# The Role of Space-Based Data for Early Response to Emergencies in Nigeria

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## ABSTRACT

The increasing frequency, complexity, and economic costs of disasters worldwide have intensified global demand for robust early warning systems and rapid emergency response mechanisms. Advances in space-based technologies—including satellite imagery, synthetic aperture radar (SAR), remote sensing, and geographic information systems (GIS)—have fundamentally transformed disaster monitoring, situational awareness, and response coordination. In developing countries such as Nigeria, where natural and human-induced disasters including riverine flooding, desertification, oil spills, drought, and coastal erosion occur with alarming regularity, space-derived data offers critical opportunities to strengthen preparedness and response systems. This paper examines the role of space-based data in enhancing early emergency response in Nigeria. It evaluates the institutional structures responsible for disaster management and space technology, including the National Emergency Management Agency (NEMA) and the National Space Research and Development Agency (NASRDA), while analysing their integration within international frameworks such as the Sendai Framework for Disaster Risk Reduction (2015–2030) and the United Nations Platform for Space-based Information for Disaster Management and Emergency Response (UN-SPIDER). Drawing on empirical disaster events, geospatial monitoring practices, and recent peer-reviewed literature, the study demonstrates how satellite technologies—particularly NigeriaSat-1, NigeriaSat-2, Sentinel-1, Sentinel-2, and cloud-based platforms such as Google Earth Engine—enhance situational awareness, hazard monitoring, and emergency coordination. Key challenges including limited technical capacity, inadequate geospatial infrastructure, high cost of high-resolution imagery, and weak institutional integration are critically examined. The paper concludes by proposing strategic policy measures for integrating satellite-derived information into Nigeria's national disaster management framework, with implications for broader sub-Saharan African contexts.

**Keywords:** disaster management, satellite imagery, remote sensing, early warning systems, emergency response, Nigeria, GIS, NigeriaSat, Sendai Framework, UN-SPIDER

## INTRODUCTION

Disasters represent one of the most profound threats to sustainable development, human security, and economic stability across the globe. The United Nations Office for Disaster Risk Reduction (UNDRR) has documented a steady escalation in both the frequency and severity of climate-related disasters over recent decades, with the most reported events in a single year reaching 142 in 2023 alone, resulting in an estimated USD 280 billion in economic losses globally (Rolla et al., 2025; UNDRR, 2023). Developing nations, particularly those in sub-Saharan Africa, bear a disproportionate burden of disaster impacts, often suffering direct economic losses exceeding 3% of GDP—more than eleven times the global average—due to structural vulnerabilities including weak institutional capacities, inadequate infrastructure, and limited early warning systems (UNDRR, 2020).

The rapid advancement of satellite technologies and remote sensing systems has fundamentally transformed the field of disaster management. Space-based information now plays a crucial role in monitoring environmental hazards, predicting disaster events, and supporting emergency response operations at national

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and sub-national scales (Kugler & Tiede, 2020). Satellite-derived data allows decision-makers to monitor environmental changes across vast geographic areas and respond rapidly to emerging threats. The emergence of cloud-based geospatial platforms such as Google Earth Engine (GEE), combined with the availability of open-access satellite data from missions such as Sentinel-1 and Sentinel-2, has significantly democratised access to high-quality geospatial information for disaster risk management in the Global South (Akintola, 2024; Odiji et al., 2024).

Recognising the importance of space-based information for disaster risk reduction, the United Nations established the UN-SPIDER initiative in 2006 under the United Nations Office for Outer Space Affairs (UNOOSA), with the mandate to ensure that all countries—particularly developing nations—have access to space-based technologies for disaster risk reduction and emergency response (UNOOSA, 2006; UN-SPIDER/NASRDA/NEMA/ZFL, 2021). Nigeria's integration into this global architecture was formalised in 2009 when NASRDA signed a cooperation agreement with UNOOSA, designating it as a Regional Support Office for space-based disaster management solutions in Africa (UN-SPIDER/NASRDA/NEMA/ZFL, 2021).

Nigeria is among the most disaster-prone nations on the African continent, exposed to a diverse range of natural and human-induced hazards. The country is ranked among the top ten most vulnerable to climate change globally, with disaster manifestations including riverine and urban flooding, drought, desertification, coastal erosion, oil spills, and conflicts over natural resources (Butu et al., 2022; IPS News, 2024). The catastrophic 2022 flooding season—the worst ever recorded in Nigeria—killed at least 662 people, injured over 3,174 more, displaced approximately 2.5 million individuals, and destroyed more than 200,000 homes (IPS News, 2024; Nkeki et al., 2022). These recurring disasters underscore the urgent need for enhanced early warning systems and data-driven emergency response mechanisms.

The establishment of the National Emergency Management Agency (NEMA) in 1999 and NASRDA in 2001 marked major institutional steps toward strengthening Nigeria's disaster management and space technology frameworks. However, effective disaster response requires reliable, timely, and actionable information to guide decision-making across multiple levels of government. Space-based data, including SAR imagery, optical satellite imagery, and multispectral vegetation indices, offers transformative potential to address this information gap. This paper examines the role of satellite technologies in improving early response to emergencies in Nigeria and proposes strategies for strengthening the integration of space-based information into national disaster management systems in alignment with the Sendai Framework for Disaster Risk Reduction 2015–2030.

## LITERATURE REVIEW

### Remote Sensing and Disaster Management

Remote sensing refers to the collection of environmental information through sensors mounted on satellites, aircraft, or unmanned aerial vehicles (UAVs). These sensors capture electromagnetic signals reflected or emitted from the Earth's surface, enabling scientists and analysts to monitor environmental conditions across vast geographic extents without direct physical contact (Campbell & Wynne, 2011; Lillesand et al., 2015). The spectral, spatial, and temporal resolution of modern satellite sensors has improved dramatically over the past two decades, enabling near-real-time monitoring of environmental hazards at unprecedented levels of detail.

Remote sensing technologies have become indispensable tools in contemporary disaster management, primarily due to their capacity to provide large-scale environmental observations that are both timely and cost-effective. Satellite imagery can detect and map natural hazards such as floods, storms, wildfires, landslides, droughts, and volcanic activity with high precision, allowing emergency managers to coordinate response efforts more effectively (Rolla et al., 2025; Kugler & Tiede, 2020). The integration of remote sensing data with artificial intelligence (AI) and machine learning algorithms has further enhanced the precision and automation of hazard detection, damage assessment, and predictive modelling (Ghorbanzadeh et al., 2024).

Kugler and Tiede (2020) demonstrate that space-based Earth observations are now deeply integrated with volunteered geographic information systems such as OpenStreetMap, significantly augmenting the richness of geospatial data available for disaster response. Similarly, Ghorbanzadeh et al. (2024) show that AI-powered models, including convolutional neural networks (CNNs) and recurrent neural networks (RNNs), have demonstrated remarkable capabilities in feature extraction, anomaly detection, and predictive modelling using satellite-derived datasets, opening new frontiers for real-time disaster situational awareness.

**Space Technology and Early Warning Systems**

Early warning systems (EWS) are critical instruments for reducing disaster mortality and economic losses by enabling timely alerts to authorities and vulnerable communities. Effective EWS require continuous monitoring of environmental conditions and rapid, multi-channel dissemination of information to decision-makers and affected populations. The 2023 Midterm Review of the Sendai Framework identified the strengthening of multi-hazard early warning systems as one of the most urgent priorities for achieving global disaster risk reduction targets by 2030, particularly in least developed and developing countries where EWS coverage remains inadequate (UNDRR, 2023; International Science Council, 2023).

Space-based technologies play a pivotal role in modern EWS architectures by enabling continuous, synoptic monitoring of atmospheric conditions, land use changes, hydrological patterns, and sea surface temperatures. Meteorological satellites provide weather forecasts and storm tracking data that are foundational to flood forecasting and cyclone early warning. Environmental monitoring satellites, including ESA's Sentinel series and NASA's Landsat programme, enable detection of drought conditions through indices such as the Normalised Difference Vegetation Index (NDVI) and the Standardised Precipitation Index (SPI), as well as monitoring of water body extents using the Normalised Difference Water Index (NDWI) (Akintola, 2024; Nkeki et al., 2022).

The United Nations Secretary-General's Early Warnings for All initiative, co-led by UNDRR and the World Meteorological Organization (WMO), underscores the growing recognition that universal access to effective early warning systems is both a human right and an economic necessity (UNDRR, 2022). Space-based data is central to the achievement of this initiative, particularly for nations in Africa where ground-based meteorological network density remains insufficient for comprehensive hazard monitoring.

**Space-Based Technologies and Disaster Response in Africa**

The role of space technology in African disaster management has attracted increasing scholarly attention in recent years. Odiji et al. (2024) used multi-sensor satellite imagery and Google Earth Engine to conduct decadal mapping of flood inundation and damage assessment in the confluence region of Rivers Niger and Benue, demonstrating the power of long time-series satellite analysis for tracking the evolution of flood hazards. Their study confirmed that the 2022 flooding in this region was the most catastrophic on record, surpassing even the devastating 2012 floods in terms of spatial extent and affected population. The application of Sentinel-2 and Sentinel-1 SAR imagery enabled the detection of flooded cropland, buildings, and infrastructure with high spatial accuracy.

At the continental level, Kganyago and Mhangara (2019) analysed the role of African emerging space agencies in Earth observation capacity building, demonstrating that indigenous satellite programmes such as NigeriaSat-1 and NigeriaSat-2 have contributed meaningfully to regional disaster monitoring capacity when integrated within international frameworks such as the Disaster Monitoring Constellation (DMC). However, the authors noted persistent gaps in the translation of satellite data into actionable early warning products, primarily due to human capacity limitations and inadequate data dissemination infrastructure.

The integration of citizen science with satellite imagery for environmental monitoring has also emerged as a promising approach in the Nigerian context. A Land Pollution Lookout project examined 368 oil spill locations in Niger Delta wetlands between 2020 and 2022, with 250 trained participants contributing 834 labels to identify pipelines, spills, and vegetation damage using satellite images (Eyang et al., 2024). This citizen-science approach highlights the potential for participatory remote sensing to complement institutional monitoring in data-sparse or access-restricted environments.

## Disaster Risk Landscape in Nigeria

Nigeria occupies a geographically diverse and climatically variable territory extending from the humid tropical belt of the Niger Delta in the south to the semi-arid and arid zones of the Sahel in the north. This geographic diversity, combined with rapid population growth, widespread poverty, urbanisation without adequate planning, and accelerating climate change impacts, creates a complex and evolving multi-hazard landscape that challenges even well-resourced emergency management systems.

### Flooding

Flooding is the most frequent and economically devastating natural disaster in Nigeria (Nkeki et al., 2022; Odiji et al., 2024). Riverine flooding occurs predominantly along major river basins including the Niger and Benue rivers, while urban flooding is endemic across major cities due to inadequate drainage infrastructure and the proliferation of impervious surfaces. The 2022 rainy season produced what is widely considered the most catastrophic flood event in Nigerian recorded history, with above-average rainfall across Cameroon and northern Nigeria contributing to soil saturation, amplified by the controlled release of water from the Lagdo Dam in Cameroon, which dramatically raised water levels in the River Benue (Iyiola et al., 2022). Over 92% of Nigerian states were affected, displacing more than 2.5 million people and killing at least 662 (IPS News, 2024).

Satellite imagery provides critical information for monitoring flood inundation extents, identifying flood-prone communities, and supporting evacuation planning and relief logistics. Akintola (2024) developed an integrated framework leveraging Google Earth Engine for near-real-time flood mapping and impact analysis in the Niger River Basin, using multi-temporal optical, radar, and terrain data to quantify flood hazards and exposure across 150,000 km$^2$ during the 2022 peak floods. Results revealed over a 50% rise in inundation compared to historical medians, with 15,000 hectares of vegetation and 143,000 residents impacted.

### Desertification

Northern Nigeria is experiencing accelerating desert encroachment driven by the combined effects of climate change, population pressure, deforestation, and unsustainable agricultural practices. According to Action Against Desertification, only half of the forests that existed in northern Nigeria in 2007 remain today, with the trend projected to worsen under future climate scenarios (IPS News, 2024). Desertification threatens agricultural livelihoods, accelerates food insecurity, and drives internal displacement—particularly among pastoral communities—creating compound humanitarian emergencies.

Remote sensing technologies, particularly Landsat, MODIS, and Sentinel-2 imagery processed through cloud platforms such as Google Earth Engine, enable analysts to monitor vegetation loss, desert expansion, and land degradation over extended time periods. Machine learning techniques including random forest and gradient tree boosting classification algorithms have been shown to achieve high accuracy in mapping desertified areas and tracking land use change trajectories relevant to disaster risk (Ouali et al., 2026). Vegetation indices such as NDVI, the Enhanced Vegetation Index (EVI), and the Soil-Adjusted Vegetation Index (SAVI) derived from satellite data provide quantitative metrics for assessing desertification severity and forecasting drought conditions.

### Oil Spills in the Niger Delta

The Niger Delta region of southern Nigeria is one of the most severely oil-polluted environments on Earth, with an estimated 80,000 to 300,000 barrels per day spilled into the environment in recent years, valued at approximately USD 6 billion (Wekpe & Idisi, 2023). These spills result from a combination of pipeline vandalism by militant groups, operational failures, and ageing infrastructure, causing catastrophic damage to mangrove ecosystems, freshwater systems, agricultural land, and the health of local communities (Ansah et al., 2022; Obida et al., 2021).

Satellite remote sensing using SAR, optical, and multispectral imagery has emerged as the most practical and scalable methodology for detecting, mapping, and monitoring the spatial extent and environmental impact of oil spills in the Niger Delta. Ozigis et al. (2019) demonstrated the effectiveness of machine learning combined with Landsat 8 OLI imagery for mapping terrestrial oil spill impacts, while Wekpe and Idisi (2023) showed that vegetation health indices derived from PlanetScope satellite data—including NDVI, GRNDVI, and GNDVI—revealed significant and statistically robust declines in vegetation health following spill events, with contaminated landcovers exhibiting Spearman's correlation coefficients of -0.68 to -0.82 ($p < 0.005$). More recently, O'Farrell et al. (2024, as cited in Boateng et al., 2026) utilised Sentinel-1 time-series data from 2016 to 2024 with an XGBoost classification model to quantitatively assess oil spill impacts on mangrove ecosystems in the Niger Delta, demonstrating the applicability of SAR for cloud-prone tropical monitoring environments.

### Drought

Recurrent drought conditions affect agricultural productivity, food security, and water availability across northern Nigeria and parts of the middle belt. Satellite-derived meteorological and vegetation data, including SPI maps generated from gridded rainfall products, MODIS-derived land surface temperature, and NDVI anomaly composites, provide valuable inputs for drought monitoring, crop yield forecasting, and climate early warning systems (Akintola, 2024; Nkeki et al., 2022). The integration of these data products into national agricultural monitoring systems has the potential to provide up to several weeks of advance warning for severe drought conditions, enabling pre-emptive humanitarian response.

### Coastal Erosion

Nigeria's 830-kilometre coastline is among the most threatened in Africa, facing accelerating erosion driven by sea level rise, anthropogenic coastal modification, and increased storm intensity associated with climate change (Affiah, 2023; IPS News, 2024). The World Bank estimated in 2012 that erosion was affecting over 6,000 square kilometres of Nigerian land, with 3,400 square kilometres at high risk and annual damages from gully erosion exceeding USD 100 million. Remotely sensed data, particularly multi-temporal Landsat and Sentinel-2 imagery combined with digital elevation models (DEMs), enable systematic monitoring of shoreline change rates and identification of at-risk coastal communities. Affiah's (2023) study of coastal erosion in Akwa Ibom State documented an average linear regression rate of -2.7 m/year over 1984–2020, with rates accelerating to -3.94 m/year in the 2015–2020 period, highlighting the urgent need for continuous satellite-based coastal monitoring systems.

## Institutional Framework for Space Technology in Nigeria

### National Emergency Management Agency (NEMA)

The National Emergency Management Agency, established under Act No. 12 of 1999, is the principal federal agency mandated to coordinate disaster management activities across Nigeria. NEMA is responsible for formulating and implementing government policies on disaster preparedness, response, and recovery; coordinating federal, state, and local government emergency response operations; and managing internally displaced persons (IDPs) in conflict and disaster-affected areas. Raji et al. (2021) assessed NEMA's response capacity in northeastern Nigeria, identifying critical resource constraints, inadequate inter-agency coordination, and insufficient geospatial data utilisation as key impediments to effective disaster response. Despite these challenges, collaboration between NEMA and international partners such as UN-SPIDER has yielded meaningful capacity gains, including the provision of flood impact maps for the Niger River basin and training on Sentinel-1-based rapid flood mapping techniques (UN-SPIDER/NASRDA/NEMA/ZFL, 2021).

### National Space Research and Development Agency (NASRDA)

NASRDA, established in 2001, is the principal agency responsible for developing Nigeria's space technology capabilities and implementing the country's national space programme. The agency operates several Earth observation satellites, most notably NigeriaSat-1 (launched 2003) and NigeriaSat-2 (launched 2011), both developed through partnerships with Surrey Satellite Technology Ltd (SSTL) of the United Kingdom. NigeriaSat-1, a component of the global Disaster Monitoring Constellation (DMC), features a 32-metre ground sampling distance, a 600-km swath width, and a 3–5-day revisit cycle, making it suited to large-area environmental monitoring (NASRDA, 2023a). NigeriaSat-2 provides high-resolution 2.5-metre panchromatic imagery, substantially enhancing the agency's capacity for detailed disaster impact assessment, infrastructure mapping, and urban monitoring (NASRDA, 2023b).

Nigeria's designation as a UN-SPIDER Regional Support Office since 2009 places NASRDA at the centre of the country's international space cooperation architecture, creating pathways for technology transfer, training, and access to global satellite datasets for disaster management applications (UN-SPIDER/NASRDA/NEMA/ZFL, 2021). However, the full operational integration of NASRDA's satellite data products into NEMA's emergency response workflows remains limited by inadequate data sharing protocols, insufficient processing infrastructure, and human capacity gaps.

**Nigerian Meteorological Agency (NiMet)**

The Nigerian Meteorological Agency provides weather forecasts, climate monitoring services, and seasonal outlooks that are foundational inputs to Nigeria's national early warning architecture. NiMet's seasonal rainfall predictions, disseminated prior to each rainy season, are critical for flood preparedness planning by NEMA and state emergency management agencies. The integration of NiMet's meteorological forecasts with satellite-derived hydrological data and terrain analysis products represents an important opportunity to build more comprehensive, multi-hazard early warning systems for Nigeria.

**Nigeria Erosion and Watershed Management Project (NEWMAP)**

NEWMAP, a World Bank-funded initiative, is an important institutional mechanism for integrating geospatial monitoring into erosion and watershed management in Nigeria. The project's information services component develops geospatial data infrastructure to strengthen erosion monitoring and disaster risk management, representing a model for how satellite-derived data can be systematically embedded in sectoral risk management programmes.

## METHODOLOGY

This study adopts a systematic qualitative analytical approach grounded in an integrative literature review methodology. The research design is structured around five analytical components:

Literature selection followed explicit inclusion and exclusion criteria to ensure transparency and replicability. Peer-reviewed studies were included if they: (a) were published between 2015 and 2026; (b) focused on satellite remote sensing, GIS, or space-based technologies in the context of disaster management, emergency response, or environmental monitoring; and (c) were conducted in Nigeria, sub-Saharan Africa, or comparable developing-country settings. Studies published prior to 2015 were included only where they constituted foundational methodological references widely cited in the field (e.g., Campbell & Wynne, 2011; Lillesand et al., 2015). Grey literature—including institutional reports, policy documents, and technical briefs from UNOOSA, UNDRR, NASRDA, NEMA, and the World Bank—was included where it provided primary institutional data not available in peer-reviewed sources. Studies were excluded if they were published in languages other than English, lacked sufficient methodological transparency, or presented findings exclusively from high-income country contexts without transferable lessons for developing nations.

The study acknowledges a key methodological limitation in its reliance on secondary data. Future research should complement this integrative review with primary data collection, including semi-structured interviews with officials from NEMA, NASRDA, and NiMet; focus group discussions with disaster-affected communities in high-risk states such as Anambra, Kogi, and Benue; and structured surveys of geospatial practitioners in Nigeria’s disaster management ecosystem. Such primary data would provide firsthand insights into the operational realities of implementing space-based disaster response, validate or challenge the assumptions underpinning the proposed ISBDRF, and capture the perspectives of community-level stakeholders whose voices are essential for ensuring that policy recommendations are contextually grounded and equitable.

- A comprehensive review of peer-reviewed literature published between 2015 and 2026 on remote sensing, GIS, satellite technology applications in disaster management, and emergency response in Nigeria and comparable developing-country contexts.
- Critical analysis of institutional policies, frameworks, and operational practices governing disaster management and space technology in Nigeria, including NEMA, NASRDA, NiMet, and their relationships with international bodies such as UNOOSA, UN-SPIDER, and UNDRR.
- Empirical examination of selected recent disaster events in Nigeria—including the 2022 floods, Niger Delta oil spill incidents (2020–2022), and ongoing desertification in the northern zones—with emphasis on documented space-based data applications.
- Assessment of satellite data platforms and processing methodologies currently available and applicable for Nigerian disaster management, including Google Earth Engine, Sentinel-1/2, Landsat, NigeriaSat-1/2, and MODIS.
- Synthesis of findings into a conceptual integrated framework and evidence-based policy recommendations aligned with the Sendai Framework for Disaster Risk Reduction 2015–2030.

Secondary data sources include peer-reviewed academic publications sourced from Scopus, Web of Science, and PubMed; institutional reports from UNOOSA, UNDRR, World Bank, NASRDA, and NEMA; and official documentation from the Sendai Framework Midterm Review (2023).

**Empirical Applications of Space-Based Data in Nigeria**

**Flood Monitoring and Mapping**

The most extensively documented application of space-based data in Nigerian disaster management is flood monitoring. Odiji et al. (2024) conducted a ten-year analysis (2012–2022) of flood inundation dynamics in the Niger-Benue confluence region using multi-sensor satellite imagery integrated within Google Earth Engine. Their analysis confirmed that the 2022 flood event was the most destructive on record, with affected populations, cropland, and building footprints all reaching peak values during this event. The use of Sentinel-2 optical imagery alongside Sentinel-1 SAR data enabled flood mapping even under cloud cover—a critical capability during the peak rainy season when optical imagery is frequently obscured.

Akintola (2024) further demonstrated the utility of near-real-time GIS-based flood monitoring, developing an integrated framework that combined multi-temporal optical, radar, and terrain data to quantify changing flood hazards and exposure across the Niger River Basin during the 2022 peak event. The NDWI, calculated from Sentinel-2 bands, was used to detect water body extents with high accuracy, while digital elevation models (DEMs) enabled flood depth estimation and exposure analysis. Results indicated more than a 50% rise in inundation compared to historical medians, with 143,000 residents and 15,000 hectares of vegetation impacted.

In 2020, UN-SPIDER generated flood impact maps for the Niger River basin and provided them to NASRDA and NEMA, alongside a virtual training course on the use of UN-SPIDER Recommended Practice for rapid flood mapping using Sentinel-1 radar imagery and Google Earth Engine (UN-SPIDER/ NASRDA/ NEMA/ZFL, 2021). This collaboration represents a concrete operationalisation of space-based tools within Nigeria's emergency response system, though it also revealed institutional gaps in the sustainability of such data flows.

**Oil Spill Detection and Environmental Monitoring**

Remote sensing applications for oil spill monitoring in the Niger Delta have advanced significantly in recent years, driven by the availability of high-resolution optical and SAR imagery and improvements in machine learning classification techniques. Obida et al. (2021) used satellite remote sensing to reveal the extensive environmental damage caused by the Niger Delta's largest oil spills, demonstrating that over one million people resided within documented spill impact zones. This study highlighted the critical role of satellite data in providing evidence-based assessments of pollution exposure that would be practically impossible to obtain through field surveys alone given issues of access, security, and cost.

Wekpe and Idisi (2023) employed PlanetScope satellite data to track vegetation health indices—including NDVI, EVI2, GRNDVI, and GNDVI—across oil-contaminated landcovers between 2016 and 2023, using Slow Moving Average regression to reveal statistically significant and consistent downward trends in vegetation health following spill events. The Nigeria Oil Spill Detection and Response Agency (NOSDRA) has also utilised Landsat-based remote sensing to support spill detection and post-incident monitoring.

**Desertification and Land Degradation Monitoring**

Monitoring the spatial progression of desertification across northern Nigeria requires temporal analysis of land cover change over large geographic extents—a task for which multi-temporal satellite imagery is uniquely suited. NASRDA's original mandate for NigeriaSat-1 explicitly included the detection and control of desertification in Nigeria's northern zone, reflecting early recognition of remote sensing's strategic value for this hazard category (NASRDA, 2023a). NDVI time-series derived from MODIS and Landsat platforms enable analysts to detect vegetation loss trends, identify areas of advancing desert encroachment, and assess the effectiveness of afforestation and land rehabilitation interventions.

**Damage Assessment and Post-Disaster Recovery**

Following major disaster events, satellite imagery provides rapid, area-wide assessments of infrastructure damage, destroyed settlements, and affected agricultural land, enabling emergency managers to prioritise relief operations and allocate resources more effectively. Change detection analysis comparing pre- and post-event imagery enables quantification of building damage, road network disruption, and vegetation loss. The combination of high-resolution NigeriaSat-2 imagery (2.5 m) with medium-resolution Sentinel-2 data (10 m) provides a complementary analytical toolkit for post-disaster damage mapping at both fine-grained and landscape scales.

**Comparative Lessons from Space-Based Disaster Management in Developing Countries**

A comparative examination of space-based disaster management initiatives in other developing nations offers valuable lessons that can inform Nigeria’s strategic approach. Three country cases—Bangladesh, India, and Ethiopia—are examined here for their instructive parallels and transferable best practices.

**Bangladesh: Community-Centred Early Warning Integration**

Bangladesh represents one of the most cited successes in translating satellite-based flood forecasting into measurable reductions in disaster mortality. The Bangladesh Flood Forecasting and Warning Centre (FFWC) integrates MODIS near-real-time flood inundation maps, Landsat-derived flood extent products, and microwave radiometer data into operational forecasting products disseminated up to 72 hours in advance of major flood events (Brakenridge et al., 2012). Critically, Bangladesh’s model extends beyond technical data integration to prioritise last-mile dissemination: satellite-derived alerts are translated into local-language text messages, community radio broadcasts, and visual warning signals transmitted through a network of more than 55,000 trained community volunteers (Islam et al., 2022). This community-centred approach has been credited with reducing flood mortality by an estimated 40% over two decades, despite population growth and increasing flood frequency attributable to climate change. For Nigeria, the Bangladeshi experience underscores the critical importance of investing in community communication infrastructure alongside satellite data systems—a lesson directly applicable to the Niger Benue floodplain communities that remain poorly served by existing early warning dissemination mechanisms.

**India: Institutional Integration of Indigenous Satellites**

India's experience integrating the Indian Space Research Organisation (ISRO)'s indigenously developed satellite constellation into the national disaster management system offers instructive parallels for Nigeria's use of NigeriaSat-1 and NigeriaSat-2. The National Remote Sensing Centre (NRSC), operating under ISRO, provides the National Disaster Management Authority (NDMA) with standardised satellite-derived damage assessment products within 24 to 48 hours of major disaster events, based on a formal data-sharing protocol embedded in India's National Disaster Management Plan (NDMA, 2019). The RESOURCESAT-2 and CARTOSAT satellite series, with resolutions comparable to NigeriaSat-2, are routinely tasked during cyclone, flood, and earthquake events, with processed outputs provided in standardised geospatial formats to all state disaster management authorities. India's approach demonstrates that the transition from satellite data availability to operational disaster response integration requires not only technical capacity but also formal legal and procedural frameworks that mandate data sharing, define agency responsibilities, and establish performance benchmarks for satellite-based disaster response products. Nigeria's current institutional arrangement between NASRDA and NEMA lacks this degree of formalisation, representing a critical gap identified in this study's policy recommendations.

**Ethiopia: Drought Early Warning and Food Security Applications**

Ethiopia's National Meteorological Agency (NMA) and the SERVIR-Eastern and Southern Africa hub have developed an integrated drought early warning system that combines MODIS-derived NDVI anomaly products, satellite-based rainfall estimates from CHIRPS and TAMSAT, and land surface temperature data from Aqua and Terra satellites to generate monthly drought monitoring bulletins disseminated to federal and regional food security authorities (Haile et al., 2020). The system has demonstrated consistent performance in predicting moderate to severe drought conditions four to six weeks in advance, enabling pre-emptive deployment of food aid and livestock support measures across vulnerable pastoral communities. Ethiopia's approach is particularly relevant for Nigeria's northern states, where recurring drought and desertification threats are compounded by complex humanitarian conditions and limited ground-based meteorological infrastructure. The SERVIR programme—jointly operated by NASA and USAID—represents an accessible partnership pathway for Nigeria to strengthen its satellite-based drought monitoring capabilities without significant upfront capital investment in proprietary systems.

Across these three cases, three cross-cutting lessons emerge for Nigeria. First, the translation of satellite data into measurable disaster risk reduction outcomes requires deliberate investment in community-level dissemination infrastructure, not merely technical data processing capacity. Second, formal institutional frameworks—including mandated data sharing agreements, standardised product formats, and defined response time benchmarks—are necessary conditions for operationalising satellite-based disaster management. Third, international partnerships through programmes such as SERVIR, ESA's Copernicus Emergency Management Service, and UN-SPIDER provide cost-effective pathways for developing nations to access advanced geospatial capabilities while building domestic institutional capacity. These lessons directly inform the policy recommendations and framework design presented in Sections 8 and 9 of this paper.

**Conceptual Model: Integrated Space-Based Disaster Response Framework for Nigeria**

Building on the empirical evidence and institutional analysis presented above, this paper proposes an Integrated Space-Based Disaster Response Framework (ISBDRF) for Nigeria comprising six operational components arranged in a cyclical process aligned with the disaster management cycle:

- Hazard Monitoring and Data Acquisition: Continuous monitoring of flood-prone river basins, desertification-vulnerable dryland zones, the Niger Delta oil infrastructure network, and coastal erosion hotspots using multi-sensor satellite platforms including NigeriaSat-1/2, Sentinel-1/2, Landsat 8/9, and MODIS.

- Data Processing and Analysis: Processing of satellite data through cloud-based platforms including Google Earth Engine and open-source GIS software (QGIS) to generate standardised hazard maps, vegetation indices, inundation extent products, and change detection outputs.
- Early Warning Dissemination: Multi-channel dissemination of satellite-derived early warning products to NEMA, State emergency management agencies, NiMet, and community-level actors through standardised geospatial data formats, web portals, and SMS-based alerting systems.
- Emergency Response Coordination: Integration of space-derived situational awareness products into NEMA's National Emergency Operations Centre to support real-time decision-making, resource mobilisation, search and rescue coordination, and evacuation planning.
- Post-Disaster Damage Assessment: Systematic satellite-based damage mapping following major events to support rapid needs assessments, insurance claims, infrastructure restoration prioritisation, and donor reporting.
- Recovery Monitoring and Risk Reduction: Long-term monitoring of recovery trajectories and disaster risk evolution using satellite time-series analysis, informing investments in risk reduction infrastructure and land use planning decisions.

This integrated model strengthens the overall disaster risk management system by improving situational awareness across all phases of the disaster management cycle, while creating documented feedback loops for institutional learning and programme adaptation.

**Quantitative Performance Indicators for the ISBDRF**

For the ISBDRF to transition from a conceptual model to an operationally accountable framework, it must be underpinned by measurable performance indicators. Drawing on benchmarks established in comparable satellite-based disaster management systems in Bangladesh, India, and Ethiopia (Section 7), the following quantitative indicators are proposed for monitoring the framework's operational performance:

- Early Warning Lead Time: Target of 48–72 hours advance warning for riverine flood events in high-risk river basins, benchmarked against the current average lead time of less than 24 hours documented in the Niger–Benue confluence region.
- Flood Mapping Accuracy: Minimum overall accuracy of 85% for satellite-derived flood inundation maps, based on validation against ground reference data or aerial survey products, consistent with accuracies reported by Odiji et al. (2024) and Akintola (2024) using Sentinel-1/2 data in the Niger Basin.
- Damage Assessment Delivery Time: Standardised post-disaster damage maps delivered to NEMA within 48 hours of a major disaster event declaration, based on NigeriaSat-2 or Sentinel-2 imagery processed through Google Earth Engine.
- Population Coverage of Early Warning Alerts: Target of 80% of residents in designated high-risk flood and drought zones receiving satellite-derived early warning information through at least one formal dissemination channel within 12 hours of alert generation, monitored through georeferenced community survey data.
- Cost Efficiency: Reduction of at least 30% in per-event satellite data acquisition costs through systematic adoption of open-access Sentinel-1/2 and Landsat datasets and Google Earth Engine cloud processing, benchmarked against current agency expenditures on commercial imagery procurement.
- Trained Personnel: At least 50 certified GIS and remote sensing analysts embedded across NEMA, NASRDA, NiMet, and state-level emergency management agencies within five years of framework adoption, monitored through a national geospatial capacity registry.

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These indicators should be reviewed and updated on a biennial basis in alignment with the Sendai Framework Monitoring System reporting cycle, and embedded within a formal performance management system administered by a multi-agency Space-Based Disaster Risk Management Coordination Committee.

**Framework Validation Pathway**

The ISBDRF as presented in this paper remains at the conceptual stage and requires empirical validation before full-scale institutional adoption. A phased validation pathway is proposed. In Phase 1 (Years 1–2), the framework should be subjected to a structured tabletop simulation exercise involving representatives from NEMA, NASRDA, NiMet, and at least two State Emergency Management Agencies (SEMAs), using the 2022 flood event as a case study to test the framework's operational logic against documented response gaps. In Phase 2 (Years 2–3), a pilot implementation should be conducted in a high-risk state—Anambra, Kogi, or Delta State are recommended given their recurrent flood exposure—with NASRDA tasked to provide satellite imagery products to the state SEMA under a structured data sharing agreement, and with the process evaluated using the quantitative indicators set out in Section 8.7. Phase 3 (Years 3–5) would involve a full-scale implementation review, independent external evaluation, and framework revision informed by primary data collected from stakeholder interviews, community surveys, and documented operational performance. This phased approach mirrors the validation methodology employed in India's National Disaster Management Plan development and would substantially strengthen the evidence base underpinning the ISBDRF's policy claims.

**Challenges in the Effective Use of Space-Based Data in Nigeria**

**Technical Capacity Limitations**

A persistent and critical challenge limiting the effective utilisation of space-based technologies in Nigerian disaster management is the shortage of trained personnel capable of acquiring, processing, analysing, and interpreting satellite imagery and geospatial data products. Many disaster management institutions lack qualified GIS specialists and remote sensing analysts, resulting in dependence on ad hoc international technical assistance rather than institutionalised domestic capacity. Raji et al. (2021) identified human resource gaps as among the most significant constraints on NEMA's operational effectiveness, while the UN-SPIDER/NASRDA/NEMA/ZFL (2021) virtual expert meeting highlighted the need for sustained investment in training programmes as a prerequisite for effective space-based disaster response in Nigeria.

**Infrastructure Limitations**

Geospatial data processing laboratories, satellite data downlink stations, high-performance computing infrastructure, and broadband internet connectivity—all of which are prerequisites for operational satellite data exploitation—remain inadequate across Nigeria's disaster management and space technology institutions. Power supply instability further undermines the operational continuity of data processing facilities. The absence of a functional National Geospatial Data Infrastructure (NGDI) creates fragmentation in data storage, sharing, and access, limiting the integration of satellite data products from multiple sources into coherent, multi-hazard risk information systems.

**Data Accessibility and Cost**

While open-access satellite datasets such as Sentinel-1/2 and Landsat have substantially reduced data acquisition costs, high-resolution imagery (sub-metre to 2.5 m) from commercial providers remains prohibitively expensive for routine operational use by most Nigerian government agencies. NigeriaSat-2's 2.5-metre resolution imagery, though domestically produced, requires institutional prioritisation and operational readiness to fully exploit its capabilities for disaster mapping and monitoring. Furthermore, cloud cover—endemic during the peak rainy season when floods are most severe—frequently limits the availability of useful optical imagery, underscoring the need to complement optical sensors with SAR data that can penetrate cloud cover.

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### Institutional Coordination Deficits

Weak coordination between NEMA, NASRDA, NiMet, the Nigeria Hydrological Services Agency (NIHSA), and state-level emergency management agencies significantly reduces the operational effectiveness of the national disaster management system. Data sharing protocols between agencies are inadequately formalised, resulting in duplication of effort, information silos, and delays in the translation of satellite-derived products into field-level decision-making. The virtual expert meeting convened by UN-SPIDER, NASRDA, NEMA, and the University of Bonn in April 2021 identified inter-agency coordination as a priority area requiring urgent policy attention (UN-SPIDER/NASRDA/NEMA/ZFL, 2021).

### Policy and Legal Framework Gaps

Nigeria lacks a comprehensive national remote sensing and geospatial data policy that clearly delineates agency responsibilities for satellite data acquisition, processing, dissemination, and archiving for disaster risk management purposes. The absence of such a policy framework creates ambiguity in budget allocation, inhibits international partnerships, and limits the alignment of Nigeria's space-based disaster management capabilities with the targets and indicators of the Sendai Framework for Disaster Risk Reduction 2015–2030.

### Policy Implications and Strategic Recommendations

The findings of this study point to several strategic policy measures necessary to maximise the contribution of space-based technologies to Nigeria's national disaster management system:

- Establish a National Geospatial Data Infrastructure (NGDI): The federal government should prioritise the development of an interoperable NGDI that enables seamless data sharing between NASRDA, NEMA, NiMet, NIHSA, and state agencies, underpinned by a national geospatial data policy and open data standards.

- Institutionalise Inter-Agency Coordination: A formal multi-agency Space-Based Disaster Risk Management Coordination Committee should be established, with clear mandates, data sharing agreements, standard operating procedures, and regular joint exercises. NASRDA should be formally mandated as the technical satellite data provider to NEMA for all major disaster events.

- Invest in Sustained Human Capacity Development: A national capacity development programme for GIS, remote sensing, and satellite data analysis should be established in partnership with Nigerian universities, NASRDA, and international bodies such as UN-SPIDER and ESA's SERVIR programme. Postgraduate scholarships in geospatial sciences should be linked to mandatory service in disaster management agencies.

- Develop an Integrated Multi-Hazard Early Warning System: Nigeria should develop a national, satellite-supported, multi-hazard early warning system that integrates flood forecasting, drought monitoring, desertification assessment, oil spill detection, and coastal erosion monitoring, with dissemination to community level through mobile platforms and local radio.

- Operationalise NigeriaSat-2 for Disaster Response: NASRDA should establish a dedicated disaster response imaging protocol for NigeriaSat-2, enabling rapid tasking, processing, and dissemination of high-resolution imagery within 24–48 hours of a major disaster event.

- Align with the Sendai Framework and International Commitments: Nigeria's national disaster risk reduction strategy should explicitly incorporate satellite data requirements, responsibilities, and performance metrics aligned with Sendai Framework Targets E and G (early warning systems and disaster risk information).

- Leverage Open-Source and Cloud-Based Geospatial Platforms: NEMA and NASRDA should accelerate adoption of Google Earth Engine, ESA's Copernicus Emergency Management Service, and the UN-SPIDER Recommended Practices for satellite-based flood mapping and drought monitoring, reducing dependence on expensive proprietary software.

- Establish Community-Level Satellite-Informed Early Warning Networks: Building on the Bangladeshi community volunteer model (Section 7.1), NEMA should establish a national programme of trained community disaster liaison officers in high-risk local government areas, equipped to receive, interpret, and disseminate satellite-derived early warning information through locally trusted channels including community radio, mosques, churches, and traditional leadership structures. A minimum of 200 trained liaison officers should be in place across the 20 most flood-prone local government areas within three years of programme launch, with performance evaluated against documented alert dissemination rates and community preparedness survey results.

- Integrate Participatory and Citizen Science Approaches: The ISBDRF should incorporate structured citizen science components to complement satellite-based monitoring, particularly in access-restricted environments such as the Niger Delta and conflict-affected northeastern Nigeria. Expanding on the Land Pollution Lookout model piloted by Eyang et al. (2024), NEMA and NASRDA should co-develop a national platform enabling trained community observers to validate satellite-derived hazard maps using georeferenced mobile reports, improving the spatial accuracy of disaster assessments and generating ground-truth data for calibrating satellite-based products. Community participation in satellite data validation also strengthens local ownership of early warning systems, improving long-term sustainability.

- Address Sub-National and Local Government Capacity Gaps: The current analysis reveals significant variation in disaster management capacity across Nigeria’s 36 states and 774 local government areas. The Federal Government should establish a differentiated capacity-building programme that classifies local governments into three tiers—high risk and low capacity, high risk and moderate capacity, and moderate risk—and targets geospatial capacity building resources accordingly. State Emergency Management Agencies in the highest-risk tier should receive dedicated satellite data subscriptions, GIS workstations, and at least two trained remote sensing analysts within three years, funded through a combination of federal disaster management allocations and international development partnerships.

## CONCLUSION

Space-based technologies offer transformative and largely underharnessed potential for improving early response to emergencies across Nigeria's complex multi-hazard landscape. The convergence of freely available satellite data from missions such as Sentinel-1/2 and Landsat, cloud-based processing platforms such as Google Earth Engine, and indigenous capabilities from NigeriaSat-1 and NigeriaSat-2 has created an unprecedented technological opportunity for data-driven disaster risk management. Empirical evidence from the 2022 floods, Niger Delta oil spill monitoring, and desertification assessments confirms that satellite-derived products can provide timely, accurate, and spatially comprehensive information for hazard detection, situational awareness, and post-disaster damage assessment.

However, realising this potential requires overcoming persistent structural barriers including limited technical human capital, inadequate geospatial infrastructure, weak inter-agency coordination, and the absence of a comprehensive national geospatial data policy. The institutional architecture—centred on NEMA and NASRDA, with critical supporting roles for NiMet, NIHSA, and international partners including UN-SPIDER, UNOOSA, and ESA—provides a foundation upon which a more integrated and effective space-based disaster management system can be constructed.

Nigeria’s alignment with the Sendai Framework for Disaster Risk Reduction 2015–2030 and its obligations under the Paris Agreement on Climate Change create both normative imperatives and practical pathways for strengthening investment in space-based disaster risk management capabilities. Comparative evidence from Bangladesh, India, and Ethiopia demonstrates that the translation of satellite data into measurable disaster risk reduction outcomes requires not only technical infrastructure but also community-centred early warning dissemination, formal institutional frameworks with mandated data sharing, and performance accountability systems anchored in quantitative indicators. Through strategic commitments to infrastructure development, human capacity building, institutional coordination, community engagement, and international partnerships, Nigeria has the opportunity to establish itself as a continental leader in space-based disaster risk management, setting a precedent for other emerging space-faring nations across sub-Saharan Africa. The phased validation pathway proposed for the ISBDRF provides a concrete roadmap for moving from the conceptual model presented here toward an empirically tested and institutionally embedded framework capable of saving lives and reducing disaster losses at scale.

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