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SCOPING REVIEW: ARTIFICIAL INTELLIGENCE IN RISK MANAGEMENT AND NATURAL DISASTERS

REVISIÓN DE ALCANCE: INTELIGENCIA ARTIFICIAL EN LA GESTIÓN DE RIESGOS Y DESASTRES NATURALES

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ABSTRACT

In recent years, natural disasters such as floods, earthquakes, wildfires, and hurricanes have had devastating impacts on human life and infrastructure. These events have intensified due to climate change and uncontrolled urbanization, highlighting the need for effective tools to manage them and mitigate their consequences. Traditional methods are often insufficient due to limitations in accuracy, response speed, and adaptability to different scenarios. Artificial Intelligence (AI) is currently a key and innovative solution for risk and disaster management, enhancing prediction, prevention, and response to such events. The objective of this scoping review is to map and analyze studies on AI applications published between 2019 and 2024 in this field through a systematic search in the Scopus database. The most commonly used techniques include neural networks and machine learning. These technologies have proven effective in improving decision-making accuracy and response speed in critical situations. However, significant challenges remain, such as limited access to high-quality data, biases in AI models, and technological barriers in resource-limited regions. Therefore, more inclusive, robust, and adaptable models are required to maximize AI's positive impact on disaster management. This review not only identifies the most relevant innovations but also highlights future research directions to optimize the use of these technologies in various risk scenarios.

Keywords: Risk Management, Natural Disasters, Artificial Intelligence (AI), Risk Reduction, Disaster Mitigation

RESUMEN

En los últimos años, los desastres naturales como inundaciones, terremotos, incendios forestales y huracanes han tenido impactos devastadores en la vida humana e infraestructura. Estos se han intensificado debido al cambio climático y urbanización descontrolada, lo que resalta la necesidad de herramientas efectivas para su gestión y mitigar así sus consecuencias. Los métodos tradicionales suelen ser insuficientes por limitaciones en precisión, velocidad de respuesta y adaptabilidad a distintos escenarios. La Inteligencia Artificial (IA) actualmente es una solución clave e innovadora para la gestión de riesgos y desastres, para la predicción, prevención y respuesta ante estos eventos. El objetivo de esta revisión de alcance es mapear y analizar los trabajos acerca de aplicaciones de la IA publicados durante 2019 y 2024 en este ámbito mediante una búsqueda sistemática en la base de datos Scopus. Las técnicas más utilizadas incluyen redes neuronales y aprendizaje automático. Estas tecnologías han demostrado su efectividad, mejorando la precisión y velocidad en la toma de decisiones en situaciones críticas. Sin embargo, aún hay desafíos importantes, como el acceso limitado a datos de calidad, sesgos en los modelos de IA y barreras tecnológicas en regiones con menos recursos. Entonces, se requieren modelos más inclusivos, robustos y adaptables que maximicen el impacto positivo de la IA en la gestión de desastres. Esta revisión no solo identifica las innovaciones más relevantes, sino que también destaca futuras líneas de investigación para optimizar el uso de estas tecnologías en distintos escenarios de riesgo.

Palabras clave: Gestión de Riesgos, Desastres Naturales, Inteligencia Artificial (IA), Reducción de Riesgos, Mitigación de Desastres.

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1. INTRODUCTION

The increasing frequency and intensity of natural disasters, driven by climate change and uncontrolled urbanization, have created an urgent need for advanced tools to manage risks and mitigate the impacts of these adverse events (Brauch, H. G., 2003). According to the United Nations Office for Disaster Risk Reduction (UNDRR), the number of climate-related disasters has nearly doubled over the past two decades, affecting millions of people worldwide. These disasters, including floods, hurricanes, wildfires, and earthquakes, have caused extensive economic losses and disrupted infrastructure on a global scale. Traditional disaster management methods often lack the speed, precision, and adaptability required to effectively respond to these events, necessitating the integration of more advanced technologies such as Artificial Intelligence (AI).

1.1. Artificial Intelligence as a Key Tool in Disaster Management

AI has emerged as a transformative tool in disaster risk management, offering innovative solutions that enhance disaster prediction, prevention, response, and recovery. The ability of AI-driven models to process large volumes of real-time data has significantly improved early warning systems, making it possible to detect and anticipate disasters with greater accuracy. For instance, AI-based machine learning algorithms have been successfully applied to forecast floods (Liang et al., 2024), predict wildfire spread patterns (Panfilova et al., 2024), and assess earthquake vulnerability in urban areas (Rai et al., 2024). These applications demonstrate how AI can reduce uncertainty and improve decision-making for emergency response teams and policymakers.

1.2. Research Justification and Scope

Given the growing importance of AI in disaster management, this scoping review aims to map and analyze current AI applications in this field, focusing on studies published between 2019 and 2024. This study seeks to identify key trends, evaluate the most effective AI techniques, and highlight the challenges that must be addressed to maximize AI's impact on disaster risk reduction. The findings will contribute to a broader understanding of AI's potential in enhancing disaster preparedness and response strategies worldwide.

1.3. Research Questions

This study seeks to answer the following research questions:

- **What are the main areas of application of Artificial Intelligence in risk and disaster management over the past five years?**
- **Which specific AI techniques have proven to be the most effective in predicting, preventing, and responding to natural disasters?**

These questions will guide the literature review, helping to map the key contributions of AI in disaster risk management, identify the most commonly used methodologies, and highlight areas that require further research.

2. BACKGROUND

This section provides an overview of key concepts related to natural disasters, the impact of climate change, and the role of Artificial Intelligence in optimizing disaster risk management.

2.1. Natural Disasters

Natural disasters, including earthquakes, floods, cyclones, storms, wildfires, volcanic eruptions, and landslides, have shaped the Earth's landscape for millennia. However, when these events interact with human infrastructure—such as housing, agriculture, and urban areas—they result in severe socio- economic consequences, leading to significant loss of life and property damage (Chaudhary & Piracha, 2021).

2.2. Effects of Climate Change on Natural Disasters

The interaction between climate change and natural disasters has intensified, particularly in urban areas with significant land use changes (Van Aalst, 2006). Nguyen et al. (2024) investigated how alterations in land cover and climate patterns influence flood vulnerability, emphasizing the need for mitigation strategies that integrate environmental and social data.

2.3. Artificial Intelligence for Optimizing Disaster Risk Management

Advancements in technological tools have played a crucial role in improving disaster management strategies (Khan et al., 2023). Duraisamy and Natarajan (2024) propose advanced optimization techniques integrating AI and machine learning

algorithms to enhance resource allocation during emergencies. This approach has proven effective in high-complexity scenarios, allowing better decision-making prioritization.

2.4. Identification and Management of Natural Risks

In recent years, innovative methodologies have emerged for identifying and managing natural risks, significantly improving precision and effectiveness in disaster prevention and mitigation. For instance, Wan et al. (2024) developed a novel approach to detect landslide-prone areas using satellite imagery, multispectral analysis, and deep learning models, enhancing risk assessment in vulnerable zones.

The combined impact of climate change and urbanization has increased cities' vulnerability to flooding disasters. In this context, Panfilova et al. (2024) utilized neural networks to map urban areas at risk, underscoring the importance of focusing mitigation efforts on critical infrastructure and vulnerable communities. Similarly, Hanashima et al. (2024) designed dynamic decision-support systems to manage extreme disasters such as cyclones and floods. These systems integrate historical and real-time data, enabling emergency responders to prioritize actions and optimize resources in high-uncertainty scenarios.

Moreover, AI-driven decision-support systems have revolutionized disaster response. Suarez et al. (2024) developed an integrated system combining real-time data with predictive analytics, providing decision-makers with alternative scenarios to enhance resource allocation strategies efficiently.

Seismic risk assessment remains a critical challenge. Bektaş and Kegyes-Brassai (2024) implemented advanced AI models to simulate the impact of seismic events on infrastructure, using machine learning to develop structural reinforcement solutions and improve risk management. Similarly, Rai et al. (2024) explored the integration of multi-criteria decision-making methods with machine learning techniques to evaluate seismic risk, enabling more strategic and precise urban planning in vulnerable areas.

3. MATERIALS AND METHODS

This study follows a scoping review approach, a type of systematic review aimed at mapping key concepts, identifying research gaps, and synthesizing relevant studies within an emerging field (Munn et al., 2018). This methodology is particularly suitable for analyzing the application of Artificial Intelligence (AI) in issues and disaster risk management, an area undergoing rapid technological advancements and diversification.

3.1. PRISMA-ScR Framework

To ensure transparency and methodological rigor, this review follows the PRISMA-ScR (Preferred Reporting Items for Systematic Reviews and Meta-Analyses for Scoping Reviews) framework, which structures each stage of the process, from defining research questions to synthesizing and presenting results (Tricco et al., 2018).

3.2. PCC Framework

Additionally, the PCC (Population, Concept, Context) model is employed to define the study parameters, ensuring a structured and focused review (Peters et al., 2020):

- **Population:** AI applications in disaster risk management, including prediction, prevention, and response strategies for events such as floods, earthquakes, hurricanes, and wildfires.
- **Concept:** AI techniques, such as machine learning, neural networks, and early warning systems, used to enhance disaster risk assessment and response.
- **Context:** Studies published between 2019 and 2024, focusing on global disaster scenarios, particularly those affected by climate change, urbanization, and technological limitations.

3.3. Search Strategy

The literature search was conducted in the Scopus database due to its comprehensive coverage of scientific and technological publications (Schotten et al., 2017). The search query included key AI and disaster management terms:

(TITLE-ABS-KEY(("artificial intelligence" OR "machine learning" OR "deep learning" OR "neural networks") AND ("disaster management" OR "risk management" OR "disaster response" OR "hazard mitigation" OR "emergency response" OR "disaster preparedness") AND ("floods" OR "earthquakes" OR "wildfires" OR "hurricanes" OR "landslides")) AND (TITLE-ABS-KEY("early warning systems" OR "disaster prediction" OR "risk assessment")) AND PUBYEAR > 2018) AND

(LANGUAGE("English"))

3.4. Inclusion and Exclusion Criteria

To refine the selection of studies, inclusion and exclusion criteria were established:

3.4.1. Inclusion Criteria

- Studies analyzing AI applications in disaster risk management.
- Research focusing on early warning systems, disaster prediction, or risk assessment.
- Articles published between 2019 and 2024 in peer-reviewed scientific journals.
- Papers written in English to ensure accessibility and consistency in the analysis.

3.4.2. Exclusion Criteria

- Studies unrelated to AI applications in disaster risk management.
- Research not employing AI-based techniques such as machine learning or neural networks.
- Studies focused on disasters outside the defined scope (e.g., pandemics, snowstorms).
- Conference abstracts, editorials, opinion articles, and unpublished theses.

3.5. Data Analysis

The selected studies were analyzed based on key variables, including:

- **AI techniques applied** (e.g., machine learning, deep learning, neural networks).
- **Disaster type** (e.g., floods, earthquakes, wildfires).
- **Primary area of impact** (e.g., prediction, prevention, response, or recovery).

The results were synthesized into tables and visual representations to identify trends, innovations, and gaps in the literature. Graphs highlight the distribution of AI applications across different disaster types and management phases, while a PRISMA-ScR flow diagram illustrates the study selection process.

This study followed the PRISMA-ScR (Preferred Reporting Items for Systematic Reviews and Meta- Analyses for Scoping Reviews) framework to ensure methodological transparency and rigor.

The selection process for relevant studies is illustrated in Figure 1, which summarizes the identification, screening, and inclusion steps.

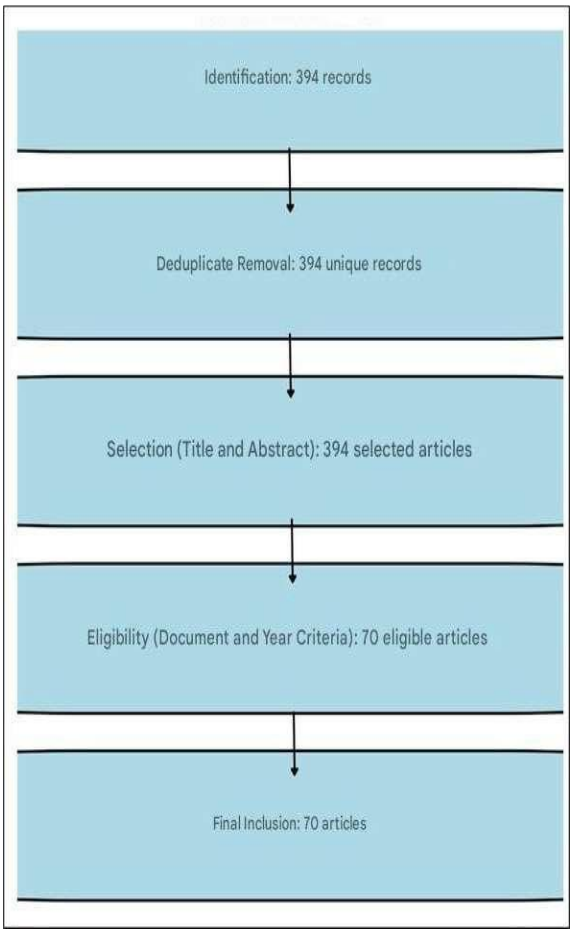

Figure 1. PRISMA-SCR Diagram

4. RESULTS AND DISCUSSION

This section presents the key findings of the scoping review, highlighting the main AI techniques used in disaster risk management, their application areas, and the challenges associated with their implementation.

4.1. AI Techniques Applied in Disaster Risk Management

The review identified neural networks, machine learning, and deep learning as the most commonly used AI techniques in disaster risk management. Figure 2 illustrates the distribution of AI techniques across the analyzed studies.

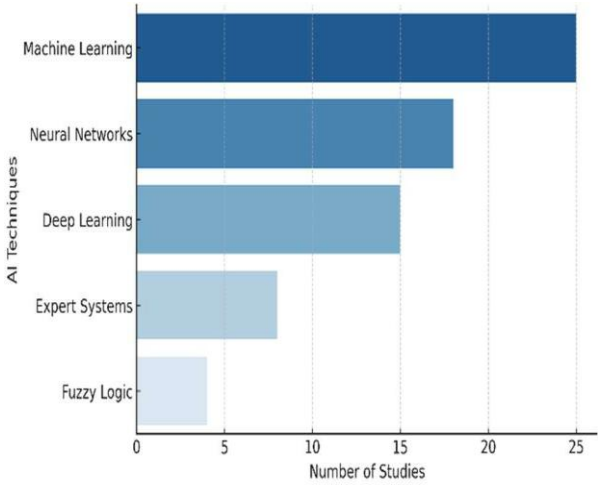

Figure 2. AI Techniques Applied in Disaster Risk Management

This figure shows that Machine Learning is the most widely used approach, followed by Neural Networks and Deep Learning. These techniques have proven effective in prediction and response phases of disaster management (Liang et al., 2024).

Additionally, the interest in AI applications in disaster risk management has significantly increased over the last five years. Figure 3 presents the trend in the number of publications related to this topic.

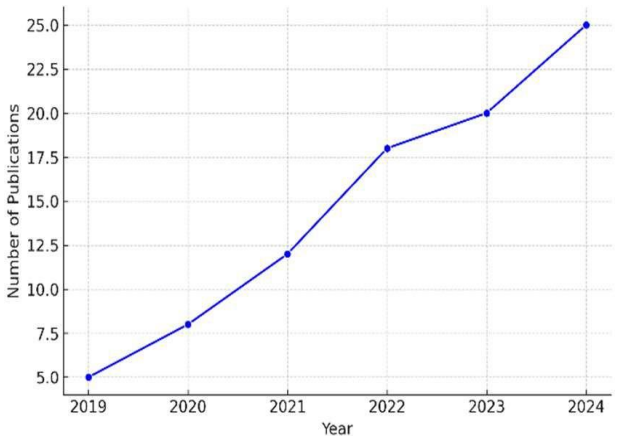

Figure 3. Trends in AI-Based Disaster Management Research (2019-2024)

This figure highlights a steady increase in AI-based disaster management research. From 5 publications in 2019 to 25 in 2024, reflecting the growing relevance of AI in disaster prevention and response strategies.

4.2. Main Areas of Application

AI has been integrated into four key areas of disaster risk management:

1. **Prevention:** AI-driven risk maps and predictive modeling improve early disaster preparedness.
2. **Prediction:** Neural networks enhance hazard forecasting for floods, wildfires, and earthquakes (Rai et al., 2024).
3. **Response:** AI-powered decision-support systems optimize emergency logistics and resource distribution (Suarez et al., 2024).
4. **Recovery:** AI-based damage assessment tools support post-disaster reconstruction efforts (Bektaş & Kegyes-Brassai, 2024).

Table 1. AI Applications in Disaster Management

Disaster Management Phase	Key AI Techniques	Example Studies
Prevention	Risk Mapping, Predictive Modeling	Liang et al. (2024)
Prediction	Neural Networks, Hazard Forecasting	Rai et al. (2024)
Response	Decision-Support Systems, Resource Optimization	Suarez et al. (2024)
Recovery	Damage Assessment, Reconstruction Planning	Bektaş & Kegyes-Brassai (2024)

Figure 4 further illustrates the distribution of AI applications across these four management phases.

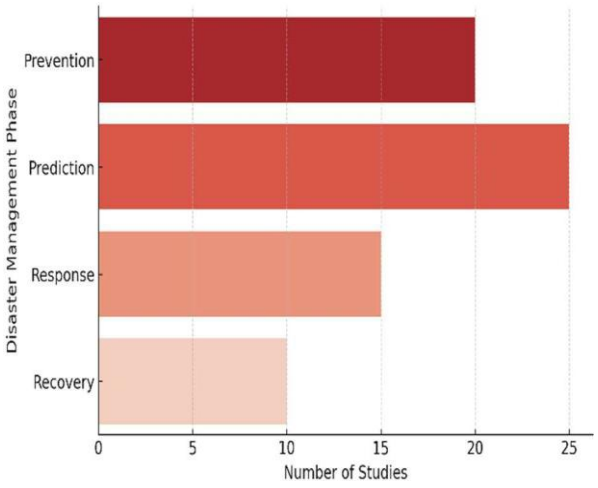

Figure 4. AI Applications Across Disaster Management Phases

This figure shows that Prediction and Prevention have received the highest attention, as early detection and preparedness significantly reduce disaster impacts.

AI models' effectiveness depends on their accuracy. Figure 5 compares the accuracy of different AI techniques used in disaster management.

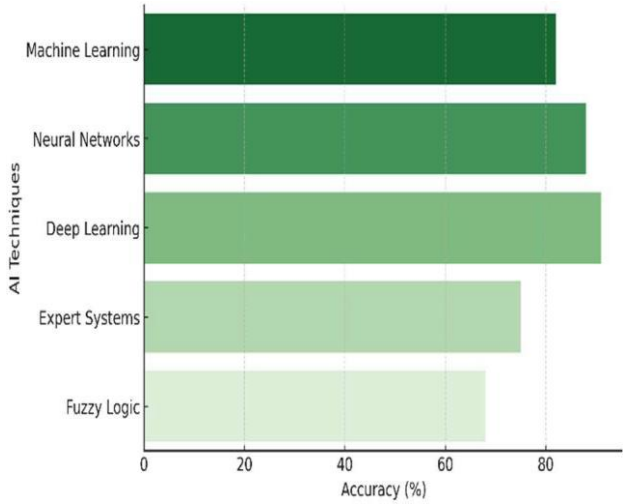

Figure 5. Accuracy of AI Models in Disaster Risk Management

This figure shows that Deep Learning (91%) and Neural Networks (88%) provide the highest accuracy, while Fuzzy Logic exhibits lower performance.

4.3. Challenges and Limitations

Despite its potential, AI implementation in disaster risk management faces several challenges:

- **Data Limitations:** Incomplete or low-quality datasets affect model accuracy.
- **Bias in AI Models:** Disproportionate training data leads to skewed predictions, impacting decision-making (Chen et al., 2021).
- **Technological Barriers:** Developing countries face infrastructure constraints, limiting AI adoption (Nguyen et al., 2024).
- **Legal and Ethical Issues:** Data privacy and accountability in AI-driven decision-making remain concerns (Van Aalst, 2006).

Figure 6 highlights the most frequently reported challenges, with data limitations and AI bias being the most critical barriers.

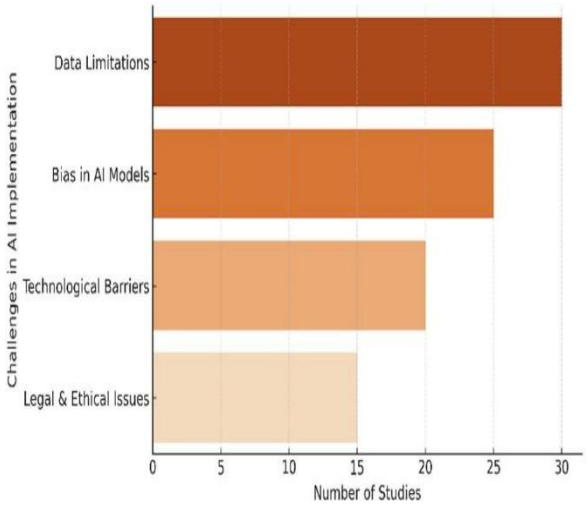

Figure 6. Challenges in AI-Based Disaster Management

4.4. Future Research Directions

To optimize AI's role in disaster management, future research should focus on:

- **Developing More Inclusive AI Models:** Reducing biases by integrating diverse datasets.
- **Enhancing Real-Time Data Processing:** Improving satellite image analysis and early warning systems.
- **Increasing AI Accessibility in Developing Regions:** Implementing cost-effective AI solutions for disaster-prone areas.
- **Strengthening AI-Governance Policies:** Establishing ethical guidelines for AI-driven decision-making.

By addressing these areas, AI can become a more effective tool in mitigating the impact of natural disasters.

The incorporation of sophisticated technologies, including artificial intelligence and robotics, is imperative for the successful execution of space mining efforts, as it improves operational efficiency and profitability. The establishment of regulatory frameworks and legal guidelines is vital to overseeing space mining efforts and ensuring compliance with international standards, thereby fostering responsible resource management. The implementation of sustainable methodologies in space mining is essential to alleviate environmental impacts and safeguard extraterrestrial ecosystems, in line with global initiatives aimed at promoting environmental management and conservatThe convergence of space mining, artificial intelligence, robotics, and

sustainability offers a promising trajectory for future exploration and utilization of resources beyond our planet, as nations such as Chile strategically position themselves as critical contributors in this dynamic industry.

5. CONCLUSIONS

Artificial Intelligence (AI) has emerged as a transformative tool in disaster risk management, offering innovative solutions to enhance prevention, prediction, response, and recovery strategies. This scoping review analyzed the most recent applications of AI in this field, identifying the key techniques, their areas of impact, and the challenges that must be addressed for broader implementation.

The findings highlight that Machine Learning, Neural Networks, and Deep Learning are the most widely used AI approaches. These techniques have demonstrated high effectiveness in forecasting hazards, optimizing emergency response systems, and improving post-disaster damage assessment. Moreover, the increasing number of publications on AI in disaster management (Figure 5) confirms the growing academic and practical interest in leveraging AI- driven solutions.

Despite these advancements, challenges remain. The review identified four main barriers to AI implementation:

1. **Data Limitations**, due to incomplete or unreliable datasets
2. **Bias in AI Models**, which affects the accuracy and fairness of predictions.
3. **Technological Barriers**, especially in developing regions with limited resources.
4. **Legal and Ethical Issues**, related todata privacy and decision-making accountability (Figure 4).

To maximize the impact of AI in disaster risk management, future research should focus on developing more inclusive models, improving real- time data processing, increasing AI accessibility, and establishing regulatory frameworks for responsible AI governance.

In conclusion, AI has the potential to revolutionize disaster risk management, significantly reducing human and economic losses. However, continued research, interdisciplinary collaboration, and responsible AI implementation are crucial to overcoming current limitations and ensuring sustainable disaster management solutions.

5.1. Final Remarks & Limitations of the Study

This study provides a broad overview of AI applications in disaster risk management, highlighting trends, challenges, and future directions. As technology evolves, integrating AI with other advanced tools— such as IoT, remote sensing, and big data analytics—will be essential for creating more adaptive and resilient disaster management systems.

While this scoping review provides valuable insights, it is subject to certain limitations:

- The study is based on publications from the Scopus database only, potentially excluding relevant studies from other sources.
- It focuses on articles published between 2019 and 2024, meaning earlier foundational research was not analyzed.
- The research primarily considers peer-reviewed journal articles, excluding conference papers, government reports, and industry case studies that may provide additional perspectives.

Future studies should aim for a more extensive dataset, including interdisciplinary sources and real- world case studies, to further validate AI's role in disaster management.

This research contributes to the growing body of knowledge on AI-based disaster risk management, offering insights for researchers, policymakers, and practitioners. As AI continues to evolve, its integration into disaster preparedness and response strategies will be essential for mitigating the increasing risks posed by climate change and urbanization

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