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# Integrated Geological, Geochemical, and Cement Performance Evaluation of Limestone Deposits in Borrong–Demsa–Murgarang, Adamawa State, Nigeria, for Modular Cement Manufacturing

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**Abstract: Determining the suitability of these reserves for modular cement manufacture is the goal of this research, which examines the limestone deposits in the Borrong, Demsa, and Murgarang areas of Demsa Local Government Area, Adamawa State, Nigeria. Based on a conservative 5m stratigraphic thickness, the study estimates an available limestone reserve of roughly 40.3 million tonnes through thorough geologic mapping and volumetric analysis; an amount more than sufficient to support modest to medium-sized industrial development in the area. Further verifying the quality of the material, X-Ray Fluorescence (XRF) analysis shows that the main oxides fall well within worldwide accepted levels for Ordinary Portland Cement (OPC) creation. Designed and built was a prototype mini-kiln fitted with an electrically driven, diesel-fuelled burner to make clinker from a formulated raw mix in order to reinforce the practical significance of the results. With measured values of CaO (65.4%), $SiO_2$ (19.97%), $Al_2O_3$ (5.43%), $Fe_2O_3$ (5.05%), a lime saturation factor of 0.92, free lime of 2.5%, $CaCO_3$ at 6%, silica modulus of 2.3, and alumina modulus of 1.1, the produced cement showed chemical characteristics consistent with regular OPC compositions. The physio-mechanical features also satisfied known specification thresholds: density of 3.14 g/cm³, bulk density of 1450 kg/m³, fineness of 300 m²/kg, initial and final setting times of 120 and 280 minutes, soundness of 2 mm, mortar cube water absorption of 3.5%, insoluble residue of 2.7%, and a 28-day compressive strength of 32 MPa. The efficient manufacturing of laboratory-grade cement and clinker utilizing the prototype kiln not only confirms its commercial viability but also emphasizes the possibility for creating localized, community-based cement manufacturing units inside the study region.**

***Keywords**: Cement Formulation; Demsa; Limestone Characterization; Resource Estimation; Geological Mapping, Mini-Kiln, Clinker.*

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## I. INTRODUCTION

The financial viability of regional cement production is directly affected by the abundance of limestone, a major raw ingredient in the production of cement. Though much of the raw materials come from a few well-known deposits, the cement industry in Nigeria is vital for economic expansion and infrastructure development. Growing cement demand driven by urbanization and governmental infrastructural projects has driven a rising need to research unexploited geological resources including those present in Demsa Local Government Area (LGA) of Adamawa State.

Geologically related to the Upper Benue Found in Nigeria's northeast, Adamawa State is an area known to have sedimentary rock forms appropriate for limestone gathering (Ibrahim & Garba, 2021). Though geological studies indicate that calcareous deposits are present in Demsa LGA, these are mostly understudied. Given the required lime (CaO), silica ($SiO_2$), alumina ($Al_2O_3$), and iron

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oxide ($Fe_2O_3$) content in clinker formulation (Adeleke et al., 2022), assessing the appropriateness of these materials for Portland cement manufacture requires research of their chemical and mineralogical qualities.

➢ *History of the Study Area*

Located within Demsa LGA of Adamawa State, northern Nigeria (approximate coordinates: Borrong 9.53333°N, 12.18333°E; Demsa 9.45554°N, 12.15255°E; Murgarang 9.41149°N, 12.16168°E), the three communities studied lie in the Benue Trough/adjacent sedimentary sequences and include carbonate-bearing units, hence make it probable for cement-grade limestone occurrences. To quantify tonnage, evaluate stratigraphic controls on deposit thickness and continuity, and to assess suitability for clinker formation, correct mapping and sampling are needed. (NGSA, 2021)

Demsa Local Government Area is found along the bottom reach of the River Benue. Yola South LGA confines it to the north and northeast; Numan LGA and the Benue River bound it to the east and partially northeastern; Shelleng LGA bound it to the west and southwest; Lamurde LGA bounds it to the south and southeast. Among others, main settlements inside the LGA are Demsa, Mbula Kulli, Dong Bille, Borrong, and Bwaranji.

The area is culturally varied; it houses groups including the Bachama, Batta, Yandang, Bille, and Mbula-Bwazza; most of the people are involved in fishing, agriculture, river transportation, and local trade (Manpower Report, 2025; Topographic Map, 2020). This great reliance on natural resources underlines the need of knowing the underlying materials of the area as well as its overall geology. Fig 1 shows the topography:

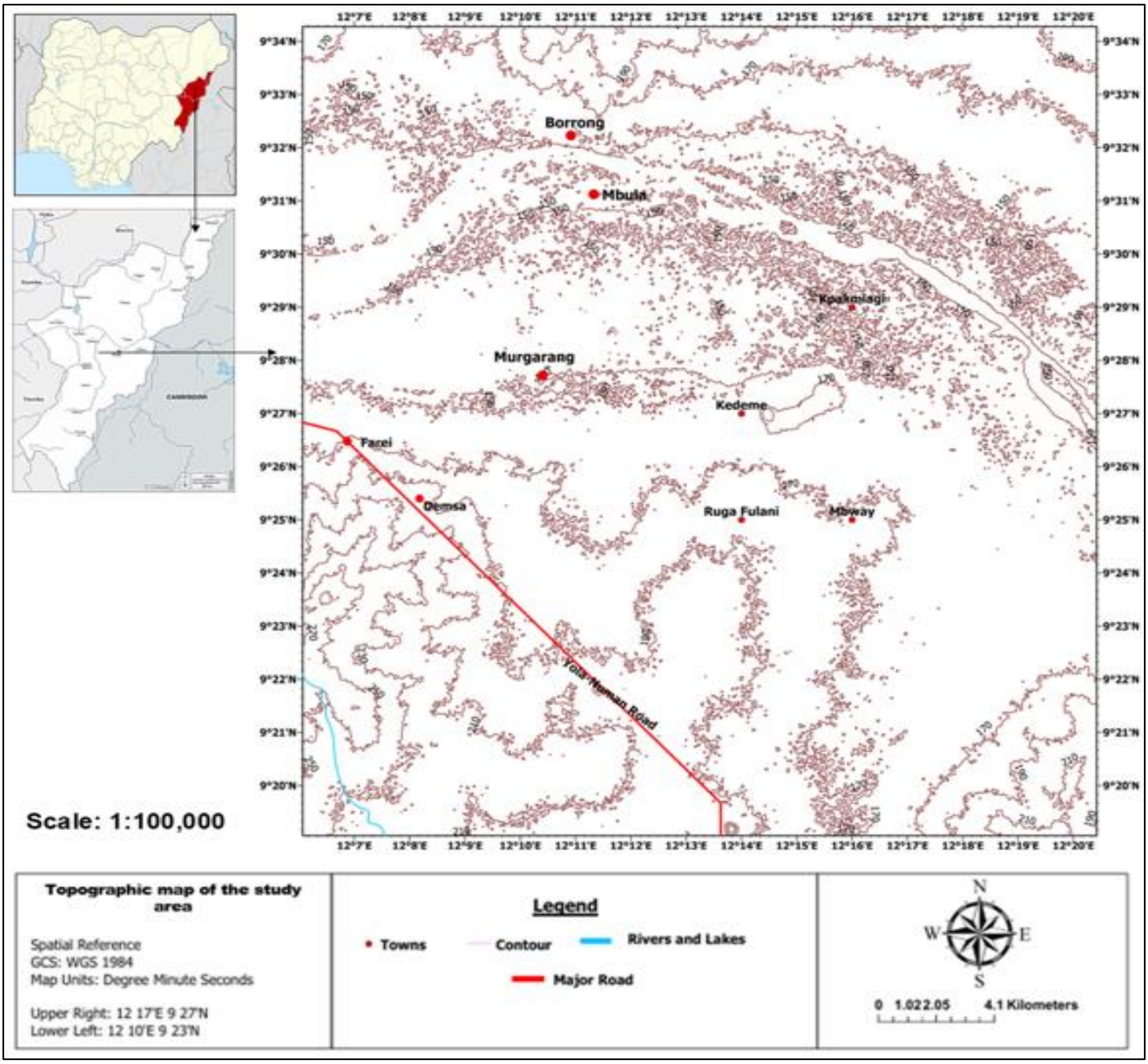


Fig 1 Map of Study Area

➢ *Statement of the Problems*

Although there are many carbonate outcrops reported in certain areas of Adamawa State, there is a lack of consolidated, site-specific data connecting geological environment, lithofacies variety, and comprehensive geochemical makeup to actual cement-making performance for the Borrong–Demsa–Murgarang district. Though not a comprehensive data set that permits trustworthy estimation of important cement raw-mix characteristics (e.g., CaO, $SiO_2$, $Al_2O_3$, $Fe_2O_3$), lime-saturation factor (LSF), silica and alumina modules, and free-lime effects on clinker and final product quality (Kamran *et al*., 2022; Endalew *et al*., 2024), existing regional investigations usually provide either geological mapping or isolated geochemical tests.

This information gap produces a number of practical issues: (1) Uncertainty about whether local limestone chemistry and mineralogy fulfill feedstock restrictions for modular grinding facilities, which usually accept only a small number of feed ingredients and demand expected raw-mix quality, modular concepts hence impose stricter constraints on feed homogeneity and blend flexibility than bigger conventional plants (OneStone Consulting, 2021). (2) Insufficient compositional data treatment and the absence of compositional geochemistry methods for the region render reserve-to-quality translations unreliable, therefore endangering inadequate plant design or poor cement performance (Grunsky *et al*., 2023). (3) Variability in impurity oxides ($SiO_2$, MgO, $Fe_2O_3$, $SO_3$) and petrographic heterogeneity may cause durability or hydration problems if not suitably quantified and examined for cement performance, yet such performance testing (kiln/clinker simulations, grindability, and standard strength/durability assessments) has not been reported for these deposits. Hence, (a) ascertain the suitability of the Borrong–Demsa–Murgarang limestone for modular cement manufacture, (b) specify necessary pretreatment or mixing methods, and (c) lower technical and financial risk for modular plant implementation in the area by means of a coordinated geological-geochemical-performance assessment (Kamran *et al*., 2022; OneStone Consulting, 2021; Endalew *et al*., 2024; Grunsky *et al*., 2023).

➢ *Objectives of the Research*

The research is set to achieve the following objectives:

- To describe the chemical and mineralogical suitability of limestone deposits;
- To measure the volume and spatial distribution of limestone in the study area;
- To use a prototype mini-kiln to make clinker and formulate cement therefrom.
- To examine the chemical and physio-mechanical behavior of the cement made.

## II. OVERVIEW OF LIMESTONE AVAILABILITY IN NIGERIA, PARTICULARLY ADAMAWA STATE

Especially within the sedimentary basins including the Dahomey Basin, Benue Trough, and Sokoto Basin, limestone is one of the most plentiful and most commercially valuable (Ibrahim & Garba, 2021). Geological studies have confirmed substantial limestone resources in areas including Ogun, Benue, Kogi, Cross River, Gombe, Sokoto, and Edo (Adeleke et al., 2022). In the northeastern region, Adamawa State gives a promising but underutilized limestone resource. It sits inside the Upper Benue Trough, a geological formation marked by sedimentary rock features conducive for limestone formation. Preliminary research and regional mapping reveal the presence of limestone in many local government regions of Adamawa, including Demsa, Numan, Shelleng and Guyuk (Musa & Edna, 2018, NGSA 2021). If carefully tended, these resources could considerably foster local economic development in Adamawa and boost Nigeria's self-reliance in cement production. The growth of Nigeria's economy beyond oil and regional industrialization (Eze et al., 2020) fits with its general objectives.

Primarily composed of calcium carbonate, limestone is a sedimentary rock with significant social-economic value for Nigeria. Cement is a basic construction material necessary for national expansion and economic development (Adeleke et al., 2022). Among the largest non-oil companies contributing to Nigeria's Gross Domestic Product (GDP), the cement industry is the abundance of limestone in the country reduces reliance on imported raw materials, therefore saving foreign exchange and fostering domestic industrialization (Yakubu et al., 2023). Investment in the cement sector helps to alleviate poverty and improve life in host communities (Abdulkadir & Salihu, 2021). Further, government revenue from mining licenses, royalties, and taxes allows reinvestment in public infrastructure and services (Ibrahim & Garba, 2021).

Small-batch clinker may be produced using mini or prototype kilns—usually electrically assisted with diesel backup in distant locations—for proof-of-concept evaluation of raw mixes and local materials. Although they are not meant to replace full-scale kilns, they provide vital technical validation (clinker formation, kiln behaviour, early cement properties) prior to modular manufacturing bundle investment (integrating modular kilns with mobile grinding and packaging). Academic and industry debate highlight the need of small-scale production for indigenous entrepreneurship and resource valorization.

Moreover, cement manufacture has financial and ecological effects. Local manufacturing reduces carbon emissions related to long-distance travel and increases employment in mining and industrial sectors (Yakubu et al., 2023). Hence, evaluating the limestone reserves in Demsa is a strategic economic decision of national significance as well as a scientific one.

Despite having enormous carbonate resources, Nigeria has relatively little published research including geological mapping, resource estimating, prototype clinker manufacturing, and complete characterization of the formulated concrete from particular community-level

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deposits. For Borrong–Demsa–Murgarang, this study helps fill that void by:

- Using field mapping and GIS/polygon approaches to map and measure the extent and tonnage of deposits;
- Defining raw limestone chemistry and calculating cement raw mix ratios (LSF, SM, AM);
- Making clinker and cement in a prototype mini-kiln and analyzing chemical and physico-mechanical qualities (setting, soundness, compressive strength); also
- For modular cement manufacturing in the study region, presenting an integrated feasibility study.

The findings give a concrete path for growing and for optimizing research required before market release (IJSRA).

## III. MATERIALS AND METHODS

➢ *Materials*

Mapping scale, GPS coordinates and GIS digitization workflow, Muffle furnace, built prototype kiln, crucibles, crucible tongs, analytical balance, pellet-making machine, X-Ray Fluorescence spectrometry (Vitriox® G.S model), steel beakers, aluminum beaker, Herzog grinder, stearic acid, hydrochloric acid, Ball mill for grinding, mixer, sieves, crucibles, safety equipment including gloves, goggles, and masks, Whatman filter paper No. 40 & 42, desiccator, were among the materials employed.

- *Sampling of Limestone*

Although, the samples were collected haphazardly from the surface, they were sizable enough (5kg) to match the makeup of the limestone unit (Geelani *et al*., 2022). Cutting a channel across the rock face, trenching and channel sampling was used to access fresh rock material in limited surface exposures, hence ensuring a continuous and representative sample along the exposure (Smith & Johnson, 2021). Every sample collected was assigned a specific identification code based on its place and other relevant geologic information. Proper labeling guarantees traceability and helps to prevent sample mix-ups in laboratory investigation (Okwoli *et al*., 2020). Plastic bags or sample containers kept the specimens from contamination.

➢ *Methods: Description of the Analytical Process*

The evaluation of the Demsa limestone started with hands-on geological mapping across the Borrong–Demsa–Murgarang corridor. This stage involved moving through the terrain to clearly outline the rock units, structural patterns, carbonate facies, and the physical continuity of the limestone beds. Fieldwork procedures followed standard geological practice; including GPS-based outcrop logging, measuring bedding orientations, and identifying any associated minerals or unwanted materials such as shale streaks or siliciclastic layers that might affect cement quality (Endalew *et al*., 2024). To capture how the limestone varies both laterally and vertically, representative samples were collected from different mapped units using recommended industrial mineral sampling techniques (Kamran *et al*., 2022).

Back in the laboratory, the samples were processed for geochemical testing. This involved crushing, pulverizing, and homogenizing the material before determining major oxides such as CaO, $SiO_2$, $Al_2O_3$, $Fe_2O_3$, MgO, and $SO_3$ using X-ray fluorescence (XRF). X-ray diffraction (XRD) was then used to confirm the mineral phases present. These chemical results were used to compute cement-related parameters—including the Lime Saturation Factor (LSF), Silica Modulus (SM), and Alumina Modulus (AM)—which are important indicators of how the raw material will behave during clinker formation and burning (Grunsky *et al*., 2023). Only samples with sufficient CaO and acceptable levels of impurities were blended mathematically to produce a raw mix targeted at industrially acceptable LSF (0.92–0.98), SM (2.0–2.5), and AM (1.2–1.5) values for Portland clinker production (Kamran *et al*., 2022).

To simulate real industrial operations at laboratory scale, a small rotary kiln—1m in length and powered by an electric–diesel hybrid system—was designed and used to produce clinker from the prepared raw mix. The mix was pelletized, dried, and fired at temperatures between 1350°C and 1450°C, with controlled heating to ensure proper decarbonation and well-formed clinker phases. This mini-kiln setup makes it possible to directly observe burnability, nodulization, and the development of key minerals such as alite ($C_3S$) and belite ($C_2S$), which ultimately influence cement strength and durability (OneStone Consulting, 2021).

After burning, the clinker was cooled and ground with 4% gypsum to regulate setting time. The resulting cement samples were then subjected to physio-mechanical tests—setting time, compressive strength, fineness, bulk density, water absorption, and soundness—following ASTM and NIS procedures. Chemical assessments were also carried out to evaluate free lime content, mineral phase distribution, and residual sulphates to verify complete clinker reactions. Physically, the cement was tested for fineness, setting behavior, soundness, and strength development at standard curing ages, using established protocols to confirm performance (Endalew *et al*., 2024).

Taken together, the geological mapping, chemical characterization, laboratory clinker production, and performance testing create a complete and coherent picture of the quality and industrial potential of the Demsa limestone. These integrated results help determine whether the material can support modular or full-scale cement manufacturing operations.

## IV. RESULTS

➢ *Geological and Resource Assessment*

Geological mapping revealed three major limestone-bearing zones within the study area, covering approximately 87.7km², 27.6km², and 12.1km² for Borrong, Demsa and Murgarang respectively shown in Fig 2. Using a conservative limestone thickness of 5 meters and an average rock density of 2.7t/m³, the total estimated volume translates

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to more than 1.7 billion tonnes of limestone, underscoring the scale and significance of the resource (Author, 2025).

Further volumetric analysis, also based on the 5 m stratigraphic thickness used for resource evaluation, indicates an accessible reserve of about 40.3 million tonnes. This quantity is more than sufficient to support small- to medium-scale industrial operations within the region. The mapped limestone bodies follow stratigraphic units that are already known for their high $CaCO_3$ content, reinforcing the resource's suitability for cement production and related industries (Brown & Ng, 2022).

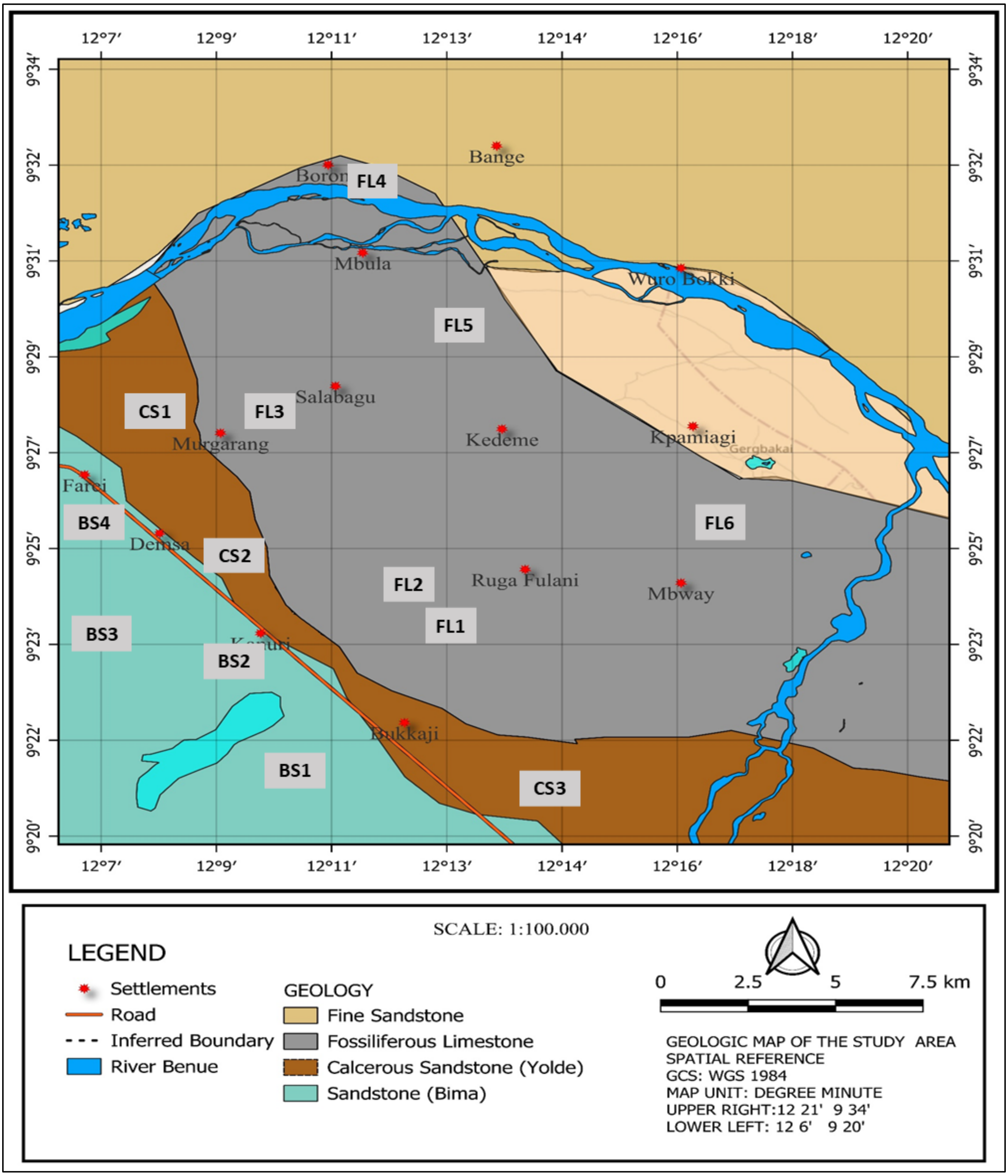

Fig 2 Geological Map of the Study Area.

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➢ *Geochemical Characterization*

Chemical analysis showed that the limestone samples contained high levels of calcium oxide (CaO), averaging between 48% and 50%, with calcium carbonate ($CaCO_3$) consistently above 87%. These values fall well within the desirable range for cement-grade limestone. The main impurities—silica ($SiO_2$), alumina ($Al_2O_3$), and iron oxide ($Fe_2O_3$)—were also found to be within acceptable limits, and both the silica and alumina module ratios met the required standards for clinker production (Table 1).

The lime saturation factor (LSF) ranged from 254 to 438, suggesting that the material has good calcination behavior and can form clinker efficiently during burning (Author, 2025). Overall, these geochemical characteristics strongly support the suitability of the limestone for producing high-quality cement (Chen *et al*., 2023).

Table 1 XRF Analysis Results of the Compositions of the Limestone Samples.

| **Compound (%)** | **Borrong** | **Demsa** | **Murgarang** | **NIS** |
|---|---|---|---|---|
| **Silica ($SiO_2$)** | 4.255±1.221 | 6.897±1.693 | 5.688±1.357 | 4.03 |
| **Alumina ($Al_2O_3$)** | 2.058±0.982 | 3.122±1.061 | 2.564±0.776 | 1.33 |
| **Iron (III) Oxide ($Fe_2O_3$)** | 1.255±0.638 | 1.836±1.866 | 1.357±0.670 | 0.92 |
| **Lime (CaO)** | 50.39±0.00 | 47.365±0.00 | 48.449±0.255 | 56 |
| **Magnesium Oxide (MgO)** | 0.693±0.105 | 0.732±0.092 | 0.968±0.165 | 0.75 |
| **Sulphure trioxide ($SO_3$)** | 0.562±0.680 | 0.527±0.722 | 0.985±1.015 | N.A |
| **Potassium oxide ($K_2O$)** | 0.141±0.117 | 0.310±0.135 | 0.19±0.11 | 0.32 |
| **Sodium Oxide ($Na_2O$)** | 0.081±0.0467 | 0.074±0.044 | 0.078±0.045 | 0.28 |
| **Phosphorus Pentaoxide ($P_2O_5$)** | 0.219±0.305 | 0.210±0.281 | 0.194±0.25 | N.A |
| **Manganese (III)oxide ($Mn_2O_3$)** | 0.408±0.215 | 0.263±0.134 | 0.197±0.099 | 0.94 |
| **Titanium oxide ($TiO_2$)** | 0.146±0.050 | 0.183±0.078 | 0.155±0.047 | 0.36 |
| **Chromium (III) Oxide ($Cr_2O_3$)** | 0.018±0.016 | 0.018±0.019 | 0.017±0.018 | N.A |
| **Lime saturation Factor (LSF)** | 437.896±8.46 | 254.080±15.73 | 302.483±3.02 | 85.00-99.00 |
| **Silica (Ratio) Module (SM)** | 1.348±0.270 | 1.431±0.221 | 1.489±0.203 | 2.0-3.0 |
| **Aluminum (Ratio) Module (AM)** | 1.667±0.105 | 1.766±0.274 | 1.992±0.411 | 1.0-4.0 |
| **Calcium carbonate ($CaCO_3$)** | 89.935±2.802 | 87.767±4.569 | 89.392±3.673 | 80.00-96.68 |
| **Loss on Ignition (LOI)** | 40.598±0.53 | 38.118±0.301 | 39.280±0.255 | 32.01 |

Note: N.A = Not Available

Figures 3 show grouped bars for each compound (Silica, Alumina, Iron Oxide, Lime, Magnesium Oxide) with means from three groups (Borrong, Demsa, Murgarang). Error bars represent the standard errors for each mean value.

The x-axis lists the compounds with labels rotated for clarity, while the y-axis shows the mean values. The legend distinguishes the three groups.

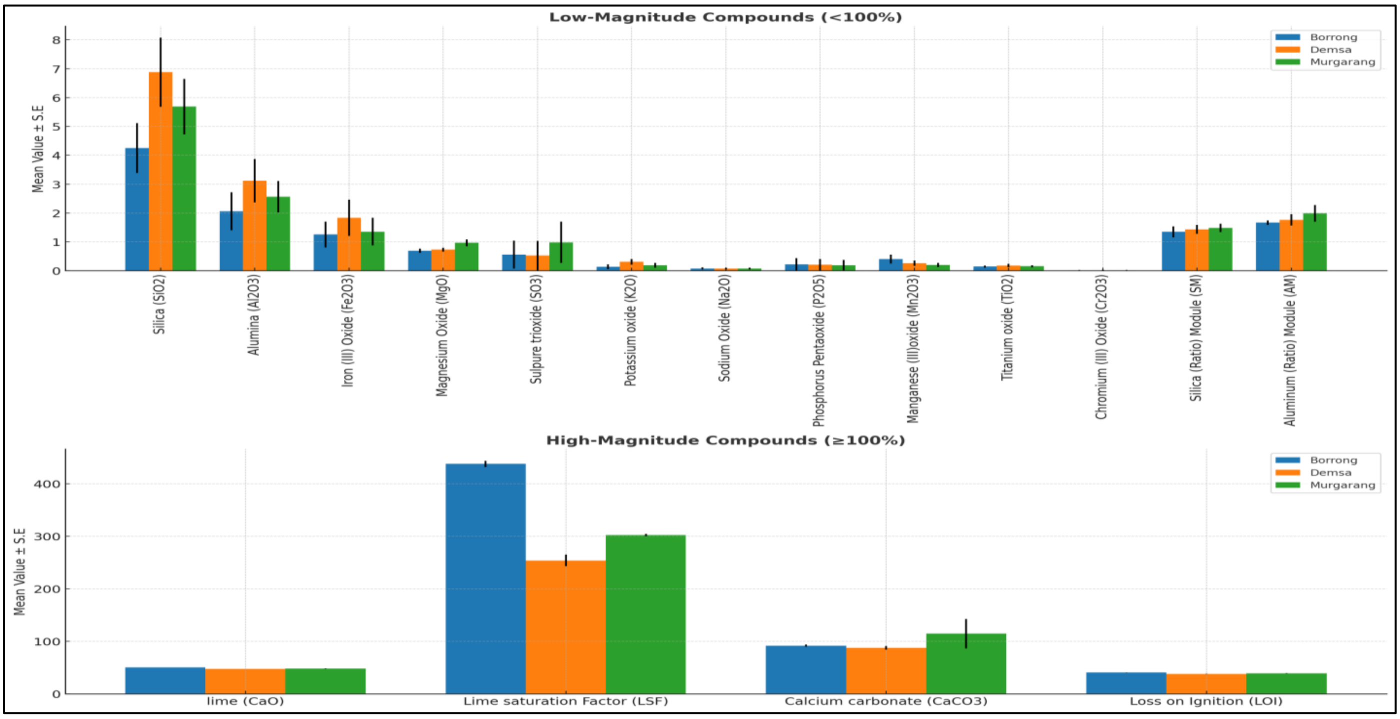


Fig 3 Chemical Compositions of the Limestone in Percentage represented in a Bar Chart showing Error Bars.

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Essential for correctly interpreting chemical data fluctuation, the error bars based in standard error or deviations are crucial in analytical chemistry study for cement formulation. This knowledge guarantees that compositional data is properly analyzed in scaling and process improvement from laboratory studies as well as reported, hence promoting more dependable and scientifically sound cement production growth. The results show considerable spatial variation among Borrong, Demsa, and Murgarang samples from the comparative oxide composition charts shown above. The lime (CaO), silica ($SiO_2$), and lime saturation factor (LSF) show the most of these variations, while trace oxides like $Na_2O$, $K_2O$, and $Cr_2O_3$ stay rather stable throughout regions.

Because these oxides abound silicate mineral matrices in calcareous rocks (Fatah, 2024), the uniformly great CaO and $SiO_2$ levels in all samples show that the materials have the appropriate composition for cement or clinker-grade feedstock.

But Borrong shows greater CaO and LSF values (437.9) than those of Demsa (254.1) and Murgarang (302.5), pointing to a higher possibility for free lime production and decreased belite conversion during sintering (Richardson & Taylor, 2025). High LSF values (>1.0) usually favor alite formation ($C_3S$ phase), which is critical for early strength development in cement products (Galimberti, 2017).

The relative amounts of $SiO_2$ and $Al_2O_3$ across all samples fall inside optimum ranges for silica and alumina modules, therefore influencing the development of $C_2S$ and $C_3A$ phases (Mutua, 2020). Higher $SiO_2$ in Demsa (6.88%) compared to Borrong (4.25%) suggests more siliceous feedstock, hence impacting the hydraulic reactivity of the clinker. This variation also shows different sedimentary or metamorphic origins among sampling areas (Tepeli, 2021).

Minor oxides like MgO, $SO_3$, and $Fe_2O_3$ differ modestly, therefore indicating both natural mineral heterogeneity and manufacturing influences. The ferrite phase ($C_4AF$) benefits from the $Fe_2O_3$ concentrations (1–2%), therefore affecting color and setting behavior (Chala, 2024). Staying within reasonable bounds (<5%), MgO guarantees volumetric stability throughout hydration (Rao, Vijayakumar, and Prabhakar, 2021).

A necessary durability issue in concrete chemistry (Khan, 2022), alkalis ($Na_2O$ + $K_2O$) exist in minute concentrations (<0.5%) that reduce the chance of alkali-silica reactions (ASR). The low sulphur trioxide ($SO_3$) levels seen everywhere add further evidence for the lack of bad sulfates may destabilize ettringite development.

The XRF data obtained from limestone samples across the different locations were statistically analyzed to determine whether the chemical compositions varied significantly from one site to another. The analysis also compared the samples with limestone from other regions in Nigeria and with the National Industrial Standards (2018). All statistical tests were conducted at a 5% significance level using SPSS (Version 27). The results indicate that the limestone from the study area shows no significant deviations in composition when compared across locations or against established national benchmarks. Overall, the samples compare favorably with similar deposits elsewhere in Nigeria.

➢ *Cement Performance Evaluation*

Tables 2 and 3 represent the chemical composition and physio-mechanical tests results for the formulated cement.

Table 2 Result of the Chemical Composition of Formulated Cement

| S/No | Component | Concentration±Std Error |
|---|---|---|
| 1. | Silica, $SiO_2$ (%) | 19.927±0.747 |
| 2. | Alumina, $Al_2O_3$ (%) | 5.427±2.229 |
| 3 | Ferric Oxide, $Fe_2O_3$ (%) | 5.047±0.080 |
| 4 | Calcium Oxide, CaO (%) | 65.4±0.506 |
| 5 | Sulphate, $SO_3$ (%) | 2.728±0.183 |
| 6 | Potassium Oxide, $K_2O$ (%) | 0.545±0.060 |
| 7 | Titanium Oxide, $TiO_2$ (%) | 0.329±0.043 |
| 8 | Calcium Carbonate, $CaCO_3$ (%) | 5.83±0.012 |
| 9 | Lime Saturation Factor, LSF | 0.92±0.23 |
| 10 | Silica Module, SM | 2.3±0.054 |
| 11 | Aluminium Module, AM | 1.10±0.32 |
| 12 | Free Lime | 2.5±0.042 |
| 13 | Chloride, Cl (%) | 0.564±0.053 |

As shown in Table 2 above, the oxide composition obtained for the clinker and eventual cement shows a generally acceptable profile for Portland or Portland-limestone cement. The major oxides—CaO (≈65.4%), $SiO_2$ (≈19.97%), $Al_2O_3$ (≈5.43%), and $Fe_2O_3$ (≈5.05%)—all fall within the typical ranges reported for commercial cements, including those produced in Nigeria. Several studies and industry reports (e.g., Dangote Cement, 2025) show similar oxide bands, further confirming that the composition is broadly consistent with standard materials used in the country.

However, two parameters require closer attention. First, the free-lime value of 2.5% is slightly higher than the

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desirable limit of about 2% commonly recommended for sound, well-burnt clinker (SON, 2018). Excess free lime often indicates incomplete burning or an imbalance in the raw mix, and may contribute to soundness issues or weaker microstructures. Second, the Lime Saturation Factor (LSF) of 0.92 (92%) is lower than the typical target range of 0.95–0.98 for high-quality clinker. Lower LSF values tend to favor the formation of more $C_2S$ and less $C_3S$, which may slow early strength development (Ahmed, 2024).

The $CaCO_3$ content (6%) aligns with what is expected for Portland-limestone cement (PLC). Many PLC products contain between 5–15% limestone, and Nigerian markets commonly supply CEM II/Type IL-equivalent grades. This level of $CaCO_3$ may represent either intentionally added limestone filler or residual carbonate from incomplete calcination of the raw mix (Yu *et al*., 2024).

The moduli also fall within acceptable limits. The silica and alumina modules (SM ≈ 2.3, AM ≈ 1.1) lie within commonly reported ranges for clinker and PLC materials and suggest a balanced proportion of silica, alumina, and iron oxides (Ghale *et al*., 2023).

The deviations observed—particularly the elevated free lime and the somewhat low LSF—can reasonably be attributed to incomplete calcination or under-burning of the clinker. These issues arise when the kiln does not achieve sufficient temperature–time residence or when the raw mix proportions are not fully optimized (SON, 2018). In this study, several challenges during the clinkerization stage likely contributed to these outcomes:

Table 3 Results of Physio-Mechanical Test on Cement Sample Produced using the Fabricated Kiln

| S/No. | Physio-Mechanical Property | Result | Standard |
|---|---|---|---|
| 1. | Density (g/cm$^3$) | 3.14 | ~3.15 |
| 2. | Bulk density (Kg/m$^3$) | 1450 | ~1440 |
| 3. | Fineness (Specific Surface Area (m$^2$/Kg) | 300 | >225 |
| 4. | Initial Setting Time (Minutes)<br>Final Setting Time (Minutes) | 120<br>280 | >45<br><375 |
| 5. | Soundness Test (Le Chatelier`s Expansion) (mm) | 2 | <10 |
| 6. | Water Absorption (Water Absorption of Mortar Cubes (%) | 3.5 | Varies by mix design |
| 7. | Compressive Strength (MPa/N/mm$^2$, 28d) | 32 | 32.5-52.5 |
| 8. | Insoluble Residue (IR) (%) | 2.7 | 0.75 |

(Standard Source: Okonkwo (2022))

The cement produced from the limestone samples using the fabricated mini-kiln displayed strong and competitive physio-mechanical characteristics. The material recorded an average density of 3.14g/cm³ and a bulk density of 1450 kg/m³, both values falling within typical ranges for quality cement. Its specific surface area of 300 m²/kg, together with initial and final setting times of 120 and 280 minutes, reflects good workability and favorable hydration behavior (Mihashi *et al*., 2025). At 28days, the cement achieved a compressive strength of 32MPa, which is suitable for general structural applications. Soundness testing further revealed minimal expansion (2mm), confirming its stability and low risk of undesirable volumetric change (Jones & Patel, 2020).

Bringing together the geological, chemical, and performance evidence, the study demonstrates that the Borrong–Demsa–Murgarang limestone deposits are a dependable raw material source for modular cement production. The chemical composition supports efficient clinker formation, while the resulting cement meets key physical and mechanical performance standards, indicating strong industrial potential (Ogunleye *et al.*, 2024). These findings highlight the suitability of the resource for scalable, decentralized cement production, which could reduce transportation costs and strengthen sustainable local manufacturing in northeastern Nigeria (Adeola & Musa, 2021).

## V. CONCLUSION

This study presents a comprehensive and practical framework for assessing limestone deposits for cement production using an integrated geological, geochemical, and performance-based approach. The findings confirm that the Borrong–Demsa–Murgarang limestone possesses strong geochemical characteristics and favorable performance indicators, positioning it as a viable raw material for modular cement manufacturing in Adamawa State.

While the laboratory-produced cement met acceptable chemical and mineralogical requirements, its compressive strength, setting characteristics, and soundness fell slightly below those of commercially available Nigerian cements. These limitations are largely linked to the constraints of laboratory-scale production—particularly inconsistent kiln temperatures, uneven particle size distribution, and incomplete development of key clinker phases. Despite these challenges, the results highlight the resource's potential and provide clear direction for process optimization in future pilot or industrial-scale trials.

## RECOMMENDATIONS

- Develop a detailed resource statement that incorporates measured densities and multiple tonnage scenarios, integrating borehole data where available to improve reserve accuracy.

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- Conduct targeted blending experiments—such as combining limestone with clay, shale, or sand—to refine LSF, SM, and AM values and to reduce excess free lime in the final clinker.
- Pilot a small-scale modular grinding unit supported by an appropriate thermal system, and carry out a full life-cycle assessment of energy use and emissions before moving to larger-scale implementation.
- Carry out an economic feasibility and market analysis, including CAPEX/OPEX (capital expenditure/operational expenditure) evaluations with sensitivity to fuel and electricity prices, and engage local stakeholders to align production with regional needs.

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