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Evaluating the effectiveness of impact-based severe weather Early Warning Systems for Flood Risk Management in South Africa: A conceptual review

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ABSTRACT

Flooding remains one of the most frequent and destructive hydro-meteorological hazards in South Africa, causing substantial socio-economic losses, infrastructure damage, and threats to human life. In response to increasing flood risks associated with climate variability and extreme weather events, the South African Weather Service has increasingly adopted impact-based severe weather early warning systems designed to communicate not only meteorological hazards but also their likely consequences for communities, infrastructure, and livelihoods. This conceptual review examined the effectiveness of these systems in strengthening flood risk management in South Africa. The paper synthesised theoretical and policy perspectives on impact-based early warning systems and critically reviewed institutional, socio-economic, and communication factors that shape their effectiveness. The findings indicate that while South Africa has made significant progress in transitioning from hazard-based to impact-based warning systems, challenges related to institutional coordination, dissemination gaps, community risk perception, and socio-economic vulnerabilities continue to undermine their effectiveness. The paper further identifies emerging opportunities linked to technological innovation, participatory governance, and community resilience. The study concludes by highlighting the need for context-specific empirical research in vulnerable flood-prone communities such as Port St Johns. This study contributes to disaster risk reduction and climate adaptation scholarship by synthesising theoretical, policy, and institutional perspectives on impact-based flood early warning systems in South Africa. It identifies key institutional, socio-economic, and communication factors that affect system effectiveness, highlights research gaps, and provides a conceptual foundation for future research and evidence-based flood risk management.

Keywords: Impact-based Warning Systems, Flood Risk Management, South Africa, Disaster Risk Reduction, Early Warning Systems.

INTRODUCTION

Flooding is one of the most widespread natural disasters globally, impacting both individuals and communities through significant damage to private property, public infrastructure, and the natural environment, while also posing serious risks to human life. Intense rainfall, storms, hurricanes, and flash

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floods, which can lead to severe consequences, cause it. These effects include displacement, fatalities, health-related challenges, and economic losses among affected populations. As a result, a robust disaster management framework is needed to effectively reduce both the immediate and long-term impacts of flooding.[1] Floods affect communities and individuals. Floods affect society, the economy, and the environment. In addition to posing a serious risk to human life, floods also have long-term negative effects on the environment, the economy and the mental health of those affected.[2] This highlights the importance of effective flood risk management and preparedness.

The primary cause of flooding in Sub-Saharan Africa is periods of intense rainfall caused by tropical cyclones and storm surges. For example, the South Indian cyclone that struck in 2018 and 2019 was a fluvial flood that caused extensive flood damage in Africa.[3] According to Aliyu et al., in sub-Saharan Africa (SSA), flooding is not a recent occurrence.[4] Since 1947, there have been reports of significant flooding in Lagos, Nigeria, which is now a yearly occurrence. Floods have been more intense in sub-Saharan Africa throughout the last ten years. The southwest Indian Ocean cyclone season of 2018–2019 caused an unprecedented amount of devastation in Africa. The ensuing cyclone Idai caused catastrophic flood damage in Mozambique and Zimbabwe, resulting in 602 and 299 fatalities, respectively, as well as $1 billion worth of damage to vital infrastructure.

The Republic of South Africa is concerned about flood threats, with the most vulnerable provinces being the North West, Eastern Cape, Limpopo, and KwaZulu-Natal. The Eastern Cape and KwaZulu-Natal provinces saw the worst floods in April 2022; however, these provinces have all seen significant flooding. In addition to serious infrastructure damage and casualties, the Eastern Cape flood catastrophe had detrimental effects on the environment and socioeconomic conditions.[5] Similarly, Dube et al. mentioned that flooding has been a major worry in South Africa's Eastern Cape and Limpopo provinces.[6] The Garden Route, which connects the Eastern and Western Cape, suffered catastrophic floods in 2004 and 2005 that negatively impacted the financial and psychological well-being of travellers and tourism industry participants. Due to their low elevation and susceptibility to storm surges and coastal floods, tourist facilities along the Wild Coast route are vulnerable. It is well known that places like Port St Johns are susceptible to regular flooding incidents.

Against this backdrop, evaluating the effectiveness of impact-based severe weather Early Warning Systems (EWS) for Flood Risk Management in South Africa becomes imperative. Ngcamu and Abrahams alluded to the government and its agencies' failure to take the necessary steps to effectively communicate through early warning systems (EWSs), which has exacerbated the consequences of natural catastrophes on vulnerable populations in South Africa.[7] In extremely susceptible informal settlements, insufficient measures for disaster preparedness at the local government level have caused suffering and catastrophic consequences. Thus, Maripe et al. asserted that in accordance with the Africa Plan of Action and the Sendai Framework for Disaster Risk Reduction (SFDRR), South Africa requires immediate action to establish a multi-hazard and people-centered early warning system or systems.[8]

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1 D. Guddo, "Conceptualization of Flooding Disaster: A Theoretical Perspective of Management," *Disaster Advances* 17, no. 2 (December 28, 2023): 40, https://doi.org/10.25303/172da040045.

2 A. F. Mohammad Aldardasawi and Beytullah Eren, "Floods and Their Impact on the Environment," *Academic Perspective Procedia* 4, no. 2 (November 6, 2021): 42–49, https://doi.org/10.33793/acperpro.04.02.24.

3 Edson Munsaka and Sebia Mutasa, "Flooding and Its Impact on Education," in *Natural Hazards - Impacts, Adjustments and Resilience* (IntechOpen, 2021), https://doi.org/10.5772/intechopen.94368.

4 Alhaji Aliyu, Khadeejah Liman-Hamza, and Aminu Lawal, "Floods in Sub-Saharan Africa; Causes, Determinants and Health Consequences," *Nigerian Medical Journal: Journal of the Nigeria Medical Association* 64, no. 1 (2023): 13.

5 Emem O. Anwana and Oluwatobi Mary Owojori, "Analysis of Flooding Vulnerability in Informal Settlements Literature: Mapping and Research Agenda," *Social Sciences* 12, no. 1 (January 11, 2023): 40, https://doi.org/10.3390/socsci12010040.

6 Kaitano Dube et al., "Mapping and Evaluating the Impact of Flood Hazards on Tourism in South African National Parks," *Journal of Outdoor Recreation and Tourism* 43 (September 2023): 100661, https://doi.org/10.1016/j.jort.2023.100661.

7 Bethuel Sibongiseni Ngcamu and Gail Abrahams, "The Preparedness Plans and Early Warning Systems During Flood Disasters in South Africa," in *The Palgrave Handbook of Language and Crisis Communication in Sub-Saharan Africa* (Cham: Springer International Publishing, 2024), 259–72, https://doi.org/10.1007/978-3-031-43059-6_14.

8 Kgosietsile Maripe et al., "Early Warning Systems in the Southern African Development Community: A Necessity," *Current Journal of Applied Science and Technology*, December 29, 2022, 45–58, https://doi.org/10.9734/cjast/2022/v41i484033.

In light of the increasing frequency and severity of flood events and their far-reaching impacts across South Africa, the effectiveness of early warning systems remains a critical area of concern. Therefore, this paper aims to evaluate the effectiveness of impact-based severe weather EWS in supporting flood risk management within the South African context. It provides a conceptual review of existing approaches, identifies key challenges that hinder the successful implementation and communication of EWS, and explores opportunities to strengthen these systems to enhance community resilience. The study concludes by highlighting the need for context-specific empirical research in vulnerable, flood-prone communities such as Port St Johns, where tailored early warning strategies can significantly improve preparedness, response, and recovery efforts.

METHODOLOGY

This study adopts a conceptual review design to critically examine the effectiveness of impact-based severe weather early warning systems for flood risk management in South Africa. A conceptual review is particularly appropriate for this study because the objective is not to systematically quantify evidence or perform a meta-analysis, but rather to synthesise and interrogate key concepts, theoretical perspectives, policy frameworks, and scholarly debates that shape understanding of early warning effectiveness within the South African context. Unlike a systematic review, which follows rigid inclusion and exclusion protocols aimed at comprehensive evidence synthesis, a conceptual review provides the flexibility to engage deeply with ideas, frameworks, and contextual interpretations that are central to theory building and policy analysis.

The choice of a conceptual review is further justified by the emerging and interdisciplinary nature of the subject matter. Impact-based severe weather early warning systems span fields such as disaster risk reduction, climatology, human geography, environmental management, governance studies, and community resilience research. As such, the literature on this topic is dispersed across multiple disciplines and includes not only peer-reviewed academic sources but also policy documents, institutional reports, and technical guidance materials. A conceptual review allows these diverse sources to be integrated into a coherent analytical framework.

To enhance methodological transparency, the literature included in this conceptual review was selected using purposive sampling. Sources were chosen based on their relevance to impact-based severe weather early warning systems, flood risk management, disaster risk reduction, and community resilience within the South African context. Priority was given to peer-reviewed journal articles published in English between 2010 and 2025 to capture contemporary developments, while seminal theoretical and policy publications published before this period were included where they provided foundational concepts or internationally recognised frameworks. Policy documents from the South African Weather Service, the National Disaster Management Centre, the United Nations Office for Disaster Risk Reduction (UNDRR), and the World Meteorological Organisation (WMO) were also incorporated because of their direct relevance to early warning policy and practice.

The review followed an iterative process of literature identification, screening, and thematic synthesis. Initially, publications were identified using keyword searches in Google Scholar, Scopus, and ScienceDirect. The retrieved literature was then screened by reviewing titles, abstracts, and full texts to determine their relevance to the study objectives. Publications focusing primarily on unrelated natural hazards or lacking conceptual relevance to impact-based flood early warning systems were excluded. Subsequently, the selected literature was subjected to thematic analysis, in which recurring concepts, theoretical perspectives, institutional issues, communication processes, socio-economic factors, and policy recommendations were identified, compared, and synthesised. These themes were interpreted through the Protective Action Decision Model (PADM) and the Sendai Framework for Disaster Risk Reduction to develop a coherent conceptual understanding of the effectiveness of impact-based severe weather early warning systems in South Africa.

The conceptual review approach adopted in this study is intended to generate a critical synthesis of existing knowledge and to identify key gaps that warrant further empirical investigation. In particular, the review seeks to provide a theoretical and policy foundation for future case-specific research in flood-prone localities such as Port St Johns, where the practical effectiveness of impact-based warning systems

remains underexplored. Conceptual reviews play an important role in integrating fragmented knowledge, refining theoretical understanding, and developing future research agendas across emerging fields.[9]

Although the conceptual review design offers flexibility and depth of interpretation, it is acknowledged that the approach does not provide an exhaustive synthesis of all available literature. Rather, its purpose is to develop a coherent conceptual understanding of the major issues, debates, and opportunities associated with impact-based severe weather early warning systems in South Africa. This approach is particularly appropriate for interdisciplinary disaster risk reduction research, where conceptual synthesis supports theory development and informs policy and practice.[10]

PRESENTATION OF FINDINGS AND DISCUSSION

Conceptualising Impact-Based Severe Weather Early Warning Systems

Early warning systems allow people, communities, governments, businesses, and others to take prompt action to reduce disaster risks before hazardous events occur. They are an integrated system of hazard monitoring, forecasting and prediction, disaster risk assessment, communication, and preparedness activities, systems and processes.[11] Šakić Trogrlić et al. highlighted that EWS aims to lower risks and prepare for hazards in a certain spatial area, such as a community, city, or region.[12] It is crucial to understand the type of risk present in the area. Risk assessments can assist in identifying vulnerable groups' locations and characteristics, regions where hazards are likely to occur, and vital infrastructure and assets in high-risk areas.

To prevent death and destruction from hydro-meteorological events, governments and civil society organisations are investing heavily in early warning systems (EWS) as climate change increases the frequency and severity of extreme weather events. Early warning systems have four components, which include risk knowledge, monitoring and warning, dissemination and communication, and response capability.[13] By providing vulnerable areas with timely information, EW plays a critical role in disaster preparedness and response efforts, saving lives, minimising damage, and boosting community resilience.[14] Potter et al. alluded to the fact that the final line of protection against impending threats is early warning systems.[15] Thus, as acknowledged by the Sendai Framework for Disaster Risk Reduction 2015–30 and the Hyogo Framework for Action 2005–15, their operation and success are crucial.

In Africa, floods significantly impact both rural and urban inhabitants' means of subsistence. The use of flood Early Warning Systems (EWS) as a preparedness mechanism against flood effects is one of the methods for mitigating their effects that have been developed.[16] Extreme weather events (EWEs) associated with climate change are a threat to South Africa. Between 1980 and 2015, these EWEs, which included floods, droughts, fires, and massive storms, caused socioeconomic disruption and damage at

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[9] John Hulland, "Conceptual Review Papers: Revisiting Existing Research to Develop and Refine Theory," *AMS Review* 10, no. 1–2 (June 29, 2020): 27–35, https://doi.org/10.1007/s13162-020-00168-7; M. Garschagen et al., "The Consideration of Future Risk Trends in National Adaptation Planning: Conceptual Gaps and Empirical Lessons," *Climate Risk Management* 34 (2021): 100357, https://doi.org/10.1016/j.crm.2021.100357.

[10] Erich Wolff, "The Promise of a 'People-Centred' Approach to Floods: Types of Participation in the Global Literature of Citizen Science and Community-Based Flood Risk Reduction in the Context of the Sendai Framework," *Progress in Disaster Science* 10 (April 2021): 100171, https://doi.org/10.1016/j.pdisas.2021.100171.

[11] Diego Fernández-Nóvoa, José González-Cao, and Orlando García-Feal, "Enhancing Flood Risk Management: A Comprehensive Review on Flood Early Warning Systems with Emphasis on Numerical Modeling," *Water* 16, no. 10 (May 15, 2024): 1408, https://doi.org/10.3390/w16101408.

[12] Robert Šakić Trogrlić et al., "Early Warning Systems and Their Role in Disaster Risk Reduction," in *Towards the "Perfect" Weather Warning* (Cham: Springer International Publishing, 2022), 11–46, https://doi.org/10.1007/978-3-030-98989-7_2.

[13] Erin Coughlan de Perez et al., "Learning from the Past in Moving to the Future: Invest in Communication and Response to Weather Early Warnings to Reduce Death and Damage," *Climate Risk Management* 38 (2022): 100461, https://doi.org/10.1016/j.crm.2022.100461.

[14] Mokbul Ahmad Morshed et al., "The Current State of Early Warning System in South Asia: A Case Study of Afghanistan," *International Journal of Disaster Risk Reduction* 100 (January 2024): 104201, https://doi.org/10.1016/j.ijdrr.2023.104201.

[15] Sally Potter, Sara Harrison, and Peter Kreft, "The Benefits and Challenges of Implementing Impact-Based Severe Weather Warning Systems: Perspectives of Weather, Flood, and Emergency Management Personnel," *Weather, Climate, and Society* 13, no. 2 (April 2021): 303–14, https://doi.org/10.1175/WCAS-D-20-0110.1.

[16] Japhet Ringo, Shadrack Sabai, and Anesi Mahenge, "Performance of Early Warning Systems in Mitigating Flood Effects. A Review," *Journal of African Earth Sciences* 210 (February 2024): 105134, https://doi.org/10.1016/j.jafrearsci.2023.105134.

an estimated cost of USD 10 billion.[17] Thus, by promoting a suitable and prompt behavioural reaction, warnings about potential hazards help reduce their effects and lower their risk. The World Meteorological Organization has pushed several hydrometeorological organisations to switch to impact-based forecasting and warning (IBFW) systems.[18] Therefore, understanding the effectiveness of impact-based early warning systems is essential to strengthen flood risk management and improve community resilience in South Africa.

The concept of impact-based warning systems can be interpreted through the framework of the Protective Action Decision Model (PADM). According to the PADM, preparedness results from the interaction of people's assessments of the threat posed by a hazard, the identification of actions that are available and capable of protecting them against the consequences of the hazard, and complementary information search and evaluation processes (evaluating information needs, identifying sources, and determining when information is needed). Creating useful connections between information suppliers and users is one of the PADM's main objectives.[19] Wu and Li highlighted that three essential elements of protective behaviour are identified by the protective action choice model (PACM): information search, emotional regulation, and a protective response.[20] As a result, this framework highlights the need for early warning systems that not only provide accurate information but also effectively guide protective behaviour to reduce flood risks. This emphasises how crucial it is to create impact-based early warning systems that efficiently convert risk data into prompt preventive measures that lessen the effects of flooding.

In South Africa, this conceptual shift has been increasingly integrated into the warning frameworks used by the South African Weather Service. According to Ngema, timely communication is essential when the effects of severe weather events worsen.[21] The Impact-Based Severe Weather Warning System, based on the South African Weather Service (SAWS), was created to warn the public about possible effects that could arise from hazardous weather conditions. It shifts the emphasis from discussing the weather itself to highlighting the potential implications of dangerous weather. SAWS determines the alert level using a risk matrix that is numbered and color-coded. The degree of impact and the probability that it will occur are combined to generate the color-coding and numbering. Nevertheless, most parts of South Africa are still prone to severe flooding, including Port St Johns, despite SAWS using the Impact-Based Severe Weather Warning System. This suggests that, despite adopting impact-based warning systems, persistent gaps in communication, local preparedness, and system effectiveness continue to limit their ability to fully mitigate flood risks in vulnerable communities.

Institutional Approaches and Governance Frameworks

There are significant disaster hazards in South Africa, particularly from fires in informal settlements, droughts, and floods. The Disaster Management Act (Act No. 57 of 2002) and associated regulations provide the legal basis for disaster management in South Africa. The Portfolio and Select Committees on Cooperative Governance and Traditional Affairs (COGTA) are two examples of parliamentary committees that keep an eye on how disaster management policies are being implemented and hold the executive branch responsible for its actions.[22]

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[17] Mary Lynch et al., "Warning System for Extreme Weather Events, Awareness Technology for Healthcare, Equitable Delivery, and Resilience (WEATHER) Project: A Mixed Methods Research Study Protocol," *Climate* 13, no. 8 (August 21, 2025): 170, https://doi.org/10.3390/cli13080170.

[18] Potter, Harrison, and Kreft, "The Benefits and Challenges of Implementing Impact-Based Severe Weather Warning Systems: Perspectives of Weather, Flood, and Emergency Management Personnel."

[19] Douglas Paton, "Disaster Risk Reduction: Psychological Perspectives on Preparedness," *Australian Journal of Psychology* 71, no. 4 (December 1, 2019): 327–41, https://doi.org/10.1111/ajpy.12237.

[20] Qunying Wu and Rui Li, "The Driving Mechanism of Citizens' Protective Behaviors for Rainstorm Flood Disasters in China: An Empirical Study Based on the Protection Motivation Theory and Protective Action Decision Model," *Heliyon* 10, no. 22 (November 2024): e38482, https://doi.org/10.1016/j.heliyon.2024.e38482.

[21] T. Ngema, "How SAWS's New Warning System Helps Save Lives during Severe Weather," Cape Argus, 2025, https://capeargus.co.za/.

[22] A Arendse et al., *Strengthening Disaster Resilience and Responses: South African Perspective (11th G20 Parliamentary Speakers Summit)* (Parliament of South Africa, 2025).

According to the Weather Service Act (Republic of South Africa (RSA), 2001), the SAWS is the legally required institution in charge of weather and climate forecasting, as well as the issuance of severe weather-related alerts in South Africa. All weather forecasts, which are based on radar observation stations, geostationary satellite imagery, and mathematical weather models, are mostly handled by SAWS. SAWS has a nationwide monitoring network that monitors hydrological, terrestrial, and meteorological factors for hazards such as destructive winds, fires, and floods[23]

SAWS is a required national meteorological agency that was founded in compliance with the South African Weather Service Act (Act No 8 of 2001). The goal of SAWS's vision is to create "A WeatherSMART Nation," where people and organisations can use the organisation's high-quality, trustworthy weather and climate-related data to improve their quality of life, increase resilience to extreme weather events, and lessen the effects of climate change.[24] The National Disaster Amendment Act of 2015, the Disaster Management Framework of 2004, and the Disaster Management Act of 2002 all govern how disaster risk is mitigated in South Africa. One of the main requirements of the Disaster Management Framework of 2004 is the issuance of warnings through the application of EWS so that preventative actions can be taken promptly in the case of threats due to natural hazards, technical accidents, or environmental degradation.[25] This emphasises how crucial it is to create impact-based early warning systems that efficiently convert risk data into prompt preventive measures that lessen the effects of flooding.

Thus, the literature reviewed indicates that the effectiveness of impact-based severe weather early warning systems in South Africa is strongly influenced by the institutional and governance structures within which these systems operate. Although technological advancements in weather forecasting have improved the ability to predict severe weather events, translating these forecasts into effective preparedness and response actions depends largely on the efficiency of institutional coordination, governance arrangements, and operational response mechanisms. Overall, the findings indicate that institutional effectiveness remains one of the most critical determinants of whether impact-based severe weather early warning systems achieve their intended purpose of reducing flood risk and enhancing community preparedness.

Communication and Dissemination Challenges

An early warning system is the set of capacities required to generate and disseminate timely and meaningful warning information to enable individuals, communities, and organisations threatened by a hazard to respond. The provision of timely and effective information through identified institutions allows hazards to be used for communication to the public, to prepare them for the hazard's arrival, and to take actions to reduce hazard risk.[26] However, Raphela and Ekeke mentioned that none of the developing nations that are vulnerable to flooding has yet to establish such standardised systems.[27] Every year, several communities in South Africa suffer as a result of catastrophic events that can be lessened by implementing efficient early warning systems. Heavy rainfall, tornadoes, and flooding were caused by a severe storm system in 2024, which primarily affected the provinces of KwaZulu-Natal and the Eastern Cape. These catastrophes draw attention to the nation's ongoing flooding problems, highlighting the need for strong disaster management plans that include efficient early warning systems and infrastructure to mitigate future effects.

Gaps in the EWS in South Africa have been identified, which pose difficulties for its functioning, uptake, and M&E. From an institutional standpoint, financing disaster risk reduction initiatives makes it difficult to effectively distribute alerts and leads to low stakeholder participation in disaster

[23] Tirusha Thambiran et al., "Initiative for Climate Action Transparency-ICAT First Set of Refined Tools and Methodologies Based on Lessons Learned in Pilot Testing: Multi-Hazard Early Warning Systems Monitoring and Evaluation Framework for South Africa," 2023.

[24] South African Weather Service, "Annual Report 2023/24. ," 2024.

[25] Thambiran et al., "Initiative for Climate Action Transparency-ICAT First Set of Refined Tools and Methodologies Based on Lessons Learned in Pilot Testing: Multi-Hazard Early Warning Systems Monitoring and Evaluation Framework for South Africa."

[26] Collins Muhame, Alice Ncube, and Yonas T. Bahta, "Dissemination and Participation in Early Warnings and Disaster Risk Reduction in South Africa," *Jàmbá: Journal of Disaster Risk Studies* 16, no. 1 (January 31, 2024), https://doi.org/10.4102/JAMBA.v16i1.1566.

[27] Tlou D. Raphela and N. Ekeke, "Resilience and the Dissemination of Flood Disaster Early Warning Messages in a Township in South Africa," *Frontiers in Communication* 10 (July 2, 2025), https://doi.org/10.3389/fcomm.2025.1503016.

management. In some places, there is insufficient geographic coverage of weather monitoring stations, which hinders good forecasting and causes EWS false alarms that undermine the validity of subsequent warnings. Disseminating and interpreting the warnings is difficult due to the wide variety of languages spoken in South Africa. Professional firefighting abilities, emergency management skills, victim management skills, disaster risk assessment, radio communication, and use of GIS are among the human capacity difficulties.[28] All recipients may not fully understand English, particularly in rural communities where indigenous languages such as isiXhosa, isiZulu, or Sesotho are more commonly used in everyday communication. Together, these challenges weaken the overall effectiveness of early warning systems in South Africa and highlight the need for improved institutional coordination, capacity building, and inclusive communication strategies to strengthen disaster preparedness and response.

To increase community resilience to natural disasters and decrease vulnerability, effective communication is essential. This is particularly important in countries like South Africa that are highly susceptible to cyclones, floods, riverbank erosion, and storm surges.[29] The disparity between public participation and the distribution of Disaster Risk Reduction information in informal settlements promotes greater community involvement in DRR planning. Furthermore, ward committee members and community volunteers are essential in starting DRR and disaster preparedness planning, according to research done in the Khayelitsha informal settlement in Cape Town. Social media, schools, and churches are the preferred avenues of communication for early warnings. Also, knowledge about urban resilience and the necessity of inclusive disaster risk reduction (DRR) methods that incorporate local communities, especially in high-risk areas, is key. To improve DRR administration and information sharing, local policy implementation and capacity building are important.[30] Thus, strengthening inclusive communication, local capacity, and community participation is essential to improve resilience and effective early warning dissemination in vulnerable areas.

Therefore, integrating formal and informal communication channels may be crucial to improve warning dissemination and strengthen flood preparedness in the South African setting, especially in vulnerable regions such as Port St. Johns. According to the results, communication success should be viewed as a socio-technical process influenced by local institutional ties, infrastructure, language, and trust. Therefore, the analysis shows that the practical efficacy of impact-based severe weather early warning systems for the management of flood risk in South Africa is still significantly hampered by communication and distribution issues.

Socio-Economic Vulnerability and Community Response

Aboagye and Nakamura alluded to the fact that to lessen the effects of floods, effective flood early warning systems (FEWS) are essential.[31] However, several systemic obstacles frequently impede their governance. These structural obstacles worsen flood risk management and impede the attainment of disaster justice by perpetuating social injustices. Cognitive limitations, mistrust, sociocultural influences, inadequate technology and infrastructure, inadequate funding, institutional weaknesses, the exclusion of important social groups, a lack of political will, and limited resources are just a few of the governance barriers in FEWS that have been highlighted. These obstacles expose the underlying socioeconomic inequities that require serious attention in addition to highlighting systemic failures. Addressing these challenges is therefore critical to strengthening equitable flood early warning systems and improving community resilience through more inclusive and effective governance.

Spatial planning from the apartheid era placed marginalised communities in floodplains, further establishing risk. Governance shortcomings such as inadequate early warning systems, disjointed

[28] Thambiran et al., "Initiative for Climate Action Transparency-ICAT First Set of Refined Tools and Methodologies Based on Lessons Learned in Pilot Testing: Multi-Hazard Early Warning Systems Monitoring and Evaluation Framework for South Africa."

[29] Mousumi Khatun and Pradip Kumar Panday, "Communication for Disaster Risk Reduction in Bangladesh: A Review of NGOs and Media Interventions," *Khulna University Studies*, February 17, 2026, https://doi.org/10.53808/KUS.2026.23.01.1539-ss.

[30] A. M Editor, *Enhancing Disaster Risk Reduction in South Africa: Community Engagement and Digital Strategies* (African Researchers Magazine, 2024).

[31] Prince Dacosta Aboagye and Shinichiro Nakamura, "Dominant Barriers and Social Injustices in Flood Early Warning Systems Governance: Insights from Topic Modeling and Content Analysis," *Frontiers in Water* 8 (April 7, 2026), https://doi.org/10.3389/frwa.2026.1759855.

institutional coordination, and weak disaster risk reduction (DRR) strategies increase flood vulnerabilities. The April 2022 floods in KwaZulu-Natal (KZN), the Eastern Cape (EC), and the Western Cape (WC) serve as examples of the impacts of catastrophic disasters. In the last 20 years, there have been more than 1500 recorded flood-related deaths nationwide. Urban-rural disparities, gender-sensitive responses, spatial flood modeling, and policy implementation continue to have significant gaps.[32] In South Africa, township settlements are particularly affected by flooding, caused by severe rainfall. The likelihood of flooding increases with the strength of the rainfall. Changes in socioeconomic patterns and demographics have greatly increased flood-related losses. In addition, because metropolitan areas and new settlements are likely to be developed or extended in flood-prone areas where land is free, the townships' fast urbanisation and population growth make them more vulnerable.[33] These factors highlight the urgent need for integrated, inclusive, and well-coordinated disaster risk reduction strategies to reduce socio-economic vulnerability and strengthen community resilience in flood-prone areas like Port St Johns.

There is a substantial danger of illness and injury in the 2.2 million informal houses in South Africa that lack adequate infrastructure. Other significant negative effects of climate-related disasters include poverty and disparities in access to economic opportunities and essential services. Early warning systems and prompt forecasts from the South African Weather Service (SAWS) are insufficient on their own to prepare communities for climate-related disasters, especially due to poor urban design and limited infrastructure. For instance, residential areas in mountainous regions often suffer from increased flood damage, which has a negative impact on vulnerable populations.[34] The review also shows that poverty and livelihood insecurity influence community reaction behaviour. Low-income households often have to make difficult choices between being prepared for disasters and meeting their immediate needs. Families may be reluctant to leave, for instance, if they fear losing their livestock, household belongings, or ability to engage in regular activities that generate revenue. Households in rural and agricultural areas may put the safety of their crops and livestock before their own evacuation, which can put them at increased risk of flooding.

The local governments of South Africa are trusted with the duty of ensuring that their communities live in a safe and healthy environment and of providing basic services. However, the safety of the community is at risk because most South African townships are constructed in flood-prone locations. Due to a variety of reasons, including their location and other pre-disaster conditions, the majority of township residents are consequently at risk of flooding. Township people can be vulnerable due to a variety of variables, including social networks, cultural norms, political situations, and economic standing.[35] As a result, socioeconomic vulnerability continues to be a major barrier to communities' ability to translate warning information into effective preventive action in South Africa, especially in sensitive areas such as Port St. Johns. This implies that more comprehensive measures aimed at lowering structural vulnerability, developing infrastructure resilience, and improving local preparedness capability must go hand in hand with strengthening warning systems.

Emerging Opportunities for Strengthening Warning Systems

Tozier de la Poterie et al. asserted that it is essential to establish and preserve community trust through accountability and consistency.[36] The efficiency of EWS depends on trust, which can quickly be undermined by false alarms, broken promises, or warnings that are considered irrelevant. Making sure forecasts are accurate, fulfil promises made during involvement, owning up to system failures, and showing how community input results in real improvements is of paramount importance. Connect alerts

[32] Nicholas Byaruhanga, Daniel Kibirige, and Glen Mkhonta, "Understanding South Africa's Flood Vulnerabilities and Resilience Pathways: A Comprehensive Overview," *Water* 17, no. 17 (September 3, 2025): 2608, https://doi.org/10.3390/w17172608.

[33] Tlou D. Raphela and Mollin Matsididi, "The Causes and Impacts of Flood Risks in South Africa," *Frontiers in Water* 6 (January 7, 2025), https://doi.org/10.3389/frwa.2024.1524533.

[34] Bethuel Sibongiseni Ngcamu, "Application of the Disaster Management Cycle and Climate Change: Studying Flood Disasters in South Africa," *Social Sciences & Humanities Open* 8, no. 1 (2023): 100657, https://doi.org/10.1016/j.ssaho.2023.100657.

[35] Oniccah M Motloung, "Effects of Flood Disasters on Vulnerable Residents in Informal Settlements in South Africa.," *African Journal of Development Studies* 14, no. 3 (2024): 421.

[36] A Tozier de la Poterie et al., "Strengthening Early Warning Systems for All: Evidence and Lessons from Last-Mile Communities" (Global Disaster Preparedness Center: Washington, DC, USA, 2025).

to organisations that provide financial and material resources for anticipatory action. Due to poverty, people are forced to ignore warnings and continue hazardous labor rather than risk losing their jobs or being unable to pay for an evacuation. Providing trained volunteers to help vulnerable people, incorporating cash transfers that enable protective acts, and creating early action protocols with predetermined triggers are key.

Due to its immense potential, big data is increasingly being used in EWS for multi-hazard risk management. Several studies have demonstrated that the use of AI and big data may significantly raise the level of catastrophe risk prevention, preparedness, and reduction, as well as early warning and prediction. Additionally, by offering features like monitoring hazards, forecasting exposure and vulnerabilities, managing disaster response, evaluating the adaptability of natural systems, and involving communities throughout the disaster cycle, big data can improve early warning systems and increase social resilience to natural disasters.[37] Corroborating the above, Abdalla alluded to the fact that big Data Analytics (BDA) integration with Disaster Risk Management (DRM) offers revolutionary possibilities to improve decision-making and promote environmental sustainability in preparedness, response, recovery, and resilience.[38] The potential of BDA to revolutionise risk prediction, monitoring, and management at every stage of the DRM cycle is becoming increasingly apparent. BDA facilitates risk prediction, decision-making, and resource optimisation by utilising data from sources like sensors, social media, satellite images, and Internet of Things devices.

Tozier de la Poterie et al. stated that both scientific and Indigenous risk knowledge must be updated in light of climate change to consider new "normal" risk levels, heightened uncertainties, and extreme events that might not be covered by traditional warning systems.[39] Increasing these systems' complementarities can make them more resilient. In the face of environmental change, hybrid systems that systematically examine, record and contrast traditional cues with instrumental observations are more adaptable, culturally appropriate, and better adapted to maintain community confidence. Arendse et al. posited that effective prevention, readiness, response, and recovery depend on community involvement in disaster management.[40] It entails actively assisting vulnerable communities in recognizing, evaluating, and controlling disaster risks. Increased resilience and decreased vulnerability are the eventual results of empowering communities through awareness campaigns, training, and capacity building. It is essential to have both the political will to establish policy and allocate the necessary resources, as well as enough public knowledge to identify and manage risk. Building resilience and reducing the effects of disasters requires public participation in disaster risk management, or DRM.

In EWS, real-time data sources, especially sensors and remote sensing technologies, are essential. In EWSs, sensors are essential. They gather data in real time, extract it into databases, and combine it with other systems, such as the Geographic Information System (GIS). They are essential for gathering data to evaluate the severity of crisis events, creating forecasting models, and analysing the scope of previous occurrences. Empirical data are useful for assessing the impact or severity of crisis occurrences in addition to real-time data. They play a particularly important role in crisis management within EWSs. Sensors identify the existence and value of input data based on how they are configured.[41] Therefore, the integration of real-time sensor data with analytical systems offers opportunities to strengthen warning systems and is crucial to improving the accuracy, timeliness, and effectiveness of early warning systems in disaster risk management.

ICAT highlighted that the significance of considering the M&E of MH-EWS and its results in the larger context of adaptation, and any gaps that may still exist in a nation's response to climate change,

[37] Namita Poudel et al., "Big Data Challenges and Opportunities for Disaster Early Warning System," *Prevention and Treatment of Natural Disasters* 3, no. 1 (June 24, 2024), https://doi.org/10.54963/ptnd.v3i1.283.

[38] Suliman Zakaria Suliman Abdalla, "Data-Driven Innovations in Disaster Risk Management: Advancing Resilience and Sustainability through Big Data Analytics," *Progress in Disaster Science* 27 (October 2025): 100451, https://doi.org/10.1016/j.pdisas.2025.100451.

[39] Tozier de la Poterie et al., "Strengthening Early Warning Systems for All: Evidence and Lessons from Last-Mile Communities."

[40] Arendse et al., *Strengthening Disaster Resilience and Responses: South African Perspective (11th G20 Parliamentary Speakers Summit)* .

[41] Daniel Chovanec et al., "A Component-Based Approach to Early Warning Systems: A Theoretical Model," *Applied Sciences* 15, no. 6 (March 15, 2025): 3218, https://doi.org/10.3390/app15063218.

has been another lesson learned.[42] For instance, the 2022 floods in the eThekwini Municipality showed that a variety of factors mediate the effects of weather and climate change, emphasising that MH-EWS and its M&E are just one of the essential components required in an efficient disaster risk and climate change adaptation response. In particular, a municipality may have an efficient EWS that generates trustworthy alerts shared with the public, but the effects are influenced by additional variables such as the severity and length of the hazard occurrence. This emphasises the significance of concurrently addressing elements related to loss and damage as well as the necessity of M&E of adaptation measures and resilience planning.

The perspectives are strongly aligned with the principles of the Sendai Framework for Disaster Risk Reduction. According to the Sendai Framework, lawmakers must create new or improved DRR laws, develop national and local DRR strategies, increase funding for DRR budgets, and hold governments responsible for DRR actions to lower disaster risks and safeguard their constituents.[43] A particularly promising approach to improving flood risk management for vulnerable communities such as Port St. Johns is a mix of technology innovation, participatory governance, local knowledge integration, and community awareness programs. The success of warning systems in such situations is probably going to depend on locally grounded and context-sensitive approaches, given the socioeconomic and infrastructural weaknesses mentioned in previous sections.

RECOMMENDATIONS

Community-based disaster risk reduction (CBDRR)

The community-based disaster risk reduction CBDRR strategy has been adopted by NGOs as a recognised method for building resilient communities through DRR projects. Global institutions such as the International Federation of Red Cross and Red Crescent Societies later adopted the technique, which was initially used by NGOs in impoverished countries. Local governments are gradually using this tactic to strengthen ties between grassroots organisations and the official disaster management framework. Thus, adopting CBDRR strengthens local ownership, improves community resilience, and promotes more inclusive and effective disaster risk reduction strategies.

Indigenous-Led Flood EWS

Tozier de la Poterie et al. reported that Agro-pastoralist communities in Ethiopia's South Omo Zone have created Indigenous early warning systems that combine technical, ecological, and spiritual knowledge to predict and address floods. These include community-built flood barriers, natural indicators such as plant blooming and rising river levels, and divination based on dreams. These locally-led mechanisms have been successful in increasing readiness and organising action despite having little infrastructure and insufficient connections to formal systems. Their accomplishments demonstrate the value of community ownership and the need for formal integration and the incorporation of indigenous knowledge into national frameworks for disasters. Hence, flood-prone coastal areas such as Port St Johns should try to make use of indigenous-led flood EWS.

A Multi-Hazard Approach

According to Šakić Trogrlić et al., people are vulnerable to a variety of risks, each with a distinct probability of happening. For example, individuals may reside in a multi-hazardous area that is vulnerable to geophysical and hydrometeorological hazards, and many hazards may also interact. Therefore, the adoption of a people-centric approach to early warning would create an early warning system that addresses all dangers that have an impact on the local population. This offers a comprehensive awareness of potential dangers and their intricate, interconnected relationships, including whether these hazards manifest singly, concurrently or cumulatively. Bhurtel et al. also support this view by saying Big data technology can be effectively used to manage and anticipate risks,

[42] Thambiran et al., "Initiative for Climate Action Transparency-ICAT First Set of Refined Tools and Methodologies Based on Lessons Learned in Pilot Testing: Multi-Hazard Early Warning Systems Monitoring and Evaluation Framework for South Africa."

[43] Arendse et al., *Strengthening Disaster Resilience and Responses: South African Perspective (11th G20 Parliamentary Speakers Summit)* .

as demonstrated by case studies such as the Tamil Nadu System for Multi-Hazard Potential Impact Assessment. These case studies offer specific illustrations of how comparable solutions can be advantageous in different areas or situations. Therefore, adopting a multi-hazard, people-centred approach enhances the effectiveness of early warning systems by addressing interconnected risks and improving overall community preparedness and resilience.

Alignment with Global Frameworks

The South African government is actively working to achieve the D target of the Sendai Framework for Disaster Risk Reduction, which seeks to significantly reduce interruptions in essential services and damage to vital infrastructure by 2030. According to the Sendai Framework, lawmakers should create new or improved DRR laws, develop national and local DRR strategies, increase funding for DRR budgets, and hold governments responsible for DRR actions in order to lower disaster risks and safeguard their constituents. This alignment is therefore critical for strengthening disaster resilience in South Africa, particularly in high-risk areas such as the Eastern Cape Province and Port St Johns, where improved implementation can significantly reduce vulnerability to flooding and infrastructure damage.

Invest in Communication Infrastructure

Regardless of the quality of the message, inadequate weather stations, erratic electricity, poor mobile coverage, and a lack of communication devices physically hinder warnings from reaching isolated and vulnerable people. Inclusive EWS is unattainable without consistent investment in last-mile connectivity and disaster-resistant backup systems. Community radio stations that are powered by solar panels or generators must be established or strengthened since they frequently continue to operate in the event that mobile and internet networks fail. Therefore, strengthening such communication infrastructure is essential to improve early warning reach and reliability in vulnerable regions, particularly in the Eastern Cape Province and coastal areas such as Port St Johns.

CONCLUSION

In conclusion, although South Africa has made notable progress in adopting impact-based severe weather early warning systems, their effectiveness in flood risk management remains constrained by persistent institutional, socio-economic, and communication challenges. Institutional fragmentation, weak stakeholder coordination, policy implementation gaps, and socio-economic inequalities continue to limit communities' ability to access, interpret, and act upon warning information. Furthermore, language diversity and inadequate dissemination mechanisms reduce the reach and usability of early warning messages, particularly in vulnerable and informal settlements. Nevertheless, advances in real-time data integration, remote sensing, digital communication technologies, participatory governance, and the incorporation of indigenous knowledge present important opportunities to strengthen flood preparedness and community resilience.

Beyond synthesising the existing literature, this conceptual review contributes to scholarship by integrating fragmented theoretical, policy, and institutional perspectives into a coherent framework to understand the effectiveness of impact-based flood early warning systems in South Africa. The review identifies the interrelationships between governance, communication, technological capacity, and socio-economic vulnerability as key determinants of warning effectiveness. It also highlights important knowledge gaps, including the limited empirical evidence on community responses to impact-based warnings, the effectiveness of multi-channel warning dissemination, and the integration of indigenous and scientific knowledge in flood-prone communities. These gaps underscore the need for context-specific empirical studies in high-risk localities such as Port St Johns to validate and extend the conceptual insights presented in this review. This research will support the development of more inclusive, evidence-based, and locally responsive flood risk management strategies.

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