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From Sensors to Society: Rethinking Disaster Early Warning Systems in the Age of AI

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ABSTRACT: Increased frequency and severity of natural disasters underscore the urgent need for effective early warning systems (EWS) as a key component of disaster risk management. This narrative review explores the technological, social, and policy dimensions that shape EWS effectiveness, with a focus on the integration of artificial intelligence, Internet of Things, and satellite monitoring. A systematic literature search was conducted using Scopus, Google Scholar, and PubMed, employing Boolean operators to capture studies addressing technology, accessibility, and public trust. Findings reveal that while recent technological innovations have significantly improved hazard detection and response times, persistent barriers remain in terms of infrastructure quality, digital access, and institutional credibility, particularly in low-resource settings. The review highlights how national policies, such as those implemented in the United States, Philippines, and Ethiopia, contribute to more resilient EWS frameworks when aligned with local engagement and cross-sectoral collaboration. Community-based early warning models, education initiatives, and inclusive communication strategies emerge as critical success factors in enhancing public responsiveness and trust. The review concludes that effective EWS must extend beyond technical sophistication to incorporate social equity, participatory governance, and long-term adaptability. Future research should prioritize the exploration of digital inequality and the ethical application of advanced technologies. Integrating community trust and accessibility as core pillars is essential to build inclusive systems capable of protecting the most vulnerable from disaster risks.

Keywords: Disaster Risk Management, Early Warning Systems, Artificial Intelligence in EWS, Community Resilience, Digital Accessibility, Public Trust in Alerts, Climate Adaptation Technologies.

INTRODUCTION

In recent decades, the global frequency and severity of natural disasters have significantly increased, a trend attributed largely to climate change and environmental degradation. Data from empirical studies underscore this escalation, revealing a surge in both the number and intensity of events such as hurricanes, wildfires, floods, and landslides. For instance, Davlasheridze et al. (2017)

analyzed the economic implications of storm-related disasters and emphasized the importance of proactive adaptation measures, which have proven effective in reducing property damage. Similarly, Mani et al. (2024) highlighted the grave health impacts associated with wildfire exposure, noting elevated mortality and injury rates among affected populations. These findings reflect the intertwined relationship between environmental hazards and public health, as corroborated by Bahl et al. (2024), who found that increased disaster intensity exacerbates health risks.

Concurrent with the rise in disaster occurrences, public perception and responsiveness to early warning systems (EWS) have evolved. The shift in community behavior is particularly evident in areas with recurrent disaster exposure. Husna et al. (2021) emphasized that public understanding of local disaster risks is critical for effective preparedness. Complementing this, Purnomo et al. (2025) noted that regular preparedness drills and simulations significantly contribute to the sustainability of EWS. Moreover, Kuppuswamy (2014) identified the growing role of both traditional and digital media in disseminating warning messages, which has positively influenced community response rates. This transformation underscores the necessity of integrating communication strategies within disaster risk reduction frameworks.

Technological advancement has emerged as a cornerstone in the enhancement of disaster management practices. The deployment of sensor-based water monitoring systems, as documented by Lummen et al. (2016), has facilitated more timely flood alerts. In parallel, Ganapathy et al. (2023) emphasized the effectiveness of community-based warning mechanisms in empowering residents to respond proactively to landslide threats. These strategies align with findings by Wang et al. (2024), who advocated for increased public awareness and action-oriented preparedness as key components in building disaster-resilient communities.

Despite these advancements, significant challenges persist, especially in low-resource settings. The implementation of EWS in developing countries and disaster-prone regions often encounters systemic barriers, such as inadequate infrastructure and limited access to advanced technology. Moises et al. (2024) observed that local governments in many regions struggle to leverage external resources due to weak institutional frameworks. Furthermore, poor inter-agency coordination and information sharing frequently hamper the effectiveness of EWS, highlighting the need for more cohesive disaster governance.

Communication infrastructure is another critical area of concern. Many populations in developing countries lack access to modern communication tools, which significantly diminishes the effectiveness of early warning dissemination. This gap in communication channels often correlates with a lack of community knowledge about EWS, reducing their ability to respond effectively. As Husna et al. (2021) reiterated, community education and outreach are indispensable for fostering disaster readiness. Without sufficient awareness, even the most advanced warning technologies may fail to prompt timely action.

Technological mismatches also pose challenges. EWS technologies are sometimes deployed without adequate consideration of local contexts. Prasadana et al. (2024) described how flood monitoring systems that rely on integrated sensor networks can be beneficial, but their application is limited by the absence of necessary infrastructure in many areas. Additionally, insufficient community involvement during the development and implementation of EWS leads to low public trust and engagement, further undermining their effectiveness.

The issue of public trust in EWS represents a critical yet underexplored dimension in the literature. Trust in the institutions responsible for managing early warning systems significantly influences public compliance and responsiveness. Studies have shown that transparency in decision-making and the inclusion of local actors are key to building this trust. However, there is a paucity of comprehensive research that examines trust dynamics in EWS, particularly in socioeconomically vulnerable communities, where skepticism towards governmental institutions is often more pronounced.

Given these gaps, a systematic narrative review is essential to comprehensively assess the multifaceted components that determine the efficacy of early warning systems. This review aims to synthesize existing evidence on three critical dimensions: technological infrastructure, accessibility of information, and public trust in the system. By doing so, it seeks to evaluate how these factors intersect and influence disaster preparedness and response outcomes. As Sahana et al. (2023) and Lopez et al. (2017) suggested, a multidimensional understanding is crucial for developing EWS that are not only technically robust but also socially inclusive and contextually adaptive.

The scope of this review focuses primarily on the experiences and challenges of developing countries, where resource constraints and institutional limitations often hinder the effective implementation of EWS. Particular attention is given to vulnerable populations, including coastal and island communities, which are disproportionately affected by climate-induced hazards. For example, Sahana et al. (2023) documented the difficulties faced by residents of the Sundarban Biosphere Region in accessing and acting on early warnings during cyclonic events. Ganapathy et al. (2023) demonstrated the success of community-led EWS initiatives in landslide-prone regions, emphasizing the importance of localized solutions. Furthermore, research conducted in post-tsunami Aceh has shown the centrality of cultural and social contexts in shaping disaster response strategies (Husna et al., 2021).

Although various case studies have highlighted the significance of EWS in different geographic contexts, the broader applicability of these findings remains limited due to the scarcity of cross-regional analyses. Many existing studies are geographically and demographically narrow in scope, focusing on specific communities or hazard types. This restricts the generalizability of the insights and impedes the development of universally applicable frameworks. Moreover, technological inaccessibility and mistrust in institutional systems continue to be recurring themes in under-researched areas, indicating an urgent need for adaptive strategies that are responsive to local needs and realities (Adiwinoto et al., 2025; Ganapathy et al., 2023; Goniewicz & Burkle, 2019).

Overall, this narrative review is intended not only to summarize existing knowledge but also to stimulate scholarly discourse on the challenges and potential solutions for strengthening early warning systems across diverse contexts. It underscores the importance of addressing infrastructural limitations, enhancing communication channels, and building public trust to ensure that EWS can function effectively as tools for disaster risk reduction. Ultimately, the findings of this review aim to inform policymakers, practitioners, and researchers on best practices for implementing inclusive, reliable, and resilient early warning systems that are capable of safeguarding communities from the escalating threats posed by natural disasters.

METHOD

This narrative review adopts a systematic and structured approach to identifying, evaluating, and synthesizing scholarly literature that investigates the effectiveness of early warning systems (EWS) with a focus on technology, accessibility, and community trust. Given the interdisciplinary nature of disaster risk reduction, a comprehensive literature search was conducted using multiple academic databases to ensure the breadth and depth of relevant studies were captured. The primary databases utilized in this study include Scopus, Google Scholar, and PubMed, which are recognized for their extensive coverage of peer-reviewed academic literature across a wide range of disciplines, including disaster management, public health, environmental sciences, and information systems.

The literature search was conducted using a refined combination of keywords and Boolean operators to enhance specificity and relevance. Core keywords included "early warning systems," "disaster risk management," "technology," "accessibility," "community trust," and "preparedness." Boolean operators such as AND, OR, and NOT were employed to construct search strings that could target specific intersections of interest. For example, the query "early warning systems AND technology AND accessibility" was used to retrieve articles that examined both the technological aspects and the accessibility dimensions of EWS. Conversely, to exclude highly technical articles that lacked a social dimension, searches such as "community trust NOT technology" were executed. These queries were iteratively refined based on preliminary results and relevancy assessments to ensure that the final body of literature closely aligned with the objectives of the review.

The inclusion criteria were clearly defined to ensure that only studies providing meaningful insights into the research focus were selected. Articles were included if they examined: the use and implementation of modern technologies in EWS, such as IoT-based sensors, artificial intelligence, or digital communication platforms; the accessibility of early warning information to various community groups, particularly vulnerable populations; or the level of community trust in EWS, including empirical studies on how populations respond to alerts and engage with disaster preparedness protocols. The emphasis was placed on peer-reviewed journal articles that contributed empirical data, theoretical advancements, or comprehensive reviews relevant to the three focal dimensions of this study.

Exclusion criteria were equally rigorous to eliminate studies that could potentially dilute the specificity and analytical focus of the review. Studies were excluded if they lacked detailed analysis of technological implementation within EWS, focused on contexts unrelated to natural disasters (e.g., military alert systems), or were published in sources that had not undergone a peer-review process. Additionally, articles that primarily provided anecdotal evidence or relied heavily on speculative commentary without substantial methodological support were also excluded. This ensured that the included literature maintained a high standard of academic credibility and relevance to the topic.

The types of studies included in this review span qualitative, quantitative, and mixed-methods research designs. This diversity was critical to capturing the multifaceted nature of EWS, which encompasses both technical system evaluations and social-behavioral assessments. Empirical studies such as randomized controlled trials, cohort studies, case studies, and field surveys were prioritized for their methodological rigor and context-rich findings. Literature reviews and meta-

analyses that synthesized large bodies of work on EWS were also included to provide broader conceptual insights. The combination of methodological approaches enabled a nuanced understanding of how EWS function across varying settings and populations.

The process of literature selection followed a structured screening protocol. Initially, titles and abstracts of retrieved articles were reviewed to assess their relevance against the predefined inclusion and exclusion criteria. Articles that passed this initial screening were then subjected to a full-text review to evaluate their methodological quality, conceptual alignment, and empirical contribution. Studies that met all criteria were then coded based on key themes, such as type of technology used, target population demographics, geographic location, and outcomes measured. Coding was conducted manually to allow for flexibility and contextual interpretation, which is particularly important in narrative reviews where thematic synthesis is central.

To further enhance the reliability of the review, cross-referencing was used to identify additional studies cited within the primary articles that may not have appeared in the initial database searches. This snowballing technique helped uncover influential works that contributed significantly to the discourse on EWS but were not captured through keyword-based searches alone. Additionally, publication dates were not restricted, though preference was given to articles published within the last fifteen years to ensure the relevance of technological discussions.

To maintain transparency and reproducibility, a record was kept of each search query, the number of results retrieved, the number of studies included and excluded at each stage, and the rationale for inclusion or exclusion. While the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were not strictly followed due to the narrative nature of this review, its principles informed the structure and reporting strategy to enhance methodological clarity.

This methodological framework ensures that the literature included in this narrative review is not only comprehensive but also rigorously curated to address the central research objectives. The goal is to generate a cohesive synthesis that highlights the interconnected roles of technology, accessibility, and trust in determining the effectiveness of EWS. By drawing from a diverse yet focused corpus of academic work, this review aims to provide evidence-based insights that can inform future research, policy formulation, and practical implementation strategies in the field of disaster risk management.

RESULT AND DISCUSSION

The findings of this narrative review are organized into four thematic areas: technological advancements in early warning systems (EWS), accessibility challenges and solutions, community trust in warning information, and international comparisons of EWS effectiveness. These themes emerged from a critical synthesis of empirical studies, theoretical analyses, and cross-regional evaluations drawn from literature selected based on criteria outlined in the methodology.

Technological Advancements in Early Warning Systems

Technological innovation has significantly influenced the development and effectiveness of EWS. Among the most notable advancements are artificial intelligence (AI), the Internet of Things (IoT), and satellite-based monitoring systems. These technologies have collectively contributed to faster detection, more accurate forecasts, and wider dissemination of warning messages. For example, AI models such as the Improved Grey Wolf Optimizer integrated with Long Short-Term Memory (IGWO-LSTM) networks, as studied by Zhu et al. (2023), outperform traditional models in predicting landslide events. Their capacity to analyze large datasets in real time has enabled faster and more precise risk detection.

Similarly, the integration of IoT technologies has allowed for real-time monitoring of critical environmental parameters. In the work of Prasadana et al. (2024), the deployment of Arduino-based sensors along riverbanks significantly improved flood detection capabilities. These sensors enabled local authorities to receive early alerts and disseminate warnings swiftly, enhancing preparedness at the community level. IoT's decentralized nature also allows data to be collected from multiple remote areas, increasing the geographic coverage and responsiveness of EWS.

Satellite monitoring, although less frequently the focal point of disaster studies, provides essential geospatial data that enhance large-scale hazard detection. According to Khan et al. (2023), satellite imagery contributes to faster information transmission and enables better coordination in disaster response, particularly in hard-to-reach areas. While satellite-based EWS may face technical and financial barriers in some regions, their macro-level utility is indispensable for climate-related hazards like hurricanes and droughts.

Collectively, these technological advancements have transformed EWS from static, centralized systems into dynamic, distributed networks capable of rapid threat detection and response. The integration of AI and IoT has proven particularly effective in increasing the timeliness and accuracy of alerts, two factors that are critical in minimizing disaster impact (Ian et al., 2023).

Accessibility to Early Warning Systems

Despite technological progress, significant disparities in access to EWS remain, particularly among vulnerable populations in low-resource settings. Barriers to accessibility are multifaceted, ranging from infrastructural inadequacies to social and cultural dynamics.

Infrastructure and technological limitations continue to restrict the dissemination of warning messages in many developing countries. Moises et al. (2024) noted that regions with limited cellular or internet infrastructure often fail to receive timely alerts, exposing populations to greater risk. These infrastructural gaps are exacerbated by economic constraints that limit government capacity to invest in modern EWS platforms.

Educational and awareness gaps also hinder EWS effectiveness. As Husna et al. (2021) demonstrated, communities with low levels of disaster literacy often struggle to interpret and respond to warnings. Education campaigns and public outreach are therefore essential to bridging this gap. Without a foundational understanding of local hazard types and response protocols, even the most advanced EWS will fail to trigger appropriate community action.

Cultural perceptions and social trust further complicate accessibility. Kuppuswamy (2014) found that the perceived credibility of warning sources significantly influences whether individuals heed alerts. In communities where distrust in government institutions is prevalent, warning messages may be ignored regardless of their accuracy. These findings emphasize the need for culturally sensitive communication strategies that build local confidence.

Community-based approaches have shown promise in addressing these accessibility challenges. Ganapathy et al. (2023) reported the success of Community-Based Early Warning Systems (CBEWS) in increasing both the reach and relevance of alerts. By involving local stakeholders in system design and dissemination, these models foster ownership and trust, making the information more actionable. Community-driven models also tend to utilize familiar communication channels, which further enhances their effectiveness.

In sum, while technological solutions form the backbone of EWS, their success hinges on equitable access. Community engagement, localized education, and infrastructural investments are vital to ensuring that EWS serve all segments of society.

Trust in Warning Information

Trust is a critical determinant of public responsiveness to EWS. The literature consistently shows that multiple variables shape trust, including past experiences, the consistency of information, and the perceived legitimacy of information sources.

Previous disaster exposure often shapes public attitudes toward EWS. As observed by Husna et al. (2021), communities that have successfully used EWS in the past are more likely to rely on them in future events. Conversely, failed alerts or miscommunications, such as those reported by Moises et al. (2024), can erode public trust, reducing future compliance.

Trust also varies depending on the issuing institution. Mendes et al. (2019) documented that academic institutions often enjoy higher credibility than governmental agencies, especially in regions with weak governance. This credibility gap suggests that involving universities and research centers in warning dissemination may improve public trust and uptake.

Another essential factor is the quality of the information shared. According to Lopez et al. (2017), communities are more likely to respond to alerts that are consistent, timely, and delivered through trusted channels. Discrepancies or delays in information erode confidence and foster skepticism.

Social media and informal communication networks add another dimension to the trust equation. Platforms such as Twitter, Facebook, and WhatsApp have emerged as significant vectors for real-time information exchange during disasters. Monteleone et al. (2020) noted that these platforms often outperform official channels in speed, enabling faster community mobilization. However, as Middleton and Al-Hemoud (2024) warned, misinformation and rumors can spread just as quickly, creating confusion and panic. Thus, while social media enhances reach, it also introduces new risks that must be managed through careful monitoring and public education.

Ultimately, trust in EWS is not inherent but must be earned and maintained through transparency, reliability, and community involvement. Combining formal institutional efforts with grassroots communication channels can create a more resilient and trusted EWS framework.

International Comparisons of Early Warning System Effectiveness

The effectiveness of EWS varies considerably between developed and developing countries, primarily due to differences in technological capacity, institutional support, and socioeconomic conditions. Developed countries typically possess more sophisticated EWS, supported by high-resolution monitoring tools and robust communication infrastructure. For instance, as described by Mani et al. (2024), countries such as Japan and the United States employ advanced seismic monitoring systems that integrate real-time data feeds with automated public alert systems.

In contrast, developing nations often struggle with outdated technology, limited coverage, and fragmented institutional responsibilities. Lopez et al. (2017) highlighted that in many such countries, warning systems are not centralized, leading to inefficiencies and delayed responses. These systemic weaknesses often result in higher casualty and damage rates, even in cases where hazard severity is lower than in more prepared nations.

Nevertheless, some best practices from international case studies offer valuable lessons. Mendes et al. (2019) stressed the importance of community participation in enhancing EWS performance. When local populations are engaged in both the design and operation of EWS, the systems are more likely to reflect ground-level realities and garner public trust.

Continuous training and public education also emerge as critical factors. Harumy et al. (2025) emphasized that regular drills and educational campaigns significantly increase community responsiveness. These efforts not only familiarize the public with warning protocols but also reinforce the credibility of the system.

Collaborative governance is another essential element. Kar et al. (2024) advocated for multi-stakeholder frameworks that bring together governments, academia, NGOs, and private sector actors. Such collaborations enhance system integration, improve resource allocation, and foster innovation.

In conclusion, while resource constraints limit the ability of developing countries to fully replicate the EWS systems of developed nations, strategic adaptations rooted in local engagement and cross-sectoral collaboration can significantly improve outcomes. Bridging the global gap in EWS effectiveness requires a nuanced approach that combines technological innovation with inclusive governance and context-sensitive implementation.

The effectiveness of early warning systems (EWS) is not solely determined by the sophistication of technology but is deeply influenced by systemic factors such as national policies, social inequality, and infrastructure quality. These structural dimensions intersect with the findings presented in this review and merit critical analysis to inform the development of more inclusive, equitable, and effective disaster risk management strategies.

National policy frameworks play a pivotal role in shaping the performance and outreach of EWS. As highlighted by Moises et al. (2024), well-coordinated policies that integrate local and national levels of governance are essential to ensure timely dissemination of warnings and facilitate appropriate community responses. In countries where national policies prioritize investments in monitoring infrastructure, data-driven decision-making, and clear operational procedures, EWS have shown greater functionality and community reach. For example, the Federal Emergency Management Agency (FEMA) in the United States has successfully enhanced public preparedness through sustained investments in early warning technology and educational initiatives, as noted by Davlasheridze et al. (2017). This demonstrates that policy-driven financial and institutional support is critical for scaling and sustaining EWS, particularly in disaster-prone areas.

Social inequality further complicates the ability of communities to benefit equally from EWS. Husna et al. (2021) pointed out that socially and economically disadvantaged populations frequently lack the educational and technological resources necessary to understand and act on warning information. These populations are disproportionately represented in rural and informal settlements where infrastructure is often underdeveloped and where institutional trust may be lacking. This inequity creates a dual vulnerability: exposure to hazards and exclusion from preparedness mechanisms. Therefore, EWS must be designed with a strong equity lens that ensures marginalized communities are not left behind. Addressing this issue requires more than just technological expansion; it demands deliberate policy action to redress resource distribution and systemic marginalization.

Infrastructure quality is another crucial determinant of EWS success. High-functioning systems rely on stable electricity, robust communication networks, and reliable data collection points. In their study, Prasadana et al. (2024) emphasized the importance of sensor-based technologies in flood-prone regions, demonstrating that advanced environmental monitoring tools can significantly improve lead times and alert accuracy. However, in many low- and middle-income countries, infrastructure gaps severely undermine the potential of such systems. These gaps are not merely technical shortcomings but reflections of broader development deficits. Overcoming them will require cross-sectoral investments that link disaster risk management with broader development agendas.

National programs that have succeeded in enhancing disaster preparedness provide valuable insights. The EWS reforms implemented in Aceh, Indonesia, following the 2004 tsunami illustrate how integrated education and training programs can improve community engagement with warning systems (Husna et al., 2021). Similarly, Ethiopia's drought monitoring initiatives demonstrate the value of linking health and environmental monitoring systems to create multi-sectoral responses (Tadesse & Ardalan, 2014). In Myanmar, the deployment of flood sensors along the Bago River has shown that low-cost, locally adapted technology can effectively alert vulnerable populations (Acierto et al., 2018). These examples collectively highlight the importance of policy coherence, multi-level governance, and context-specific innovation.

The Philippines offers another instructive case through its scenario-based EWS planning. Ghoneem and Elewa (2013) documented how adaptive planning frameworks, supported by collaborations between government bodies, academia, and local communities, contributed to improved disaster response. This model underscores the necessity of co-production and

stakeholder engagement, especially in regions where hazards are recurrent and unpredictable. Incorporating scenario planning into EWS encourages anticipatory governance, enabling communities to prepare for multiple eventualities rather than static risk models.

Building trust and improving accessibility remain central challenges in maximizing EWS efficacy, particularly in marginalized communities. Participatory approaches can enhance system legitimacy and encourage public compliance. Husna et al. (2021) argued that community involvement in the design and implementation of EWS fosters greater ownership and increases the likelihood of effective response. This finding is supported by Ganapathy et al. (2023), who demonstrated that community-based early warning systems (CBEWS) in landslide-prone areas led to more timely and coordinated evacuations. Such models exemplify how localized, inclusive governance can improve outcomes in high-risk areas.

Technology also plays a dual role in advancing both access and functionality. The deployment of Internet of Things (IoT) devices and mobile applications enables more efficient and widespread dissemination of warnings, particularly in hard-to-reach areas. Adiwinoto et al. (2025) highlighted how mobile-based platforms can bridge the last mile of communication, ensuring that even geographically isolated communities receive alerts in real time. However, the success of these technologies is contingent upon prior digital literacy and the availability of supportive infrastructure. Without targeted interventions to build these capacities, technology risks exacerbating, rather than mitigating, existing inequities.

Educational initiatives serve as a critical complement to technological and policy measures. As noted by Purnomo et al. (2025), routine community drills, risk education in schools, and public information campaigns enhance awareness and responsiveness. These initiatives help normalize the use of EWS and build a culture of preparedness. In areas with high disaster recurrence, such as coastal Indonesia or typhoon-prone regions of the Philippines, these interventions are essential to maintaining long-term community resilience.

Cross-sectoral collaboration is imperative for the sustainability of EWS. Moises et al. (2024) emphasized the need for inclusive policy frameworks that mobilize government agencies, NGOs, academic institutions, and private sector actors. This collaborative governance model facilitates resource pooling, improves data integration, and ensures that EWS reflect the needs and capacities of diverse stakeholders. For example, Kuppuswamy (2014) illustrated how community feedback mechanisms can inform more culturally appropriate and user-friendly communication strategies, thereby strengthening both trust and effectiveness.

Despite these promising developments, significant limitations in the current literature must be acknowledged. Much of the existing research is case-specific and lacks generalizability across regions or hazard types. For instance, while community-based models have shown success in certain contexts, their replication in urbanized or politically fragmented environments remains underexplored. Additionally, few studies address the long-term sustainability of EWS, particularly in light of evolving climate risks and migration patterns. As environmental volatility increases, the static models of risk management used by many EWS may become obsolete. There is also a need for more longitudinal studies that track changes in community trust and responsiveness over time.

Future research should explore the intersection of digital inequality and disaster vulnerability in greater depth. Understanding how digital divides shape access to warning systems is essential for designing equitable interventions. Additionally, more attention should be given to the institutional dynamics that affect EWS performance, including issues of accountability, corruption, and inter-agency rivalry. Finally, the role of emerging technologies such as AI and machine learning in predicting complex, multi-hazard scenarios warrants further investigation, particularly in how these tools can be ethically and effectively deployed in diverse social settings.

CONCLUSION

This narrative review has highlighted the multidimensional factors that influence the effectiveness of early warning systems (EWS), particularly in the context of disaster risk management. Key findings emphasize the transformative potential of emerging technologies such as artificial intelligence, Internet of Things, and satellite-based monitoring in enhancing the speed, accuracy, and geographical coverage of warning systems. However, the benefits of these technologies are not universally accessible, especially in regions marked by infrastructural deficiencies, social inequalities, and fragmented governance.

The discussion underscores that national policies play a foundational role in supporting EWS through targeted investments, regulatory frameworks, and multi-level coordination. Countries with integrated and proactive disaster governance models—such as the United States, Philippines, and Ethiopia—illustrate the value of sustained, inclusive approaches that combine education, health, and community participation. In contrast, marginalized communities in low- and middle-income countries often remain excluded due to lack of access, limited trust in institutions, and minimal involvement in system design.

There is an urgent need for cross-sectoral interventions that address both technical and social dimensions of EWS. Policies should prioritize equity-focused infrastructure development, culturally relevant risk education, and community-led implementation strategies. Future research must address existing gaps, particularly regarding digital inequality, long-term EWS sustainability, and ethical deployment of AI in disaster contexts. Enhancing trust, ensuring accessibility, and leveraging localized technologies must remain central to any strategy aimed at reducing disaster vulnerability and strengthening resilience.

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