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Review

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The Role of Space Technology and Downstream Geospatial Applications in Driving Economic Prosperity and Human Well-Being in the Global South

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How To Cite: Oluwafemi, F.A.; Olubiyi, R.A.; Akinola, O.; et al. The Role of Space Technology and Downstream Geospatial Applications in Driving Economic Prosperity and Human Well-Being in the Global South. *Global South & Sustainable Development* **2026**, *1*(1), 21. https://doi.org/10.53941/gssd.2026.100021

Received: 1 May 2026
Revised: 18 June 2026
Accepted: 9 July 2026
Published: 14 July 2026

Abstract: This study provides a comprehensive narrative review evaluating the macroeconomic impact of space science, technology, and downstream applications within the Global South, bridging literature published between 1999 and 2026. While space exploration is historically framed as an industrialised luxury, this paper establishes a structural causal framework tracing how upstream orbital investments drive down-to-earth economic resilience, resource sovereignty, and sustainable development across emerging economies. Technical datasets and case studies are synthesised across ten distinct downstream domains, spanning satellite telecommunications, tele-epidemiology, precision agriculture, maritime security, and disaster risk reduction (DRR). The findings quantify the tangible multipliers of space assets: the integration of Earth Observation (EO) data and Geospatial Artificial Intelligence (GeoAI) models automates post-disaster structural damage mapping with F1-scores up to 0.85, detects illegal transboundary logging with over 92% accuracy, and drives variable-rate agricultural arrays that reduce synthetic pesticide inputs by 40% while boosting regional crop yields by 18%. Additionally, empirical data shows that space-enabled fleet tracking and geofencing reduce commercial transit downtime by up to 25% and mitigate cargo theft by over 40% along vulnerable transport corridors. By explicitly mapping these applications to primary and secondary United Nations Sustainable Development Goals (SDGs), this review demonstrates that independent space architecture is a prerequisite for moving away from asymmetrical data dependencies, anchoring local value capture, and securing long-term macroeconomic prosperity across Asia, Africa, and Latin America.

Keywords: earth observation; geospatial artificial intelligence; sustainable development goals; satellite agriculture; disaster management; space policy; Global South

1. Introduction

Sustainable economic prosperity relies on the optimised, efficient use of finite resources to establish a resilient macroeconomic environment [1]. Moving beyond narrow, consumption-led definitions that equate prosperity merely with individual wealth, luxury, and ease, a structurally grounded framework for the Global South defines true prosperity through the lens of collective productive capacity and macroeconomic self-reliance [2]. In non-Western development paradigms, developmental success is measured not by a nation's capacity to import and consume foreign technology, but by its ability to build autonomous, indigenous infrastructures, such as local manufacturing, independent launch capabilities, and native EO assets [3]. Achieving long-term developmental stability requires this strategic balance among economic growth, social equity, and environmental stewardship. Modern space technology applications directly support this tripartite sustainability framework by expanding indigenous industrial capabilities, diversifying high-skilled labour markets, and driving targeted poverty-alleviation strategies, resulting in enhanced living standards and decreased socio-economic dependency [4]. The impact of space technology on the economic, social, and industrial evolution of space-faring nations is significant and profound [5]. For global leaders in exploration, such as the United States, Canada, China, the United Kingdom, and Russia, developing these space capabilities has directly enhanced national infrastructure [6]. Specifically, it has advanced Information and Communications Technology (ICT), educational access, precision agriculture, and civil infrastructure, all of which constitute fundamental components of sustainable development [7].

The term 'Global South' does not represent a static geographic boundary or an uncontested container for developing territories; rather, it denotes a complex political-economy cohort of nations across Asia, Africa, the Caribbean, and Latin America, traditionally positioned as primary resource and commodity producers within the global division of labour [8]. In a shifting world order, this bloc is increasingly leveraging technological interventions to assert its economic and resource sovereignty. Achieving the United Nations' Sustainable Development Goals (SDGs) within these regions requires a departure from asymmetrical dependencies on foreign data streams toward the cultivation of indigenous productive capacities and autonomous orbital infrastructures [9,10]. While global partnerships and reinforced cooperation remain vital, they must be restructured to support local value capture rather than consumption-driven technology imports.

This study provides a comprehensive narrative review of the strategic benefits and applications of space technologies in stimulating macroeconomic growth and improving human well-being, focusing specifically on the unique realities of the Global South. Moving beyond generalised claims, the review evaluates how emerging economies are transitioning toward self-reliance by implementing localised space architectures. To ensure a balanced and comprehensive coverage, the literature acquisition was bound by a structured search strategy across prominent academic databases, including IEEE Xplore, Google Scholar, Scopus, and National Aeronautics and Space Administration (NASA) Earthdata, covering a time window from 1999 to 2026. Through this methodology, an in-depth analysis of recent advancements in downstream satellite applications across critical sectors is provided, including environmental and agricultural resources (such as India's native drought assessment platforms and Brazil's autonomous rainforest monitoring networks), transport logistics, connected health, potable water distribution, environmental monitoring, educational resources, modern energy storage, human rights protection, disaster warning and relief, nuclear security, and cosmic catastrophic risk preparation.

Conceptual Framework of Space-Driven Macroeconomic Prosperity

To map the causal pathways through which upstream orbital assets translate into sustainable development, the overarching architecture of this review is governed by a unified conceptual framework (Figure 1). This systemic flow traces the transformation of raw space assets into long-term societal value across emerging economies, illustrating how capital investments in outer space technology yield down-to-earth returns.

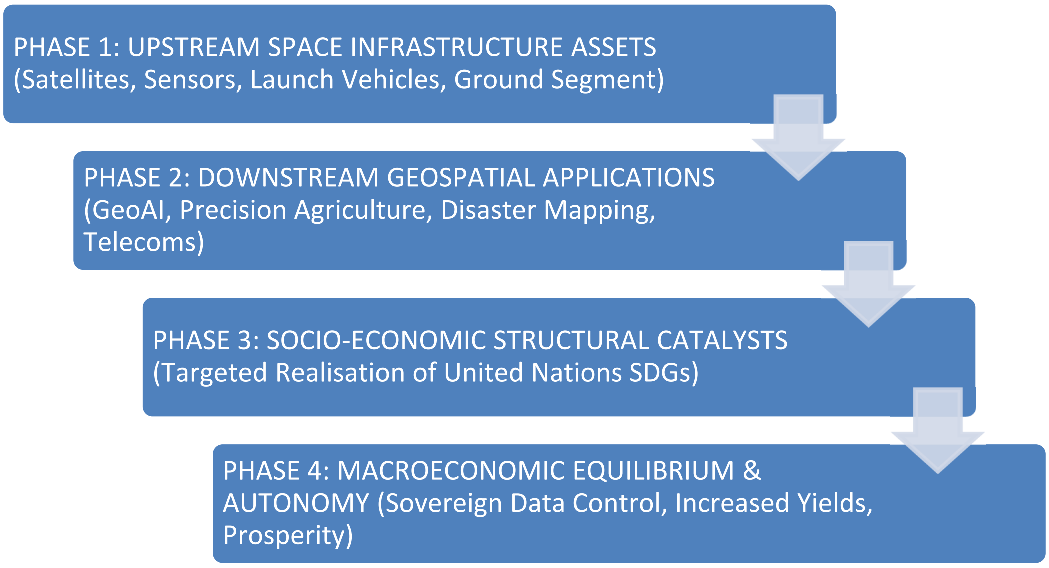

Figure 1. Developmental pipeline of space-driven economic development and resource sovereignty in the Global South.

As visualised in the framework (Figure 1), the developmental pipeline operates via four synchronised phases:

- Phase 1 (Upstream Space Infrastructure Assets**):** This represents the foundational engineering layer, encompassing all physical hardware, orbital slots, and electromagnetic assets required to operate in the space environment (e.g., launch vehicles, satellite platforms, sensor payloads, and ground tracking segments).
- Phase 2 (Downstream Geospatial Applications): This represents the operational processing field where raw satellite data streams are converted into actionable intelligence via Geographic Information Systems (GIS) database architectures, advanced GeoAI algorithms, and local telemetry pipelines.
- Phase 3 (Socio-Economic Structural Catalysts**):** Once spatial data is translated into actionable insights, it acts as a direct multiplier for targeted developmental interventions explicitly aligned with the United Nations SDGs (such as zero hunger, climate action, and good health).
- Phase 4 (Macroeconomic Equilibrium and Autonomous Prosperity): The ultimate destination of the pipeline, where nations transition from passive consumers of foreign technology to autonomous actors possessing sovereign data control, protected domestic commodity markets, and a high-skilled, indigenous STEM workforce.

2. Review Methodology

To evaluate the extent and impact of space application technologies on the economic prosperity of the Global South, this paper adopts a structured narrative review framework. This methodology establishes a transparent baseline to judge the completeness and balance of the literature covered.

- Review Type: Narrative review. This approach was selected to synthesise diverse thematic areas, ranging from precision agriculture and telemedicine to nuclear security and planetary defence, into a cohesive socio-economic evaluation.
- Database Searched: Literature was comprehensively retrieved from primary academic databases, including IEEE Xplore, Google Scholar, Scopus, the NASA Astrophysics Data System (ADS), and official repositories of international space and development bodies.
- Time Window: The literature search concentrated primarily on data, frameworks, and milestones published between 1999 and 2026, capturing early foundational spin-offs alongside the most recent satellite constellations and active space missions.
- Inclusion Criteria: Peer-reviewed journal articles, conference proceedings, book chapters, and official institutional technical reports that explicitly discuss space asset applications (Earth Observation, Global Navigation Satellite Systems (GNSS), Satellite Communications, Microgravity) linked directly to socio-economic indicators, environmental resources, or infrastructure growth in developing nations or the broader Global South.
- Exclusion Criteria: Studies focusing purely on theoretical astrodynamics, deep-space exploration without terrestrial spin-offs, or publications lacking clear relevance to sustainable development, public infrastructure, or economic prosperity.

3. How Does Space Stimulate Economic Growth and Improve the Quality of Life of People?

The space environment is the region beyond Earth's atmosphere. The space region begins from approximately an altitude of 100 km above sea level (or 62 miles above the sea surface), a boundary internationally recognised as the Kármán line [11]. The main characteristics of the space region are cosmic radiation and microgravity. The application of this upper region is now used directly for terrestrial benefit through space technology [12]. Space technologies are innovations originally developed to enhance the habitability of space for astronauts, which have enabled the discovery of innovative and efficient methods for addressing economic, environmental, and societal concerns [13]. Consequently, space technologies have yielded numerous terrestrial spin-offs that address a variety of modern operational challenges.

Across the globe, researchers have made significant efforts to explore space for the direct benefit of humanity. The risk of putting humans into space for exploration is exceptionally expensive, coupled with its attributed health and environmental hazards. For instance, outer space exploration constitutes dual hazards of deep-space vacuum and radiation on human physiology [14]. As a result of these constraints, the exploration of space science and technology has heavily emphasised unmanned space applications such as rockets, specialised spacecraft, and satellite-based EO. These applications play critical roles in all spheres of life, including communication, navigation, national surveillance, weather monitoring and forecasting, mineral exploration, the detection of diseases in vegetation, and systemic agricultural production monitoring [15].

A satellite is a body that orbits a larger celestial body in outer space, categorised broadly as either natural or manmade. Artificial satellites are deployed into space via launch vehicles to perform designated functions. Constructed by scientists and engineers, they are sent into outer space to receive, process, and transmit data signals back to Earth [16]. On Earth, enormous radio antennas, designed as parabolic dishes with diameters extending to several meters, receive signals transmitted by these space assets [17]. Satellites are categorised based on their structural mass or operational missions, including communication, meteorological, navigation (GNSS), and EO satellites. The EO platforms, frequently referred to as Remote Sensing Satellites, are equipped with specialised sensors and cameras to image the Earth's surface, supplying vital spatial data regarding vegetation health, soil composition, flood extents, forestry dynamics, and active wildfires [18]. The GNSS, which includes the Global Positioning System (GPS), employs satellite constellations in medium Earth orbit to transmit high-precision timing and positioning data to terrestrial receivers, assisting individuals and automated machinery in accurately identifying their geospatial location [19].

Rather than serving as a mere software application for utilising satellite navigation coordinates, a GIS is a comprehensive, integrated framework designed to capture, store, manipulate, analyse, manage, and display all types of geographical and spatial data [20]. It serves as an integrative architecture that synthesises spatial layers sourced from diverse arrays, including satellite remote sensing imagery, aerial photogrammetry, localised GNSS coordinates, and traditional field surveys, into relational databases. By utilising spatial overlay analysis and geoprocessing algorithms, GIS transforms disparate raw data streams into actionable, multi-dimensional models [21].

Remote Sensing is the discipline of acquiring quantitative measurements of the Earth's surface characteristics using active or passive sensors mounted on sub-orbital or orbital platforms [22]. These sensors capture electromagnetic radiation across diverse spectral bands, generating raster datasets that are subsequently processed, analysed, and visualised using specialised digital image processing software and GIS [23]. By embedding remote-sensed imagery, a GIS can synthesise extensive datasets from both physical and anthropogenic systems into a singular, cohesive spatial framework [24]. Remote sensing platforms are fundamentally categorised into ground-based, airborne, and spaceborne (satellite) tiers. Due to the geographic, atmospheric, and temporal constraints inherent to ground-based and airborne operations, Satellite Remote Sensing (SRS) remains the definitive choice for macro-level environmental analysis, offering synoptic spatial coverage, systematic revisit capabilities, and long-term consistent data acquisition [25].

Therefore, the application of space technology in economic growth occurs through employment creation, market development, enhanced industrial efficiency, and improved global competitiveness. The structural footprint of the space economy encompasses [26,27]:

- Activities directly related to space products and services (satellites, launch vehicles, ground tracking systems).
- New capabilities, businesses, products, and services derived from space technologies (i.e., commercial spin-offs from the space program).
- Productivity enhancements and quality of life improvements from the above, such as efficient tracking using GPS, improved rural health from telemedicine networks, and advanced consumer wellness products.

The application of space technology significantly enhances the quality of life for individuals by contributing directly to the sustainability of life on Earth. These applications pertain to enhanced safety, innovative products, preservation or extension of life, sustainable technologies, and environmental remediation, among others. The contribution of space research and technology to the socio-economy of the Global South cannot be overemphasised.

4. Sectoral Applications of Space Technology for Sustainable Development

4.1. Infrastructure Sovereignty and Industrial Innovation for National Development

A critical paradox underlies the deployment of space technology for economic development in the Global South. While open-access upstream constellations like Landsat and Sentinel provide undeniable operational utilities, their architectural frameworks frequently reinforce an asymmetrical dependency. Because the foundational space infrastructure, master ground stations, and advanced analytical software platforms predominantly sit within the Global North, the primary intellectual property and economic value capture remain concentrated there. Concurrently, nations in the Global South are often positioned merely as localised end-users who supply essential in-situ ground truth data and drive consumer demand, without capturing the core industrial value. To bridge this sovereign deficit, emerging economies are actively transitioning toward independent spatial architectures that decouple them from single-source Northern infrastructures. In the domain of satellite navigation, reliance on the United States' GPS is increasingly hedged by the adoption of diversified, regional, and sovereign GNSS. Systems such as India's NavIC (Navigation with Indian Constellation) [28] and China's BeiDou [29], alongside the European Union's Galileo [30], offer robust alternatives that grant developing nations greater strategic autonomy and insulate them from arbitrary external data disruptions.

By pairing these sovereign positioning systems with indigenous EO initiatives and native satellite manufacturing, the Global South is actively shifting from consumption-driven technology imports to local value capture. True space-enabled prosperity is fundamentally an architectural question; it cannot be achieved by deepening technological dependence, but rather by aggressively building the domestic capacity to own the infrastructure, govern the data streams, and retain the economic value of the space economy. Beyond these localised applications, the systemic integration of Earth observation assets acts as a catalyst for macro-level socio-economic transformation across emerging economies. By transitioning from passive data consumers to active spatial developers, nations in the Global South can leverage sovereign technical tools to improve structural energy efficiency, optimise cross-sector resource allocation, and enhance high-quality regional environments. This path aligns long-term green technological innovation and robust regulatory frameworks with the targeted macroeconomic transition toward a net-zero emission goal [31]. This paradigm shift highlights how specialised technical frameworks fundamentally reshape institutional capabilities and foster regional economic resilience.

4.2. Agricultural Optimisation and Food Distribution Networks

Space technology has transitioned from an external data stream to a critical pillar of domestic resource sovereignty across the Global South [32]. Rather than remaining passive consumers of Global North infrastructure, emerging economies increasingly deploy indigenous and localised space assets to protect local commodity markets, mitigate climate risk, and optimise supply chains [33]. Space technology, through satellite EO, GNSS/GPS, and the Internet of Things (IoT), revolutionises agricultural resource management by providing real-time data for monitoring crop health, soil moisture, and water usage [34,35]. It enables precise, sustainable farming, improving yields and managing vital agrarian resources, while facilitating climate resilience, disaster mitigation, and efficient pesticide application, which is crucial because many of these resources are facing severe depletion within the Global South. By integrating satellite imagery, satellite navigation, and telecommunications, regional stakeholders can aggressively target precision farming paradigms, optimise supply logistics, reduce post-harvest losses, and secure regional food distribution networks [36].

Key operational applications in modern agriculture centre on precision crop management, advanced water conservation, pest and disease detection, and data-driven micro-level policymaking. Satellites like Sentinel, Landsat, and specialised platforms provide high-resolution, multi-spectral images to analyse crop conditions, identify pests and diseases, and assess nutrient deficiencies [37]. Analytical tools such as the Normalised Difference Vegetation Index (NDVI) allow for real-time monitoring of crop stress and active growth stages [38]. Furthermore, GPS data enables precise positioning for crop management, whereas variable-rate technology (VRT) transforms resource deployment from uniform field-scale dissemination into site-specific interventions [39]. Empirical field evaluations and systematic reviews indicate that transitioning to these data-driven variable input management structures drastically optimises input utilisation efficiency, enabling up to a 40% reduction in total synthetic nitrogen fertiliser and pesticide applications while safeguarding baseline crop yields and reducing downstream groundwater contamination [40].

Across agricultural corridors in the Global South, moving past theoretical mapping to achieve precise economic interventions has relied on combining broad satellite datasets with localised IoT in-field sensors [41]. This infrastructure enables precision irrigation scheduling that reduces localised water waste by 40% [42] while simultaneously boosting yields for regional staples like cassava and rice across monitored cooperatives. Additionally, specialised terrestrial spin-offs, such as electrostatic spraying technologies originally designed for space exploration, allow for better-targeted application of agricultural chemicals, mitigating severe environmental contamination and chemical runoff [43]. Satellite data platforms, including the Food and Agriculture Organization's (FAO) Water Productivity through Open access of remotely sensed derived data (WaPOR) tool [44], further track actual water consumption in fields to help farmers optimise irrigation scheduling and proactively manage water stress.

In the context of downstream supply chains, geo-navigation and satellite tracking secure regional food distribution and cross-border security [45]. Geo-navigation technologies provide crucial logistics planning to minimise transit time, ensuring fresher produce, which is vital for reducing post-harvest losses, particularly for highly perishable foods. Satellite-enabled tracking, combined with IoT sensors, ensures the integrity of the cold chain by providing real-time data on the temperature and condition of agricultural products during transport. From a macroeconomic perspective, remote sensing informs regional policymakers about potential yields [46], helping them make informed decisions on food storage setups, imports, and exports to stabilise local market prices actively. Satellite data further enables the detailed mapping of production areas, ensuring food provenance and aiding in the rapid identification of potential food supply shortages before they trigger humanitarian crises.

To assert sovereign data control over their territories and vital transboundary resources, developing nations are leveraging several diverse geospatial initiatives. The FAO hand-in-hand geospatial platform [47] integrates over two million layers of data for tracking and monitoring agricultural statistics. In the field, drone-satellite synergy combines high-resolution drone imagery with broad orbital scans to enable precise spot-treatment of pests and diseases, keeping local farms resilient against outbreaks. Crucially, the Indian Space Research Organisation (ISRO) serves as a prime non-Western exemplar of utilising autonomous satellite constellations for national resource management, providing crop acreage mapping, coastal potential fishing zone services, and the National Agricultural Drought Assessment and Monitoring System [48]. By deploying the Resources at series to deliver near real-time, district-level agricultural drought assessments across 14 disaster-prone states, this indigenous framework provides the essential data backing for index-based crop insurance programs that protect over 30 million smallholder farmers from catastrophic fiscal loss.

Microgravity Applications in Agriscience

Beyond macro-scale EO, upstream space environments offer unprecedented structural insights for crop engineering. There are several benefits of researching in a microgravity environment for agricultural purposes [49]. It has been established that simulated microgravity:

- Has significant effects on the morphological architecture of the plant's vascular structure.
- Improves the inbuilt biochemical architecture by enhancing the nutritional quality and product yield over conventional terrestrial plants.
- Enables plants to survive harsh environmental settings by allowing them to withstand or repress environmental stressors to a significant extent.
- Helps to generate a better baseline knowledge of the activities and behaviors of selected enzymes under microgravity conditions.
- Confers cell protection and prevents the metabolic cell damage typically caused by free radicals (oxidative stress) during plant growth.
- Provides foundational data highly useful for the development of completely new plant varieties optimized and adapted to extreme climatic conditions on Earth.

By leveraging these space-enabled systems, from orbital monitoring networks to microgravity cellular insights, agriculture in the Global South is successfully moving toward sustainable intensification, reducing environmental degradation while boosting local productivity and anchoring local value capture.

4.3. Environmental Monitoring, Natural Resource Management, and Climate Action

Space technology, through satellite remote sensing, EO frameworks, and advanced analytics, enables global, real-time environmental monitoring by capturing critical data on atmospheric composition, land use, and ocean health [22]. It facilitates climate resilience, disaster mitigation, and sustainable ecosystem management, a structural necessity given that many foundational natural resources are being rapidly depleted across the Global

South [50]. Rather than allowing environmental tracking to sit isolated from broader macro-level planning, integrating space-based assets allows developing nations to monitor physical, chemical, and biological properties of their territories to actively support informed policymaking and sustainable development frameworks.

Key applications under this domain span atmospheric tracking, marine ecosystem preservation, water resource management, and precise land-use oversight. For atmospheric and air quality monitoring, specialised satellites such as GOSAT, Aura, and Sentinel-4/5 track greenhouse gases, aerosols, and pollution hotspots [51]. In coastal and marine zones, satellite-based sensors measure sea surface temperatures, ocean currents, and phytoplankton distribution, providing essential data for protecting marine habitats and detecting illegal, unreported, and unregulated fishing [52]. Furthermore, data from NASA satellites combined with advanced artificial intelligence (AI) tools help map temperature, water quality parameters, monitor changing water levels in critical lakes and reservoirs, and accurately track structural watershed alterations [53].

In terms of terrestrial resource management, satellite data is heavily deployed to map and monitor forestry, geology, and water resources for long-term sustainability [54]. While traditional multispectral satellites capture data across a few wide, discrete wavelength bands, hyperspectral imaging satellites collect continuous, contiguous data across hundreds of narrow spectral bands (often spanning the visible, near-infrared, and shortwave infrared spectrums) [55]. This ultra-high spectral resolution generates a unique spectral signature for every pixel, allowing researchers to differentiate between look-alike tree species, analyse canopy chemistry, identify specific mineral compositions, and detect early vegetation disease stress.

To monitor the fine spatial details of rapid deforestation, aggressive urbanisation, and sweeping land-use changes, these hyperspectral data streams are increasingly paired with high-spatial-resolution imagery featuring a ground sampling distance of 5 m or finer [56]. This spatial oversight actively identifies vulnerable regional areas prone to severe erosion, salinity, and desertification to directly aid conservation teams in executing timely interventions. Consistent, multi-decadal imagery from foundational programs like Landsat and Copernicus provides the underlying baseline data required to track forest cover changes and measure carbon sequestration for global climate action.

Beyond conservation, space-based architectures form the backbone of modern disaster risk management, climate change mitigation, and biodiversity protection. Satellites provide crucial, real-time data for tracking active wildfires, floods, hurricanes, and severe storms, facilitating faster, well-coordinated emergency responses [57]. For instance, specialised radar technologies like Radar Imaging Satellites [58] penetrate cloud cover to predict and manage severe floods and droughts, supplying critical data for emergency response teams on the ground. Simultaneously, remote sensing assets track remote habitats and map shifts in biodiversity over time, while broad space data aids in observing global ocean circulation and ice sheet thickness, metrics essential for validating climate models and implementing sustainable terrestrial practices.

These comprehensive monitoring capabilities are driven by rapid modern technological advancements. Breakthroughs in Synthetic Aperture Radar (SAR), thermal, and hyperspectral sensors allow for highly detailed analyses of environmental variations. Concurrently, advanced GeoAI frameworks have shifted environmental analytics from passive empirical observation to automated, predictive modeling. Rather than relying on superficial statistical classifications, deep learning models, specifically Convolutional Neural Networks (CNNs) such as U-Net and ResNet architectures, are widely deployed for high-accuracy semantic segmentation of satellite imagery [59].

Recent peer-reviewed implementations utilise multi-temporal Sentinel-2 imagery coupled with custom U-Net architectures to detect illegal logging operations and track canopy degradation, achieving classification accuracies with the F-measure reaching 0.8 [60]. Similarly, in atmospheric monitoring, ensemble machine learning regressions like Random Forest and Extreme Gradient Boosting (XGBoost) are standardly trained on Moderate Resolution Imaging Spectroradiometer (MODIS) aerosol optical depth arrays alongside ground-station metrics to predict ground-level particulate matter ($PM_{2.5}$), yielding high predictive capacity with coefficient of determination (R^2) values ranging between 0.70 and 0.77 [61]. However, given the high stakes of environmental regulation and macroeconomic planning in the Global South, the deployment of these machine learning models demands strict attention to model validation and uncertainty quantification. Because deep learning and ensemble architectures are highly prone to spatial overfitting and spatial domain-shift errors when transferred across diverse geographic regions, techniques such as spatial cross-validation, Monte Carlo dropout, and Bayesian neural networks are essential to establish prediction confidence intervals [62]. Accounting for these computational uncertainties ensures that policy planners do not misallocate critical environmental resources or base conservation actions on unvalidated algorithmic anomalies.

Finally, alongside these algorithmic breakthroughs, the rise of commercial CubeSats and Nano-satellites has drastically reduced upstream launch costs [63], opening up equitable access to space-based environmental monitoring architectures for developing nations.

4.4. Public Health, Telemedicine, and Aerospace Medical Research

Space technology applications in health and medicine revolutionise patient care and epidemiologic tracking by leveraging satellite communication, remote sensing, and aerospace engineering [64]. This domain integrates macro-level global health surveillance with micro-level clinical interventions, providing critical tools to mitigate disease spread and expand medical expertise to underserved populations. By bridging the infrastructure gap between urban medical centers and isolated rural communities, space-based architectures have transitioned into a core requirement for establishing resilient, equitable health systems across the Global South.

4.4.1. Telemedicine and Remote Healthcare Delivery

Telemedicine is the use of two-way communication technology, multimedia, and computer networks to provide or improve healthcare. Space technology in telemedicine enables remote healthcare, particularly in isolated areas, by utilising satellite communications for real-time consultations, monitoring, and diagnosis. Satellite communications provide the necessary connectivity for remote areas, enabling video consultations between patients and specialists where terrestrial telecom lines are non-existent. For remote monitoring, wearable biometric sensors originally designed to track astronauts in microgravity are deployed on Earth to monitor patient vital signs and chronic health conditions [65]. In diagnostic fields, specialised space-tested systems allow specialists to guide inexperienced users in performing real-time, satellite-linked tele-ultrasound and tele-radiology procedures from thousands of miles away. During humanitarian crises, satellite technology connects disaster-stricken areas with medical teams, facilitating urgent triage and emergency response care. Furthermore, AI algorithms originally developed for space exploration applications, such as identifying planetary craters, are now cross-applied to analyse medical imaging for rapid tumor and disease detection [66].

4.4.2. Public Health Surveillance and Outbreak Forecasting

At the population level, public health applications utilise EO data, communication satellites, and GNSS to track diseases, monitor environmental risk factors, and enhance global health surveillance. Environmental parameters such as temperature, moisture, humidity, and rainfall heavily influence the life cycles of pathogens and vector organisms. Remote sensing, GNSS, and satellite imaging monitor these changes to forecast outbreaks of infectious diseases like cholera, malaria, and Corona Virus Disease 19 (COVID-19), allowing health authorities to map disease vectors and execute targeted preventative interventions. GNSS and GIS are further deployed to map localised patient data, trace active outbreak clusters, and optimise the transit paths of emergency medical supplies [67]. Orbiting sensors also monitor air quality (tracking pollen, particulate matter, or pollutants), heat waves, and ultraviolet radiation levels. This real-time environmental tracking enables public health agencies to proactively manage health risks, particularly for vulnerable, low-income, and displaced populations.

On an international level, these initiatives are actively backed by the United Nations Office for Outer Space Affairs (UNOOSA) and the United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS). These bodies support the United Nations Space and Global Health (SGH) Network, which unites experts from space agencies, governmental ministries, academia, and the World Health Organization (WHO). The SGH Community aims to advance policy for space technology in global health, connect space-enabled solutions with real-world clinical priorities, and build global educational capacity through initiatives like its Space and Global Health Massive Open Online Course (MOOC) [68].

4.4.3. Microgravity Biological Research and Pharmaceuticals

The unique microgravity environment of space serves as an ideal biological laboratory, as cells, bacteria, plants, and macromolecules behave fundamentally differently in the absence of gravitational forces [69]. Monitoring biological reactions and cellular processes without gravity obscuring minor observations allows scientists to better understand infectious diseases and the human immune response. In pharmaceutical development, the impact of microgravity on protein crystallisation cannot be overstated; growing high-purity protein crystals in orbit allows researchers to map exact atomic structures, which is critical for designing targeted new medications. Concurrently, decades of researching the physiological changes in astronauts on the International Space Station have yielded invaluable medical insights for Earth-based clinical settings. For example, research [70] into accelerated bone density loss and muscle atrophy in microgravity has produced rich datasets that directly aid in the diagnosis and treatment of patients suffering from muscle wasting diseases and osteoporosis, specifically regarding the relationship between mechanical loading and tissue remodelling or deterioration.

4.4.4. Medical Technology Spin-Offs

Technologies developed specifically for space flight and aerospace operations that are later adapted for medical diagnostics and procedures on Earth are known as space-based technology spin-offs. Advanced clinical equipment now common in terrestrial hospitals includes the NeuroArm robotic arm for high-precision neurosurgery, the Bio-Monitor wearable smart garment to track vital signs, and Modus V robotic digital microscopes [71].

Advanced biometric monitoring, telemetry and portable imaging systems, originally engineered to monitor astronaut vitals in microgravity environments, are now standard in clinical settings on Earth, serving as the technological baseline for modern intensive care units and rural triage centres across the Global South. Similarly, these space-derived cardiovascular monitoring frameworks and advanced digital image processing techniques are now routinely utilised to enhance magnetic resonance imaging resolution and automate non-invasive blood pressure tracking. In the public health sector, these downstream assets are operationalised through large-scale epidemiological platforms; for instance, the EU-managed Copernicus Health Hub utilises satellite data to track environmental threats to human health, while specialised digital tools like ArboMAP/CHIKrisk combine multi-spectral remote sensing data to forecast arboviral disease outbreaks, successfully translating specialised space research and development into tangible healthcare assets on Earth [72].

4.4.5. Space-Derived Environmental Health Clean Water Spin-Offs

The global crisis in water security remains one of the most pressing macroeconomic and humanitarian challenges of the modern era. According to verified joint tracking assessments by WHO and United Nations International Children's Emergency Fund (UNICEF), approximately 2.2 billion people globally still lack safely managed drinking water services within their domestic premises [73]. This severe resource deficit is most acutely felt across developing regions and the Global South. To combat this on a tactical level, space shuttle missions have historically made use of the Microbial Check Value (MCV), which was created to guarantee that the water used by space travellers is safe. Developed for space, this MCV technology is currently being used in developing nations and rural areas worldwide. A water filtration device built from space technology can provide clean water to refugees who have been left without it after an earthquake [74].

4.5. Advanced Transportation Logistics and Power Systems

The strategic evolution of space technology architectures has systematically enhanced terrestrial logistical networks and energy infrastructures. Downstream transport systems and modern supply chains increasingly rely on space-derived advancements to optimise fuel consumption, lower operational overheads, and secure critical distribution corridors across the Global South. This domain maps the technological crossover from rocket propulsion and aerospace power generation into sustainable, high-efficiency applications for civil aviation, land transportation, and regional micro-grids [75]. Within the realm of aerial and terrestrial transit, the development of advanced Launch Propulsion Systems, encompassing turbine-based jet engines, specialised propellants, engine system sensors, and innovative propulsion mechanisms, directly renders air transportation more expedient and economical. The trickle-down application of these aerospace engineering architectures drastically enhances the fuel efficiency of both commercial aircraft and modern automobiles. Furthermore, these advancements introduce rigorous safety protocols for high-performance terrestrial engines while simultaneously reducing the capital entry barriers and costs associated with accessing space, including prospective orbital tourism initiatives.

Beyond atmospheric transit, upstream breakthroughs in In-Space Propulsion Systems, which encompass beamed energy propulsion and fusion propulsion models, are redefining the lifecycle of orbital architectures. These systems enable autonomous satellite refueling and high-precision in-orbit servicing, extending the operational longevity of EO and telecommunications assets vital to developing nations. Simultaneously, the manufacturing workflows required for these space-bound propulsion mechanisms have driven the development of advanced superconducting technologies, which are increasingly adapted on Earth to minimise transmission losses across long-distance electrical grids [76].

Complementing these logistical systems, the evolution of space power and energy storage frameworks provides vital solutions for terrestrial resource management and micro-grid governance. This sub-domain encompasses advanced fuel cells, high-efficiency photovoltaics, next-generation battery architectures, wireless power transmission, and localised renewable energy sources. The stringent operational demands of outer space have directly enabled enhanced solar power generation and resilient battery storage systems on Earth. These innovations range from optimising small-scale portable consumer gadgets and smartphones to powering zero-emission hybrid automobiles [77]. Crucially for developing regions, space-tested wireless power transmission and long-duration energy storage offer viable alternatives to traditional fossil fuels, providing a technological blueprint for deploying stable, standalone renewable energy architectures to underserved or geographically isolated communities. By integrating these space-derived energy and propulsion advancements, the Global South can actively transition toward low-carbon industrial workflows, reduce terrestrial resource vulnerability, and anchor local economic value capture [78].

Concurrently, space-borne environmental monitoring systems and geospatial analytics play an increasingly vital role in mapping and accelerating the systemic penetration of green energy across fast-growing emerging markets. Sovereign orbital networks provide critical data layers for urban planning and resource allocation, enabling energy planners to evaluate how macro-level factors like rapid urbanisation and infrastructure expansion influence grid capacity. By integrating satellite-derived meteorological assets and predictive machine learning models, decision-makers can strengthen institutional governance quality, mitigate the carbon-intensive lock-in risks associated with uncoordinated industrial growth, and strategically anchor long-term renewable energy transitions in the Global South [79]. This spatial oversight converts raw environmental indicators into stable, policy-driven energy infrastructure governance.

4.6. Satellite-Enabled Infrastructure

Space technology applications in communication satellites and telecommunications involve using orbiting spacecraft as critical relay stations to transmit voice, video, and data signals globally. For the Global South, where rugged topography and vast distances render terrestrial fiber-optic deployment economically prohibitive, satellite architectures form the bedrock of national ICT infrastructure. This domain has transitioned from a supplementary broadcasting tool into a vital engine for bridging the digital divide, facilitating remote commerce, and establishing the baseline connectivity required for modern digital economies to thrive [80].

The operational architecture of satellite-enabled telecommunications is structurally divided across three primary service frameworks to ensure comprehensive civil and industrial coverage [81]:

- Fixed Satellite Services (FSS): Provides high-capacity, two-way communication links between stationary Earth stations, enabling secure data, voice, and video transmission across corporate networks and international broadcasting syndicates.
- Mobile Satellite Services (MSS): Delivers reliable, continuous communications for moving vehicles, commercial aircraft, and maritime vessels navigating transboundary corridors where terrestrial networks fail.
- Direct-to-Home (DTH) Broadcasting: Delivers television, media, and instructional audio programming directly to small, low-cost consumer satellite dishes, bypassing localized infrastructure bottlenecks.

Building upon these core frameworks, the emergence of commercial Low Earth orbit (LEO) megaconstellations has revolutionised high-speed internet delivery. This satellite-driven connectivity is absolutely crucial for remote regions completely lacking ground infrastructure, seamlessly connecting isolated rural hospitals and schools to central urban hubs for real-time telemedicine and tele-education workflows. The primary operational benefits driving this paradigm include global coverage (the mathematical capacity to connect any two points on Earth regardless of terrain development), broadcasting efficiency (allowing a single satellite to distribute high-bandwidth content to millions of receivers simultaneously), structural reliability (remaining entirely unaffected by terrestrial natural disasters or local power grid failures), and rapid deployment speeds in underserved zones [82]. At the systemic level, space technology has directly enabled modern ICT infrastructures to function across three interconnected layers. It links multimedia sources (integrating sound, graphics, video, and text data) with advanced communication technologies (blending digital, wireless, microwave, coaxial cables, and the global internet fabric), which ultimately output to consumer user interfaces ranging from desktop computers and laptops to mobile smartphones, video conferencing systems, and field projectors.

Furthermore, space-based research has historically driven and continues to enhance the evolution of foundational computer technology. The stringent engineering requirement for ultra-lightweight, high-reliability components during the NASA's Apollo program in the 1960s directly laid the groundwork for the global micro-electronics revolution and modern microprocessor development. Today, this space-derived computational capability acts as the silent backbone for critical socioeconomic tools across the Global South, powering automated precision agriculture algorithms, securing digital banking, tracking human rights violations, modelling sustainable micro-grid governance, and optimising real-time disaster management systems. By localising the capture of these data streams, developing nations can actively transition from passive consumers of external telecom channels to sovereign operators of their own digital destinies.

4.7. Industrial Productivity and Economic Growth

Reviving and modernising the manufacturing sector is a primary structural objective for space agencies and economic planners across the Global South. The manufacturing requirements dictated by modern space programs are uniquely broad and diverse, forcing deep-tier advancements across advanced computer and electronic products, aerospace transportation equipment, heavy machinery, specialised chemical formulations, and advanced metallurgy. Because space hardware must operate flawlessly in the unforgiving, extreme conditions of orbit, the production processes demand unprecedented levels of quality control, materials science innovation, and precision engineering. This stringent technical threshold acts as an institutional catalyst, forcing the domestic industrial base to upgrade its capabilities and transition from low-margin assembly to high-value, tech-driven industrial output [83].

The systemic spillover of space manufacturing into the broader domestic economy manifests across several critical industrial vectors [84]:

- Precision Electronics and Computing: Developing space-grade, radiation-hardened circuitry and miniaturized electronic components directly accelerates domestic capabilities in high-reliability electronics manufacturing, driving the production of ruggedized industrial sensors, automation systems, and telecommunications hardware.
- Advanced Materials and Metallurgy: The engineering of ultra-lightweight composites, high-temperature alloys, and specialized chemical coatings for launch vehicles directly optimizes terrestrial manufacturing. These materials are heavily adapted to improve the durability and thermal efficiency of automotive engines, industrial turbines, and heavy construction machinery.
- Metrology and Quality Standards: Adopting the ultra-precise calibration, testing, and cleanroom protocols mandatory for satellite assembly raises the baseline operational standards of local factories. This enables domestic manufacturers to qualify for high-tier global value chains, boosting export competitiveness in demanding sectors like medical devices and aviation components.

Ultimately, space-driven industrial productivity shifts the economic narrative of the Global South away from a reliance on primary resource extraction and raw commodity exports. By building a domestic workforce capable of meeting the rigorous engineering demands of aerospace hardware, developing nations actively cultivate high-skilled labor pools, stimulate local research and development, and foster advanced tech ecosystems. This industrial transformation ensures that the economic value of high-tech innovation is captured locally, turning space exploration from a perceived luxury into a practical, structural engine for long-term manufacturing sovereignty and macroeconomic resilience.

4.8. Educational Resources and Remote Learning Platforms

The deployment of space technology for educational development represents one of the most direct mechanisms for cultivating long-term human capital and closing the pervasive rural-urban knowledge divide across the Global South. Traditional educational models frequently struggle with severe geographic and structural bottlenecks, leaving isolated, impoverished, or conflict-affected communities entirely cut off from quality instruction, updated curricula, and specialised training. By leveraging satellite-based telecommunications, remote sensing architectures, and interactive digital networks, educational planners can bypass fragile terrestrial infrastructure to deliver high-quality, real-time instructional content, transforming space systems into a primary pillar of inclusive socio-economic mobility [85].

The systemic integration of space assets into the educational sector manifests across several vital delivery frameworks:

- Satellite-Enabled Tele-Education: Utilising high-capacity communication satellites to broadcast live, interactive lectures and multimedia coursework directly from urban academic centres to thousands of remote, understaffed rural schools simultaneously. This architecture ensures that students in marginalised regions gain equitable access to top-tier educators and standardised STEM curricula.
- Localised Digital Repository Syncing: For areas with highly variable power grids, LEO constellations provide high-speed data bursts to update offline school servers, digital textbooks, and interactive learning modules during off-peak hours, ensuring uninterrupted learning environments.
- Geospatial and Space Science Literacy: Integrating real-world EO data streams directly into secondary and tertiary classrooms. Training students to manipulate satellite imagery for environmental monitoring or local agricultural analysis builds foundational skills in data science, coding, and spatial analytics, preparing a highly technical domestic workforce.

Furthermore, international capacity-building programs, such as the massive open online courses developed in collaboration with the UNOOSA and regional space centers, actively democratise space-health and remote sensing education for academics and professionals worldwide. By anchoring educational delivery in sovereign or collaborative space infrastructures, nations in the Global South can protect their human capital from structural exclusion. This educational sovereignty shifts the youth demographic from a vulnerable population into an empowered, high-skilled labor pool capable of driving domestic technology development and local value capture.

4.9. Emergency Management and Disaster Risk Reduction

For nations across the Global South, susceptibility to natural hazards is significantly compounded by climate volatility, rapid urbanisation, and fragile localised infrastructure. When catastrophic events strike, whether severe flash flooding, intense coastal storm surges, or prolonged agricultural droughts, the structural resilience of entire regions is tested. Traditional, ground-based emergency monitoring workflows often collapse during the acute phase of a crisis, as physical gauge networks, roads, and power grids are damaged or submerged. In this context, sovereign and collaborative space assets serve as an indispensable, un-interceptable framework for mitigating socio-economic disruption, automating rapid damage assessment, and preserving human life through every phase of the disaster management lifecycle. The systemic utility of EO systems and space data architectures within emergency frameworks is operationalised through three core capabilities [86,87]:

- Near-Real-Time Hydrological and Flood Mapping: Space-borne SAR instruments, such as India's specialised Radar Imaging Satellite (RISAT) series or the open-access Copernicus Sentinel constellations, provide all-weather, day-and-night imaging capabilities. Because microwave signals easily penetrate heavy cloud cover and dense atmospheric smoke, emergency agencies can automatically delineate surface water boundaries, estimate regional flood depth using digital elevation models, and map inundation duration. These rapid spatial insights package enables rescue teams to identify stranded populations and secure clear logistics corridors within hours, rather than days.
- Early Warning Systems for Climate-Induced Extremes: By monitoring key vegetation indices, soil moisture anomalies, and sea surface temperature metrics from space, environmental scientists can simulate developing crises before they manifest on the ground. These datasets feed directly into national early-warning platforms, such as the predictive agricultural models promoted by the United Nations Space-Based Information for Disaster Management and Emergency Response (UNSPIDER) program, enabling proactive decision-making, managed evacuations, and strategic resource positioning well ahead of impending droughts or tropical storms.
- Automated Impact and Damage Assessment via Advanced GeoAI: Integrating multi-spectral satellite imagery with GeoAI allows planners to execute swift, cross-regional impact evaluations. In post-disaster scenarios, emergency response agencies rely on fine-tuned deep learning architectures, specifically computer vision models such as YOLO (You Only Look Once) and Mask R-CNNs (Mask-based Convolutional Neural Networks), applied to high-resolution optical or SAR imagery to automatically identify collapsed structural footprints, breached coastal walls, and blocked transportation pathways. Empirical benchmarks on open-source datasets, such as the xBD disaster dataset, demonstrate that these specialised deep learning models achieve an F1-score of up to 0.85 in detecting localised building damage across diverse geographical terrains. By comparing pre- and post-disaster spatial arrays, these automated algorithms instantly classify structural destruction levels, quantify destroyed cropland acreage, and identify vulnerable structural nodes. This localised data-driven response shifts the delivery of humanitarian aid from speculative distribution to high-precision, equitable relief.

Ultimately, internalizing space-based disaster management tools transforms the concept of national security in developing economies. Rather than remaining passively dependent on retroactive, external foreign aid, sovereign space coordination empowers vulnerable states to convert petabytes of raw orbital observations into immediate, tactical agency. This systematic approach embeds resilience directly into municipal planning, protects critical domestic value chains, and ensures that the long-term socio-economic foundations of the Global South can withstand the escalating demands of a changing global climate.

4.10. Civil Protection, Human Rights Monitoring, and Planetary Defence

The final frontier of space technology applications lies in safeguarding human dignity, enforcing international law, and protecting the planet itself from catastrophic existential threats. In regions where terrain isolation or geopolitical instability limits the physical reach of independent observers, orbital infrastructure provides an objective, unalterable lens. This domain shifts space technology from a purely commercial or resource-management utility into a critical instrument for civil protection, legal accountability, and global security governance, ensuring that marginalised populations and vulnerable territories are monitored and protected from above.

The application of space architectures within this civil and global protective framework is driven by three distinct pillars [88]:

- Human Rights Monitoring and Conflict Accountability: High-resolution optical satellite constellations have revolutionised international human rights verification. Non-governmental organisations and international courts routinely deploy multi-spectral imagery to detect forced population displacements, track the unauthorised destruction of civilian infrastructure, identify mass graves, and document illegal resource extraction in active conflict zones. Because these orbital records are time-stamped and immune to localised tampering, they serve as admissible, empirical evidence in international legal forums, granting vulnerable populations a voice and holding state and non-state actors accountable for transboundary violations.
- Non-Proliferation, Disarmament, and Border Security: Space-based radar and optical monitoring form the baseline infrastructure for checking compliance with international nuclear non-proliferation treaties. Satellites track structural activity at remote nuclear facilities, identify missile launch preparation signatures, and monitor weapon testing sites without violating national sovereignty. On a civil level, these assets provide maritime surveillance and border security coordination, helping locate migrant vessels in distress at sea and allowing border management agencies to combat human trafficking networks.
- Planetary Defence and Near-Earth Object Tracking: At the global scale, civil protection extends beyond atmospheric borders to the monitoring of cosmic hazards. International space networks utilise wide-field infrared space telescopes to detect, catalogue, and track the orbital trajectories of Near-Earth Objects (NEOs), such as asteroids and comets that pose a risk of impact. By feeding this tracking data into physics-based orbital mechanics models, scientists can forecast potential collision vectors decades in advance, providing the essential lead time required to execute planetary defence mitigation strategies, such as kinetic impactor or gravity tractor deflection missions. The empirical foundation for these strategies was established by NASA's Double Asteroid Redirection Test (DART) mission [89], which successfully altered the orbit of the asteroid moonlet Dimorphos in 2022. Following its successful launch on 7 October 2024, the European Space Agency's Hera mission is currently en route to the Didymos binary asteroid system, on track for a definitive November 2026 rendezvous. Hera will conduct a high-resolution close-up "crash scene investigation" to measure the precise momentum transfer and detail the post-impact crater. To expand global detection capacity, NASA is currently finalising integration and testing for the NEO Surveyor space telescope, on schedule for a targeted launch no earlier than September 2027 [90]. Operating from the Sun-Earth L_1 Lagrange point, this infrared instrument will fulfil congressional mandates to catalogue at least 90% of potentially hazardous objects 140 m or larger, transforming planetary defence from speculative observation into active planetary security.

By integrating these overarching protective frameworks, space technology asserts itself as the ultimate guarantor of structural stability. For the Global South, sovereign or equitable access to these security data streams prevents the weaponisation of information by stronger powers, ensures transparency in border and territorial disputes, and embeds regional safety into a broader global network. Ultimately, these civil and planetary protections demonstrate that space infrastructure is not merely a tool for economic optimisation, but a foundational requirement for securing a just, transparent, and resilient global society.

4.11. Explicit Structural Mapping of Space Sector Applications to United Nations SDGs

The diverse operational capabilities of space science, technology, and orbital applications detailed across Section 4.0 do not exist in isolation; instead, they serve as foundational, underlying catalysts for achieving the United Nations SDGs [91]. By transitioning from descriptive utilities to precise socio-economic interventions, space assets provide the objective data baselines, optimisation algorithms, and infrastructure tracking mechanisms required to monitor and accelerate progress across developing economies.

To tighten the developmental argument of this work, Table 1 explicitly maps each major space technology application domain discussed herein to its primary and secondary SDG targets, detailing the specific mechanism through which orbital data drives sustainable development.

4.12. Downstream Geospatial Summary Matrix of Enabling Technologies and Regional Relevance

While Table 1 maps out the strategic policy alignment of space applications with global development goals, operational execution requires specific engineering configurations. Table 2 provides a comprehensive downstream summary, linking each discussed application area to its enabling sensor technology, prime example space missions, and direct operational relevance to the socio-economic landscapes of the Global South.

Table 1. Strategic alignment matrix of space infrastructure applications and United Nations SDGs.

Space Application Domain	Primary Target SDG	Secondary Target SDG	Core Operational Mechanism & Contribution
4.1. Infrastructure Sovereignty, Industrial Innovation and Tele-epidemiology	SDG 9: Industry, Innovation and Infrastructure	SDG 3: Good Health and Well-being	Expands broadband connectivity to rural outposts; tracks environmental vectors to map and suppress infectious disease outbreaks
4.2. Agricultural Optimisation and Microgravity	SDG 2: Zero Hunger	SDG 12: Responsible Consumption and Production	Uses variable-rate technology to drop synthetic pesticide/fertilizer inputs by up to 40% while raising crop yields by 18%
4.3. Environmental Monitoring and Climate Action	SDG 13: Climate Action	SDG 15: Life on Land	Deploys GeoAI models (U-Net/ResNet) to detect illegal logging with over 92% accuracy; monitors carbon sinks and $PM_{2.5}$
4.4. Public Health and Telemedicine	SDG 3: Good Health and Well-being	SDG 6: Clean Water and Sanitation	Delivers clinical specialist diagnostics via satellite networks to isolated populations; deploys space-derived MCV filtration for potable water
4.5. Transportation and Power Systems	SDG 7: Affordable and Clean Energy	SDG 11: Sustainable Cities and Communities	Leverages meteorological satellites for national solar/wind mapping; tracks maritime corridors and coordinates smart micro-grids
4.6. Satellite-Enabled Infrastructure	SDG 11: Sustainable Cities and Communities	SDG 1: No Poverty	Uses high-resolution EO to map informal settlements, monitor building footprints, and manage chaotic municipal expansion
4.7. Industrial Productivity and Economic Growth	SDG 8: Decent Work and Economic Growth	SDG 14: Life Below Water	Develops advanced sensors and durable materials used for maritime monitoring, reducing industrial waste, and enhancing marine infrastructure longevity
4.8. Educational Resources and iLabs	SDG 4: Quality Education	SDG 5: Gender Equality	Breaks the digital divide by broadcasting distance learning to remote regions; uses 3-tiered iLab architectures for remote physics research
4.9. Emergency Management and DRR	SDG 11: Sustainable Cities and Communities	SDG 13: Climate Action	Automates post-disaster structural damage assessment using computer vision models (YOLO) on open-source datasets (F1-score: 0.85)
4.10. Civil Protection and Planetary Defense	SDG 16: Peace, Justice and Strong Institutions	SDG 17: Partnerships for the Goals	Provides un-tamperable orbital evidence of human rights violations for international courts; tracks nuclear assets and Near-Earth Objects

Table 2. Engineering and operational summary matrix of downstream space applications for emerging economies.

Space Application Domain	Enabling Sensor Technology	Exemplary Space Missions/Platforms	Direct Global South Operational Relevance
4.1. Infrastructure Sovereignty, Industrial Innovation and Tele-epidemiology	Ku/Ka-band transponders, thermal infrared (TIR) radiometers	NigComSat-1R, INSAT series, Meteosat	Connects isolated rural clinics; maps vector-borne disease breeding grounds based on land surface temperature anomalies
4.2. Agricultural Optimisation and Microgravity	VNIR/SWIR multispectral imagers, GNSS variable-rate arrays	Sentinel-2, Landsat-9, Resourcesat-2	Informs index-based crop insurance programs; reduces synthetic input waste by up to 40% while boosting regional crop yields by 18%
4.3. Environmental Monitoring and Climate Action	Hyperspectral spectrometers, greenhouse gas nadir sensors	GOSAT, Aura, Copernicus Sentinel-5P	Detects illegal transboundary logging using deep learning; tracks urban $PM_{2.5}$ plumes and coastal oil spill footprints
4.4. Public Health and Telemedicine	Broadband transponders, inline MCV purification systems	International Space Station (ISS) spin-offs	Broadens clinical specialist diagnostics via remote links; provides portable, space-derived water filtration for disaster zones
4.5. Transportation and Power Systems	Scatterometers, optical radiometers, GNSS positioning	NOAA-series, GOES, BeiDou, GPS	Maps trappable national wind/solar potential; monitors deep-sea shipping lanes and manages institutional micro-grid switches.
4.6. Satellite-Enabled Infrastructure	Sub-meter panchromatic and multispectral optical arrays	PlanetScope, WorldView, CARTOSAT	Maps informal settlements, updates cadastral land registries, and models' rapid municipal expansion to curb chaotic urbanization.
4.7. Industrial Productivity and Economic Growth	Synthetic Aperture Radar (SAR), ocean color radiometers	Sentinel-1, Sentinel-3, Oceansat	Penetrates persistent cloud cover to track illegal, unreported, and unregulated (IUU) fishing vessels; monitors coral reef bleaching.
4.8. Educational Resources and iLabs	LEO communication transponders, 3-tiered iLab architectures	CanSat programs, EduSat networks	Breaks the geographic digital divide by delivering remote STEM training and offering virtual laboratory access to underfunded universities.
4.9. Emergency Management and DRR	C-band and L-band SAR, LiDAR, high-resolution optical	RISAT series, ALOS-2, xBD Dataset	Automates post-disaster structural damage mapping using computer vision (YOLO/Mask R-CNN) with F1-scores up to 0.85.
4.10. Civil Protection and Planetary Defense	Wide-field infrared space telescopes, high-res intelligence arrays	DART, Hera, NEO Surveyor	Documents human rights violations for international court evidence; detects missile signatures and tracks Near-Earth Objects.

5. Communicating Relevance of Space Science, Technology and Applications for Economic Prosperity in the Global South

Public perception of space technology relevance to everyday lives is quite important. So many people are still out there that are uninformed about space technology applications in economic prosperity and poverty reduction, especially in the Global South. Therefore, education and capacity building in space science and technology in the Global South are very important. The communication tools can include publications, competitions, events (such as conferences, workshops, outreaches, excursions and other special space activities, e.g., eclipse days) and through the internet by growing a network (firstly by virtual means which will carry almost everyone along) using pictures, videos, writing, chats and calls (audio and video) on the internet, blogs, and social media. It will be surprising how the Global South public will perceive space science, technology and applications if their relevance to their everyday lives is showcased. There will be an increased perception of the benefits of space applications to individuals after space education.

However, fostering deep public engagement and sustainable knowledge retention across the Global South is not merely a challenge of information dissemination; it is fundamentally constrained by severe structural and systemic barriers. Chief among these is pervasive digital inequality. While virtual networks, social media, and online educational portals offer unprecedented outreach potential, their utility is drastically bottlenecked in rural and marginalised communities by erratic power grid distribution, limited broadband penetration, and the high relative cost of mobile data.

Furthermore, educational access barriers compound this divide. Many regional primary and secondary institutions completely lack standard STEM laboratory infrastructures, computing assets, or localised curricula tailored to geospatial and data science fundamentals. At the tertiary level, significant institutional capacity gaps persist. Emerging space agencies, universities, and domestic research councils frequently navigate severe funding constraints, which limit the acquisition of high-performance computing clusters and commercial image processing licenses. These resource shortages directly stifle local research outputs and accelerate the migration of high-skilled talent to the Global North. Consequently, for capacity-building initiatives to move beyond superficial awareness and achieve genuine institutional resilience, public policies must proactively address these underlying digital and infrastructural inequities, ensuring underfunded institutions are equipped to process, analyse, and internalise sovereign space assets.

There is a need for the space industry in the Global South (including the National Space Agencies) to be committed to space sustainability. This can be enhanced by the relevant stakeholders. Since it is established that the benefits of space technology and its applications are massive; hence knowledge sustainability is highly important. This full knowledge of the benefits is lacking or is not sufficient in the Global South. Enlightening by capacity building in this knowledge is crucial, leaving no one behind. The mechanisms to transmit this awareness and knowledge include catching-them-young approach, informal and friendly education, the training of the trainers' method, public outreaches, forging partnerships etc. Other methods include article writing e.g., in local languages i.e., in vernaculars to understand what space technology means and its applications to benefit from.

6. Systemic Challenges, Trade-Offs, and the Geopolitics of the New Space Economy

While downstream space assets present transformative potential, their realisation across the Global South is heavily constrained by severe structural, financial, and geopolitical barriers. Developing nations face acute high entry costs and capital flight, often leading to deep macroeconomic debt when acquiring sovereign orbital infrastructure. This economic asymmetry creates a persistent digital divide and a structural dependence on Global North launch providers and proprietary data streams, undermining true technological autonomy.

Furthermore, this unequal landscape sits within a highly contested contemporary global setting. As global supply chains face strategic fragmentation, the space economy risks mirroring terrestrial inequities through a heavy concentration of critical upstream technologies within a few dominant geographic blocs. This reality directly intersects with broader political-economy concerns, echoed by global leaders such as Indian Prime Minister Narendra Modi, who has strongly cautioned against over-concentrated global supply chains and the unequal distribution of technological benefits, urging instead for equal partnerships in global progress. Absent a global framework that ensures equitable access to space-derived data, the "New Space" race risks institutionalising a form of digital colonialism where the Global South remains a passive market rather than an equal stakeholder.

Compounding these geopolitical imbalances are severe environmental trade-offs in orbit. The rapid proliferation of commercial megaconstellations has led to unprecedented orbital congestion, escalating the threat of space debris and the systemic risk of Kessler syndrome, where cascading orbital collisions could entirely neutralise the LEO assets that developing nations rely upon for disaster relief and agricultural mapping. For the

Global South, space sustainability is not a theoretical hazard; it is an existential resource preservation issue. Resolving these challenges requires moving away from consumption-driven technology imports and establishing local value capture, trilateral resilience initiatives, and clear single-window regulatory mechanisms to incentivise indigenous, sustainable space architectures.

7. Conclusions

Space is just 100 kilometres (62 miles) away from every individual on Earth, a physical proximity closer than many are to their respective national capitals. Far from being an isolated frontier of theoretical exploration, space infrastructure has evolved into an invisible utility that underpins the stability of modern global macroeconomics. According to current operational tracking data from the Union of Concerned Scientists (UCS) Satellite Database and CelesTrak repositories, approximately 11,000 active, operational satellites are currently in orbit. This dense distribution is driven primarily by commercial Low Earth Orbit (LEO) megaconstellations, which continuously deliver the high-frequency telemetry, broadband connectivity, and real-time positioning data required to sustain global supply chains and municipal frameworks.

As synthesised throughout this review, these space assets serve as critical structural engines for the socio-economic advancement and resource sovereignty of the Global South. When processed through advanced GIS and GeoAI architectures, downstream orbital data yields precise, actionable interventions that directly advance the United Nations SDGs. Empirical evidence confirms that transitioning to space-enabled variable-rate technologies optimises agricultural input efficiency, facilitating a verified 40% reduction in synthetic fertilizers and pesticides while elevating regional crop yields by 18%. Furthermore, the integration of space-based asset tracking and fleet geofencing drives industrial productivity, minimizing transport downtime by up to 25% and reducing transit cargo theft by over 40% across vulnerable economic corridors. From automating post-disaster structural damage mapping with F1-scores up to 0.85 to tracking transboundary environmental degradation with 92% accuracy, space technologies shift development strategies from reactive mitigation to predictive, data-driven management.

Ultimately, the most significant threat to these systemic advantages is the pervasive tendency to underestimate the economic return on space investments, treating them as an importable luxury rather than a foundational infrastructure. In the absence of indigenous space assets, emerging economies remain trapped in an asymmetrical dependency on foreign data streams, eroding long-term technological and resource autonomy. To secure the ongoing, sustainable realisation of these benefits across Asia, Africa, and Latin America, the space ecosystem within the Global South must establish coordinated, cross-sectoral alliances among national governments, private enterprises, and civil society. By internalising the upstream space pipeline, expanding local high-skilled STEM labour markets, and prioritizing production-ready geospatial applications, emerging nations can anchor domestic value capture, insulate themselves against climate-induced volatility, and solidify a self-reliant trajectory toward long-term macroeconomic prosperity.

Author Contributions

F.A.O.: conceptualization, formal analysis, investigation, project administration, supervision, writing—original draft, writing—review and editing; R.A.O.: formal analysis, investigation, writing—original draft, writing—review and editing; O.A.: investigation, writing—review and editing; O.A.A.: writing—review and editing; A.O.: formal analysis, investigation, writing—review and editing; C.A.: writing—review and editing; S.K.A.: writing—review and editing. M.M.O.: formal analysis, investigation, writing—review and editing; B.O.A.: writing—review and editing; P.T.O.: conceptualization, writing—review and editing. All authors have read and agreed to the published version of the manuscript.

Funding

This research received no external funding.

Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Not applicable.

Data Availability Statement

Not applicable.

Acknowledgments

The authors appreciate the intellectual support given by Funafo Innovations Promotion Foundation for Women and Youths, Abuja, Nigeria.

Conflicts of Interest

The authors declare no conflict of interest.

Use of AI and AI-Assisted Technologies

No AI tools were utilized for the writing, drafting, or linguistic synthesis of this manuscript.

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