



## TEXTURAL AND MINERALOGICAL PROPERTIES OF HYDROMORPHIC SOILS IN ONDO, SOUTHWESTERN NIGERIA: ITS IMPLICATIONS FOR PEDOGENESIS AND NUTRIENT RESERVE POTENTIALS

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### ABSTRACT

The research analyzed two hydromorphic soil pedons in Ondo, Southwestern Nigeria, to assess a correlation between particle-size distribution and mineral composition as indicators of nutrient-reserve capacity. Particle-size analysis indicated that the soils are coarse-textured, primarily composed of sand (mean 84.2%), with silt (8.0%) and clay (7.8%) fractions. The silt/clay ratio of 1.06 suggests moderate weathering and textural immaturity. Mineralogical analysis indicated a predominance of quartz (67–76%), succeeded by mica (5–20%), feldspar (6–15%), matrix materials (2–8%), heavy minerals (1–3%), and minor rock fragments (~1%). The elevated quartz content and sandy texture indicates a silica enrichment, minimal secondary-clay development, and restricted leaching under intermittent hydromorphic conditions. Recalculated abundances of quartz, feldspar, and rock fragments suggests a low to moderate potential for nutrient reserves. Agriculturally, these soils exhibits low fertility and nutrient-holding capacity; however, improvements can be achieved through addition of organic matter, enhancement of drainage, and application of fertilizers. The soils are classified as quartz-rich, texturally immature hydromorphic soils characterized by low mineral nutrient reserves, which are typical of humid tropical lowland landscapes. The findings indicated that Ondo hydromorphic soils exhibited physical maturity; though chemically deficient, characterized by low nutrient reserves and restricted cation-exchange capacity. Effective management strategies that improve organic matter and nutrient cycling are crucial for maintaining agricultural productivity in these soils.

**Keywords:** Hydromorphic, Soils, Sand, Quartz, Dominance, Weathering.

### INTRODUCTION

Soil is a heterogeneous natural body resulting from the multifaceted interaction of several pedogenic factors which includes climate, parent material, topography, biological activity, and time (Cahyana and Mulyanto 2024). These factors operate at varying intensities and scales, resulting into distinct soil types across different landscapes. Hydromorphic soils are one of such soil type which forms under conditions of poor drainage and prolonged water saturation, where availability of oxygen is very limited. Periods of saturation or consistently poor drainage, which lower soil oxygen availability and cause active redox cycling of essential elements like iron (Fe) and manganese (Mn), are characteristics of hydromorphic soils. Redox transformations, such as Fe/Mn reductions, depletions, and concentrations, are driven by alternating waterlogging and aeration under such water-dominated conditions. These redoximorphic features have a significant impact on soil-formation processes, morphology, and physicochemical properties (Rubinić *et al.*, 2022; Mapeshoane *et al.*, 2013).

Recurrent oxidation-reduction (redox) processes under anaerobic conditions linked to poor drainage and saturation cause hydromorphic soils to frequently exhibit distinctive color, structure, and chemical signatures, according to recent reviews (Rubinić *et al.*, 2022). Iron ( $\text{Fe}^{3+} \rightarrow \text{Fe}^{2+}$ ) and manganese oxides are usually reduced in these redox processes, which can result in the dissolution and mobilization of Fe and Mn. When conditions become aerobic, re-precipitation occurs, resulting in



mottling, gleying, and other redoximorphic features (Kronberg *et al.*, 2024). These changes, which include variations in the abundance and crystallinity of Fe/Mn oxides and other minerals, represent the degree and extent of hydromorphism in hydromorphic soils by reflecting the length and intensity of saturation (Xu *et al.*, 2025). Under saturated conditions, clay mineral content often increases as fine particles are being translocated. Studies in the Russian taiga on alluvial sands show that increasing soil hydromorphism correlates with higher clay content, altered distributions of Fe, Al, and Si species, and greater acidity. Correspondingly, in the Central Amazon region, studied shows that hydromorphic profiles show reduced hematite and goethite in deeper horizons relative to non-hydromorphic soils, demonstrating the great influence of saturation on iron mineral phases (Likhanova *et al.*, 2022).

Understanding these interactions is critical for interpreting soil genesis, nutrient dynamics, and land use potential in wetland and seasonally waterlogged environment. This research attempted to provide information on mineral composition of hydromorphic soils, its implications for Pedogenesis and Nutrient Reserve Potential in a selected site in Ondo, Southwestern Nigeria. The specific objectives of the study were to characterize the particle size distribution and mineralogical composition of hydromorphic soils in Ondo.

## **MATERIALS AND METHODS**

### **Study Site**

The study was carried out in inland valley swamp of Wesley University Teaching and Research Farm, Ondo, Ondo State, Nigeria (approx. 6°55'N, 4°55'E), characterized by humid tropical climate with annual rainfall of 1,800 – 2,000 mm and mean temperature of 27 – 30°C. The parent materials are mainly crystalline basement complex rocks (granite and gneiss), weathered to sandy regoliths under prolonged tropical conditions.

### **Soil Profile Description and Sampling**

Two pedons were excavated at the site to the depth of 120- 137 cm. They were 100 m apart based on their physiographical position. They were described morphologically according to FAO (2015) guidelines. Samples were collected horizon-wise for laboratory analysis. Particle size distribution was determined by the hydrometer method, it was carried out at the Soils Laboratory of the Institute of Agricultural Research and Training, Ibadan. Mineralogical composition was studied using petrographic thin-section microscopy and point counting at Laboratory of Geology Department, University of Ibadan, Oyo state, Nigeria.

### **Petrographic Analysis**

Thin sections of selected eight grain samples represented the three layers of the pedon OND 1 and five layers of the pedon OND 2 were prepared for petrographic analysis at thin sectioning laboratory of Geology Department, University of Ibadan. Samples were first impregnated with resin and allowed solidifying for 24 hours before cutting. The samples were then mounted on a glass slide and then ground with carborundum 90 and 400 grit for good and smooth surfaces respectively. This was followed with manual grinding with sludge of fine abrasive on a glass plate until the glass was thin enough for individual mineral identification. The slides were warmed to remove bubbles and thin-out using section micro-cutting machine and then thoroughly washed with water and allowed to dry before covering with a cover slip and labeled.

The compositional characteristics of each thin section were observed under the calibrated scale microscope and photomicrographs of features of interest were then taken. The framework constituents of each thin section were counted randomly with grid spacing adjusted to allow 350-400 counts, without counting a grain more than once. The Gazzi-Dickinson method of point counting was used to minimize the dependence of rock composition on grain size and crystals larger than 0.0625 mm within lithic fragments were counted as monocrystalline grains (Eduardo Garzanti 2019; He *et al.*, 2018).

### **Statistical Analysis**

The statistical analysis adopted in analyzing the obtained data were range, mean, standard deviation and coefficient of variation.

## RESULTS

### Physical Characteristics

Table 1 presented result of the selected physical properties of the soils and study site, while the range, mean, standard deviation and coefficient of variance are shown in table 2. The mechanical analysis showed that sand fractions were the dominant soil and irregularly distributed within the profiles, with mean values of 84.2%. The silt has a mean values of 8.0%. The clay contents were low in the surface horizons but increased gradually in the subsoil horizons with no definite pattern of distribution having mean value of 7.8%. The silt / clay ratios ranged from 0.5 – 1.3 with mean values of 1.06. This reflects weak pedogenic differentiation, poor profile development, and minimal clay eluviation–illuviation processes.

**Table 1:** Selected Physical Properties of Soils of the Inland Valley Area Studied

Depth (cm)	Sand	Silt	Clay	Textural Class	Silt: Clay
	_____ % _____				
Pedon OND – Pt 1					
0 – 38	86.0	7.2	6.8	Loamy Sand	1.1
38 – 85	84.0	5.2	8.8	Loamy Sand	0.5
85 – 124	82.4	8.8	10.8	Loamy Sand	0.8
Pedon OND – Pt 2					
0 – 23	84.0	8.8	5.2	Loamy Sand	1.7
23 – 52	84.0	8.8	7.2	Loamy Sand	1.2
52 – 87	88.0	6.8	7.2	Loamy Sand	0.9
87 – 102	81.2	11.2	7.6	Loamy Sand	1.5
102 – 130	84.0	7.2	8.8	Loamy Sand	0.8

**Table 2:** Range, Mean (X), Standard Deviation (SD) and Coefficient of Variance (CV %) for Some Physical Properties of (Wesley University Research Farm) Ondo Inland Valley Swamp

Variables	Range	Mean (X)	SD	CV %
Sand	81.2 – 88.0	84.2	1.94	2.30
Silt	5.2 – 11.2	8.00	1.64	21.13
Clay	5.2 – 10.8	7.8	1.56	20.03
Silt: Clay	0.5 – 1.3	1.06	0.37	34.96

### Petrographic Analysis

Table 3 showed the framework parameters of detrital modes identified on the slides. The detrital framework grains in the studied slides include quartz, feldspar, rock fragment, matrix and mica. There are also heavy minerals such as tourmaline, hornblende, zircon and rutile. Few opaque specs were seen on the slides as well and are most likely iron-oxide species such as haematite and ilmenite which identified with hydromorphic soils.

Table 4 shows the petrographic data of the analysis carried out on the soil samples, primary minerals were discovered with the domination of quartz. The quantities were recalculated and were used to determine the nutrient reserve of the soils.

Quartz is the most dominant detrital mineral species scattered across the slides, it ranges from 67 – 76 and 81.7% - 91.6% for recalculated abundances for nutrient reserve. It is irregularly distributed within the profile. The samples have few polycrystalline crystals. The quartz grains show angular to subrounded shapes. Many of the quartz grains were not morphologically elongated or flattened and do not show parallel crystallographic orientation.

Fresh feldspars with abundance of both plagioclase and potassium feldspars occurred in the samples. It ranges from 7.2 – 15 from petrographic analysis and 7.2 % - 18.3% for recalculated abundances for nutrient reserve, it follows the same pattern of distribution with quartz but it is very low compare with quartz. Feldspar grains are typically smaller to quartz grains.



**Table 3:** Framework Parameters of Detrital Modes Identified on Petrographic Slides

Qz	Monocrystalline quartz
Qpq	Polycrystalline quartz
P	Plagioclase feldspar
KF	Potassium feldspar
RF	Total unstable rock fragments
Mi	Mica

**Table 4:** Petrographic Analysis Data for Ondo

DEPTH	QUARTZ	FELDSPAR	ROCK FRAGMENT	MICA	MATRIX	HEAVY MINERALS
<b>PEDON OND 1</b>						
0 – 38	75	10	-	5	7	3
38 – 85	76	10	-	6	7	1
85 – 124	75	10	-	5	8	2
<b>PEDON OND 2</b>						
0 – 23	76	6	1	8	7	2
23 – 52	72	10	1	8	6	3
52 – 87	67	15	-	10	5	3
87 – 102	72	13	-	20	2	1
102 – 130	73	12	-	10	8	1

**Table 5:** Recalculated Abundances of Quartz, Feldspar, Rock Fragment for Mineral Base Nutrient Reserve.

DEPTH	QUARTZ	FELDSPAR	ROCK FRAGMENT	Weatherable Mineral (F + RF)%	Nutrient reserve
<b>Pedon OND – Pt1</b>					
0 – 38	88.2	11.8	-	11.8	Fair
38 – 85	88.4	11.6	-	11.6	Fair
85 – 124	88.2	11.8	-	11.8	Fair
<b>Pedon OND – Pt2</b>					
0 – 23	91.6	7.2	1.2	8.4	Low
23 – 52	86.7	12.0	1.2	13.2	Fair
52 – 87	81.7	18.3	-	18.3	Fair
87 – 102	84.7	15.3	-	15.3	Fair
102 – 130	85.9	14.1	-	14.1	Fair
<b>&lt; 10%</b>	<b>Low reserve</b>				
<b>10 – 20%</b>	<b>Fair reserve</b>				
<b>&gt;20%</b>	<b>High reserve</b>				

This interpretation for the Nutrient reserve shadowed published classification systems for soil mineralogy and pedogenesis (Ferrer *et al.*, 2023)

## DISCUSSION

The coarse texture and high sand fraction as identified in this study support limited clay formation and weak profile differentiation typical of young or rejuvenated hydromorphic soils. The quartz predominance is consistent with intense silica leaching and the mobile bases removal, leaving behind resistant minerals. The low nutrient reserve values of these soils substantiate the nutrient-poor nature of these soils, as quartz was the dominant minerals which in tune had non to little nutrient to supply. Mica and feldspar fractions, though limited, remain crucial for slow nutrient release,



particularly potassium and trace elements. Hydromorphic conditions further inhibit complete weathering of feldspars, preserving some nutrient-bearing phases but constraining secondary clay synthesis.

The findings align with Ugbe *et al.*, 2020 studies from similar humid lowland soils which labels hydromorphic pedons as nutrient deficient soils yet pedogenically active under unstable redox regimes. The texture of the studied sands generally indicated fine grains, angular and coarser grains. This heterogeneous roundness of grains of different sizes reflects the importance of mechanical factors over chemical mechanisms for final grain shapes (Etemad-Saeed *et al.*, 2011). Quartz occurred in all of the horizons, demonstrating the high mineralogical uniformity of Ondo soils in Southwestern Nigeria.

The presence of rutile inclusion indicates quartz mostly from igneous origin. This is an indication that the sediments were probably sources from acid igneous rocks with minor input from metamorphic sources (Tucker, 2023). In all of the profiles and horizons the predominant particle size fraction was sand, favoring the leaching of organic-metallic complexes and contributing to the podzolization process. Under tropical conditions, the presence of sandy-quartz parent material along with subsurface impediments such as a shallow water table or hydromorphic conditions can facilitate podsolization / Spodosol type pedogenesis (Mafra *et al.*, 2002).

According to Esu, 2010 and Buol *et al.*, 2011, quartz (SiO<sub>2</sub>) remained one of the most pronounced chemically and physically stable minerals in the Earth's crust. The persistence of quartz in soil systems indicates its high resistance to alteration under tropical weathering regimes where temperature and rainfall are elevated. In such conditions, feldspars which falls under less stable silicate minerals undergo expansive hydrolysis and decomposition, releasing soluble bases and secondary clay minerals while leaving quartz as a residual mineral component. In hydromorphic environments, fluvial and depositional processes further enhance quartz concentration. The selective transportation during runoff which carries the lighter or more weathered materials often results in the accumulation of quartz rich sands in the valley bottom or low lying areas. These processes aid the coarse texture and relatively low clay content of the studied soils as seen in the tables.

The parent materials of the studied pedons are derived largely from Precambrian Basement Complex rocks which are inherently rich in quartz and siliceous minerals. According to Akinola and Ola Olorun, 2021, the soils formed over these rocks exhibit a high siliceous composition and at the same time are characteristically dominated by quartz in both the sand and silt fractions.

From an agricultural and environmental implications standpoint, the high quartz content has always had direct impacts on soil fertility and its usability. Brady and Weil, 2019 states that quartz are characterized with minimal surface charge and minute cation exchange capacity (CEC) thereby making the nutrient adsorption as well as retention ineffective for the soils. Consequently, any soils which is being dominated by quartz will be poor in terms of nutrient reserve and supply, acidic, and low in fertility, most especially exchangeable bases and available phosphorus. In a positive effect, the dominance of quartz in any soils are very beneficial for root development and microbial activity in terms of good drainage, porosity, and aeration.

The particle size analysis classified this hydromorphic soils as predominantly loamy sand, a texture that reflects the predominance of coarse sand-sized particles. This will give rooms for low water holding capacity and high permeability due to the pore space of sandy soils. The loamy component of the loamy sand texture of this soils may be as a results of the presence of minor amounts of feldspar present in the sample and the fine silt fractions which slightly improve the soil structure and contribute to cation exchange capacity. This textural characteristic is in line with the mineralogical composition which shows the dominance of quartz as observed through the mineral analysis. This makes the soil to be suitable for crops such as cassava, yam, groundnut, and maize because they are moderately tolerate to drought and they require well drained conditions for temporary submerged hydromorphic soils. The recalculated mineral ratios, therefore, provide an important insight into the soil's nutrient reserve index.



## CONCLUSION AND RECOMMENDATION

Quartz is a mineral which is very stable chemically and extremely resistant to both the influences of physical weathering and chemical disintegration. Therefore, its dominance in the sand fraction of the hydromorphic soils studied is very much expected. During weathering and transportation processes, feldspars and micas which are all less resistant minerals compare to quartz will break down, disband and modify into clay minerals, while quartz remains basically inviolate. The persistence of quartz grains explains the sandy nature of the soil and its classification as loamy sand and also indicates that the soils are highly weathered. However, the overall quartz dominance limits the nutrient holding capacity and water retention ability of the soils, making them inherently low in fertility unless enriched with organic matter and fertilizer. The quartz dominance observed across the thin sections of the two pedons studied is indicating a strong influence of both parent material and intense weathering processes typical of the humid tropical environment.

The silt – clay ratio (1.06) supports the immature pedogenic stage, reflecting limited clay illuviation. The recalculated abundances of quartz, feldspar, and rock fragments reveal that the soils are nutrient poor but pedogenically mature, where quartz dominance reflects chemical stability and low fertility, and the subordinate feldspar and rock fragments represent the residual sources of essential soil nutrients. For sustainable management and mineralogical balance there will be need for nutrient replenishment and organic matter management to enhance soil productivity in the hydromorphic landscapes of Ondo. The mulching practices is recommended also to improve water retention and nutrient supply in addition to organic matter enrichment. Quartz, being chemically inert, contributes little to the soil's nutrient reserves or cation exchange capacity, leading to low base saturation and poor nutrient retention. Consequently, such soils have limited natural fertility and are prone to leaching losses, especially under high rainfall and periodic flooding typical of hydromorphic environments.

For sustainable agricultural use, these soils require intensive management, proper drainage systems practices including the incorporation of organic matter, mulching, and balanced fertilization to improve nutrient availability and water holding capacity.

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