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Evaluation of Natural Sudanese Sands as Potential Sources for High-Purity Silica (Sio₂)

Ibrahim Y.I. Elgady[1], Yousif A. A[2], Mohammed.H. G[3], Abdul Rahman. A. B[4], Ahmed. A. B[5], Othman. A.H[6], Jbarh . B. S[7]

[1,2,3,4,5,6,7] Department of Polymer Engineering, Sudan University of Science and Technology

ABSTRACT: The growing global demand for high-purity silica (SiO_2) has encouraged extensive research on the identification and beneficiation of natural silica resources. Silica plays a fundamental role in several industrial sectors including glass manufacturing, electronics, semiconductors, ceramics, solar energy technologies, polymer composites, and chemical catalysis. The objective of this study is to evaluate the potential of natural sand deposits from three Sudanese regions—Bara (North Kordofan), North Omdurman (Khartoum State), and Al-Matamma (River Nile State)—as possible raw materials for high-purity silica production. Representative sand samples were collected from the selected locations and subjected to physical and chemical characterization processes. The experimental methodology included drying, particle size analysis through mechanical sieving, silt content determination, bulk density measurement, alkali fusion treatment using sodium carbonate, acid leaching using hydrochloric acid, and thermal calcination at elevated temperatures. The chemical composition of the treated samples was determined using X-ray fluorescence (XRF) analysis. The results demonstrated significant variations in silica concentration among the studied deposits. The sand collected from Bara exhibited the highest SiO_2 content reaching approximately 96.43%, followed by North Omdurman with 94.84% and Al-Matamma with 92.42%. The purification process effectively reduced impurity levels, particularly iron oxides and alumina. These findings indicate that Bara sand deposits represent a promising raw material for the development of local silica-based industries in Sudan. The study highlights the economic and industrial potential of utilizing indigenous silica resources to support national mineral processing industries.

KEYWORDS: Silica sand, Sudanese sand deposits, XRF analysis, silica purification, chemical beneficiation.

I. INTRODUCTION

Silica (SiO_2) is one of the most widely used industrial minerals due to its remarkable physical and chemical properties such as high thermal stability, chemical inertness, hardness, and resistance to corrosion. These properties make silica an essential raw material in numerous industries including glass manufacturing, ceramics, electronics, semiconductors, water treatment systems, polymer reinforcement, abrasives, and solar energy technologies. As industrialization continues to expand worldwide, the demand for high-purity silica has increased significantly [1].Natural silica sand deposits are generally formed through long-term geological weathering processes involving the breakdown of silicate rocks followed by sediment transport and deposition. The mineralogical composition of sand deposits varies widely depending on the geological source, environmental conditions, and transportation mechanisms. Consequently, natural sands often contain impurities such as iron oxides, alumina, calcium compounds, and organic materials that reduce silica quality and must be removed through beneficiation processes Recent research efforts have focused on developing efficient and environmentally sustainable methods for silica extraction and purification from natural resources and waste materials. Various techniques including mechanical beneficiation, acid leaching, alkaline fusion, and thermal treatments have been widely investigated to improve silica purity and enhance its suitability for advanced technological applications [3].Islam et al. (2024) synthesized silica powder from river sand collected from the Padma River using a microwave-assisted alkali fusion technique. The researchers used sodium hydroxide fusion followed by acid leaching to remove metallic impurities. The process successfully produced amorphous silica with a purity of approximately 91.4%, demonstrating that microwave heating can provide an efficient and energy-saving approach for silica production [4].Gaber et al. (2024) investigated the purification of silica sand from the Wadi El-Dakhal region in Egypt through chemical leaching techniques. Hydrochloric acid treatment was applied to remove iron and alumina impurities after particle classification. Their results indicated that silica purity increased from 98.60% to 99.99%, which makes the treated sand suitable for optical glass and photovoltaic industries [5].Zeboudj and Hamzaoui (2023) evaluated the extraction of silica from natural sand and diatomite deposits for photovoltaic silicon production. The researchers used acid leaching combined with thermal processing to reduce impurity levels. The study confirmed that both sand and diatomite can serve as promising raw materials for high-purity silica used in solar energy technologies [6].Meftah et al. (2023) produced silica nanoparticles from desert dune sand through an eco-friendly sodium silicate process. The procedure involved alkaline dissolution of silica followed by precipitation and calcination steps. The resulting silica nanoparticles exhibited a purity of approximately 99%, demonstrating the feasibility of producing nanostructured silica from desert sand resources [7].Li et al. (2022) proposed a low-cost purification route combining alkaline fusion and acid leaching to extract silica from natural sand deposits. Their study successfully produced silica with purity exceeding 96 wt%, highlighting the potential of simple chemical methods for silica beneficiation [8].Rahayu et al. (2018) investigated the conversion of kaolin clay into silica-alumina materials and zeolite Y. Their study involved calcination and chemical extraction processes to isolate silica components, demonstrating that clay minerals can serve as alternative silica sources [9].Research published in the Journal of Minerals and Materials Characterization and Engineering (2021) examined the purification of silica sand using wet sieving and mechanical attrition without chemical additives. The process achieved silica purity levels above 99%, emphasizing the importance of physical beneficiation methods [10].Rampe (2023) studied coastal sand from Sumatra as a precursor material for silicon carbide production. After chemical purification and thermal treatment, the silica-rich sand demonstrated excellent potential for advanced ceramic synthesis [11]Gödeke et al. (2025) investigated the mineralogical composition of white sand deposits from Brunei. XRF analysis showed silica concentrations exceeding 99.5%, indicating their suitability for high-technology industries such as semiconductor manufacturing [12].

II. MATERTIALS &METHODS

a. Study Area and Sample Collection

Silica sand samples were collected from three different geological regions in Sudan:

1. **Bara region (North Kordofan State)**
2. **North Omdurman (Khartoum State)**
3. **Al-Matamma (River Nile State)**

These areas were selected based on geological surveys indicating the presence of silica-rich sand deposits. The samples were collected from surface deposits at depths ranging from 0.5 to 1 meter to ensure representative material. Each sample was placed in sealed plastic containers to prevent contamination during transportation to the laboratory.

Figure 1. Natural silica sand sample collected from Bara region.

Figure 2. Sand samples collected from North Omdurman and Al-Matamma regions.

b. Sample Preparation

Prior to analysis, the collected sand samples were subjected to preliminary preparation procedures. The samples were washed thoroughly with distilled water to remove dust and organic contaminants. After washing, the samples were dried in a laboratory oven at **105°C for 24 hours** to remove moisture content. The dried samples were then homogenized and stored in airtight containers for further physical and chemical characterization.

c. Particle Size Distribution Analysis

Particle size distribution was determined using **mechanical sieve analysis**. A standard set of sieves with decreasing mesh sizes was used to classify sand particles into different size fractions. Approximately **500 g of each sand sample** was placed on the top sieve and subjected to mechanical vibration using a sieve shaker for **10 minutes**. The mass retained on each sieve was recorded, allowing the calculation of particle size distribution percentages.

Figure 3. Mechanical sieve shaker and standard sieves used for particle size classification.

d. Silt Content Determination

The silt content test was conducted to determine the percentage of fine particles and clay impurities present in the sand samples. A representative sample of **200 g** from each sand deposit was mixed with distilled water and stirred vigorously. The mixture was allowed to settle for several minutes to separate heavier sand particles from lighter silt materials. After separation, the sand fraction was dried again at **105°C for 24 hours**, and the mass difference was used to determine the silt content percentage.

Figure 4. Silt test apparatus used for determining fine particle impurities.

e. Bulk Density Measurement

Bulk density was determined using a calibrated container with a known volume of **902.75 cm^3**.The dried sand was carefully poured into the container without compaction, and the mass was measured using a precision digital balance. Bulk density was calculated using the relationship:

$$\text{Bulk Density} = \frac{\text{Mass of Sand}}{\text{Container Volume}}$$

Figure 5. Standard container with known volume used for bulk density determination.

f. Chemical Purification Process

To increase silica purity, the sand samples were subjected to **alkali fusion treatment** followed by acid leaching. In the fusion stage, sand was mixed with **sodium carbonate (Na_2CO_3)** at a weight ratio of **1:4**. The mixture was placed in ceramic crucibles and heated in an electric furnace at **1000°C for 30 minutes**. The fusion process converts silica into soluble sodium silicate, facilitating impurity removal in subsequent steps.

Figure 6. Electric furnace used for alkali fusion treatment.

g. Acid Leaching and Silica Extraction

After fusion, the fused material was dissolved in **hydrochloric acid (HCl)** solution and heated for approximately **10 minutes** to dissolve metallic impurities such as iron oxides and alumina. The solution was then evaporated using a water bath until silica precipitate was obtained. The precipitate was filtered, washed with distilled water, and dried. The dried material was finally calcined at **1000°C for one hour** to produce purified silica powder.

Figure 7. Purified silica obtained after chemical treatment.

h. Chemical Composition Analysis

The chemical composition of the treated sand samples was determined using **X-ray Fluorescence (XRF) spectroscopy**. XRF analysis enables accurate determination of elemental concentrations by measuring characteristic X-ray emissions produced when the sample is irradiated with high-energy X-rays.

The main oxides analyzed included:

- SiO_2
- Fe_2O_3
- Al_2O_3
- CaO
- MgO

Figure 8. X-ray fluorescence (XRF) spectrometer used for elemental analysis.

III. RESULTS AND DISCUSSION

The physical and chemical characterization results demonstrated clear variations among the studied sand deposits. Mechanical sieve analysis showed that most particles were distributed within the medium-to-fine grain size range, which is suitable for industrial processing. Silt content analysis indicated that Bara sand exhibited the lowest impurity levels compared to the other locations.

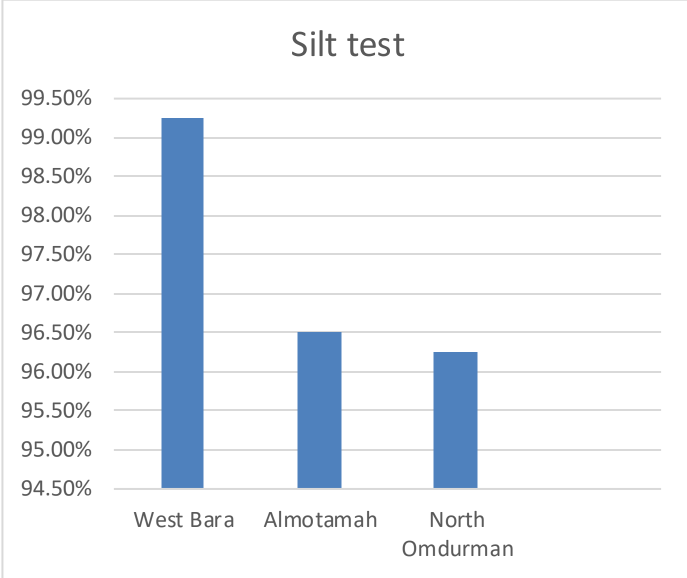

Figure 9. Silt test results for the three sand samples.

XRF analysis confirmed that silica concentration varied significantly among the samples.

The results showed:

- Bara: **96.43% SiO_2**
- North Omdurman: **94.84% SiO_2**
- Al-Matamma: **92.42% SiO_2**

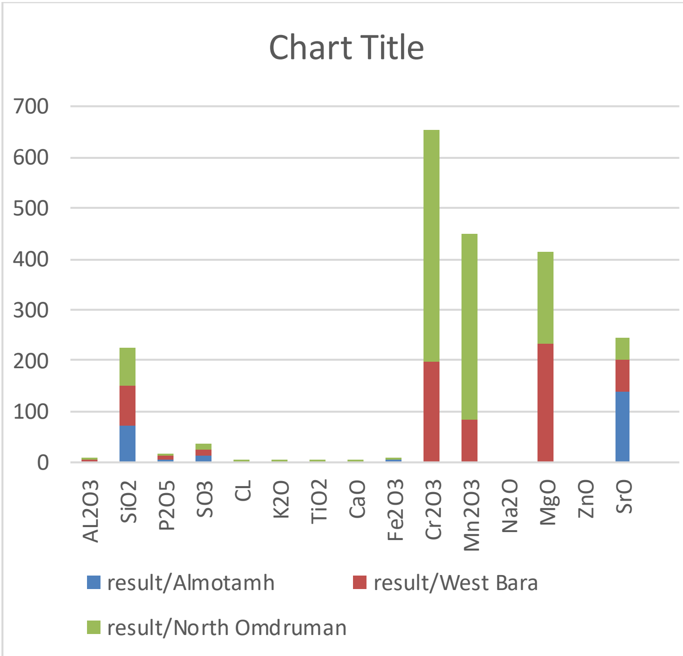

Figure 10. XRF analysis results showing silica concentration in the studied samples.

The reduction in iron oxide concentration after chemical treatment further improved the suitability of the sand for high-purity industrial applications.

IV. CONCLUSION

This study evaluated the potential of natural Sudanese sand deposits as raw materials for high-purity silica production. The experimental results confirmed that:

1. Sudanese sand deposits contain high silica concentrations suitable for industrial applications.
2. The applied chemical purification process significantly enhanced silica purity.
3. Bara sand exhibited the highest silica concentration and lowest impurity levels.

   The findings suggest that Sudan possesses significant silica resources that could support the development of local silica-based industries, reducing dependence on imported materials and promoting sustainable mineral resource utilization.

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