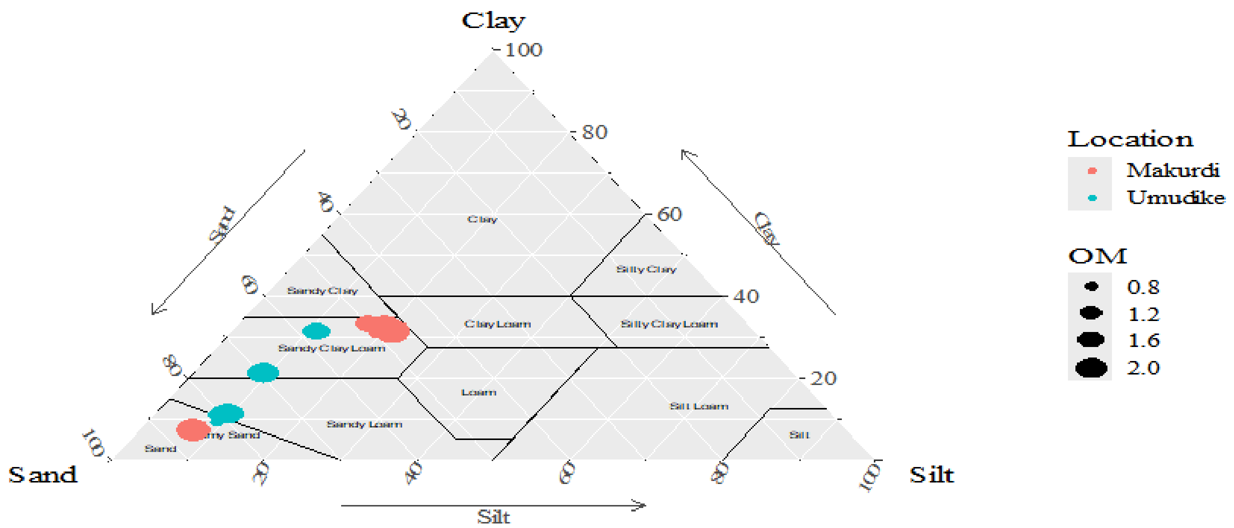



**Figure: 2** Aquaculture pond soil texture of Makurdi and Umudike during the dry season (2023)

**Physical and Chemical Characteristics of the Pond Soils**

The results from Table 2 revealed that Makurdi had significantly higher pH (5.68) than Umudike (5.40) during dry season. Both locations had similar pH values (Makurdi:5.31, Umudike:5.30) during the wet season. There were significant effects of season (<0.001) location (0.019) and season x location interaction (0.019) on soil pH. Organic Carbon was relatively consistent across both locations and seasons with values ranging between 0.89% and 0.91%. No significant effects were found for season (0.898), location (0.942), or the interaction (0.942) on Organic Carbon. Organic matter values were also consistent across seasons and locations, ranging from 1.50% to 1.54%. No significant effects were found for season (0.883), location (0.894), or the interaction (0.857) on Organic matter.

Makurdi (1130 S.cm-3) and Umudike (1110S.cm-1) had higher Electrical conductivity values during the dry season. Both Makurdi (1070S.cm-1) and Umudike (1050 S.cm-1) had lower values during the wet season. Significant effects were observed for season (<0.001) and location (0.042), but not for the interaction (0.568). Both locations had similar moisture levels (Makurdi:18%, Umudike:17.7 %) during the dry season while both locations showed higher moisture content (Makurdi:23.4%, Umudike:23.9%) during the wet season. There was a significant effect of season (<0.001) but no significant effects of location (0.928) or interaction (0.705). Makurdi and Umudike had similar porosity values (~27-28%) during the dry season while both locations exhibited much higher porosity (~42.44%) during the wet season. There was a significant effect of season (<0.001), but no significant effects of location. There was a significant effect of season (<0.001), but no significant effects of location (0.51 or interaction 0.376)

Makurdi and Umudike had similar values (~1.21-1. 23g.cm$^{-3}$) during dry season while both showed higher values (~1.46 -1. 49g.cm$^{-3}$) during the wet season. Season had a significant effect (<0.001), but location (0.587) and interaction (0.899) were not significant. Makurdi had a significantly higher particle density (2.52 g.cm$^{-3}$) than Umudike (2. 21g.cm$^{-3}$) during dry season. Makurdi (2. 40g.cm$^{-3}$) also had a higher particle density compared to Umudike (2. 20g.cm$^{-3}$) during wet season. Significant effects were found for both seasons (0.032) and location (<0.001), but not for the interaction (0.175).

Season had a significant effect on soil permeability, with higher permeability observed in the wet season (Makurdi: 2.42 cm/s, Umudike:2.46 cm/s). Neither location nor the interaction between season and location significantly affected permeability. Location had a significant impact on soil stiffness with Makurdi having consistent higher stiffness values (15.00MPa) than Umudike (11.25MPa in the dry season.

**Table 2:** Physical and Chemical Characteristics of the Soils

| Variable | Dry | | Wet | | P-value | | |
|---|---|---|---|---|---|---|---|
| | Makurdi (n = 18) | Umudike (n = 12) | Makurdi (n = 18) | Umudike (n = 15) | Season | Location | S×L1 |
| pH | 5.68 ± 0.07[a] | 5.40 ± 0.03[b] | 5.31 ± 0.05[b] | 5.30 ± 0.05[b] | <0.001 | 0.019 | 0.019 |
| OC (%) | 0.90 ± 0.08 | 0.91 ± 0.09 | 0.89 ± 0.06 | 0.89 ± 0.04 | 0.898 | 0.942 | 0.942 |
| OM (%) | 1.54 ± 0.14 | 1.50 ± 0.15 | 1.54 ± 0.08 | 1.54 ± 0.06 | 0.883 | 0.894 | 0.857 |
| EC (µs/cm) | 1130.00 ± 2.93[a] | 1110.00 ± 2.56[a] | 1070.00 ± 11.80[b] | 1050.00 ± 13.80[b] | <0.001 | 0.042 | 0.568 |
| Moisture (%) | 18.00 ± 0.36[b] | 17.70 ± 0.22[b] | 23.40 ± 0.87[a] | 23.90 ± 2.05[a] | <0.001 | 0.928 | 0.705 |
| Porosity (%) | 27.90 ± 1.57[b] | 28.20 ± 1.24[b] | 44.00 ± 0.92[a] | 42.20 ± 0.623[a] | <0.001 | 0.51 | 0.376 |
| BD (g.cm-3) | 1.21 ± 0.05[b] | 1.23 ± 0.06[b] | 1.46 ± 0.03[a] | 1.49 ± 0.03[a] | <0.001 | 0.587 | 0.899 |
| PD (g.cm-3) | 2.52 ± 0.05[a] | 2.21 ± 0.05[b] | 2.40 ± 0.03[a] | 2.20 ± 0.02[b] | 0.032 | <0.001 | 0.175 |
| Permeability (cm.s-1) | 2.42 ± 0.04[b] | 2.46 ± 0.10[b] | 4.35 ± 0.21[a] | 3.92 ± 0.23[a] | <0.001 | 0.22 | 0.171 |
| Stiffness (MPa)2 | 15.00 ± 0.00[a] | 11.25 ± 1.13[b] | 15.00 ± 0.00[a] | 10.5 ± 0.98[b] | 0.392 | <0.001 | 0.561 |

Values are means ± SEM. [a-b] Means in a row without a common superscript letter differ ($P < 0.05$) as analyzed by two-way ANOVA and the TUKEY test.
[1]S × L = Season × Location interaction effect.
[2] Represented as Cone resistance ($q_c$), n = 2 per treatment group

**Water Quality of the Ponds.**
The results obtained from table 3 revealed that Makurdi had a lower pH (5.38) compared to Umudike (6.28) during dry season while Makurdi had a higher pH (7.76) similar to Umudike (7.31) during the wet season. There were significant effects of season (<0.001) and season x location interaction (<0.001) on pH but no significant effect of location (0.359). The range of pH in the ponds water also reveals that it is within the optimal range (6.5 - 9.0) suitable for fish production. Makurdi had a higher Total Dissolved Solids (190mg/L) compared to Umudike (144mg/L) during the dry season while Makurdi had a Total Dissolved Solids of 52.7mg/L, while Umudike had 18.6mg/L during the wet season. Season had a significant effect (<0.001), but location (0.133) and the interaction (0.816) were not significant.

Dissolved Oxygen was lower in Makurdi (2.41mg/L) than in Umudike (5.13mg/L) during the dry season. Dissolved Oxygen in Makurdi increased to 3.91mg/While Umudike reached 5.77mg/L during the wet season. Significant effects were observed for both season and location (<0.001 for both), but no significant effect of the interaction (0.318) However, Umudike Ponds whose range of dissolved Oxygen is 5.13-5.77mg/L for dry season and wet season respectively is still above the critical concentration of 3mg/L. Biological Oxygen Demand Values were similar across both locations and seasons ranges from 0.07 to 0.15mg/L. There were no significant effects of season (0.506), location (0.099), or interaction (0.54). There is no significant difference between the two locations and seasons. Both locations had similar water temperatures (~29.6~29.7ºC) during the dry season while temperatures were lower, ranging from 27.7ºC to 28.6ºC during the wet season. There was no significant difference in the pond water temperature of the two locations. Significant effects were observed for season, location and interaction (<0.001 for all).

Hardness values ranged from 1.28mg/L to 5.05mg/L across seasons and locations. No significant effects of season (0.074), location (0.197), or interaction (0.726). Electrical Conductivity Low values were observed in both locations (~0.20 ~0.28 $S.cm^{-1}$) during dry season while a sharp increase was observed especially in Makurdi (107 S $cm^{-1}$) compared to Umudike (38. 80$S.cm^{-1}$) during the wet season. Significant effects were found to season, location and interaction (<0.001 for all).

Turbidity values varied across seasons with Makurdi showing higher turbidity in the dry season (12.80NTU) compared to the wet season (6.37NTU). No significant effects were found for season (0.396), location (0.362), or interaction (0.062). The high turbidity, as observed especially in Makurdi ponds during the dry season, could result from the reduction in pond water, increment of sedimentations, and presence of algae. Alkalinity Values ranged from 4.42 mg/L to 7.21 mg/L across locations and seasons. There was a significant effect of location (0.028), but no significant effects for season (0.523) or interaction (0.672).

**Table 3:** Water Quality of the Ponds

| Variable | Dry | | Wet | | *P*-value | | |
|---|---|---|---|---|---|---|---|
| | **Makurdi (n = 12)** | **Umudike (n = 12)** | **Makurdi (n = 18)** | **Umudike (n = 15)** | **Season** | **Location** | **S×L[1]** |
| Ph | $5.38 \pm 0.19^{c}$ | $6.28 \pm 0.17^{b}$ | $7.76 \pm 0.12^{a}$ | $7.31 \pm 0.07^{a}$ | <0.001 | 0.359 | <0.001 |
| TDS (mg/L) | $190.00 \pm 33.70^{a}$ | $144.00 \pm 50.40^{ab}$ | $52.7 \pm 5.17^{bc}$ | $18.6 \pm 3.71^{c}$ | <0.001 | 0.133 | 0.816 |
| DO (mg/L) | $2.99 \pm 0.0723^{d}$ | $5.13 \pm 0.17^{b}$ | $3.91 \pm 0.10^{c}$ | $5.77 \pm 0.17^{a}$ | <0.001 | <0.001 | 0.318 |
| BOD (mg/L) | 0.07 ± 0.02 | 0.15 ± 0.06 | 0.07 ± 0.02 | 0.11 ± 0.03 | 0.506 | 0.099 | 0.54 |
| Temp (°C) | $29.70 \pm 0.05^{a}$ | $29.60 \pm 0.07^{a}$ | $27.7 \pm 0.03^{c}$ | $28.60 \pm 0.04^{b}$ | <0.001 | <0.001 | <0.001 |
| Hardness (mg/L) | 1.28 ± 0.55 | 2.35 ± 1.23 | 3.13 ± 1.06 | 5.05 ± 1.51 | 0.074 | 0.197 | 0.726 |
| EC (μs/cm) | $0.28 \pm 0.05^{c}$ | $0.20 \pm 0.07^{c}$ | $107.00 \pm 9.93^{a}$ | $38.80 \pm 7.33^{b}$ | <0.001 | <0.001 | <0.001 |
| Turbidity (NTU) | 12.80 ± 2.90 | 9.67 ± 4.26 | 6.37 ± 0.57 | 12.50 ± 1.88 | 0.396 | 0.362 | 0.062 |
| Alkalinity (mg/L) | 4.55 ± 0.47 | 7.21 ± 1.64 | 4.42 ± 0.76 | 6.25 ± 0.82 | 0.523 | 0.028 | 0.672 |

Values are means ± SEM. [a-d]Means in a row without a common superscript letter differ ($P < 0.05$) as analyzed by two-way ANOVA and the TUKEY test. [1]S × L = Season × Location interaction effect.

**Correlations Between Pond Soil Properties and Pond Water Quality Parameters at Umudike (2023/24)** (ns p ≥ 0.05; * p < 0.05; ** p < 0.01; and *** p < 0.001)

Figure 3 showed that there is a moderate negative correlation of soil pH with water pH (-0.637), indicating that as soil pH decreases, water pH tends to increase slightly. There is a very weak positive sand percentage correlation with soil electrical conductivity (EC) (0.281) and a weak positive relationship with water pH (0.221). Clay % showed strong negative correlation with % Sand (-0.998), which is expected since sand and clay have opposite textural properties. Negative correlation with water pH (-0.637), indicating an inverse relationship. Soil Organic Matter (OM): Negatively correlated with soil moisture (-0.632), suggesting that higher soil organic matter is associated with lower moisture content. Positively correlated with water properties like TDS (0.680), BOD (0.633), and Hardness (0.632).

Soil EC (Electrical Conductivity): Strongly positively correlated with water EC (0.998), indicating that higher soil conductivity is associated with higher water conductivity. Also positively correlated with turbidity (0.998), indicating a strong relationship with water clarity. Water pH was Positively correlated with water turbidity (0.997), suggesting higher pH water is associated with more turbid conditions. TDS and BOD are strongly correlated with turbidity and other water quality indicators like EC and hardness, showing interrelated water quality factors. % Sand and % Clay are almost perfectly negatively correlated (-0.998), indicating that as the sand content increases, clay content decreases, which is expected in soil texture analysis. A weak positive correlation exists between % Sand and Water pH (0.221), suggesting that higher sand content is slightly associated with higher water pH, although this is not statistically significant.

There is a moderate negative correlation between % Clay and Water pH (-0.637). This indicates that as the clay content in the soil increases, the water pH tends to decrease. This relationship might suggest that soils with higher clay content retain more acidic conditions in water. Soil OM has significant positive correlations with several water quality parameters such as TDS (Total Dissolved Solids): 0.680, BOD (Biological Oxygen Demand): 0.633 and Water Hardness: 0.632. These correlations indicate that as soil organic matter increases, there is an increase in water quality parameters like TDS, BOD, and hardness. This suggests that organic matter content in the soil influences water nutrient levels, which could affect water clarity and biological activity.

A significant negative correlation (-0.632) exists between Soil OM and Soil Moisture. This suggests that higher organic matter in the soil is associated with lower soil moisture, possibly due to organic matter affecting water retention or evaporation rates. There is an almost perfect positive correlation (0.998) between Soil EC and Water EC, indicating that higher soil conductivity is strongly linked to higher water conductivity. This means that soils with higher salinity or dissolved ions are associated with higher concentrations of ions in water. Similarly, Soil EC is highly correlated with Water Turbidity (0.998), showing that soils with higher EC contribute to higher turbidity in water. This suggests that dissolved particles in soil might transfer to water, affecting its clarity. Water pH shows a very strong positive correlation with Water Turbidity (0.997). This suggests that more alkaline water tends to be more turbid, indicating a relationship between water clarity and pH.

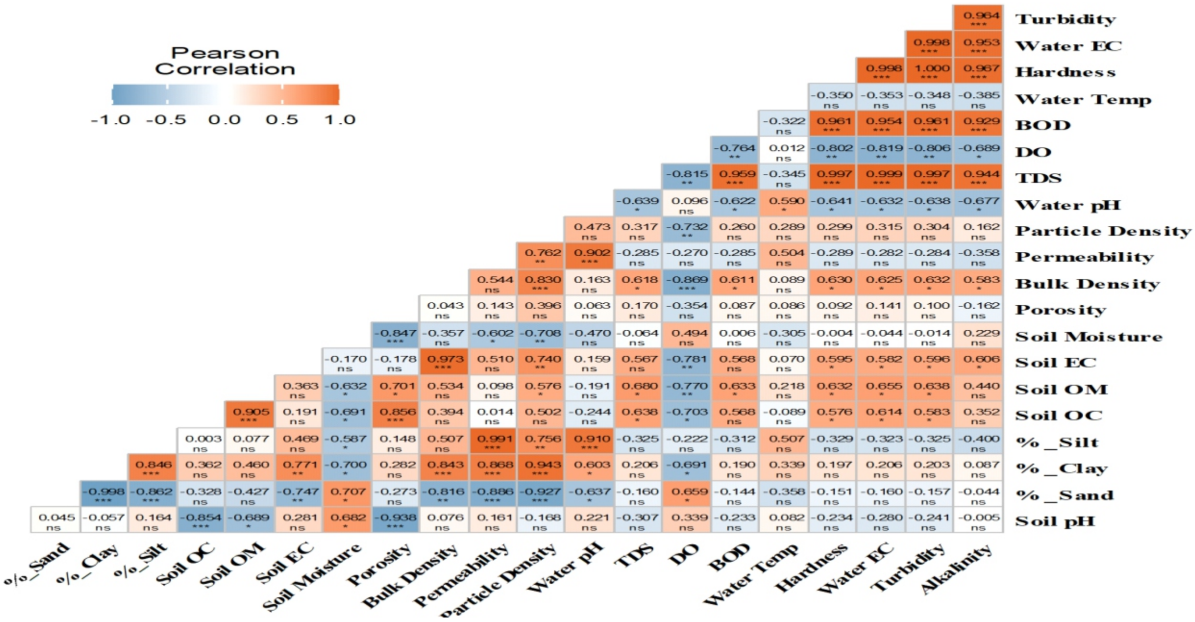



**Figure: 3** Correlations between Pond Soil Properties and Pond Water Quality Parameters at Umudike.

**Correlations Between Pond Soil Properties and Pond Water Quality Parameters at Makurdi (2023/24)** (ns $p \geq 0.05$; * $p < 0.05$; ** $p < 0.01$; and *** $p < 0.001$)

Figure 4 showed that % Sand and % Clay have a very strong negative correlation (-0.998), which is typical since soils with more sand tend to have less clay. A weak positive correlation (0.221) exists between % Sand and Water pH, though it is not statistically significant. There is a significant negative correlation between % Clay and Water pH (-0.637), suggesting that soils with higher clay content tend to have lower water pH. Soil OM has several significant positive correlations with water quality indicators such as TDS (Total Dissolved Solids): 0.680, BOD (Biological Oxygen Demand): 0.633 and Water Hardness: 0.632 these positive correlations suggest that higher organic content in soil contributes to higher nutrient content and biological activity in water.

There is a negative correlation between Soil OM and Soil Moisture (-0.632), indicating that soils with more organic matter tend to retain less moisture. Soil EC is almost perfectly correlated with Water EC (0.998), showing that higher electrical conductivity in the soil is strongly related to increased ion content in the water.

There is also a strong positive correlation between Soil EC and Water Turbidity (0.998), suggesting that soils with higher EC tend to lead to more turbid water. Water pH and Water Turbidity are strongly positively correlated (0.997), suggesting that more alkaline water tends to be more turbid.

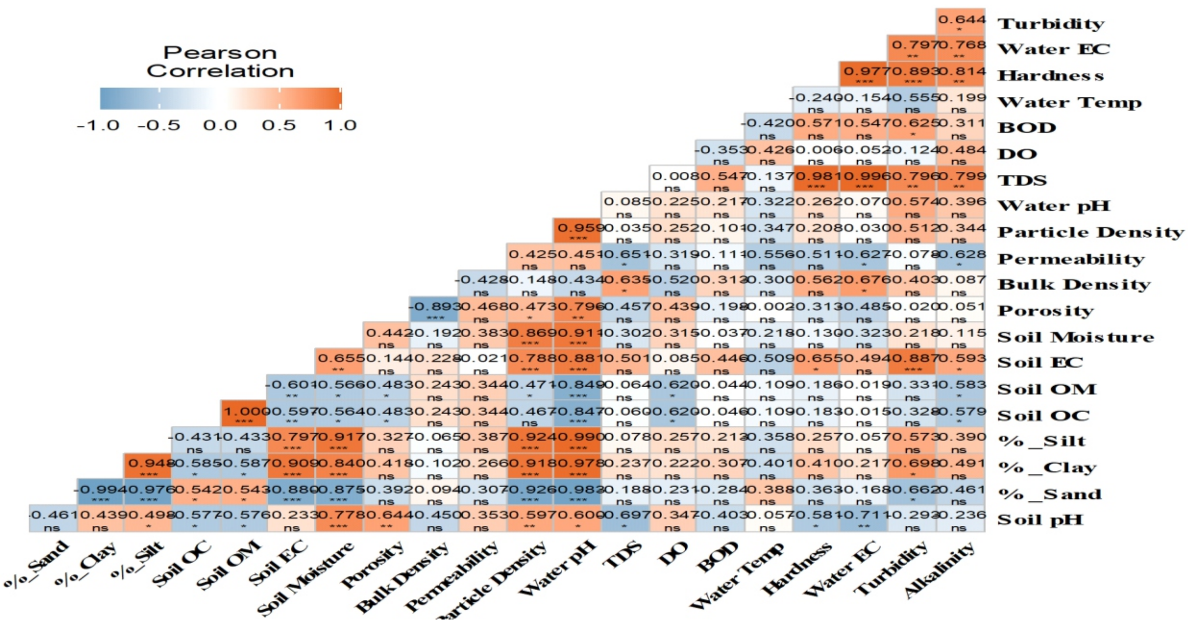



**Figure: 4** Correlations between Pond Soil Properties and Pond Water Quality Parameters at Makurdi.

## DISCUSSION

### Soil Profile and Textural Characteristics.

The findings from this study showed that the sand content, clay content and silt content varied significantly across both seasons and locations, Umudike consistently had higher sand content than Makurdi in the wet season. Conversely, clay content was significantly higher in Makurdi than Umudike in both seasons. This suggests that the clay loamy soil which is better for aquaculture ponds is higher in Makurdi than Umudike and Makurdi soils have better water retaining capacity which are very good for aquaculture ponds. This is in line with the submission of (Hena *et al*., 2018) who's stated that the pond soils must contain 20% to 30% clay-sized particles in other to provide a barrier against seepage, but clayey-loam soil are generally better for fish production than the heavy clay soils.

Furthermore, Makurdi had higher silt content than Umudike in the dry season but in the wet season, Umudike's silt content slightly surpassed Makurd. The Makurdi samples generally show slightly larger sizes, indicating higher organic matter content than the Umudike samples and the majority of the samples from both locations fall within the sandy loam and sandy clay loam. This is an indication that Makurdi and Umudike had adequate sand, clay and silt and the level of their deposit were determined by season and other environmental factors. The findings also suggest that the two locations have similar soil texture that can support aquaculture. This is in agreement with the work done by Mobilian *et al* (2021) who described sand, silt and clay as the comparative quality components of soil texture.

The findings from this work, disclosed that Makurdi and Umudike soils have similar textural characteristics, falling into sandy loam and Sandy clay loam categories. This suggests that the soils of the two locations during the seasons had a high proportion of sand, moderate clay and a small percentage of silt.

The findings further revealed that Makurdi experienced a significant decrease in silt content from the dry season to the wet season and the silt percentage was much higher in the dry season, indicating that Makurdi's pond soil retains more silt during drier conditions. Umudike on the other hand, shows a slight increase in silt content from the dry season to the wet season, suggesting that more silt was present during the wet period while Makurdi had a much higher silt content during the dry season compared to Umudike, suggesting that the environmental conditions such as lack of rainfall, less water flow etc. allowed more silt to settle in the pond soil. The above results are in agreement with the work done by Mobilan, *et al* (2021).

### Physical and Chemical Characteristics of the Soils.

The results of this study indicate a significant positive correlation between soil electrical conductivity and aquaculture. The findings support previous research suggesting that soil electrical conductivity can be a reliable indicator of soil fertility and water availability ( Hena *et al.,* 2018). The findings also showed that Makurdi had higher particle density, organic matter, pH than Umudike during the two seasons. The presence of higher organic matter in Makurdi soil suggest more presence of phytoplanktons and zooplanktons which enhance aquaculture ponds productivity. The average soil pH range of 6.0 and 8.0 in the two locations suggest that the pH for the two locations favour aquaculture and this is in conformity with the work of Boyd (2008) who described pH range of 7.5 -8.5 mg/L as being most suitable for fish production. The results also agree with the work of Boyd, (2015) who disclosed that low soil pH inhibits the decomposition of organic matter and allows its accumulation in pond soils to cause high oxygen demand at the interface of bottom soil and pond water. Organic carbon was relatively consistent across both locations and seasons with values ranging between 0.89% and 0.91%. This result is contrary to the findings of Rana *et al,* (2017) who disclosed that the organic carbon content of 1.5% to 2% and calcium carbonate content of more than 5% are best suitable for shrimp aquaculture. Organic matter values were also consistent across seasons and locations, ranging from 1.50% to 1.54%. This conforms with the work of Rana *et al*., (2017), who recorded an average organic matter of 2.02% but contrary to the work of Siddique *et al*.,(2012 ) who recorded organic matter range of 7.6 %-13.4%.

### Water Quality of the Ponds.

Makurdi had a higher total dissolved solids during the two seasons and had a significant effect even though location and interaction were not significant based on the results. Umudike, on the other hand, had higher dissolved oxygen levels during the two seasons, and this may be attributed to higher rainfall in Umudike than in Makurdi. There was a significant difference in the dissolved oxygen between the ponds of the two locations which may be as a result of a bloom that has retarded photosynthetic activities by impeding the penetration of the sunlight, which is the source of energy in the process of producing oxygen. The low dissolved oxygen recorded expecially in Makurdi could be attributed to competition between algae and other plankton, as well as fish over oxygen respiration. This is in line with the work of Adagbo *et al*., (2020), who reported that almost all problems with dissolved oxygen in fish culture result from heavy plankton blooms. However, Umudike ponds, whose range of dissolved oxygen is 5.13 -5.77mg/L for dry season and wet season respectively, is still above the critical concentration, is good for fish growth according to Boyd, (2023) Conversely, the dissolved oxygen range of Makurdi ponds (2.41-3.91gm/L) for dry and wet seasons was less than the minimum range for fish growth.

The study also disclosed that there was no significant difference in the pond water temperature of the two locations. This shows that the activities of plankton and other organic matter does not have any significant effect on the water temperature. These findings are in line with the work done by (Okomoda *et al*. 2006). The results obtained from this work also revealed that Makurdi had higher values of turbidity during the dry season and this could be as a result of short rainfall and other water management practices in Umudike Ponds.

The average water pH range of 6.0 and 8.0mg/L in the two locations suggests that their pH favours aquaculture. The above pH range conforms with work done by (Abowei, 2010, Okayi *et al*, 2011), who described a pH range of 6.5 to 9.0 being the most suitable for fish production.

## CONCLUSION

An Aquaculture system is always balanced by pond soil as the soil properties play a vital role in the growth and survival of aquatic organisms. The results obtained from this study showed that Makurdi had higher clay content in the dry season and in the wet season compared to Umudike. Umudike earthen ponds water quality is preferable, especially in terms of dissolved oxygen, turbidity, biological oxygen demand, hardness, and alkalinity. This suggests that the Makurdi soil can provide a better barrier against seepage than Umudike soil. The findings from this work also showed that the clay content, sand content, and silt content varied significantly across both seasons and locations, with Umudike consistently having higher sand content than Makurdi in the wet seasons. Clay content was, however significantly higher in Makurdi than Umudike. This suggests that the clay loamy soil, which is better for aquaculture ponds is higher in Makurdi than Umudike. The findings also proved that Makurdi and Umudike had adequate sand, clay and silt and the level of their deposits was determined by seasons and locations. The two locations, on the other hand, recorded favourable temperatures, biological oxygen demands, electrical conductivity, hardness and turbidity, which were normal for the optimal growth of aquaculture.

## RECOMMENDATION

**Based on the findings of this study, the following recommendations are made:**

- Makurdi earthen ponds demonstrated higher clay loam soil and better water retaining capacity which are better for aquaculture earthen ponds than Umudike soils. Hence, Makurdi soil texture is preferable.
- Makurdi earthen Pond soils recorded better particle density, soil pH ,stiffness and electrical conductivity. Consequently, Makurdi soil's physical and chemical properties are preferable.
- Umudike earthen ponds water quality is preferable, especially in terms of dissolved oxygen, turbidity, biological oxygen demand, hardness, and alkalinity.

## EFERENCES


Abowei, J.F.N. (2010). Salinity, Dissolved Oxygen, pH and Surface Water Temperature Condition in Nkoro River, Nigeria, Niger Delta, *Nigeria.*

Adagbo, A. P and Mtomga .F. (2020). Evaluation of Water Quality Parameters in Earthen Ponds of the University of Agriculture, Makurdi Fish Farm. *International Journal of Agricultural, Management and Technology,* **4**( 2),2020**.**

Bansode, V. V., Sharangdhar, M. T., Mohite and More, S. S. (2020). Soil and Water Quality Parameters of Brackish Water Shrimp Farms of Raigad District of Maharashtra.

Boyd, C. E.(2008). Pond Bottom Soil Analysis. *Global Aquaculture Advocate*, **11**(4**):** 64-66

Boyd, C. E. (2015). Water Quality: An Introduction.Springer International Publishing. *1st Edition.Springer Nature, Switzerland AG (2015).*

Boyd, C. E. (2020). Water Quality Management in Aquaculture.In C. E. Boyd and H.S.Egna(Eds.), Dynamics of Pond Aquaculture (pp .124-154).

Chumnanka, N., Boyd, C. E., Viriyatum, R and Tunkijjanukij, S. (2015). Bottom Soil Characteristics, Survival and Production of Shrimps in low Salinity, Inland Ponds in Alabama and Florida (USA).

Eaton,A. D. (2015).Standard Methods for the Examination of Water and Waste Water, 21st ed.American Public Health Association, American Water Works Association, Water Environment Federation , Washington .DC,USA.

Hatfield ,J., Sauer, T. J and Cruse, R.M. (2017). Chapter one-soil:the forgotten piece of the water.Food.Energy Nexus Adv.Agron.**143**-1-46.

Hena, A., Kamal, M., Hishamuddin, O and Boyd, C.E. (2018). Physical and Chemical Characteristics of Soil from tiger shrimp aquaculture ponds at Malacca ,Malaysia.

*Journal of Research in Forestry, Wildlife and Environment* .**12**(1) March 2020.

Mobilian, C and Craft, C.B. (2021). Wetland Soil: Physical and Chemical Properties and Biogeochemical Processes .Reference Module in Earth System and Environmental Sciences.

Ojwala, R. A., Elick, O. O and Nzula, K. K. (2018). *Effect of Water Quality on the Parasite Assemblages Infesting Nile Tilapia in Selected Fish Farms in Nakuru County, Kenya. Parasitology Research,* **117**(2018):3459-3471**.**

Okayi, R. G; Chokom, A. A and Angera ,S. M. (2011). *Aquatic Macrophytes and Water Quality Parameters of Selected Flood Plains and River Benue ,Makurdi,Benue State.*

Okomoda ,V.T., Tiamiyu, L. O and Iortim, M . (2016). The Effect of Water Renewal on Growth of Clarias gariepinus Fingerlings. *Journal of Fisheries*.74.25-29.Do I.10.1515/cjf -2016-0005.

Pantjara, B and Kristano, A .H. (2020). Pond Bottom Management and Probiotic Application in Extensive Tiger Prawn(Danaeus monodon) Culture on Acid Sulphate Soil. Aquaculture, Aquarium, Conservation and Legislation (AACL )Bioflux 13(2):974-983.

Pond Soil Characteristics and Dynamics of Soil Organic Matter and Nutients.In:K.MC Elwee,D.Burke, M.Niles,X Cumings ,and H.Egna (Editors*) Seventeenth Annual Technical Report Pond Dynamics /Aquaculture CRSP, Oregon State University Corvallis ,Oregon*. pp 1-8.

Pouila, S., Reza, S., Jacques, S., Ahmad, S., Gusnia, K., Khazaidan, H. E, Amang, B and Domenico, P. C. (2019). *Nutrient Budgets in a Small-Scale Freshwater Fish Pond System in Indonesia*

*Aquaculture,* **504** (2019):.267-274.10.1016/j.aquaculture.2019.01.0

Rana, M. E. U ., Hossain, S., Tapadar, M. A., Hossain, M. B and Sarkar, B.S. (2017). Effects of Pond Age and Depth on Bottom Soil Nutrients ,PH and Salinity in Commercial Farm ,World Journal of Fish and Marine Sciences ,9(4),25-30

*Resource Journal of Environmental Earth*. Sci.**2**(I).16-21**.**

Sarasworthy, R., Moturi, M., Dad, S., Periyamuthu, K., Sukumaran, S., Natarayan, L., Vinaya, K. K and Arunachalam, N. (2019). Changes in Soil and Water Quality at Sediment -Water Interface of Penaeus Vannamei Culture Pond at Varying Salinities. *Aquaculture Research,* **50** (2019):1096-1106,10.111/are.13984.

Shafi, J., Waheed , K. N., Mirra, Z. S and Zafarulla, M. (2022). Variation in Bottom Soil Quality with increasing Pond Age in Freshwater Aquaculture.Turkish Journal of Fisheries and Aquatic Sciences,22(2).TRJFAS 18305.

Siddique, M. A. M., Barua, P and Ghani, H. M. (2012). Comparative Study of Physico-chemical Properties of Soil according to the Age of Aquaculture Ponds of Bangladesh. *Mesopotamian Journal Marine Science* **27**(1) (2012):29-38

Wang, H., Xing, I., Zhang, H. C., Jin, S., Lin, H and Cheng, C. (2021). Key factors to Enhance Soil Remediation by Bio Electrochemical System(BES). *A Review Chemical Engineering Journal,* 419,129600

Zubiamasood, G. N., Mussaa B and Masoods, Z . (2015). Study of Some Physiochemical Properties of Soil in Fish Pond at Circuit House, District Sibi of Province Balochistan, Pakistan.