

Article



Protecting Development Gains Beyond 2030: From Earth Observation to Resilient Decisions

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Abstract: Post-war multilateral institutions, national policies, public investment and scientific advances contributed to substantial, though unevenly distributed, development gains. Climate change, water-related hazards, environmental degradation, economic instability, debt pressures, conflict and weakening institutional trust increasingly threaten the physical and institutional assets accumulated through decades of development. This article reorients the discussion around a central proposition—protecting development gains requires a shift from reactive risk management towards anticipatory resilience supported by science, Earth observation and frontier technologies. The article develops a conceptual framework linking three ideas such as development gains, resilience and Earth intelligence and examines how the evolution of science, technology and innovation (STI) governance has shaped societies' capacity to produce and use scientific knowledge. A longitudinal review of seven UNESCO World Science/Science Reports published between 1993 and 2021 is used to trace changes in STI governance across six dimensions, i.e., framing and context, national governance architectures, funding and political economy, international coordination, emerging-technology governance, and implementation capacity. Water resilience is then used as an Earth-observation case study because water simultaneously supports agriculture, settlements, ecosystems, energy and economic activity while also transmitting many climate-related risks. The article demonstrates the complementary roles of Earth observation satellite systems like Landsat, Sentinel, MODIS, SRTM, NISAR, SWOT, GRACE/GRACE-FO, including the techniques as GNSS-Reflectometry and data products as OPERA in observing different components of the water system. It then proposes a Data–Information–Knowledge–Wisdom–Action (DIKWA) pathway through which raw Earth-observation data can be transformed into locally relevant policy action. The central argument is that access to data alone does not generate resilience. Development protection depends on institutional capacity to transform data into information, information into knowledge and knowledge into context-sensitive decisions through the integration of scientific evidence with local wisdom. The article concludes that the post-2030 agenda should place Earth intelligence within an enabling ecosystem of infrastructure, institutions, skills, governance, open and equitable data access and international cooperation. The article defines six policy recommendations concerning development-gain assessments, federated Earth-intelligence infrastructure, durable institutional capacity, inclusive knowledge-sharing, responsible AI governance and iterative monitoring.



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1. Introduction

The international development system constructed after the Second World War (WWII) contributed to substantial, though unevenly distributed, gains across multiple development domains, although their scale and distribution varied across and within countries [1–3]. Institutional frameworks of international cooperation, national policies aligned with international policy instruments, scientific progress and related proliferation, infrastructure investment and financial mechanisms contributed to documented improvements across several development domains [4]. These development achievements represent accumulated stocks of physical infrastructure, human capital, institutions, knowledge, productive capacity and social welfare. The central concern of this article is that these gains are increasingly exposed to reversal. It is important to note that the contemporary risk landscape differs substantially from the conditions under which many development institutions and policies were established in post WWII conditions. Climate change is intensifying pressures on water, land and ecosystems; floods, droughts, landslides and other hazards are causing damage to infrastructure and productive assets [5]; debt and fiscal constraints reduce governments' capacity to invest in adaptation and reconstruction. In addition, geopolitical tensions, in many instances, disrupt cooperation and technology flows; and, overall, the declining trust is weakening the legitimacy of collective action. This article, in this context, identifies this as a polycrisis of implementation capacity in which interacting shocks have slowed down the development progress and also causing the already-achieved development gains eroding away. The Sustainable Development Goals (SDG) Report 2025, for example, indicates that only 35 per cent of assessable SDG targets are on track or showing moderate progress, while 18 per cent have regressed below their 2015 baselines [6]. The challenge is not only to define future ambitions, it is also the increasing difficulty of sustaining and protecting achievements already made. This creates a fundamental policy question for the post-2030 period—how can societies use the scientific and technological capabilities accumulated over recent decades to anticipate risks, protect development assets and sustain progress under conditions of increasing uncertainty? This article examines this question and shows how geospatial and frontier technologies could play roles in this tail-end of SDG operations and in post-2030 conditions.

Earth observation is particularly important because development gains are embedded in landscapes, natural resources and infrastructures that change through time. These changes, especially the out-of-pattern changes, resulted from natural and anthropogenic factors or both in the occurrence of natural resources jeopardize the rhythms of development progress. For example, rivers continuously shift their course causing bank erosion, they become polluted, dry up in many instances, water in the reservoirs fluctuate, groundwater declines, coastlines retreat, cities expand in unplanned ways, agricultural systems intensify to meet the growing need of food supply and hazards repeatedly affect the same locations. Satellite observations provide a means of observing these changes at various spatial and temporal scales by facilitating dynamic data collection dynamically that conventional ground observations alone cannot provide. Many national and subnational institutions, particularly in settings with limited technical and financial resources, face constraints in converting Earth-observation data into operational decision. The article argues that the problem is not only data scarcity. It presents constraints in analytical and institutional capacity, skilled professionals, interoperable systems, financing and mechanisms for integrating scientific knowledge with local experience and wisdom. The article consequently shifts the focus from 'more data' to the institutional and analytical pathway through which data become actionable intelligence. Against this background, the article asks three related research questions.

- I. First, how has the governance of science, technology and innovation evolved in ways that have shaped countries' capacity to generate and use knowledge for development?
- II. Second, how can Earth observation demonstrate the transition from development gains to resilience-building, using water as a representative Earth-system case?
- III. Third, what methodological pathway can enable developing countries to convert Earth-observation data into locally appropriate policy action rather than treating satellite data as an end in themselves?

The article addresses a gap between three bodies of discussion that are often considered separately. These are (i) the historical evolution of Science Technology and Innovation (STI) systems, processes and governance that contributed in achieving development gains, (ii) the rapidly expanding technological capabilities of Earth observation and frontier analytics and, (iii) the practical problem of translating geospatial observations into policy decisions that can support current development processes and also to protect development gains, especially in the developing country contexts. Existing discussions commonly demonstrate the technical capabilities of individual

missions, or examine STI policy at national and international levels, and less attention is given to the complete chain linking development gains, risk, Earth observation, analytical knowledge and locally grounded action. The contribution of this article is therefore integrative rather than a new algorithm or satellite-data product. The article makes four contributions. First, it conceptualizes development gains as assets that require active protection rather than as irreversible outcomes. Second, it connects development resilience to Earth intelligence, understood here as the capacity to integrate Earth-observation data, analytical technologies, models, socioeconomic information and local knowledge into actionable understanding. Third, it provides a longitudinal stocktaking of STI governance using seven UNESCO World Science/Science Reports as a consistent documentary lens. Fourth, it proposes a Data–Information–Knowledge–Wisdom–Action (DIKWA) pathway for moving from Earth-observation measurements to context-sensitive policy action, illustrated through water resilience. The resulting argument is that technology is an enabling capability, while institutions, people, governance and local knowledge determine whether that capability produces resilient development. By integrating these four contributions, the article moves beyond technology-centric accounts of Earth observation and offers an institutionally grounded framework for protecting development gains, a perspective that is currently underrepresented in both the resilience literature and the science-policy interface. It is imperative to mention that water-resilience component is used in this article for conceptual and illustrative purposes and to show how multiple observations form Earth intelligence, not claim to quantify resilience or policy outcomes in any specific country or basin.

2. Conceptual Framework

2.1. Development Gains as Accumulated Assets

Development gains are treated in this article as accumulated stocks rather than as isolated improvements in indicators. The assets are categorized into five groups. They include, first, physical assets such as roads, bridges, reservoirs, irrigation systems, power infrastructure, housing, schools and health facilities. Second, productive assets such as agricultural land, enterprises and livelihoods. Third, human assets such as education, skills and health. Fourth, institutional assets such as public agencies, regulatory systems and scientific organizations. Fifth, knowledge assets generated through research, monitoring and experience. This asset-based interpretation draws on the capital approach to development, which understands development as the accumulation of stocks—physical, human, natural, and institutional that generate flows of well-being over time [7]. The conceptual shift is important because it reframes development from a question of whether a target has been achieved at a particular point in time to a question of whether the underlying assets that support that achievement are being sustained. This aligns with the resilience literature's emphasis on maintaining system functions under shock [8] and with recent calls to protect development gains as an explicit policy objective in the post-2030 agenda.

This interpretation is important because hazards do not merely create short-term losses. Repeated shocks can destroy or degrade the capital accumulated through decades of investment and thereby move a society backwards. The distinction also changes the meaning of development policy. If development is regarded only as the achievement of a target at a particular point in time, a country can appear to have succeeded even when the assets supporting that achievement are becoming increasingly vulnerable. A resilience perspective instead asks whether the underlying systems can continue to perform when exposed to shocks. Protecting development gains therefore becomes a core component of development policy rather than an additional activity under disaster or challenge management. This asset-based interpretation nevertheless requires attention to distribution and difference. Development gains are neither uniformly distributed nor experienced. Improvements in aggregate national indicators may coexist with regional disparities, social inequalities and unequal exposure to environmental risks. The framework therefore considers not only whether development assets are preserved, and whose assets, livelihoods and capabilities are protected, who bears residual risk, and who participates in defining protection priorities. It is also important to note here that development gains are therefore not the same as development outcomes or indicators; they are the underlying assets, infrastructure, institutions, skills, knowledge, and productive capacity that make those outcomes possible and sustainable.

Operational Definitions of Development Assets

For analytical clarity, this article operationalizes development gains as five interrelated categories of accumulated assets, i.e., material, productive, human, institutional and knowledge assets (Table 1). These categories provide a conceptual basis for identifying what development policies and investments create, what environmental and socioeconomic pressures may threaten, and what resilience-oriented interventions should seek to protect. The categories are analytically distinct but functionally interconnected. For example, the resilience of

productive assets depends partly on material infrastructure, human capabilities, institutional support and access to relevant knowledge.

Table 1. Operational definitions and illustrative assessment indicators for development assets.

Asset Category	Operational Definition	Illustrative Indicators or Assessment Methods
Material	Physical infrastructure and built facilities accumulated through development investment.	Infrastructure extent; service coverage; physical condition; functionality; accessibility; hazard-related damage and service interruption.
Productive	Resources, enterprises and livelihood capacities that generate goods, services and income.	Productive land area; agricultural output; employment; enterprise continuity; livelihood diversity; income or production losses.
Human	Health, education, skills and individual capabilities that support development and responses to risk.	Educational attainment; technical skills; health status; access to essential services; risk awareness; capacity to interpret information.
Institutional	Organizations, governance arrangements, regulatory systems and implementation capabilities that support collective action.	Institutional continuity; service-delivery performance; interagency coordination; staffing and skills; implementation capacity; regulatory effectiveness.
Knowledge	Scientific, technical, experiential and locally grounded knowledge available for understanding conditions and informing decisions.	Data availability and quality; monitoring continuity; accessibility of records; knowledge-sharing arrangements; integration of scientific and local knowledge; use of evidence in decisions.

Material assets refer to tangible physical infrastructure and built facilities accumulated through public and private investment, including roads, bridges, reservoirs, irrigation systems, electricity infrastructure, housing, schools and healthcare facilities. Their condition can be assessed through indicators such as physical extent, service coverage, structural condition, functionality, accessibility and the extent of damage or service disruption following a hazard.

Productive assets refer to the natural and economic resources, enterprises and livelihood-related capacities that enable individuals, households and communities to generate goods, services and income. They include agricultural land, productive natural resources, livestock, enterprises, equipment and livelihood infrastructure. Their condition can be assessed through indicators such as productive land area, agricultural output, enterprise continuity, employment, livelihood diversity, income-generating capacity and losses attributable to environmental or socioeconomic disturbances.

Human assets refer to the health, education, skills, knowledge and capabilities of individuals that enable them to participate in development processes, maintain livelihoods and respond to changing conditions. Potential indicators include educational attainment, literacy, relevant technical skills, health status, access to essential services and the capacity to understand, interpret and act upon risk information. These assets also include the capabilities required to use scientific and technological information effectively.

Institutional assets refer to the organizations, governance arrangements, regulatory systems, administrative capabilities and established mechanisms through which societies coordinate resources, deliver services, manage risks and implement development policies. Their condition can be assessed through indicators such as institutional continuity, service-delivery performance, coordination across agencies, implementation capacity, availability of skilled personnel, regulatory effectiveness and the capacity to mobilize resources and respond to emerging risks.

Knowledge assets refer to the accumulated scientific, technical, experiential and locally grounded knowledge generated through research, monitoring, education, institutional memory and community experience. They include environmental observations, geospatial datasets, historical records, analytical models, documented practices and local or Indigenous knowledge. Their condition can be assessed through the availability, quality, accessibility, continuity and practical use of relevant information, as well as the capacity to integrate different sources of evidence into decision-making.

These operational definitions establish potential dimensions for assessing the condition and vulnerability of development assets. They do not imply that the present study measures each category empirically. Rather, they provide an analytical foundation for subsequent applications in which context-appropriate indicators can be selected according to the development objectives, geographical setting, available data and nature of the risks under consideration. Within the proposed framework, protecting development gains therefore means not only maintaining the physical existence of assets but also sustaining their functionality, productive value, institutional support and capacity to generate and use knowledge over time.

2.2. Resilience as the Capacity to Protect and Sustain Development Gains

Resilience is used here as the capacity of coupled human–environment systems to anticipate, absorb, adapt to and recover from shocks while maintaining essential functions and preserving the assets required for future development. The concept is deliberately broader than post-disaster recovery. A resilient system, in this sense, is not merely one that recovers after a shock; it is one that anticipates change, maintains critical services during disruption, learns from experience, and adjusts its institutions and infrastructure over time so that development gains are not eroded. Anticipatory resilience is used here to describe the forward-looking dimension of resilience, such as the capacity to identify emerging risks, reduce exposure and vulnerability before shocks occur, and adjust institutions and infrastructure in anticipation of changing conditions. This distinguishes it from reactive risk management, which responds to shocks after they have occurred. Anticipatory resilience draws on the literature on adaptive capacity and transformative resilience [9,10] and connects directly to the article’s central argument that protecting development gains requires a shift from reactive to anticipatory approaches. This interpretation also connects resilience directly to development gains. For instance, a flood warning system that protects people and allows critical infrastructure and productive assets to be repeatedly damaged is only partially successful from a development-protection perspective. Similarly, groundwater monitoring that identifies depletion but is not linked to appropriate water allocation rules, agricultural planning and community institutions may fail to translate scientific observations into effective water management and long-term water resilience. Resilience therefore requires a feedback system linking observation, interpretation, decision, intervention and learning.

2.3. Earth Intelligence as an Enabling Capability

Earth intelligence (EI) is used in this article to describe the integrated capability to observe Earth-system conditions, detect change, understand processes, assess risks, anticipate future states and support decisions. Earth intelligence extends the idea of Earth observation beyond the acquisition of images or measurements. It combines satellite observations with ground observations, weather information, digital elevation models, hydrological and other process-based models, socioeconomic information and different frontier technologies like artificial intelligence, cloud computing. Finally, expert interpretation of the results has to be done by the experienced professionals, researchers and scientists housed in knowledge agencies. The emphasis is consequently on the intelligence produced from observations rather than on the observations alone. The conceptual relationship can be expressed as a chain, like development gains create assets and services; environmental and socioeconomic pressures expose those assets to risk; resilience provides the capacity to anticipate and manage those risks; and Earth intelligence strengthens resilience by providing timely, spatially explicit and repeatable evidence. It is important to note here that the institutional and human capacities determine whether data and observations become useful information and whether information is converted into knowledge and finally knowledge fused with local wisdom contribute in informed decision making.

The conceptual relationship is better understood as a multidirectional and iterative system rather than a linear chain (Figure 1). Development gains generate physical, productive, human, institutional and knowledge assets, while environmental and socioeconomic pressures expose these assets to changing risks. Resilience provides the capacity to anticipate, absorb, adapt to and recover from disturbances, as well as to learn and transform in response to changing conditions. Earth intelligence strengthens this capacity by integrating Earth-observation data, ground measurements, analytical models, socioeconomic evidence and local knowledge. These relationships are reciprocal, the protection of development gains depends on effective resilience, while the performance of resilience measures generates new evidence that informs subsequent analysis, decisions and interventions. The DIKWA pathway operationalizes this iterative process by transforming data into information, knowledge, context-sensitive wisdom and action, with monitoring and evaluation feeding the outcomes back into the decision-making process. The effectiveness of the overall system consequently depends not only on technological capabilities but also on institutional coordination, professional expertise, inclusive knowledge-sharing and the capacity to learn from experience.

2.4. The Conceptual Logic

The framework proposed in this article therefore contains four linked layers (Figure 1). The methodological components of this figure are given in Table 2. The first is the development layer, comprising accumulated assets such as physical, productive, human, institutional and knowledge resulted from development gains. The second is the risk and resilience layer, where hazards and systemic pressures threaten those gains and where anticipatory, adaptive and transformative capacities are developed. The third is the Earth-intelligence layer, which integrates Earth observation, frontier technologies and other knowledge sources. The fourth is the policy-action layer, where

scientific knowledge is combined with institutions, governance arrangements and local wisdom to determine priorities and interventions. Constraints at any layer can reduce the effectiveness of the overall system.

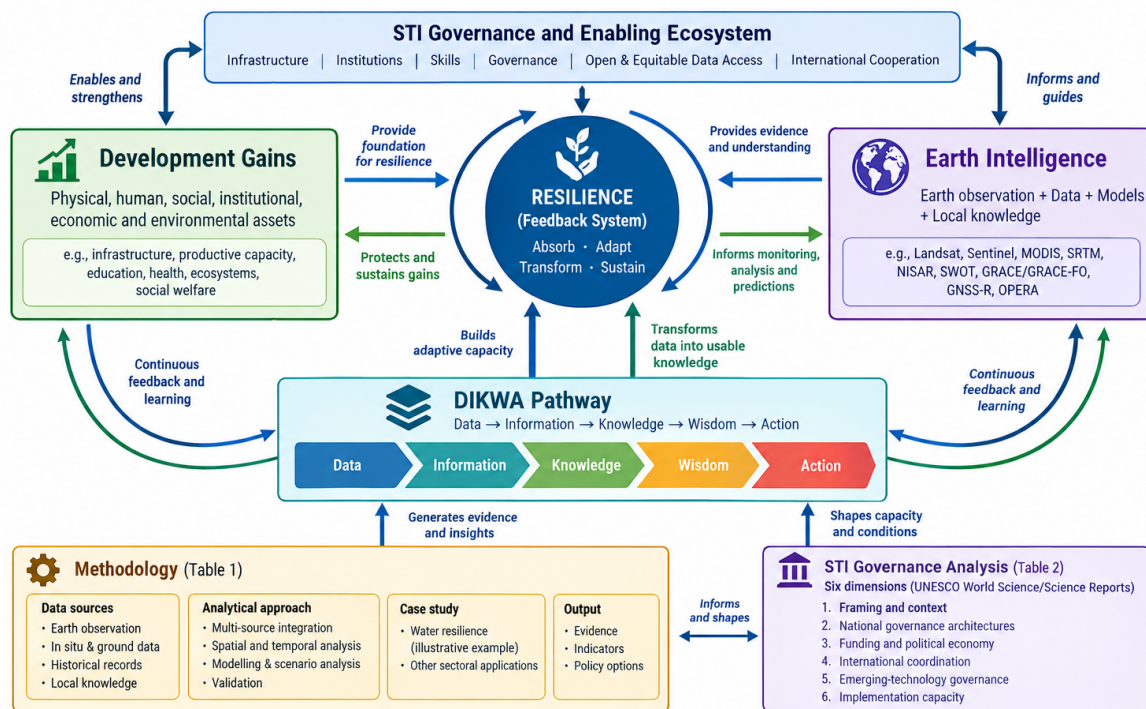


Figure 1. Resilience concept from the protection of development-gain perspective. Resilience here is broader than commonly used in disaster risk management literature.

3. Methodology

The article uses a qualitative, integrative documentary methodology combined with a technology-oriented analytical case study. The methodology is designed to trace how STI governance, Earth-observation capability and decision-making can be connected to the protection of development gains and also to support ongoing development activities. Three methodological components were used for performing necessary activities in this article. First, relevant documents were selected for review; secondly, analytical discussions based on expert-opinions were included and finally, the mission-selection criteria of geospatial data sources were examined so that recommendations can be made in the use of this state-of-the-art geospatial data and methods to protect and sustain development gains towards resilience.

3.1. Selection of Documents and Related Literature

The principal documentary body of literature consists of seven UNESCO World Science/Science Reports published between 1993 and 2021. These are World Science Report 1993, 1996 and 1998, followed by UNESCO Science Reports 2005, 2010, 2015 and 2021. The seven UNESCO World Science/Science Reports were selected because they (i) form a temporally distributed series produced by a single international organization; (ii) were published under a consistent institutional mandate; (iii) explicitly address science, research capacity, innovation policy, and the science–development relationship; and (iv) provide an internally comparable documentary lens across nearly three decades. These reports are used as a deliberately bounded and internally comparable documentary series, not as a representative sample of global STI scholarship, and that no claim is made that they capture the full universe of STI policy literature or national STI systems. Each report was reviewed using a directed qualitative content analysis structured by the six analytical dimensions already identified (framing and context; national governance architectures; funding and political economy; international coordination; emerging-technology governance; implementation capacity). The six dimensions were retained from the original analytical work and function as a pre-defined coding framework, applied consistently across all seven reports. For each dimension, we systematically extracted (a) explicit statements of policy orientation, (b) institutional arrangements described, (c) financing and coordination mechanisms, and (d) identified constraints and gaps. These extractions were then compared across the seven reports to identify continuities, shifts, and persistent themes. The UNESCO Science reports are used as a structured stocktaking of STI governance narratives, not as a systematic review of

all national STI systems, and that interpretations drawn from them should be understood as analytically bounded rather than universally generalisable.

The first three reports were published under the World Science Report title, while the later reports adopted the UNESCO Science Report title. They were selected because they form a temporally distributed series produced by the same international organization and explicitly examine science, research capacity, innovation, policy and the relationship between science and development. This continuity provides a consistent documentary lens through which changes in STI governance can be traced over nearly three decades. UNESCO is also institutionally appropriate for this purpose because its STI work explicitly connects science, technology and innovation with economic, social and environmental development and focuses on creating enabling environments, capacity-building and international collaboration. The 2021 Science Report in particular monitors trends in science governance and scientific endeavour from the perspective of development and examines the transition towards digitally and ecologically smart development [11]. The selection should therefore not be interpreted as claiming that UNESCO reports represent all STI scholarship. Rather, they are used as a deliberately bounded and internally comparable documentary series for tracing the evolution of global STI governance. Additional international reports and technical literature are used selectively where needed to contextualize contemporary development pressures, water resilience and Earth-observation missions. These sources do not replace the UNESCO documents; they complement it by connecting the governance narrative to current water and Earth-observation applications.

3.2. Analytical Dimensions

The UNESCO reports were reviewed across six analytical dimensions: (i) framing and context of STI, (ii) national STI governance architectures, (iii) funding mechanisms and the political economy of innovation, (iv) international coordination and multilateral governance, (v) governance of emerging technologies and (vi) implementation capacity. These dimensions were retained from the original analytical work because together they capture both the evolution of STI institutions and the constraints that affect whether scientific capability reaches society. For the Earth-observation case, the analysis asks four questions. These are (i) what development function does water support, (ii) what pressures threaten that function, (iii) what observable Earth-system variables are needed to understand the threat, and (iv) how can those observations be translated into action? This creates a direct bridge between the conceptual framework and the technology case.

3.3. Selection Criteria of Earth Observation Missions and Geospatial Data Sources

Earth-observation systems were selected purposively rather than as an exhaustive inventory (Table 2). Five criteria were applied, these are (i) direct relevance to water-system observation, (ii) complementarity with other observations rather than duplication, (iii) ability to contribute to temporal or spatial coverage in data-scarce environments (iv) operational or emerging relevance to resilience applications, and (v) potential to be integrated into analytical workflows that transform observations into information and knowledge. On this basis, the case emphasizes Landsat, Sentinel, MODIS (instrument aboard the Terra and Aqua satellites) and SRTM (Shuttle Radar Topography Mission, an 11-day Shuttle mission in 2000 and its elevation datasets remain in use) as foundational systems and NISAR (NASA–ISRO Synthetic Aperture Radar), SWOT (Surface Water and Ocean Topography), GRACE/GRACE-FO (The Gravity Recovery and Climate Experiment and the Gravity Recovery and Climate Experiment—Follow On), GNSS-R (Global Navigation Satellite System-Reflectometry) and OPERA (Observational Products for End-Users from Remote Sensing Analysis) as complementary contemporary capabilities.

Table 2. Methodological procedures adopted in the work.

Methodological Components	Selection/Analytical Rule	Purpose
1. Literature review		
Documents, literature	Seven UNESCO World Science/Science Reports, 1993–2021	Trace STI governance evolution through a consistent longitudinal source
2. Analytical dimension and discussions		
STI dimensions considered	Framing; governance architecture; funding; international coordination; emerging technologies; implementation	Identify institutional change and persistent constraints
3. Selection criteria of earth observation missions and geospatial data sources		
Case-study domain	Water and water-related development functions	Connect development gains, threats and resilience
EO missions/systems	Relevance, complementarity, coverage, operational relevance, analytical integrability	Demonstrate how multiple observations form Earth intelligence

4. Evolution of Science, Technology and Innovation Governance

The analysis of the selected UNESCO reports suggests a broad transformation in the governance of using STI from predominantly state-led and linear approaches towards distributed, multi-stakeholder, mission-oriented and increasingly systemic arrangements. The applications of STI in wide range of sectors such as agriculture, health, industry, education, security, communication supported societies to overcome different development challenges. The reports document persistent inequalities in scientific capacity, financing and access to technology, which constrain some national STI systems' ability to translate scientific advances into development outcomes. However, this evolution matters for development protection because the ability to use Earth intelligence depends on the wider STI ecosystem such as research institutions, funding, human resources, data systems, technology-transfer mechanisms, international cooperation and public-sector capacity.

4.1. From Scientific Capacity to Innovation and Mission Orientation

The early reports [12–14] placed strong emphasis on unequal scientific capacity, the relationship between science and society, technological change and the need to strengthen scientific infrastructure. The reports also identified tensions between science as a public good and science as a market good and also between rapid technological change and regulatory capacity. The 2005 and 2010 reports marked a stronger innovation orientation, with greater attention to commercialization, intellectual property, knowledge transfer and government–university–industry relationships. By 2015, STI was increasingly framed in relation to the SDGs and global development challenges, while local and indigenous knowledge received greater recognition. The 2021 report reflects a more complex context characterized by digital and green transitions, the COVID-19 pandemic and geopolitical competition [11–17].

4.2. National Governance Architectures and the Political Economy of Innovation

The reports indicate a transition of STI from centralized, state-dominated governance towards collaborative and mission-oriented systems. Across the selected UNESCO reports, three partially overlapping governance orientations can be identified: state-led coordination; facilitative arrangements involving research councils, universities and firms; and more systemic, cross-sectoral and mission-oriented approaches. These orientations are analytical tendencies rather than universal stages followed by all countries. They may coexist within the same national STI system, with their relative importance varying across institutional and political contexts. This is particularly relevant to Earth intelligence because geospatial problems rarely fit within a single administrative sector. For example, flood risk, groundwater depletion or change in the coastal environment may simultaneously involve water, agriculture, environment, urban development, infrastructure, disaster management and finance. At the same time, implementation constraints remain significant like policy discontinuity, limitations in institutional capacity, coordination or continuity, lack of inter-agency coordination and limited private-sector absorptive capacity can interrupt the accumulation of scientific and technological capability. The reports identify policy discontinuity in some national contexts, where changes in government or administrative priorities have interrupted long-term STI investment and institutional learning. Such discontinuity is especially damaging for Earth-intelligence systems because they require long time series, stable institutions with appropriate policy directives, enabling conditions to retain trained professionals and maintenance of data and computing infrastructure.

The UNESCO reports document a shift from predominantly public funding towards greater private-sector participation, while persistent global inequalities remain. The concentration of research spending, researchers and patents in a relatively small number of countries creates an uneven technological landscape. Market incentives accelerated innovation in commercially attractive fields, and technologies serving public goods and less profitable sustainability challenges generally received inadequate investment. Intellectual-property (IP) arrangements similarly encouraged innovation while potentially restricting diffusion of technologies that are important for climate adaptation, health and public resilience. For development protection, this suggests that Earth intelligence should not be treated solely as a commercial technology market. Open and interoperable data, public research, regional capacity-building and long-term institutional support are necessary where the social value of information exceeds its immediate commercial value. This is particularly important for countries and subnational jurisdictions with constrained analytical, institutional or financial capacity, where technological dependence can otherwise persist even when satellite data are nominally open.

4.3. International Coordination and Strategic Interdependence

The reports show a transition from predominantly North–South cooperation and large-scale international scientific projects towards a more multipolar system involving South–South cooperation and strategic interdependence. Emerging economies have developed greater endogenous scientific capacity, while international scientific networks continue to support cooperation. At the same time, geopolitical competition and technological sovereignty have fragmented technology ecosystems. Earth observation illustrates this tension clearly. For instance, the Earth system is shared and requires global observation, while data infrastructures, satellite capabilities and advanced analytics are increasingly embedded in strategic competition. The implication is that resilient development requires both technological capability and cooperative governance. Open science, equitable access to data, regional training centres, science diplomacy and South–South cooperation can reduce capacity divides and help prevent Earth intelligence from becoming concentrated in a small number of states, firms and research organizations with highly concentrated technical and financial capabilities. It is also important to mention that open data alone does not eliminate technological inequality and that federated, regionally shared infrastructure is necessary to reduce capacity divides.

4.4. Emerging Technologies: Innovation Faster Than Governance

A persistent theme across the reports is regulatory lag. Technologies are developing faster than institutions can establish appropriate governance. The issue, first visible in discussions of biotechnology and information technology, has expanded to AI, gene editing, nanotechnology and space technologies. Contemporary governance therefore requires adaptive regulation, ethical oversight, accountability and inclusion. AI adds another dimension because systems trained on incomplete or non-representative data can reproduce bias, while automated decisions can obscure responsibility. The same principle applies to Earth intelligence. Automated classification, change detection and prediction can improve decision-making, even if their outputs remain dependent on data quality, model assumptions and contextual interpretation. Consequently, Earth intelligence should augment rather than replace professional judgement, institutional accountability and local knowledge.

A central implication of this analysis for the present article is that STI governance ultimately matters because it determines whether scientific capability becomes developmental capability. The UNESCO reports repeatedly identify policy discontinuity, weak coordination, inadequate implementation, limited data availability, accessibility or continuity. The reports also point towards permanent scientific advisory mechanisms, stronger STI and SDG data systems, mission-oriented research and development provisions, Open Science, local and indigenous knowledge and stronger regional cooperation [11]. These priorities provide the institutional bridge between the evolution of STI governance and the Earth-intelligence framework proposed here.

5. Water Resilience as an Earth-Observation Case Study

Water is used as the case study because it sits at the centre of development and resilience. Water supports drinking-water and sanitation services, agriculture and food production, energy, industry, ecosystems and settlements. At the same time, many of the most damaging climate-related shocks are transmitted through water related issues such as floods, droughts, changing precipitation, glacier and snow dynamics, groundwater stress, sea-level rise and changing river regimes. Water therefore provides a useful system to demonstrate both the value of development gains and the need to protect them. The water-development relationship is not one-directional. Investments in water supply, sanitation, irrigation, drainage, reservoirs, flood protection, hydropower and water-resource institutions generate development gains. These gains improve health, food security, productivity, energy access and economic activity. Yet the same assets can become vulnerable when hydrological conditions change. The UN World Water Development Report has emphasized that climate change affects water availability, quality and quantity and can consequently threaten water supply, food security, energy, health, economic development and poverty reduction [18]. Groundwater provides another example—it can buffer drought and support rural and urban water supply, while excessive abstraction can undermine long-term water security [19]. The case example is therefore not a single basin-specific experiment. It is a system-level Earth-observation case demonstrating how complementary observations can be assembled to understand water-related development risks. The purpose is to show why no single satellite provides a sufficient representation of the water system and why the practical value of Earth observation emerges through integration. In this case study satellite missions, data products and related geospatial techniques are mentioned. The distinction among them (Table 3) include, a satellite mission is the satellite system and its programmatic framework (e.g., SWOT, NISAR, GRACE-FO), a data product is a processed dataset derived from one or more missions (e.g., OPERA-DSWx), and a technique is a methodological approach that may be implemented across missions (e.g., GNSS-R).

Table 3. Distinguishing Missions, Products, and Techniques.

Category	Definition	Examples	Role in the Manuscript
Satellite system	A satellite system with defined sensors and instruments, orbit, and programmatic objectives	Landsat, Sentinel-1/2, MODIS (on Terra/Aqua), SRTM, NISAR, SWOT, GRACE/GRACE-FO, CYGNSS	Provide the foundational observation capability; each mission is a distinct system with specific sensors and coverage
Data product	A processed dataset derived from one or more missions, often distributed by a program	OPERA-DSWx (surface water extent), OPERA RTC-S1 (radar backscatter), GRACE mascons (terrestrial water storage)	Represent the analysis-ready output; products operationalize mission data for specific applications
Technique	A methodological approach for deriving geophysical information, implementable across missions	GNSS-R (GNSS-Reflectometry), InSAR (Interferometric SAR), optical change detection, data fusion	Enable the extraction of information from mission data; techniques are not missions themselves

5.1. Foundational Earth-Observation Systems

Landsat satellite series provide a long historical record for mapping rivers, lakes, wetlands, floodplains, land-use change and watershed conditions. Sentinel-1 and Sentinel-2 add more frequent observations and complementary radar and optical information, while MODIS (Moderate Resolution Imaging Spectroradiometer) instruments onboard the Terra and Aqua satellites provide broad-area and high-frequency observations useful for floods, droughts and vegetation dynamics. SRTM supplies the topographic framework required for watershed delineation, drainage analysis, flood modelling and understanding terrain-controlled water movement [20–22]. Together these systems demonstrate that resilience depends on the continuity and complementarity of observations.

5.2. Satellite Missions and Geospatial Data Sources for Water Resilience: NISAR SWOT GRACE/GRACE FO GNSS-R and OPERA

Five satellite based geospatial data sources have been used in the article with the purpose is to demonstrate complementarity across observation types, not to provide a comprehensive mission inventory. These satellite based remote sensing data sources were selected purposively using the five criteria already stated in Section 3.3. NISAR (NASA-ISRO Synthetic Aperture Radar) satellite adds high-resolution, all-weather radar observations that are particularly valuable for detecting change in the land surface deformation. Its interferometric capability can detect small changes in land elevation, while repeated observations can support the assessment of land subsidence and other processes associated with water extraction, especially from the groundwater aquifers. Groundwater is not directly measured by NISAR, rather, radar observations can reveal surface consequences and near-surface conditions that become informative when combined with broader water-storage observations and hydrological information [23,24]. SWOT (Surface Water and Ocean Topography) satellite provides a major advance in the observation of surface water by measuring water-surface elevation and spatial extent across rivers, lakes, reservoirs and wetlands. This moves analysis beyond the simple question of where water is located towards questions of how water level, area, storage and discharge are changing. Such information is especially valuable in basins where in-situ monitoring networks are sparse, discontinuous or not openly accessible. SWOT can be combined with rainfall, DEMs (Digital Elevation Models), hydrological models and surface-water products to improve flood, drought and water-resource assessments [25,26].

GRACE and GRACE-FO (The Gravity Recovery and Climate Experiment and the Gravity Recovery and Climate Experiment—Follow On) satellites provide a fundamentally different observation of the water cycle by detecting changes in Earth’s gravity field associated with mass redistribution. At appropriate spatial and temporal scales, these measurements reveal changes in terrestrial water storage, including groundwater, soil moisture, surface water, snow and ice. Their coarse spatial resolution means that groundwater changes are normally inferred by combining terrestrial-water-storage anomalies with other information, but their ability to reveal large-scale storage changes complements the surface observations provided by optical and radar missions [27–29]. GNSS-Reflectometry (Global Navigation Satellite System-Reflectometry) uses reflected navigation signals to infer characteristics of the Earth’s surface. Spaceborne GNSS-R observations can contribute frequent information on near-surface soil moisture and surface-water dynamics, making them useful for observing rapid changes following rainfall, flooding and drying. It is important to note that GNSS-R should not be interpreted as a direct groundwater-storage measurement; its value lies in constraining the near-surface component of the hydrological cycle and helping connect rainfall, soil moisture, surface water and deeper storage when combined with other datasets [30,31].

The OPERA (Observational Products for End-Users from Remote Sensing Analysis; OPERA is a satellite-data processing and product-generation project) program states the transition from individual satellite images to analysis-ready Earth-observation products. Its dynamic surface water extent products use optical and radar

observations to provide pixel-level information on surface-water presence. Optical observations provide detailed surface information, while radar can provide water related information even in cloud cover conditions and at night. OPERA is therefore particularly useful for identifying where surface water occurs and how its spatial extent changes, while SWOT and GRACE/GRACE-FO provide complementary information on water elevation, storage and broader terrestrial-water changes [32,33].

5.3. From Observations to Protection of Water-Related Development Gains

The value of the missions becomes clearer when the water system is represented as an interconnected set of processes. It has already been mentioned that data received from satellites like Landsat and Sentinel can reveal changes in water bodies, land cover and floodplains. For instance, MODIS can provide frequent large-area observations, SRTM (Shuttle Radar Topography Mission) provides terrain conditions, OPERA identifies surface-water extent, SWOT measures water-surface elevation and storage-related dynamics, GNSS-R provides near-surface moisture information, NISAR contributes information on inundation, soil-water conditions and deformation and GRACE/GRACE-FO provides large-scale terrestrial-water-storage change. The evidence linking these observations to outcomes is drawn from the published application literature cited in the sections, and that the article's contribution is to synthesize that evidence into a decision-oriented framework, not to generate new empirical findings. However, it is imperative to note that no individual satellite observation is sufficient, but their combination can reveal changes that are otherwise difficult to detect. This integrated perspective is directly relevant to development protection. For example, emerging flood can threaten roads, bridges, agricultural land, settlements and power infrastructure. Drought can reduce agricultural production, increase pressure on groundwater and undermine energy and household water supplies. Persistent groundwater depletion can affect water security and induce land subsidence. Coastal and deltaic change can alter freshwater availability and increase exposure of settlements and productive land. The Earth-observation system therefore shifts the management question from responding after damage occurs to identifying changes early enough to influence planning, infrastructure management, allocation, preparedness and investment.

6. From Earth Observation to Policy Action

The central practical argument of this article is that Earth-observation data do not automatically generate policy value. The transformation requires a sequence through which measurements become meaningful information, multiple information streams become knowledge and knowledge is interpreted with local experience, wisdom and institutional priorities to produce appropriate action. The proposed pathway is expressed as Data–Information–Knowledge–Wisdom–Action (DIKWA). In the present context, DIKWA is not presented as a rigid hierarchy or as a claim that scientific knowledge is superior to local knowledge. Rather, it is a practical framework for organizing the transformation from observation to decision making and prioritizing actions.

6.1. The DIKWA Framework for Multi-Level Operations of Geospatial Application

The DIKWA framework builds on the well-established DIKW hierarchy which describes the progression from data to information to knowledge to wisdom [34,35]. However, DIKWA (Table 4) differs from DIKW in three important respects. First, DIKWA adds a fifth level, *Action*, which explicitly recognizes that the purpose of the pathway is not merely understanding but intervention. The inclusion of *Action* addresses a persistent criticism of the DIKW hierarchy, that it is descriptive rather than decision-oriented and does not account for the institutional, political, and practical factors that determine whether knowledge is actually used [36]. Second, DIKWA is designed specifically for Earth observation and resilience applications, where the transition from data to action is mediated by geospatial technologies, analytical workflows, and institutional decision-making processes. Third, DIKWA is not presented as a rigid hierarchy but as a feedback system (Figure 1) in which action generates new data, and monitoring and evaluation feed back into the pathway. This reflects the iterative and adaptive nature of resilience-building, in which interventions are continuously tested and revised in light of new evidence.

Table 4. DIKWA framework for utilizing geospatial data for informed decision making.

Level	Core Question	Typical EO/Frontier Tools	Human/Institutional Requirement	Policy Value
Data	What is observed?	Landsat, Sentinel, MODIS, SRTM, NISAR, SWOT, GRACE/GRACE-FO, GNSS-R, field sensors	Data infrastructure, metadata, quality control, access	Evidence base

Table 4. Cont.

Level	Core Question	Typical EO/Frontier Tools	Human/Institutional Requirement	Policy Value
Information	What pattern or change is occurring?	Classification, time series, change detection, cloud computing, AI/ML; different computational tools are used to derive information by processing data	Skilled analysts, computing, validation	Situation awareness
Knowledge	What does the change mean and why?	Data fusion, hydrological models, socioeconomic layers, expert systems	Domain experts, institutions, interdisciplinary collaboration	Prediction, prioritization, programme design
Wisdom	Which option is justified, legitimate and feasible in this context?	Scientific evidence, Indigenous and other place-based knowledge, institutional memory, ethical and distributional analysis.	Knowledge-sharing protocols, representative participation, deliberation, conflict-resolution mechanisms, documented agreement and accountability.	Context-sensitive, legitimate and revisable collective judgment.
Action	What should be done and monitored?	Early warning, decision support, digital governance, operational services	Authority, finance, implementation capacity, accountability	Protection of development gains

6.1.1. Level 1—Data: Observing the Earth

Data are measurements or observations of conditions, events and processes. In Earth observation they may be optical reflectance, radar backscatter, interferometric phase, water-surface elevation, gravity-derived storage anomalies, soil-moisture indicators or digital elevation. Data may be primary or derived, spatially referenced or non-spatial and may come from satellites, field instruments, GNSS stations, weather stations, river gauges or socioeconomic systems. The critical requirements at this level are reliable acquisition, metadata (i.e., data about data), accuracy and quality control, appropriate spatial and temporal resolution, continuity and accessibility. The most important limitation at this level is that data are observations rather than explanations. A satellite may show that a wetland has expanded, a river has migrated or a region has lost terrestrial water storage, but it does not by itself establish why the change occurred or what public authorities, affected groups and other relevant actors consider appropriate about it.

6.1.2. Level 2—Information: Extracting Patterns and Meaning

Information emerges when data are processed and organized so that meaningful patterns and relationships become visible. Remote-sensing classification, change detection, time-series analysis, and AI-assisted interpretation are tools at this level. Cloud platforms and workflow processes such as Google Earth Engine (GEE) and specialized infrastructures such as the Alaska Satellite Facility (ASF) can reduce the computational and technical barriers to processing large Earth-observation archives. AI and machine learning can assist with segmentation, pattern recognition and anomaly detection, provided that model outputs are validated and interpreted in context. For water resilience, information may include flood extent, rates of river migration, changes in reservoir area, trends in surface-water elevation, patterns of soil moisture, spatial distribution of land subsidence or regional terrestrial-water-storage anomalies. The transition from data to information is therefore a methodological and professional process, not simply a computational operation.

6.1.3. Level 3—Knowledge: Integrating Multiple Information Streams

Knowledge emerges when information from different sources is integrated to explain the state and dynamics of a phenomenon. This may involve combining Earth observation with rainfall, hydrological models, DEMs, river gauges, groundwater records, infrastructure databases, agricultural statistics, demographic information and historical observations. Knowledge requires domain expertise because the same observed pattern may have different causes in different environments. For example, a detected reduction in groundwater storage becomes more useful when combined with rainfall deficits, water abstraction records, land-use change, soil moisture, crop patterns and land-deformation observations. Similarly, a flood map becomes decision-relevant when overlaid with infrastructure, population, agricultural land, evacuation routes and critical facilities. At this level, the central question changes from ‘what has changed?’ to ‘what does the change mean for the functioning of the system?’

6.1.4. Level 4—Wisdom: Contextualizing Knowledge through Local Understanding

Wisdom is understood here as provisional and context-sensitive collective judgment about what ought to be done. It emerges through structured mechanisms for sharing scientific, professional, Indigenous and other place-based knowledge; inclusive deliberation among affected groups, public authorities and relevant organizations; and

transparent consideration of uncertainties, competing values and distributional consequences. Legitimate action does not necessarily require unanimity, but it should rest on procedurally fair participation and sufficiently broad, documented agreement. Dissent should be acknowledged, and decisions should remain open to monitoring, learning and revision. A technically optimal intervention in one river basin may be inappropriate in another because fluvial-hydrological-climatological contexts of the basin, settlement patterns, livelihoods, land tenure, cultural practices, governance arrangements and historical experience may differ from other river basin conditions. This is where local and indigenous knowledge becomes particularly important. Communities often possess long-term knowledge of flood pathways, seasonal water behaviour, drought signals, groundwater access, ecosystem change and coping strategies that may not be captured in satellite observations. Integrating such deep-rooted local knowledge (i.e., the wisdom) with scientific information does not weaken the scientific basis of decision-making; it can rather improve contextual validity and social acceptance of the results.

6.1.5. Level 5—Actions: From Wisdom to Policy Actions

The final transition is from understanding to intervention. Policy action requires institutional authority, financing, legal mandates, operational procedures and mechanisms for accountability. An Earth-intelligence system should therefore be designed around decisions rather than around data availability. For each policy problem, decision-makers should identify what decision must be made, what evidence is required, what uncertainties remain, who has authority to act and how the intervention will be monitored. This leads to a practical workflow, such as (i) identify the development gain to be protected (ii) define the threat and decision point, (iii) select complementary Earth-observation and ground datasets, (iv) generate analysis-ready information, (v) integrate multiple information streams into knowledge, (vi) validate and contextualize that knowledge with local expertise, (vii) determine intervention options, (viii) implement through responsible institutions and, (ix) monitor outcomes using repeated observations. However, this final step, i.e., Level 5, creates a feedback loop in which new observations test whether interventions are working.

6.2. Enabling Ecosystem for Developing Countries

The DIKWA pathway cannot function without an enabling ecosystem. Four mutually dependent conditions are particularly important in this context. First, foundational infrastructure that will include reliable energy, telecommunications and digital connectivity that will support continuous data access and computation. Second, institutional and physical infrastructure must include research organizations, data centres, training facilities, skilled personnel and maintenance systems. Third, advanced digital ecosystems must provide cloud computing, AI, interoperable data systems, sensor networks and related technologies. Fourth, application ecosystems must connect technology with policy, regulation, governance, developers, practitioners and users. The other barriers (see Section 4.2 for illustration) such as institutional, technical, financial and governance barriers need to be addressed as well. These requirements explain why simply providing open satellite data may not eliminate technological inequality. The public institutions within a country may have formal access to global archives of satellite data but lack the capacity to process it, validate results, maintain workflows, retain skilled professionals or connect outputs to public decisions will not ensure that country to define, design and perform appropriate, informed actions using geospatial resources (i.e., data, methods) including allied frontier technologies. Capacity-building should therefore move beyond training individuals in software towards building durable institutional capabilities.

Several practical pathways may follow from the proposed framework. AI capacity-building for policymakers and technical professionals can improve the ability to interpret analytical outputs. Innovation-led pathways can connect Earth intelligence with productivity, employment and small-enterprise development. Weather and climate services should increasingly protect not only lives but also infrastructure, livelihoods, productive assets and economic and productive systems accumulated over time. Needs assessments should precede major technology investments so that technology choices respond to actual development priorities. Smart public governance can use geospatial intelligence to strengthen service delivery and monitoring. Finally, demonstration projects using Earth observation and frontier technologies in different sectors can create evidence of value and enable people to participate as users and co-producers rather than passive beneficiaries.

Additionally, a number of barriers may impede implementation of DIKWA pathway. These include (i) *institutional barriers* such as policy discontinuity, weak inter-agency coordination, and lack of mandates linking Earth-observation outputs to public decisions, so that even good information does not reach a decision point (ii) *technical barriers* like absence of interoperable data systems, limited computing infrastructure, insufficient analytical capacity, and inability to validate or maintain workflows, so that data do not become information, (iii) *financial barriers*, i.e., the dependence on short-term project funding, high cost of sustained data infrastructure

and skilled personnel, and market underinvestment in public-good applications, so that information systems are not durable, and (iv) *governance barriers* restricted or inequitable data access, weak accountability, limited participation of affected groups, and unresolved distributional questions, so that knowledge is not converted into legitimate, context-sensitive action.

7. Conclusions and Recommendations

The central argument of this article is that development progress should no longer be treated as irreversible. The world has accumulated substantial development gains through decades of cooperation, investment, scientific advancement and institution-building, but climate change, environmental pressures, disasters, debt, geopolitical tensions and weakening institutional trust can erode those gains. Protecting development gains should be considered as an explicit objective of development planning and of the post-2030 agenda. The review of seven UNESCO World Science/Science Reports shows that STI governance has evolved from centralized and relatively linear models towards increasingly collaborative, innovation-oriented, mission-oriented and systemic arrangements. Yet persistent gaps in financing, coordination, implementation capacity, knowledge access and institutional continuity remain. Advanced technologies, by themselves, are unlikely to overcome constraints arising from limited institutional capacity, coordination or continuity. Long-term resilience requires an ecosystem in which science, infrastructure, skills, data, governance and international cooperation reinforce one another.

In this article, water, as a case, is used to demonstrate how geospatial technologies in association with a range of frontier technologies may contribute to protecting and sustaining development gains towards resilience building. Water is simultaneously a foundation of development and a major pathway through which climate and environmental risks can damage development assets. The complementary capabilities of Landsat, Sentinel, MODIS, SRTM, NISAR, SWOT, GRACE/GRACE-FO, GNSS-R and OPERA show that Earth observation can provide a much richer understanding of water-system change than any single sensor. The strategic opportunity lies in integrating these observations rather than treating missions as isolated technologies. The proposed Data–Information–Knowledge–Wisdom–Action (DIKWA) pathway provides the article’s principal practical contribution. It shows that raw data provide observations, information reveals patterns, knowledge integrates multiple evidence streams to explain system behavior and wisdom contextualizes that knowledge through local experience, institutional memory and societal priorities. Under these conditions, evidence is more likely to support legitimate and context-sensitive action. The pathway therefore reframes Earth observation from a data-delivery activity into a decision-support and resilience-building process.

For the post-2030 agenda, the implication is not that every country should acquire every frontier technology. National and subnational governments, in deliberation with affected groups and relevant organizations, should identify the development gains requiring priority protection, otherwise, the risks most likely to erode them, the information required to anticipate those risks and the institutional capabilities needed to act. International cooperation should support equitable access to space-derived data, open and interoperable infrastructures, regional capacity-building, North–South, South–South scientific cooperation and responsible governance of AI and space activities. Frontier technologies should be embedded within these systems, not pursued as stand-alone solutions. The post-2030 agenda should consequently combine two objectives. First, advancing new development ambitions and second, safeguarding the development gains already achieved. Earth intelligence can help make this possible by enabling societies to see change earlier, understand risks more comprehensively, anticipate emerging threats and monitor whether interventions protect the assets on which future development depends. A central policy question, however, is not how much data the world can collect, but how effectively societies can convert data/observations into knowledge, knowledge into wise choices and wise choices into sustained action.

This article has some limitations. First, the STI governance review is deliberately bounded to seven UNESCO World Science/Science Reports. These reports provide a consistent longitudinal lens but do not represent the full universe of STI-policy scholarship, and interpretations drawn from them should therefore be understood as a structured stocktaking rather than a systematic review of every national STI system. Second, the water section is an analytical Earth-observation case study rather than a basin-specific empirical validation. It demonstrates the logic and complementarity of observations without the quantification of the performance from an integrated operational system in a particular country. Third, the DIKWA framework is conceptual and normative; its effectiveness will depend on institutional context, data quality, professional expertise and the mechanisms through which local knowledge is incorporated. Finally, Earth-observation missions and AI capabilities evolve rapidly, so operational specifications and product availability require periodic updating.

The preceding analysis suggests that access to Earth-observation data and frontier technologies is necessary and also insufficient to protect development gains. Their contribution depends on institutional continuity,

analytical capacity, integration across policy sectors, and legitimate mechanisms for combining scientific, professional, Indigenous and other place-based knowledge. On this basis, the following recommendations are proposed for the post-2030 agenda.

- (i) **Make the protection of development gains an explicit policy objective.** National and subnational governments should identify the stocks of physical infrastructure, human capital, institutions, knowledge, productive capacity and social welfare built over the decades as development gains most exposed to environmental and socioeconomic risks. These assets should be incorporated into development planning, public investment decisions and resilience assessments.
- (ii) **Develop federated and equitable Earth-intelligence infrastructure.** Governments, space agencies and international organizations should support interoperable Earth-observation platforms that combine satellite, ground-based and socioeconomic data. Regional or federated arrangements can reduce duplication and enable countries to share infrastructure and analytical capabilities without requiring every country to acquire its own satellite systems.
- (iii) **Invest in durable institutional capacity.** International capacity-building should move beyond short-term training and technology transfer. Investment should support permanent analytical teams, data infrastructure, professional career pathways, institutional memory and the integration of Earth intelligence into routine public decision-making.
- (iv) **Establish knowledge-sharing and deliberative mechanisms.** Earth-intelligence systems should include formal mechanisms through which scientific experts, public authorities, affected groups, Indigenous Peoples and other knowledge holders can share evidence, examine uncertainties and deliberate over policy options. Decisions should rest on transparent and sufficiently broad agreement, while documenting dissent and remaining open to revision.
- (v) **Ensure responsible use of AI and automated analysis.** AI-supported Earth intelligence should be subject to data-quality requirements, model validation, transparency, human oversight and clear institutional accountability. Automated outputs should inform rather than replace professional judgment and legitimate public decision-making.
- (vi) **Use monitoring to support institutional learning.** Policy interventions should include measurable objectives and repeated observation of outcomes. Monitoring should generate new data that feed back into the DIKWA pathway, allowing assumptions, models and interventions to be revised when conditions or evidence change.

Ultimately, taken together, these recommendations translate the DIKWA framework into an institutional agenda for the post-2030 period. Their central premise is that Earth observation contributes to resilience not through data access alone, and through the capacity of institutions and affected groups to interpret evidence, deliberate over priorities, implement legitimate decisions and learn from their outcomes. Thus, Earth-observation data protect development gains only when institutions can transform observations into context-sensitive, legitimate and revisable action.

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The authors declare no conflict of interest.

Use of AI and AI-Assisted Technologies

ChatGPT was used solely for grammar checking and language improvement during the preparation of this article. The authors remain fully responsible for the content, interpretation, arguments, and conclusions presented in the manuscript.

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