# The Role of Space Science and Technology in Advancing National Infrastructural Development

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***Abstract:*** The role of Space Science and Technology in advancing national infrastructural development has become increasingly significant, particularly through the application of satellite communication, remote sensing, Geographic Information Systems (GIS), Global Navigation Satellite Systems (GNSS), and Earth observation technologies. This study reviewed recent literature on the application of space science and technology to eight major infrastructure areas: smart transportation networks, energy infrastructure management, water-resource management, urban spatial planning, telecommunication networks, agricultural infrastructure, disaster management infrastructure, and critical infrastructure security. The review examined studies published between 2023 and 2026, with emphasis on the technologies employed, their applications, and reported outcomes. The findings indicate that space-based technologies contribute to infrastructure planning, monitoring, resource management, connectivity, agricultural development, disaster assessment, and infrastructure security. The study concludes that greater integration of space-derived information and technologies into national planning and infrastructure management can improve efficiency, resilience, sustainability, and the overall development of infrastructure in Nigeria.

***Keywords:*** *Space Science and Technology, National Infrastructural Development, Remote Sensing, Satellite Communication, Geospatial Technology.*

## I. INTRODUCTION

Space science and technology has increasingly become an important component of national infrastructural development because satellite-based systems provide information, communication, navigation, and monitoring capabilities that are difficult to obtain through conventional terrestrial infrastructure alone. Earth observation satellites, geographic information systems (GIS), Global Navigation Satellite Systems (GNSS), satellite communications, and geospatial analytics now support decision-making across transportation, energy, water resources, urban development, agriculture, disaster management, and security. The International Telecommunication Union (2024) noted that space technologies contribute to transportation optimisation, precision agriculture, water-resource management, renewable-energy deployment, connectivity, and disaster response, linking space applications directly with sustainable development and infrastructure provision.

The importance of these technologies is particularly relevant to developing countries such as Nigeria, where geographical scale, uneven infrastructure distribution, rapid urbanisation, environmental challenges, and difficulties in monitoring remote locations create a need for reliable spatial information. The National Space Research and Development Agency (NASRDA) identifies space-derived data as a planning resource capable of improving resource allocation, environmental management, land-use planning, agriculture, urban planning, water-resource management, project implementation, and infrastructure monitoring. Similarly, Nigeria's national space programme recognises remote sensing, satellite meteorology, communication technology, and related applications as important components of national socio-economic development.

In line with this development, Raza et al. (2023) demonstrated through GIS and multi-criteria analysis that spatial information can support the identification of suitable locations for renewable-energy infrastructure, while Peng et al. (2024) showed that satellite remote sensing combined with deep-learning techniques can improve crop monitoring and land-use classification. Betterle and Salamon (2024) further highlighted the usefulness of satellite observations for flood-extent and water-depth assessment, supporting emergency planning and disaster response. Nakalembe (2024) also highlighted the increasing importance of Earth observation for crop monitoring and food security in Africa, while identifying limitations related to local capacity and data access.

The telecommunications sector provides another important dimension. Lagunas et al. (2024) showed that the development of low-Earth-orbit satellite constellations is expanding global communication connectivity, particularly in areas where terrestrial infrastructure is limited. Satellite communication can therefore complement conventional infrastructure by improving coverage, redundancy, and connectivity in underserved and geographically difficult areas. More broadly, recent research indicates that Africa has considerable opportunities to use space science and technology for socio-economic development, although limitations in infrastructure, funding, technical expertise, data access, and institutional coordination remain important challenges.

Against this background, this research examines the contribution of space science and technology to major areas of Nigeria's infrastructural development, including smart transportation networks, energy infrastructure management, water-resource management, urban spatial planning, telecommunication networks, agricultural infrastructure, disaster-management infrastructure, and critical infrastructure security. The discussion draws on recent studies to establish how satellite navigation, remote sensing, GIS, Earth observation, and satellite communication can improve infrastructure planning, monitoring, resilience, accessibility, and security.

## II. METHODOLOGY

This study adopted a review research method to examine the application of space science and technology to national infrastructural development. Recent scholarly works published between 2023 and 2026 were considered, with emphasis on studies addressing transportation, energy, water resources, urban planning, telecommunications, agriculture, disaster management, and critical infrastructure. Literature was identified through academic databases and publisher platforms, including ScienceDirect, Springer Nature, IEEE, MDPI, Nature, and other relevant scholarly sources. The selected studies were screened based on their relevance to space technology, infrastructure development, research methodology, and reported findings. Preference was given to empirical and analytical studies employing different approaches, including GIS and multi-criteria analysis, satellite remote sensing, machine learning, deep learning, geospatial modelling, and satellite communication analysis. The reviewed studies were analysed thematically according to the eight infrastructure areas. Attention was given to the purpose of each study, methods adopted, major findings, and conclusions in order to establish the contribution of space technology to infrastructure planning, monitoring, management, resilience, and security. This approach provides a structured synthesis of recent evidence while highlighting the relevance of space applications to Nigeria's infrastructural development.

## III. RESULTS AND DISCUSSION

Below are some ways in which space science and technology is contributing in advancing national infrastructural development.

### *A. Smart Transportation Networks*

The use of satellite navigation (like GPS) and GIS mapping makes it much easier to plan and manage roads and railways across Nigeria. With accurate location data coming from space, engineers can easily spot traffic choke points, check damaged roads, and pick the best routes for new highways or rail lines. This real-time spatial tracking helps reduce heavy traffic in busy cities, saves fuel for drivers, and brings down the cost of maintaining federal and state roads. Furthermore, satellite tracking helps logistics companies monitor haulage trucks moving goods between ports and inland markets, preventing cargo theft along major transit routes. It also gives urban planners the exact data needed to design proper bypasses around overpopulated commercial hubs like Lagos and Kano. By integrating space technology into everyday transit systems, state governments can automate toll collection and improve emergency response times during highway accidents. At the end of the day, using satellite technology turns our usual roads into smart, well-organized transport systems that keep the economy moving smoothly.

According to Zaroujtaghi et al. (2025) who examined the evolution and application of GIS in transportation planning, GIS applications have expanded to transportation accessibility, mobility planning, real-time monitoring, sustainability, and integration with emerging technologies. The study further identified the growing use of advanced data sources and analytical techniques for evidence-based transportation decisions. The authors concluded that GIS has become an important component of data-driven and sustainable transportation planning. Also, Steuer et al. (2025**)** studied the application of Global Navigation Satellite Systems (GNSS) in railway transportation and traffic control. The study adopted a review research method**,** synthesising literature from the previous 20 years on satellite positioning in railway systems. The results showed that GNSS supports precise railway vehicle localisation, navigation, signalling, and traffic control, particularly through the European Train Control System (ETCS). The review further indicated that satellite positioning can improve railway safety and optimise the utilisation of rail infrastructure. The authors concluded that GNSS provides an important basis for developing efficient and cost-effective railway traffic management systems.

### *B. Energy Infrastructure Management*

Remote sensing satellites give useful weather and environmental data that help in building and protecting power installations across the country. By tracking sunshine levels, wind speeds, and river flows from space, these satellite tools help energy planners find the best locations for solar plants, wind farms, and hydro dams. Satellite radar and high-resolution imaging also make it possible to monitor high-voltage transmission lines from far away, spotting fallen trees or overheating cables before they cause total system collapses. Beyond monitoring hardware, space-based imagery helps power companies map out energy demand in fast-growing informal settlements where official maps do not exist. It also assists security agencies in detecting pipeline vandalism, illegal oil bunkering, and electricity theft that disrupt power generation in the Niger Delta and major industrial zones. Additionally, seasonal rainfall tracking from space helps dam managers control water release to prevent both flooding and unexpected hydro-power shutdowns.

Raza et al. (2023) worked on assessing the suitable locations for utility-scale solar photovoltaic and wind energy infrastructure in developing countries while considering the technical, environmental, economic, and geographical conditions influencing renewable-energy development. The study adopted a Geographic Information System (GIS) and Multi-Criteria Decision Analysis approach, with the Analytical Hierarchy Process (AHP) used to assign importance to eight major selection criteria. The results showed that the integration of GIS and AHP was effective in identifying areas suitable for both large-scale renewable-energy facilities and decentralised solar installations in remote areas that were poorly connected to electricity distribution networks. The study demonstrated that satellite-derived spatial information can support systematic assessment of terrain, accessibility, energy resources, and other factors required for infrastructure planning. The authors concluded that GIS-based multi-criteria analysis provides a practical decision-support tool for locating renewable-energy infrastructure, particularly in developing countries where infrastructure resources must be carefully allocated.

Similarly, Sayyaadi et al. (2023) developed an environmentally responsible approach for selecting locations and determining suitable capacities for renewable-energy infrastructure. The researchers employed a remote sensing and GIS-based spatial analysis combined with optimisation and weighted decision-making techniques, using socio-economic, terrain, meteorological, and energy-related variables in the assessment. The study showed that integrating satellite-derived spatial information with optimisation techniques can improve both the technical and economic planning of renewable-energy facilities. The authors concluded that remote sensing and GIS can provide an effective basis for selecting renewable-energy infrastructure locations while simultaneously improving energy output and economic viability.

### *C. Water Resource Management*

The use of satellite remote sensing technology provides accurate environmental data that helps in managing Nigeria's rivers, dams, and underground water supplies. By tracking rainfall patterns, river basin volumes, and soil moisture from space, hydrologists can plan effective irrigation networks for large-scale farming and locate clean underground water sources. Satellite radar also gives early warnings on rising water levels along major rivers like the Niger and Benue, allowing authorities to manage dam discharge and prevent catastrophic flooding in surrounding communities. Furthermore, space imagery helps track water pollution, weed infestation, and siltation in vital reservoirs that feed major urban waterworks. It also enables state governments to monitor drought-prone areas in northern Nigeria, ensuring proper water distribution during dry seasons. Additionally, space data supports the planning of long-distance water pipelines to supply growing towns and industrial hubs. Overall, space-based water tracking improves drought resilience, secures clean drinking water, and boosts agricultural productivity nationwide.

Ali et al. (2025) investigated the application of satellite remote sensing and geospatial analytics to improve water-resource and agricultural management in South Africa’s North West Province. The study used 30-metre satellite imagery, integrating the Water Ratio Index (WRI), Normalized Difference Chlorophyll Index (NDCI), Land Use/Land Cover (LULC) mapping, and Cellular Automata–Markov (CA–Markov) modelling, together with temperature data, for the period 2016–2023. The results showed that irrigated land declined from 25,732 km² to 24,322 km², while built-up areas increased from 4,146 km² to 6,581 km². The WRI also decreased from 0.40 in 2016 to 0.28 in 2023, indicating increasing water stress, while the CA–Markov model projected further agricultural and water-resource pressure by 2033. The authors concluded that integrating satellite remote sensing with geospatial modelling provides useful evidence for monitoring water availability, irrigation demand, land-use changes, and future water-resource management.

In the work by Zhang and Liu (2025), they developed a satellite-based framework for monitoring water quality in the Changjiang and Yellow River systems in China. The results showed that LightGBM and Random Forest were among the best-performing models, achieving an average adjusted $R^2$ of 0.76 across nine water-quality parameters, with individual performance ranging from 0.58 for ammonia nitrogen to 0.95 for electrical conductivity. The study concluded that multi-algorithm satellite remote sensing can provide an effective basis for large-scale water-quality monitoring, pollution-source identification, and evidence-based watershed management.

### *D. Urban Spatial Planning*

High-resolution satellite imagery and GIS mapping give urban planning agencies the precise visual tools needed to design organized, sustainable cities across Nigeria. Planning authorities can easily map out residential layouts, commercial zones, and proper drainage systems to prevent urban sprawl and flash flooding in rapidly expanding cities. Satellite tracking also allows government officials to detect illegal structures, unauthorized land encroachments, and building code violations early before projects are completed. Beyond physical structures, space data helps waste management agencies locate ideal sites for landfills, waste transfer stations, and recycling facilities away from residential quarters. It also aids state revenue boards in mapping properties accurately for land administration, street naming, and property tax assessment. Furthermore, space-based mapping helps urban planners preserve green spaces, forest reserves, and wetlands from indiscriminate development. In short, satellite mapping turns messy, unstructured urban growth into well-planned, modern environments that improve living standards.

Masha et al. (2025) carried out research on urban expansion and land-use/land-cover (LULC) changes in Wolaita Sodo City, South Ethiopia, to provide evidence for sustainable urban planning. The study adopted a remote sensing and GIS approach, using Landsat satellite images from 2003, 2013, and 2023. The maximum likelihood supervised classification algorithm was applied to generate LULC maps and quantify changes in the urban environment. The results showed that built-up areas increased from 4,654 ha (10.82%) in 2003 to 7,914.9 ha (18.4%) in 2013 and 11,681.5 ha (27.2%) in 2023, indicating substantial urban expansion and increasing pressure on peri-urban agricultural land. The authors concluded that effective management of urban expansion and protection of agricultural land are important for sustainable urban development and recommended improved spatial planning to control unplanned horizontal expansion.

In the same way, Bawa et al. (2026) who examined the spatial and temporal dynamics of urban expansion and sprawl in Keffi, Nigeria, over a 21-year period, using Landsat satellite imagery from 2002 to 2023, LULC classification, landscape metrics, and Shannon's Entropy to measure the pattern and degree of urban sprawl, it was revealed that the built-up area increased from 495 ha (3.12%) in 2002 to 1,813.05 ha (11.45%) in 2023. Landscape metrics indicated increasing fragmentation and aggregation, while Shannon's Entropy increased substantially in the outer zones, from 0.007 to 0.356, indicating dispersed urban growth particularly in the eastern and northwestern parts of Keffi. The study concluded that the rapid and sprawling expansion of Keffi requires proactive urban planning and continuous geospatial monitoring to support sustainable urban development.

### *E. Telecommunication Networks*

Deploying communication satellites provides the essential backbone needed to extend reliable internet, phone, and television services across all parts of Nigeria. Space-based connectivity bypasses the massive cost and physical difficulty of laying fiber-optic cables through thick forests, rocky terrains, and remote riverine communities. This allows rural schools, primary healthcare centers, and small local businesses in under-served areas to access fast internet and modern digital tools. Satellite links also serve as crucial backup connections for commercial banks, mobile network operators, and government offices during major fiber cuts or terrestrial network outages. Furthermore, space communications enable mobile network operators to extend 4G and 5G coverage to rural cell towers without spending heavily on long-distance ground infrastructure. It also provides the radio and TV broadcast signals needed to inform, educate, and entertain citizens living far away from state capitals. Additionally, satellite systems support mobile banking, e-learning platforms, and telemedicine services that uplift rural livelihoods. In short, space technology closes the digital divide, connects isolated communities to national trade, and drives inclusive economic growth.

Lagunas et al. (2024) investigated the development of low-Earth-orbit (LEO) satellite constellations and their potential contribution to global communication network connectivity. The study adopted a technical review and analytical approach, examining the development of broadband LEO constellations, their integration with terrestrial 5G and emerging 6G networks, and their applications in remote connectivity, government services, and emergency communications. The study found that reductions in satellite manufacturing and launch costs have accelerated the deployment of LEO constellations, while their broad coverage and resilience make them useful for extending connectivity to remote and underserved areas. The authors concluded that LEO satellite systems can serve as an important complement to terrestrial communication infrastructure and contribute to the development of integrated space–terrestrial networks.

Also, Almekhlafi et al. (2025) investigated access inequality in LEO satellite networks, with particular attention to communication coverage in high-latitude regions. The study used a comparative analytical and numerical modelling approach to evaluate the coverage characteristics of Starlink, Telesat-like, Kuiper-like, and OneWeb constellations in Northern Québec and compare them with New York City. The results showed that high-latitude regions have fewer visible satellites, greater transmission delays, and lower network reliability, while higher satellite elevation angles in mid-latitude regions contribute to better signal quality and transmission rates. The researchers proposed an inter-constellation roaming mechanism that could combine the strong polar coverage of some constellations with the higher satellite density of others. The study concluded that cooperation between satellite constellations, together with terrestrial network expansion, could improve the reliability, scalability, and geographical inclusiveness of satellite-based telecommunications

### *F. Agricultural Infrastructure*

Satellite remote sensing and spatial data give agricultural agencies and farmers the precise insights needed to build strong food production networks across the nation. By monitoring crop health, soil moisture levels, and weather patterns from orbit, agricultural experts can guide farmers on the best planting times, fertilizer applications, and harvesting schedules. Satellite imagery helps state governments identify fertile land, design efficient irrigation canals, and locate optimal sites for grain silos, processing factories, and cold storage facilities near farming clusters. Space-based tracking also detects early signs of pest invasions, crop diseases, and bushfires, giving farming cooperatives enough time to protect their fields. Beyond crop management, satellite mapping helps livestock planners track pastoral migration corridors and grazing reserves, reducing conflicts between farmers and herders over land resources. It also aids agricultural banks and insurance companies in accurately assessing farm sizes and flood damages for credit delivery and prompt claim payouts. Furthermore, space data supports long-term yield prediction, helping the country plan food reserves and stabilize commodity prices. Ultimately, space technology boosts national food security, reduces farm losses, and transforms traditional agriculture into a highly profitable industry.

Peng et al. (2024) in their work, examined the effectiveness of deep-learning techniques for crop monitoring and land-cover classification using satellite remote-sensing imagery. The study adopted a comparative machine-learning approach in which four pre-trained Convolutional Neural Network (CNN) models, namely VGG16, MobileNetV2, DenseNet121, and ResNet50, were fine-tuned and evaluated for agricultural land-cover classification. The results showed that DenseNet121 and ResNet50 performed particularly well in distinguishing different crop types from satellite imagery. The study concluded that integrating satellite remote sensing with pre-trained deep-learning models can improve crop classification and provide useful information for precision agriculture, resource allocation, and agricultural management.

Lateef et al. (2025) assessed an integrated approach for assessing crop damage, loss, and recovery following flooding in Hadejia, Nigeria. The study employed a multi-source earth-observation approach that combined time-series Sentinel-1 and Sentinel-2 imagery, PlanetScope imagery, machine learning, and participatory mapping involving farmers. The results showed that the developed flood mapping and crop-recovery assessment achieved more than 90% accuracy, while only 13% of flooded cropland recovered in 2020 and 16% recovered in 2022. In addition, 91% of farmers who reported total crop loss had no observed recovery. The authors concluded that integrating satellite observations with participatory information and machine learning provides a reliable framework for assessing agricultural damage and recovery and can support post-disaster agricultural planning and food-security management in Nigeria.

### *G. Disaster Management Infrastructure*

Satellite-based early warning systems provide the critical spatial intelligence needed to predict, monitor, and respond to natural and man-made disasters across Nigeria. High-resolution orbital sensors continuously monitor river basins, weather fronts, and coastal zones, giving emergency agencies early alerts on impending floods, severe droughts, and ocean surges. This advance warning allows state governments to plan safe evacuation routes, set up temporary relief camps, and deploy emergency medical supplies before disaster strikes. During active crisis situations, satellite imagery gives disaster management teams real-time maps of flooded roads, submerged villages, and damaged bridges, helping search-and-rescue teams navigate safely. Space observation also plays a major role in tracking gullies, coastal erosion, and desert encroachment in vulnerable regions, guiding the construction of shoreline defenses and drainage networks. Furthermore, post-disaster satellite assessments allow insurance firms and humanitarian bodies to evaluate property damage accurately and distribute rehabilitation funds without delay. Additionally, space data aids environmental agencies in monitoring oil spills and industrial hazards, ensuring quick containment and cleanup operations.

Akintola (2024) aimed to develop an integrated geospatial framework for near-real-time flood monitoring and impact assessment within the flood-prone Niger River Basin in Nigeria. The study adopted an empirical geospatial research method, integrating Google Earth Engine with satellite-based observations and the Normalized Difference Water Index (NDWI) to identify and map flood-affected areas. The results demonstrated that the integration of Earth observation data and cloud-based geospatial processing could support rapid identification of inundated areas and provide spatial information for assessing flood impacts. The study further showed that near-real-time GIS processing can reduce the time required to obtain flood information and improve the availability of spatial evidence for emergency response and resilience planning. The author concluded that integrating satellite Earth observation with cloud-based GIS platforms provides a practical approach for strengthening flood monitoring and disaster-response activities in the Niger River Basin and other flood-prone areas of Nigeria.

Razavi-Termeh et al. (2025) aimed to improve the prediction and spatial assessment of multiple natural hazards through the integration of satellite remote sensing and optimized machine-learning techniques. The study employed an empirical modelling approach using Sentinel-1 and Sentinel-2 satellite imagery collected between 2015 and 2022. Random Forest models were optimized using Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) techniques to produce susceptibility maps for floods, wildfires, landslides, and land subsidence. The results showed that the optimized RF-GA model achieved accuracies of 91.1% for floods, 83.8% for wildfires, and 99.1% for landslides, while the RF-PSO model achieved 95.9% accuracy for land subsidence. The results further showed that different parts of the study area experienced different levels of multi-hazard susceptibility, demonstrating the usefulness of satellite observations for spatial disaster-risk assessment. The authors concluded that combining satellite remote sensing with optimized machine-learning models can improve multi-hazard susceptibility mapping and provide useful spatial information for disaster preparedness, risk reduction, and emergency planning.

### *H. Critical Infrastructure Security*

Satellite surveillance and high-resolution remote sensing give security agencies and infrastructure managers the operational intelligence required to protect national assets across wide geographical areas. Orbital sensors provide continuous monitoring over thousands of kilometers of oil and gas pipelines, high-voltage power lines, railway tracks, and remote border crossings that are difficult to patrol on foot. This eye-in-the-sky capability helps security forces detect illegal pipeline tapping, cable theft, track vandalism, and unauthorized human movements long before major sabotage occurs. Satellite mapping also supports maritime domain awareness, tracking vessel movements along Nigeria’s territorial waters to combat crude oil theft, illegal fishing, and sea piracy around major ports. Furthermore, space-based surveillance helps border control agencies monitor porous land borders, preventing smuggling and unauthorized cross-border incursions in remote frontier communities. It also provides law enforcement with tactical mapping data needed to protect strategic assets like dams, telecommunication towers, and military installations from physical attacks. Additionally, real-time spatial intelligence enhances quick-response capabilities, allowing security teams to coordinate ground interventions with high precision.

Ozor et al. (2025) examined the security challenges affecting oil and gas pipelines in Nigeria’s Niger Delta and assessed the feasibility of remote-sensing technologies for improving pipeline surveillance. The study employed a mixed-methods research approach, combining structured questionnaires and semi-structured interviews with stakeholders from oil companies, government institutions, security agencies, and local communities. The results indicated that third-party interference, particularly pipeline vandalism, sabotage, and crude-oil theft, remains a major threat to critical petroleum infrastructure in the region. The study further showed that remote-sensing technologies could support wider-area surveillance by identifying changes around pipeline corridors and providing spatial information for detecting potential threats and vulnerable locations. The authors concluded that integrating remote sensing with conventional security operations could strengthen pipeline monitoring, improve early identification of security threats, and support more effective protection of critical oil and gas infrastructure in the Niger Delta.

Similarly, O’Farrell et al. (2025) investigated the application of satellite remote sensing and artificial intelligence to assess the environmental impacts associated with oil pipelines in the Niger Delta. The study used Sentinel-1 Earth-observation data and machine-learning techniques to analyse spatial and temporal changes in mangrove ecosystems between 2016 and 2024 across a 9,000 km² area of Rivers State. The results identified significant mangrove degradation and enabled the researchers to map pipeline locations requiring intervention, while also identifying previously unreported sites showing evidence of oil-spill damage. The authors concluded that integrating satellite remote sensing with artificial intelligence can provide valuable spatial intelligence for monitoring vulnerable infrastructure corridors, supporting environmental protection, and improving intervention planning in Nigeria’s oil-producing regions.

## CONCLUSION

The work, the Role of Space Science and Technology in Advancing National Infrastructural Development has been done using the review research method. The review established that space science and technology provide significant opportunities for improving national infrastructural development through remote sensing, GIS, GNSS, satellite communication, Earth observation, and geospatial intelligence. Evidence from recent studies shows applications in infrastructure planning, energy-site selection, water-resource monitoring, urban expansion assessment, telecommunications, agriculture, and disaster management. However, effective utilisation requires adequate technical capacity, funding, data accessibility, institutional coordination, and supporting infrastructure. For Nigeria, strengthening the integration of space-derived information into infrastructure planning and management can contribute to more efficient, resilient, and sustainable national development.

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