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NARRATIVE REVIEW

Applications of Artificial Intelligence in Disaster Risk Reduction Management in Flood: A Narrative Review

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ABSTRACT

Introduction: Floods are among the most frequent and destructive natural disasters globally, exacerbated by climate change, urbanization, and population growth in high-risk areas. The increasing complexity of flood events has intensified the demand for innovative technologies to enhance Disaster Risk Reduction (DRR). This study aims to review the applications of Artificial Intelligence (AI) in flood-related DRR management.

Materials and Methods: A narrative review was conducted following PRISMA guidelines. A comprehensive literature search was performed on July 16, 2025, across Scopus, Web of Science, PubMed, and Google Scholar. Then, keyword combinations targeting AI and flood management were applied to titles, abstracts, and keywords of peer-reviewed articles published between 2015 and 2025. Studies were included if they presented empirical data or technical modeling focused on AI applications in flood risk reduction.

Results: 20 eligible studies revealed diverse AI applications across four key phases: flood prediction, preparedness, emergency response, and post-disaster recovery. Techniques such as machine learning, deep learning, and reinforcement learning improved forecasting accuracy, resource allocation, and damage assessment. However, challenges including data scarcity, model bias, ethical concerns, and limited infrastructure were consistently reported, particularly in vulnerable regions.

Conclusion: AI holds significant promise for enhancing flood DRR, but its implementation requires inclusive design, standardized evaluation frameworks, and stronger community engagement. Future research should prioritize interdisciplinary collaboration to ensure that AI tools are not only technically robust but also socially equitable and contextually relevant.

Keywords: Artificial Intelligence; Disaster; Risk Reduction; Floods

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Introduction

Floods are among the most frequent and devastating natural disasters worldwide, affecting millions of people annually and causing extensive damage to infrastructure, natural resources, and human communities (1, 2). Climate change, rapid population growth, and urban expansion in high-risk areas have increased the likelihood of more severe and complex flood events. In this context, the need for innovative tools to support flood prediction, preparedness, response, and recovery has become more urgent than ever (3).

In recent years, artificial intelligence (AI) has emerged as a transformative technology in the field of disaster risk reduction (DRR) (4). By leveraging machine learning algorithms, deep learning, natural language processing, and computer vision, AI can analyze large and complex datasets, identify hidden patterns, and generate optimized decisions in real time (5). These capabilities make AI a powerful tool for flood management, particularly in areas such as flood forecasting, early warning system design, emergency resource allocation, damage assessment, and public education.

However, the use of AI in flood management is not without challenges (6). Issues such as data quality and accessibility, high computational costs, false alarms, and ethical concerns related to automated decision-making must be carefully considered (7). Moreover, many countries still lack the technical and institutional infrastructure needed to implement AI effectively in disaster contexts (8).

Although numerous studies have explored the applications of AI in flood management, most are scattered and lack a cohesive analytical framework (1, 3-9). Therefore, a comprehensive and critical narrative review is needed to consolidate existing findings and evaluate the strengths, weaknesses, opportunities, and threats associated with AI in flood-related DRR. This paper aims to address that need by reviewing and analyzing recent research in the field and proposing a conceptual framework to guide future studies.

Materials and Methods

This study employed a narrative review approach to analyze the applications of AI in flood-related DRR. To enhance transparency and ensure reproducibility, the review process was designed and executed following the PRISMA guidelines. The literature search was conducted on July 16, 2025, across four prominent academic databases: Scopus, Web of Science, PubMed, and Google Scholar. The search strategy used Boolean operators (AND/OR) to combine terms related to artificial intelligence, floods, and disaster risk reduction. The main search strategy was structured as follows: ("Artificial Intelligence" OR "AI" OR "Machine Learning" OR "Deep Learning" OR "Neural Network" OR "Reinforcement Learning") AND (Flood* OR "Flood Risk" OR "Flood Management" OR "Flood Prediction" OR "Flash Flood*") AND ("Disaster Risk Reduction" OR "Disaster Management" OR "Emergency Response" OR Preparedness OR Recovery OR "Early Warning"). The search strategy was adapted to the syntax of each database*.

Studies were included if they were peer-reviewed journal articles focusing directly on the application of AI techniques in managing flood risks, presenting empirical data, technical modeling, or detailed analysis, and published in English. Exclusion criteria were set to remove review articles lacking critical analysis, theoretical papers without practical applications, non-peer-reviewed sources such as news reports or opinion pieces, and research addressing disasters other than floods unless directly related to flood management. Because this study was designed as a narrative review rather than a systematic review, a formal risk-of-bias assessment using standardized systematic review tools was not performed. Instead, study selection was guided by predefined inclusion and exclusion criteria, including peer-reviewed publication status, direct relevance to AI applications in flood risk management, presentation of empirical data, technical modeling, or detailed analysis, and publication in English. Studies were excluded if they were unrelated to flood management, lacked practical AI applications, were non-peer-reviewed sources,

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were theoretical studies without practical application, or addressed other disasters without a direct connection to flood management.

Initially, 312 articles were identified through database searching. After removing duplicates, 278 unique records remained. Screening of titles and abstracts led to 87 articles being selected for full-text review. Following thorough evaluation against inclusion criteria, 20 articles were finally included in the analysis. A PRISMA flow diagram illustrating the study selection process is provided in Figure 1.

Data extracted from the selected studies were thematically organized according to AI application areas such as flood prediction, emergency resource allocation, and post-disaster damage assessment. For each thematic category, the employed AI methods reported advantages, limitations, and evidence quality were synthesized and compared. Contradictions and knowledge gaps identified across studies were also critically examined to provide a comprehensive understanding of current strengths and weaknesses in the field. This structured approach allowed for an informed and balanced analysis of AI's role in flood disaster risk reduction.

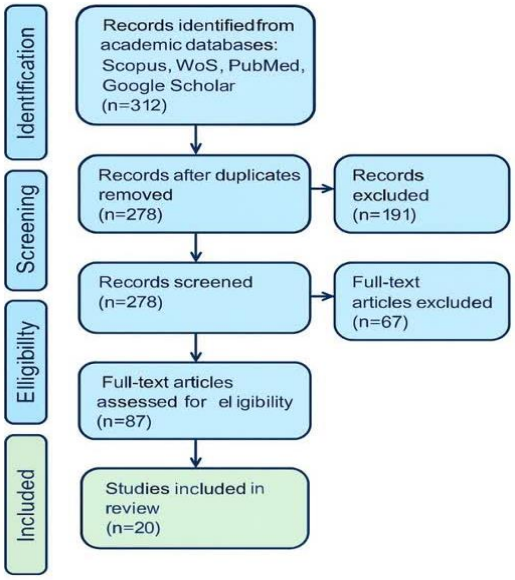


Figure 1. The process of selecting resources

Results

The final set of 20 peer-reviewed articles included in this review revealed a diverse range of AI applications across the four main phases of flood disaster risk reduction: prediction, preparedness, emergency response, and post-disaster recovery. Community engagement was considered as a cross-cutting component relevant to these phases.

-Flood prediction and arly warning systems

Flood prediction emerged as the most extensively studied application of AI (10). Machine learning models such as support vector machines (SVM), random forests, and artificial neural networks (ANN) were frequently employed to forecast flood events using historical rainfall data, river discharge levels, and satellite imagery (11). Deep learning approaches, particularly convolutional neural networks (CNNs) demonstrated superior performance in spatial pattern recognition and image-based flood mapping (12).

While most studies reported improved accuracy and lead time compared to traditional hydrological models, several limitations were noted (13). Many models relied on high-resolution datasets that were not readily available in low-resource settings, leading to reduced generalizability. Additionally, model bias was observed in regions with uneven data distribution, and false alarms were reported in cases where models overfit to local anomalies (14).

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Only a few studies validated their models across multiple geographic contexts, highlighting a gap in cross-regional applicability (15).

-Resource allocation and emergency response

AI-based decision support systems were applied to optimize resource allocation during flood emergencies (16). Moreover, reinforcement learning algorithms and multi-agent simulations were used to model evacuation strategies, prioritize rescue operations, and allocate medical supplies (17). These systems showed promise in reducing response time and improving coordination among agencies (18).

However, the evidence base remains limited. Most studies were simulation-based and lacked real-world deployment data (19). Ethical concerns were raised regarding automated decision-making in life-threatening scenarios, particularly when algorithms lacked transparency or failed to incorporate human judgment. Furthermore, the computational complexity of some models posed challenges for real-time use in disaster settings with limited infrastructure (20).

-Damage assessment and post-flood recovery

AI techniques were also used for post-disaster damage assessment, primarily through image classification and remote sensing (21). Unsupervised learning models and clustering algorithms helped identify flood-affected zones and estimate damage severity. These tools enabled rapid mapping of impacted areas, supporting insurance claims and reconstruction planning (22).

Despite their efficiency, these models faced challenges in image quality, especially in cloud-covered or low-light conditions. The lack of standardized validation protocols across studies made it difficult to compare performance (23). Moreover, few studies addressed the integration of AI outputs into official recovery workflows, limiting their practical impact (24).

-Community engagement and risk communication

A smaller subset of studies explored AI's role in public education and risk communication. Chatbots, predictive dashboards, and mobile applications were developed to disseminate flood warnings and safety instructions (25). While these tools improved outreach, their effectiveness depended heavily on digital literacy and access to technology, which varied significantly across regions (26).

Notably, community engagement was often treated as a secondary outcome rather than a core design principle (27). This oversight may reduce trust in AI systems and hinder adoption, especially in vulnerable populations (28).

This results section highlights both the potential and the limitations of AI in flood DRR. While technical advancements are evident, the lack of standardized evaluation, ethical frameworks, and inclusive design remains a barrier to widespread implementation (29).

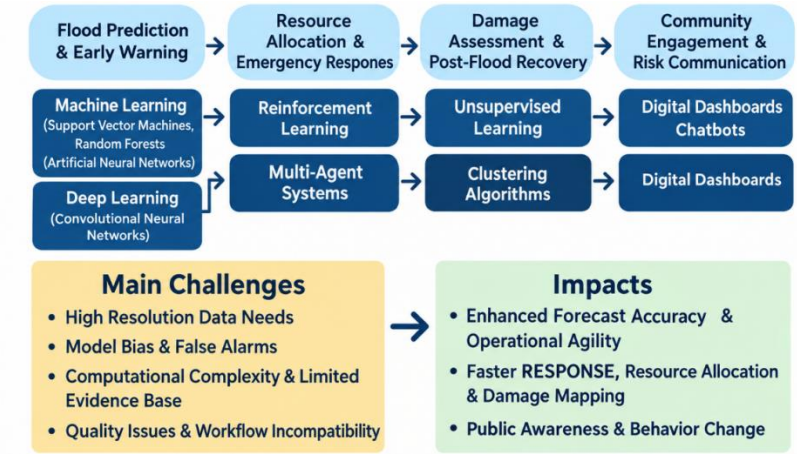


Figure 2. Model of AI Applications in Flood Disaster Risk Reduction

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Discussion

The findings of this review underscore the transformative potential of AI in flood DRR, while simultaneously revealing critical gaps that hinder its widespread and equitable implementation. Across the four phases of flood management prediction, preparedness, emergency response, and recovery AI technologies have demonstrated measurable improvements in accuracy, speed, and operational efficiency. However, these advancements are not uniformly distributed, and their effectiveness is often contingent on contextual factors such as data availability, infrastructure readiness, and institutional capacity.

One of the most salient observations is the dominance of technical performance metrics in the reviewed literature, often at the expense of social and ethical considerations (30). For example, while machine learning models have significantly enhanced flood forecasting capabilities, their reliance on high-resolution datasets limits their applicability in low-resource settings. This raises concerns about geographic bias and the potential exclusion of vulnerable populations from the benefits of AI-driven systems (31). Moreover, the lack of standardized evaluation frameworks across studies makes it difficult to compare model performance or establish best practices, thereby impeding knowledge transfer and scalability (32).

Ethical challenges were acknowledged but rarely explored in depth. Automated decision-making in emergency contexts such as evacuation planning or resource allocation introduces complex questions about accountability, transparency, and human oversight (33). The absence of clear ethical guidelines or participatory design processes may erode public trust, particularly in communities that have historically been marginalized or underserved (2). Notably, community engagement was often treated as a secondary outcome rather than a foundational design principle. This oversight risks reinforcing existing inequalities and undermines the legitimacy of AI interventions in disaster contexts (34).

Another limitation was the disconnect between technical innovation and policy integration (35). Few studies addressed how AI outputs are incorporated into official disaster management protocols or how stakeholders such as local governments, NGOs, and affected communities interact with these systems. Without deliberate efforts to bridge this gap, AI tools may remain confined to academic or pilot settings, failing to achieve meaningful impact on the ground (8).

Taken together, these findings suggest that future research should move beyond performance optimization and embrace a more holistic, interdisciplinary approach. This includes developing inclusive datasets, designing culturally sensitive interfaces, and embedding ethical safeguards into AI systems. Additionally, collaborative frameworks that involve end-users, policymakers, and technologists are essential to ensure that AI applications are not only technically sound but also socially responsible and contextually relevant.

Conclusion

AI has shown remarkable potential in enhancing flood disaster risk reduction across multiple phases, from early prediction to post-disaster recovery. Techniques such as machine learning, deep learning, and reinforcement learning have improved forecasting accuracy, optimized emergency resource allocation, and accelerated damage assessment. However, challenges including data scarcity, model bias, ethical concerns, and limited infrastructure continue to hinder widespread adoption, especially in vulnerable regions. To ensure equitable and effective implementation, future research must prioritize inclusive design, standardized evaluation frameworks, and stronger community engagement.

Authors' Contributions

A.M and P.E designed research and conducted research; P.E analyzed data; A.M wrote the manuscript. All authors read and approved the final manuscript.

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Competing Interests
The authors declare no competing interests.

Data Availability Statement
All data generated or analyzed during this study are included in this published article and its supplementary information, where applicable.

Ethical Considerations
This article was based on the analysis of published sources, with full adherence to academic integrity and intellectual property rights. As no direct human data collection was involved, ethical approval was not required; however, the study emphasizes the importance of ethical considerations in the design and application of AI in disaster management.

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Artificial Intelligence Use Disclosure Statement
The authors used artificial intelligence (AI) tools during the preparation of this manuscript for language and editorial refinement and for figure design. AI-assisted outputs were reviewed, revised, and validated by the authors, who take full responsibility for the accuracy, integrity, and final content of the manuscript.

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