



## **Monitoring Reservoir Formation Using Remote Sensing and Terrain Analysis: A Case Study of Gurara Reservoir**

### **Abstract**

A water reservoir is an enclosed area for the storage of water to be used at a later date (L. Votruba, V., Broža 1989). Reservoir systems play a critical role in water storage, irrigation, hydropower generation and climate resilience, particularly in semi-arid regions vulnerable to environmental change. This study explores the formation of the Gurara Reservoir in Kaduna State, Nigeria, between 2001 and 2010 using remote sensing imagery, Digital Elevation Models (DEM), and hydrological flow analysis. Landsat timelapse imagery revealed a major land cover transition from a natural drainage basin to a permanent water body following dam construction. Elevation and flow direction analyses further demonstrated how terrain morphology and hydrological pathways influenced water accumulation and reservoir expansion. Beyond visual landscape transformation, the study highlights the broader socioeconomic and environmental implications of reservoir development, including agricultural support, rural infrastructure growth, and ecosystem modification. The analysis also introduces an emerging research direction involving the integration of Artificial Intelligence (AI) and Earth Observation systems to predict future reservoir lifecycle changes under climate variability. The study demonstrates the importance of geospatial monitoring for understanding long-term land cover dynamics and supporting SDG 15.3.1 monitoring, climate adaptation planning, and predictive environmental intelligence systems.

### **1. Introduction**

Climate change and environmental degradation are increasingly reshaping landscapes across the

world. In many developing regions, reservoirs have become essential infrastructure for supporting water security, irrigation, hydropower generation, and community resilience. However, these systems are also highly sensitive to climatic shifts (Caelan Simeone, 2024), hydrological variability, and land cover change.

Remote sensing and geospatial technologies now provide the ability to monitor environmental transformations over time using satellite imagery and terrain analysis. These technologies are particularly important within the context of Sustainable Development Goal (SDG) 15.3.1, which focuses on monitoring the proportion of degraded land relative to total land area. One of the key indicators used in SDG 15.3.1 assessment is land cover change, which helps identify how landscapes transition over time due to natural or human-induced processes (UNCCD Good Practice Guidance, 2025).

This study investigates the formation of the Gurara Reservoir in Kaduna State, Nigeria, through geospatial analysis of landscape transformation between 2001 and 2010. By integrating Landsat imagery, DEM analysis and hydrological flow mapping, the study demonstrates how terrain characteristics and water movement contributed to reservoir formation. Additionally, the research introduces the potential role of Artificial Intelligence (AI) in predicting future reservoir lifecycle changes under evolving climate conditions.

### **2. Study Area**

The study focuses on the Gurara Reservoir located in Kaduna State, Nigeria. The reservoir is a valley-dammed reservoir formed through the

43A Ruwan Godiya Street, Opposite Gwandu Plaza, U/Sarki, Kaduna, Nigeria

Website: <https://nestafrica.ai> Email: [info@nestafrica.ai](mailto:info@nestafrica.ai)



construction of a dam across a river channel, resulting in the flooding of the surrounding drainage basin.

Prior to reservoir formation, the landscape primarily functioned as a natural drainage basin influenced by surrounding elevated terrain and hydrological flow pathways. Following dam construction, the area transformed into a permanent water body that now supports multiple socioeconomic functions including water storage, agricultural activities, and regional development.

The surrounding terrain consists of varying elevation zones that strongly influence runoff accumulation and drainage direction, making the area suitable for hydrological and landscape transition analysis.

### 3. Data and Methodology

#### 3.1 Data Sources

The analysis utilized multiple geospatial datasets and Earth Observation products, including:

- Landsat satellite imagery for historical landscape monitoring and timelapse visualization between 2001 and 2010.
- SRTM Digital Elevation Model (USGS/SRTMGL1\_003) for terrain and elevation analysis.
- MERIT Hydro dataset (MERIT/Hydro/v1\_0\_1) for hydrological flow direction and drainage interpretation.
- Copernicus Global DEM (COPERNICUS/DEM/GLO30) for additional elevation and terrain characterization.

#### 3.2 Image Processing and Visualization

The Landsat timelapse visualization utilized the SWIR1 / NIR / Red band combination, which is particularly effective for distinguishing water

bodies, vegetation, moisture conditions, and land surface characteristics.

Within this spectral combination:

- water bodies appear in darker tones,
  - vegetation appears in green,
  - while exposed surfaces and dry land areas become more distinguishable.
- ### 3.3 Software and Analytical Tools

The study employed:

- Google Earth Engine,
- Earth Engine Python API,
- QGIS

#### 3.4 Analytical Approach

Satellite timelapse imagery was used to compare pre- and post-reservoir landscape conditions. Land cover transitions were visually interpreted to identify changes from natural drainage systems to permanent water bodies.

DEM analysis was conducted to understand elevation patterns and terrain influence on water accumulation. Flow direction analysis was further applied to identify the dominant hydrological pathways contributing to reservoir filling and expansion.

The combined analyses enabled interpretation of how terrain morphology, hydrology, and infrastructure development collectively transformed the landscape.

### 4. Results and Discussion

#### 4.1 Reservoir Formation and Land Cover Transition

The Landsat imagery revealed a major landscape transformation between 2001 and 2010. In 2001, the study area primarily consisted of a drainage basin with visible river pathways and surrounding vegetated terrain. By 2010, the construction of the dam had resulted

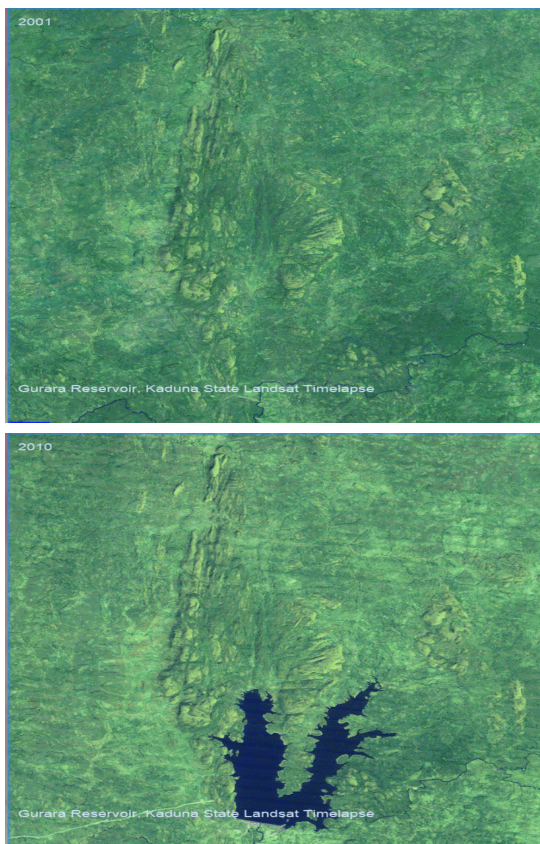
43A Ruwan Godiya Street, Opposite Gwandu Plaza, U/Sarki, Kaduna, Nigeria

Website: <https://nestafrica.ai> Email: [info@nestafrica.ai](mailto:info@nestafrica.ai)



in the formation of a permanent reservoir system.

This transition represents a significant land cover change from terrestrial surfaces to an artificial water body. Within SDG 15.3.1 monitoring frameworks, such transitions are important because they contribute to understanding long-term environmental dynamics and land condition changes.



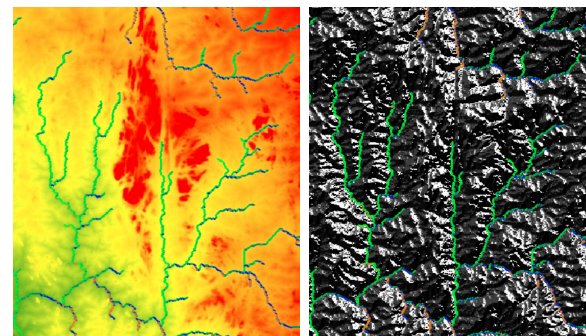
**Fig. 1.** From the top image, it displays the landscape view using landsat remote sensing data in **2001**, a sparse vegetation dryland before dam construction and reservoir formation in **2010** (image on the bottom).

#### 4.2 Terrain and Hydrological Influence

DEM analysis showed that surrounding

high-elevation zones (top region of the map) directed runoff toward lower valley regions where the reservoir eventually formed. The hydrological flow analysis further confirmed dominant drainage pathways feeding into the reservoir basin.

The findings demonstrate how terrain morphology plays a critical role in reservoir development and water accumulation processes. Valleys and natural drainage corridors created favorable conditions for reservoir expansion following dam construction.



**Fig. 2.** Water flow color codes - **1:** East (Green), **2:** Southeast (Teal), **4:** South (Blue), **8:** Southwest (Purple) - THE MAIN FLOW DIRECTION, **16:** West (Yellow), **32:** Northwest (Olive), **64:** North (Red), **128:** Northeast (Orange) - THE MOUNTAIN DIRECTION

#### 4.3 Environmental and Socioeconomic Implications

Reservoir systems provide multiple benefits to surrounding communities including irrigation and agricultural productivity, water storage, energy generation, fisheries and local livelihoods, and rural infrastructure development.

However, reservoir formation also alters ecosystems, hydrological balance, vegetation distribution, and land cover patterns over time.



Such environmental transformations emphasize the importance of continuous geospatial monitoring for sustainable environmental management.

### 5. Climate Intelligence and Future Research Direction

As climate variability intensifies, integrating Artificial Intelligence with remote sensing systems creates opportunities to move beyond environmental monitoring toward predictive climate intelligence.

This study raises an important research question: “If geospatial systems can explain how reservoirs form today, can AI help predict how climate change may influence their long-term survival in the future?”

Using Earth Observation data and machine learning techniques, future studies could model drought vulnerability, reservoir shrinkage, evaporation trends, flood risks, sedimentation patterns, and long-term water availability. Predictive environmental intelligence systems could help governments, agencies, and communities anticipate climate-related risks before critical infrastructure systems begin to fail.

Such approaches may contribute to improved climate adaptation planning, water governance, and sustainable land management strategies.

### 6. Limitations

This study was exploratory in nature and relied primarily on remote sensing interpretation and terrain analysis. The analysis did not incorporate in-situ hydrological measurements, sedimentation records, or long-term climate projection datasets.

Future studies should integrate climate models, rainfall and temperature datasets, reservoir depth measurements, and advanced AI predictive modeling approaches.

### 7. Conclusion

The study demonstrates how remote sensing and geospatial analysis can effectively monitor large-scale environmental transformations over time. The formation of the Gurara Reservoir between 2001 and 2010 illustrates the significant influence of terrain, hydrology, and infrastructure development on landscape evolution.

Beyond mapping environmental change, the study highlights the growing importance of combining AI, remote sensing, and climate analytics to support predictive environmental intelligence systems. As climate pressures continue to reshape water systems globally, understanding reservoir lifecycle dynamics may become increasingly important for resilience planning, SDG monitoring, and sustainable development.

Understanding how landscapes evolve is no longer only about observation; it is becoming essential for building predictive systems that help communities and institutions prepare for future environmental change.

### References

- [United Nations Convention to Combat Desertification \(UNCCD\). Good Practice Guidance for SDG Indicator 15.3.1.](#)
- [L. Votruba, V. Broža 1989 Water management in Reservoirs.](#)
- [Caelan Simeone, 2024. US water reservoirs are shrinking and becoming less reliable](#)
- [United States Geological Survey \(USGS\) Landsat Program.](#)
- [USGS Shuttle Radar Topography Mission \(SRTMGL1 003\).](#)
- [MERIT Hydro Global Hydrography Dataset \(MERIT/Hydro/v1 0 1\).](#)
- [Copernicus Global DEM \(COPERNICUS/DEM/GLO30\).](#)

43A Ruwan Godiya Street, Opposite Gwandu Plaza, U/Sarki, Kaduna, Nigeria

Website: <https://nestafrica.ai> Email: [info@nestafrica.ai](mailto:info@nestafrica.ai)