GIS Enhanced Disaster Management Coupled with Supporting Technologies in Intelligent Urban Environments

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Abstract.

Efforts to understand the role of Geographic Information Systems (GIS) in the context of disasters are no longer enough to only look at their function as a mapping tool. This research departs from the problem of data integration that tends to be fragmented, and then tries to see how GIS works when dealing with data sources that are not always in line. The approach used was an Integrative Literature Review of 25 Scopus indexed articles, which were selected through several stages of screening, although not all studies offered the same depth. The analysis process is carried out through data extraction and thematic readings to capture emerging patterns, including parts that have not been discussed much. The results show that GIS tends to act as a meeting point for various types of data, ranging from satellite imagery to information based on public participation that is not always stable. In practice, technologies such as the Internet of Things, digital twins, Unmanned Aerial Vehicles, and WebGIS expand the way systems respond to situations, especially through real-time data and simulations that are predictive in nature. However, not all integrations go smoothly. Limited Interoperability, variations in data quality, and infirm governance are still quite noticeable obstacles. At this point, the potential of the system is obvious, but it is not yet fully ripe for reliability without further adjustments.

Keyword: *Geographic Information Systems, Smart city, Disaster management, Internet of Things and Digital twins.*

I. INTRODUCTION

The development of information and communication technology in recent times has not only had an impact on the technical aspect, but also changed the way cities are run in daily practice. Within the *framework* of *smart cities*, attention is no longer centered on physical infrastructure alone, but shifts to how data is collected, connected, and then utilized as a basis for *decision-making* [1]. This kind of approach requires a system that is able to unify various sources of information into a single interconnected structure, despite the fact that not all data has uniform characteristics [2]. When it comes to *disaster management*, the need becomes much more urgent. The system is not only required to work quickly, but it must also be accurate enough to read situations that change in a short period of time [3]. The problem that arises is not the availability of data, but the difficulty of integrating diverse data into information that can really be used. This condition often slows down the analysis process, and in some cases it even has the potential to affect the accuracy of decisions during emergency situations.

In this situation, *Geographic Information Systems* (*GIS*) is widely used as an approach that is able to bridge data diversity [4]. *GIS* allows the aggregation of spatial and non-spatial data in a single, structured analysis environment. Various *data sources*, from *satellite imagery* to environmental sensors, can be processed simultaneously in a single platform [5], [6]. On the other hand, information obtained through community participation also enriches the available data, although it is not always consistent in format or quality [7]. The role of *GIS* itself has undergone a significant shift. No longer just as a map visualization tool, but evolving into an analytical system that is directly involved in the *decision-making process* [8]. With these capabilities, *GIS* helps build a more comprehensive understanding of the situation in the context of *disaster management* [9], [10], while supporting risk identification and the development of more targeted mitigation strategies [11]. This position makes *GIS* one of the important components in a *technology-based disaster management system.*

GIS capabilities are then strengthened by the presence of various supporting technologies that are developing quite rapidly. The *Internet of Things* presents data in *real-time* through a network of sensors spread across various locations, although the stability of the data is not always maintained [5]. *Crowdsourcing* adds another dimension through the contribution of information from the community, which is often contextual and relevant under certain conditions [7]. The use of *Unmanned Aerial Vehicles* (*UAVs*) allows for the collection of *high-resolution* spatial data in a relatively short time, especially in hard-to-reach areas [12]. Meanwhile, digital twin technology opens up opportunities to simulate city conditions virtually, so that various disaster scenarios can be tested before they actually occur [9]. *Three-dimensional city modeling* also provides a more detailed perspective in the analysis [9], [13]. The use of *geospatial techniques* is essential in preparing accurate *3D models* that support *spatial analysis* and *urban planning processes* [14]. When viewed as a whole, the integration of this technology shows considerable potential in improving the effectiveness of *disaster management systems* [2], while opening up the possibility of developing systems that are more adaptive to field dynamics.

However, the implementation of *GIS-based systems* cannot be separated from various obstacles. *Interoperability* is one of the problems that arises quite often, especially when systems are built with different data standards ([15]. As a result, the data exchange process does not always go smoothly and sometimes requires additional adjustments. In addition, *data quality* is also an important concern, especially for data from *IoT* and *Crowdsourcing*, which is not always consistent [7]. Less stable data can have an impact on the results of the analysis as well as the resulting decisions [5]. Beyond the technical aspect, *governance issues* cannot be ignored either. Issues related to *security*, *privacy*, and *data management policies* are still not fully well structured in many implementations [4]. This shows that the challenges in *disaster management* are not only related to technology, but also to institutional and regulatory aspects. This complexity signals the need for a more integrated approach.

If you look closely, most previous studies still look at technology separately. Some focus on *IoT*, some focus on *UAVs*, and some only discuss *digital twins* without linking them to the broader system [15]. This approach makes the understanding less comprehensive, because the relationship between technologies is not explored much [4]. In fact, the needs in the field actually lead to cross-technology integration in one complete *framework*. Therefore, a more comprehensive study is needed, especially one that places *GIS* as the center of integration in *smart city-based disaster management*.

Based on this background, this study aims to systematically examine the role of *GIS* in integrating various heterogeneous *data sources* [1]. In addition, the study also evaluates the contribution of supporting technologies in increasing system capacity [2], as well as identifying future development challenges and directions [3]. Through this approach, it is hoped that a more complete picture will be obtained regarding the development of an adaptive, integrated, and data-based *disaster management* system in a *smart city* environment.

II. METHODS

Research Stages

This study utilizes the *Integrative Literature Review* (*ILR*) approach to systematically examine the role of *Geographic Information Systems* in the context of *smart city-based disaster management*. This approach was chosen because it allows the incorporation of various relevant research findings, so as to form a broader and non-fragmented understanding [1]. The research flow is arranged through several interrelated stages, with the aim of maintaining consistency between the process carried out and the goals to be achieved.

The initial stage starts from the identification of the literature through searching for scientific articles on the *Scopus indexed database*. The search process is not carried out randomly, but rather uses a combination of *keywords* related to *GIS*, *smart city*, and *disaster management*. After that, a literature selection process is carried out by filtering articles based on certain *inclusion criteria*, such as topic suitability, relevance to *GIS* integration, and relevance to supporting technology [2]. Through this stage, 25 articles were obtained that were considered the most suitable to be used as the main source in the research.

The next stage is *data extraction*, which focuses on gathering important information from each article. The information collected includes the purpose of the research, the methods used, the type of technology discussed, and the main findings produced. The data that had been collected was then analyzed using a *thematic approach* to identify patterns, relationships, and trends that emerged among the various studies [4].

In the final stage, the *synthesis of results* is carried out in stages by comparing findings from various studies. This process is not always linear, as in some cases *re-readings* are required to ensure the linkage between the findings. The results of this synthesis are used to build a more comprehensive understanding of the integration of *GIS* and supporting technologies in *disaster management*, particularly in the *framework* of *smart cities*.

Research Method and Analysis

The analysis method used in this study is *descriptive-qualitative*, with an emphasis on grouping and interpretation of data obtained from selected literature. The sample selection was carried out purposively, taking into account the level of relevance to *GIS*-based *disaster management* and its relevance to the concept of *smart cities* [3]. The articles analyzed cover various supporting technologies, such as the Internet of Things, *digital twins*, *Crowdsourcing*, and *Unmanned Aerial Vehicles*, which play a role in spatial data management [5].

Research instruments in the form of *data extraction* sheets are used to organize information from each article in a more structured manner. Through this instrument, data such as research methods, technologies used, and the main contributions of each study can be recorded systematically. Not only that, other aspects such as system *Interoperability*, data quality, and governance were also analyzed to provide a more complete picture of the implementation of *GIS-based systems* [15].

In the analysis process, the data that has been collected is then grouped into several main themes, namely the integration of *GIS* data, the role of supporting technology, and challenges in system implementation. In it, attention is also directed to the utilization of *real-time* data and sensor integration, which in many studies are considered to contribute to increasing the effectiveness of the system [8]. The use of *WebGIS* was also analyzed as a visualization medium that allows for a wider and easily accessible dissemination of information [16].

The results of the analysis were then compiled descriptively to show the relationship between findings from various studies. This approach helps identify patterns, similarities, and differences between studies, which then becomes the basis for the preparation of research conclusions.

III. RESULT AND DISCUSSION

Acrylic The Role of GIS and Data Integration in Disaster management

The results of the literature search show that there are a number of studies that can be used to understand how *Geographic Information Systems* (*GIS*) play a role in *smart city-based disaster management*. From the synthesis process, it can be seen that the function of *GIS* is no longer limited to the presentation of maps. Its role has shifted to an integrative platform that is able to bring together different types of data with different characteristics. The data includes satellite imagery, *Internet of Things* (*IoT*) sensors, infrastructure information, and data obtained through community participation or *Crowdsourcing* [1]. In *disaster management* practice, the ability to integrate this data becomes critical. It's not just a matter of speed, but also accuracy in reading situations. *GIS-based systems* allow the incorporation of spatial and non-spatial data in a single analysis environment, resulting in a more complete information [17]. This condition provides benefits in various stages, from risk identification to mitigation planning and decision-making when disasters occur [4], [18]. Spatial decision-making in urban environments can also be supported through *GIS*-based models that optimize location planning and resource allocation [18]. Geospatial *data-driven* approaches have also shown a contribution to improving the effectiveness of sustainable urban management, especially when data is optimally utilized [1], [6].

No.	Author & Year	Article Title	Research Methods	Research Focus	Findings
	Attah, Rita Uchenna Patrick Garba, Baalah Matthew Gil-Ozoudeh, Ifechukwu Iwuanyanwu, Obinna (2024)	Leveraging *Geographic Information Systems* and Data Analytics for Enhanced Public Sector Decision-Making and Urban Planning	This study uses a literature review approach that evaluates various studies and cases related to the use of *GIS* and data analysis in the public sector and urban planning.	*GIS* and data analytics have been shown to improve *data-driven* decision-making processes through the incorporation of spatial information and predictive analytics, although there are still challenges such as data quality, resource limitations, and privacy concerns.	The study indicates that the integration of *GIS* and data analytics contributes to improving efficiency, transparency, and sustainability in public sector management and supporting the development of *smart cities*.
	Bazargani, Jalal Safari Sadeghi-Niaraki, Abolghasem Choi, Soo-Mi (2021)	A Survey of *GIS* and *IoT* Integration: Applications and Architecture	Using a literature review of the study of *GIS* and *IoT* integration.	The integration of *GIS* and *IoT* allows for more effective *real-time* data processing and monitoring.	The combination of *GIS* and *IoT* supports the development of more sophisticated and integrated *smart city* systems.
	Hong, Jung-Hong Shi, Yi-Tin (2023)	Integration of Heterogeneous Sensor Systems for Disaster Responses in *Smart cities*: Flooding as an Example	Using a conceptual approach with the development of a metadata-based *framework* for the integration of heterogeneous sensor systems.	Heterogeneous sensor management through metadata enables cross-system data integration to support faster disaster response.	The proposed *framework* is able to improve the effectiveness of disaster response and can be applied to various *smart city* applications.
	Omrany, Hossein Ghaffarianhoseini, Amirhosein GhaffarianHoseini, Ali Clements–Croome, Derek 2022)	The Uptake of *City Information Modelling* (*CIM*): A Comprehensive Review of Current Implementations, Challenges and Future Outlook	Using systematic literature review using the PRISMA method on 195 *CIM*-related articles.	Nine areas of *CIM* implementation were identified as well as various key challenges such as data integration, data quality, and *Interoperability*.	This research provides a comprehensive understanding of *CIM* implementation as well as recommendations for its future development and implementation.
	Riaz, Khurram McAfee, Marion Gharbia, Salem (2023)	Management of Climate Resilience: Exploring the Potential of Digital Twin Technology, 3D City Modelling, and Early Warning Systems	Using a systematic literature review using the PRISMA method on 68 studies related to *digital twins*, 3D city modelling, and early warning	Digital twin technologies, 3D city modelling, and early warning systems have the potential to improve climate resilience through the integration of *real-time* data and virtual models.	This research shows that the two-way flow of data between digital models and the real environment is the key to improving resilience, but Implementation It is still in the conceptual stage and requires further development.

			systems.		
	Costa, Daniel G N. Bittencourt, João Carlos Oliveira, Franklin Just Peixoto, João Paulo Jesus, Thiago C (2024)	Achieving Sustainable *Smart cities* Through Geospatial *Data-driven* Approaches	Using a literature review on the development of a *data-driven* geospatial approach in *smart cities*.	Geospatial data-based approaches through *GIS*, satellites, and sensors are able to improve understanding and solutions to urban problems.	This research shows that the use of geospatial data supports the development of sustainable *smart cities*, but there are still challenges in the optimal use of technology.
	Alamri, Sultan (2024)	The Geospatial Crowd: Emerging Trends and Challenges in Crowdsourced Spatial Analytics	Using literature review with case study analysis related to crowdsourced spatial analytics.	*Crowdsourcing* in geospatial analytics is supported by *GIS*, AI, and cloud computing, but faces data quality and privacy challenges.	This research shows that crowdsourced data has great potential in various sectors, but requires good management to overcome its limitations.
	Ye, Xinyue Du, Jiaxin Han, Yu Newman, Galen Retchless, David Zou, Lei Ham, Youngjib Cai, Zhenhang (2022)	Developing Human-Centered Urban *Digital twins* for Community Infrastructure Resilience: A Research Agenda	Using scoping reviews to analyze studies related to urban *digital twins* (UDTs).	Urban *digital twins* have the potential to increase infrastructure resilience, but still face challenges in system integration and human-centered approaches.	This research resulted in a conceptual *framework* of UDT that emphasizes the integration of AI, multi-agent interactions, and social-physical systems to support community resilience.
	Quamar, Md Muzakkir Al-Ramadan, Baqer Khan, K A Shafiullah, Md Ferik, Sami El (2023)	Advancements and Applications of Drone-Integrated Geographic Information System Technology—A Review	Using a literature review on the development and application of drone integration with *GIS*.	The integration of drones and *GIS* improves the efficiency, accuracy, and *real-time* geospatial data collection capabilities.	This research shows that the use of drones in *GIS* supports more effective decision-making and monitoring in various fields including *disaster management* and *smart cities*.
).	Shahat, Ehab Hyun, Chang Taek Yeom, Chunho (2021)	City Digital Twin Potentials: A Review and Research Agenda	Menggunakan literature review untuk menganalisis potensi dan tantangan city digital twin.	Digital twin cities have the potential to improve city management, but still face the challenge of data integration and comprehensive system development.	This research resulted in a research agenda that emphasizes improving data efficiency, system integration, and developing a more complete digital twin.

Table 1. Summary of Analyzed Articles

If we refer to Table 1, we see a tendency that most studies place *GIS* as a system that is able to combine data from various sources to support disaster risk analysis [19]. This integration not only improves the completeness of information, but also allows the system to be more responsive to changing environmental conditions [20]. On the other hand, *GIS* also functions as a link between systems that were previously independent, so that coordination between stakeholders can run more effectively. However, this potential cannot be separated from a number of limitations. The performance of the system is still greatly

influenced by the quality of the data used. Inaccurate or poorly integrated data can degrade the effectiveness of the resulting analysis. In other words, *GIS* development is not enough to rely solely on technology, but also requires good data management and adequate infrastructure support.

Application Implementation

Technological developments show that *GIS* rarely stands alone in its implementation. These systems tend to require support from other technologies to expand their functionality. One of the most prominent is the *Internet of Things* (*IoT*), which allows *real-time* data collection through a network of sensors spread across multiple locations [8], [21]. The data is then integrated into *GIS* to provide an overview of the environmental conditions that are constantly updated. In addition, technologies such as *digital twins* and *Three-dimensional city* modeling provide a different approach to understanding the conditions of the region. A human-centered approach in digital twin development is also important to ensure that infrastructure resilience aligns with community needs [11]. Through virtual representations connected to actual data, simulations of various disaster scenarios can be carried out before real events take place [9], [13]. Digital twin technology is also recognized for its potential to improve urban system integration and decision-making processes in *smart city* environments [22]. On the other hand, the use of *Unmanned Aerial Vehicles* (*UAVs*) offers advantages in the collection of *high-resolution* spatial data in a short period of time, especially in areas that are difficult to reach directly [10], [12]. *UAV* systems are also developed with autonomous trajectory control to support monitoring and navigation within *smart city* environments. Not only relying on formal systems, *Crowdsourcing* also acts as an additional source of data. Information that comes from the community often provides context that is not always captured by censors or official systems [7]. When these technologies are integrated into *GIS*, a more dynamic system *framework* is formed, as illustrated in Figure 1.

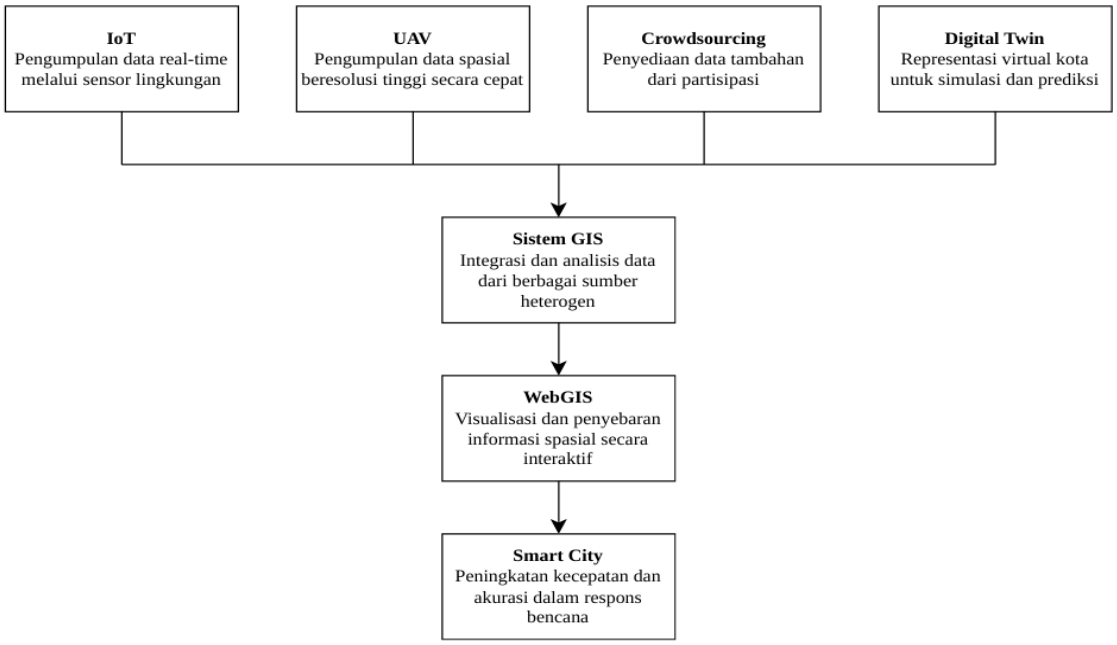

Fig 1. *IoT* and *GIS* Integration *Framework* in Disaster Response

The image shows how the relationship between sensors, monitoring systems, and *GIS* can accelerate and improve the accuracy of disaster response. In addition, *WebGIS* also plays an important role in distributing information to the public through interactive data visualization [23]. In a broader context, this integration contributes to the development of *smart cities* that are more resilient to disaster risks. The application of *smart city* approaches in real cases has also demonstrated the importance of technology integration in responding to crisis situations [24].

Discussion

Although the integration of *GIS* with various supporting technologies shows considerable potential, there are still a number of challenges that have not been fully resolved. One of the most frequently raised

issues is *Interoperability* between systems. Differences in data standards, especially between *GIS* and other technologies such as *Building Information Modelling* (*BIM*) or *City Information Modelling* (*CIM*), often hinder the integration process [13], [15]. In addition, data quality is a problem that cannot be ignored. Data from *IoT* and *Crowdsourcing* have a level of validity that is not always consistent [7]. These inconsistencies can affect the results of the analysis and ultimately impact the quality of the decisions taken [6]. In emergency situations, decision-making is closely related to evacuation planning strategies that require accurate and integrated information [25]. Beyond the technical aspect, challenges also arise in terms of governance, such as *data management policies*, information security, and coordination between institutions that are not fully optimal [4].

These challenges can be seen in Figure 2.

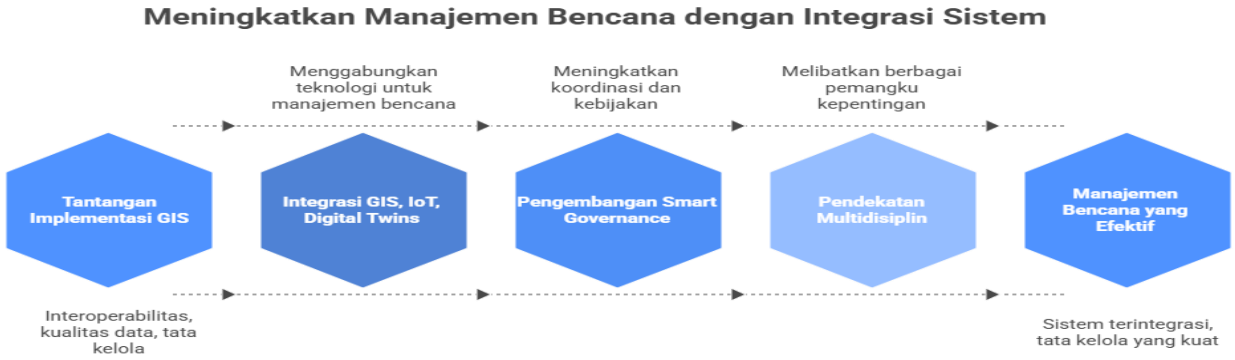

Fig. 2. Challenges and Directions of *GIS* Development in *Smart cities*

The picture indicates that the main issues still revolve around system integration, data quality, and governance. These findings are in line with various previous studies that emphasize that the success of *GIS* implementation is not only determined by technological sophistication, but also by organizational readiness as well as policy support [3], [21]. Going forward, the direction of development is likely to lead to wider integration between *GIS*, *IoT*, and artificial intelligence-based technologies. A cross-disciplinary approach is becoming increasingly important to address existing complexities. With these efforts, *GIS*-based *disaster management systems* are expected to develop to be more adaptive and responsive in dealing with various disaster situations.

IV. CONCLUSION

This study shows that *Geographic Information Systems* (*GIS*) have a very important role in *smart city-based disaster management*, especially in integrating various heterogeneous *data sources* into more structured and easily analyzed information. *GIS*'s ability to combine spatial and non-spatial data allows for improved decision-making quality, both in the mitigation, response, and disaster recovery stages. In addition, integration with supporting technologies such as the Internet of Things, *digital twins*, *Unmanned Aerial Vehicles*, and *Crowdsourcing* has been proven to be able to improve system capabilities through the provision of *real-time* data, predictive simulations, and increased situational awareness. This shows that a technology integration-based approach makes a significant contribution to creating a more adaptive and responsive *disaster management* system.

However, this study also identifies a number of limitations that are still challenges in the implementation of *GIS-based systems*. The main problems include *Interoperability* between systems that are not optimal, variations in the quality of data generated from various sources, and governance aspects that include security, privacy, and coordination between stakeholders. These limitations suggest that successful implementation depends not only on technology, but also on organizational readiness and supportive policies. Therefore, further research is recommended to develop a more comprehensive integration approach involving artificial intelligence-based technology and strengthen aspects of smart governance to improve the

overall effectiveness of the system. Thus, the development of *GIS* in the context of *smart cities* is expected to make a more optimal contribution in increasing the resilience of cities to various types of disasters.

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