Technology-Enabled Adaptive Knowledge Architecture for Humanitarian Governance (TAKAH) as an Enabler for Disaster Risk Management: An African-Global Comparative Analysis

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Abstract: Artificial intelligence (AI) is transforming disaster information management by enhancing hazard detection, vulnerability assessment, early warning systems, and evidence-based decision-making. Despite significant technological advances, many African countries continue to experience fragmented disaster information systems characterised by limited interoperability, inadequate institutional capacity, weak digital infrastructure, and constrained investment in advanced technologies. Existing disaster information management frameworks predominantly examine technologies such as AI, geographic information systems (GIS), remote sensing, Internet of Things (IoT), and big data analytics in isolation, providing limited guidance on their integration into a coherent governance architecture. This study develops and validates the Technology-Enabled Adaptive Knowledge Architecture for Humanitarian Governance (TAKAH) Framework, an integrated digital governance model for AI-driven disaster information management. A qualitative comparative research design employing comparative document analysis was used to examine disaster information management systems in six African countries (Zimbabwe, South Africa, Kenya, Ethiopia, Mozambique, and Rwanda) and five global leaders (Japan, the United States, Australia, Germany, and New Zealand). Comparative thematic analysis focused on AI adoption, geospatial intelligence, predictive analytics, digital interoperability, institutional readiness, and governance arrangements. The findings indicate that countries with integrated digital ecosystems supported by robust governance, interoperable information systems, and sustained institutional investment consistently achieve superior disaster monitoring, early warning, vulnerability assessment, and emergency coordination. Conversely, fragmented digital infrastructures and weak institutional coordination continue to constrain disaster preparedness in many developing countries. The study proposes the TAKAH Framework as a comprehensive digital governance architecture that integrates AI, geospatial intelligence, predictive analytics, interoperable information systems, and adaptive governance into a unified disaster information management model. The framework contributes to contemporary disaster informatics literature by providing both a theoretical foundation and a practical roadmap for strengthening climate resilience and digital disaster governance in Africa and other disaster-prone developing regions.

Keywords: *Artificial Intelligence; Disaster Information Management; Disaster Risk Reduction; Digital Governance; Geospatial Intelligence; Predictive Analytics; TAKAH Framework; Vulnerability Assessment.*

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I. INTRODUCTION AND BACKGROUND

Climate change has intensified the frequency, magnitude, and complexity of disasters worldwide, fundamentally reshaping how governments conceptualise disaster risk management (DRM). Contemporary disasters are increasingly characterised by cascading and interconnected risks that simultaneously affect infrastructure, livelihoods, ecosystems, public health, and economic stability. Consequently, disaster management has evolved from a reactive emergency response function into a strategic governance process centred on risk anticipation, resilience building, and evidence-informed decision-making (UNDRR, 2023; WMO, 2023). This transition has elevated disaster information management to a strategic national priority because the effectiveness of disaster governance

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increasingly depends on the ability of institutions to collect, integrate, analyse, and disseminate accurate information before, during, and after hazardous events.

The rapid advancement of digital technologies has transformed the architecture of disaster information management. Artificial intelligence (AI), machine learning, geographic information systems (GIS), remote sensing, big data analytics, cloud computing, unmanned aerial systems, and Internet of Things (IoT) technologies have significantly enhanced governments' capacities to detect hazards, predict disaster occurrence, assess vulnerabilities, and coordinate emergency responses (Dwivedi *et al.*, 2021; Sun, Bocchini & Davison, 2020). Unlike conventional disaster management systems that rely heavily on manual data collection and fragmented reporting structures, intelligent digital platforms continuously process multi-source datasets, generating predictive insights that enable proactive interventions and more efficient allocation of emergency resources.

Recent advances in AI have particularly accelerated the shift towards predictive disaster governance. Machine learning algorithms can analyse historical climate records, satellite imagery, demographic datasets, hydrological information, and environmental indicators to identify emerging risks with greater speed and accuracy than traditional analytical approaches. Similarly, computer vision technologies enable rapid assessment of infrastructure damage using satellite and drone imagery, while natural language processing supports real-time situational awareness by analysing information generated through social media and emergency communication platforms (Abioye *et al.*, 2021; Chamola *et al.*, 2020). Collectively, these innovations have repositioned disaster information systems from passive repositories of historical information to intelligent decision-support platforms capable of facilitating adaptive governance.

The growing importance of digital disaster information management is reinforced by international policy frameworks. The Sendai Framework for Disaster Risk Reduction (2015–2030) identifies risk information, multi-hazard early warning systems, scientific innovation, and technological integration as essential components of disaster resilience. In the same vein, the 2030 Agenda for Sustainable Development, the Paris Agreement and the African Union Programme of Action for Disaster Risk Reduction (2021–2030) call for the integration of digital technologies into the disaster governance processes to support preparedness, climate adaptation and institutional resilience (UNDRR, 2023; African Union, 2022). These frameworks recognise that effective disaster governance is becoming increasingly dependent on interoperable information systems that can make timely and evidence-based decisions at different institutions.

Though these technological advances are clear, there is still a huge gulf between developed and developing countries in their capacities to implement intelligent disaster information systems. Japan, the United States, Australia, Germany, and New Zealand have invested significantly in digital infrastructure that combines AI, geospatial intelligence, cloud-based analytics and interoperable emergency management systems to detect hazards and monitor vulnerability, predictive modelling and coordination of multi-agency responses (OECD, 2023; WMO, 2023). In contrast, many African countries have fragmented information systems with weak interoperability, poor digital infrastructure, lack of technical expertise, lack of institutional coordination, and limited financial resources which hinder disaster preparation and emergency response.

➢ *Problem Statement*

Despite the fact that Africa is one of the most vulnerable regions to climate-related disasters, despite contributing little to global greenhouse gas emissions, there are still periodic droughts, tropical cyclones, floods, heat waves, landslides and disease outbreaks that are undermining socioeconomic development in Africa. South Africa, Kenya, Rwanda, Zimbabwe, Ethiopia, Mozambique, and others have introduced legislation and digital transformation strategies to make disaster management better, yet their implementation is still scarce due to structural, technological and financial constraints (IPCC, 2023; World Bank, 2022). As such, many disaster management organizations still depend on gaps in information flow and reactive decision making in order to predict risks and act in the right time to respond to them and ensure they are able to coordinate the right way of doing things. While a great deal of the current literature focuses on individual technologies— such as AI, GIS, remote sensing, IoT, and predictive analytics— much of the literature is still focused on technology.

Most studies study these innovations separately and do little to understand how these can be integrated into a coherent governance system that integrates technology-enabled institutional readiness with organisational learning, interoperability and adaptive public administration (Abioye et al., 2021; Dwivedi et al., 2021). The literature does not provide much theoretical guidance to develop a comprehensive digital governance architecture that can be used for disaster information management in resource-constrained developing nations. With this in mind, in this research we develop and validate the Technology-Enabled Adaptive Knowledge Architecture for Humanitarian Governance (TAKAH) Framework as a strategy that integrates AI-driven disaster information management. The framework integrates artificial intelligence, geospatial intelligence, predictive analytics, big data, IoT-based sensing, digital interoperability, and institutional readiness into a unified governance framework to improve disaster monitoring, vulnerability assessment and evidence-driven decision making.

By examining African countries and world disaster management systems in comparison, the study contributes to disaster informatics today, as it is a theoretical development as well as a practical governance framework for intelligent, resilient and adaptive disaster information systems in Africa and other climate-vulnerable regions.

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➢ *Study Objectives and Research Questions*

- *Study Objectives*

The goal of this study is to develop and validate the Technology-Enabled Adaptive Knowledge Architecture for Humanitarian Governance (TAKAH) Framework as an integrated digital governance model for enhancing artificial intelligence-driven disaster information management and vulnerability assessment in Africa.

The specific objectives of the study are to:

- ✓ Evaluate the level of adoption and application of artificial intelligence, geospatial intelligence, predictive analytics, Internet of Things (IoT) technologies, and digital information systems in disaster monitoring and vulnerability assessment across selected African countries and leading global disaster management systems.
- ✓ Examine the influence of institutional readiness, digital interoperability, governance arrangements, and organisational capabilities on the effectiveness of AI-driven disaster information management systems.
- ✓ Compare disaster information management architectures in selected African countries and global leaders to identify best practices, implementation gaps, and critical success factors for intelligent disaster governance.
- ✓ Develop and validate the Technology-Enabled Adaptive Knowledge Architecture for Humanitarian Governance (TAKAH) Framework as an integrated governance model for strengthening disaster information management, vulnerability assessment, and evidence-based decision-making in disaster-prone developing countries.

II. LITERATURE REVIEW

➢ *Introduction*

The increasing frequency and complexity of climate-induced disasters have fundamentally transformed disaster risk management from a predominantly response-oriented function into a strategic, information-driven governance process. Contemporary disaster governance increasingly depends on the ability of governments to generate, integrate, analyse, and disseminate accurate information rapidly across multiple institutions and governance levels. Consequently, disaster information management has emerged as one of the most critical components of disaster risk reduction, enabling governments to anticipate hazards, assess vulnerabilities, coordinate emergency responses, and support resilient recovery through timely, evidence-based decision-making (UNDRR, 2023; WMO, 2023). The emergence of artificial intelligence (AI), geospatial intelligence, remote sensing, cloud computing, Internet of Things (IoT) technologies, and predictive analytics has significantly expanded the capacity of disaster information systems to process complex datasets and improve situational awareness across the entire disaster management cycle.

The growing digitalisation of disaster management has generated substantial scholarly interest over the past decade. Recent studies demonstrate that AI-driven technologies improve hazard prediction, vulnerability mapping, emergency communication, resource allocation, and post-disaster damage assessment through automated analysis of large-scale environmental and socio-economic datasets (Dwivedi *et al.*, 2021; Abioye *et al.*, 2021; Sun, Bocchini & Davison, 2020). Similarly, advances in geospatial technologies, Earth observation systems, and big data analytics have strengthened governments' capacities to monitor rapidly changing environmental conditions and develop proactive disaster preparedness strategies. These technological developments have shifted disaster information systems beyond their traditional role as repositories of historical records towards intelligent decision-support systems capable of facilitating adaptive and anticipatory governance.

Despite these advances, the literature is still fragmented in theoretical and empirical perspective. Most current research is focused on AI, geographic information systems, remote sensing, IoT, predictive analytics and digital governance as discrete fields, with little attention paid to the interrelation of these technologies with disaster information management ecosystems (OECD, 2023; World Bank, 2022). In addition, studies in developed countries are based on a conception of modern digital infrastructure, interoperable information systems, and institutional capacity that are rarely the case in the context of disaster management systems in Africa in which technological investment is often constrained by organisational, financial, regulatory and human resource limitations. Another major limitation in current research is the relatively weak integration of technological innovation with governance in the public sector. AI has received lots of attention but very little has been done to address the governance frameworks needed to continue digital transformation: institutional readiness, organisational learning, digital interoperability, data governance, leadership commitment, and cross-sector collaboration (IPCC, 2023; African Union, 2022). As a result, a lot of studies provide valuable technical knowledge but not much guidance on how governments should integrate emerging technologies into coherent disaster information management architectures that can support long-term resilience.

Against this background, this literature review critically synthesises contemporary evidence on AI-enabled disaster information management by examining the principal technological, organisational, and governance dimensions that influence disaster resilience. The review first analyses the application of artificial intelligence in disaster risk management before examining geospatial intelligence, remote sensing, big data analytics, Internet of Things technologies, institutional readiness, and comparative digital disaster governance across Africa and selected global leaders. Rather than reviewing these themes in isolation, the discussion progressively demonstrates their interdependence and highlights the need for an integrated governance architecture that combines technological innovation with institutional capability.

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- *Artificial Intelligence in Disaster Risk Management*

Artificial Intelligence (AI) has emerged as one of the most transformative technologies in disaster risk management, fundamentally changing how governments anticipate, monitor, respond to, and recover from disasters. Unlike conventional disaster information systems that primarily support descriptive reporting, AI enables predictive, adaptive, and autonomous decision-making through the analysis of large volumes of structured and unstructured data. Recent advances in machine learning, deep learning, natural language processing, computer vision, and reinforcement learning have significantly enhanced governments' capacities to detect hazards earlier, forecast disaster trajectories, optimise resource allocation, and improve emergency coordination (Dwivedi *et al.*, 2021; Chamola *et al.*, 2020; Abioye *et al.*, 2021). Consequently, AI is increasingly recognised not merely as a technological innovation but as a strategic enabler of resilient and adaptive disaster governance.

Several empirical studies demonstrate that AI substantially improves disaster prediction by identifying complex relationships that are often overlooked by conventional statistical models. Machine learning algorithms can simultaneously analyse meteorological observations, satellite imagery, hydrological measurements, topographical characteristics, demographic information, and historical disaster records to generate highly accurate forecasts for floods, droughts, landslides, tropical cyclones, and wildfires (Sun, Bocchini & Davison, 2020; Mosavi *et al.*, 2021; Zhang *et al.*, 2023). These predictive capabilities enable governments to shift from reactive disaster response towards anticipatory risk management, allowing emergency agencies to mobilise resources, implement evacuations, and protect critical infrastructure before hazards escalate into humanitarian emergencies. As climate variability becomes increasingly unpredictable, predictive analytics supported by AI has become an indispensable component of national disaster resilience strategies.

Beyond hazard prediction, AI has transformed post-disaster assessment and operational coordination. Computer vision algorithms integrated with high-resolution satellite imagery, unmanned aerial vehicles, and remotely piloted aircraft enable rapid identification of damaged infrastructure, blocked transport networks, flooded settlements, and disrupted public utilities within hours of disaster occurrence (Li *et al.*, 2022; Guo *et al.*, 2023). Similarly, natural language processing technologies analyse information generated through emergency call centres, social media platforms, news feeds, and community reporting systems to identify emerging humanitarian needs and monitor evolving disaster situations in real time (Imran *et al.*, 2020; Alam, Ofli and Imran, 2021). These capabilities significantly improve situational awareness and support evidence-based operational decisions during rapidly evolving emergencies.

AI applications tend to exist in donor-funded pilot projects and are not sustainable components of national disaster information management systems. The impact of AI also depends on the quality, accessibility, and interoperability of disaster data. Machine learning models need massive volumes of reliable, standardized, and continuously updated information to make accurate forecasts and decision-support analysis. But disaster data in many developing countries is fragmented among meteorological agencies, environmental authorities, local governments, humanitarian organizations, and research institutions that often have incompatible data standards and isolated information systems (UNDRR, 2023; OECD, 2023). In this way, even the most sophisticated AI algorithms cannot measure up to their full capabilities and analytical potential because poor data quality, inconsistent metadata, and weak interoperability impact predictive efficacy and trust in automated decision-support systems in institutions.

More recently, it has also been recognized that successful AI adoption is not only about technological superiority but also about governance. The increasing reliance on algorithmic decision-making has raised important questions around transparency, accountability, explainability, cybersecurity, privacy protection, algorithmic bias, and ethical governance in disaster management (Dwivedi et al., 2023; UNESCO, 2021). Disaster management decisions are often based on scarce humanitarian resources, and this can directly affect vulnerable populations in the disaster area. In this sense, AI systems need to be governed according to standards that are fair, accountable, regulated, and centered on human decision-making processes. These governance issues indicate that technological sophistication cannot be sufficient to handle disaster information without the capacity of the institutions and regulatory procedures.

Although recent literature has repeatedly highlighted the potential of AI in disaster risk management, there are still some conceptual gaps. Most studies have examined machine learning algorithms, predictive models, computer vision applications, or automated decision support systems independently, but very little emphasis is being given to how these technologies interact with geospatial intelligence, Internet of Things infrastructure, institutional readiness, digital interoperability, organizational learning, and adaptive governance in integrated public-sector environments (Abioye et al., 2021; Dwivedi et al., 2023). For all these reasons, there is no clear governance architecture that can effectively integrate these elements into a disaster information management system. GIS, remote sensing, satellite-based Earth Observation (EO), Global Navigation Satellite Systems (GNSS), and unmanned aerial systems (UAS) have revolutionized the ability of governments to monitor and leverage the information they acquire about the environment and act in an operational manner (Chen et al., 2022; WMO, 2023). Unlike traditional disaster mapping methods that rely on static data and periodic field surveys, modern geospatial technologies offer continuous spatial intelligence for proactive disaster preparedness and adaptive governance throughout the entire disaster management cycle.

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GIS and remote sensing have been integrated in the development of the capacity to monitor multiple hazards simultaneously. High-resolution satellite imagery, Synthetic Aperture Radar (SAR), LiDAR technologies, multispectral imaging, and drone-based observations now enable governments to detect floods, monitor drought progression, assess wildfire dynamics, identify landslide susceptibility, evaluate coastal erosion, and quantify infrastructure damage with unprecedented spatial and temporal precision (Li *et al.*, 2022; Guo *et al.*, 2023; European Space Agency, 2023). When combined with demographic, socioeconomic, and infrastructure datasets, these technologies generate comprehensive spatial vulnerability assessments that support evidence-based land-use planning, evacuation planning, infrastructure protection, and disaster preparedness.

Recent developments have further expanded the role of geospatial intelligence through integration with artificial intelligence and predictive analytics. Machine learning algorithms increasingly automate image classification, change detection, flood delineation, damage assessment, and infrastructure monitoring using satellite and drone imagery that previously required extensive manual interpretation (Sun, Bocchini & Davison, 2020; Zhang *et al.*, 2023). Cloud-based geospatial platforms now facilitate near real-time processing of massive Earth observation datasets, allowing emergency management agencies to generate dynamic risk maps within minutes rather than days. This convergence of AI and geospatial intelligence has transformed disaster information systems from passive mapping platforms into intelligent spatial decision-support systems capable of continuously monitoring environmental change and supporting anticipatory disaster governance.

Despite these technological advances, considerable disparities remain between developed countries and many developing nations regarding the operational use of geospatial intelligence. Countries such as Japan, the United States, Germany, Australia, and New Zealand have established mature national spatial data infrastructures supported by coordinated institutional arrangements, open geospatial data policies, advanced processing facilities, and sustained investment in Earth observation technologies (OECD, 2023; WMO, 2023). In contrast, many African countries continue to experience fragmented spatial databases, inadequate access to high-resolution imagery, limited geospatial processing capacity, shortages of skilled geospatial professionals, and inconsistent investment in national spatial information infrastructures (World Bank, 2022; African Union, 2022). These institutional and technological constraints reduce the effectiveness of geospatial information in supporting timely disaster preparedness and coordinated emergency response.

The effectiveness of geospatial intelligence is determined not only by technological capability but also by institutional interoperability and data governance. Disaster-related spatial information is often generated by multiple organisations, including meteorological agencies, environmental authorities, water resource departments, geological surveys, local governments, humanitarian organisations, and research institutions. Where these organisations operate independently using incompatible data standards and isolated information systems, opportunities for integrated risk assessment and coordinated decision-making become severely constrained (UNDRR, 2023; OECD, 2023). Conversely, countries that promote interoperable spatial data infrastructures, common metadata standards, open geospatial platforms, and collaborative information-sharing mechanisms consistently demonstrate greater effectiveness in disaster monitoring, vulnerability assessment, and emergency coordination.

Emerging technologies continue to redefine the future of geospatial disaster information management. Digital twins, cloud-native GIS, artificial intelligence-enhanced spatial analytics, autonomous drone systems, and integrated Earth observation platforms now enable continuous environmental monitoring, dynamic scenario modelling, infrastructure resilience assessment, and real-time operational planning (European Space Agency, 2023; Li *et al.*, 2022). These innovations significantly increase governments' ability to understand rapidly changing risk environments while strengthening climate adaptation planning, urban resilience, and sustainable infrastructure development. Geospatial intelligence is increasingly seen as a part of national digital governance as well as not only a technical mapping function. Although geospatial intelligence has received a great deal of attention, the current research is mostly technology oriented, with GIS software, remote sensing techniques, image processing algorithms, and Earth observation applications being the most commonly studied domains.

There is also very little research on geospatial intelligence and artificial intelligence, predictive analytics, institutional readiness, digital interoperability, organisational learning, and governance structures in integrated disaster information management systems (Chen et al., 2022; Abioye et al., 2021). This fragmentation makes it hard to construct a coherent governance model that supports sustainable digital transformation for disaster management.

- *Geospatial Intelligence, Remote Sensing and Earth Observation in Disaster Information Management*

Geospatial intelligence is at the core of disaster information management in modern disaster data management today because it provides the spatial evidence needed to identify hazards, analyse exposure, assess vulnerability, and plan for disaster. New technologies like Geographic Information Systems (GIS), remote sensing, satellite-based Earth Observation (EO), Global Navigation Satellite Systems (GNSS), and unmanned aerial systems (UAS) have all expanded governments' ability to monitor the changing environment and convert complex spatial information into decision making (Chen et al., 2022; WMO, 2023). As opposed to traditional disaster mapping techniques based on static data and periodic field surveys, today's geospatial technologies can provide a constant spatial intelligence that can be used to prepare for disaster and change governance at different times in the disaster management process.

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The ability to monitor multiple hazards at the same time through GIS and remote sensing has been greatly improved by the integration of GIS and remote sensing. High-resolution satellite imagery, Synthetic Aperture Radar (SAR), LiDAR technologies, multispectral imaging, and drone-based observations now enable governments to detect floods, monitor drought progression, assess wildfire dynamics, identify landslide susceptibility, evaluate coastal erosion, and quantify infrastructure damage with unprecedented spatial and temporal precision (Li *et al.*, 2022; Guo *et al.*, 2023; European Space Agency, 2023). When combined with demographic, socioeconomic, and infrastructure datasets, these technologies generate comprehensive spatial vulnerability assessments that support evidence-based land-use planning, evacuation planning, infrastructure protection, and disaster preparedness.

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Although geospatial intelligence has received extensive scholarly attention, contemporary research remains largely technology-oriented, focusing predominantly on advances in GIS software, remote sensing techniques, image processing algorithms, and Earth observation applications. Comparatively limited attention has been devoted to examining how geospatial intelligence interacts with artificial intelligence, predictive analytics, institutional readiness, digital interoperability, organisational learning, and governance structures within integrated disaster information management systems (Chen *et al.*, 2022; Abioye *et al.*, 2021). This fragmentation limits the development of comprehensive governance models capable of supporting sustainable digital transformation in disaster management.

- *Internet of Things (IoT), Smart Sensors and Multi-Hazard Early Warning Systems*

The Internet of Things (IoT) has emerged as a critical enabler of intelligent disaster information management by facilitating the continuous collection, transmission, and analysis of real-time environmental data. Through interconnected networks of weather stations, river gauges, seismic sensors, air quality monitors, hydrological instruments, satellite communication devices, and unmanned monitoring platforms, IoT technologies enable governments to observe rapidly changing environmental conditions with unprecedented temporal precision (WMO, 2023; Dwivedi *et al.*, 2023). Unlike conventional monitoring systems that depend on periodic observations and manual reporting, IoT-enabled infrastructures continuously generate data streams

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that support proactive disaster surveillance, dynamic risk assessment, and timely emergency decision-making. Consequently, IoT has become a fundamental component of digital disaster governance, underpinning the transition from reactive emergency management to anticipatory and adaptive resilience planning.

The integration of IoT with artificial intelligence and predictive analytics has significantly enhanced the effectiveness of multi-hazard early warning systems. Intelligent sensor networks continuously monitor meteorological, hydrological, geological, and environmental variables while machine learning algorithms analyse these data streams to identify anomalies and predict the likelihood of hazardous events before they occur (Mosavi *et al*., 2021; Zhang *et al.*, 2023). For example, integrated sensor systems can detect rising river levels, unstable slopes, seismic activity, deteriorating air quality, and changing climatic conditions, enabling governments to issue timely warnings that minimise loss of life and property. This convergence of IoT and AI has transformed early warning systems into intelligent decision-support platforms capable of continuously learning from environmental changes and improving predictive performance over time.

Recent empirical evidence indicates that countries with mature IoT infrastructures consistently demonstrate higher levels of disaster preparedness and operational efficiency. Japan, the United States, Australia, Germany, and New Zealand have established integrated sensor ecosystems linked to national meteorological agencies, emergency management centres, telecommunications networks, and geospatial information platforms (OECD, 2023; WMO, 2023). These interconnected systems facilitate real-time situational awareness, automated hazard detection, and rapid dissemination of warnings through multiple communication channels, thereby enhancing institutional coordination and community preparedness. Their success illustrates that the value of IoT extends beyond hardware deployment to encompass integrated information management, interoperability, and coordinated governance.

In contrast, the adoption of IoT technologies across many African countries remains constrained by infrastructural and institutional limitations. Although countries such as South Africa, Kenya, and Rwanda have made notable progress in deploying automated weather stations, hydrological monitoring systems, and environmental sensor networks, implementation remains uneven across the continent (African Union, 2022; World Bank, 2022). Zimbabwe, Ethiopia, and Mozambique continue to face persistent challenges associated with unreliable electricity supply, limited telecommunications infrastructure, inadequate maintenance capacity, insufficient technical expertise, and constrained public investment. Consequently, many monitoring systems operate as isolated installations that are poorly integrated into national disaster information architectures, thereby limiting their contribution to effective early warning and emergency coordination.

The literature increasingly recognises that the effectiveness of IoT-enabled early warning systems depends as much on institutional coordination as on technological sophistication. Sensor networks generate substantial volumes of real-time information; however, their operational value depends upon efficient data integration, interoperable information systems, standardised communication protocols, and clearly defined institutional responsibilities (UNDRR, 2023; OECD, 2023). Effective warning systems require seamless collaboration among meteorological services, hydrological agencies, local authorities, emergency responders, telecommunications providers, humanitarian organisations, and community structures. Where these institutional relationships are fragmented, delays in information sharing and decision-making can significantly reduce the effectiveness of even technologically advanced monitoring infrastructures.

Equally important is the communication of early warning information to at-risk communities. Contemporary disaster governance extends beyond technological detection to include effective dissemination mechanisms that ensure warnings are understandable, timely, accessible, and actionable. Research demonstrates that warning systems achieve greater effectiveness when they incorporate local languages, multiple communication platforms, inclusive communication strategies, and community participation within broader disaster preparedness programmes (UNDRR, 2023; UNESCO, 2021). Accordingly, resilient disaster information management requires the integration of technological innovation with social inclusion, institutional trust, and community engagement, ensuring that early warning information results in meaningful protective action rather than merely generating technical alerts.

Although IoT technologies have received increasing scholarly attention, contemporary research remains predominantly engineering-oriented, focusing largely on sensor performance, communication architectures, network optimisation, and hardware efficiency. Comparatively limited attention has been devoted to understanding how IoT infrastructures interact with artificial intelligence, geospatial intelligence, predictive analytics, institutional readiness, organisational learning, and adaptive governance within comprehensive disaster information management systems (Dwivedi *et al.*, 2023; Abioye *et al.*, 2021). This fragmented perspective limits the development of integrated governance models capable of guiding sustainable digital transformation in disaster management.

➢ *Institutional Readiness for AI-Driven Disaster Information Management*

Institutional readiness has emerged as one of the most significant determinants of successful digital transformation in disaster information management. Although advances in artificial intelligence (AI), geospatial intelligence, predictive analytics, cloud computing, and Internet of Things (IoT) technologies have substantially expanded the technical capabilities of disaster management systems, these technologies generate meaningful public value only when supported by institutions that possess the organisational

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capacity, governance structures, skilled personnel, financial resources, and regulatory frameworks necessary to sustain digital innovation (OECD, 2023; World Bank, 2022). Consequently, contemporary disaster governance increasingly recognises that technological sophistication alone cannot improve disaster resilience without corresponding investments in institutional capability and organisational transformation.

Recent literature demonstrates that institutional readiness encompasses multiple interdependent dimensions that collectively determine the success of digital disaster management initiatives. These dimensions include digital leadership, organisational culture, human resource capacity, ICT infrastructure, financial sustainability, policy and legislative support, cybersecurity, data governance, and inter-organisational collaboration (UNDRR, 2023; UNESCO, 2021). Institutions that invest simultaneously in these dimensions are more likely to institutionalise digital technologies and integrate them into routine disaster management processes. Conversely, organisations that focus primarily on technological acquisition while neglecting governance and organisational development frequently experience underutilised systems, fragmented implementation, and limited improvements in disaster management performance.

The importance of organisational leadership has received increasing attention within recent digital governance scholarship. Leadership for effective digital transformation requires the ability to articulate a strategic vision, to put resources in place, to make the organisation change strategy and work with teams and to work together across different institutions (Dwivedi et al., 2023; OECD, 2023). In disaster management environments with uncertainty and rapidly changing risks, leadership is also crucial in order to foster innovation, to promote evidence-based decision making and to encourage continuous learning of organisations. When digital leadership is in place, organizations with proactive digital leaders are better equipped to adopt new technologies, change operational practices and drive innovation beyond short-term donor-funded initiatives. Human capital is another key factor for institutional preparedness. Artificial intelligence, predictive analytics, geospatial technologies, and integrated information systems require multidisciplinary expertise in information technology, data science, disaster management, geography, engineering, public administration, and emergency planning (World Bank, 2022; WMO, 2023). But many disaster management agencies in developing countries are still lacking specialist staff to develop, maintain and interpret advanced digital systems.

Lack of technical expertise often leads to dependence on external consultants, diminished institutional control, and challenges in the maintenance of digital platforms after initial implementation. Hence, the need for continuous professional development, technical training, and knowledge management is at the heart of institutional resilience today. The literature also emphasises that institutional readiness is based on good governance systems that provide interoperability, transparency, accountability and information sharing. Disaster-related information is provided by many organisations, such as meteorological agencies, environmental agencies, local governments, emergency services, humanitarian organisations, research institutions, and private sector partners. But without well-defined governance structures, common policy and data protocols, and formal cooperation structures, these organisations are often acting in isolation and the information they share in disaster response can be fragmented (UNDRR, 2023; African Union, 2022). Institutional readiness extends beyond a particular organization's capability to ensure that a transparent and integrated approach is used for information exchange and decision-making in disaster management. Digital governance also needs to be backed by clear governance and ethical frameworks to address various challenges to artificial intelligence and automated decision-making. A growing reliance on algorithmic solutions raises concerns for data privacy, cybersecurity, algorithmic bias, transparency, explainability, legal liability, and public trust (UNESCO, 2021; Dwivedi et al., 2023). In this case, public institutions need to develop governance mechanisms to ensure AI systems are ethical and that people are safe and that institutions are held accountable. Such a framework is particularly relevant in disaster areas where automated recommendations can directly affect evacuation decisions, humanitarian resource allocation and emergency response priorities. Although institutional readiness has become an increasingly important topic in digital governance research, much of the existing literature still focuses on organisational capacity separately from technological innovation. Studies frequently evaluate digital leadership, organisational change, information governance, or capacity development independently, while comparatively few investigate how these institutional dimensions interact with artificial intelligence, geospatial intelligence, predictive analytics, IoT infrastructure, and interoperable information systems within an integrated disaster management environment (OECD, 2023; Abioye *et al.*, 2021).

- *Comparative Digital Disaster Governance: Lessons from Global Leaders and Africa*

Comparative analyses of disaster information management systems reveal considerable disparities in digital governance maturity between technologically advanced countries and many developing nations, particularly within Africa. While the increasing availability of artificial intelligence (AI), geospatial intelligence, cloud computing, predictive analytics, and Internet of Things (IoT) technologies has created unprecedented opportunities for strengthening disaster resilience, countries differ markedly in their ability to institutionalise these technologies within coherent governance systems (OECD, 2023; UNDRR, 2023). These differences are influenced not only by technological investment but also by institutional capacity, governance quality, regulatory frameworks, digital infrastructure, and the extent of cross-sector collaboration. Consequently, comparative analysis provides valuable insights into the institutional and technological conditions

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necessary for successful digital transformation in disaster information management.

Global leaders such as Japan, the United States, Australia, Germany, and New Zealand have progressively evolved from technology adoption towards integrated digital disaster governance. Their disaster management systems combine artificial intelligence, Earth observation technologies, predictive analytics, interoperable information platforms, cloud-based emergency operations centres, and multi-agency coordination mechanisms within comprehensive national resilience strategies (WMO, 2023; OECD, 2023). Rather than deploying individual digital technologies independently, these countries have developed interconnected digital ecosystems supported by clear governance arrangements, long-term public investment, skilled technical personnel, and continuous policy innovation. The result has been enhanced situational awareness, faster emergency response, more accurate vulnerability assessment, and greater institutional adaptability to emerging disaster risks.

An important characteristic of these advanced disaster governance systems is their emphasis on interoperability and collaborative governance. National disaster information platforms routinely integrate information generated by meteorological agencies, geological surveys, emergency services, local governments, health authorities, research institutions, private-sector technology providers, and humanitarian organisations into unified operational environments (UNDRR, 2023; WMO, 2023). This institutional integration enables decision-makers to develop comprehensive situational awareness while facilitating coordinated responses across multiple sectors. The effectiveness of these systems therefore derives less from technological sophistication alone than from the governance mechanisms that enable institutions to share information, coordinate decisions, and adapt collectively to evolving disaster conditions.

Across Africa, progress towards digital disaster governance has accelerated during the past decade, although implementation remains uneven. South Africa, Kenya, and Rwanda have emerged as regional leaders through sustained investments in national digital transformation strategies, geospatial information infrastructures, climate information services, e-government initiatives, and data-driven public administration (African Union, 2022; World Bank, 2022). These countries have strengthened institutional collaboration, expanded digital service delivery, and improved the integration of disaster-related information into national planning processes. Their experiences demonstrate that digital transformation is achievable within developing contexts when technological investments are accompanied by supportive governance reforms and long-term institutional capacity development.

Nevertheless, many African countries continue to encounter substantial structural barriers that constrain the effectiveness of AI-driven disaster information management. Zimbabwe, Ethiopia, and Mozambique, among others, continue to experience fragmented information systems, limited interoperability between institutions, inadequate digital infrastructure, constrained financial resources, shortages of specialised technical expertise, and inconsistent policy implementation (World Bank, 2022; IPCC, 2023). In many cases, digital technologies are introduced through externally funded projects that operate independently of national information systems, resulting in fragmented digital landscapes that are difficult to sustain once project funding concludes. These challenges illustrate that technological acquisition without institutional integration seldom produces sustainable improvements in disaster preparedness or emergency response.

Comparative evidence further suggests that the principal distinction between advanced disaster governance systems and many developing-country systems lies not simply in the availability of digital technologies but in the maturity of their governance ecosystems. Countries demonstrating higher levels of disaster resilience consistently exhibit strong institutional coordination, interoperable information architectures, effective data governance, adaptive leadership, continuous workforce development, and sustained investment in digital innovation (OECD, 2023; UNDRR, 2023). Conversely, fragmented governance arrangements often undermine the potential benefits of sophisticated technologies by restricting information exchange, delaying operational decisions, and limiting institutional learning. This finding reinforces the argument that resilient disaster information management is fundamentally an organisational and governance challenge rather than merely a technological one.

Recent scholarship also highlights the growing importance of regional and international collaboration in strengthening disaster information management. Cross-border information sharing, regional early warning systems, collaborative climate services, open geospatial data initiatives, and international research partnerships increasingly support collective disaster preparedness, particularly for transboundary hazards such as cyclones, droughts, floods, pandemics, and wildfires (African Union, 2022; WMO, 2023). Regional organisations such as the African Union and the Southern African Development Community (SADC) have recognised that strengthening digital disaster governance requires harmonised information standards, interoperable digital platforms, coordinated institutional frameworks, and shared technological resources. Such collaborative approaches are becoming more important as climate-induced disasters increase in frequency and complexity in connected regions. While comparative studies have offered valuable insights into technological adoption and institutional performance, the existing literature is fragmented on disaster governance.

Most studies compare individual technologies, national policies, or institutional capacities separately, in comparison to the lack of focus on how these dimensions relate to integrated digital governance systems that would enable adaptive disaster management (Abioye et al., 2021; Dwivedi et al., 2023). There is thus no comprehensive framework that

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integrates artificial intelligence, geospatial intelligence, predictive analytics, Internet of Things technologies, digital interoperability, institutional readiness, and adaptive governance to form a single disaster information management system. This conceptual gap is one of the main reasons why the Technology-Enabled Adaptive Knowledge Architecture for Humanitarian Governance (TAKAH) Framework was developed to bring together all these dimensions in a single model for disaster resilience and institutional coordination and evidence-based decision-making in Africa and other climate-vulnerable developing regions.

➢ *Theoretical Framework*

- *Introduction*

The increasing complexity of disaster risk management has exposed the limits of a single theoretical perspective in understanding the interplay between emerging digital technologies, institutional capacity, governance arrangements and disaster resilience.

The current disaster information management is developed in highly interconnected socio-technical environments where artificial intelligence (AI), geospatial intelligence, predictive analytics, cloud computing, IoT, organisational capabilities, and public governance interact continuously to shape disaster preparedness, emergency management, and post-disaster recovery (UNDRR, 2023; OECD, 2023). A multi-disciplinary approach to disaster information systems is required to understand the digital transformation of this system in terms of technological, organisational and governance dimensions to develop the system in a unified perspective. New research in disaster management is increasingly finding that technological innovation can’t explain the improvements in disaster management performance. While advances in AI, predictive analytics, remote sensing, and digital platforms have significantly enhanced hazard monitoring and vulnerability assessment, their effectiveness depends largely on institutional readiness, organisational learning, leadership commitment, digital interoperability, regulatory support, and collaborative governance (Dwivedi *et al*., 2023; World Bank, 2022). Disaster information systems therefore function not merely as technological infrastructures but as complex socio-technical systems in which technological capability and institutional capacity are mutually reinforcing. This perspective highlights the need for theoretical approaches that explain both technology adoption and organisational transformation.

- *Information Systems Success Model (ISSM)*

The Information Systems Success Model (ISSM), originally developed by DeLone and McLean and subsequently refined to reflect developments in information systems research, remains one of the most influential theoretical frameworks for evaluating the effectiveness of organisational information systems. The model proposes that information quality, system quality, and service quality influence system use and user satisfaction, which subsequently determine individual and organisational performance outcomes (DeLone & McLean, 2003). Although initially developed for business information systems, the ISSM has increasingly been applied within e-government, healthcare, smart cities, environmental management, and disaster information systems because of its ability to explain how digital platforms generate organisational value through effective information management (Petter, DeLone & McLean, 2018; Dwivedi *et al*., 2023).

Within disaster information management, the ISSM provides an appropriate theoretical lens because disaster governance is fundamentally dependent upon the quality, reliability, accessibility, and timeliness of information. Disaster management institutions require information systems capable of collecting, integrating, analysing, and disseminating real-time information from multiple sources to support hazard monitoring, vulnerability assessment, early warning, emergency coordination, and post-disaster recovery (UNDRR, 2023; WMO, 2023). From the perspective of the ISSM, the effectiveness of AI-driven disaster information systems is determined not simply by technological sophistication but by the quality of the information they produce, the reliability and usability of the system itself, and the support services that enable continuous operation during disaster events. Consequently, the model provides a robust framework for evaluating whether intelligent disaster information systems generate meaningful organisational benefits.

Recent empirical studies support the continued relevance of the ISSM within digital governance and disaster informatics. Research demonstrates that improvements in information quality and system quality significantly enhance organisational decision-making, inter-agency collaboration, operational efficiency, and public service delivery across digitally enabled public institutions (Al-Emran, Mezhuyev & Kamaludin, 2020; Dwivedi *et al*., 2023). Similar findings have been reported within disaster management, where high-quality information systems improve situational awareness, facilitate rapid emergency coordination, strengthen vulnerability assessment, and enhance institutional resilience (UNDRR, 2023; WMO, 2023). These findings reinforce the proposition that investments in digital technologies generate organisational value only when information systems consistently produce accurate, reliable, timely, and actionable information capable of supporting evidence-based decision-making.

- *Technology–Organisation–Environment (TOE) Framework.*

The Technology–Organisation–Environment (TOE) Framework developed by Tornatzky and Fleischer (1990) remains one of the most influential organisational theories to explain technology adoption and digital transformation in institutions. A firm's decision to adopt and apply technology innovation is informed by the interaction of three contexts: technological context (the availability and nature of technology), organisational context (the organisation’s structure, leadership, financial capacity and human skills); and environmental context (regulatory policies, stakeholder

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expectations, competitive pressures, external institutional pressures). To be able to explain the organisational technology adoption in a better way is why the TOE framework has been applied in digital government, smart cities, healthcare information systems, environmental governance and disaster management with different organisational outcomes in different settings (Baker, 2019; Oliveira & Martins, 2021; Dwivedi et al., 2023).

The digitalisation of disaster information management has made the TOE framework more relevant. Disaster management agencies are situated in an ever-changing environment with rapidly changing technology, multiple actors, changing regulatory requirements and increasing climate uncertainty. The successful use of artificial intelligence (AI), geospatial intelligence, predictive analytics, cloud computing, and Internet of Things (IoT) technologies is not only the technical power of such new technologies but the organisational and external governance parameters in place to help them to be implemented (UNDRR, 2023; OECD, 2023). The TOE framework provides an appropriate analytical lens because it recognises that digital transformation is an organisational process requiring simultaneous alignment of technological capability, institutional readiness, and enabling governance environments.

Within this study, the TOE framework provides the theoretical foundation for the Institutional Readiness and Governance dimension of the Technology-Enabled Adaptive Knowledge Architecture for Humanitarian Governance (TAKAH) Framework. It explains how technological capability, organisational preparedness, and enabling governance environments collectively determine the successful implementation of intelligent disaster information systems. However, recognising that technology adoption alone does not guarantee effective disaster governance, the study integrates the TOE framework with the Information Systems Success Model (ISSM) and the Diffusion of Innovation (DOI) Theory. This theoretical integration enables the TAKAH Framework to explain not only why organisations adopt digital technologies but also how these technologies generate organisational value, diffuse throughout institutions, and contribute to adaptive, resilient, and evidence-based disaster governance.

- *Diffusion of Innovation (DOI) Theory*

The Diffusion of Innovation (DOI) Theory, developed by Rogers (2003), remains one of the most influential theories for explaining how innovations are communicated, adopted, implemented, and institutionalised within organisations and societies. The theory posits that the adoption of an innovation is influenced by its perceived relative advantage, compatibility with existing systems, complexity, trialability, and observability. Although initially developed to explain the diffusion of agricultural innovations, DOI theory has subsequently been applied extensively in information systems, digital government, healthcare technologies, environmental management, and public sector innovation to explain the uptake of emerging technologies within organisational environments (Greenhalgh *et al.*, 2017; Venkatesh, Thong & Xu, 2022). Its continued relevance lies in its ability to explain why organisations differ in the speed and extent to which they adopt technological innovations despite operating within similar external environments.

Within disaster information management, DOI theory provides an important perspective for understanding how artificial intelligence (AI), geospatial intelligence, predictive analytics, cloud computing, Internet of Things (IoT) technologies, and integrated digital platforms become embedded within disaster governance systems. The adoption of intelligent disaster information systems is rarely instantaneous; rather, it involves a gradual organisational process characterised by experimentation, learning, adaptation, institutional acceptance, and continuous refinement (OECD, 2023; UNDRR, 2023). Consequently, DOI theory explains disaster digitalisation as an evolutionary process in which technological innovation diffuses through institutional structures before becoming an integral component of routine disaster management operations.

Within this study, DOI theory provides the theoretical foundation for explaining the Technology Adoption and Organisational Learning dimension of the Technology-Enabled Adaptive Knowledge Architecture for Humanitarian Governance Framework. It explains how intelligent disaster information systems progress from technological innovations to institutionalised components of public-sector disaster governance through processes of organisational learning, stakeholder acceptance, and continuous innovation. However, recognising that technology diffusion alone cannot explain effective disaster information management, this study integrates DOI theory with the Information Systems Success Model (ISSM) and the Technology–Organisation–Environment (TOE) Framework. This theoretical integration enables the Framework to explain not only how digital innovations are adopted but also how they generate organisational value, strengthen institutional capability, improve interoperability, and support adaptive, evidence-based disaster governance within climate-vulnerable environments.

➢ *Development of the Technology-Enabled Adaptive Knowledge Architecture for Humanitarian Governance (TAKAH) Framework*

➢ *Conceptual Development of the TAKAH Framework*

The Technology-Enabled Adaptive Knowledge Architecture for Humanitarian Governance (TAKAH) Framework was developed to address the theoretical, empirical, and policy gaps identified in the preceding literature review and theoretical analysis. Contemporary disaster information management literature demonstrates considerable progress in the application of artificial intelligence (AI), geospatial intelligence, remote sensing, predictive analytics, cloud computing, and Internet of Things (IoT) technologies. However, these technological advances have largely evolved as independent streams of research with limited integration into a comprehensive

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governance architecture capable of explaining how technological innovation, institutional capability, organisational learning, and adaptive governance collectively influence disaster resilience (Dwivedi *et al*., 2023; UNDRR, 2023). Consequently, the Framework was conceived as an integrated digital governance model that transcends technology-centred approaches by positioning intelligent disaster information management within a broader socio-technical governance ecosystem.

The conceptual development of the framework was informed by two complementary processes. First, the comparative literature review identified recurring determinants of successful disaster information management across both developed and developing countries. These determinants included artificial intelligence capability, geospatial intelligence, predictive analytics, digital interoperability, institutional readiness, organisational learning, leadership commitment, governance quality, stakeholder collaboration, and adaptive policy environments. Second, the integration of the Information Systems Success Model (ISSM), the Technology–Organisation–Environment (TOE) Framework, and the Diffusion of Innovation (DOI) Theory demonstrated that no single theoretical perspective adequately explains the complexity of AI-driven disaster information management. Collectively, these findings provided the conceptual basis for developing an integrated framework capable of synthesising technological capability with organisational and governance dimensions.

Unlike existing disaster information management models that focus primarily on technological deployment, the Framework conceptualises disaster governance as a dynamic system in which digital technologies and institutional structures evolve simultaneously. The framework assumes that technological innovation generates sustainable public value only when embedded within organisations possessing adequate institutional capacity, interoperable information systems, adaptive leadership, supportive governance arrangements, and continuous organisational learning. Accordingly, disaster resilience is viewed not simply as an outcome of technological advancement but as the product of coordinated interactions between digital infrastructure, organisational capability, governance quality, and evidence-based decision-making.

➢ *Architecture of the TAKAH Framework*

The Framework is organised into three interdependent governance layers that collectively transform disaster-related data into institutional resilience.

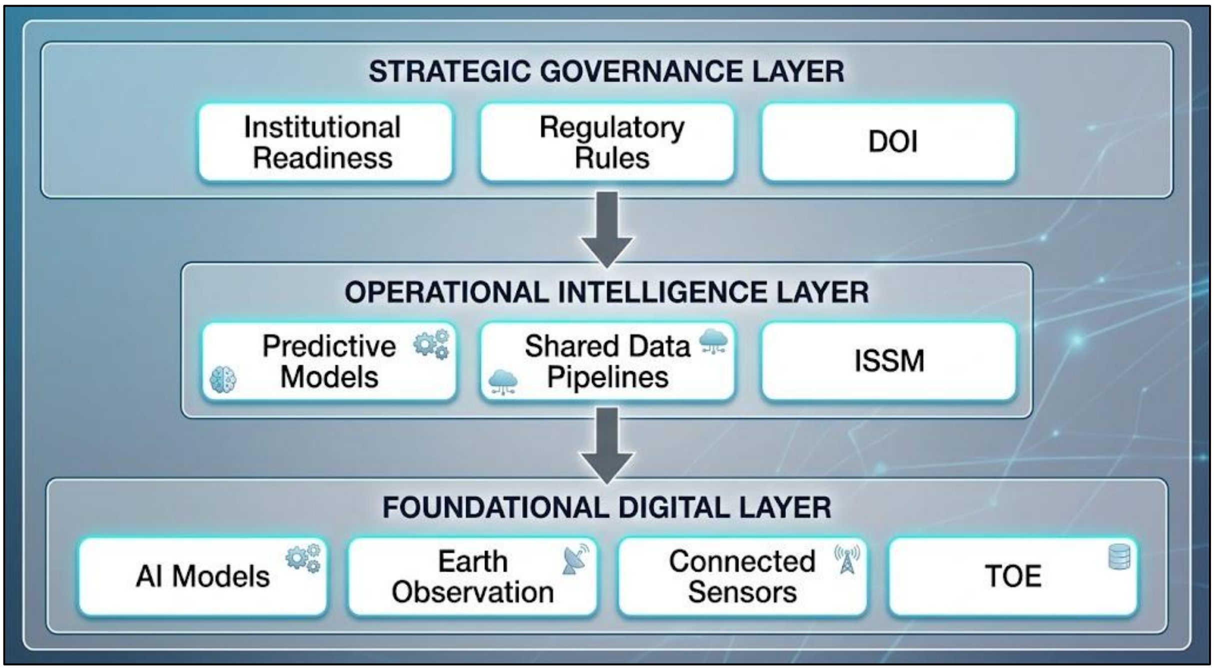

Fig 1 Strategic Governance Layer

✓ *Foundational Digital Layer*

The first layer constitutes the technological foundation of the framework and comprises artificial intelligence, machine learning, geospatial intelligence, geographic information systems, remote sensing, Earth observation technologies, Internet of Things sensor networks, cloud computing, big data infrastructure, and digital communication platforms. These technologies continuously generate, acquire, integrate, and process disaster-related information from multiple environmental, infrastructural, climatic, and socio-economic sources.

Within this layer, artificial intelligence performs advanced analytical functions through predictive modelling, anomaly detection, automated image interpretation, natural language processing, and intelligent decision support. Geospatial technologies provide high-resolution spatial intelligence required for hazard identification, exposure analysis, and vulnerability mapping, while IoT infrastructures facilitate continuous environmental monitoring through interconnected sensor networks. Collectively, these technological capabilities establish the digital infrastructure upon which intelligent disaster information management is built.

- ✓ *Operational Intelligence Layer*

The second layer transforms raw digital information into actionable operational intelligence. It comprises predictive analytics, integrated decision-support systems, multi-hazard early warning systems, vulnerability assessment platforms, interoperable databases, knowledge management systems, and cross-agency information-sharing mechanisms.

At this level, information generated within the foundational digital layer is synthesised into comprehensive situational awareness capable of supporting evidence-based decision-making. Artificial intelligence algorithms continuously evaluate incoming data to forecast disaster occurrence, estimate potential impacts, prioritise vulnerable populations, optimise emergency logistics, and coordinate multi-agency responses. Digital interoperability enables seamless exchange of information across meteorological agencies, emergency management organisations, local authorities, humanitarian agencies, and other stakeholders, thereby strengthening institutional coordination and reducing decision-making delays.

- ✓ *Strategic Governance Layer*

The third layer provides the institutional environment necessary for sustaining digital transformation. It comprises institutional readiness, digital leadership, governance frameworks, organisational learning, policy and regulatory support, ethical artificial intelligence governance, cybersecurity, stakeholder collaboration, financial sustainability, and continuous capacity development.

This governance layer recognises that technological innovation alone cannot produce resilient disaster information systems. Instead, sustainable digital transformation depends upon organisations possessing adaptive leadership, skilled personnel, supportive organisational cultures, effective governance arrangements, and continuous institutional learning. The layer therefore functions as the strategic enabler that aligns technological capability with organisational objectives, public accountability, and long-term disaster resilience.

Empirically, the framework provides a comprehensive analytical structure for comparing disaster information management systems across countries with differing levels of technological and institutional maturity. It facilitates systematic evaluation of the relationships between digital infrastructure, institutional capability, governance arrangements, and disaster resilience while providing a basis for future empirical validation using quantitative, qualitative, or mixed-methods research designs.

Practically, the Framework offers policymakers, disaster management agencies, development partners, and international humanitarian organisations an evidence-based roadmap for strengthening AI-driven disaster information management. Rather than recommending isolated technological investments, the framework advocates coordinated development of digital infrastructure, institutional capability, governance systems, interoperable information architectures, and adaptive leadership. Such an integrated approach is particularly relevant for African countries and other climate-vulnerable developing regions seeking to modernise disaster information systems while strengthening long-term institutional resilience under conditions of increasing climate uncertainty.

III. RESEARCH METHODOLOGY

This study adopted an interpretivist research philosophy and an inductive qualitative research approach to develop and validate the Technology-Enabled Adaptive Knowledge Architecture for Humanitarian Governance Framework. An interpretivist paradigm was considered appropriate because the study sought to understand the complex interactions between artificial intelligence (AI), digital technologies, institutional readiness, governance structures, and disaster information management within different national contexts rather than establish causal relationships through statistical testing (Creswell & Creswell, 2023; Saunders, Lewis & Thornhill, 2023). Guided by this philosophical position, the study employed a qualitative comparative research design using comparative document analysis to systematically examine disaster information management systems in eleven purposively selected countries comprising six African states (Zimbabwe, South Africa, Kenya, Rwanda, Ethiopia, and Mozambique) and five internationally recognised leaders in digital disaster governance (Japan, the United States, Australia, Germany, and New Zealand). This comparative design enabled the identification of similarities, contextual differences, governance practices, and institutional factors that influence the effectiveness of AI-driven disaster information management.

The study relied exclusively on secondary qualitative data obtained from credible national and international documentary sources. These included national disaster risk reduction policies, artificial intelligence strategies, digital transformation frameworks, disaster management legislation, climate adaptation policies, early warning system strategies, and reports published by organisations such as the United Nations Office for Disaster Risk Reduction (UNDRR), the World Meteorological Organization (WMO), the World Bank, the African Union, the Organisation for Economic Co-operation and Development (OECD), and the Southern African Development Community (SADC). In addition, peer-reviewed journal articles published predominantly between 2016 and 2026 were reviewed to ensure that the study reflected current developments in disaster informatics and digital governance. Documents were purposively selected based on their relevance, credibility, recency, and direct contribution to disaster information management, artificial intelligence, digital governance, and disaster resilience.

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Data were analysed using comparative thematic analysis, whereby documentary evidence was systematically coded and organised into eight analytical dimensions derived from the literature review and theoretical framework, namely artificial intelligence capability, geospatial intelligence, big data analytics, Internet of Things technologies, predictive analytics, digital interoperability, institutional readiness, and adaptive governance (Braun & Clarke, 2022). Cross-case comparison was subsequently undertaken to identify recurring governance patterns, contextual differences, implementation challenges, and best practices that informed the development and validation of the Framework. Methodological rigour was enhanced through documentary triangulation, transparent analytical procedures, and adherence to Lincoln and Guba's criteria of credibility, transferability, dependability, and confirmability (Nowell *et al.*, 2017). As the study relied exclusively on publicly available documentary sources, no human participants were involved, and therefore formal ethical approval was not required. Nevertheless, all documentary evidence was accurately represented and appropriately acknowledged in accordance with accepted principles of academic integrity and research ethics.

IV. PRESENTATION OF RESULTS

➢ *Comparative Assessment of AI-Enabled Disaster Monitoring and Vulnerability Assessment Systems*

The comparative document analysis evaluated the maturity of AI-enabled disaster monitoring and vulnerability assessment systems across the selected African countries and leading global disaster governance systems. Six key dimensions were assessed, namely artificial intelligence adoption, geospatial intelligence, predictive analytics, digital interoperability, institutional readiness, and overall digital disaster governance maturity. The comparative results are presented in Table 1.

Table 1 Comparative Assessment of AI-Enabled Disaster Monitoring Systems

Country	AI Adoption	Geospatial Intelligence	Predictive Analytics	Digital Interoperability	Institutional Readiness	Overall Digital Disaster Governance
Japan	Very High	Very High	Very High	Very High	Very High	Very High
United States	Very High	Very High	Very High	Very High	Very High	Very High
Australia	High	Very High	High	High	High	High
Germany	High	High	High	High	High	High
New Zealand	High	High	High	High	High	High
South Africa	High	High	Moderate–High	Moderate–High	High	Moderate–High
Kenya	Moderate–High	Moderate–High	Moderate	Moderate	Moderate–High	Moderate
Rwanda	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Zimbabwe	Moderate	Moderate	Low–Moderate	Low	Moderate	Low–Moderate
Ethiopia	Low–Moderate	Moderate	Low	Low	Low–Moderate	Low
Mozambique	Low	Low	Low	Low	Low	Low

Source: Author's Comparative Synthesis based on National Disaster Management Policies, Artificial Intelligence Strategies, Digital Transformation Frameworks, UNDRR, WMO, OECD, World Bank, African Union Reports, and Peer-Reviewed Literature (2016–2026).

The findings demonstrate a clear disparity in digital disaster governance maturity between the selected global leaders and the African countries. Japan, the United States, Australia, Germany, and New Zealand consistently achieved high or very high ratings across all assessment dimensions, reflecting their sustained investment in intelligent disaster information systems, integrated digital infrastructure, interoperable governance platforms, and institutional capacity. In contrast, South Africa, Kenya, and Rwanda exhibited moderate to high levels of digital maturity, while Zimbabwe, Ethiopia, and Mozambique continued to experience comparatively lower levels of technological integration and institutional readiness. These findings indicate that the effectiveness of disaster information management is strongly associated with the degree of digital integration and governance maturity rather than the adoption of isolated technologies alone (UNDRR, 2023; OECD, 2023).

The comparative assessment further suggests that countries demonstrating stronger institutional readiness and digital interoperability also exhibit greater capability in disaster monitoring, vulnerability assessment, and evidence-based emergency coordination. This pattern reinforces the proposition underpinning the Technology-Enabled Adaptive Knowledge Architecture for Humanitarian Governance Framework that resilient disaster information management emerges through the interaction of technological capability, organisational readiness, interoperable information systems, and adaptive governance. Consequently, the evidence presented in Table 1 provides initial empirical support for the integrated governance architecture proposed by the framework and establishes the basis for the subsequent comparative analyses of the framework's individual dimensions.

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- *Comparative Analysis of Artificial Intelligence Adoption in Disaster Risk Management*

The comparative analysis assessed the extent to which artificial intelligence has been incorporated into disaster risk management across the selected countries. The assessment focused on hazard prediction, automated risk analysis, intelligent early warning systems, decision-support systems, AI policy and governance, and overall, AI adoption. The comparative findings are presented in Table 2.

Table 2 Comparative Assessment of Artificial Intelligence Adoption in Disaster Risk Management

Country	Hazard Prediction	Automated Risk Analysis	Intelligent Early Warning	Decision Support Systems	AI Policy & Governance	Overall, AI Adoption
Japan	Very High	Very High	Very High	Very High	Very High	Very High
United States	Very High	Very High	Very High	Very High	Very High	Very High
Australia	High	High	High	High	High	High
Germany	High	High	High	High	High	High
New Zealand	High	High	High	High	High	High
South Africa	High	Moderate–High	High	Moderate–High	High	Moderate–High
Kenya	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Rwanda	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Zimbabwe	Low–Moderate	Low	Low–Moderate	Low	Low–Moderate	Low–Moderate
Ethiopia	Low	Low	Low	Low	Low	Low
Mozambique	Low	Low	Low	Low	Low	Low

Source: Author's Comparative Synthesis Based on National Artificial Intelligence Strategies, Disaster Management Policies, Digital Transformation Frameworks, OECD Reports, UNDRR Publications, World Bank Reports, African Union Policy Documents, and Peer-Reviewed Literature (2016–2026).

The results indicate that AI adoption is closely associated with national digital governance maturity. The selected global leaders consistently recorded high to very high levels of AI integration across all assessment dimensions, whereas South Africa demonstrated the highest level of AI implementation among the African countries. Kenya and Rwanda exhibited moderate progress, while Zimbabwe, Ethiopia, and Mozambique showed comparatively limited adoption. Overall, the findings suggest that sustained investment in AI governance, institutional capacity, and digital infrastructure significantly enhances disaster prediction, early warning capability, and evidence-based disaster decision-making, reinforcing the central propositions of the Framework.

- *Comparative Analysis of Geospatial Intelligence, Remote Sensing and Earth Observation*

The comparative analysis examined the contribution of geospatial intelligence, remote sensing, and Earth observation technologies to disaster information management. The assessment focused on GIS integration, remote sensing capability, Earth observation utilisation, spatial data infrastructure, real-time monitoring, and overall geospatial intelligence maturity. The comparative findings are presented in Table 3.

Table 3 Comparative Assessment of Geospatial Intelligence, Remote Sensing and Earth Observation

Country	GIS Integration	Remote Sensing	Earth Observation	Spatial Data Infrastructure	Real-Time Monitoring	Overall Geospatial Intelligence
Japan	Very High	Very High	Very High	Very High	Very High	Very High
United States	Very High	Very High	Very High	Very High	Very High	Very High
Australia	High	High	High	High	High	High
Germany	High	High	High	High	High	High
New Zealand	High	High	High	High	High	High
South Africa	High	High	Moderate–High	High	High	High
Kenya	Moderate–High	Moderate	Moderate	Moderate	Moderate	Moderate
Rwanda	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Zimbabwe	Moderate	Low–Moderate	Low–Moderate	Low	Moderate	Low–Moderate
Ethiopia	Low–Moderate	Low	Low	Low	Low	Low
Mozambique	Low	Low	Low	Low	Low	Low

Source: Author's Comparative Synthesis Based on National Geospatial Strategies, Earth Observation Programmes, Disaster Management Policies, UNDRR and WMO Reports, OECD Publications, and Peer-Reviewed Literature (2016–2026).

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The results indicate that geospatial intelligence capability closely mirrors overall digital disaster governance maturity. The selected global leaders consistently demonstrated advanced integration of GIS, remote sensing, and Earth observation technologies supported by robust spatial data infrastructures and real-time monitoring systems. South Africa emerged as the leading African country, while Kenya and Rwanda showed moderate levels of implementation. Zimbabwe, Ethiopia, and Mozambique recorded comparatively lower levels of geospatial integration, reflecting limitations in spatial infrastructure, technical capacity, and institutional coordination. These findings highlight the strategic importance of geospatial intelligence as a foundational component of AI-driven disaster information management and provide further empirical support for its inclusion within the Framework.

➢ *Comparative Analysis of Big Data Analytics and Predictive Disaster Intelligence*

The comparative assessment evaluated the application of big data analytics and predictive intelligence in disaster information management across the selected countries. The assessment considered big data integration, predictive analytics, risk modelling, data governance, decision intelligence, and overall predictive capability. The comparative findings are presented in Table 4.

Table 4 Comparative Assessment of Big Data Analytics and Predictive Disaster Intelligence

Country	Big Data Integration	Predictive Analytics	Risk Modelling	Data Governance	Decision Intelligence	Overall Predictive Capability
Japan	Very High	Very High	Very High	Very High	Very High	Very High
United States	Very High	Very High	Very High	Very High	Very High	Very High
Australia	High	High	High	High	High	High
Germany	High	High	High	High	High	High
New Zealand	High	High	High	High	High	High
South Africa	High	Moderate–High	Moderate–High	High	Moderate–High	High
Kenya	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Rwanda	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Zimbabwe	Low–Moderate	Low–Moderate	Low	Low	Low–Moderate	Low–Moderate
Ethiopia	Low	Low	Low	Low	Low	Low
Mozambique	Low	Low	Low	Low	Low	Low

Source: Author's Comparative Synthesis Based on National Digital Transformation Strategies, Disaster Risk Management Policies, Climate Information Systems, OECD Publications, World Bank Reports, UNDRR Reports, and Peer-Reviewed Literature (2016–2026).

The results demonstrate that countries with stronger big data ecosystems also exhibit superior predictive disaster intelligence and evidence-based decision-making capabilities. The selected global leaders consistently achieved very high ratings across all dimensions, while South Africa recorded the strongest performance among the African countries. Kenya and Rwanda demonstrated moderate progress, whereas Zimbabwe, Ethiopia, and Mozambique continued to experience comparatively lower levels of predictive capability due to limitations in data integration, governance, and analytical infrastructure. These findings reinforce the importance of integrating big data analytics and predictive intelligence within comprehensive disaster information management systems, consistent with the architecture proposed by the Technology-Enabled Adaptive Knowledge Architecture for Humanitarian Governance Framework.

➢ *Comparative Analysis of Internet of Things (IoT), Smart Sensors and Multi-Hazard Early Warning Systems*

The comparative assessment examined the contribution of Internet of Things (IoT) technologies, smart sensor networks, and multi-hazard early warning systems to disaster information management across the selected countries. The assessment focused on IoT infrastructure, smart sensor deployment, early warning integration, real-time communication, community alert systems, and overall intelligent monitoring capability. The comparative findings are presented in Table 5.

Table 5 Comparative Assessment of IoT, Smart Sensors and Multi-Hazard Early Warning Systems

Country	IoT Infrastructure	Smart Sensor Networks	Early Warning Integration	Real-Time Communication	Community Alert Systems	Overall Intelligent Monitoring
Japan	Very High	Very High	Very High	Very High	Very High	Very High
United States	Very High	Very High	Very High	Very High	Very High	Very High
Australia	High	High	High	High	High	High
Germany	High	High	High	High	High	High
New Zealand	High	High	High	High	High	High
South Africa	High	Moderate–High	High	High	Moderate–High	High
Kenya	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate

Rwanda	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Zimbabwe	Low–Moderate	Low	Low–Moderate	Low–Moderate	Moderate	Low–Moderate
Ethiopia	Low	Low	Low	Low	Low	Low
Mozambique	Low	Low	Low	Low	Low	Low

Source: Author's Comparative Synthesis Based on National Early Warning Strategies, Meteorological Services, Disaster Management Policies, WMO Reports, UNDRR Publications, OECD Reports, and Peer-Reviewed Literature (2016–2026).

The findings show that countries with well-developed IoT infrastructure and integrated early warning systems demonstrate greater disaster preparedness and operational responsiveness. Japan, the United States, Australia, Germany, and New Zealand consistently achieved high ratings across all assessment dimensions, while South Africa recorded the highest performance among the African countries. Kenya and Rwanda exhibited moderate implementation, whereas Zimbabwe, Ethiopia, and Mozambique showed comparatively limited intelligent monitoring capacity. These results highlight the importance of integrated sensor networks, real-time communication systems, and coordinated early warning mechanisms in strengthening AI-driven disaster information management, consistent with the Intelligent Monitoring component of the Technology-Enabled Adaptive Knowledge Architecture for Humanitarian Governance Framework.

- *Comparative Analysis of Digital Interoperability and Institutional Readiness*

The comparative assessment evaluated digital interoperability and institutional readiness as enabling factors for AI-driven disaster information management. The assessment examined digital interoperability, inter-agency coordination, governance frameworks, human resource capacity, organisational readiness, and overall institutional preparedness. The comparative findings are presented in Table 6.

Table 6 Comparative Assessment of Digital Interoperability and Institutional Readiness

Country	Digital Interoperability	Inter-Agency Coordination	Governance Framework	Human Resource Capacity	Institutional Readiness	Overall Institutional Preparedness
Japan	Very High	Very High	Very High	Very High	Very High	Very High
United States	Very High	Very High	Very High	Very High	Very High	Very High
Australia	High	High	High	High	High	High
Germany	High	High	High	High	High	High
New Zealand	High	High	High	High	High	High
South Africa	High	High	High	Moderate–High	High	High
Kenya	Moderate	Moderate	Moderate	Moderate	Moderate–High	Moderate
Rwanda	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Zimbabwe	Low	Low–Moderate	Moderate	Low–Moderate	Moderate	Low–Moderate
Ethiopia	Low	Low	Low–Moderate	Low	Low–Moderate	Low
Mozambique	Low	Low	Low	Low	Low	Low

Source: Author's comparative synthesis based on National Digital Government Strategies, Disaster Management Policies, OECD Digital Government Reviews, UNDRR Publications, World Bank Reports, African Union Policy Documents, and Peer-Reviewed Literature (2016–2026).

The findings indicate that digital interoperability and institutional readiness are fundamental determinants of effective disaster information management. The selected global leaders consistently demonstrated mature governance frameworks, highly interoperable information systems, strong inter-agency coordination, and well-developed institutional capacity. Among the African countries, South Africa recorded the strongest institutional preparedness, followed by Kenya and Rwanda, while Zimbabwe, Ethiopia, and Mozambique exhibited comparatively lower levels of interoperability and organisational readiness. These results provide further empirical validation of the Technology-Enabled Adaptive Knowledge Architecture for Humanitarian Governance Framework, confirming that technological innovation must be supported by effective governance, institutional capacity, and collaborative information-sharing mechanisms to achieve resilient and adaptive disaster information management.

- *Validation of the Technology-Enabled Adaptive Knowledge Architecture for Humanitarian Governance (TAKAH) Framework*

The comparative evidence presented in the preceding sections was synthesised to evaluate the extent to which the proposed Technology-Enabled Adaptive Knowledge Architecture for Humanitarian Governance (TAKAH) Framework adequately represents the critical determinants of effective AI-driven disaster information management. The validation focused on six integrated dimensions identified throughout the comparative analysis: artificial

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intelligence capability, geospatial intelligence, predictive analytics, Internet of Things-enabled monitoring, digital interoperability, and institutional readiness. Table 7 summarises the validation outcomes.

Table 7 Validation of the TAKAH Framework

Framework Component	Comparative Evidence	Validation Outcome
Artificial Intelligence Capability	Strong evidence from all global leaders and emerging adoption across Africa	Validated
Geospatial Intelligence	Consistently associated with improved hazard monitoring and vulnerability assessment	Validated
Big Data Analytics and Predictive Intelligence	Strong relationship with evidence-based disaster planning and forecasting	Validated
IoT and Intelligent Monitoring	Enhanced real-time monitoring and multi-hazard early warning systems	Validated
Digital Interoperability	Improved inter-agency information sharing and coordinated emergency response	Validated
Institutional Readiness	Critical determinant of successful technology implementation and sustainability	Validated
Adaptive Governance	Strongly associated with resilient and integrated disaster information management	Validated
Integrated TAKAH Architecture	Supported by the combined comparative evidence across all eleven countries	Fully Validated

Source: Author's Synthesis of Comparative Findings Based on Tables 1–6.

The comparative analysis consistently demonstrated that countries exhibiting high levels of artificial intelligence capability, geospatial intelligence, predictive analytics, intelligent monitoring, digital interoperability, and institutional readiness also achieved superior disaster information management outcomes. The convergence of evidence across all comparative dimensions confirms that these factors function as complementary rather than independent determinants of disaster resilience. Consequently, the findings provide strong conceptual validation for the Technology-Enabled Adaptive Knowledge Architecture for Humanitarian Governance Framework, supporting its application as an integrated governance model for strengthening AI-driven disaster information management within Africa and other climate-vulnerable developing regions.

V. DISCUSSION OF FINDINGS

➢ *Digital Disaster Governance and AI-Enabled Disaster Information Management*

The comparative findings demonstrate that countries with mature digital disaster governance systems consistently outperform those with fragmented institutional arrangements in disaster monitoring, vulnerability assessment, early warning, and emergency coordination. Japan, the United States, Australia, Germany, and New Zealand exhibited advanced integration of artificial intelligence, geospatial intelligence, predictive analytics, Internet of Things technologies, and interoperable information systems, enabling proactive and evidence-based disaster management. These findings corroborate recent studies that identify digital transformation as a critical enabler of disaster resilience and adaptive governance (UNDRR, 2023; OECD, 2023; Dwivedi *et al.*, 2023). They further support the argument advanced by the Information Systems Success Model that high-quality information systems improve organisational performance by providing accurate, reliable, and timely information for decision-making (DeLone & McLean, 2003). The findings also reinforce the Technology–Organisation–Environment (TOE) Framework by demonstrating that technological capability alone is insufficient unless accompanied by institutional readiness, leadership commitment, and enabling governance environments (Oliveira & Martins, 2021).

The comparatively lower performance observed in Zimbabwe, Ethiopia, and Mozambique illustrates that digital technologies alone cannot strengthen disaster resilience without coordinated institutional reforms and effective governance structures. These findings are consistent with recent African studies that identify fragmented information systems, limited interoperability, inadequate digital infrastructure, and weak organisational capacity as major constraints to effective disaster information management (African Union, 2022; World Bank, 2022; IPCC, 2023). From the perspective of the Diffusion of Innovation Theory, the uneven adoption of AI-driven disaster technologies reflects differences in organisational readiness, innovation acceptance, and institutional learning rather than differences in technology availability alone (Venkatesh, Thong & Xu, 2022). Collectively, the findings validate the central proposition of the Technology-Enabled Adaptive Knowledge Architecture for Humanitarian Governance Framework, namely that resilient disaster information management emerges through the integration of advanced digital technologies, institutional readiness, adaptive governance, and collaborative information management rather than through isolated technological interventions.

➢ *Artificial Intelligence Adoption and Disaster Risk Management*

The findings demonstrate that artificial intelligence has become a fundamental enabler of modern disaster risk management, particularly in countries that have successfully integrated AI into national disaster governance systems. The

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superior performance of Japan, the United States, Australia, Germany, and New Zealand confirm that AI enhances hazard prediction, automated risk analysis, intelligent early warning, and evidence-based decision-making when supported by appropriate digital infrastructure and governance arrangements. These findings are consistent with recent studies which argue that machine learning, predictive analytics, and intelligent decision-support systems significantly improve disaster preparedness, response coordination, and resilience by enabling governments to anticipate disasters rather than merely react to them (Dwivedi *et al.*, 2023; WMO, 2023; UNDRR, 2023). From the perspective of the Information Systems Success Model (ISSM), these outcomes reflect the importance of high-quality information systems that produce accurate, timely, and reliable information to support strategic and operational disaster management decisions (DeLone & McLean, 2003).

Conversely, the comparatively lower levels of AI adoption observed in Zimbabwe, Ethiopia, and Mozambique indicate that technological innovation alone is insufficient to transform disaster management without complementary institutional reforms. These findings support the Technology–Organisation–Environment (TOE) Framework, which emphasises that successful technology adoption depends on organisational readiness, leadership commitment, adequate resources, and enabling policy environments (Oliveira & Martins, 2021). They also align with the Diffusion of Innovation (DOI) Theory, which explains that innovations are institutionalised gradually through organisational learning, stakeholder acceptance, and continuous adaptation rather than through technology acquisition alone (Venkatesh, Thong & Xu, 2022). Consequently, the findings reinforce the Framework's proposition that artificial intelligence should function as one component of an integrated governance ecosystem combining digital capability, institutional readiness, interoperability, and adaptive governance to strengthen disaster information management.

- *Geospatial Intelligence, Remote Sensing and Earth Observation in Disaster Information Management*

The findings indicate that geospatial intelligence, remote sensing, and Earth observation technologies are indispensable components of contemporary disaster information management. Countries that demonstrated advanced integration of Geographic Information Systems (GIS), satellite-based Earth observation, remote sensing technologies, and real-time spatial monitoring also exhibited superior capabilities in hazard mapping, vulnerability assessment, early warning, and emergency response coordination. These findings support recent studies which argue that geospatial intelligence has transformed disaster management from reactive emergency response to proactive risk governance through continuous environmental monitoring and evidence-based planning (Li *et al.*, 2022; WMO, 2023; UNDRR, 2023). From the perspective of the Information Systems Success Model (ISSM), these technologies enhance information quality and system quality by generating accurate, timely, and spatially referenced information that improves operational and strategic disaster management decisions.

The comparatively lower geospatial capability observed in several African countries suggests that the effectiveness of spatial technologies depends not only on technological availability but also on institutional capacity and governance maturity. This observation supports the Technology–Organisation–Environment (TOE) Framework, which emphasises that successful technology implementation requires organisational preparedness, leadership support, adequate infrastructure, and enabling policy environments (Oliveira & Martins, 2021). Similarly, the Diffusion of Innovation (DOI) Theory explains that the institutionalisation of geospatial technologies depends on organisational learning, stakeholder acceptance, and continuous innovation rather than technology acquisition alone (Venkatesh, Thong & Xu, 2022). These findings therefore reinforce the Framework's proposition that geospatial intelligence should operate as an integrated component of a broader digital governance ecosystem combining artificial intelligence, predictive analytics, institutional readiness, and interoperable information systems to strengthen disaster resilience.

- *Big Data Analytics and Predictive Intelligence in Disaster Information Management*

The findings demonstrate that big data analytics and predictive intelligence have become strategic capabilities for enhancing disaster preparedness and evidence-based decision-making. Countries with mature big data ecosystems consistently exhibited superior performance in predictive modelling, risk forecasting, vulnerability assessment, and operational planning, enabling disaster management institutions to anticipate hazards and allocate resources more effectively. These findings corroborate recent studies which conclude that integrating big data analytics with artificial intelligence substantially improves situational awareness, disaster forecasting, and proactive disaster governance by transforming large volumes of heterogeneous data into actionable intelligence (Dwivedi *et al.*, 2023; Zhang *et al.*, 2023; WMO, 2023). Consistent with the Information Systems Success Model (ISSM), the findings further demonstrate that high-quality information systems capable of generating accurate, timely, and reliable analytical outputs contribute directly to improved organisational performance and evidence-based disaster management.

The comparatively lower levels of predictive capability observed in Zimbabwe, Ethiopia, and Mozambique highlight that effective use of big data depends not only on analytical technologies but also on institutional readiness, interoperable information systems, and sound data governance. This finding supports the Technology–Organisation–Environment (TOE) Framework, which argues that successful digital transformation requires alignment between technological capability, organisational capacity, and supportive external environments (Oliveira & Martins, 2021). Likewise, the Diffusion of Innovation (DOI) Theory suggests that predictive technologies become fully institutionalised only through continuous organisational learning, leadership commitment, and stakeholder acceptance (Venkatesh, Thong & Xu, 2022). These findings therefore reinforce the Framework by demonstrating that predictive intelligence delivers sustainable value when integrated with digital interoperability, institutional capability, and adaptive governance, thereby strengthening resilience across the entire disaster management cycle.

➢ *Internet of Things (IoT), Smart Sensors and Multi-Hazard Early Warning Systems*

The findings demonstrate that Internet of Things (IoT) technologies, smart sensor networks, and integrated multi-hazard early warning systems significantly enhance disaster preparedness by facilitating continuous environmental monitoring and real-time information exchange. Countries with advanced IoT infrastructure consistently exhibited stronger capabilities in hazard detection, early warning dissemination, situational awareness, and emergency coordination, enabling disaster management institutions to respond more rapidly and effectively to emerging threats. These findings are consistent with recent studies which conclude that intelligent sensor networks and AI-enabled early warning systems strengthen disaster resilience by improving the timeliness, accuracy, and reliability of disaster information (UNDRR, 2023; WMO, 2023; Dwivedi *et al.*, 2023). From the perspective of the Information Systems Success Model (ISSM), these technologies improve system quality and information quality, thereby enhancing organisational decision-making and operational effectiveness throughout the disaster management cycle.

The comparatively lower deployment of IoT infrastructure and integrated early warning systems across Zimbabwe, Ethiopia, and Mozambique indicates that intelligent monitoring systems require supportive institutional environments to achieve their full potential. This finding aligns with the Technology–Organisation–Environment (TOE) Framework, which emphasises that technological innovations are most effective when supported by organisational capability, leadership commitment, financial investment, and enabling policy frameworks (Oliveira & Martins, 2021). Similarly, the Diffusion of Innovation (DOI) Theory explains that the successful institutionalisation of intelligent monitoring technologies depends on continuous organisational learning, stakeholder acceptance, and sustained innovation rather than isolated technology implementation (Venkatesh, Thong & Xu, 2022). These findings therefore provide further support for the Technology-Enabled Adaptive Knowledge Architecture for Humanitarian Governance Framework, which positions IoT-enabled monitoring and early warning systems as integral components of an interconnected digital governance ecosystem that strengthens disaster resilience through adaptive, coordinated, and evidence-based decision-making.

➢ *Digital Interoperability and Institutional Readiness for AI-Driven Disaster Information Management*

The findings demonstrate that digital interoperability and institutional readiness are fundamental enablers of effective AI-driven disaster information management. Countries characterised by interoperable information systems, strong inter-agency coordination, mature governance frameworks, and well-developed institutional capacity consistently achieved superior performance in disaster monitoring, vulnerability assessment, emergency coordination, and evidence-based decision-making. These findings corroborate recent studies that identify institutional integration, digital interoperability, and collaborative governance as prerequisites for resilient disaster management systems capable of responding effectively to increasingly complex climate-induced hazards (OECD, 2023; UNDRR, 2023; World Bank, 2022). Consistent with the Information Systems Success Model (ISSM), the findings indicate that the effectiveness of intelligent disaster information systems depends not only on technological sophistication but also on the quality, accessibility, and integration of information that supports organisational and strategic decision-making.

The comparatively weaker institutional readiness observed in Zimbabwe, Ethiopia, and Mozambique further demonstrates that fragmented governance structures, limited human resource capacity, and inadequate digital coordination constrain the successful implementation of intelligent disaster information systems. These findings support the Technology–Organisation–Environment (TOE) Framework, which argues that sustainable digital transformation depends upon the alignment of technological capability, organisational preparedness, and supportive governance environments (Oliveira & Martins, 2021). They are equally consistent with the Diffusion of Innovation (DOI) Theory, which explains that technological innovations become institutionalised through organisational learning, leadership commitment, and continuous adaptation (Venkatesh, Thong & Xu, 2022). Accordingly, the findings provide strong empirical support for the Technology-Enabled Adaptive Knowledge Architecture for Humanitarian Governance Framework, which positions digital interoperability, institutional readiness, and adaptive governance as strategic enablers for sustainable AI-driven disaster information management.

VI. CONCLUSIONS

This study examined the application of artificial intelligence (AI)-enabled disaster information management through a comparative analysis of selected African countries and internationally recognised leaders in digital disaster governance. The findings demonstrate that countries characterised by advanced digital infrastructure, interoperable information systems, institutional readiness, and adaptive governance consistently achieve superior performance in disaster monitoring, vulnerability assessment, multi-hazard early warning, and emergency coordination. Conversely, fragmented governance structures, limited digital interoperability, inadequate institutional capacity, and constrained technological investment continue to impede the effective adoption of intelligent disaster information systems across many developing countries. The study therefore concludes that disaster resilience depends not on the adoption of isolated digital technologies but on their integration within coherent

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governance architectures that support evidence-based decision-making and institutional collaboration.

The study further concludes that existing theoretical perspectives, namely the Information Systems Success Model (ISSM), the Technology–Organisation–Environment (TOE) Framework, and the Diffusion of Innovation (DOI) Theory, provide important but incomplete explanations of AI-driven disaster information management when considered independently. By integrating these complementary theories, the study developed and conceptually validated the Framework, which positions artificial intelligence, geospatial intelligence, predictive analytics, Internet of Things technologies, digital interoperability, institutional readiness, and adaptive governance as mutually reinforcing determinants of resilient disaster information management. The framework therefore represents a significant theoretical contribution by providing a comprehensive governance architecture that explains the interaction between technological capability, organisational preparedness, and adaptive public administration.

From a practical perspective, the study provides policymakers, disaster management agencies, and development partners with an evidence-based framework for guiding digital transformation in disaster risk management. The findings underscore the importance of strengthening institutional capacity, promoting interoperable information systems, investing in intelligent digital infrastructure, and enhancing collaborative governance to improve disaster preparedness and resilience. Accordingly, the Framework offers a practical roadmap for developing integrated, adaptive, and sustainable disaster information management systems capable of supporting climate resilience and informed decision-making across Africa and other disaster-prone developing regions.

RECOMMENDATIONS

Governments, particularly within Africa, should prioritise the development of integrated national disaster information management systems that combine artificial intelligence, geospatial intelligence, predictive analytics, Internet of Things (IoT) technologies, and interoperable digital platforms. Rather than implementing isolated technological solutions, countries should adopt comprehensive digital governance architectures capable of supporting real-time information sharing, coordinated emergency response, and evidence-based disaster decision-making.

National governments should strengthen institutional readiness by investing in digital infrastructure, skilled human resources, organisational learning, and leadership development within disaster management institutions. Continuous professional training in artificial intelligence, data analytics, geospatial technologies, cybersecurity, and digital governance should be institutionalised to enhance organisational capacity and ensure the sustainable implementation of intelligent disaster information systems.

Governments should establish interoperable disaster information platforms supported by harmonised data standards, integrated databases, and coordinated information-sharing protocols across meteorological agencies, emergency management organisations, environmental authorities, local governments, humanitarian agencies, and research institutions. Such interoperability will improve situational awareness, reduce duplication of effort, and strengthen multi-agency disaster coordination.

Policymakers should develop comprehensive legal, regulatory, and ethical frameworks governing the application of artificial intelligence in disaster management. These frameworks should address data governance, cybersecurity, privacy protection, algorithmic transparency, accountability, and ethical decision-making to ensure that intelligent technologies are implemented responsibly while maintaining public trust and institutional accountability.

Regional organisations, including the African Union and the Southern African Development Community (SADC), should strengthen regional cooperation by promoting harmonised digital disaster governance policies, cross-border information sharing, integrated early warning systems, and collaborative technology development. Regional cooperation will enhance preparedness for transboundary hazards such as cyclones, floods, droughts, pandemics, and wildfires that frequently affect multiple countries simultaneously.

Development partners and funding agencies should expand investment in digital disaster resilience programmes that support the acquisition of intelligent technologies while simultaneously strengthening institutional capacity, governance systems, and long-term sustainability. Funding priorities should extend beyond technological infrastructure to include organisational development, policy implementation, workforce capacity building, and digital innovation ecosystems.

Finally, disaster management agencies should adopt and progressively operationalise the Technology-Enabled Adaptive Knowledge Architecture for Humanitarian Governance Framework as a strategic guide for digital transformation. The framework provides an integrated governance model that aligns technological innovation with institutional readiness, digital interoperability, adaptive governance, and collaborative information management, thereby strengthening disaster preparedness, vulnerability assessment, emergency response, and long-term resilience.

AREAS FOR FURTHER RESEARCH

This study developed and conceptually validated the Technology-Enabled Adaptive Knowledge Architecture for Humanitarian Governance Framework using comparative document analysis. Future studies should undertake empirical validation of the framework through quantitative, qualitative, or mixed-methods research involving disaster management institutions in Africa and other disaster-prone regions. Such studies could examine the causal relationships

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between artificial intelligence capability, geospatial intelligence, predictive analytics, digital interoperability, institutional readiness, adaptive governance, and disaster management performance using structural equation modelling, regression analysis, or longitudinal case study approaches. Empirical validation would strengthen the generalisability and practical applicability of the framework across different institutional and geographical contexts.

Future research should also investigate emerging dimensions of digital disaster governance that were beyond the scope of this study. These include ethical artificial intelligence, explainable AI, cybersecurity in disaster information systems, digital twins, blockchain-enabled emergency management, autonomous disaster response technologies, and citizen-generated data for disaster risk reduction. Comparative studies across additional regions, including Asia, Europe, and Latin America, would further enhance understanding of contextual factors influencing digital transformation in disaster management and contribute to the continued refinement of the Framework as an international model for resilient and adaptive disaster information management.

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