

## Assessment of the Potential and Impact of Solar Energy Utilization for Sustainable Land-Use Development in Sokoto State

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Received: 23/07/2025

Revised: 13/08/2025

Accepted: 2/01/2026

Fossil fuels are widely used for transport, electricity, and industries, but their extraction and use cause serious environmental damage and health problems due to resource depletion and increased CO<sub>2</sub> emissions. In response, this paper examines the potential and impact of using solar energy to support sustainable land-use development in Sokoto State, Nigeria. This study adopts a geospatial approach using Sentinel 2 satellite imagery to analyse land-type classification and land-cover patterns and to identify suitable sites for photovoltaic (PV) solar energy development. Supervised land-cover classification was conducted to delineate five land-use categories, agricultural land, bare land, vegetation, settlements, and rivers, while classification accuracy was validated using high-resolution reference imagery. The result revealed that approximately 1,603,281 hectares of bare land are suitable for large-scale solar installations, with an overall classification accuracy of 92%, indicating high data reliability. Additionally, Sokoto State records high solar irradiance levels averaging 5.5-6.0 kWh/m<sup>2</sup>/day, further strengthening its suitability for solar energy deployment. The finding demonstrates that solar energy development in Sokoto State can significantly enhance energy security, promote sustainable land use and, support environmental sustainability. The study concludes that Sokoto State possesses substantial solar energy potential and recommends the establishment of supportive policy frameworks, strengthened public-private partnerships, and active community participation to facilitate large-scale solar energy adoption.

**Keywords:** Solar Potential and Impact, Sentinel-2 Satellite Imagery, Land Use, Renewable Energy, Sustainable Development, Sokoto

### Introduction

Global electricity demand is projected to increase by about 3.3 percent in 2025, with a strong upwards trend that is expected to push total global electricity consumption to over 29,000 terawatt-hours by 2026 (IEA, 2025). This global increase in the electricity consumption calls for transition to a cleaner energy mix and limit global warming to 1.5°C above pre-industrial levels, as outlined in international climate agreements. By 2030, electricity is projected to account for nearly 30% of global final energy consumption with current policy pathways, driving by increasing electrification across major sectors (IEA, 2024). The growing global economy and the corresponding demand for heating, cooling, and industrial processes are key drivers behind this increase in energy consumption.

Traditionally, fossil fuels, coal, oil, and natural gas, have been the mainstay of global energy production. In 2018, fossil fuels accounted for about 70% of global energy demand, contributing to a 1.7% rise in carbon dioxide (CO<sub>2</sub>) emissions (Jungcurt, 2019). Fossil fuel-based energy is integral to various sectors, from transportation to electricity generation and industrial production. The extraction, refinement, and utilisation of fossil fuels have substantial environmental and public health repercussions due to the emission of considerable volumes of greenhouse gases, such as CO<sub>2</sub>, which exacerbate climate change and disrupt ecosystems

(Institute for Environmental Research and Education, 2025; Environmental Literacy Council, 2024). The processes involved in fossil fuel extraction and refining further lead to the degradation of habitats and the contamination of water resources (Institute for Environmental Research and Education, 2025), while the air pollution resultant from fossil fuel consumption is associated with respiratory and cardiovascular ailments, as well as millions of premature fatalities on a global scale (Environmental and Energy Study Institute, 2021; Global Science Research Journals, 2025).

Nigeria, with a population of over 216 million (NBS,2022) and a landmass of 910,800 square kilometres, faces a dual challenge of energy deficiency and environmental degradation (Worldometer, 2021; Chien *et al.*, 2021). In 2020, Nigeria set ambitious national electricity targets of 40 GW, aiming to increase capacity to 77,450 MW by 2025 and 119,200 MW by 2030 (Falobi, 2019). Despite these targets, the country faces a severe energy shortfall, with approximately 60% of the population, around 74 million people, lacking access to electricity and a staggering 94% (171 million) without access to clean energy (Popoola & Adeleye, 2020). The reliance on fossil fuel-based generation and inadequate grid infrastructure further increases the country's environmental problems, including land degradation, deforestation, and air pollution (World Bank, 2022).

For Nigeria to achieve economic stability and development, reliable and sustainable energy sources are paramount. Energy plays an important role in all facets of human survival, from domestic use to industrial production and infrastructure development (Ogundipe *et al.*, 2020a). However, the continued reliance on fossil fuels will only impact environmental challenges. Transitioning to renewable energy (RE) sources such as solar, wind, and biomass presents a viable pathway for Nigeria to reduce its carbon emissions while addressing its energy deficit. Renewable energy, particularly solar power, has immense potential in Nigeria, especially in regions like Sokoto State, which experiences high solar radiation levels.

Despite the clear benefits of renewable energy, its implementation is challenging. Renewable energy infrastructure, especially for large-scale solar and wind projects, requires vast expanses of land. According to Chigbu (2021), land is a contentious resource that plays a multifaceted role in socio-economic development. It is critical for agriculture, human settlement, and economic production. The increasing demand for land to accommodate renewable energy projects often leads to conflicts, especially in regions where land tenure systems are poorly regulated or where there is competition for land use between agriculture, infrastructure, and human settlements (Kiesecker *et al.*, 2019). This is particularly relevant in African countries like Nigeria, where land tenure insecurity, inefficient land governance, and ineffective land administration systems complicate access to land (Chigbu & Babalola, 2025).

Sokoto State located in the semi-arid region of north-western Nigeria, offers favourable climatic conditions for renewable energy development, particularly solar power, due to its high solar irradiance, averaging over 6.5 kWh/m<sup>2</sup>/day, which positions it among the Nigerian states with the most significant solar energy potential (Sokoto State PPP Platform, 2025). Despite this potential for clean energy generation, land use in the state is shaped by competing demands from agricultural expansion, settlement growth, and natural ecosystem dynamics, which can lead to land-use pressures and ecological changes over time (Jibrillah *et al.*, 2023). These competing interests call for the need for integrated land-use planning and management to balance renewable energy development with food production, environmental conservation, and the socio-economic needs of local communities. This study therefore aims to evaluate the potential impact of solar energy development on land use patterns in Sokoto State, Nigeria. Using Sentinel-2 satellite imagery and land cover classification techniques, the research identifies suitable areas for solar projects and assesses the implications of such developments on existing land use and sustainable development in the region.

## Renewable Energy and Potential in Nigeria

The quest for sustainable energy solutions is paramount for nations striving for economic development and environmental sustainability. Energy is crucial in driving industrial activities, transportation, healthcare, education, and communication (WEF, 2025). As global energy demands rise, so too do concerns about carbon emissions. The atmospheric concentration of CO<sub>2</sub> has increased by approximately 50% since the pre-industrial era, now exceeding 422.03 parts per million in 2024 (NOAA, 2025). This alarming trend highlights the urgent need for cleaner energy sources to mitigate climate change and reduce the health impacts associated with traditional energy consumption. Indoor air pollution, primarily from inefficient energy use, contributes to a global disease burden, causing approximately 3.8 million premature deaths annually (Ranathunga *et al.*, 2019; Bu *et al.*, 2021). The challenges posed by political, economic, environmental, and social factors have catalysed interest in renewable energy sources. Literatures emphasise the need for diverse, sustainable energy systems to enhance energy security, protect ecosystems, promote regional development, and ensure long-term energy stability (Mardani *et al.*, 2015; Martin, 2016). The United Nations Sustainable Energy for All initiative (SE4All) aims to facilitate universal access to modern energy services by 2030, advocating for balanced land-use strategies to accommodate renewable energy infrastructure.

Nigeria has substantial renewable energy potential and covers a total land area of approximately 923,768 square kilometres, making it one of the largest countries in Africa in terms of size (World Bank Group, 2024; United Nations Statistics Division, 2023). The country's climate varies significantly from south to north, with the northern region characterised by hot, semi-arid to arid conditions, where temperatures often rise well above the national average, while the southern region experiences a more humid and tropical climate with relatively milder temperatures (World Bank Group, 2024; Climate-Zone.com, 2025). This climatic diversity and geographical factors, such as desertification and runoff, present significant opportunities for developing Photovoltaic (PV) solar power (Milbrandt *et al.*, 2014). Marginal lands, defined as areas with limited agricultural productivity and little value for conventional crop production, are increasingly identified as suitable locations for solar energy installations, offering the dual advantage of expanding renewable energy generation while avoiding competition with prime farmland and helping to optimise land use. (Centre for Rural Affairs, 2025; Sustainability-Directory, 2025).

Existing studies indicate that solar energy could contribute significantly to Nigeria's energy mix, potentially reducing reliance on fossil fuels (Adaramola & Markal, 2015). Recent advancements in solar

technology have led to decreased costs, enhancing the feasibility of large-scale solar projects (IRENA, 2020). However, barriers such as inadequate infrastructure, financing challenges, and regulatory hurdles remain significant obstacles to the widespread adoption of solar energy (Nwafor, 2021). Comparative analyses with countries like India and Kenya demonstrate the importance of robust policy frameworks, public-private partnerships, and community engagement in overcoming these challenges and promoting renewable energy uptake (Raina & Sinha, 2019).

### **Land Accessibility in Nigeria**

Land accessibility is an important determinant of economic development and resource utilisation, and a source of material wealth which also plays a vital role in producing biomass, food, and renewable energy (Udoekem *et al.*, 2014; Oladehinde *et al.*, 2018). In Nigeria, land access and ownership are influenced by a complex interplay of actors, including government entities, community leaders, families, and estate agents (Oluwatayo *et al.*, 2019). The Land Use Act of 1978, which governs land tenure in Nigeria, centralised land administration under state control, complicating access for local communities and hindering investment in renewable energy projects (Ogunlela *et al.*, 2016). The spatial requirements for solar power generation are substantial, with estimates suggesting that 5 to 10 acres are necessary to generate just 1 megawatt (MW) of solar energy (SEIA, 2021). The rapid growth of Nigeria's population, projected to reach over 400 million by 2050, bring about competition for land resources, leading to increased urbanisation and land consumption (Fmhud,2024).

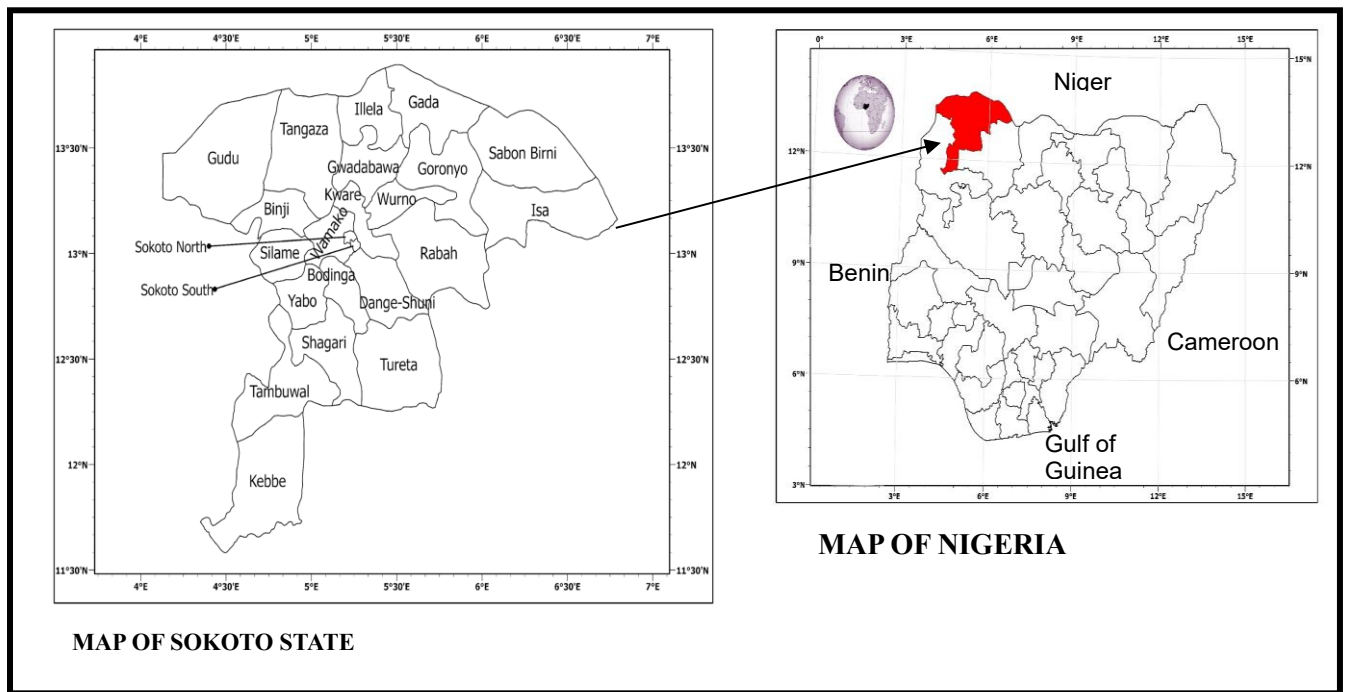
Gandapa (2018) utilised remote sensing and GIS techniques to assess land-use changes in the Hong Local Government Area of Adamawa State, revealing that land-use categories such as agricultural land, built-up areas, and vegetation cover are dynamically influenced by population growth. The analysis showed that agricultural land decreased significantly, emphasising the need for sustainable land management practices that accommodate the growing demand for energy infrastructure without compromising food security or environmental integrity. Incorporating advanced technological approaches such as remote sensing and GIS allows for comprehensive monitoring and analysis of land use patterns and resource depletion. Studies have demonstrated that these tools can effectively classify satellite imagery, facilitating better understanding and

management of land resources (Al-Ahmadi & Hames, 2008). The implementation of these technologies is crucial for developing strategies that align land use with renewable energy initiatives, ensuring that areas unsuitable for agriculture are identified and leveraged for solar energy projects (Amna, Shabbir, Ahmad, & Aziz, 2015; Rahaman, Aruchamy, Balasubramani, & Jegankumar, 2017; Nitheshnirmal, Rahaman, Balasundareshwaran, Nivedita Priyadarshini, Balasubramani, & Kumaraswamy, 2017).

### **Study Area Sokoto State**

Sokoto State is located in the north-western region of Nigeria, between latitudes 10° to 14° North and longitudes 4° to 7° East. The state encompasses a total area of 28,232.37 square kilometres and, as of 2021, has a population of 5,307,154, according to the National Population Commission (NPC, 2021). The region is characterised by a hot climate, with an annual average temperature of 28.3°C. During the warmest months, typically from February to April, daytime temperatures can exceed 45°C, while the cold season (October to February) is marked by the harmattan, which brings dry winds and Saharan dust. The state's arid conditions, high solar irradiance, and relatively low land cover density make it an ideal candidate for solar energy development. Sokoto State, located in the semi-arid zone of north-western Nigeria, has favourable conditions for solar energy development due to consistently high solar irradiance levels that exceed national averages, making it well-suited for photovoltaic generation (Salihi *et al.*, 2024). The state has recorded both grid-connected and off-grid solar initiatives, including a 60-kW solar PV plant in Torankawa that supplies electricity to households and small businesses, demonstrating the feasibility of integrating solar power into the local energy mix. In addition, planned investments such as the proposed 55 MW solar power project are expected to strengthen grid capacity, reduce reliance on fossil-fuel backup systems, and support rural electrification through mini-grid solutions (Sokoto State PPP Platform, 2025).

The agricultural activities are mainly concentrated in the floodplains of the Sokoto-Rima River system, leaving significant portions of land underutilised. These characteristics position Sokoto as a strategic location for exploring the potential impacts of solar energy deployment on land use patterns (Figure 1).



**Figure 1: Nigeria Showing Sokoto State.**

Source: Urban and Regional Planning Department, FUT, Minna (2025)

## Materials and Methods

### Sources of data

Data for this study was retrieved from secondary sources. The secondary sources include, books, journal articles, government databases, online repositories and satellite imageries. The study utilises Sentinel-2 satellite imagery, through the European Space Agency's Copernicus program. Sentinel-2, with its 13 spectral bands (see Table 1), provides detailed spatial resolution ranging from 10m to 60m, enabling high-precision

terrestrial observations. As demonstrated in prior studies, the dataset supports various applications, including land cover change detection and urban planning (Marangoz *et al.*, 2017). Level 2A Sentinel-2 images, captured on October 22, 2020, one of the driest periods of the year, were selected for this study. This date was chosen to optimise the detection of bare land and other land cover features due to minimal vegetation cover.

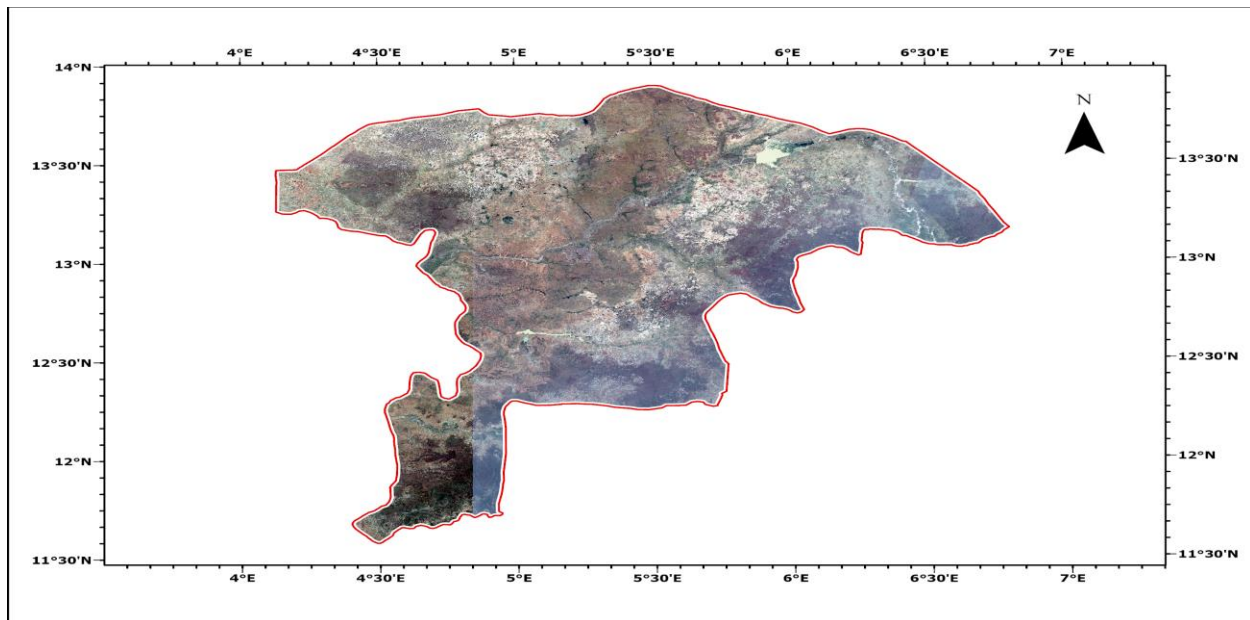
**Table 1: Sentinel-2A Band Specifications**

Band	Wavelength (nm)	Spatial resolution (m)	Application
1	0.443	60	Aerosol correction
2	0.490	10	Human-made features, forest mapping
3	0.560	10	Differentiating clear/muddy water
4	0.665	10	Vegetation, soil, urban features
5	0.705	20	Vegetation chlorophyll content
6	0.740	20	Plant water stress detection
7	0.783	20	Vegetation, forest monitoring
8	0.842	10	Vegetation monitoring
8a	0.865	20	Chlorophyll absorption, vegetation
9	0.945	60	Water vapour absorption
10	1.375	60	Cirrus clouds detection
11	1.610	20	Snow/ice detection
12	2,190	20	Soil and vegetation moisture

For this study, Bands 2, 3, and 4 (10 m spatial resolution) were primarily utilised to generate a natural colour composite image of Sokoto State (Figure 2), which facilitated the differentiation and classification of various land cover types. The image acquired on 22 October 2020 was selected because of the relatively low

vegetation cover during the post-rainy season, which enhances the visibility of surface features. While early harmattan haze can influence atmospheric clarity in northern Nigeria, the selected imagery exhibited minimal atmospheric distortion, and standard pre-processing procedures were applied to reduce potential

haze effects and ensure acceptable image quality for land-cover analysis.

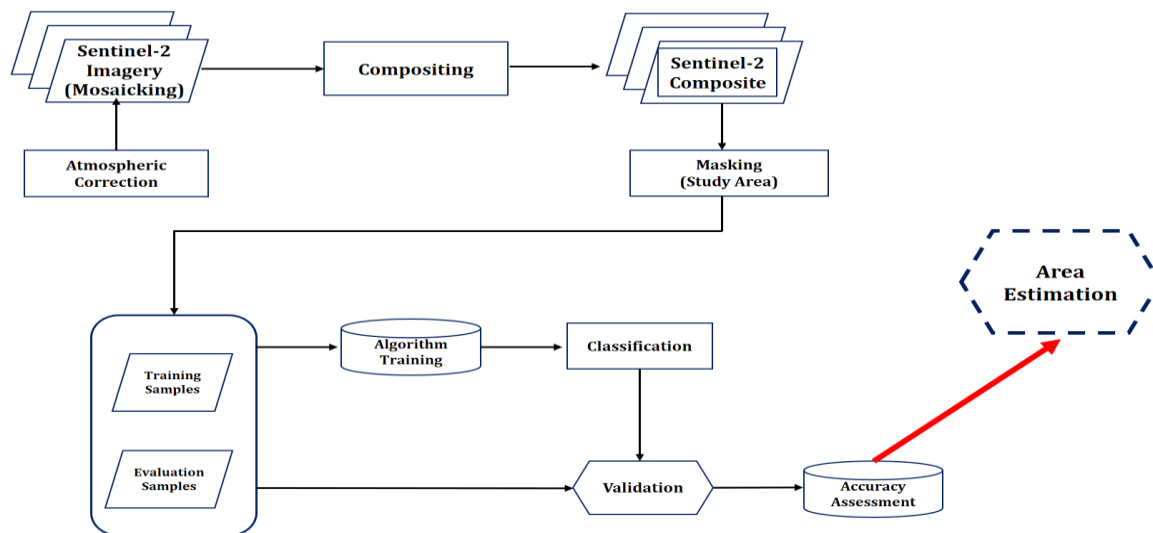


**Figure 2: Natural colour composite (RGB 4-3-2) Sentinel 2 Imagery for Sokoto State**  
 (Imagery Date: October 22, 2020)

### Methodological framework

The methodological framework in Figure 3, outlines the Sentinel-2 images using supervised classification techniques. This includes mosaicking, composite

creation, masking, training sample selection, and classification using the Maximum Likelihood Classifier (MLC).



**Figure 3: Flowchart of the Applied Methodology**

### Pre-processing

Pre-processing involved mosaicking 16 overlapping raster scenes of Sokoto State using the Raster Analyst Tool in ArcGIS Pro to create a seamless dataset for land cover analysis. A natural colour composite was generated by combining Bands 4, 3, and 2 (Environmental Systems Research Institute, 2020), enabling clear visual discrimination of vegetation, water

bodies, settlements, and exposed surfaces for training sample collection. The imagery was further refined by masking the administrative boundary of Sokoto State to restrict the analysis to the study area. Land type classification was then conducted using a supervised approach with the Maximum Likelihood Classifier (MLC) algorithm in ArcGIS. Five land classes, Bare Land, Settlement, Vegetation, Agricultural Fields, and

Waterbody, were adopted, drawing conceptually from standard Land Use/Land Cover (LULC) classification frameworks such as those recommended by the FAO, while being simplified to reflect the dominant land-use

patterns and renewable-energy planning needs of the Sokoto environment (see Table 2). The classifications were visually inspected and validated using ancillary data to ensure the accuracy and relevance of the identified land cover types.

**Table 2: Land Cover Classification**

Land Cover Class	Definition	Spectral Characteristics
Bare Land	Potential sites for solar installations due to minimal existing use.	High reflectance in red bands
Waterbody	Rivers and lakes may act as natural boundaries or constraints for solar development.	Low reflectance in NIR, high in blue
Settlement	Areas that may pose constraints for solar development due to population density and infrastructure.	Mixed spectral response, brownish
Vegetation	Includes both natural and agricultural vegetation, which could be impacted by land conversion for solar projects.	High reflectance in NIR, dark green
Agricultural Fields	Cultivated lands, typically seasonal crops	Moderate reflectance in red, distinct patterns

*Training samples and pixel-based classification*

Supervised classification requires representative training samples for each class; therefore, 20 training samples per class were selected using the Training Samples Manager based on visual interpretation, spectral consistency, and expert knowledge of local land-use characteristics. This sample size was considered statistically sufficient given the relatively homogeneous spatial structure of Sokoto State's landscape and is consistent with standard practice in medium-resolution (10 m) satellite image classification. Potential misclassification between bare land and agricultural fields, particularly during the dry season when croplands may appear spectrally similar to exposed soil, was mitigated through careful visual inspection, contextual analysis of field patterns, and the use of ancillary knowledge of cultivation zones. Based on the derived training signatures, the MLC algorithm assigned each pixel to the land-use class with the highest probability, producing a classified map suitable for assessing land-use dynamics and the implications of solar energy development.

*Accuracy assessment*

An accuracy assessment was conducted using a confusion matrix to compare the classified land-use map with reference data, providing a basis for validating the classification's reliability. The evaluation produced an overall classification accuracy exceeding 80% with a Kappa coefficient above 0.75, indicating strong agreement beyond chance and confirming the suitability

of the classification results for subsequent land-use and solar energy impact analyses. Detailed accuracy statistics are presented in the results section.

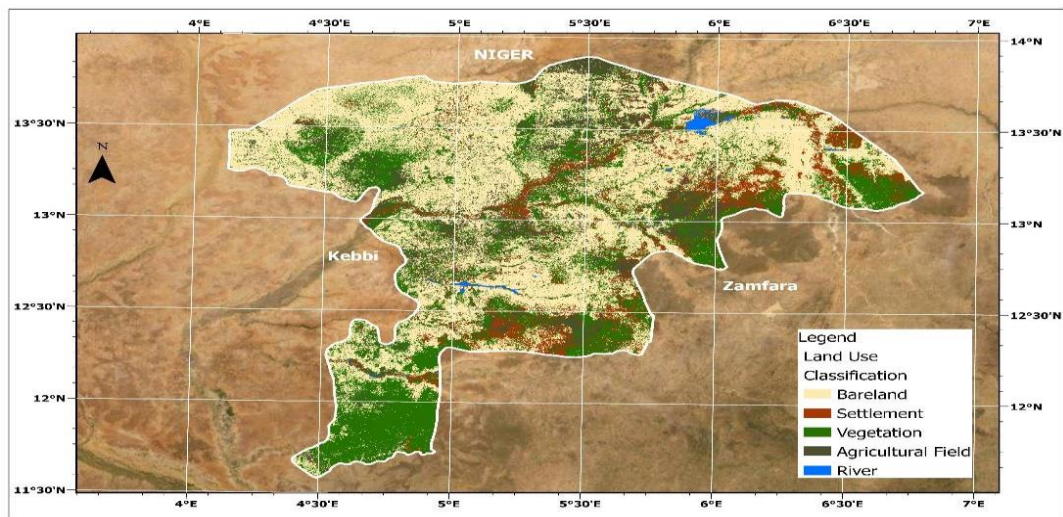
**Results and Discussion**

**Land type classification analysis**

This section presents the results of the land classification and solar energy suitability analysis for Sokoto State. The findings reveal extensive areas of suitable land for solar development, predominantly within the bare land category, with high solar irradiance and limited conflict with existing agricultural and settlement uses. These spatial patterns provide a strong basis for identifying priority zones for solar installations while accounting for environmental and socio-economic constraints.

*Land type classification map*

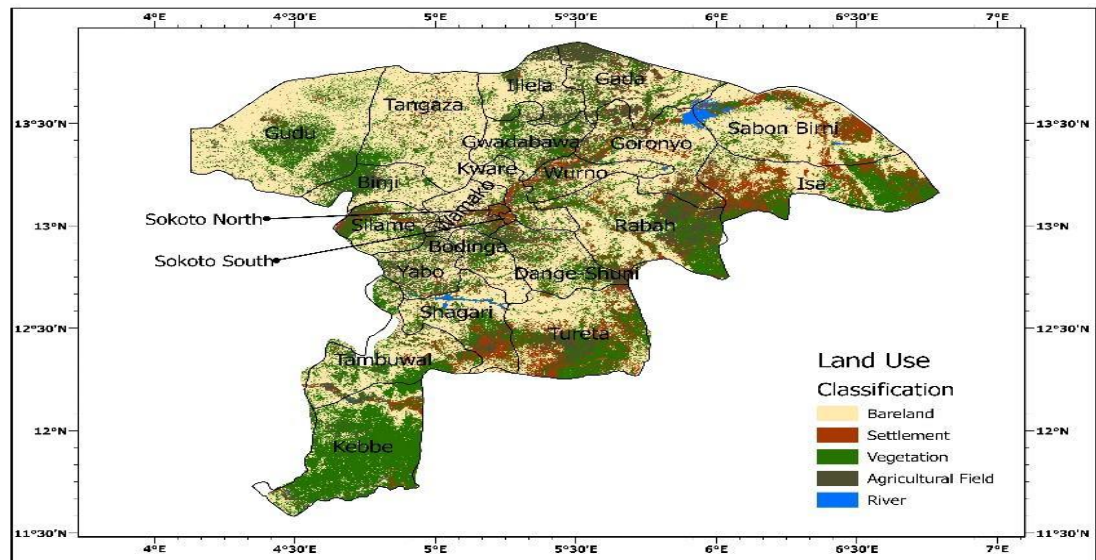
Figure 4 illustrates the spatial distribution of land classes across Sokoto State, revealing a clear dominance of *bare land*, particularly in the central and northern parts of the state, which reflects the semi-arid environmental conditions and sparse vegetation cover. Agricultural fields are primarily concentrated in the southern and riverine zones, where access to water and relatively fertile soils support cultivation. Meanwhile, vegetation is distributed in fragmented patches, mainly along river corridors and in protected areas. Settlements exhibit a clustered pattern around major urban centres and transport corridors, indicating the influence of infrastructure on land-use organisation, whereas rivers and water bodies are spatially limited and largely confined to specific drainage networks.



**Figure 4: Land Type Classification Map of Sokoto State**

Figure 5, which overlays Local Government Area (LGA) boundaries, highlights pronounced intra-state variations in land type composition. Several LGAs are characterised by extensive contiguous bare land with minimal settlement or agricultural interference, suggesting high suitability for large-scale solar energy development with limited land-use conflict. In contrast, LGAs with higher proportions of agricultural fields and

areas of settlement expansion exhibit more constrained opportunities for solar installations, underscoring the need for context-specific planning approaches. These spatial contrasts demonstrate that the solar energy potential in Sokoto State is not uniformly distributed, reinforcing the importance of LGA-level analysis for targeted renewable energy planning and sustainable land-use management.



**Figure 5: Land Type Map with Local Government Area Boundaries**

*Quantification of land type classes*

The quantified area of each land type class is presented in Table 4. The table shows the cell count and the corresponding area in hectares for each class, highlighting the extent of land cover types across Sokoto State. The formula used for calculating the area in hectares is as follows:

$$\text{Area (ha)} = N \times (10\text{m} \times 10\text{m}) \div 10,000$$

where  $N$  represents the number of raster cells (cell count)

The area of each land-use class was calculated by multiplying the number of raster cells by the pixel area (10 m × 10 m) and converting square metres to hectares by dividing by 10,000

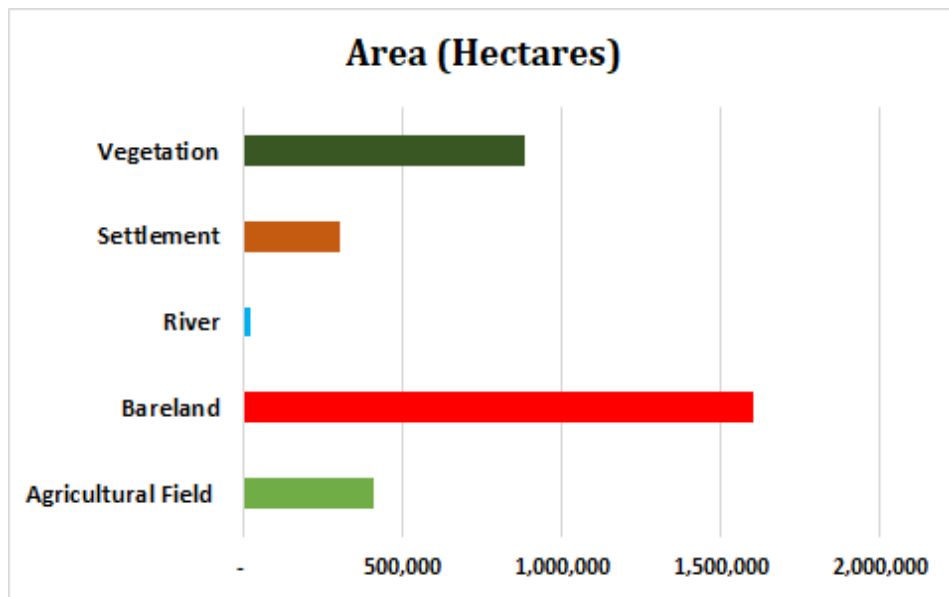
**Table 4: Quantification of Land Type Classes**

Class Name	Cells Count	Area (Hectares)	Percentage of Total (%)
Agricultural Field	40,672,400	406,724	12.6
Bareland	160,321,840	1,603,218	49.8
River	2,084,455	20,845	0.6
Settlement	30,144,330	301,443	9.4
Vegetation	88,483,186	884,832	27.5
<b>Total</b>	-	<b>3,217,062</b>	<b>100.0</b>

The "Bareland" class, covering approximately 1,603,218 hectares, constitutes the largest land type in the state. This significant expanse of unused land presents a prime opportunity for solar energy

development, subject to further suitability analysis and environmental considerations.

Figure 6 provides a graphical representation of the area covered by each land type class, illustrating the relative proportion of each category.



**Figure 6: Hectares Covered by Each Land Type Class**

*Suitability analysis for solar energy development*

To evaluate the suitability of land for solar energy development in Sokoto State, a GIS-based multi-criteria analysis was conducted by integrating spatial patterns of solar irradiance (Figure 7b) with classified land type characteristics (Figure 8a) and accessibility considerations. The study adopted a weighted overlay approach in which all criteria were standardised to a common scale and assigned relative weights based on their influence on photovoltaic feasibility. Solar irradiance was given the highest weight (50%) due to its direct control over energy generation potential, as reflected in Figure 7b, which shows consistently high irradiation values across much of the local government areas, with slightly stronger gradients in the northern and central zones. Land characteristics derived from the classification map (Figure 7b) were incorporated with a weight of 20%, prioritising extensive bare land areas while constraining agricultural fields, vegetation, settlements, and river corridors to reduce land-use conflict. Proximity to infrastructure, particularly major

roads and existing transmission lines, was weighted at 30% to account for construction and power evacuation costs, with areas within a 10 km buffer considered more favourable.

Environmental and social constraints, including river buffers, dense settlements, and protected or ecologically sensitive areas, were treated as exclusionary layers and removed from the suitability model to minimise environmental degradation and socio-economic disruption. These constraints collectively account for approximately 15–20% of the state's total land area. The resulting composite suitability map (Figure 7b) delineates Sokoto State into three classes: high, moderate, and low suitability. High suitability zones, covering roughly 45–50% of the state, are spatially concentrated in extensive areas of bare land that coincide with high solar irradiance values and relatively low land-use competition. Moderate suitability zones (approximately 30–35%) largely overlap with agricultural and mixed vegetation landscapes, where solar development may be feasible under controlled or

hybrid land-use arrangements. Low suitability and excluded zones (approximately 15–20%) correspond mainly to settlements, river networks, and environmentally sensitive areas. Overall, the combined interpretation of Figures 8a and 7b demonstrates that

Sokoto State possesses substantial, spatially concentrated opportunities for solar energy development, while also highlighting the necessity of targeted, environmentally responsible planning to guide sustainable deployment.



Figure 7a: GIS-based AHP Workflow for Solar Energy Suitability Assessment of Sokoto State

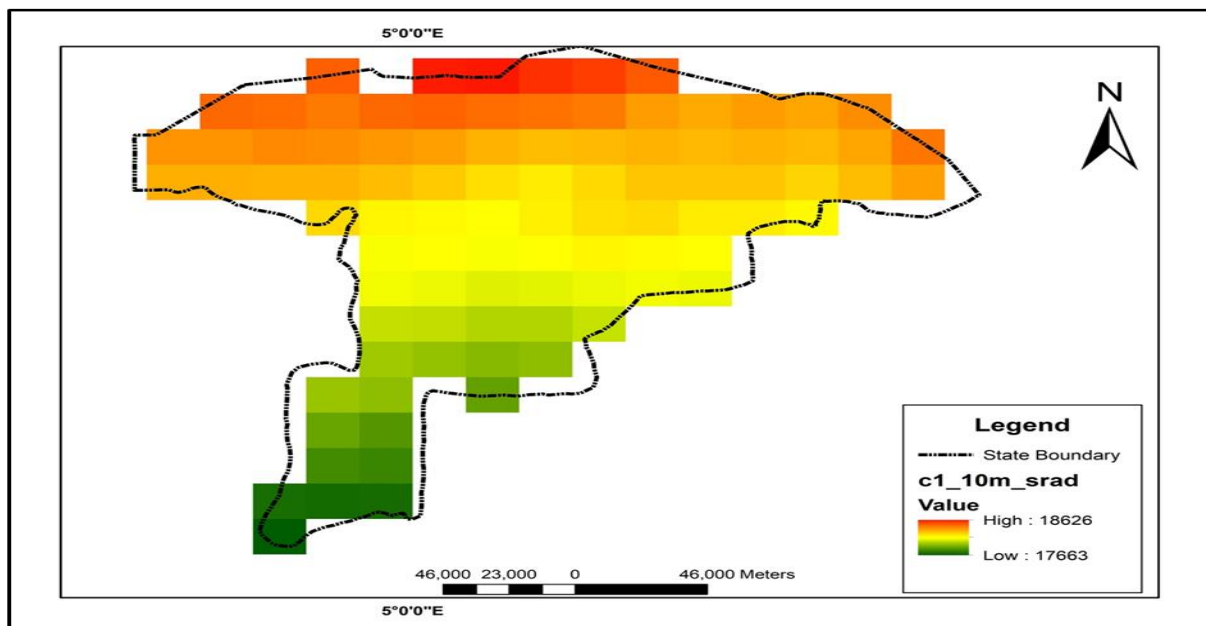
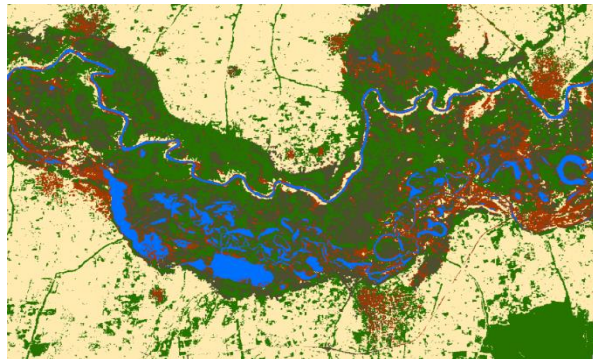


Figure 7b: Solar Energy Suitability Map of Sokoto State

*Comparative analysis with high-resolution imagery*  
 A comparative analysis was performed using high-resolution images from Google Earth Pro to validate the classification results. Figure 8 juxtaposes the land use classification results (Figure 8A) with Google Earth satellite imagery (Figure 8B), demonstrating high accuracy in the classification process.

The accuracy assessment revealed an overall classification accuracy of 92%, indicating that the land use classes were correctly identified in most instances. This high accuracy level supports the classification's reliability for further land use planning and solar energy suitability analysis.



A. Classification Analysis Result



B. Google Earth Satellite Imagery

**Figure 8: Comparison of Land Use Classification with High-Resolution Imagery**

### Findings

The results indicate that Sokoto State has substantial potential for solar energy development, particularly in the "Bareland" areas. With 1,603,218 hectares of underutilised land, Sokoto State can host large-scale solar projects that could significantly contribute to Nigeria's renewable energy goals, specifically through photovoltaic (PV) solar installations. This finding aligns with Milbrandt *et al.* (2014) who highlighted that marginal lands could support the country's transition to a clean energy economy while reducing pressure on valuable agricultural and residential lands.

Given the vast availability of bare land and the high solar irradiance levels in Sokoto State, the region is well-positioned to become a hub for solar energy production. For instance, the Abengoa Mojave solar plant in California generates approximately 250 MW of electricity from a 7 km<sup>2</sup> area, demonstrating the efficiency and feasibility of such projects. Similarly, utilising marginal lands for solar energy production could transform Sokoto State into a leader in Nigeria's renewable energy sector, contributing to energy security and economic development.

### Conclusion

This study demonstrates that Sokoto State possesses substantial potential for solar energy development, driven mainly by the availability of extensive bare land areas and favourable solar irradiance conditions. The land classification and suitability analysis reveal that approximately 1,603,218 hectares of bare land are available, much of which coincides with zones of high solar suitability and limited land-use competition. These spatial characteristics position Sokoto State as a strategic location for photovoltaic (PV) solar deployment that can contribute meaningfully to Nigeria's renewable energy transition while avoiding encroachment on productive agricultural land and dense settlements.

The integration of solar irradiance patterns, land-use characteristics, and accessibility considerations further indicates that targeted, spatially informed planning is essential for maximising the benefits of solar development. Harnessing this potential will require coordinated investments in supporting infrastructure, particularly grid expansion and power evacuation facilities, alongside clear policy frameworks that encourage private-sector participation. Beyond energy generation, large-scale solar projects in Sokoto State offer broader socio-economic and environmental benefits, including employment creation, reduced greenhouse gas emissions, and enhanced regional energy security. Overall, the findings suggest that solar energy development in Sokoto State provides a viable pathway toward sustainable development, aligning with both national renewable energy objectives and global climate action commitments.

Based on the results, policy-relevant recommendations are proposed to advance solar energy development in Sokoto State. First, the State Government should prioritise large-scale photovoltaic investments within the identified high-suitability bare land zones, thereby utilising over 1.6 million hectares of underutilised land without displacing agricultural activities or residential areas. This can be achieved by integrating solar energy zoning into state and regional land-use plans, formally designating suitable marginal lands for renewable energy development. Second, targeted public-private partnerships should be strengthened to attract both domestic and international investors, supported by transparent land access mechanisms, fiscal incentives, and streamlined approval processes. Third, investments in grid reinforcement and transmission infrastructure are essential to ensure the efficient evacuation and distribution of generated solar power, particularly from high-suitability clusters. Finally, solar energy policies in Sokoto State should be aligned with national renewable energy targets and the Sustainable Development Goals to ensure that solar expansion contributes to job

creation, energy security, and sustainable economic growth while minimising land-use conflicts and environmental impacts.

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