Literature Study: Trends in GIS Sustainability and Remote Sensing in the Era of Smart Infrastructure

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ABSTRACT

The advancement of geospatial technology has significantly transformed spatial management and infrastructure development in the digital era. This study aims to identify trends in the application of Geographic Information Systems (GIS) and Remote Sensing to support sustainability and the development of smart infrastructure. A systematic literature review was conducted on scientific publications from 2015 to 2024 focusing on the integration of geomatics, artificial intelligence, and cloud computing in spatial planning. The analysis categorized the findings into digital transformation, sustainability, and the challenges and opportunities of spatial technology implementation. The results indicate that the integration of GIS and remote sensing enhances the efficiency of planning, environmental monitoring, and infrastructure resilience through real time spatial analysis and data driven decision making. The main challenges include data interoperability, spatial privacy, and technological gaps, while opportunities emerge from the adoption of Spatial Data Infrastructure and AI-based spatial analytics. In conclusion, geomatics plays a pivotal role as a foundation for developing efficient, resilient, and sustainable smart infrastructure both in Indonesia and globally.

Keywords: *Geomatics*, *GIS, Remote Sensing, Smart Infrastructure.*

1. INTRODUCTION

Advances in digital technology, artificial intelligence, machine learning, and cloud computing have driven major transformations in the field of geomatics. These transformations have brought about significant changes in the way we observe the earth, analyze the environment, and plan and monitor infrastructure. In the context of smart infrastructure development and sustainable regional management, geomatics has become the foundation that enables spatial data-based analysis to be carried out more quickly, accurately, and efficiently than conventional methods [1]. However, amid these opportunities, the sector still faces a number of challenges, such as the complexity of big data integration, information security issues, and the need for interoperability between platforms [2]. These conditions make studies on the role and contribution of geomatics technology increasingly relevant to support the sustainability of modern infrastructure. GIS (Geographic Information System) plays a key role in geomatics because it provides a framework for integrating spatial and non-spatial data into a comprehensive analysis system [3]. With its ability to process location-based data, GIS enables spatial modeling, disaster risk assessment, infrastructure condition monitoring, and real-time decision making. The development of GIS integration with artificial intelligence and machine learning has improved mapping accuracy and predictive capacity, especially in analyzing complex spatial relationships [4]. In addition, the use of cloud GIS has further expanded inter-agency and inter-regional collaboration through simultaneous data updates, thereby supporting more efficient and standardized spatial data management [5].

Remote Sensing (RS) serves as the main source of Earth surface observation data that complements the GIS system. [6] Through satellites, drones, or aerial sensors, RS is able to record energy reflections and produce images that represent environmental conditions without the need for direct contact with objects. This technology enables monitoring of land changes, early disaster detection, environmental quality analysis, and periodic and multi-resolution vegetation cover assessment. In addition, Remote Sensing is used for mapping relatively large areas, such as road networks and regional boundaries [7]. Research [8] shows that the use of satellite data combined with spatial analysis can reduce the risk of land degradation by up to 18% in urban areas of Africa, confirming the important contribution of RS in sustainable environmental monitoring. When RS is integrated with GIS, the two produce more comprehensive and accurate spatial analysis and support strategic decision-making in infrastructure and resource management.

2. RESEARCH METHODOLOGY

This study uses a literature review method by analyzing various relevant scientific articles to understand the development of digital transformation in geomatics, particularly the application of GIS and remote sensing (RS) in sustainable smart infrastructure. The articles collected were from the period 2015–2024 through databases such as Google Scholar, ScienceDirect, IEEE Xplore, and MDPI to ensure that the sources used were credible and up-to-date. All articles were then classified based on research focus, year of publication, methods or instruments used, and key findings that support the development of sustainable

geomatics systems. This approach allows researchers to obtain a comprehensive overview of technology trends, innovations, and research development directions in the field of digital geomatics in smart infrastructure.

2.1 Data Collection

The data collection stage involves gathering scientific articles published between 2015 and 2024 from academic databases and scientific literature platforms, including Google Scholar, ScienceDirect, IEEE Xplore, and MDPI. The collected articles are selected based on their relevance to the research topics, particularly Geomatics, Geographic Information Systems (GIS), and Smart Infrastructure. This selection process ensures that the literature provides a relevant scientific foundation for analyzing technological developments, research trends, and their applications in the field of geomatics.

2.2 Literature Classification

The selected articles were grouped according to their main themes to facilitate systematic analysis. Three thematic categories were established: (1) GIS, (2) Smart Infrastructure, and (3) Sustainability and the Sustainable Development Goals (SDGs). This classification made it easier to identify patterns, research focuses, and relationships among topics across the reviewed literature.

2.3 Digital Transformation Analysis

In this stage, trends in the application of Artificial Intelligence (AI), the Internet of Things (IoT), and GIS technologies within the field of geomatics were analyzed. In addition, the contribution of geomatic applications to the efficiency of digital transformation and energy use was evaluated. This analysis provides an understanding of how emerging technologies are reshaping geospatial practices and supporting more efficient infrastructure systems.

2.4 GIS and Remote Sensing Integration Study

This stage examined the relationship between GIS and Remote Sensing in spatial monitoring and decision-making systems. The study also analyzed the application of spatial modeling in supporting environmental sustainability. The integration of these two technologies was reviewed to understand how it improves the accuracy, timeliness, and usefulness of spatial information for planning and management.

2.5 Mapping Challenges and Opportunities

The findings from the previous stages were used to map the key challenges and opportunities in applying geomatics to smart infrastructure. The main challenges identified include data interoperability, spatial privacy, technology alignment, and human resource capacity. On the other hand, significant opportunities lie in the integration of AI, Spatial Data Infrastructure (SDI), and GIS, which can strengthen data driven planning and decision making.

3. RESULT AND DISCUSSION

3.1 Effectiveness of Smart Infrastucture

The implementation of smart infrastructure in Indonesia has shown significant improvements in operational efficiency, environmental resilience, and urban sustainability through the integration of GIS (Geographic Information System), Remote Sensing, and Internet of Things (IoT) technologies. Smart infrastructure is an important foundation for smart cities because it enables real-time management of public resources and assets based on integrated spatial data [9]. The cognitive city platform concept in Indonesia has shown high effectiveness in supporting city resilience through the digitization of public infrastructure and the use of spatial data for energy management, transportation, and disaster management. This system utilizes AI and machine learning to increase the speed of spatial data analysis, thereby accelerating decision-making at the local government level [10].

The integration of remote sensing and GIS in irrigation water management has increased efficiency by up to 40% compared to conventional methods. This proves that smart infrastructure is not only effective in urban contexts but also in the sustainable agriculture sector, which requires smart water management based on digital spatial maps [11]. The use of remote sensing in mapping urban green spaces can also strengthen the effectiveness of environmental policies in large cities such as Yogyakarta and Bandung. By integrating surface temperature, NDVI, and building density data, this system helps local governments determine priority areas for greening to reduce the urban heat island effect [12]. The implementation of smart infrastructure in Indonesia and globally has demonstrated significant operational efficiency, environmental resilience, and spatial sustainability through the integration of GIS, Remote Sensing (RS), and Internet of Things (IoT) technologies as presented in Table 1.

3.2 The Role of GIS and Remote Sensing

The role of GIS and remote sensing in the era of smart infrastructure can be categorized into three main categories as follows.

- **Sustainable monitoring and management of natural resources.** GIS and Remote Sensing play a major role in supporting efficient and sustainable natural resource management. With spatial and temporal monitoring capabilities, this technology

Table 1. Effectiveness of Smart Infrastructure Implementation

No	Regional / Global Focus	Technological Integration	Application Area	Impact & Key Findings
1	Indonesia (Urban)	Cognitive City Platform + AI	Urban public infrastructure & energy	Accelerated spatial decision-making and real-time asset monitoring.
2	Indonesia (Bali)	Remote Sensing + GIS + Geo-IoT	Irrigation water management	Improved water management efficiency by up to 40%.
3	Indonesia (Yogya/Bandung)	NDVI + Surface Temp + GIS	Urban Green Space (RTH) mapping	Optimized priority zones to mitigate Urban Heat Island (UHI) effects.
4	Global / International	Earth Observation (EO) + GIS	SDG Monitoring (SDG 9, 11, 13, 15)	Multi-temporal spatial tracking for land degradation and emission controls.
5	Indonesia (Semeru)	Geo-IoT + Visual Analytics	Disaster evacuation & recovery	Generated spatial risk maps with >90% accuracy.

can map changes in land cover, water quality, and mineral resource availability in real time. The role of remote sensing and GIS in irrigation water management in Bali has shown an increase in water management efficiency of up to 40%. This technology enables spatial analysis of drought vulnerability and adaptive water distribution planning in response to climatic conditions [11]. In addition, the application of GIS with overlay and scoring methods to rainfall, slope, and elevation parameters can identify the level of flood vulnerability in the Kayan River area, Bulungan Regency. The results of the analysis show that rainfall above 2,500 mm/year is a dominant factor in determining the level of flood risk, while flat topography also expands areas with high vulnerability [13].

- **Disaster risk analysis and adaptation to climate change.** GIS and Remote Sensing are important instruments in disaster risk mapping and climate change impact mitigation. Through spatial modeling, this technology helps identify areas prone to landslides, floods, and volcanic eruptions with precision. The use of Geo-Internet of Things (Geo-IoT) and Geostatistical Visual Analytics to assess the impact of the eruption of Mount Semeru. This model produces spatial risk maps with an accuracy of over 90%, accelerating the evacuation and rehabilitation process [14]. In addition, the application of GIS integrated with the Multi-Criteria Decision Making (MCDM) method can be used to determine priority water catchment areas in the Bengawan Solo River region, thereby improving the accuracy of spatial-based spatial planning [15]
- **Digital infrastructure and smart energy planning**. GIS and Remote Sensing also play an important role in supporting the development of digital infrastructure and smart energy. In research on Geospatial Intelligence models for planning BTS towers in remote areas of Indonesia, this GIS-based system helps determine the optimal location by considering topography, population density, and network accessibility [16]. Meanwhile, research on the application of GIS (Geographic Information System) and IoT (Internet of Things) technologies to improve the efficiency and reliability of electrical systems, particularly in monitoring power transformers in urban energy distribution networks, shows the effectiveness of GIS in managing electrical transformers and smart grid systems, which reduces the risk of network damage by up to 30% [17].

3.3 The Relationship Between SDGs and Resilience

The use of Earth Observation (EO) and Geographic Information System (GIS) has a significant contribution in supporting the achievement of sustainable development goals (SDGs). In SDG 9 on industry and infrastructure, the integration of EO GIS enables spatial modeling to improve resource use efficiency and determine strategic locations for smart and efficient infrastructure development [18]. Meanwhile, for SDG 11, spatial data from EO and GIS plays a role in mapping population density, transportation networks, and green open space planning as part of smart city development. In the context of SDG 13, EO is used to monitor surface temperature, emissions, and other climate parameters to support climate change adaptation and mitigation efforts. Furthermore, in SDG 15, the integration of satellite imagery and spatial analysis enables the monitoring of land cover, forest degradation rates, and changes in biodiversity in a sustainable manner.

From a resilience perspective, each technology component makes a specific contribution. EO provides historical and extensive data that is essential for detecting environmental changes such as floods, droughts, and deforestation. GIS then facilitates the integration of various types of data, including topography, social, economic, and infrastructure data, to map risks and determine intervention priorities. On the other hand, IoT sensors provide early signals of changes or disturbances, such as rising river levels, building vibrations, or extreme temperature fluctuations. Finally, Artificial Intelligence and Big Data Analytics play a key role in predicting and analyzing patterns, including identifying areas most vulnerable to damage or disasters [19]. In addition to these findings, according to [20], there are other correlations, such as:

- Physical infrastructure resilience, bridge monitoring with vibration sensors + UAV imagery
- The environment's ability to adapt to pressure, mapping land cover changes with Sentinel-2
- Community participation and awareness, crowdsourced GIS for flood reports by residents
- System ability to recover quickly from disruptions, real-time GIS dashboard for emergency response coordination.

3.4 Research Gaps and Future Research Direction

Based on the analysis, several research gaps and prospective future research direction are outlined as follow.

- **Data interoperability and fragmentation.** Data interoperability is the ability of spatial information systems to exchange and utilize data across agencies without losing meaning or accuracy. This challenge arises because many agencies in Indonesia still use different data formats and standards, making integration difficult. [5] explains that many developing countries, including Indonesia, do not yet have a mature Spatial Data Infrastructure (SDI) framework to support efficient data exchange.
- **Limitations of digital infrastructure and human resources.** Limitations in technological infrastructure and human resources (HR) are major obstacles to the implementation of cloud-based geomatics and artificial intelligence (AI) systems. [21] emphasizes the need to increase technical capacity so that GIS professionals in developing countries can master modern spatial data analysis.
- **Spatial security and privacy.** The application of GIS in smart infrastructure often involves sensitive data, such as the location of important facilities and community activities. Without strong regulations, the risk of data leaks and misuse is very high. Research on GIS models linked to artificial intelligence (AI) confirms that spatial privacy is a major obstacle to the implementation of AI-based GIS systems in urban areas [22].

3.5 Opportunity

The identified opportunities are summarized below.

- **Blockchain for data transparency.** Blockchain technology has the potential to create a traceable and transparent system for geospatial data management, so that every change in data can be publicly tracked. [5] highlights the potential of blockchain-based SDIs for transparent and verifiable spatial data exchange.
- **Global policy and collaboration.** Emphasizes that national policies such as the One Map Policy are essential for connecting sustainable urban planning with spatial data governance.

4. CONCLUSION

Advances in geomatics technology, particularly GIS (Geographic Information System) and Remote Sensing, have brought significant changes in supporting sustainable smart infrastructure development in Indonesia, where these two technologies function not only as mapping tools but also as intelligent analytical systems capable of monitoring, predicting, and optimizing real-time regional management. The integration of spatial data with AI, IoT, and cloud computing opens up enormous opportunities for evidence-based decision-making in spatial planning, disaster mitigation, transportation, and natural resource management, although its implementation still faces challenges such as data interoperability, limited digital infrastructure, human resource capacity gaps, and spatial security and privacy issues. Indonesia has great potential to develop geomatics-based smart infrastructure through the strengthening of the One Map Policy, the development of a national Spatial Data Infrastructure (SDI), and the enhancement of research capacity and cross-sector collaboration. With strategic steps and continuous innovation, geomatics can become a key pillar in realizing efficient, resilient, and environmentally friendly national development in line with the vision of Smart and Sustainable Indonesia. Geospatial technologies, specifically GIS and Remote Sensing, are fundamental enablers of resilient and sustainable smart infrastructure. This review established a clear methodological protocol and synthesized recent technological advances into an integrated four-layer conceptual framework. Addressing data interoperability, spatial privacy, and technical capacity gaps through national Spatial Data Infrastructure (SDI) and One Map Policy enforcement will be crucial. Future research must focus on real-time Edge-AI processing, standardized spatial data governance, and cross-sectoral decision support platforms to fully realize sustainable spatial transformation.

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