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Characterisation of Yobe State Quartz Sands for Photovoltaic Cell Production

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Abstract

This study investigates the potential of sand obtained from Yobe State, Nigeria, as a local raw material for photovoltaic (PV) cell production by examining its silica content and properties. With the growing demand for renewable energy, particularly solar power, there is a need to explore sustainable, affordable, and locally available materials that can support PV manufacturing in Nigeria. In this study, soil samples were systematically collected from five locations in Yobe State: Nguru, Karasuwa, Gashua, Jakusko, and Machina. The samples were characterised using X-ray diffraction (XRD), Energy-Dispersive X-ray Fluorescence (EDXRF) spectroscopy, Scanning Electron Microscopy (SEM), and Brunauer–Emmett–Teller (BET) analysis. The results showed that the sand samples contain considerable amounts of silica, making them potentially useful for PV-related applications. XRD analysis confirmed the presence of quartz (SiO_2) in the samples. Among the locations studied, the Karasuwa sample recorded the strongest quartz peak, with an intensity of approximately 4000 cps, while the Gashua sample had the lowest intensity at about 2000 cps. EDXRF analysis further confirmed the presence of silica in all the samples, with the highest concentration recorded in the Karasuwa sample at 77.75%. SEM analysis revealed the granular nature of the samples and provided information on their particle size distribution, both of which are important considerations when assessing materials for PV applications. BET analysis also showed that the samples possess appreciable specific surface areas and well-defined pore structures, with the Gashua sample recording the highest specific surface area of 475.095 m^2/g. Overall, the findings indicate that sand from Yobe State has promising potential as a locally sourced silica material for PV cell manufacturing. Utilising this resource could help reduce dependence on imported raw materials, lower production costs, and contribute to local industrial and economic development. However, further studies are needed to identify and quantify impurities in the sand and to determine whether the material can meet the purity requirements for large-scale PV cell production. The study highlights the value of investigating locally available resources as part of efforts to promote sustainable development, renewable energy production, and energy security in Nigeria.

Keywords: Quartz sand, Silica (SiO_2), Yobe-Nigeria, XRD, EDXRF, SEM, BET

1. Introduction

The global demand for photovoltaic (PV) technology is growing rapidly, creating increasing pressure on the supply of high-purity quartz, which is an important raw material in the production of solar-grade silicon. However, high-purity quartz is found in relatively limited geological deposits, making its availability a growing concern for the expanding solar industry. This situation highlights the need to identify and assess alternative and more widely available sources of silica that could support PV manufacturing (Chaa *et al*., 2026; Yu *et al*., 2025).

PV cells, commonly referred to as solar cells, are devices that convert sunlight directly into electricity through the photovoltaic effect. They form the basic building blocks of solar panels and are widely used in residential, commercial, and large-scale power generation systems. Silicon remains the most widely used material for producing solar cells, with monocrystalline and polycrystalline silicon being the two main types (Choi *et al*., 2020; Sugianto, 2020). When sunlight falls on a solar cell, it provides energy that excites electrons within the semiconductor, generating an electric current. The electricity produced is initially in the form of direct current (DC), which can be converted into alternating current (AC) using an inverter for use in homes, businesses, and electricity grids. The continued development of solar cell technology has improved efficiency, reduced production costs, and increased the range of applications for solar energy (Borah *et al*., 2023). Solar energy is particularly important in the transition towards cleaner energy systems because it provides a renewable source of electricity and can help reduce dependence on fossil fuels and associated environmental impacts (Muñoz-García *et al*., 2021).

However, factors such as the accumulation of dust and dirt on solar collectors can affect the amount of sunlight reaching the surface and consequently influence their performance (Olorunfemi *et al*., 2022).

The characterisation of quartz-rich sand is therefore an important step in assessing its suitability as a source of raw materials for photovoltaic applications. Through characterisation, the physical and chemical properties of sand can be determined, including its silica content, mineral composition, particle morphology, and the presence of impurities. These properties provide useful information about whether a particular deposit can serve as a suitable source of silicon for PV production. Quartz deposits can vary considerably in composition, and even small amounts of impurities may affect the quality of the silicon obtained from them. For this reason, understanding the chemical composition and purity of potential raw materials is essential when evaluating their suitability for solar-cell manufacturing. The presence of certain impurities can adversely affect the electrical properties and overall performance of solar cells (Fouad *et al*., 2017).

In addition to chemical composition, other properties of quartz sand, such as particle size, morphology, surface area, and electrical characteristics, can provide valuable information about its potential applications. These characteristics influence the behaviour of materials during processing and can affect the quality of the silicon produced. In particular, a sufficiently high silicon or silica content is important for the production of high-quality solar-cell materials. Therefore, identifying and characterising locally available quartz-rich soils with suitable silica concentrations is an important step towards developing alternative sources of raw materials for photovoltaic manufacturing (Park *et al*., 2016). In this context, investigating the silica content and properties of sand deposits in Yobe State, Nigeria, could provide useful information on their potential contribution to local PV material production and the broader development of renewable energy technologies.

As the solar industry progresses, technological innovations in silicon production is key for its sustainability (Ansanelli *et al*., 2021; Daniela-Abigail *et al*., 2022). The potential to utilise local sand deposits for PV cell production in Yobe State – Nigeria remains largely unexploited, despite its geographical advantages and the pressing need for sustainable energy solutions. Despite the region's extensive sand deposits, which have potential as a raw material for photovoltaic (PV) cell manufacturing to mitigate the energy shortfall, to our knowledge, no comprehensive studies have assessed the quality of these sand resources within Yobe State for this specific application. However, Mohammed *et al*. (2026) presented a comprehensive and integrated technical methodology for synthesising photovoltaic-grade silicon from River Alau sand sourced from Maiduguri, Borno State, Nigeria.

High-purity Silica (SiO_2) is the main feedstock for silicon production sourced from quartz sand deposits. Nigeria has abundant silica sand deposits but still rely on imported PV materials. Utilising its local sand deposits for silicon production will provide job opportunities for the populace, reduce cost of production, improved energy security, and enhanced industrial development (Mohammed *et al.*, 2026). This study examined the silicon dioxide (SiO_2) content of soil samples obtained from five locations within Yobe State, Nigeria, as a prospective raw material for photovoltaic cell manufacturing.

The five soil samples collected for this study were analysed using EDXRF, XRD, SEM, and BET techniques. These analytical methods were used to determine the chemical composition, mineral phases, surface characteristics, and other properties of the samples that are relevant to their potential use in photovoltaic (PV) applications.

The study is important because it provides useful information on the possibility of using locally available quartz sand as a raw material for solar panel production in Yobe State. The findings could help guide the State Government, researchers, and potential investors in assessing the feasibility of developing a local PV manufacturing industry. Using locally sourced materials could also reduce dependence on imported raw materials and create opportunities for local economic development. More broadly, increasing the use of solar energy can support the transition from fossil fuels to cleaner and renewable energy sources, while contributing to efforts to reduce greenhouse gas emissions and address climate change.

Despite the promising results, further research is needed to improve the extraction and purification of silica from the quartz sands. Additional studies should also focus on identifying and quantifying impurities and determining whether the extracted silica can meet the purity requirements for large-scale PV cell production. Such investigations will help establish the practical and economic feasibility of using Yobe State quartz sands as a local source of raw material for photovoltaic manufacturing.

2.0 Materials and Methods

2.1 Site Selection and Description

Figure 1 presents a map of Yobe State, Nigeria, showing the five locations where the soil samples were collected: Nguru, Karasuwa, Gashua, Jakusko, and Machina. These areas are generally characterised by dry, sandy soils with

relatively low organic matter content. The selected locations provided a range of sand samples for assessing their silica content and determining their suitability for potential use in photovoltaic applications.



Figure 1: Map of Nigeria (a) and Yobe State (b) showing the five locations where the soil samples were collected. Adapted and modified from Eze and Onokala (2022)

2.2 Soil Sample Collection

The soil samples were collected using a standard sampling procedure to obtain samples that represent the study areas. A 5 cm diameter soil auger was used to collect soil cores from selected locations. The sampling points were arranged in a systematic grid pattern to provide good coverage of each study area. At each location, the auger was inserted into the soil and samples were collected from depths ranging from 0 to 30 cm. The soil cores were approximately 20 cm long. A separate soil auger was used at each sampling location to reduce the risk of cross-contamination. After collection, each sample was labelled with a unique identification code based on its location. The sampling depth and geographical coordinates were also recorded.

The Nguru sample was collected at a depth of 10 cm at coordinates 12.8770° N, 10.4554° E. The Karasuwa sample was collected at 12.9621° N, 10.5611° E, while the Gashua sample was collected at 12.8765° N, 11.0316° E. The Jakusko sample was collected at 12.371° N, 10.774° E, and the Machina sample was collected at 13.1124° N, 10.1255° E. The collected samples were then properly stored and prepared for laboratory analysis.

2.3 Characterisation of Soil Sample

The soil samples were analysed using four techniques: EDXRF, XRD, SEM, and BET analyses. These techniques were used to determine the chemical composition, mineral content, surface structure, particle shape, and surface area of the soil samples.

2.3.1 Energy Dispersive X-ray Fluorescence (EDXRF)

The soil samples were analysed using EDXRF to determine their elemental composition, following the method reported by Silva *et al.* (2019). A handheld EDXRF analyser was used to carry out the measurements. This method is fast and non-destructive, making it suitable for analysing the chemical composition of soil samples. During the analysis, the instrument directed X-rays onto the surface of each soil sample. The X-rays excited the atoms present in the sample, causing them to release characteristic X-rays. The detector then measured the energy and intensity of these signals, which were used to identify and determine the concentration of the elements present in the soil samples.

2.3.2 X-ray Diffraction (XRD)

XRD was used to identify the minerals present in the soil samples. During the analysis, an X-ray beam was directed at each sample, and the resulting diffraction pattern was recorded by a detector. The patterns showed different peaks, with each peak representing a particular crystalline mineral. The position and intensity of these peaks were used to identify the minerals present and estimate their relative amounts in the samples.

2.3.3 Scanning Electron Microscopy (SEM)

SEM was used to study the surface features of the soil samples. Small portions of each sample were prepared for examination and coated with a thin conductive layer to produce clearer images. The SEM images showed the surface structure and appearance of the soil particles in detail. The analysis provided information about the size, shape, and texture of the particles, which helped in understanding the physical characteristics of the soil samples.

2.3.4 Brunauer-Emmett-Teller (BET)

Five soil samples were analysed using the BET method to determine their specific surface area. However, the samples were ground prior to the analysis. The BET analysis involved exposing the soil samples to a gas (typically nitrogen) at varying pressures and measuring the amount of gas adsorbed onto the soil surfaces. The resulting isotherm was used to calculate the soil's specific surface area.

3.0 Results And Discussion

3.1 EDXRF Analysis

The concentrations of chemical compounds in the soil samples from the five locations in Yobe State - Nigeria are presented in Table 1.

Table 1: EDXRF Analysis of soil samples

Compounds	Nguru	Karasuwa	Machina	Jakusko	Gashua
SiO_2	**77.46%**	**77.75%**	**77.53%**	**77.27%**	**77.41%**
Fe_2O_3	0.10%	0.08%	0.10%	0.09%	0.09%
Al_2O_3	2.19%	1.98%	2.21%	2.53%	2.54%
MgO	1.55%	1.25%	1.48%	1.20%	1.28%
P_2O_5	0.18%	0.14%	0.20%	0.17%	0.17%
SO_3	0.05%	0.13%	0.05%	0.05%	0.06%
TiO_2	2.10%	1.93%	1.71%	2.02%	1.94%
MnO	0.01%	0.01%	0.01%	0.01%	0.01%
CaO	1.24%	1.32%	1.36%	1.38%	1.41%
K_2O	4.75%	5.09%	4.24%	4.08%	4.11%
CuO	0.02%	0.00%	0.02%	0.02%	0.03%
ZnO	0.00%	0.00%	0.00%	0.00%	0.00%
Cr_2O_3	2.87%	2.91%	2.61%	2.65%	3.17%
V_2O_5	0.06%	0.00%	0.00%	0.00%	0.00%
As_2O_3	0.00%	0.00%	0.00%	0.00%	0.00%
PbO	0.00%	0.00%	0.00%	0.00%	0.00%
Rb_2O	0.00%	0.00%	0.00%	0.00%	0.00%
Ga_2O_3	0.00%	0.00%	0.00%	0.00%	0.00%
NiO	0.00%	0.00%	0.00%	0.00%	0.00%
Cl	0.06%	0.05%	0.09%	0.08%	0.08%
ZrO_2	0.03%	0.09%	0.02%	0.03%	0.03%
Ta_2O_5	0.01%	0.00%	0.01%	0.01%	0.01%
Br	0.00%	0.00%	0.00%	0.00%	0.00%
SrO	0.21%	0.21%	0.23%	0.22%	0.21%
Nb_2O_5	1.12%	1.52%	1.75%	1.46%	1.62%
Bi_2O_3	0.00%	0.04%	0.00%	0.00%	0.00%
Sb_2O_3	2.60%	1.98%	2.65%	2.78%	2.45%
Co_3O_4	0.00%	0.00%	0.00%	0.00%	0.00%
CdO	0.00%	0.00%	0.00%	0.00%	0.00%
HfO_2	0.00%	0.00%	0.00%	0.00%	0.00%
CeO_2	0.00%	0.00%	0.00%	0.00%	0.00%
BaO	2.80%	2.96%	2.95%	2.98%	2.64%
Au	0.00%	0.00%	0.00%	0.00%	0.00%
WO_3	0.10%	0.09%	0.09%	0.09%	0.09%
MoO_3	0.01%	0.01%	0.01%	0.01%	0.01%
La_2O_3	0.00%	0.00%	0.00%	0.00%	0.00%
ThO_2	0.00%	0.00%	0.00%	0.00%	0.00%
SnO_2	0.48%	0.45%	0.67%	0.86%	0.64%

According to SiO_2 purity, high-purity quartz sands are categorised into four grades: premium-grade ($SiO_2 \geq$ 99.998%), high-grade ($SiO_2 \geq$ 99.995%), mid-grade ($SiO_2 \geq$ 99.99%), and low-grade (SiO_2) $\geq$ 99.9%) (Deshui *et al.*, 2025). Based on Table 1, the soil sample from Karasuwa shows the highest SiO_2 content of 77.75%. Conversely, the soil sample from Jakusko shows the least SiO_2 content of 77.27%. Moreover, the presence of SiO_2 in the soil samples render them promising to produce high-grade silicon for PV cell production. The silica and other oxides contents obtained from unrefined/unpurified quartz sand used in this study and that of Mohammed *et al.*, 2026, is presented in Table 2. Optimistically, if these quartz sands are refined and impurities removed, they will produce high-grade silica for subsequent silicon production for PV applications. However, this is out of scope of this current study.

Table 2: Silica and Other Oxides Content Comparison

Oxides	This study					Mohammed *et al.*, 2026 (Alau - Maiduguri)
	Nguru	Karasuwa	Machina	Jaskuko	Gashua	
SiO_2	**77.46%**	**77.75%**	**77.53%**	**77.27%**	**77.41%**	**77.63%**
K_2O	4.75%	5.09%	4.24%	4.08%	4.11%	6.31%
Al_2O_3	2.19%	1.98%	2.21%	2.53%	2.54%	2.10%
TiO_2	2.10%	1.93%	1.71%	2.02%	1.94%	2.08%
CaO	1.24%	1.32%	1.36%	1.38%	1.41%	1.46%

3.2 XRD Analysis

The XRD patterns of the soil samples show peaks corresponding to the crystalline phases present in each sample. The position of each peak, represented by the 2θ value, is determined by the crystal structure of the material and can be used to identify specific minerals. Peak intensity indicates the relative amount of a crystalline phase present, with stronger peaks generally suggesting a higher concentration. By comparing the observed peak positions and intensities with standard reference patterns, the mineral phases in the samples can be identified. In this study, particular attention was given to quartz and other SiO_2-containing phases because of their importance as potential raw materials for solar cell production. XRD analysis was conducted with scan axes of θ/2θ and a 1.25-degree DS to scan the samples and produce the results depicted in Figures 2-6. In XRD analysis, SiO_2 exhibits its major characteristics peaks at $2\theta = 20.8^o$, 26.7^o, 50.3^o, and 60.1^o. However, the peak at 26.7^o is the most intense and serves as the primary fingerprint for quartz in soil samples. For the samples analysed in this study, the Karasuwa soil sample has the most intense peak (4000 cps), while the Gashua soil sample has the least intense peak (2000 cps).

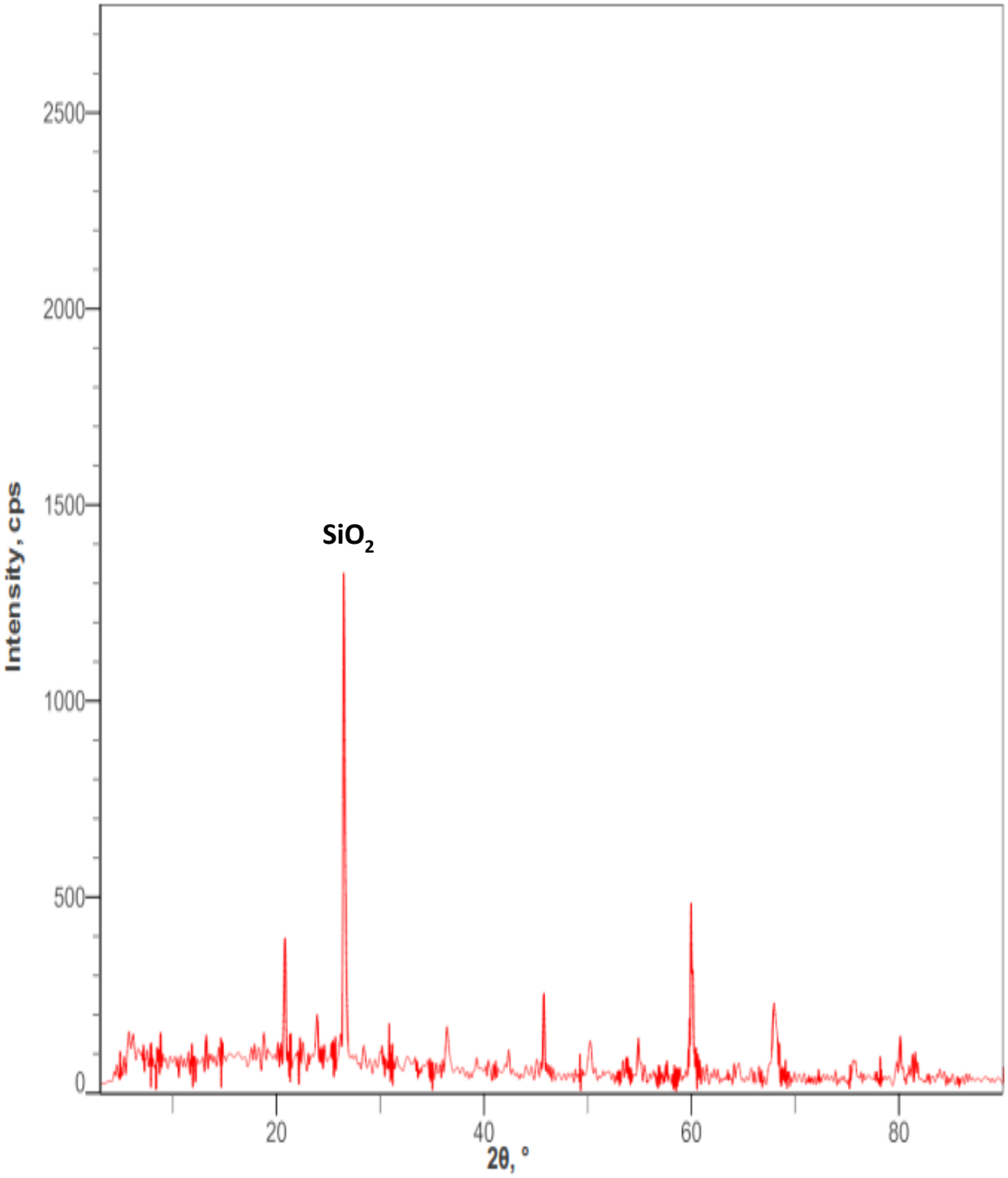


Figure 2: XRD Analysis of Nguru Soil Sample

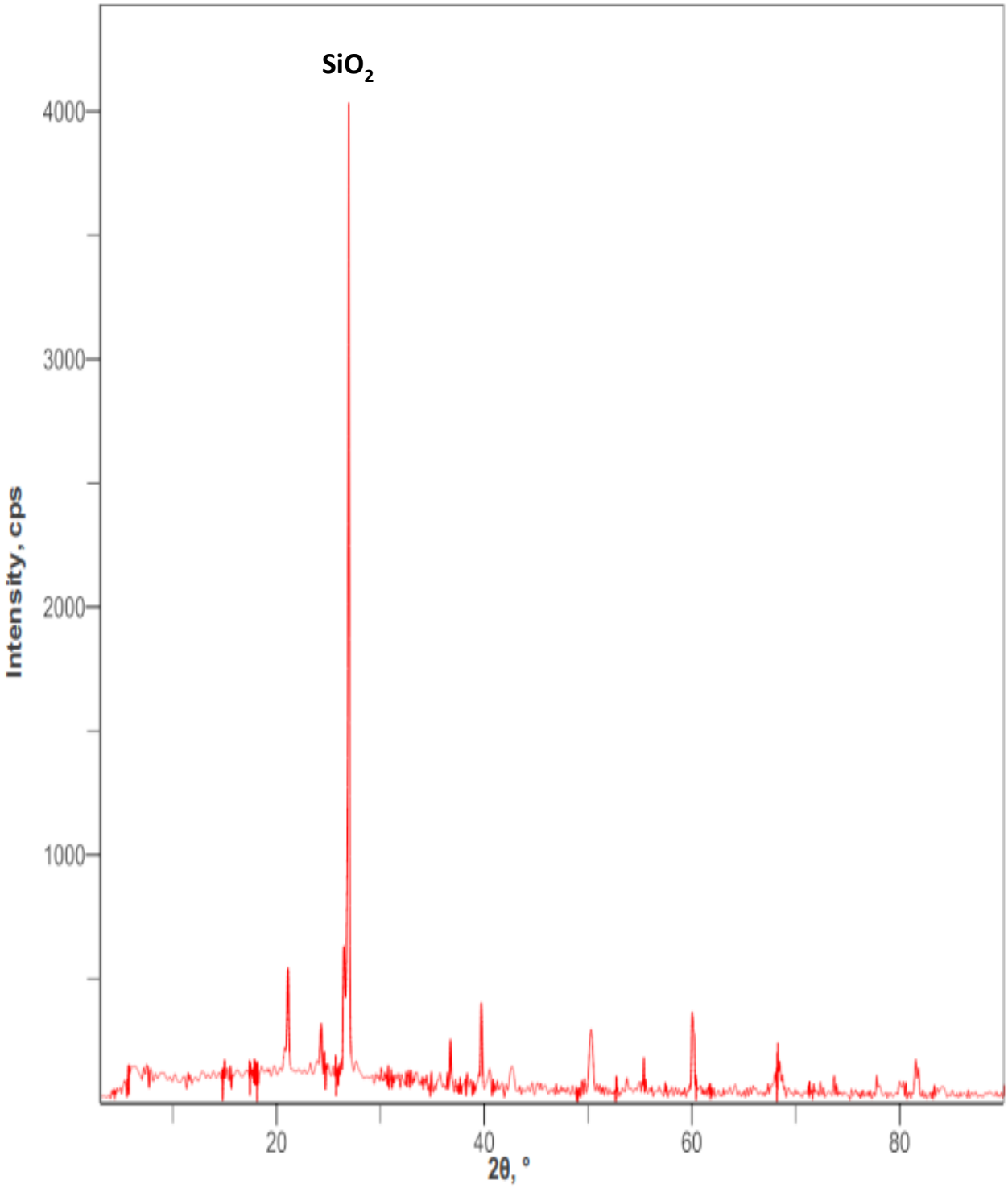


Figure 3: XRD Analysis of Karasuwa Soil Sample

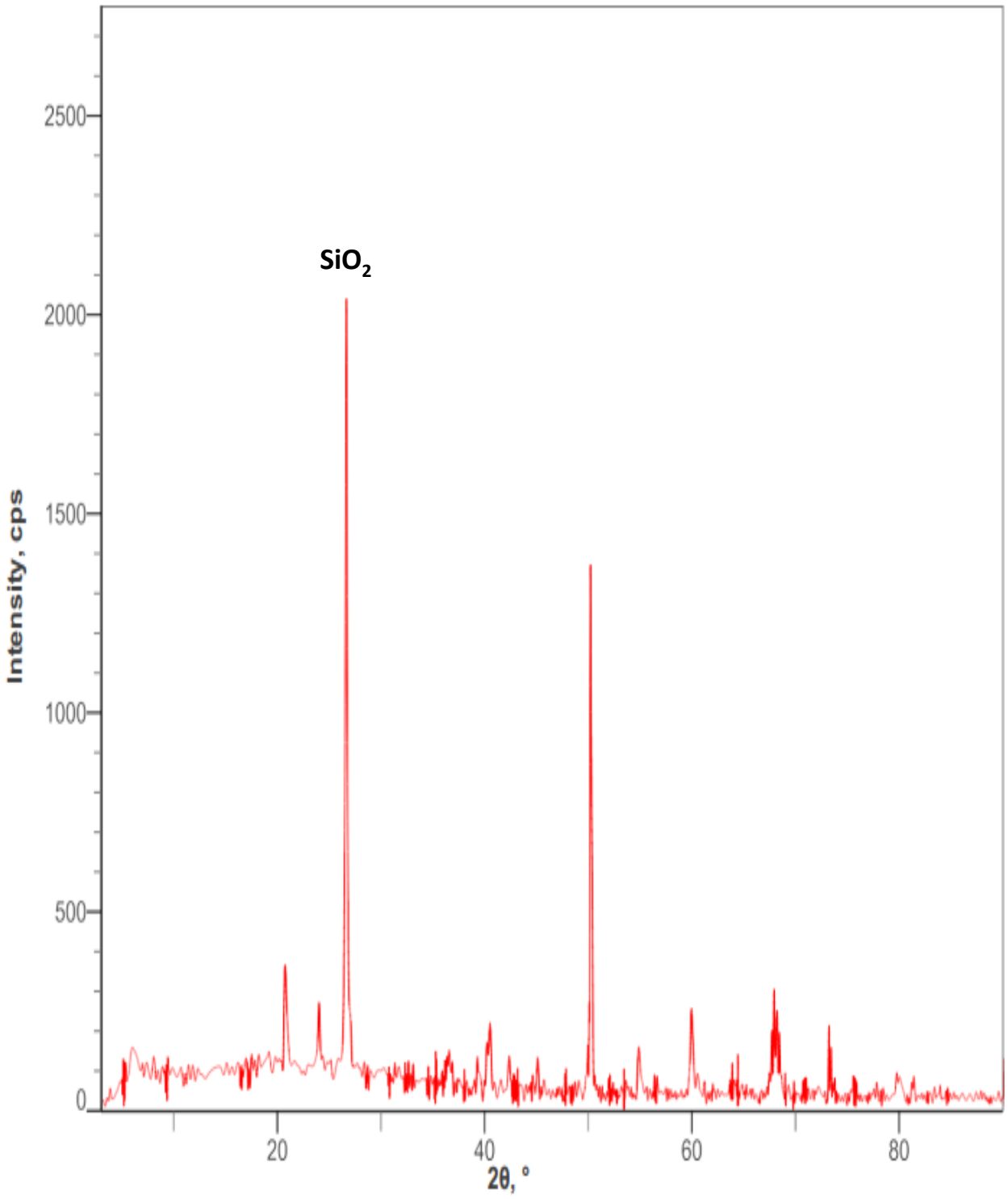


Figure 4: XRD Analysis of Gashua Soil Sample

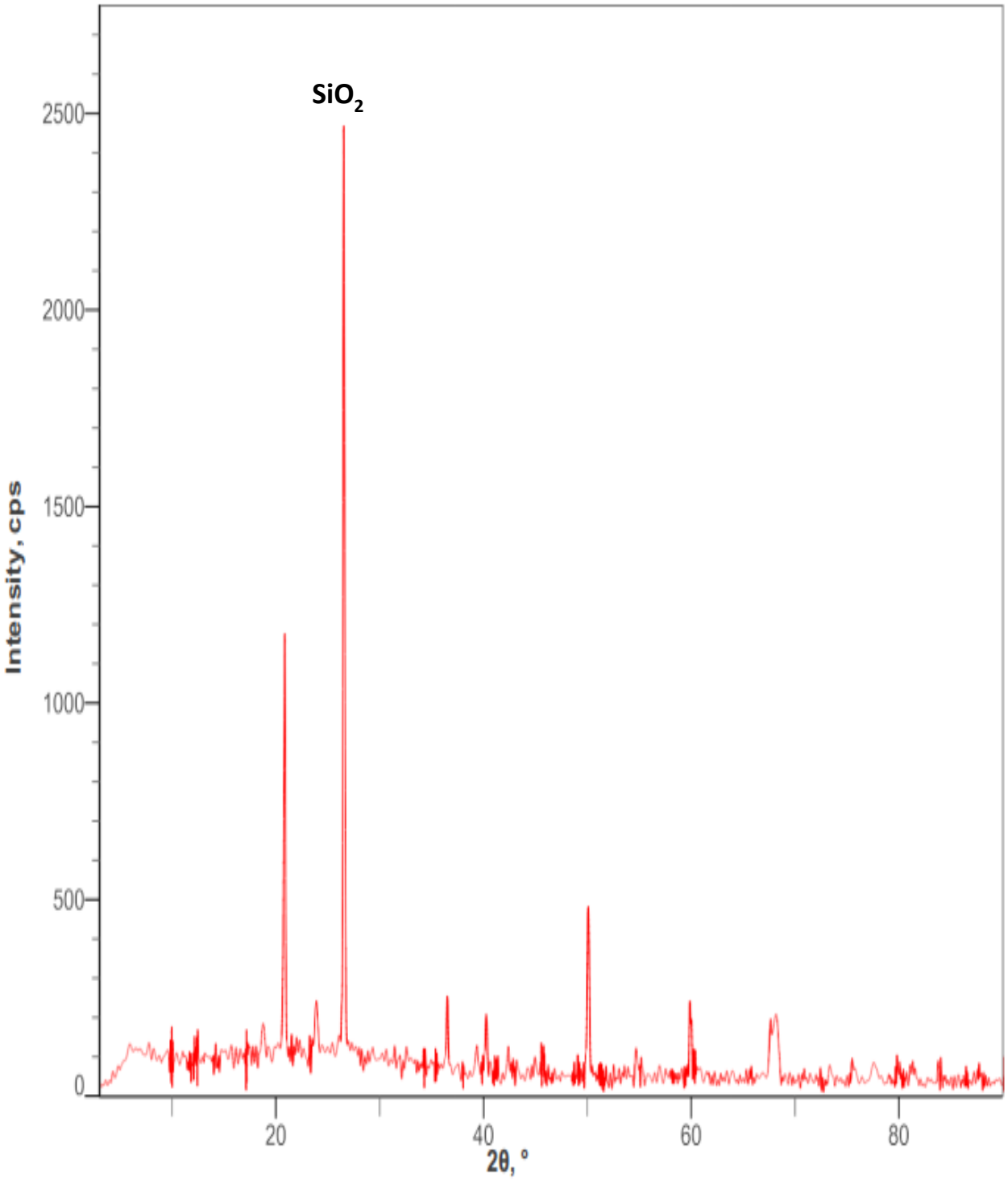


Figure 5: XRD Analysis of Jakusko Soil Sample

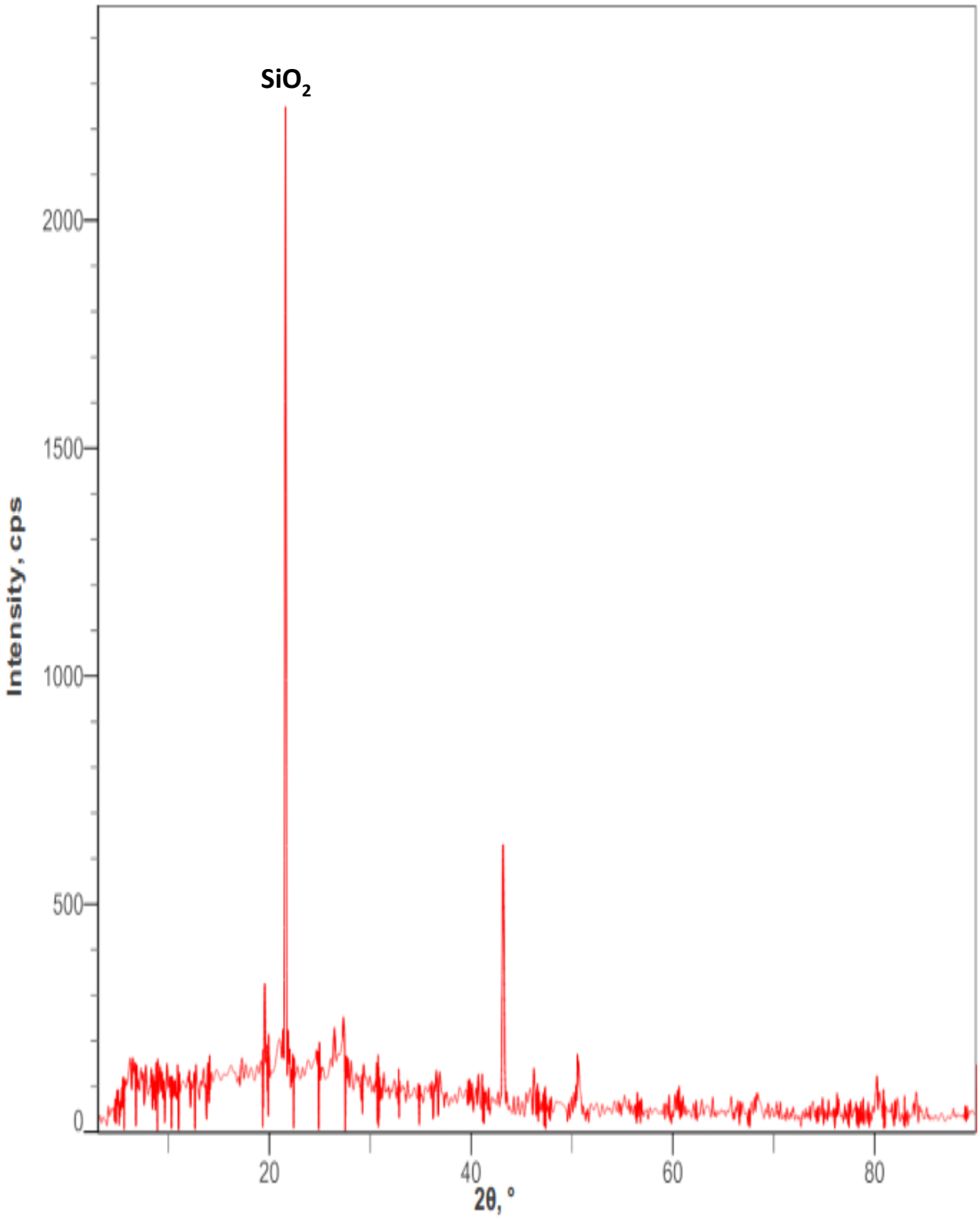


Figure 6: XRD Analysis of Machina Soil Sample

3.3 SEM Analysis

SEM images of the soil samples collected from the five locations in Yobe State, Nigeria, at 500× magnification are shown in Figures 7–11. The images show particles of different sizes and shapes, with both angular and rounded forms. The particle surfaces appear rough and uneven, with visible pores, cracks, and spaces between the particles. These features suggest that the samples have a porous structure and a relatively large surface area, which may influence how the material interacts with and retains other substances.

However, the SEM results alone cannot confirm whether the soil is suitable for solar cell production. Other properties, such as its chemical composition and electrical characteristics, also need to be considered. The presence of SiO_2 in the samples, as confirmed by other analyses, is a positive indication of their potential as a source of silica. Further testing is therefore needed to determine whether the extracted silica can meet the requirements for solar cell production.

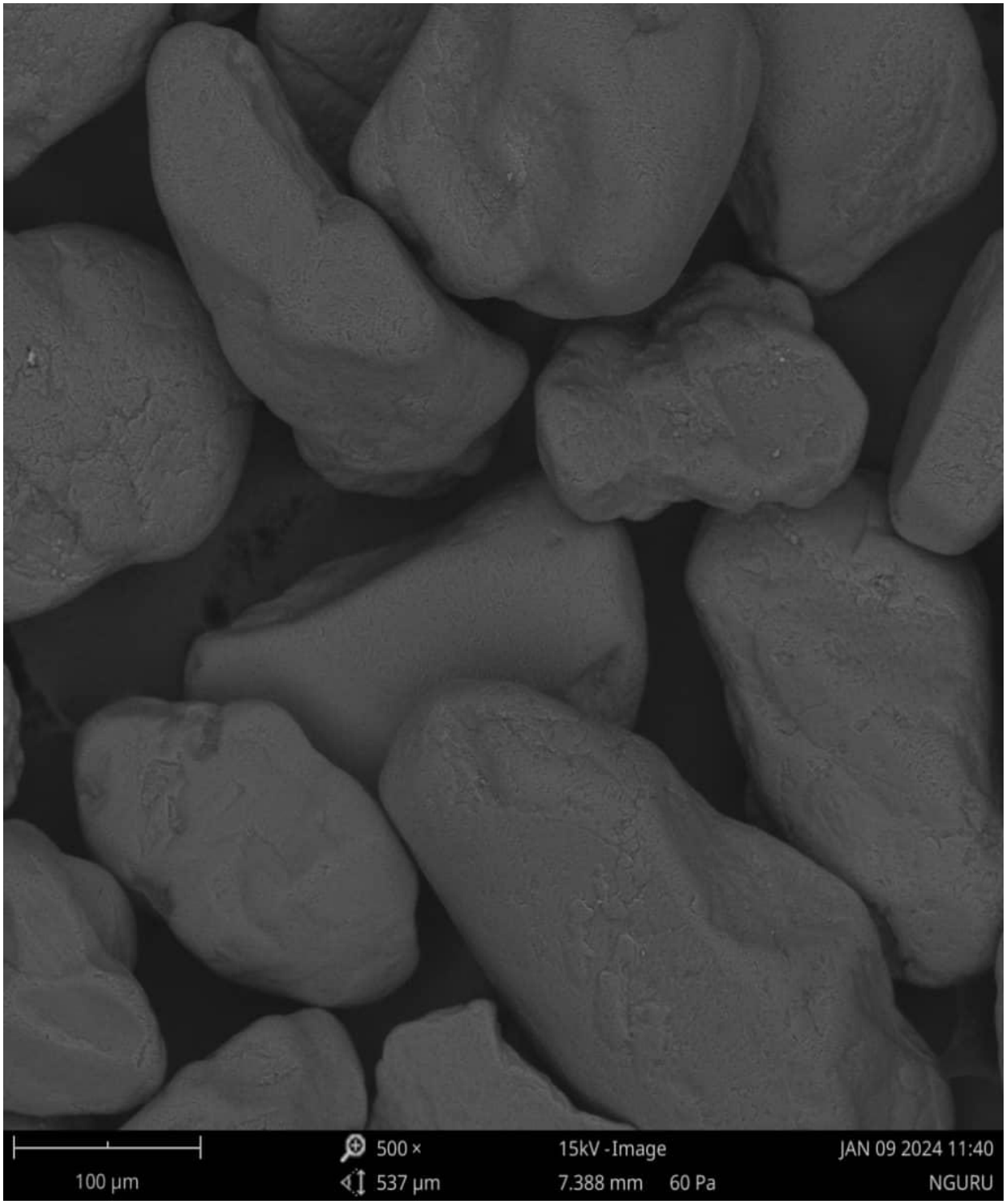


Figure 7: SEM Analysis (Nguru)

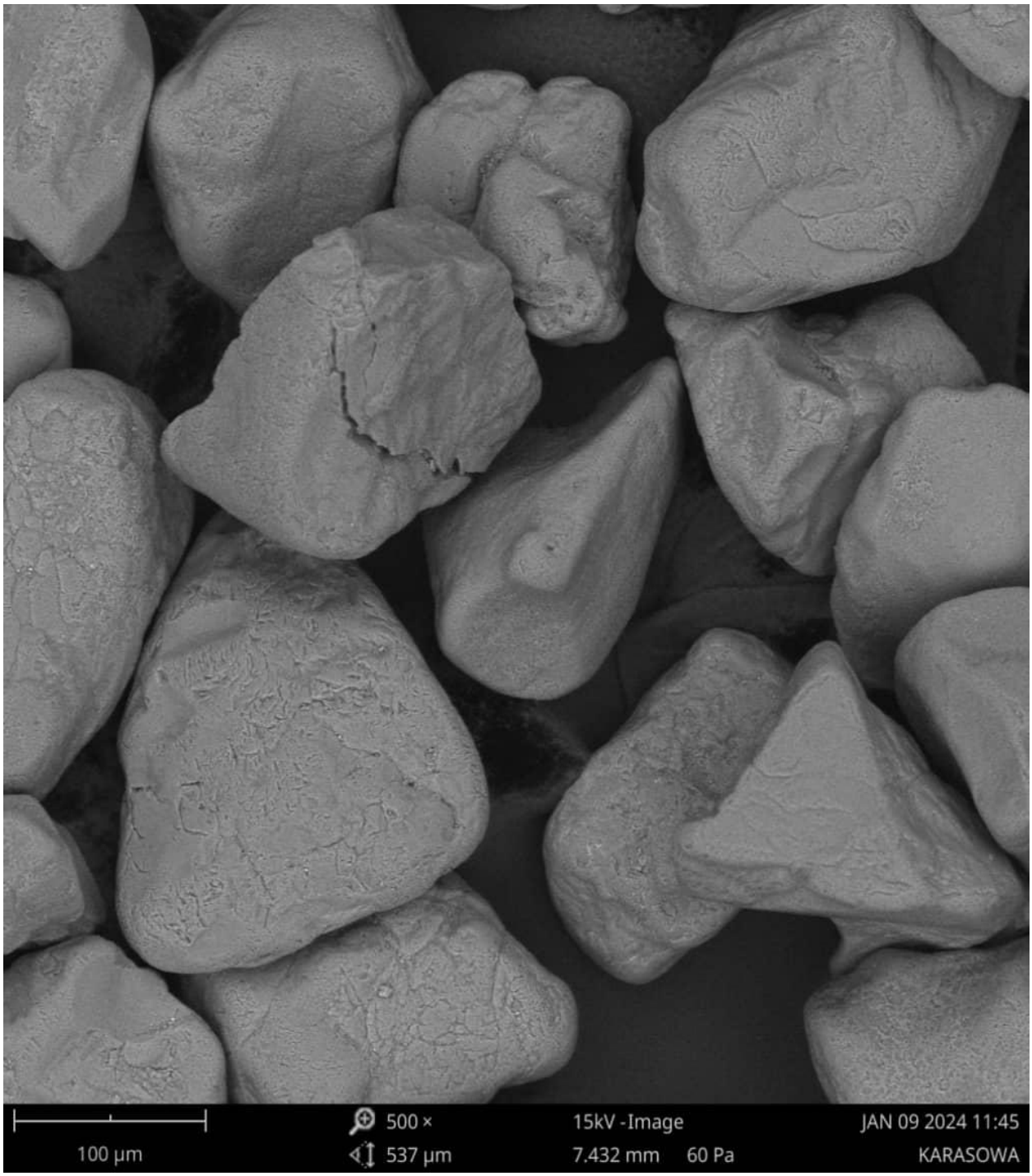


Figure 8: SEM Analysis (Karasuwa)



Figure 9: SEM Analysis (Gashua)

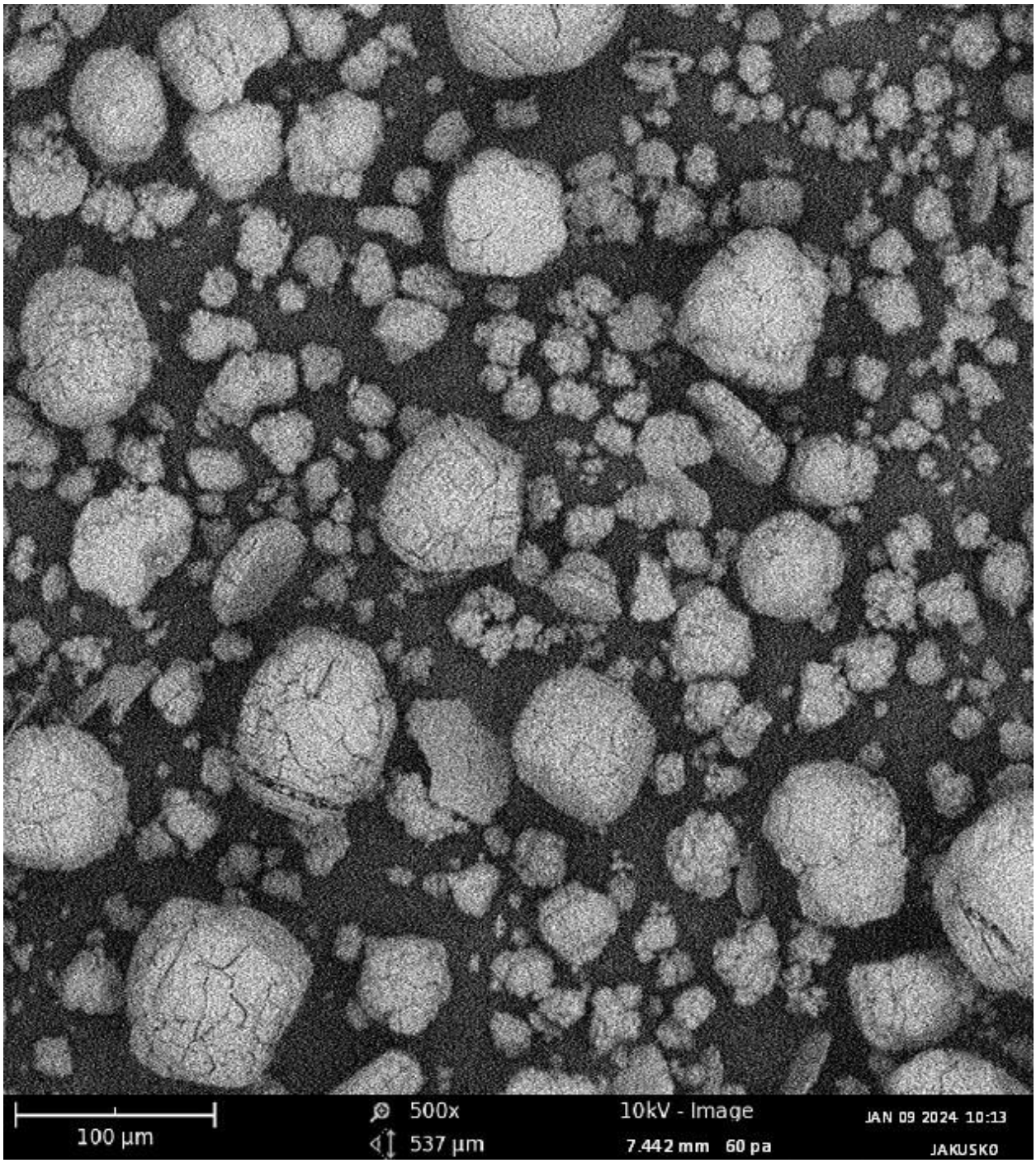


Figure 10: SEM Analysis (Jakusko)



Figure 11: SEM Analysis (Machina)

3.4 BET Analysis

Table 2 shows the BET results for soil samples collected from five locations in Yobe State, including their surface area and pore volume.

Table 2: BET Analysis of Soil Samples

Sample locations	Surface area	Pore size volume
Karasuwa	424.815m^2/g	0.123cc/g
Gashua	475.095m^2/g	0.120cc/g
Machina	352.490m^2/g	0.119cc/g
Nguru	380.076m^2/g	0.096cc/g
Jakusko	356.276m^2/g	0.115cc/g

The BET analysis showed that the Gashua sample had the highest specific surface area among the five samples. A larger surface area provides more space for surface reactions, which may be useful during material processing. However, surface area alone is not enough to determine the suitability of a material for photovoltaic applications. Other factors, including optical, thermal, electrical, stability, and processing properties, should also be considered. Therefore, the Gashua sample shows good potential, while the other samples may also be suitable. Further analysis is needed to determine their overall suitability for PV cell production.

4.0 Conclusion

High-purity silica (SiO_2) obtained from quartz sand is an important raw material for producing silicon used in photovoltaic (PV) cells. Although Nigeria has abundant silica sand deposits, the country still depends largely on imported PV materials. Developing local silica resources could help reduce production costs, improve energy security, and support local industrial development.

This study investigated the silica content and properties of soil samples collected from Nguru, Karasuwa, Gashua, Jakusko, and Machina in Yobe State, Nigeria, using XRD, EDXRF, SEM, and BET analyses. XRD confirmed the presence of quartz (SiO_2) in the samples, with Karasuwa showing the strongest quartz peak at about 4000 cps, while Gashua recorded the lowest at about 2000 cps. EDXRF further confirmed SiO_2 in all five samples, with the highest concentration of 77.75% recorded in Karasuwa. BET analysis showed that Gashua had the highest specific surface area of 475.095 m^2/g, while SEM revealed porous structures with irregular and rough particle surfaces.

These results show that the Yobe State sand samples, particularly Karasuwa in terms of SiO_2 content and Gashua in terms of surface area, have potential as local sources of silica for photovoltaic applications. However, the results do not by themselves confirm that the materials are suitable for direct solar cell production.

5.0 Recommendation

Further work is needed to determine the level of impurities and assess the thermal, electrical, and optical properties of the extracted silica. Such studies will be important for establishing whether the sand can meet the purity and performance requirements for large-scale PV material production.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) used Grammarly in order to proofread the manuscript. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

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