



Science Forum (Journal of Pure and Applied Sciences)



Journal Homepage: <https://atbuscienceforum.com.ng/index.php/jpas>

Deciphering Paleoclimate and Provenance Signals in Niger Delta Clay Deposits Using Major Oxide Geochemistry and Weathering Indices

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Abstract

This study investigates the major oxide geochemistry of clay deposits within the Niger Delta to evaluate their provenance, weathering characteristics, depositional environment, and industrial suitability through integrated geochemical and statistical approaches. Twelve representative clay samples were collected from selected locations across the study area and analyzed for major oxide composition using Inductively Coupled Plasma–Optical Emission Spectrometry (ICP–OES). The analyzed oxides include SiO₂, Al₂O₃, Fe₂O₃, MnO, MgO, CaO, Na₂O, K₂O, TiO₂, and P₂O₅, together with Loss on Ignition (LOI). Geochemical results indicate that SiO₂ is the dominant oxide, with concentrations ranging from 42.21% to 91.91% and an average value of 71.06%, suggesting quartz-rich, compositionally mature, and highly weathered sediments. Al₂O₃ and Fe₂O₃ recorded average concentrations of 13.58% and 3.44%, respectively, reflecting appreciable contributions from clay minerals and ferruginous components. The generally low concentrations of CaO and MgO indicate minimal marine influence and support deposition within predominantly fluvial to deltaic settings. Statistical analyses reveal a strong negative correlation between SiO₂ and Al₂O₃, indicating silica enrichment associated with sediment recycling and prolonged chemical weathering under tropical climatic conditions. In contrast, positive correlations between Fe₂O₃ and Al₂O₃ suggest a common lithogenic origin and similar geochemical behavior during sedimentation. Graphical and statistical interpretations further indicate felsic continental provenance, advanced weathering intensity, and significant sediment maturity. The study concludes that the clay deposits were principally derived from intensely weathered continental source rocks and, although limited in high-grade industrial applications due to elevated silty content, remain suitable for the production of building blocks, pottery, and thermal insulation materials.

Keywords

Major Oxide Geochemistry,
Clay Deposits,
Provenance,
Paleoweathering,
Tropical Weathering,
Sedimentary Environment

ISSN 1119-4618



1119 4618

JPAS



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1. INTRODUCTION

Major oxide geochemistry involves the use of geochemical analysis and techniques to determine the concentration of major oxide present in sediments in the study area (Jones and Manning, 1994). Geological elements are defined as those composed of 95% of the earth crust. They include silicon (Si), aluminum (Al), calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), titanium (Ti), manganese (Mn) and phosphorous (P). Etc. oxides are chemical compounds with one or more oxygen atoms combined with another elements e.g. H_2O , CO_2 etc. They are termed oxides because oxygen is in combination with an element (Ogala, et al. 2009; Ocheli & Aigbadon, 2024).

The Niger Delta is located on the continental margin of Southern Nigeria and covers an area of 70,000km (Amiewalan & Lucas, 2020). It lays between latitudes 30° and $60^{\circ}N$ and longitudes 5° and $8^{\circ}E$ (Short and Stauble, 1967). Stable mega tectonic frame such as the Benin and Calabar flank mark the Northwest and Eastern boundaries, the Anambra basin and the Abakaliki high mark the Northern boundary and it is bounded to the South by Gulf of Guinea and extends throughout the Niger Delta Province as defined by Kelt and others (1997). From the Eocene to the present, the delta has prograded southwestward, forming depobelts that represent the most active portion of the delta at each stage of its development (Weber, 1971). These depobelts from one of the largest regressive deltas in the world with an area of 300.000km² (Kulke, 1995), and a sediment thickness of over 10km in the basin depocenter (Kaplan and others, 1994). Major oxide distribution and accumulation in sediments is due to highly dynamic nature of the environment which allows rapid assimilation of these elements into sediments by process such

as degradation, dispersion, dilution and ocean currents. Owing to the oil prospecting and processing activities going on in this area and it is suspected that the soil must have been contaminated by elements. Therefore, there is need to study the major oxide presents in sediments within the region.

Few documented reports are available on this region; they include Egboh et al., 2000. They studied the concentration of selected heavy metals in sediments from road side gutters in Warri Delta state; this was supported by Ataikwu (1997) in her work- determination of Fe, Cd, Ni, Pb and Hg in soil at Oviwian Alakia, Nigeria as well as Ihenyen and Aghimien (2000). Variations in heavy metal concentrations following the dredging of an oil well canal access in the Niger Delta by Elijah et al., (2008). However, much work has not been done within the study area.

This research work focuses on the major oxide composition of clay samples from selected communities in Niger Delta. It also examines the average mean concentration of each variable as well as their associated environment studied through the computation of multivariate correlation matrix of all variables.

2. Materials and Methods

Sampling

Sediment samples were taken from the study area using a random sampling manner. The samples were taken with the help of an auger 7cm diameter and 20cm long. Immediately after sampling, the sampled sediment was wrapped with an aluminum foil and placed inside a seal bag to prevent contamination. Materials used for sampling include the following a base map of the study area, global positioning

system (G.P.S) which helped to locate the positions sampled, an auger which was used to collect the sediment samples, aluminum foil paper, seal bag and a black sample bag. The

samples were taken to the laboratory and were subjected to drying in an ambient temperature for 7 days prior to pulverizing.

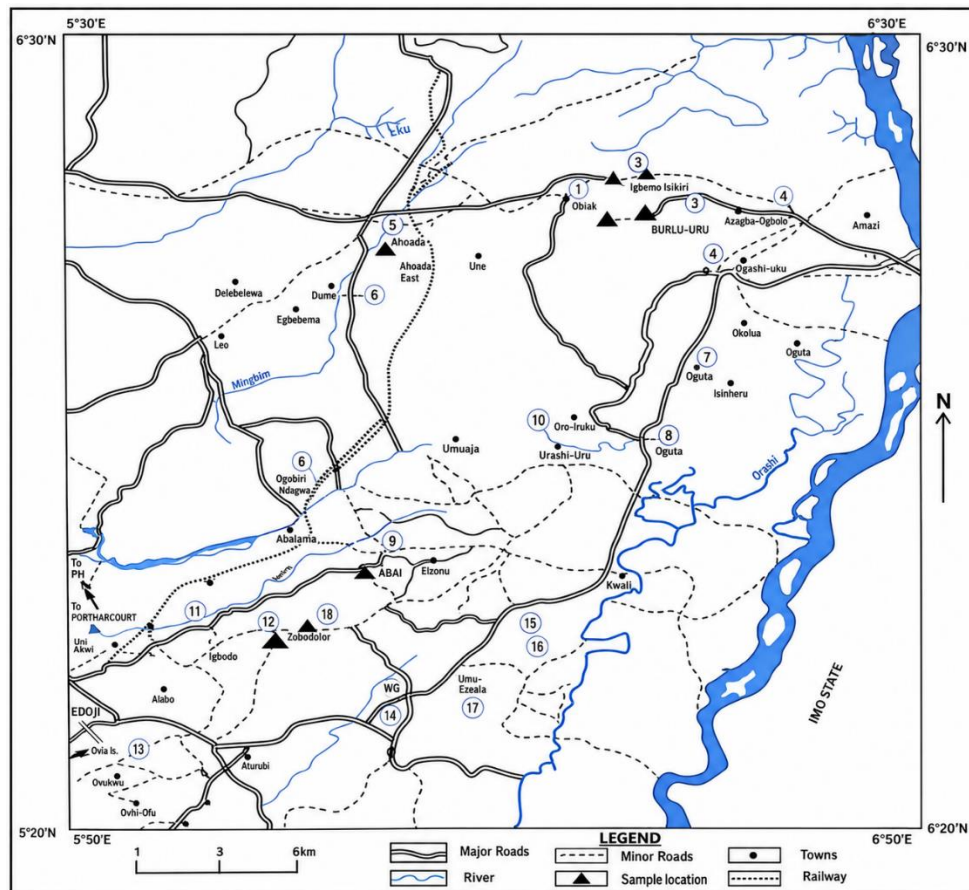


Figure 1 showing map of the study area and sample collection point

Sample Preparation

The samples were pulverized using manual pestle and mortar and passed through a 150 μ mesh. 50g of the sieved fraction were weighed with a weighing balance and stored in an aluminum foil with appropriate labeling.

Laboratory Analysis

Elemental were carried out on the 12 clay samples collected from Agbor, Orogun, Amai, Ukua-Nzu, Orhunwhorhun, Otor-Edo, Bomadi,

Asaba, Ubulubu, Ubuluku, Akabuka. Laboratory analyses were performed at the activation laboratories Ontario Canada, using the inductive coupled plasma-optical emission spectrometry (ICP-OES). LOI was determined by weighing before and after ignition at 1050 $^{\circ}$ C.

The fusion technique was used for analysis of major elements. The samples were mixed with a flux of lithium metaborate and lithium tetraborate and fused in an induction furnace. The molten melt is immediately poured into a solution of 5% nitric acid containing an internal

standard and mixed continuously until completely dissolved (approximately 50 minutes). The samples were assayed for major oxide in a combination fusion technique followed by ICP-OES using a thermo Jarel Ash Environ simultaneous/sequential ICP.

3.0 Results and Discussion

Table 1 showing the geochemical analysis of the sample location

Analyte Symbol	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃ ^(T)	MnO	MgO	CaO	Na ₂ O	K ₂ O	TiO ₂	P ₂ O ₅	LOI	Total
Unit Symbol	%	%	%	%	%	%	%	%	%	%	%	%
Detection Unit	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Analysis Method	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP	FUS-ICP
Amai	84.83	7.04	1.48	0.019	0.13	0.04	0.39	0.39	1.583	0.04	4.66	100.6
Ubulu-Uku	73.85	13.59	2.43	0.014	0.18	0.04	0.57	0.4	1.129	0.03	7.98	100.2
Asaba	68.9	13.25	4.12	0.032	0.34	0.6	1.56	2.7	1.041	0.04	6.26	99.04
Orhunwhurun	58.02	17.66	7.41	0.037	0.68	0.32	1.95	2.12	1.268	0.06	10.76	100.3
Otor-Edo	54.8	18.8	9.47	0.023	0.66	0.07	0.69	1.54	1.178	0.1	12.17	99.5
Orogun	80.68	8.14	1.95	0.017	0.19	0.18	0.86	0.51	1.323	0.04	6.28	100.2
Agbor	75.0	11.97	1.77	0.019	0.16	0.06	0.76	0.43	1.144	0.03	7.90	99.27
Orogun 2	42.21	26.99	3.59	0.014	0.09	0.09	3.52	0.16	1.649	0.09	15.87	99.26
Akabuka	91.19	4.4	1.09	0.014	0.07	0.03	0.06	0.44	0.726	0.04	2.4	100.5
Ukuwa-Nzu	67.12	19.91	2.29	0.012	0.06	0.08	0.03	0.1	1.896	0.08	9.0	100.6
Bomadi	64.67	12.99	5.08	0.068	0.6	0.72	0.64	2.34	1.182	0.38	11.3	99.96
Ubulubu	86.41	8.16	0.65	0.006	0.03	0.02	0.03	0.03	0.745	0.03	3.9	99.99

The highest concentration of sodium oxide was recorded at Orogun (3.52%), while Ukwa-Nzu and Ubulubu had the lowest concentration (0.03%). Other locations had concentrations ranging from 0.039-1.95%. The average mean concentration within the study area is 0.92%.

Bomadi has the highest concentration of potassium oxide (2.34%), while the lowest concentration was recorded at Ukwa-Nzu (0.1%). The average mean concentration of potassium oxide within the study area is 0.93% with a detection limit of 0.01%. The highest and lowest concentration of titanium oxide were recorded as Ukwa-Nzu (1.896%) and Akabuka (0.726%). Its detection limit is 0.001% with an average mean concentration.

Highest concentration of phosphorous oxide (0.38%) was obtained from Bomadi while the least concentration was recorded at Ubulu-Uku, Agbor and Ubulubu as (0.03%). Its detection limit is 0.01% with an average mean concentration of 0.08%.

LOI was determined by weighing before and after ignition at 1050^oc. It is highest at Orogun2 (15.87%) and lowest at Ubulubu (3.9%). It has no detection limit; its average mean is 8.20%.

Result Discussion

From the result of the analysis, the concentration of SiO₂ (91.9-47.2 with an average of 71.06%) Al₂O₃ (26.99-4.4% with an average of 13.58%) and Fe₂O₃^(T) (9.47-0.01%-

0.01% with an average of 3.44%) implies that they are basic rock forming minerals (Temitayo et al. 2024). The low level of some of the major oxides such as TiO₂, K₂O, CaO and Na₂O are due to low level of feldspar present in clastic deposits (Ogala, 2012; Ogala et al. 2009; Temitayo et al. 2024). CaO is a suggestive of a cementing agent that binds the grains and the matrix together. The MgO is associated with smectic and chloritic clays (Pettijhon, 1975).

MgO and CaO helps to determine the marine influence of sediments, their low levels MgO (0.68-0.03%) and CaO (0.72-0.02%) defines a non-marine environment, while high concentration of SiO₂ within the area implies silicious and a non-marine environment. The titanium oxide (TiO₂) occurs in trace to rare. The source of which is acclaimed mostly with the heavy minerals such as rutile and ilmenite because of its association with rare elements. The level of Na₂O suggests infiltration of saline water from both the Atlantic Ocean and lagoon as post depositional event.

Descriptive Statistics of Major Oxides

Univariate Statistics

The univariate statistics performed on the measured parameters in terms of their minimum, maximum, mean and standard deviation (S.D) for results obtained for samples of 10 major oxides are summarized in the table below. Also, the statistics of the loss on ignition are calculated.

Table 2. showing the statistical analysis

Variable	Min	Max	Mean	S.D
	%	%	%	%
SiO ₂	47.21	91.91	71.06	13.75
Al ₂ O ₃	4.4	26.99	13.58	6.15
Fe ₂ O ₃ (T)	0.65	9.47	3.44	2.57
MnO	0.006	0.068	0.023	0.016
MgO	0.03	0.68	0.28	0.25
CaO	0.02	0.72	0.19	0.23
Na ₂ O	0.03	3.52	0.92	0.96
K ₂ O	0.1	2.34	0.93	0.92
TiO ₂	0.726	1.896	1.24	0.32
K ₂ O ₅	0.03	0.38	0.08	0.09
LOI	3.9	15.85	8.21	3.69

Of the major oxides in these samples SiO₂, Al₂O₃ and Fe₂O₃ were dominant with average of (71.06, 13.58 and 3.44) wt% respectively indicating the prevalence of quartz, pyrite and feruginised minerals. This is in general agreement with result from previous work in Anambra basin by Ogala et al., (2009). With the exception of SiO₂, Al₂O₃, Fe₂O₃, Na₂O and TiO₂ the other measured element were not normally distributed, therefore the non-parametric Spearman's which appears the ranking order of variables was utilized in the determination of the correlation coefficient.

Multivariate Statistics

Table 3: Correlation matrix of major elements

	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MnO	MgO	CaO	Na ₂ O	K ₂ O	TiO ₂	P ₂ O ₅
SiO ₂	1.000									
Al ₂ O ₃	-0.895	1.000								
Fe ₂ O ₃	-0.419	0.643	1.000							
MnO	-0.575	0.041	0.327	1.000						
MgO	-0.525	0.127	0.468	0.869	1.000					
CaO	-0.586	0.407	0.386	0.708	0.665	1.000				
Na ₂ O	-0.287	0.369	0.278	0.552	0.621	0.643	1.000			
K ₂ O	-0.497	-0.028	0.308	0.851	0.867	0.673	0.502	1.000		
TiO ₂	-0.692	0.451	0.024	0.047	0.035	0.403	0.221	-0.231	1.000	
P ₂ O ₅	0.643	0.507	0.413	0.441	-0.734	0.730	0.274	0.350	0.538	1.000

The negative correlation of silica (SiO_2) as shown in the correlation matrix with other major oxides except P_2O_5 demonstrate influence of weathering process through enrichment of silica and depletion of Fe and Mg as well as decrease in LOI. It also implies the occurrence of these oxides in different correlation between SiO_2 and Al_2O_3 is also an indication of the fact that most of the silica is present as quartz grains that has reworked. However, the positive correlation between Fe_2O_3 and Al_2O_3 is an indication of common

source and suggest possible control by the proportion of clay content in the study area as products of weathering or ferruginisation processes. It can be concluded that the depletion and low concentration of other major oxides in the study area is related to the removal of ferromagnesian mineral and feldspars through reworking and transportation of the source materials by denudational processes.

Graphical Statistical Analysis

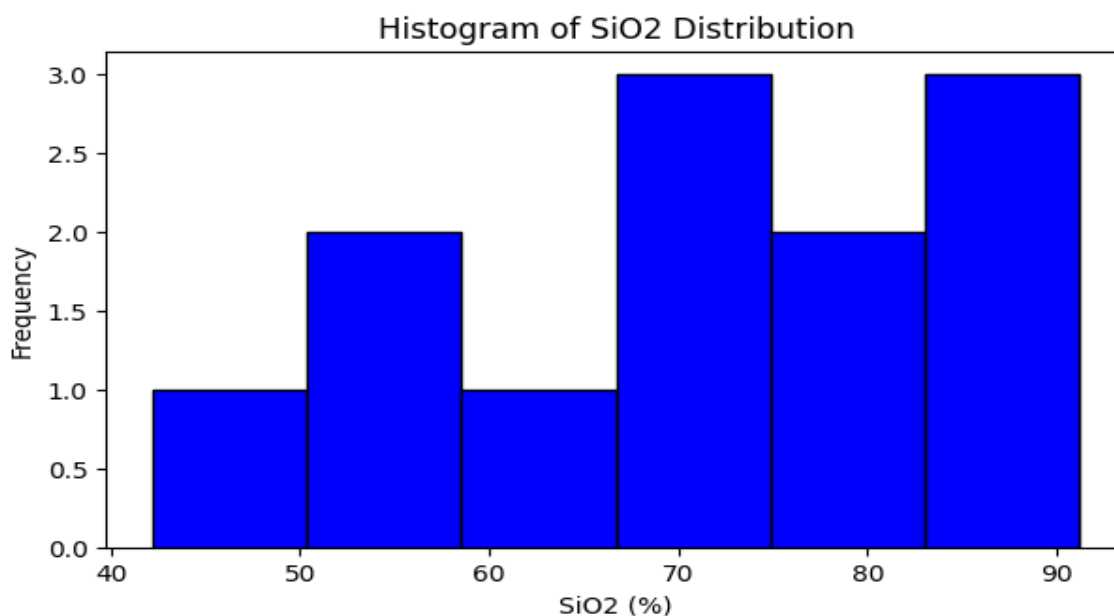


Figure 2 Histogram plot of SiO_2 distribution

Fig. 2 above reveals that most clay samples are enriched in silica (SiO_2), indicating quartz-dominated sediments. High silica concentrations suggest sediment maturity, prolonged weathering, and recycling of continental source rocks. This supports the paleoenvironmental interpretation of a fluvial to deltaic depositional system within the Niger Delta Basin.

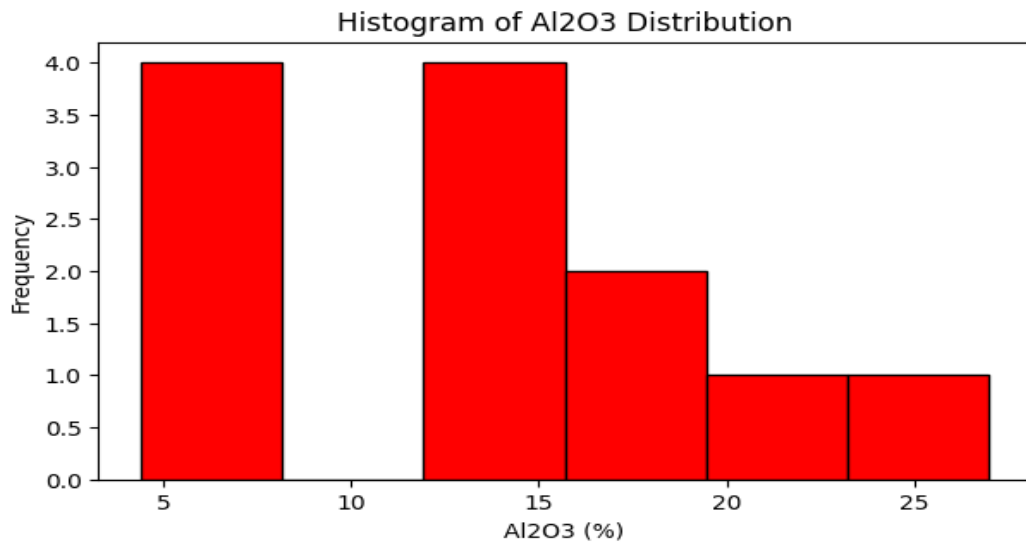


Fig. 3 Histogram plot of Al₂O₃ distribution

The histogram of Al₂O₃ (Fig. 3) indicates moderate variability in alumina content across the samples. Elevated Al₂O₃ concentrations are linked to clay mineral abundance, especially kaolinite and illite, which form during intense tropical chemical weathering.

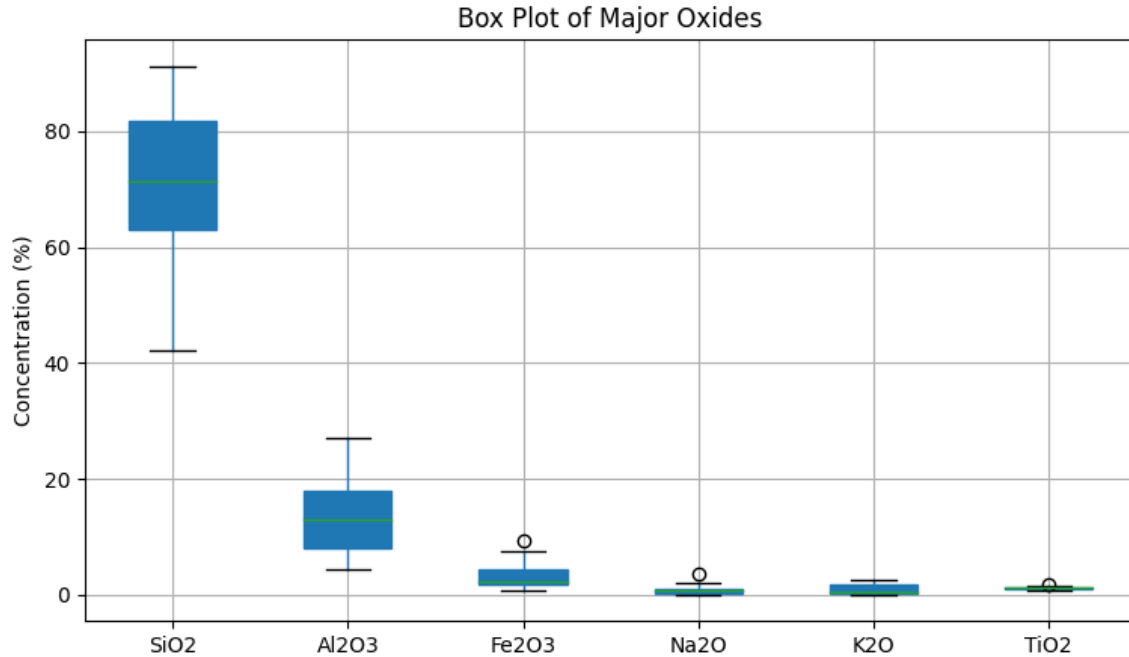


Figure 4 Box plot of major oxides

The colored box plot (fig.4) demonstrates that SiO_2 has the highest median and distribution range among all oxides, confirming quartz enrichment. The variability in Na_2O and K_2O reflects differences in feldspar alteration and

weathering intensity across the study area. Orogun 2 behaves as an outlier due to elevated Al_2O_3 and Na_2O values, suggesting localized geochemical alteration or distinct provenance.

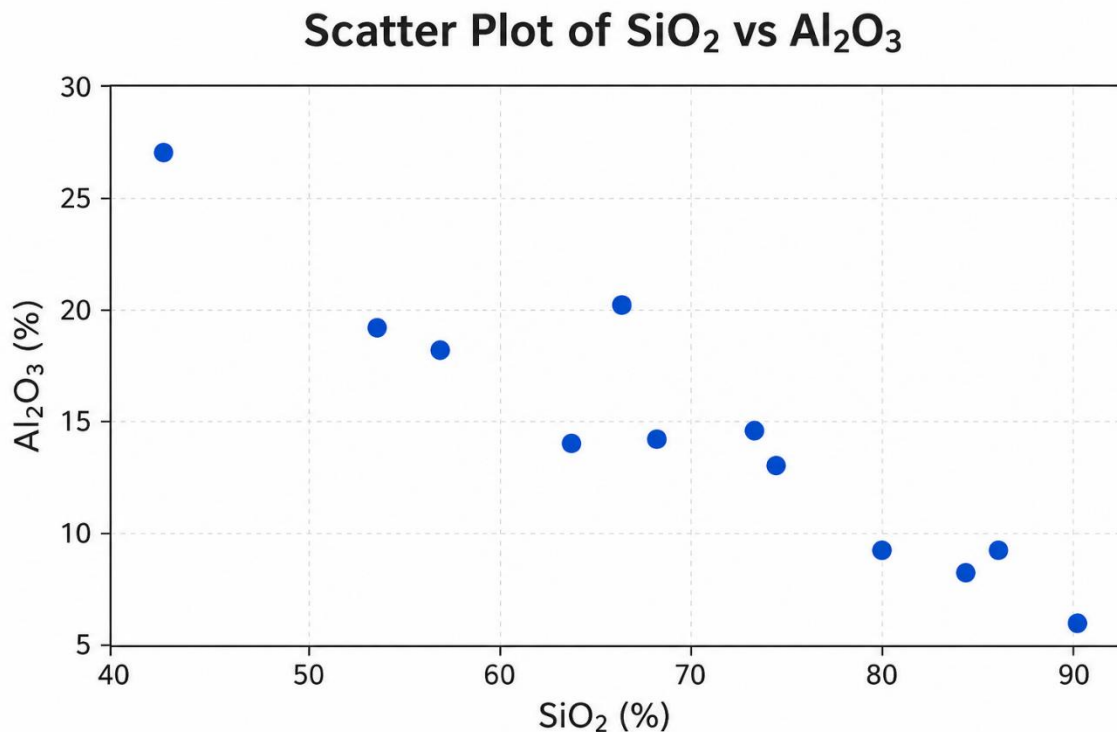


Figure 5 Scatter Plot of SiO_2 vs Al_2O_3

Figure 5 presents a scatter plot illustrating a strong negative correlation between SiO_2 and Al_2O_3 concentrations within the analyzed clay samples. This pronounced inverse relationship suggests that silica is predominantly present as free quartz grains, whereas alumina is chiefly associated with aluminosilicate clay minerals. The depletion of Al_2O_3 with increasing SiO_2 content reflects progressive silica enrichment resulting from sediment recycling, mineral sorting, and prolonged chemical weathering. Such geochemical behavior is characteristic of compositionally

mature sediments in which resistant quartz becomes concentrated during transportation and depositional reworking, while less stable alumina-bearing minerals are reduced. The observed trend further indicates differential mineral partitioning within the depositional system and supports the interpretation of intense tropical weathering conditions in the source area. Additionally, the relationship provides evidence of significant sedimentary reworking and textural maturation, which contributed to the enrichment of quartz relative to clay fractions during deposition.

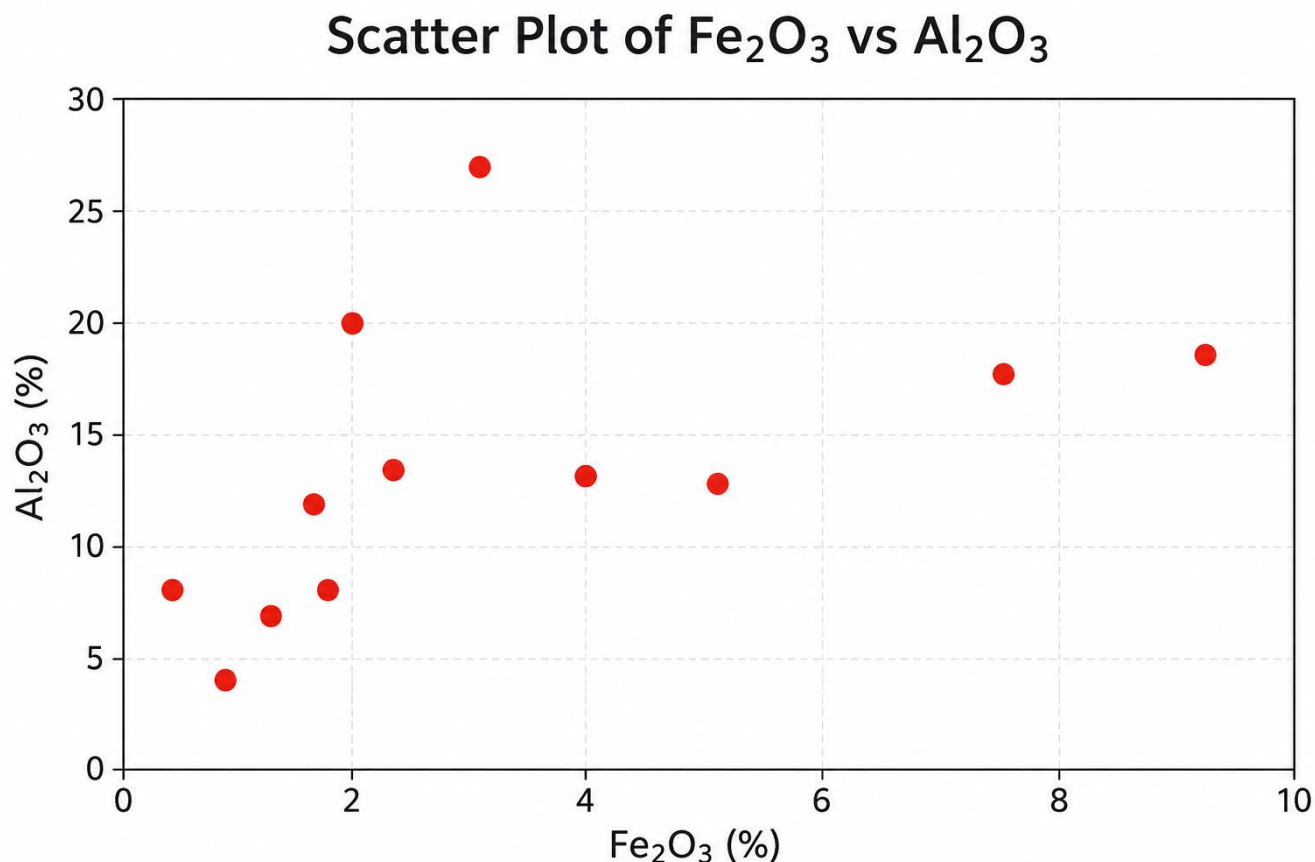


Figure 6 Scatter Plot of Fe_2O_3 vs Al_2O_3

The red scatter plot demonstrates a strong positive correlation between Fe_2O_3 and Al_2O_3 , suggesting that both oxides are derived from a common lithogenic source and exhibit similar geochemical behavior during weathering, transportation, and deposition. This association indicates that ferruginous minerals are closely linked with aluminosilicate clay minerals within the sediment matrix. The enrichment of Fe_2O_3 alongside Al_2O_3 reflects the accumulation of iron-bearing clay fractions and secondary oxide minerals formed through intense chemical weathering of continental parent rocks. The relationship further implies that the sediments were subjected to predominantly oxidizing environmental

conditions, which favored the oxidation and stabilization of iron minerals such as hematite and goethite. These ferruginous phases are commonly incorporated within clay-rich sediments during pedogenic and depositional processes. Additionally, the positive trend supports the interpretation of limited carbonate dilution and reinforces the dominance of terrigenous input within the depositional system. Overall, the correlation provides evidence for a shared provenance, significant weathering intensity, and the influence of oxidizing tropical conditions on sediment geochemistry.

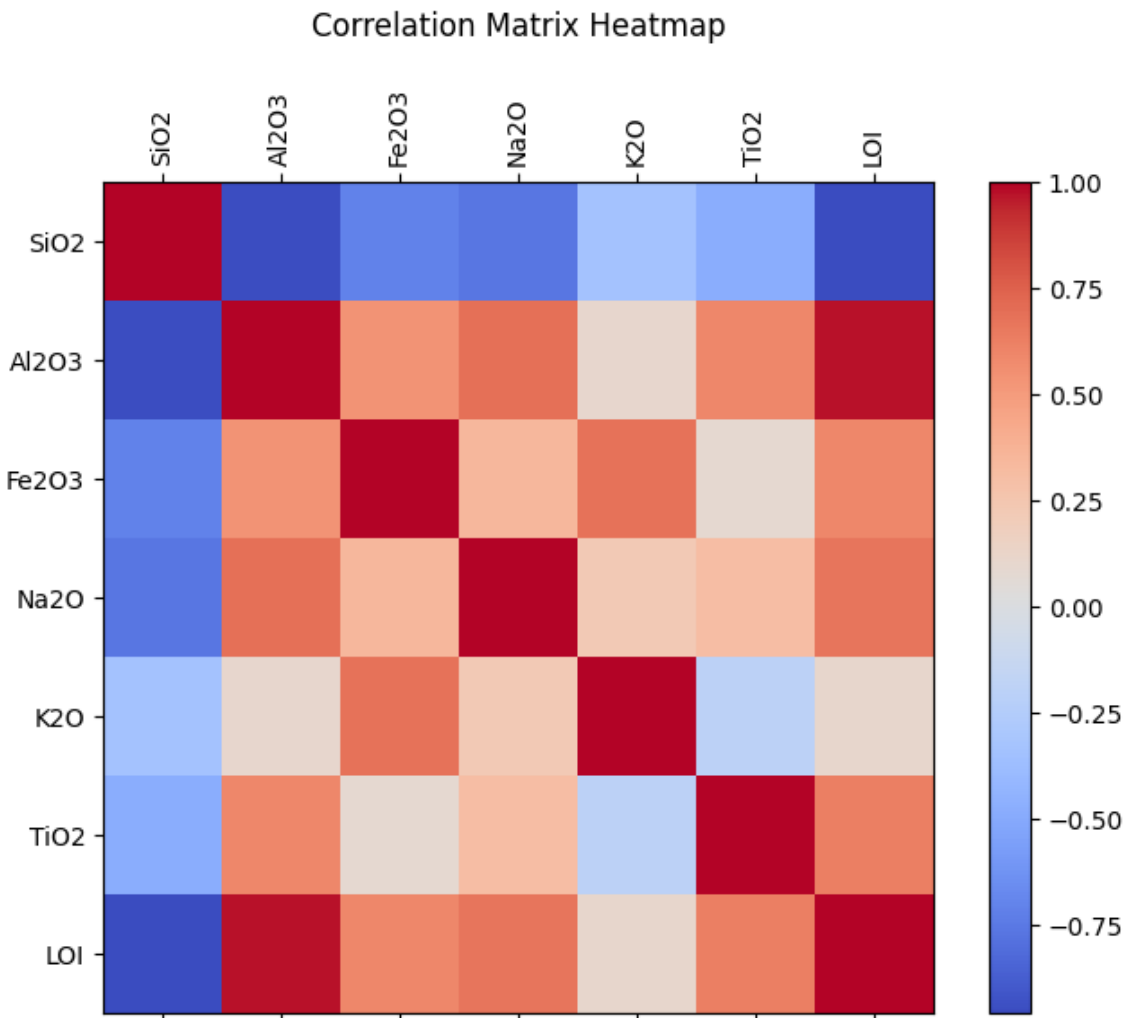


Figure 7 Correlation Matrix Heatmap

The blue-red heatmap presented in Figure 7 provides a comprehensive visualization of the positive and negative geochemical relationships among the analyzed major oxides within the clay deposits. The intensity and distribution of the color gradients clearly demonstrate the degree of elemental association and geochemical affinity between the various oxide components. Notably, the strong negative correlations observed between SiO₂ and Al₂O₃ reflect pronounced quartz dilution effects, whereby increasing quartz enrichment corresponds to a relative reduction in alumina-bearing clay minerals. This relationship is indicative of sedimentary maturation, mineral sorting, and extensive

sediment recycling processes that enhanced silica concentration within the deposits.

Conversely, the positive correlations among Fe₂O₃, MgO, and K₂O suggest a shared lithogenic origin and indicate derivation from the weathering of ferromagnesian minerals and feldspathic parent rocks. The association of these oxides reflects the persistence of iron-bearing and potassium-rich silicate minerals during weathering and deposition. In particular, K₂O enrichment may be linked to the presence of feldspars and illitic clay minerals, while MgO and Fe₂O₃ are associated with mafic and ferruginous mineral constituents. These geochemical relationships

collectively indicate significant chemical alteration under humid tropical climatic conditions, where intense leaching and prolonged weathering modified the original mineral assemblages. Overall, the heatmap strongly supports a felsic to intermediate continental provenance, advanced weathering intensity, and deposition within a predominantly continental to fluvio-deltaic sedimentary environment.

Conclusion

Geochemical analysis was carried out on 12 clay samples collected from different locations in southern Nigeria precisely Niger delta region to determine the major oxide composition of the clay minerals. This analysis has shown through the average mean concentration that SiO_2 has the highest concentration showing high acidic content. It also shows through correlation that the silica is present as quartz grain deposit through the marked negative correlation between SiO_2 and other major oxide. The positive correlation between Fe_2O_3 and Al_2O_3 and some other composition is an indication of common source.

The statistical graphical results collectively support the interpretation that the clay deposits within Delta State and the Niger Delta Basin are silica-rich and derived predominantly from felsic continental source rocks. The graphical patterns indicate intense tropical weathering, sediment recycling, and deposition within fluvial to deltaic environments. Low concentrations of CaO and MgO further indicate minimal marine carbonate influence, while the enrichment of silica suggests prolonged transportation and sediment maturity. The unified classification of some of the clay minerals indicates that it has limited industrial potential because of high silty organic content. However, the clay sample

is suitable for making building blocks, traditional pots and insulation bricks.

Declaration of Competing Interest: The authors declare that they have no conflict of interest and that the study did not receive any funding from external source.

References

- Aigbadon, G. O., Wesley, J. R. N., & Ogbikaya, F. (2018). Foraminiferal biostratigraphy of Oshi-13 Field, Niger Delta Basin, Nigeria. *International Journal of Advanced Geosciences*, 6(1), 1-10. <https://doi.org/10.14419/ijag.v6i1.10907>
- Amiewalan, F. O., & Lucas, F. A. (2020). Geochemical characterization of FE-1 well, Onshore Western Niger Delta Basin, Nigeria. *Journal of Applied Sciences and Environmental Management*, 24(2), 26-35. <https://doi.org/10.4314/jasem.v24i2.26>
- Barker, A. J., & Allen, P. A. (2005). Calcium carbonate saturation state in the Southern Ocean. *Geochemistry, Geophysics, Geosystems*, 6(4), 1-15.
- Chinyem F. I., Abriku E. O., Ovwamuedo G. O., Sikiru A. S., Igili C. O., Nwugha V. N., and Osieke J. O. (2026). Hydrogeophysical Investigation of Groundwater Potential, Lithological Strata and Aquifer Vulnerability in Parts of Delta North District, Nigeria. *FUDMA Journal of Sciences*. 10(2): 375 - 389 DOI: <https://doi.org/10.33003/fjs-2026-1002-4482>

- Doust, H., & Omatsola, E. (1990). Niger Delta. In J. D. Edwards & P. A. Santogrossi (Eds.), *Divergent/passive margin basins* (pp. 201-238). AAPG Memoir 48.
- Egboh, S. H. O., Nwaujei, I. I., & Adaikpoh, E. O. (2000). Concentration of selected heavy metals in sediments of roadside gutters in Warri, Nigeria. *Environmental Monitoring and Assessment*, 62(1), 1-10.
- Elijah, E. O., Obot, I. B., & Imeokparia, E. G. (2008). Variations in heavy metal concentrations following dredging activities in the Niger Delta. *Journal of Applied Sciences and Environmental Management*, 12(2), 31-37.
- Elueze, A.A., Ekwere, A.S., and Nton, M.E., 2009. Geoenvironmental assessment of the environs of the Aluminium Smelting Company in Ikot Abasi, southeastern Nigeria. *Journal of Mining and Geology*, 45(2), 115-128
- Haruna, K. A., Raji, J. K., & Jimoh, A. Y. (2025). Biostratigraphy and paleoenvironment studies of shale from Owan-1 Well, Niger Delta Basin, Nigeria. *Journal of the Nigerian Society of Physical Sciences*, 9(1), 28-32.
- Jones, B., and Manning, D.A.C., 1994. Comparison of geochemical indices used for the interpretation of palaeoredox conditions in ancient mudstones. *Chemical Geology*, (111), 111-129.
- Kaplan, A., Lusser, C. U., & Norton, I. O. (1994). Tectonic map of the world. *AAPG Memoir*, 44, 1-45.
- Kelt, K., et al. (1997). Geological evolution of the Niger Delta basin. *Marine and Petroleum Geology*, 14(3), 1-20.
- Kogbe, C.A., 1976. Paleogeographic history of Nigeria from Albian times. In: Kogbe, C.A. (Ed.), *Geology of Nigeria*. Elizabethan Publishers, Lagos, 237-252.
- Kulke, H. (1995). Regional petroleum geology of the world. Part II: Africa, America, Australia and Antarctica. *Beine Verlag*.
- Lambert-Aikhionbare, D. O., & Shaw, H. F. (2018). Significance of clays in the petroleum geology of the Niger Delta. *Clay Minerals*, 53(2), 1-18. <https://doi.org/10.1180/claymin.2018.053.2.01>
- Ocheli, A., & Aigbadon, G. O. (2024). Mineralogical and geochemical evaluation of Quaternary clay formation in the Niger Delta Basin. *Communications in Physical Sciences*, 10(2), 1-15.
- Ogala, J. E. (2012). Geochemistry of lignite from the Ogwashi-Asaba Formation, Niger Delta Basin, southern Nigeria. *Earth Sciences Research Journal*, 16(2), 1-12.
- Ogala, J.E., Akaegbobi, I.M., Omo-Irabor, O.O., and Finkelman, R.B., (2009). Statistical analysis of geochemical distribution of major and trace elements of the Maastrichtian coal measures in the Anambra Basin, Nigeria. *Petroleum and Coal*, 54(4), 261- 270.
- Ogala, J.E., Omo-Irabor, O.O., Finkelman, R.B., and Akaegbobi, I.M., 2010a. Major and

- trace element distributions in coal and coaly shale seams in the Enugu Escarpment of southeastern Nigeria. *Global Journal of Geological Sciences*, 8(2), 175-186.
- Pettijohn, F. J. (1975). *Sedimentary rocks* (3rd ed.). Harper & Row.
- Porrenga, D. H. (2024). Clay minerals in recent sediments of the Niger Delta. *Clays and Clay Minerals*, 72(1), 1-15. <https://doi.org/10.1180/claymin.2024.072.1.01>
- Short, K. C., & Stauble, A. J. (1967). Outline of geology of Niger Delta. *AAPG Bulletin*, 51(5), 761-779.
- Temitayo D. J., Abiodun E. A., Oladotun A. O., Erepamo J. O., Oyinebielador D. O., Igili C. O., & Nils L. (2024). Elemental geochemistry of Cretaceous deposits in the Dahomey Basin (Nigeria): Implications for paleoclimatic and paleoenvironmental reconstructions. *Journal of African Earth Sciences* 216 105311
- Tucker, M. E. (2001). *Sedimentary petrology: An introduction to the origin of sedimentary rocks* (3rd ed.). Blackwell Science.
- Vine, J. D., & Tourtelot, E. B. (1970). *Geochemistry of sedimentary rocks. US Geological Survey Bulletin*, 1314-C, 1-29.
- Weber, K. J. (1971). Sedimentological aspects of oil fields in the Niger Delta. *Geologie en Mijnbouw*, 50, 559-576.
- Wright, V. P., & Tucker, M. E. (1991). Climatic controls on sedimentation. *Sedimentary Geology*, 70(1-2), 1-8.