State of National Spatial Data Infrastructure (NSDI) Globally

Research Paper

Version 1.0

September 2025

Open Geospatial Consortium

Note

The Open Geospatial Consortium prepared this document as part of the National Spatial Data Infrastructure Initiative

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Acknowledgements

The author wishes to thank all the experts and practitioners who generously contributed their time and insights through interviews conducted during this research. Their diverse perspectives and experiences were invaluable in shaping the findings and recommendations presented in this paper. Appreciation is also extended to colleagues and reviewers who provided feedback and guidance throughout the development of this work. In particular, many thanks to Peter Rabley, Nigel Edmead, Lynne Weil and Andrew Maruska, all of whom have been supporting this broader effort on modernizing NSDI.

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OGC Executive Summary

Spatial Data Infrastructure (SDI), traditionally conceived as a technical framework—composed of data, standards, policies, and institutional structures—has long enabled the discovery, sharing, and application of geographic information. However, the accelerating pace of digital transformation, the proliferation of artificial intelligence (AI), and the growing complexity of societal challenges demand a reimagining of SDI—not as a static repository of data, but as a dynamic, intelligent, and inclusive ecosystem that operates as a critical layer of broader Digital Public Infrastructure (DPI).

This paper presents a global assessment of National SDI (NSDI) programs and argues for a strategic shift toward geospatial ecosystems that are embedded within broader digital public infrastructure frameworks. The research draws on the United Nations Integrated Geospatial Information Framework (UN-IGIF), expert interviews, and lessons from international experiences to examine the current landscape of spatial data infrastructures from a national government perspective, including policy and governance trends, emerging technologies, stakeholder roles, and maturity assessment frameworks. Through analysis of global best practices and persistent challenges, the paper identifies critical gaps, lessons learned, and future directions for SDI development. The paper is not meant to be the final word on spatial data infrastructure, and will include future Addenda to address specific, evolving issues around SDI, including case studies.

Many countries have made substantial progress in establishing core geospatial infrastructure; however, SDI remains uneven in maturity and impact, particularly at the national level. Challenges such as institutional fragmentation, limited legal and policy frameworks, inconsistent funding, and outdated systems continue to hinder the ability of SDI to fully support national priorities. At the same time, our evolving understanding of how to integrate diverse digital datasets—coupled with unprecedented opportunities to do so—demands more sophisticated, real-time, and decision-ready geospatial capabilities. The proliferation of digital data across sectors creates new possibilities for addressing societal challenges from environmental change and public health to infrastructure management and disaster response, yet this wealth of information remains largely fragmented and unintegrated. Furthermore, modern cost-benefit perspectives increasingly require SDI development to be more targeted and needs-focused, challenging traditional comprehensive SDI approaches while highlighting the critical importance of strategic data integration.

A central theme emerging from the research is the evolving role of SDI—not simply as a data infrastructure, but as a foundation for educated AI agents that exploit the analysis-ready data coming out of (national) digital transformation. This revolution is leaving behind even modern concepts such as Geospatial Knowledge Infrastructure (GKI). Instead, SDI needs to be rethought, and aspects such as decision-ready insights, integration with broader digital ecosystems, and alignment with public value creation, all based on solid, machine-readable, and machine-understandable data, are gaining a previously unknown significance. The resulting geospatial ecosystems require countries to build geospatial platforms that serve users across government, business, academia, and civil society—not just through data access, but through insight generation, scenario modeling, and responsive service delivery.

Modern SDI emphasizes the need for seamless integration of geospatial data with emerging technologies, moving beyond the traditional focus on data availability and standardized interfaces. The SDI of the future must embrace semantic interoperability, scenario-centric design, and AI-readiness—enabling geospatial data to be consumed by intelligent systems, integrated into everyday tools like digital assistants and mobile applications, and used to generate real-time insights for decision-making. All of these need to leverage cloud-native APIs and data storage models for efficient integration of geospatial data with data stored in data warehouses.

The shift toward a geospatial ecosystem entails more than technology: it requires reimagining governance with federated, stakeholder-driven models; prioritizing interoperability in complex intellectual property (IP) regimes paired with inconsistent or even missing license models and monetization approaches. The

resulting ecosystem model places the user at the center, tailoring solutions around real-world scenarios—such as resilient planning and resource management—rather than around data silos. It embeds spatial capabilities within national digital strategies and DPI frameworks, reinforcing foundational interoperability between identity, payments, data exchange, and location systems.

The paper explores the growing role of emerging technologies in reshaping the geospatial landscape. AI, machine learning (ML), and large language models (LLMs) offer powerful new capabilities, from automated mapping and feature extraction to predictive modeling, semantic search, and multilingual data interpretation. These technologies are making geospatial data more accessible, intelligent, and user-centered, expanding the reach and impact of SDI programs. However, to realize these benefits, countries must invest in enabling infrastructure, interoperability standards, and responsible data governance.

Looking forward, the paper recommends a shift from infrastructure-centric models to ecosystem-based approaches, where NSDI is embedded within national digital strategies and contributes to broader goals such as climate resilience, smart cities, environmental sustainability, and inclusive economic development. Instruments such as UN-IGIF help in this context. The UN-IGIF provides a multi-dimensional model that countries can use to guide them and help them maintain an overview of the complex transition process. In consequence, institutional reform and policy coherence; greater investment in AI-powered, cloud-native platforms that enable real-time, scalable services; data governance systems that support trust, privacy, and equitable access; multi-stakeholder governance models that elevate citizen voices and build collaborative innovation ecosystems; and new performance metrics that move beyond technical outputs to track social, environmental, and economic outcomes need to be harmonized and transformed into a functional whole.

The inclusion of spatial data infrastructure within the DPI paradigm is essential. While digital identity, payments, and data exchange have been widely recognized as core DPI components, spatial data provides the critical "where" dimension underpinning service delivery, emergency response, logistics, urban planning, and climate resilience. Treating geospatial infrastructure as DPI ensures that location intelligence is accessible, trusted, and embedded in the digital fabric of society.

In conclusion, SDI is entering a pivotal phase of transformation. To remain relevant and impactful, it must evolve from managing data to delivering knowledge and advice—serving as a catalyst for data-informed governance, economic innovation, and digital public services. By re-casting SDI as a living geospatial ecosystem—rather than a standalone infrastructure—this research envisions a future where spatial information is fluid, intelligent, and foundational. One where infrastructure is not an endpoint but a platform for innovation—fueling resilient, inclusive, and knowledge-driven societies. Countries that embrace this vision and invest in future-ready geospatial ecosystems will be better positioned to respond to complex challenges, unlock new opportunities, and build more resilient, inclusive, and sustainable societies.

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1. INTRODUCTION

1.1 BACKGROUND ON NATIONAL SPATIAL DATA INFRASTRUCTURE (NSDI) AND ITS SIGNIFICANCE

Spatial Data Infrastructure (SDI) refers to the foundational data, technologies, policies, frameworks, and institutional arrangements that facilitate the discovery, access, and sharing of geospatial data. National SDI initiatives are critical for coordinated and timely response in decision-making across multiple domains, including environmental management, urban planning, disaster response, government service delivery, and infrastructure development. By enabling seamless data integration and interoperability across all levels of government, a national SDI (NSDI) enhances collaboration among stakeholders, supports data-driven governance, and fosters innovation in the geospatial sector.

1.2 PURPOSE AND SCOPE OF RESEARCH

This research aims to assess the global landscape of SDI programs, identifying key trends in governance, policy, and technology. The study will also analyze successful implementations, emerging challenges, and lessons learned to inform future SDI strategies, particularly from a national government perspective. A particular focus will be placed on modernizing the U.S. NSDI framework and strengthening its alignment with international geospatial initiatives.

1.3 ALIGNMENT WITH THE MODERNIZATION OF U.S. NSDI AND GLOBAL GEOSPATIAL INITIATIVES

Historically, NSDI in the United States has been driven by federal government agencies through top-down approaches. However, recent developments emphasize a more decentralized and collaborative model, incorporating contributions from state and local governments, private sector entities, academia, and international organizations. This shift aligns with broader global geospatial initiatives, including the United Nations Global Geospatial Information Management (UN-GGIM), the Open Geospatial Consortium (OGC), and the World Bank's geospatial programs, fostering greater data sharing and interoperability worldwide.

In this context, the United Nations Integrated Geospatial Information Framework (UN-IGIF) has emerged as a critical reference point for countries aiming to develop or modernize their NSDI (UN-GGIM, 2018). Developed and endorsed by the UN-GGIM Committee of Experts, the UN-IGIF provides a comprehensive, country-led approach for strengthening geospatial governance and delivering location-based services for sustainable development. Its adoption by over 100 countries underscores its relevance as a global blueprint for effective geospatial information management.

While 93 countries are in various stages of implementing the UN-IGIF, according to a survey of UN Member States conducted by UN-GGIM in early 2024. However, of those, approximately 40% are still in the early planning phase. The survey also noted that while awareness of the framework is high, **few countries have developed detailed country-level action plans** or moved into operational phases. Many implementations remain **conceptual or strategic**, lacking concrete deliverables, funding, or institutional alignment. Reports from regional workshops and alliances (e.g., SDG Data Alliance) show that even countries with action plans often struggle with localizing the UN-IGIF pathways, aligning them with national priorities, and securing sustained funding, demonstrating the challenges of implementation of SDIs.

Examining how NSDI has been approached globally is essential for informing the modernization of any national framework, including in the U.S. Various countries have implemented NSDI with differing governance structures, technological approaches, and policy frameworks, all of which have influenced their success. By studying these global models, the U.S. can leverage best practices in governance,

interoperability, and policy alignment to enhance its own NSDI efforts. Furthermore, the role of emerging technologies—such as AI, cloud computing, and automation—has significantly shaped NSDI implementations worldwide, with spatial data increasingly seen as a critical component of the digital public infrastructure (DPI) that is critical for public and private services.

In addition to governance and technology, understanding the economic impact and return on investment (ROI) of NSDI initiatives is a critical driver for continued development. Countries that have prioritized geospatial data infrastructure have reported measurable benefits in areas such as economic productivity, cost savings in infrastructure planning, improved environmental management, and enhanced public services. Incorporating these insights into U.S. NSDI modernization efforts will ensure that the framework is not only technically robust but also economically sustainable and valuable for a broad range of stakeholders.

1.4 KEY RESEARCH QUESTIONS

To achieve a comprehensive understanding of NSDI programs globally, this study will address the following key research questions:

- What is the current state of NSDI implementation across different regions?
- What are the key policy and governance trends shaping NSDI development?
- How are emerging technologies, such as AI and cloud computing, influencing NSDI frameworks?
- What are the best practices and lessons learned from successful NSDI implementations?
- How can the modernization of the U.S. NSDI be informed by international experiences and trends?
- What are the primary challenges and risks associated with NSDI development and sustainability?

By answering these questions, this study aims to provide actionable insights for policymakers, geospatial professionals, and industry stakeholders working to advance NSDI frameworks both in the United States and globally.

2. OVERVIEW OF THE GLOBAL NSDI ECOSYSTEM

2.1 ADOPTION AND DEVELOPMENT TRENDS

The implementation and evolution of National Spatial Data Infrastructures vary significantly across regions, reflecting differences in governance structures, technological capabilities, and financial investments. Developed countries such as the United States, European Union members, Canada, the UK, Australia and others have established comprehensive NSDI frameworks supported by strong legal mandates, open data policies, and robust technological infrastructures. Meanwhile, developing nations face challenges such as limited funding, inadequate technological resources, and fragmented data governance frameworks. Nonetheless, international collaboration and capacity-building efforts are helping bridge these gaps.

Several emerging trends are shaping the development of NSDI worldwide:

- **Decentralized and Federated Approaches**: Increasingly, countries are moving away from centralized, government-led NSDI models toward federated structures that engage multiple stakeholders - including the private sector, civil society and academia – in data stewardship and innovation. These federated models support the dynamic, scalable, and interconnected environments emphasized by the Open Geospatial Consortium (OGC), enabling more adaptive and resilient geospatial systems.
- **Open Data Initiatives**: The push for open geospatial data is gaining traction, with governments recognizing its role in fostering innovation, economic growth, and transparency.
- **Integration with Emerging Technologies: Artificial intelligence (AI), cloud computing, and the Internet of Things (IoT)** are being integrated into NSDI frameworks to support real-time analytics, automation, and decision-making. Semantic interoperability and AI-readiness are increasingly seen as essential capabilities for enabling intelligent, machine-readable geospatial systems.
- **Cross-Border Collaboration**: International partnerships, such as the UN-GGIM and the OGC, are facilitating harmonization of geospatial standards and data sharing across borders.

As NSDI evolves, many countries are transitioning toward a broader concept of a “geospatial ecosystem”—a dynamic, multi-stakeholder environment where data, technology, governance, and services are integrated to deliver real-time insights and public value. This framing better reflects the interconnected nature of modern geospatial infrastructure and aligns with global trends in digital transformation.

2.2 GLOBAL FRAMEWORKS - ROLE OF THE UN-IGIF IN SHAPING NATIONAL POLICIES

The United Nations Integrated Geospatial Information Framework (UN-IGIF) plays a foundational role in shaping national and global SDI programs (UN-GGIM, 2018). It provides a structured approach organized around nine strategic pathways: governance, legal and policy frameworks, financial sustainability, data, innovation, standards, partnerships, capacity development, and communication. By aligning NSDI development with these pathways, countries can ensure a holistic and resilient geospatial strategy that transcends technical implementation and embeds geospatial information within broader national development goals.

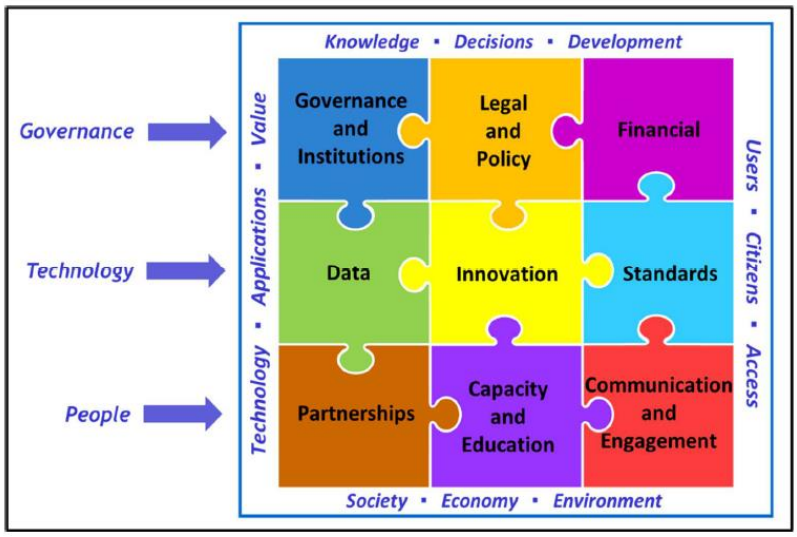

Figure 1 - The nine strategic pathways of the United Nations Integrated Geospatial Information Framework (UN-IGIF)

Importantly, the UN-IGIF encourages governments to transition from siloed data systems toward integrated national geospatial ecosystems. It promotes multi-stakeholder participation, clear legal mandates, and the mainstreaming of geospatial information into public service delivery. Countries such as Indonesia, Jamaica, Uganda and the United States have applied the UN-IGIF to develop actionable roadmaps that guide long-term investment in geospatial infrastructure, capacity building, and data governance.

3. GOVERNANCE IN NSDI

3.1 GOVERNANCE AND INSTITUTIONS

3.1.1 KEY STAKEHOLDERS IN THE NSDI ECOSYSTEM

The development and implementation of NSDI involve a diverse array of stakeholders, each playing a crucial role in shaping its success:

- **Government Agencies**: National and sub-national mapping agencies and organizations, statistical agencies, land and cadastral departments, and environmental ministries lead NSDI efforts by establishing policies, funding initiatives, and ensuring compliance with standards. These agencies also play a central role in geospatial data collection, processing, analysis, and dissemination.
- **Private Sector**: Companies specializing in geospatial data collection, processing, and analysis contribute cutting-edge technology and innovative solutions to NSDI development. Their involvement is increasingly vital in building scalable, interoperable platforms aligned with national digital strategies.
- **Academia and Research Institutions**: Universities and research centers provide technical expertise, conduct studies, and develop geospatial models that support NSDI advancement.
- **International Organizations**: Entities such as UN-GGIM, the World Bank, the International Hydrographic Organization (IHO), and others promote best practices, standardization, and capacity-building programs.
- **Non-Governmental Organizations (NGOs)**: NGOs play an active role in advocating for open data, community-driven geospatial initiatives, and the use of NSDI for social and environmental sustainability.

This multi-stakeholder collaboration is foundational to building a geospatial ecosystem—an inclusive, adaptive environment where data, governance, and technology converge to support national priorities and public value. The collaboration between these stakeholders ensures that NSDI frameworks are robust, inclusive, and capable of addressing evolving geospatial challenges.

3.2 LEGAL AND POLICY

3.2.1 COMMON POLICY FRAMEWORKS AND REGULATIONS FOR NSDI GOVERNANCE

Effective NSDI governance relies on well-defined policy frameworks and regulations that establish the responsibilities, standards, and protocols for geospatial data management. Countries with mature NSDI programs typically implement national geospatial policies that outline data-sharing principles, privacy protections, and inter-agency cooperation. Additionally, international frameworks such as those provided by UN-GGIM and OGC standards serve as guiding structures for NSDI governance.

Several key elements are common across strong NSDI governance frameworks:

- **Data Standardization and Interoperability**: The adoption of international standards (e.g., ISO 19100 series) ensures seamless data exchange between different organizations and systems. Semantic interoperability and AI-readiness are increasingly recognized as essential for enabling intelligent, machine-readable geospatial platforms.
- **Legal and Institutional Frameworks**: Policies that define data ownership, access rights, and the role of public-private partnerships enhance NSDI functionality.

- **Strategic Oversight**: Programmatic governance bodies and committees often at a strategic and technical level providing strategic and technical guidance to the program.
- **Funding and Sustainability Models**: Establishing long-term funding mechanisms ensures continuous NSDI development and maintenance.

While strategic planning is essential for NSDI advancement, interviewees emphasized that such plans often fall short of implementation without operational and financial backing. As Deirdre Dalpiaz Bishop of the U.S. Census Bureau noted, *"Strategic plans are just words on paper. Implementation is where the real challenge lies."* This implementation gap is especially visible at sub-national levels, where agencies often lack the budget and technical capacity to ensure alignment with an NSDI.

Another recurring theme was the limited awareness of NSDI among local and state contributors. Although these entities provide vital data, many are unaware of their role in a broader national geospatial system. The term 'NSDI' may not resonate with stakeholders outside federal agencies, prompting calls for clearer communication and a shift toward more intuitive concepts such as “national geospatial ecosystem.”

Australia exemplifies a federated governance model that supports dynamic, scalable, and interconnected environments without centralized mandates. As highlighted by Maree Wilson from Geoscience Australia, its approach is based on voluntary coordination, trust, and federated responsibility among states and territories. Unlike countries with legal enforcement structures, Australia relies on inter-jurisdictional relationships to maintain NSDI alignment.

The U.K. has evolved its NSDI model to focus less on infrastructure labels and more on outcomes. As David Henderson of Ordnance Survey noted, *"NSDI isn’t the goal. Outcomes are."* The UK integrates geospatial infrastructure into broader digital strategies, prioritizing alignment with national objectives like management of land and property, environmental priorities, security and economic growth. Governance is federated and sector-driven, with contributions from national mapping agencies, utilities, and environmental bodies coordinated through policy levers rather than a centralized NSDI authority.

These examples reflect a growing global trend toward embedding NSDI within broader Digital Public Infrastructure (DPI) frameworks—where spatial data systems are treated as foundational infrastructure alongside identity, payments, and data exchange.

3.2.2 COMPARATIVE ANALYSIS OF NSDI POLICIES IN LEADING NATIONS

Different countries have adopted varying approaches to NSDI governance based on their legal, political, and technological landscapes. These differences reflect the need for flexible, context-sensitive models that can evolve into resilient geospatial ecosystems.:

Country	Legislative Mandate & Highlights	Strategic Framework & Highlights
United States	Geospatial Data Act (2018) - Formalized NSDI governance - Established FGDC as lead body - Mandated open data policies and common geospatial standards	US NSDI Strategy – National Strategy Document - Promotes federated, outcome driven approach - Aligns NSDI with broader digital transformation goals - Support innovation and public-private collaboration.
European Union	INSPIRE Directive -Legally required harmonization of spatial data across all EU member states.	EU SDI Framework - Enabled coordinated implementation of SDI across sectors and jurisdictions within the EU.

	-Mandated standardized metadata, data specifications, and open access policies. -Established a legal foundation for interoperability, particularly in environmental and infrastructure-related datasets.	- Fostered intergovernmental collaboration and cross-border data sharing for policy alignment. - Supported integration of geospatial data into EU-wide digital services, sustainability initiatives, and emergency response systems.
Australia	Data Availability and Transparency Act 2022 - Establishes a legal framework for sharing public sector data securely and ethically across jurisdiction	Australia National Spatial Data Strategy - Open-access policy approach - Collaboration across federal, state, and local governments - Engaged private sector in SDI development
Kenya	County Government Act (2012) - Mandates counties to establish GIS-based spatial plans and databases, forming a legal basis for decentralized geospatial governance	Kenya National Digital Master Plan 2022–2032: Includes Kenya National Spatial Data Infrastructure (KNSDI) - Integrated NSDI with land-use planning - Strong use of geospatial tools for growth and disaster resilience
Saudi Arabia	Council of Ministers Resolution No. 90 (2020) - Formally established the General Authority for Survey and Geospatial Information (GEOSA), granting it regulatory authority over the geospatial sector Draft Data Sovereignty Public Policy - Sets principles for national control over data, including spatial data, and emphasizes its role as a national asset	Saudi Arabia National Geospatial Strategy (NGS) - Aligned with Vision 2030 - Focused on smart cities, infrastructure, and national security - Heavy investments in AI and open geospatial data

3.2.3 LEGAL AND REGULATORY CHALLENGES

Despite progress in NSDI governance, several legal and regulatory challenges persist:

- **Data Privacy and Security**: Regulations such as the European General Data Protection Regulation (GDPR) impose strict controls on geospatial data, affecting how NSDI programs manage personal and sensitive information.
- **Cross-Border Data Sharing Issues**: Differing national policies and lack of interoperability hinder seamless geospatial data exchange between countries and regions.
- **Institutional Resistance and Bureaucracy**: Government agencies may be reluctant to share geospatial data due to concerns over data ownership, security risks, or a lack of incentives.
- **Legal Ambiguities**: In many countries, geospatial data governance lacks clear legal definitions regarding data ownership, access rights, and responsibilities for updates and maintenance.
- **High-Level Political Buy-in:** Interviews with experts from Africa, Europe, and the private sector consistently point to the disconnect between technical teams and policy actors, resulting in delayed or blocked policy adoption. Without legislative mandates and political sponsorship, NSDI initiatives remain vulnerable to institutional inertia and shifting priorities.

By addressing these governance and policy trends, countries can strengthen their NSDI frameworks, evolve toward geospatial ecosystems, and ensure that geospatial data serves as a strategic asset for sustainable development, digital transformation, and informed decision-making**.**

3.2.4 THE ROLE OF OPEN DATA POLICIES AND PRIVACY CONSIDERATIONS

Open data policies play a critical role in modern NSDI frameworks by enhancing accessibility, fostering innovation, and driving economic growth. Countries with well-implemented open data initiatives have seen

increased private sector engagement, the development of new geospatial applications, and improved public service delivery.

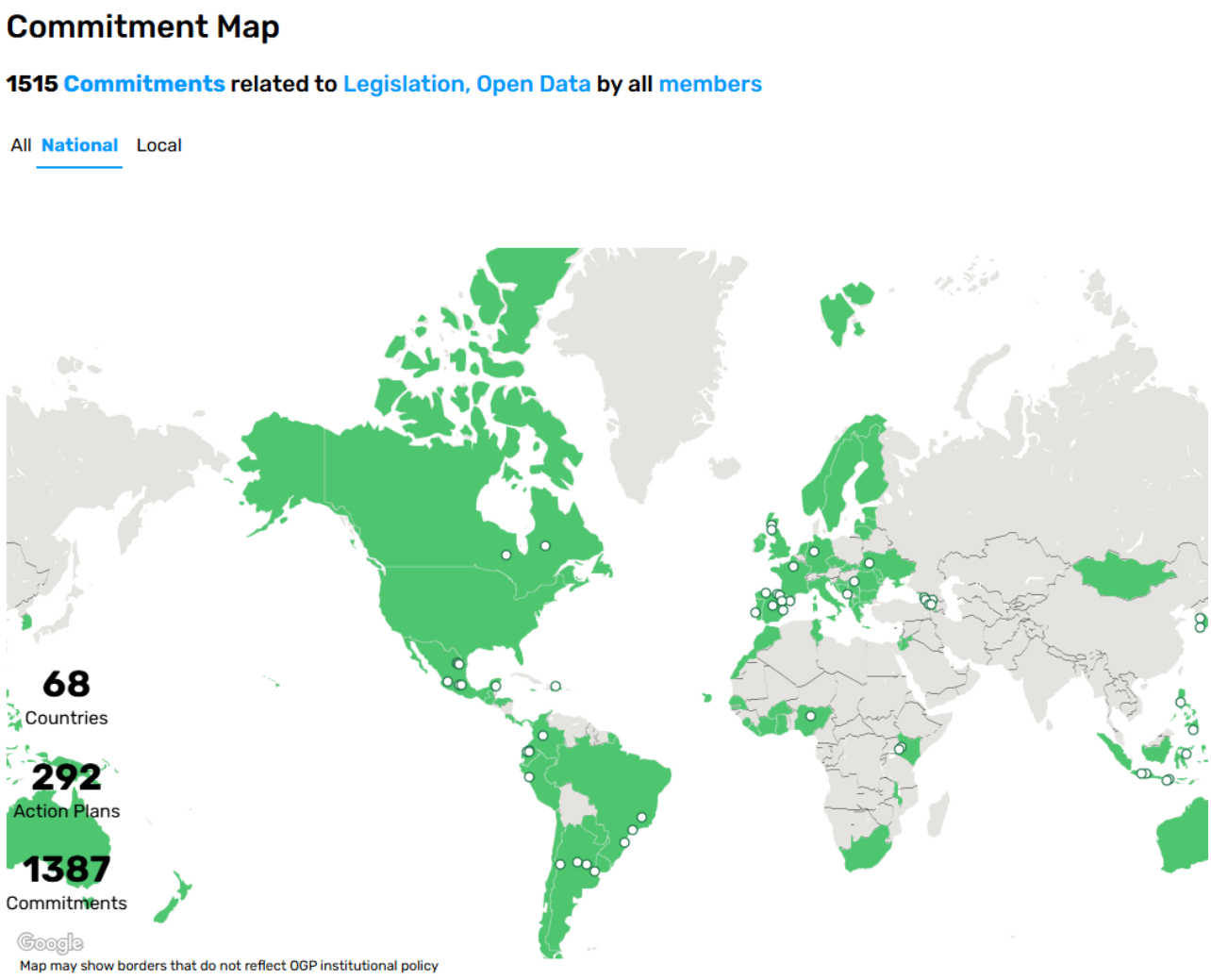

Figure 2 - Countries with national open data legislation in force or in development

However, balancing open data policies with privacy concerns remains a challenge:

- **Benefits of Open Data in NSDI**: Open access to geospatial data enables businesses, researchers, and policymakers to create innovative solutions in fields such as transportation, agriculture, and disaster management.
- **Privacy Risks and Ethical Considerations**: The proliferation of location-based services raises concerns about data misuse, surveillance, and unintended exposure of personal information. Robust data governance policies, including anonymization techniques and ethical guidelines, are essential to mitigate these risks.
- **Public-Private Collaboration**: Establishing data-sharing agreements between government agencies and private companies can enhance NSDI effectiveness while maintaining ethical and legal compliance.

As emphasized in the broader context of a public good, or digital public infrastructure, spatial data infrastructure must be treated as a public good—open, interoperable, and ethically governed—to ensure equitable access and societal benefit. By addressing these governance and policy trends, countries can strengthen their NSDI frameworks, enhance global collaboration, and ensure that geospatial data serves as a valuable asset for sustainable development and decision-making.

3.3 FINANCIAL - THE ECONOMIC IMPACT AND ROI OF NSDI

3.3.1 BENEFITS OF NSDI INVESTMENTS

Investing in NSDI involves significant costs related to infrastructure, technology, and governance. However, these costs are often outweighed by the economic benefits derived from improved data accessibility, decision-making efficiency, and cross-sector applications. In the United States alone, the geospatial market was valued at USD 133 billion in 2023, with the wider geospatial economy reaching USD 185 billion, including all related services and sectors (Geospatial Media and Communications, 2024). While a study commissioned by Google and conducted by AlphaBeta found that digital maps and geospatial services support over $1 trillion in annual business sales globally, and deliver consumer benefits worth over $550 billion per year, the sector directly supports over 1 million professionals, with employment spanning data science, software development, analytics, and field operations.

The U.S. total socio-economic benefit derived from geospatial technologies in 2023 is estimated at USD 660 billion to USD 1.09 trillion, driven by gains in operational efficiency, infrastructure optimization, and decision-making (Geospatial Media and Communications, 2024). Further, according to Trimble's 2024 industry white paper, the total economic impact of geospatial technologies on the global economy is projected to reach $10.2 trillion by 2025, driven by advances in location intelligence. These impacts extend well beyond government services, influencing agriculture, transportation, defense, telecommunications, and environmental management.

Strategic public investments—through agencies like U.S. Geological Survey (USGS), National Geospatial Intelligence Agency (NGA), and FGDC—have helped catalyze geospatial modernization. Open data policies and emerging technologies such as AI and cloud computing have further amplified economic returns, reinforcing NSDI's role as a foundational component of national digital infrastructure.

The Landsat satellite program, jointly managed by NASA and the USGS, is a cornerstone example of the economic value generated by open-access geospatial data. Since adopting a free and open data policy in 2008, the program has seen widespread global use across the government, academic, and private sectors. A 2019 study (Straub et al. 2019) by the USGS estimated that Landsat imagery generated $3.45 billion in annual economic benefits for users in 2017 alone, an increase from $2.19 billion in 2011. The study emphasizes that charging even modest fees for data access would significantly reduce usage and associated societal value, underscoring the importance of open data policies in maximizing the return on investment from public geospatial infrastructure.

A compelling example of geospatial ROI comes from the U.S. Census Bureau, which used satellite imagery and machine learning to review and update the Master Address File/Topologically Integrated Geographic Encoding and Referencing (MAF/TIGER) system, its national geospatial database of addresses, roads and boundaries for the 2020 Census. This machine learning approach avoided more than $674 million in field operation costs, illustrating how geospatial technologies can significantly improve government efficiency.

In Canada, the economic impact of geospatial data infrastructure was estimated to contribute USD 20.7 billion (1.1%) to real GDP in 2013 (Natural Resources Canada, 2013). Integration of geospatial information led to measurable increases in private consumption (USD 8.6 billion) and government spending (USD 3.7 billion), demonstrating NSDI's broad economic influence. Similarly, in Africa, the Digital Earth Africa (DE Africa) initiative is projected to generate over $2 billion annually in socioeconomic benefits by 2024 (World Economic Forum, 2021). This impact is attributed to accelerated industry growth ($500 million), increased agricultural productivity ($900 million), and better regulation of mining activities ($900 million).

Research from Deloitte Insights (2025) further underscores the economic potential of Earth observation data in catalyzing sustainable growth. The global Earth Observation industry contributes over USD 60

billion annually, with continued expansion driven by advances in AI, cloud-native platforms, and public-private partnerships. These findings reinforce the need for well-structured NSDI frameworks to unlock and scale these benefits.

When assessing potential ROI from NSDI, key economic drivers to assess include:

- **Data Accessibility vs. Cost of Implementation**: Open access to geospatial data reduces redundancy, lowers operational costs, and enhances public service delivery. Open data initiatives alone were found to contribute $695 million (0.04%) to Canada's GDP (Natural Resources Canada, 2013).
- **Operational Efficiencies**: NSDI reduces duplication of effort in data collection and processing across agencies, leading to streamlined workflows and improved service delivery.
- **Long-Term Returns**: Investments in geospatial infrastructure yield sustained economic benefits, including innovation in commercial sectors, enhanced public sector performance, and more resilient infrastructure planning.

3.3.2 ECONOMIC RETURNS FROM GEOSPATIAL DATA

The economic impact of NSDI is evident across multiple sectors, improving efficiency, reducing costs, and generating new opportunities. Some key areas of economic benefit include:

- **Infrastructure Planning and Asset Management**: NSDI enhances infrastructure planning through accurate, interoperable geospatial data, reducing project costs and improving asset management.
- **Agriculture**: Precision agriculture benefits from geospatial insights, optimizing land use, water management, and crop monitoring. The DE Africa program is expected to generate at least $900 million in benefits per year through water savings, increased productivity, and insurance benefits (World Economic Forum, 2021).
- **Disaster Response**: NSDI enables real-time disaster management, improving preparedness and reducing economic losses from natural disasters.
- **Mining Regulation**: The use of geospatial data in regulating mining activities is estimated to save at least $900 million per year in Africa by reducing environmental damage and fiscal evasion (World Economic Forum, 2021).
- **Urban Development**: Deloitte (2025) reports that geospatial intelligence has significantly improved infrastructure planning and real estate valuation, contributing up to $10 billion in annual savings in major metropolitan areas worldwide.
- **Transportation and Utilities**: NSDI supports efficient traffic management, energy distribution, and smart city planning, contributing to long-term economic sustainability and service optimization.

United Kingdom: Geospatial Data as an Economic Ecosystem

The UK's 2024 *Frontier Economics Geospatial Data Market Study* (2024), commissioned by the Geospatial Commission, reframes the geospatial economy not as a discrete market but as a diverse and dynamic ecosystem with substantial untapped value. The study identifies that:

- A core subset of ~2,000 geospatial firms accounted for over £6 billion in turnover in 2018, with substantial growth since. These firms span tech, engineering, and professional services sectors.
- More than 115,000 people were employed across these firms by 2019, growing from ~20,000 in 2009—a 45% annual employment growth rate.
- Fundraising in geospatial SMEs has grown at 20% annually, with R&D grant values growing from £2 million to £61 million between 2009 and 2019.

- The indirect and spillover benefits of geospatial data, including environmental improvements, consumer time savings, and innovation enablement, suggest the true economic value is far greater than direct turnover figures indicate.
- If just 5% of the digital technology market's turnover were attributed to geospatial services, the sector's contribution would exceed £9.2 billion, with potential spillovers valued at £11 billion per year.

The report highlights location-aware consumer applications, crowd-sourced mobility data, and geospatial components in large tech platforms (e.g., mapping, navigation, advertising) form the bedrock of a self-reinforcing feedback loop across industries. However, fragmented data infrastructure, inconsistent access mechanisms, and skill shortages limit widespread adoption.

Key policy recommendations from the study include:

- Enabling broader reuse of privately collected geospatial data through clearer intellectual property (IP) and licensing frameworks.
- Modernizing access to public sector geospatial data via flexible APIs and usage-based pricing models.
- Investing in geospatial skills, including data science integration and apprenticeship pathways.
- Strengthening ethical and privacy safeguards to ensure public trust in location data usage.

These findings suggest that the UK's geospatial economy is poised for expansion but requires targeted investment, governance innovation, and cross-sector engagement to fully unlock its potential.

Australia: A High-Growth National Model

Australia's geospatial ecosystem provides a compelling model for evaluating the ROI in NSDI. The Geospatial Council of Australia's 2024 report highlights that geospatial services contributed an additional AUD 38.6 billion to GDP in 2023–24, and under a favorable operating scenario, this figure is projected to rise to AUD 89.5 billion by 2033–34.

The sector also supported over 12,000 full-time equivalent (FTE) jobs in 2023–24, with potential to create 31,849 FTEs by 2033–34. Real income gains attributable to geospatial services reached AUD 29.3 billion in 2023–24, projected to exceed AUD 76.9 billion by 2033–34.

Notably, sectors with high geospatial adoption—such as mining, agriculture, construction, and government services—realized the largest productivity gains. For example:

- The mining sector alone saw a projected cumulative output increase of AUD 161 billion over 10 years.

- The agriculture, fisheries, and forestry sectors experienced a AUD 41 billion gain in gross value added over the same period.

Consumer benefits were equally substantial, with AUD 10.5 billion in value generated in 2023–24, including time saved from geospatially enabled apps and services. This value is expected to grow to AUD 13 billion by 2033–34.

The report emphasizes that strategic investment in technologies like geospatial digital twins, AI/ML, and real-time positioning systems (e.g., SouthPAN), along with improved data governance and intergovernmental collaboration, are critical levers to fully unlocking NSDI value.

3.3.3 CHALLENGES IN MEASURING NSDI ROI AND HOW TO ADDRESS THEM

- Despite clear benefits, measuring the return on investment (ROI) of NSDI remains complex and context-dependent, due to several persistent challenges:
- **Lack of Standardized Metrics**: Countries and agencies use different indicators to measure economic benefits, making comparative analysis and global benchmarking difficult.
- **Long-Term Impact vs. Short-Term Costs**: The benefits of NSDI investments often materialize over extended periods, requiring sustained funding**,** political commitment, and institutional continuity.
- **Quantifying Indirect Benefits**: Many benefits, such as improved decision-making and environmental sustainability, are difficult to measure in direct economic terms, yet are central to NSDI's public value.

To address these challenges, governments and stakeholders should:

- Develop standardized NSDI impact assessment frameworks, aligned with national development priorities and international best practices.
- Foster collaboration between economic analysts, geospatial experts, and policy planners to refine ROI metrics and ensure relevance to decision-makers.

Leverage case studies, scenario modeling, and international benchmarking to track economic, social, and environmental outcomes over time.

By focusing on outcome-based impact rather than infrastructure-centric metrics, NSDI programs can justify continued investments, attract private sector participation, and enhance geospatial infrastructure for long-term national development.

Stakeholders across regions emphasized that ROI narratives need to be reframed for policymakers and funders. Rather than focusing solely on data infrastructure, NSDI value must be tied to sectoral outcomes such as reduced infrastructure costs, accelerated permitting and service delivery, improved disaster response, and enhanced public trust and transparency. This helps make the case for multi-year funding and policy support, especially in contexts where NSDI is embedded within broader Digital Public Infrastructure (DPI) strategies.

NSDI proponents may consider adaptive and trust-based financing models, which prioritize long-term systems change over short-term outputs—moving beyond narrow infrastructure-focused investment paradigms toward models that emphasize resilience, equity, and innovation.

According to David Henderson from the UK Ordnance Survey, traditional project-based funding models fail to capture the long-term value generated by NSDI. He advocates for shifting to outcome-based investment logic, where funding is tied to impact areas like infrastructure efficiency, climate adaptation, and public service optimization. This view reinforces the argument for NSDI as a foundational digital public good, not just a technical system.

The UN-IGIF offers practical tools to help countries address these challenges. It recommends:

- Developing impact pathways and economic justifications for geospatial investments.
- Tracking returns through performance metrics aligned with national development goals.
- Embedding NSDI within broader digital transformation strategies, ensuring that geospatial systems contribute to inclusive growth, sustainability, and service innovation.

By leveraging the UN-IGIF framework, governments can more effectively articulate the public value of NSDI and justify ongoing investment in geospatial ecosystems.

4. DATA AND TECHNOLOGICAL ADVANCEMENTS IN NSDI

4.1 DATA

Data is the cornerstone of any National Spatial Data Infrastructure (NSDI). The effectiveness of NSDI depends not only on access to vast quantities of geospatial data, but also on the quality, interoperability, timeliness, and governance of that data.

4.1.1 FOUNDATIONAL DATASETS

Successful NSDI systems maintain authoritative and high-quality foundational datasets. These typically include:

- Cadastral and land parcel data
- Topographic and hydrographic information
- Transportation networks
- Administrative boundaries
- Elevation and imagery basemaps
- Address registers

Frameworks such as Australia's Foundation Spatial Data Framework (FSDF) and the U.S. National Geospatial Data Asset (NGDA) portfolio demonstrate how curated, standardized layers can serve multiple sectors, from land administration to climate resilience. These foundational datasets form the basis for location-aware services, digital addressing systems, and spatial analytics, all of which are increasingly recognized as core components of the digital infrastructure needed for effective governance.

4.1.2 DATA READINESS AND ACCESSIBILITY

NSDI must enable data that is current, trusted, and accessible to a wide range of users. This includes digitization of legacy datasets, standardizing metadata, and ensuring datasets are machine-readable and interoperable. Increasingly, spatial data infrastructures are adopting data mesh architectures and federated models, which allow decentralized data custodianship while maintaining national-level coherence and discoverability.

4.1.3 OPEN DATA AND LICENSING MODELS

Open data policies play a central role in improving data discoverability, reusability, and public trust. When implemented with clear licensing and privacy safeguards, open NSDI datasets foster innovation, civic engagement, and transparency. However, in some jurisdictions, tension remains between treating data as a public good versus a revenue-generating asset, particularly in land administration and utility sectors. Balancing openness with sustainability and privacy is essential for inclusive geospatial governance.

4.1.4 DATA GOVERNANCE AND CUSTODIANSHIP

Governance structures for spatial data often lag behind technological developments. Clear custodianship roles, updated cycles, and quality control mechanisms are essential to maintain data integrity. National-level mandates and coordination mechanisms - as seen in the U.S. and UK- can help resolve data duplication, fragmentation, and inconsistent attribution, especially across federal, state, and local levels.

4.1.5 DATA INTEROPERABILITY AND METADATA

Effective data sharing depends on consistent metadata standards, naming conventions, and semantic frameworks. Without a shared taxonomy, even open datasets may be difficult to interpret or combine. Metadata catalogs and APIs—aligned with standards like ISO 19115 or OGC's GeoDCAT—enable better data discovery and integration across domains. Semantic interoperability is especially critical for AI-readiness, allowing intelligent systems to consume and interpret geospatial data in real time.

Ultimately, the value of data in NSDI is only realized when it is embedded into decision-making processes—supporting climate adaptation, infrastructure planning, health services, agriculture, and economic development. Countries looking to modernize their geospatial ecosystems must prioritize foundational data stewardship, improve metadata practices, and invest in platforms that make data accessible, usable and trustworthy to all sectors.

4.2 TECHNOLOGY AND INNOVATION

4.2.1 ADVANCES IN CLOUD COMPUTING, AI, AND BIG DATA FOR NSDI

The integration of advanced technologies such as cloud computing, AI, and big data analytics is revolutionizing the NSDI landscape. Cloud-based platforms enhance scalability, accessibility, and cost efficiency, allowing stakeholders to store, process, and share geospatial information more effectively.

AI-powered algorithms enable automated data classification, object detection, and predictive analytics, improving decision-making processes in urban planning, environmental monitoring, and disaster management. Big data technologies support the processing of vast geospatial datasets, enabling real-time applications, dynamic mapping, and scenario modeling.

These technologies are central to the evolution of NSDI into intelligent geospatial ecosystems, as envisioned by OGC and UN-GGIM, where data is not just stored but actively used to generate insights and support responsive public services.

4.2.2 OPEN-SOURCE VS. PROPRIETARY GEOSPATIAL TECHNOLOGY

The debate between open-source and proprietary geospatial technology continues to influence technology adoption within geospatial communities. Open-source platforms such as QGIS, GeoServer, and PostGIS provide cost-effective solutions with community-driven support, enabling customization and adaptability for various NSDI applications. Proprietary software solutions, such as Esri's ArcGIS and Google Earth Engine, offer robust, enterprise-level capabilities, including advanced analytics, high-performance computing, and technical support. The choice between open-source and proprietary platforms depends on organizational needs, financial resources, and long-term sustainability goals.

Hybrid models and interoperability between platforms are increasingly favored, allowing NSDI programs to leverage the strengths of both ecosystems while maintaining flexibility and scalability.

4.2.3 EMERGING TRENDS: DIGITAL TWINS, BLOCKCHAIN FOR GEOSPATIAL DATA, AND IOT

- **Digital Twins**: The concept of digital twins, where real-world environments are replicated in virtual models, is gaining traction in NSDI. These models enable governments and industries to simulate and analyze urban development, infrastructure resilience, and environmental changes in real-time, supporting proactive planning and risk mitigation.

- **Blockchain for Geospatial Data**: Blockchain technology is emerging as a tool for enhancing data security, transparency, and provenance in NSDI. It enables irreversible record-keeping for land registries, geospatial transactions, and geospatial metadata management, reducing fraud and improving trust in data-sharing ecosystems.
- **Internet of Things (IoT)**: IoT-powered geospatial applications are expanding the reach of NSDI, with smart sensors providing continuous real-time data on weather patterns, traffic conditions, land use, and environmental hazards. The integration of IoT with geospatial infrastructure allows for more accurate, efficient and responsive decision-making processes.

By leveraging these technological advancements, NSDI programs can enhance efficiency, expand accessibility, and support a broader range of applications across government, industry, and civil society. Embedding these technologies within broader digital public infrastructure strategies ensures that geospatial systems remain future-ready, inclusive, and impactful.

4.3 TECHNOLOGY AND STANDARDS

4.3.1 THE IMPACT OF STANDARDS AND INTEROPERABILITY FRAMEWORKS (OGC, ISO)

Interoperability is a cornerstone of effective NSDI implementation, ensuring seamless data exchange between different systems and stakeholders. Standards developed by organizations such as the OGC and the International Organization for Standardization (ISO) play a crucial role in enabling interoperability. The ISO 19100 series provides standardized protocols for geospatial data management, while OGC's web services standards and API-based frameworks ensure compatibility between geospatial data sources, applications, and platforms. Adherence to these standards enhances data integration, improves user access, and facilitates cross-border collaboration, particularly in federated and multi-stakeholder environments.

"The core function of really making information more interoperable is still probably one of the most important things that NSDI should be doing." - Ryan Ahola, Natural Resources Canada

While OGC and ISO standards offer essential guidance, interviewees highlighted a persistent 'standards vacuum' at the national level in the U.S., where inconsistent implementation across jurisdictions undermines interoperability. Local and state agencies often lack the capacity, incentives, or mandates to adopt standardized practices, resulting in fragmented data ecosystems and limited reuse.

This fragmented adoption underscores the need for stronger leadership, clearer mandates, and support structures that promote nationwide interoperability. Embedding standards into national digital strategies and DPI frameworks can help bridge these gaps, ensuring that geospatial data is discoverable, usable, and trusted across sectors.

In Australia, jurisdictions often favor lightweight, pragmatic standards. Complex standards can create barriers to adoption, especially for under-resourced agencies. Instead, shared practice and flexible frameworks supported through peer networks and collaborative governance have proven more successful than rigid compliance.

> "Geospatial standards are not just about technical specifications; they are foundational to collaboration and data sharing." - Linda van den Brink, Geonovum

David Henderson from the UK Ordnance Survey emphasized the importance of *fit-for-purpose standards* that promote discoverability and usability over rigid technical compliance. The UK experience highlights the need for federated metadata systems and simplified access interfaces to make geospatial data actionable

across sectors. Rather than focusing solely on adherence to frameworks, efforts center on whether users—technical and non-technical—can find and use authoritative data, with a strategic priority to grow downstream market use.

5. PEOPLE

5.1 PARTNERSHIPS

5.1.1 PUBLIC-PRIVATE PARTNERSHIPS

Public-private partnerships (PPPs) play a crucial role in the successful implementation and sustainability of NSDI. Governments often collaborate with private-sector entities to leverage advanced geospatial technologies, data analytics, and cloud computing capabilities. Deloitte's research (2025) indicates that PPP-driven investments in geospatial technologies have accelerated economic growth in multiple sectors, including agriculture, urban planning, and environmental sustainability. Key benefits of PPPs in NSDI include:

- **Enhanced Technical Expertise**: Private sector companies bring cutting-edge technologies, agile development practices, and domain expertise to NSDI programs.
- **Sustainable Funding Models**: Shared investment models ensure long-term sustainability and minimize financial burdens on government budgets.
- **Commercial Innovation**: Geospatial data generated through NSDI initiatives fosters innovation in applications and services for industries such as agriculture, insurance, real estate, and logistics.

The US Census Bureau's StatVentures program exemplifies a novel public-private partnership model. This innovation challenge enables private sector actors to develop scalable geospatial solutions—such as improving address geolocation—through a phased, collaborative, and outcome-focused process. StatVentures demonstrates the value of flexible partnerships that extend beyond traditional procurement, encouraging experimentation and rapid iteration.

Another model expanding the concept of public-private partnerships is the USGS National Map Corps (TNM Corps), which leverages citizen science to crowdsource updates to national geospatial datasets. While not a traditional PPP, TNM Corps demonstrates the power of distributed data stewardship—where members of the public, universities, and private sector professionals contribute authoritative data updates through a collaborative platform. This approach reduces government overhead, accelerates data validation, and strengthens community engagement. It shows how co-investment in data maintenance, even in the form of time and expertise, can complement formal PPPs and extend the reach of national geospatial programs.

The UK has built a robust public-private innovation ecosystem around its geospatial data assets. Ordnance Survey collaborates with SMEs and major tech firms to develop services ranging from location-based APIs to sustainability analytics platforms. This model illustrates how NSDI can support dynamic economic applications beyond traditional mapping functions.

5.2 CAPACITY AND EDUCATION

5.2.1 DEVELOPING HUMAN CAPITAL FOR A GEOSPATIAL FUTURE

Building a capable, inclusive and future-ready geospatial workforce is essential to the success and sustainability of NSDI. This includes not only training technical specialists but also equipping decision-makers, planners and public administrators with the knowledge to understand and apply spatial data in policy and operational contexts.

Investments in capacity development should span formal education systems, professional training, and on-the-job learning. Academic institutions should be supported to integrate modern geospatial curricula that blend spatial science, data analytics, and policy relevance. Concurrently, government agencies and private sector organizations need access to training programs that build practical skills in data management, data governance, platform use, and geospatial ethics.

Beyond the technical workforce, it is critical to raise awareness among decision-makers about the strategic value of NSDI. Empowering leaders to champion geospatial investments and use evidence-based insights can accelerate adoption and funding support. Regional knowledge hubs, peer learning platforms, and cross-sector networks all play a role in strengthening institutional and individual capacity over time.

A strong human capital foundation ensures that NSDI evolves alongside technological advancement and national development priorities, enabling more effective governance, innovation, and service delivery. Embedding geospatial capacity-building within broader digital transformation and DPI strategies will be key to long-term success.

5.3 COMMUNICATION AND ENGAGEMENT

5.3.1 BUILDING TRUST AND AWARENESS THROUGH INCLUSIVE OUTREACH

Effective communication and engagement are vital for building awareness, trust, and momentum around NSDI initiatives. Clear, consistent messaging helps stakeholders—from policymakers and data providers to civil society and the public—understand the purpose and value of geospatial investments.

Strategic communication should emphasize real-world outcomes that NSDI enables, such as improved emergency response, smarter infrastructure planning, and more efficient service delivery. Demonstrating use cases, success stories, and tangible benefits can make abstract geospatial concepts relatable, thereby encouraging buy-in and support.

Engagement must also be inclusive and participatory. This means creating feedback loops with users, consulting stakeholders during the design of platforms and services, and ensuring that marginalized communities have access to and benefit from spatial data applications. Transparency, ethical data use, and responsiveness to community needs are central to maintaining public trust.

Building a culture of engagement around NSDI not only increases adoption but also ensures that data infrastructures are designed to respond to societal needs—now and in the future.

Country	Name of the Strategy	Key Achievements	Challenges	Opportunities	Looking Ahead
United States	Geospatial Data Act & NGDA Building the Geospatial Future Together – the NSDI Strategic Plan 2025-2035	- Formalized FGDC role through 2018 Act- 170+ NGDA datasets s 18 themes- atform.gov for open data s- Standardized metadata ecycle governance	- Jurisdictional interoperability- Inconsistent local funding- Balancing open data and security	- Public-private collaboration (e.g., Esri, Microsoft)- AI, cloud integration- NSDI support for climate resilience	- Strengthen federal governance and agency alignment- Enhance GeoPlatform usability- Expand local and global collaboration
European Union	INSPIRE Directive	- Legal foundation for cross-border SDI- Standardized metadata/data models- EU and national geoportals- Enabled data-sharing for environmental policy	- Uneven national implementation- Complex technical and semantic requirements- Institutional fragmentation	- Regional data-sharing for integration- Supports climate, biodiversity, disaster resilience- Fuels private sector innovation	- Simplify through APIs/cloud services- Align with EU data governance laws- Improve user design and engagement
Australia	Foundation Spatial Data Framework (FSDF)	- Federated coordination across 10 themes- Strong intergovernmental working groups- User-centered tools (data.gov.au, LIF)- Flexible adoption of standards	- No central NSDI authority- Informal governance- Inconsistent funding- Jurisdictional disparity in standards	- Co-investment in infrastructure- Broaden private/citizen engagement- Leverage regional leadership position	- Build formal governance mechanisms- Promote national vision for innovation- Integrate AI, digital twins, and climate tools
Kenya	National Spatial Plan (2015–2045)	- Digitized land and boundary records- Urban planning in major cities- Disaster risk mapping- Aligned with Vision 2030	- Reliance on donor funding- Limited cloud/data infrastructure- Skills shortages- Fragmented data practices	- Leverage mobile/cloud tech for land governance- Expand regional leadership roles- Use open data for transparency and participation	- Develop national data sharing policies- Expand GIS education- Strengthen PPPs and open-source infrastructure
Saudi Arabia	National Geospatial Strategy (NGS)	- Cross-ministry data harmonization- Unified geoportal and metadata protocols- AI/ML analytics for infrastructure and environment- Space agency partnerships	- Inter-ministerial silos- Security vs. openness tension- Low domestic geospatial capacity	- Regional/global leadership role- Smart city and digital government applications- Strong PPP and tech investments	- Enforce national standards- Grow domestic talent pool- Align open data with national security- Institutionalize PPP co-creation models

6. LESSONS LEARNED FROM PAST NSDI IMPLEMENTATIONS

Over the years, various NSDI programs worldwide have provided valuable insights into what works and what does not in spatial data infrastructure as both an ecosystem and a critical layer of digital public infrastructure (DPI). Some of the key lessons learned include:

- **Strong Governance and Leadership is Essential**: Countries with clear institutional roles, legal mandates, accountability and well-defined data policies tend to establish more resilient and sustainable NSDI frameworks. Governance must be federated, outcome-driven, and inclusive, in line with UN-IGIF principles.
- **Sustainability Requires Long-Term Funding**: NSDI initiatives require continuous investment in technology, infrastructure, and capacity-building programs.
- **Standards and Interoperability Enable Ecosystems:** Successful NSDI programs emphasize interoperability by adopting open international standards (OGC, ISO) and increasingly focus on semantic interoperability to ensure that both machines and humans can meaningfully use geospatial data.
- **Public-Private Partnerships Drive Innovation**: Collaboration across government, the private sector, academia, and civil society stimulates innovation, expands use cases, and ensures relevance to real-world challenges.
- **User-Centric Approaches Enhance Adoption**: Programs that engage end-users from design through implementation achieve higher utilization rates. Modern geospatial ecosystems emphasize usability, accessibility, and low-code/no-code platforms, lowering barriers for non-technical users.

Interviews reinforced that successful NSDI programs are anchored in clear governance, sustainable funding, and political will. Equally important is the shift in thinking from 'build it and they will come' to embedding NSDI in real-world decision-making processes. For example, stakeholders in both developed and developing contexts highlighted that demonstrating concrete benefits (e.g., faster flood response or better land titling) was essential to sustaining NSDI momentum.

> “There was more of a ‘build it and they will come’ approach. I think the successful SDIs now really focus on the application of the data.” - Jill Saligoe-Simmel, Esri

The UK demonstrates that a federated, outcome-driven geospatial ecosystem can be highly effective when geospatial data is embedded in core service delivery. Success is not measured by NSDI architecture, but by its contribution to societal outcomes such as housing planning, environmental management, or climate adaptation.

6.1 BEST PRACTICES FOR SUSTAINABLE NSDI PROGRAMS

Based on case studies and global experience, as well as emerging frameworks such as UN-IGIF, best practices for developing and maintaining sustainable SDI programs should:

- **Establish Legal and Policy Frameworks**: Ensure governance is supported by legislation that promotes open data, interoperability and cross-sector collaboration.
- **Ensure Interoperability and Data Sharing**: Standardize data formats, metadata, semantic models and application programming interfaces (APIs) to facilitate seamless integration across the ecosystem

- **Leverage Emerging Technologies**: Incorporate cloud computing, artificial intelligence, blockchain, geospatial data spaces, and the Internet of Things (IoT) to deliver decision-ready insights and services
- **Invest in Capacity and Data Literacy:** Strengthen expertise through training, academic curricula, and programs that empower both experts and non-experts to use geospatial data.
- **Embed Monitoring and Evaluation**: Use outcome-based performance metrics aligned with national development goals to assess SDI impact, and drive improvements.

6.2 COMMON CHALLENGES AND BARRIERS

Despite the benefits of SDI, several challenges hinder its successful implementation:

- **Data Privacy and Security Concerns**: Ensuring sensitive geospatial data is protected while maintaining accessibility.
- **Institutional Resistance and Bureaucracy**: Overcoming reluctance from agencies and organizations hesitant to share data.
- **Technological Gaps and Infrastructure Limitations**: Addressing disparities in data readiness, and funds for data collection, processing, and storage, particularly in developing countries.
- **Financial Constraints**: Ensuring sustainable and adaptive funding models to maintain NSDI operations beyond short-term packages
- **Lack of Awareness and Political Will**: Raising awareness among policymakers, industry leaders, and the public about the importance and benefits of SDI.
- **Applicability to End Users**: Value must be demonstrated through practical, high-impact use cases, measured in **social, environmental, and economic outcomes**.

Another recurring issue is the complexity of geospatial standards. While indispensable, they can appear overly technical for policymakers and non-specialist users. As Andre Nonguierma (UNECA) noted, *"We couldn't make it in a way that the policy aspect of the NSDI was fully endorsed, adopted, and validated by policymakers."* Addressing this requires simplified, user-oriented guidance, scenario-based demonstrations, and investment in broad-based data literacy. Australia's experience highlights the risk of NSDI terminology losing relevance outside the geospatial community. Maree Wilson from Geoscience Australia shared that the term "NSDI" is not commonly used in external communications, and there is a growing need to reframe the value of geospatial systems using terms that resonate with broader audiences and policymakers.

David Henderson echoed concerns heard from other countries that the term "NSDI" may lack resonance with policymakers and stakeholders. In the UK, the term is rarely used externally, having been replaced with phrases like "location-enabled infrastructure" or "digital services powered by geospatial" having been replaced with phrases like "resilient data ecosystem anchored on place" or "digital services powered by location." This signals a broader need to modernize language and communication around geospatial governance, framing spatial data as a living, adaptive ecosystem embedded in the core digital public infrastructure rather than as a static mapping project.

6.3 STRATEGIES FOR IMPROVING DATA STANDARDIZATION AND GOVERNANCE

To enhance the effectiveness of NSDI programs, countries and organizations can adopt the following strategies:

- **Adopting International Standards**: Aligning with ISO, OGC, and UN-GGIM frameworks to ensure technical and semantic interoperability across systems, applications, and AI-ready platforms.

- **Developing Clear Data Governance Policies**: Defining data ownership, sharing agreements, and ethical considerations to promote responsible geospatial data usage while embedding principles of trust, privacy, and equity as emphasized in UN-IGIF and FGDC's NSDI 2035 vision.
- **Encouraging Cross-Sector Collaboration**: Establishing multi-stakeholder partnerships across government agencies, private enterprises, academia, and civil society, ensuring that governance models are federated, inclusive, and outcome-driven rather than purely top-down.
- **Implementing Cloud-Based NSDI Solutions**: Leveraging cloud infrastructure, open APIs, and data spaces for scalable and cost-effective geospatial data storage, and analysis and service delivery.

By applying these lessons, best practices, and strategies, SDI programs worldwide can be strengthened, ensuring that geospatial data ecosystems—recognized as critical layers of Digital Public Infrastructure (DPI)—are more effective, sustainable, and capable of delivering measurable social, economic, and environmental outcomes to a wide range of stakeholders.

7. FUTURE DIRECTIONS FOR NSDI DEVELOPMENT

7.1 INTEGRATION WITH ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING

Artificial intelligence and machine learning are reshaping the landscape of national SDIs by enabling a new generation of capabilities that go far beyond traditional mapping and data management. These technologies bring automation, predictive power, and deeper analytical insight into the processing and interpretation of geospatial data, transforming how governments, the private sector, and researchers use NSDI to make decisions, allocate resources, and plan for the future.

At their core, AI and ML algorithms are designed to learn from data patterns and improve performance over time, making them ideal tools for geospatial environments where datasets are vast, complex, and constantly evolving. From satellite imagery and LiDAR scans to cadastral maps and demographic data, AI/ML models can ingest, classify, and analyze large volumes of geospatial information with unprecedented speed and precision.

7.1.1 AI AND ML APPLICATIONS IN NSDI

AI/ML integration with NSDI has already yielded significant benefits:

- **Automated Feature Extraction**
  ML models, particularly convolutional neural networks (CNNs), can process satellite and aerial imagery to detect and classify land cover types, buildings, roads, and other features with high accuracy. They also enable automated monitoring of environmental change and infrastructure development, reducing reliance on costly manual surveys.
- **Predictive Analytics and Risk Modeling**
  AI algorithms can model geospatial phenomena such as urban sprawl, deforestation, flood risk, or land degradation, enabling anticipatory governance and better resource allocation.
- **Smart Urban and Infrastructure Planning**
  AI tools support scenario planning for transport networks, utilities, and housing, factoring in geospatial, demographic, and socio-economic data to recommend optimal layouts or investment strategies.
- **Anomaly Detection and Quality Assurance**
  ML systems can flag inconsistencies or outdated records in geospatial datasets, enabling continuous validation, semantic consistency checking, and alignment with international standards (OGC, ISO, UN-GGIM).

7.1.2 THE EMERGING ROLE OF LLMS IN NSDI

LLMs potentially bring new capabilities to the NSDI ecosystem:

- **Semantic Search and Natural Language Querying of Geospatial Data**
  LLMs could enable users—technical and non-technical alike—to interact with geospatial databases using plain language. Instead of complex SQL or GIS-specific queries, users can ask: *"Show me areas with high flood risk and low-income populations,"* or *"Find recent satellite imagery for coastal erosion in eastern Kenya."*
- **Automated Metadata Generation and Documentation**
  One of the major challenges in NSDI is maintaining consistent, rich metadata. LLMs could help generate or standardize metadata descriptions, data dictionaries, and usage notes by analyzing

dataset content and associated documentation—**improving discovery and compliance with FAIR (Findable, Accessible, Interoperable, Reusable) principles**.

- **Knowledge Synthesis and Decision Support**
  LLMs could analyze and summarize policy documents, technical reports, and stakeholder inputs alongside geospatial data, offering decision-makers clear, contextual insights without requiring deep GIS expertise.
- **Geospatial Data Interpretation and Reporting**
  With the ability to generate narratives, executive summaries, and policy briefs, LLMs could turn raw geospatial outputs into actionable insights and communication materials for different audiences—policy makers, media, or the public.
- **Multilingual Accessibility**
  LLMs could support translation and localization of geospatial content, enabling NSDI platforms to reach users in multiple languages—a critical factor for equity in multilingual regions and global collaborations.

The combination of AI/ML for data processing and predictive modeling and LLMs for interpretation and communication can make SDI more intelligent, user-friendly, and scalable. These tools open new avenues for public engagement, smart infrastructure development, and service delivery.

However, adoption requires robust data governance, interoperability frameworks, responsible AI policies, and capacity building to ensure ethical use and effective integration. Countries investing in these technologies must prioritize federated governance, transparency, semantic interoperability, and human-centered design to fully realize their potential. In short, the convergence of AI, ML, and LLMs represents a transformative leap for NSDI— moving it from static data repositories to dynamic, predictive, and user-centric geospatial intelligence ecosystems embedded within DPI.

7.2 GEOSPATIAL KNOWLEDGE INFRASTRUCTURE: IMPLICATIONS FOR NSDI

As geospatial systems mature, there is growing recognition that traditional SDIs —which have primarily focused on data collection, management, and access—must evolve to support the creation and application of geospatial knowledge. The concept of Geospatial Knowledge Infrastructure (GKI) represents a forward-looking framework for this evolution. Developed through global collaboration among public, private, and academic stakeholders, GKI shifts the focus from data as an end goal to infrastructure that enables insight, innovation, and public value.

GKI integrates geospatial systems with broader digital infrastructure—such as cloud platforms, open APIs, AI/ML tools, semantic standards, and knowledge services—embedding geospatial capabilities into the wider Digital Public Infrastructure (DPI). This integration supports decision-making across government, business, and society. Building on GKI, the emerging idea of a national geospatial ecosystem envisions an even more dynamic and interconnected environment—one where geospatial knowledge flows seamlessly across sectors, technologies, and communities to drive inclusive development and resilience.

From Data to Knowledge

The GKI model emphasizes the Data → Information → Knowledge → Wisdom (DIKW) continuum, highlighting the need for systems that not only manage data but translate it into actionable knowledge and real-time intelligence. NSDI programs should be designed to enable automation, semantic interoperability, real-time analytics, and integration into everyday decision systems—from shifting climate conditions to transport simulations and smart city dashboards.

Six Pillars of GKI
To operationalize this shift, NSDI programs can align with six core elements of the GKI framework:

1. **Integrated Policy Frameworks** – Embedding geospatial within digital and national policy environments.
2. **Foundation Data** – Maintaining trusted, interoperable, and continuously updated datasets across domains.
3. **Partnerships and Collaboration** – Fostering multi-sector co-creation of knowledge and services.
4. **Industry Leadership** – Recognizing the private sector as both a user and innovator in geospatial technology and services.
5. **Applications, Analytics, and Modeling** – Investing in systems that deliver decision-ready outputs, not just data.
6. **Digital Integration** – Ensuring geospatial is a first-class citizen in digital public infrastructure (e.g., IoT, 5G, AI systems).

7.2.1 TOWARD KNOWLEDGE-AS-A-SERVICE

GKI promotes a model of "knowledge-as-a-service," where foundational geospatial insights—such as flood alerts, land suitability models, or climate-related impact forecasts—are delivered seamlessly, accessibly, and in real time. NSDI must be positioned as a platform for intelligence, not just access.

Implications for National Strategies
To align with this vision, NSDI programs should:

- **Embrace federated, distributed architectures (e.g., data mesh, data spaces)** for greater flexibility and scalability.
- Build value-sharing models with industry, academia, and citizens that reward co-creation and innovation.
- Prioritize impact tracking—measuring how geospatial knowledge improves outcomes in health, safety, sustainability, and governance.
- Incorporate citizen engagement and feedback loops as part of core infrastructure design.

Integrating GKI principles will help reposition NSDI not just as a data repository, but as a critical enabler of digital transformation, innovation, and national development.

7.3 TOWARD A NATIONAL GEOSPATIAL ECOSYSTEM

As geospatial needs evolve in complexity, the vision for NSDI must also expand. According to the UN-GGIM's 2022 report, *Defining the Desired Geospatial Ecosystem of the Future*, the next generation of geospatial governance will require a shift from viewing NSDI as a static infrastructure to positioning it within a broader, dynamic "national geospatial ecosystem."

This ecosystem model moves beyond traditional NSDIs and even beyond the emerging concept of GKI, toward an integrated, intelligent, outcome-driven environment that enables real-time decision-making across government, business, and society. Rather than a single platform, the ecosystem comprises interconnected systems—data ecosystems, stakeholder networks, operational platforms, and policy frameworks—all federated and interoperable to generate impact.

Key features of this ecosystem model include:

- **Distributed architectures** such as data mesh, federated systems, and semantic interoperability frameworks enabling seamless interoperability across institutions.
- **Knowledge-as-a-service**, where geospatial insights are delivered through intelligent, AI-powered, cloud native tools to policymakers, businesses, and citizens alike.

- **Ecosystem of ecosystems thinking,** recognizing that national platforms must interoperate with global, regional, and sectoral systems.
- **Human-centered design**, focusing on equitable access, trust, and public value rather than purely technical metrics.

The UN-IGIF is increasingly seen as an essential enabler of this evolution. By providing a comprehensive policy and implementation framework that integrates governance, innovation, and service delivery, UN-IGIF equips countries to move beyond static infrastructures and toward responsive, demand-driven geospatial ecosystems capable of supporting digital government, environmental resilience, and inclusive economic growth.

To assess readiness for such transformation, the UN-GGIM encourages the use of the PEST framework—evaluating political, economic, social, and technological factors influencing geospatial modernization. Countries are urged to adopt multi-stakeholder governance models and shift toward impact-based measurement, such as contributions to national priorities, service delivery, disaster resilience, and sustainable development.

By embracing this broader vision, NSDI can become more than a data platform—it can evolve into a **catalyst for national digital transformation**, responsive to both strategic goals and local needs. This transition will require new capacities, adaptive governance, sustained funding, and investment in technologies that support interoperability, automation, semantic clarity, and participatory engagement.

7.4 BUILDING TRUST AND RESILIENCE IN FUTURE NSDI SYSTEMS

Recent technical advancements in geospatial infrastructure emphasize the need for resilient, secure, and trustworthy data systems—particularly in the face of climate-related risks, growing privacy concerns, and increasing demand for real-time decision-making. Findings from OGC's Testbed 20 (2024) offer key directions for enhancing the integrity and adaptability of future NSDI frameworks.

Resilient Data Services for Risk-Informed Decision-Making
Geospatial infrastructures must go beyond basic data delivery to support national resilience, sustainability and service delivery. OGC advocates for the design of robust data services that are continuously tested, stress-tested for reliability under adverse conditions, and optimized for accessibility across diverse network environments and devices. These services play a vital role in enabling effective disaster response, long-term planning for environmental risks, and the development of nationally relevant resilience strategies.

Integrity, Provenance, and Trust (IPT) Mechanisms
A cornerstone of future geospatial ecosystems is the implementation of Integrity, Provenance, and Trust (IPT) frameworks. These enable users and systems to:

- Verify the source and authenticity of geospatial data;
- Detect tampering or alteration;
- Support secure sharing and re-use of geospatial data.

OGC's proposed IPT building blocks are encoding-agnostic and can be embedded within OGC API endpoints. This means users could request not only a dataset but also metadata verifying its lineage, digital signatures, and timestamps—ensuring a higher level of data accountability across the NSDI ecosystem.

Decentralized Identity and Selective Disclosure
Privacy-preserving mechanisms like Decentralized Identifiers (DIDs) and Verifiable Credentials (VCs) are becoming increasingly important. These tools empower both data providers and users to control the disclosure of sensitive information and verify access rights without compromising security. For instance,

location data could be shared under strict terms, ensuring only relevant parties have access to specific data attributes.

Selective disclosure further supports privacy by allowing users to reveal only necessary pieces of identity or metadata during a transaction—critical for public trust in open geospatial platforms.

Implications for NSDI Governance and Standards
The incorporation of these trust-enhancing mechanisms necessitates an evolution in geospatial governance:

- National NSDI strategies must include IPT protocols and privacy-by-design principles.
- Standards bodies (like OGC and ISO) should prioritize next-generation API interoperability that supports secure, verifiable data exchange and semantic consistency.
- Investment in prototype systems and edge-computing deployments should begin immediately to ensure national readiness for future crises.

By embedding resilience, trust, and privacy at the architectural level, NSDI frameworks can evolve from static data repositories into secure, adaptive, and user-centered platforms—supporting not only economic growth but societal resilience and digital sovereignty.

7.5 SUMMARY

The future of NSDI lies not only in improving data access and interoperability, but also in reimagining it as a dynamic, intelligent system that delivers actionable insights for the public good. Emerging technologies—especially AI, ML, and LLMs—are transforming how geospatial data is processed, interpreted, and communicated. These tools enable automated mapping, predictive modeling, natural language interfaces, and real-time reporting, expanding the reach and impact of geospatial systems.

At the same time, there is a broader shift underway: from viewing NSDI as a static infrastructure to embedding it within a national geospatial ecosystem—distributed, federated, interoperable, and a core piece of the nation's broader digital public infrastructure. The concept of GKI furthers this evolution, placing emphasis on multi-sector collaboration, citizen engagement, and delivering geospatial intelligence as a public service.

To meet this moment, NSDI programs must:

- Integrate geospatial with broader digital transformation and national development agendas.
- Embrace open, federated architectures, semantic interoperability, and knowledge-as-a-service models.
- Build inclusive governance frameworks that foster innovation and trust.
- Focus on measuring outcomes, not just outputs—using geospatial knowledge to advance national priorities like resilience, sustainable development, and equitable service delivery.

NSDI is no longer just about managing data; it is about enabling nations to make better, faster, and more informed and trusted decisions. Its future will be defined by how well it can adapt to this expanded role and deliver value in a world that increasingly depends on knowing not just what is happening, but where, when, and why—and being able to trust that information.

8. CHALLENGES AND RISKS TO WATCH

8.1 DATA SECURITY AND PRIVACY CONCERNS IN NSDI

As geospatial data becomes more accessible, concerns about data security and privacy are increasing. Many NSDI frameworks promote open data policies, but balancing openness with the protection of sensitive information remains a significant challenge. Key risks include:

- Unauthorized access to critical geospatial infrastructure data, potentially exposing national security vulnerabilities.
- Privacy concerns related to the collection of location-based information from individuals and businesses.
- The need for robust cybersecurity frameworks and integrity frameworks (e.g., IPT—Integrity, Provenance, Trust) to prevent data breaches and misuse.

8.2 INSTITUTIONAL AND POLITICAL CHALLENGES

Governance structures for NSDI vary widely, and political and institutional challenges often hinder progress. Key issues include:

- Lack of clear mandates and responsibilities among government agencies, leading to data silos and inefficiencies.
- Resistance from stakeholders who fear losing control over their geospatial data assets.
- Changing political priorities that impact long-term investment in NSDI programs.
- Coordination challenges in multi-stakeholder environments, particularly between national and local governments and across government agencies.

8.3 SUSTAINABILITY ISSUES: FUNDING AND LONG-TERM MANAGEMENT

Sustaining NSDI initiatives requires continuous funding for infrastructure, software, and workforce development. Challenges in this area include:

- Insufficient government budgets and reliance on short-term project-based funding.
- Limited private sector investment in public geospatial infrastructure.
- The high cost of maintaining geospatial datasets and ensuring data accuracy over time.
- The need for sustainable business models and outcome-based investment frameworks that support ongoing NSDI development and operations.

Australia's federated model, while functional, faces vulnerabilities due to the absence of dedicated national investment. The continued reliance on informal coordination and goodwill among jurisdictions poses a risk to long-term sustainability, innovation, and infrastructure upkeep. National investment strategies and cross-jurisdictional funding models are needed to ensure continued alignment and modernization.

David Henderson (UK Ordnance Survey) cautioned that without outcome-based investment models, NSDI efforts risk a lack of commitment and sponsorship without a clear link to the downstream value enabled by the resilient data ecosystems underpinned by effective NSDI. The UK is addressing this by ensuring key public sector bodies work together to align respective digital transformation budgets, APIs and innovation programs towards national policy priorities and defined market opportunities.

8.4 TECHNOLOGY DISPARITIES: BRIDGING THE GAP FOR DEVELOPING NATIONS

Many developing nations struggle with inadequate technological infrastructure to support NSDI. Disparities in geospatial capabilities pose challenges such as:

- Limited access to high-resolution satellite imagery and real-time geospatial data.
- Lack of skilled professionals trained in geospatial sciences and NSDI management.
- Dependence on foreign-developed technologies and proprietary software solutions.
- The digital divide that prevents equitable access to NSDI benefits.

Addressing these disparities requires capacity building, open standards adoption, and international cooperation under frameworks like UN-IGIF to ensure developing nations are not left behind in the evolution of geospatial ecosystems.

8.5 MONETIZATION OF DATA

While many NSDI programs emphasize open data policies, questions around data monetization and commercial use remain unresolved. Key considerations include:

- Determining the balance between free public access, fair pricing models and commercial licensing.
- Managing revenue generation through paid geospatial services while ensuring broad accessibility.
- Encouraging private sector participation in NSDI without creating monopolies over critical geospatial datasets.
- Ensuring that revenue models align with national development priorities and public interest.

By proactively addressing these challenges and risks, NSDI programs can enhance their resilience, effectiveness, and ability to support sustainable development.

8.6 PERCEIVED RELEVANCE AND UNDERSTANDING OF NSDI OUTCOMES

Despite increasing recognition of geospatial data's potential, many NSDI efforts continue to struggle with broader understanding and relevance, especially among senior policymakers and potential funders. NSDI is often perceived as a technical or infrastructural initiative rather than a strategic enabler of national outcomes and digital government services. This disconnect leads to underinvestment and missed opportunities.

Key issues include:

- Lack of Clear Narrative Linking NSDI to Tangible Outcomes: Without clear illustrations of how NSDI contributes to public service delivery, climate resilience, or economic growth, decision-makers may see it as a background function rather than a strategic asset.
- Communication Gaps Between Technical and Policy Communities: Technical terminology and process-focused framing (e.g., metadata standards, system architecture) can alienate non-specialists, making it harder to build support.
- Difficulty Articulating the Value Proposition: NSDI's role in enabling "resilient data ecosystems anchored on place" needs to be communicated in a way that resonates with public priorities—such as faster disaster recovery, efficient infrastructure investment, or smarter urban planning.

To address this, countries must shift NSDI messaging from "process" to "purpose"—clearly linking geospatial infrastructure to outcomes that matter for government performance, citizen wellbeing, and national competitiveness. This means:

- Using real-world use cases and economic value estimates to show return on investment.

- Building political sponsorship through cross-ministry alignment, especially in digital transformation, climate, and infrastructure programs.
- Creating plain-language impact dashboards that show how geospatial infrastructure improves services on the ground.

8.7 ETHICAL USE OF LOCATION DATA: INSIGHTS FROM THE LOCUS CHARTER

As geospatial technologies become increasingly embedded in public services, private sector offerings, and daily life, the ethical governance of location data has emerged as a foundational concern. The Locus Charter, developed by EthicalGEO and the Benchmark Initiative (2021), proposes ten globally relevant principles to guide the responsible use of location data. These principles are increasingly viewed as critical to ensuring public trust, transparency, and accountability in National Spatial Data Infrastructure (NSDI) systems.

Key themes from the Locus Charter relevant to NSDI development include:

- **Privacy and Minimization**: NSDI programs must adopt data minimization practices—collecting only what is necessary—and ensure robust safeguards to prevent the identification or re-identification of individuals.
- **Do No Harm and Protect the Vulnerable**: Ethical geospatial governance involves proactively assessing potential harms and considering disproportionate impacts on vulnerable communities. For NSDI, this translates into inclusive data governance and socially responsible data use.
- **Bias and Representation**: NSDI systems must address and mitigate systemic biases embedded in geospatial datasets, which can lead to unequal service provision or skewed policy decisions.
- **Transparency and Accountability**: Clear lines of responsibility must be established for how geospatial data is collected, shared, and used. NSDI agencies should provide public-facing documentation on their ethical commitments and operational protocols.
- **Empowerment through Informed Use**: NSDI should facilitate not just access to data but understanding of it—enabling communities and policymakers to make informed, responsible, and equitable use of location-based insights.

Implications for NSDI:
To remain relevant, trusted, and equitable, NSDI programs should embed the Locus Charter's principles into their governance frameworks. This could include:

- Requiring ethical impact assessments for new geospatial data initiatives.
- Aligning open data policies with privacy-by-design principles.
- Creating ethics advisory committees to support geospatial governance bodies.
- Incorporating the Locus Charter into national geospatial strategies and training curricula.

By integrating ethical principles at the core of NSDI design and implementation, governments and stakeholders can ensure that geospatial infrastructure advances societal benefit while protecting rights and dignity in the digital age.

9. CONCLUSION

The Digital Public Infrastructure has become a cornerstone of modern governance, and the spatial component of it–the NSDI–is a critical component, enabling integrated decision-making across sectors such as environment, sustainability, urban planning, and disaster response. While progress has been made globally, the continued relevance and effectiveness of NSDI hinges on its ability to evolve from static infrastructure into adaptive, federated, and trusted ecosystems—technologically, institutionally, and politically.

This report has illustrated both the value and complexity of NSDI, drawing on global experience and emerging trends. As countries face rising demand for real-time, interoperable, and actionable geospatial intelligence, the path forward must focus less on building infrastructure as an end in itself and more on cultivating intelligent, user-centered, and service-oriented geospatial ecosystems embedded in broader Digital Public Infrastructure (DPI).

The future of NSDI will depend on several key shifts:

- Embedding NSDI within broader digital transformation strategies and aligning with national priorities such as climate-related risks, sustainable infrastructure, and inclusive growth.
- Moving from siloed data systems to interconnected, interoperable platforms that enable semantic integration, real-time insights, and cross-sector coordination across government, the private sector, and civil society.
- Investing in enabling environments—governance, legislation, funding, and capacity building—that allow geospatial systems to thrive, scale and sustain.
- Embracing emerging technologies not as add-ons but as integral components of the NSDI lifecycle, including AI, cloud infrastructure, and large language models that democratize access and usability.
- Focusing on impact over implementation, where success is measured not by the volume of data collected, but by the outcomes delivered—safer communities, resilient infrastructure, equitable services and evidence-based policy.

As geospatial systems evolve globally, the experience of NSDI implementation across regions demonstrates a consistent set of insights. The table below highlights the most critical lessons learned, emerging strategic directions, and persistent challenges that shape the effectiveness and sustainability of national spatial data infrastructures. These findings provide a forward-looking lens for policymakers, practitioners, and partners seeking to strengthen the role of geospatial data in digital transformation, resilience, and sustainable development.

Category	Highlights
Key Lessons Learned	- Legal frameworks and open data are foundational - Interoperability enables cross-platform use - Capacity building is critical to long-term success - Clear governance and monitoring drive impact - Reframing language for broader appeal
Future Directions	- Integrate AI, ML, and LLMs for automation and insight - Shift from static SDI to dynamic ecosystems - Emphasize Geospatial Knowledge Infrastructure (GKI) - Move toward knowledge-as-a-service delivery - Apply human-centered design principles
Common Challenges	- Data privacy and cybersecurity risks - Institutional resistance and siloed governance - Funding shortfalls and sustainability issues - Technology gaps in developing nations - Complexity of geospatial standards for non-experts

To be future-ready, NSDI must be seen not simply as infrastructure, but as a national asset and a strategic enabler of development and digital governance. This demands sustained leadership, inclusive and federated governance, trust-enhancing mechanisms (IPT, privacy-by-design), and bold innovation. Countries that make this leap will not only enhance their geospatial data capabilities but also position themselves as leaders in an increasingly location-aware, AI-enabled, and digitally connected world.

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