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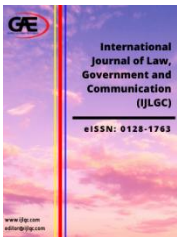


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# FLOOD EARLY WARNING SYSTEMS (FEWS) IN ENHANCING DISASTER RISK REDUCTION AND COMMUNITY RESILIENCE: A SYSTEMATIC REVIEW

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**Abstract:**

The increasing frequency and severity of flood events necessitate robust Flood Early Warning Systems (FEWS) to mitigate disaster impacts and enhance community resilience. This systematic review aims to synthesise recent advances and practices in FEWS and their effectiveness in fostering resilient communities. This study addresses challenges of integrating technological innovations and community engagement to improve flood preparedness and response. Methodologically, a comprehensive scholarly literature search was conducted using Scopus and Web of Science databases, covering publications from 2021 onwards. The flow of the study is based on the PRISMA framework. The analysis was based on a total of (n=238) articles were screened, with (n=32) studies meeting the inclusion criteria. The study yielded results indicating that integrating technological innovations, community engagement, local knowledge, policy intervention, and investment are imperative in improving community resilience through Flood EWS. The economic analyses

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indicated that such systems are cost-effective and have strong community backing. Notably, the identification and classification of digital tools in disaster education, local knowledge in context, the role of community engagement, and the technological systems, as well as the place and importance of policy and cost intervention, all emerged as important themes. In this regard, the study makes a call for further research towards the development of integrated, adaptable, and community-based FEWS frameworks that cater to the needs and conditions of specific places. By so doing, this research provides a comprehensive review that supplies critical information for practitioners, policymakers, and researchers working advancement and implementation of flood EWS to enhance resilient communities in the wake of increasing flood risk.

**Keywords:**

Flood; Early Warning Systems; Community; Resilience, Disaster Risk Reduction

## Introduction

One of several essential components of the Disaster Risk Reduction (DRR) strategy is the Early Warning System (EWS), defines a kind of system that allows to warn communities of threats, which are going to become disasters, and at the same time that will give enough time for rescue action. In other words, EWS is a warning service that can limit the death toll and the number of injured, preventing disaster's physical and economic damage. The EWS implementation cycle consists of risk surveillance, designing a set of measures, forecasting the future, informing people about the EWS introduction, their preparation and response to the alarm signals, realization, monitoring, evaluation of forced practices, and reporting of lessons learned. EWS is the first safety net that can warn the community in advance, that is, in time to take action and escape.

Climate change has increased the frequency and the severity of floods, and, by extension, the ways in which communities should be resilient to such disasters. EWS are among the most effective strategies in managing risk particularly in relation to floods. The concept of EWS is founded on the idea that the community should be warned of the threat of a flood occurring in advance, and should be provided with time to take preventive measures to reduce the impact (Barbetta et al., 2022; Shah et al., 2022). Traditionally, the methods of managing risks of flood included building flood retaining walls, drainage channels and other hard infrastructures (Fryirs et al., 2023). While such efforts are important, they are based on the assumption that the event is likely to be recognised and the flood predictable enough which is often not the case. This is the reason why technology-based solutions such as the Flood Early Warning System (FEWS) are vital, as they are based on data from different sources such as weather forecasting, hydrology, and topography data to predict flood events and deliver early warnings to at-risk communities. The objective of this article is to explore how such methods can be optimised to the best effect when it comes to improving resiliency of communities to floods and how technological innovation in FEWS can contribute to the effectiveness of this system.

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Related to the objective of this study, the review questions in this systematic review are:

RQ1: How can technological innovations improve the accuracy and reliability of FEWS?
RQ2: What role does community participation play in the effectiveness of FEWS?
RQ3: How can local knowledge be integrated with technological solutions to enhance FEWS?

***Evolution of Flood Forecasting***

Flood is the most recurring of all the natural disasters and causes great loss in terms of the life, property, and infrastructure (Shah et al., 2022). EWS being one of the most important tools in the DRR strategy, its aim is to increase community resilience during the event of flooding. The development of EWS for floods has been significantly influenced by the Sendai Framework for Disaster Risk Reduction 2015-2030. Sendai Framework being adopted by the Members of the United Nations, stresses on the need for people-centered EWS as one of the agreement's priorities. Specifically, the Sendai framework's seventh target is to "substantially increase the availability of and access to multi-hazard early warning systems and disaster risk information and assessments to the people by 2030" (UNISDR, 2015). Here, the shift has been encouraged for a more community-centered approach to the EWS. The river FEWS's evolution has covered several decades and has marked critical periods in the technologic and methodologic change towards flood risk reduction. The history supports a gradual development towards more sophisticated technologic, integrated and community-focused tools for management and orientation in flood EWS, aiming at a more reduced flood risk and resilient community.

Originally, flood warning systems were very basic, relying on direct observation and experience of local communities (Dekens, 2008). Communities often use natural signs like rainy weather and ascending of river water to predict floods (Dekens, 2008; Vandaele et al., 2023). This system, though very useful, had its drawbacks. Its accuracy is low due to the inability to predict the occasional heavy rain over the horizon, and the range of warnings is also limited. In the second half of the 20th century the progress of hydrological and meteorological technologies enabled EWSs to use scientific data to improve their forecasting accuracy. For example, installing a network of rain gauges and water levels in critical areas allows to monitor the weather and water situation more accurately (Dennis et al., 1999). Since the satellites technologies became available in 1970s and 1980s, weather and the Earth's surface monitoring stopped to be general and became detailed. The Landsat satellite is the example of these technologies; it is used in monitoring the earth's surface as well as global weather, and it is a very important part of modern EWS (Hemati et al., 2021; Molder et al., 2022). Furthermore, thanks to the introduction of high speed computing, also in the 1970s and 80s, it became possible to construct big complex models that improve the forecasting process. Really complex hydrological and meteorological models are able to process substantial amount of input data and therefore provide more accurate results (Chang & Guo, 2020; Michalakes, 2020).

In the following decades, however, there was a growing recognition of the importance of integrating scientific data with local knowledge. It has been shown that approaches that combine the scientific warnings and the experience of the local communities can enhance the effectiveness of the EWS (Hermans et al., 2022a; Meléndez-Landaverde & Sempere-Torres, 2022; Sipe et al., 2023). Today, the EWS is increasingly unified. It unites data from satellites, weather radar, and land measurement stations, as well as having more input from the community to create more comprehensive warnings and information signals (Hermans et al.,

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2022a; Meléndez-Landaverde & Sempere-Torres, 2022; Potutan & Suzuki, 2023; Sipe et al., 2023). The advancement of information and communications technology (ICT) has made it possible for the 21st century to have the first real-time warning system. The system makes use of numerous sensors, Internet of Things (IoT) technologies, and communication channels, such as SMS and mobile applications to notify potentially affected residents of the danger. For instance, several countries are now using technologies, such as WhatsApp in their flood EWS to ensure that no resident is uninformed of the warning (Kavitha et al., 2024a). An example of the implementation of the FEWS based on the IoT is provided in Figure 1 (Esposito et al., 2022). More emphasis is placed on the integration of the citizen science and participatory approach, as can be seen from the development of the community-based flood EWS in several countries.

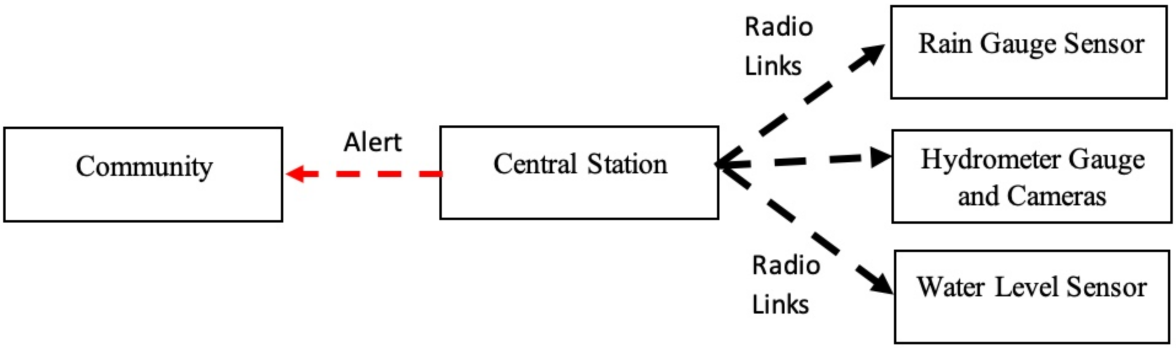


**Figure 1: Example Implementation of a FEWS based on the IoT** (Esposito et al., 2022)

***Structural and Non-Structural Components of EWS in DRR***

EWS in DRR consist of both structural and non-structural. From the structural point of view, EWS encompass the physical and technological aspects that help anticipate and deliver timely and meaningful warnings to people and at-risk communities vulnerable to disasters (N.Donratanapat et al., 2020; Perera et al., n.d.). On the other hand, from a non-structural standpoint, early warning in DRR focus on communication, risk prediction, risk, and community involvement. These systems promote preparedness, prevention, reduction, and where appropriate, forced responses. (Acosta-Coll et al., 2018; Song et al., 2019). To be truly effective, an efficient EWS must be viewed within the context of an enduring framework or system that includes various stakeholders such as a community, scientists, authorities, and policymakers engaged in ongoing interaction and communication of risks in order to strengthening DRR efforts (Hermans et al., 2022b). Therefore, EWS in DRR consist of both structural elements, such as technologically based communication systems, and non-structural elements, such as partnership building and community involvement.

***Mitigating the Flood Impact***

EWS serve as timely conveyors of the potential occurrence of floods and provide adequate time for preparation. In addition to that hazard-specific information is provided, like at-risk sub-infrastructure, projected path of flood, and other pre-warning and preventive measures, is studied provided to the local community. Proper hazard monitoring, forecasting, risk communicated to appropriate authorities for further communication to the community, creates a multi-disciplinary system that improves coordination. (Hammood et al., 2021; Hermans et al., 2022c; Hong & Shi, 2023; Perera et al., 2020). Community-based EWS are more effective as they involve the community in the early warning process and helps in enhancing the response

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capacity and preventive practices. Global approaches, like innovative flood hazard mapping methods, can complement local EWS by providing reliable flood extent forecasts based on global data, aiding in preparatory actions and enhancing overall flood-resilient practices (Pandey & Basnet, 2023a).

## Methodology

### *Identification*
The systematic review procedure employed three fundamental stages to select a substantial number of relevant publications for this study. In the initial stage, keywords were selected. Since this SLR aims to study how an EWS increases community resilience to flood events, the keyword search is configured as community AND resilience AND flood AND "early warning system". Synonymous terms were identified using an online thesaurus and prior research. Subsequently, search strings were developed for the Scopus and Web of Science (WoS) databases (refer to Table 1), encompassing all appropriate keywords. A total of 238 publications were successfully acquired for the current research project in the first phase of the systematic review procedure from both databases.

**Table 1: The Search String**

| | |
|---|---|
| Scopus | TITLE-ABS-KEY ( ( community ) AND ( resilien* OR volatile OR "quick to recover" OR rebound* OR tough OR strong ) AND flood AND ( early AND warning AND system ) ) AND ( LIMIT-TO ( DOCTYPE , "ar" ) ) AND ( LIMIT-TO ( LANGUAGE , "English" ) ) AND ( LIMIT-TO ( SRCTYPE , "j" ) ) AND ( LIMIT-TO ( PUBYEAR , 2021 ) OR LIMIT-TO ( PUBYEAR , 2022 ) OR LIMIT-TO ( PUBYEAR , 2023 ) OR LIMIT-TO ( PUBYEAR , 2024 ) )<br><br>**Date of access: May 2024** |
| WoS | ( community ) AND ( resilien* OR volatile OR "quick to recover" OR rebound* OR tough OR strong ) AND flood AND ( early AND warning AND system ) (All Fields) and 2021 or 2022 or 2023 or 2024 (Publication Years) and Article (Document Types) and English (Languages)<br><br>**Date of access: May 2024** |

### *Screening*
The collection of potentially relevant research materials is examined to identify content aligning with the predefined research questions in the screening process. Criteria related to content commonly applied in the screening phase encompass selecting research materials centred on the EWS in flood risk reduction towards community resilience. Removal of all duplicate papers from the retrieved papers occurs at this stage.

The initial screening phase excluded 141 publications, whereas the subsequent phase assessed 97 papers based on this investigation's varying exclusion and inclusion criteria (refer to Table 2). The primary criterion employed was literature (research papers), as it is a key source of practical recommendations. This category encompasses reviews, meta-syntheses, meta-analyses, books, book series, chapters, and conference proceedings that were omitted from the

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latest study. Additionally, the review was restricted to English publications. It is important to note that the approach specifically targeted the timeframe of 2021-2024. Ultimately, 21 publications were dismissed due to duplication criteria.

**Table 2: Inclusion and Exclusion Criteria**

| Criterion | Inclusion | Exclusion |
|---|---|---|
| **Language** | English | Non-English |
| **Time line** | 2021 – 2024 | < 2021 |
| **Literature type** | Journal (Article) | Conference, Book, Review |

***Eligibility***
In the third phase of the eligibility assessment, a compendium of 76 articles was compiled. At this juncture, a thorough scrutiny of the titles and fundamental content of all the articles was carried out to validate their concordance with the inclusion criteria and their pertinence to the research objectives of the ongoing study. Consequently, 44 data/papers/articles were excluded due to reasons such as being out of the field, titles lacking significance, and abstracts not being related to the study's objectives, supported by empirical evidence. Consequently, a total of 32 articles persist for the forthcoming review.

***Data Abstraction and Analysis***
An integrative analysis was utilised as a key assessment approach in this research to scrutinise and amalgamate various research frameworks (quantitative methodologies). The primary aim of the proficient investigation was to pinpoint pertinent subjects and subcategories. The data acquisition phase constituted the initial stage in formulating the central theme. As depicted in Figure 2, the authors meticulously scrutinised a compilation of 32 publications for assertions or content germane to the subjects under investigation. Subsequently, the authors assessed the noteworthy present studies concerning flood resilience communities utilising the EWS. The methodologies employed across all studies, alongside the research findings, are under scrutiny. Subsequent to this, the author engaged in a collaborative effort with fellow co-authors to delineate themes grounded in the evidence within the specific context of this study. A detailed log was maintained throughout the data analysis procedure to document any analyses, perspectives, enigmas, or other considerations pertinent to the interpretation of the data. Finally, the authors juxtaposed the findings to identify discrepancies in the thematic development process. It is important to highlight that in the event of any disparities among the concepts, the authors engage in internal discussions to address them. The resultant themes were subsequently refined to ensure coherence. The analysis was selected by two specialists, one specialising in EWS studies and the other in disaster risk management, to ascertain and affirm the validity of the issues at hand. The expert evaluation stage guarantees every subtopic's significance, lucidity, and appropriateness by establishing the domain's validity.

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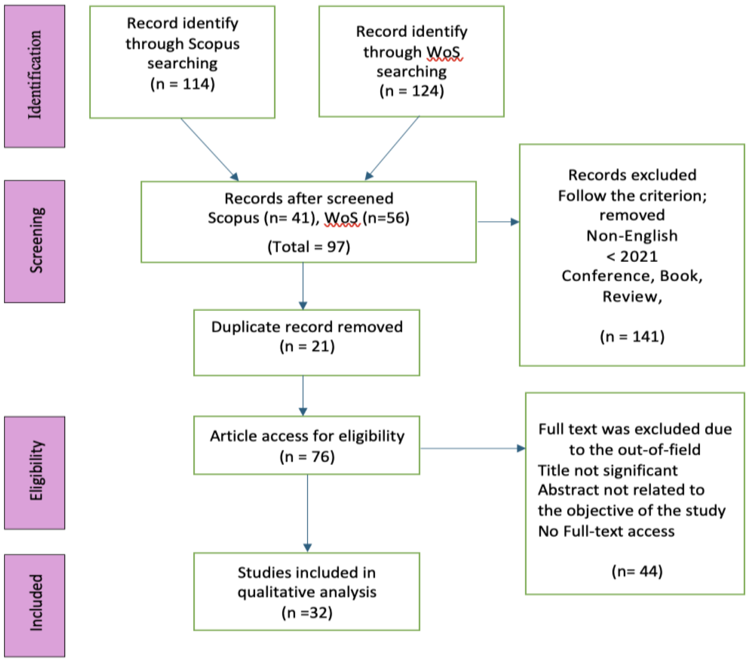


**Figure 2: Flow Diagram Of The Proposed Searching Study** (Moher et al., 2009)

## Results and Finding

### *Technological Innovations in Flood Early Warning Systems*

The advances and methods of the FEWS use to help communities against floods are based on the technologies studied. With the involvement and employment of such technologies as machine learning and artificial intelligence, as well as the integration of real-time data, these innovations succeed in enhancing the accuracy, efficiency, and effectiveness of the mechanisms and tools developed to predict and forecast sequential flood threats. Various methodologies, prediction models, validation mechanisms and techniques, and the employed innovations and approaches associated with the EWS play a crucial role in reducing the overall impact of flood threats on communities susceptible to the disaster.

The development of technological means of Flood Early Warning Systems (FEWS) has become necessary to improve community resilience against the growing frequency of these natural events. They provide quick and accurate data that allows for adapted proactive steps and better flooding risk management. As shown in the study by Mitheu *et al.* (Mitheu et al., 2023), one of the most important aspects is the transition to impact-based early warning systems that incorporate flood forecasts and knowledge about local populations. This approach has been demonstrated to be much more accurate in flood detection as compared to traditional hazard-based systems. Machine learning methods are increasingly applied to improve flood prediction models. The study by Kaushik and Kumar (Kaushik & Kumar, 2023), outlines the use of Gene Expression Programming (GEP), Artificial Neural Networks (ANN), and Support Vector Machines (SVM) for this purpose. Another example is the work by Ian *et al.* (Ian et al., 2023) that introduces the Bidirectional Attention-based Long Short-Term Memory (LSTM) Storm Surge Architecture (BALSSA) model, which allows predicting the occurrences of such natural phenomenon and improve evacuation and prevention measures in coastal areas by relying on its machine learning element and the large dataset instead of manual programming

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approaches. These instances represent important steps toward improving community resilience against flooding.

The accuracy of the rainfall forecast is one of the important things to consider in Landslide and Flash-Flood (EWS). Melo et al (Melo et al., 2023), made an analysis of the accuracy of a 3-day rainfall forecast for landslides warning in R software. The results of the analysis imply that "automated procedures are essential to guarantee regional reliability". Macharia *et al.* (Machariaet al., 2023), developed a streamflow forecasting model for flood risk management in Rwanda using machine learning and remote sensing technologies. The model indicates that the Gradient Boosting Machine model has better performance. Wee *et al.,* (Wee et al., 2023) presented the Flood Impact-Based Forecasting System, which leverages fuzzy inference methodologies and Google Maps for visualising potential flood scenarios. This system aids decision-makers in comprehending the magnitude and severity of floods, facilitating pre-emptive actions to alleviate socioeconomic repercussions and bolster community resilience.

Effective communication and user-friendly forecast products are important for increasing the uptake of climate services. Gudoshava *et al.,* (Gudoshava et al., 2022) highlight the importance of co-producing climate services using real-time sub-seasonal to seasonal forecasts in Eastern Africa. Low-cost flood monitoring systems, deployed through interagency collaboration, have proven effective in managing EWS, as demonstrated by Adesina et al. (Adesina et al., 2024) in Southeast Texas. Post-flood surveys, such as Mathew *et al.* (Mathew et al., 2021), in Kerala, India, emphasise the need for advanced warning systems and environmental conservation. Khadka *et al.,* (Khadka et al., 2024) stress the importance of addressing socioeconomic and environmental vulnerabilities to enhance resilience against glacial lake outburst floods in Nepal. To bridge the gap between advanced technology and vulnerable communities, Kavitha *et al.,* (Kavitha et al., 2024b) propose integrating modern communication methods like WhatsApp into FEWS, aiming to improve disaster preparedness and response in flood-prone areas.

In summary, technological progress in FEWS, including impact-based trigger systems, machine learning methodologies, advanced forecasting models, and cost-effective monitoring systems, can greatly bolster community resilience against flood hazards. Nevertheless, successful deployment necessitates the integration of localised data, effective communication, transnational collaboration, and the consideration of socioeconomic and environmental variables. Through the utilisation of these technological breakthroughs and the adoption of a comprehensive strategy, communities can better equip themselves to face and manage the difficulties brought about by floods, ultimately strengthening their overall resilience.

**Table 3: Findings and Future Research on Technological Innovations in EWS**

| Author(s) and Year | Objectives | Methodologies | Findings | Conclusion & Future Research |
|---|---|---|---|---|
| (Mitheu et al., 2023) | Impact-based early warning trigger system integrating flood forecasts with livelihood information for | Integration of flood forecasts with crop calendars, comparison with hazard-based systems | Impact-based system showed improved flood detection probability with fewer missed events compared | Explore the application of impact-based systems in different contexts |

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|---|---|---|---|---|
| | anticipatory actions | | to hazard-based systems | |
| (Kaushik & Kumar, 2023) | To predict shear stress distribution in compound channels with smooth converging floodplains using machine learning | Gene Expression Programming (GEP), Artificial Neural Networks (ANN), Support Vector Machines (SVM) | ANN model outperformed GEP, SVM, and other approaches in predicting floodplain shear force | Focus on refining machine learning models for more complex hydraulic scenarios |
| (Ian et al., 2023) | To enhance storm surge prediction using Bidirectional Attention-Based LSTM | Bidirectional Attention-Based Long Short-Term Memory (LSTM), analysis of historical and real-time data | BALSSA model achieved high accuracy with low MAE and RMSE, | Could integrate real-time alerts and adaptive systems for comprehensive risk management |
| (Melo et al., 2023) | To validate a 3-day rainfall forecast at the regional scale for landslide and flash-flood EWS | R software for data validation, comparison of forecasted and recorded rainfall data | Developed routine effectively validates rainfall forecasts | Apply this routine to other regions and integrate additional climatic variables |
| (Macharia et al., 2023) | To predict streamflow and flood events in Rwanda using machine learning and remote sensing for rural connectivity | Gradient Boosting Machine (GBM), Random Forest Model (RFM), Generalized Linear Model (GLM), | GBM model had highest skill in predicting flood events | Focus on improving flood prediction models and their integration with community-based warning systems |
| (Wee et al., 2023) | To develop a flood forecasting system using fuzzy inference techniques | Fuzzy Inference System, Google Maps for spatial visualization | Developed FIBF model provides timely flood impact warnings. | Enhance model accuracy and expand its application to other regions |

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| (Gudoshava et al., 2022) | To co-produce tailored sub-seasonal to seasonal (S2S) climate forecasts for resilience building in Eastern Africa | Co-production process, case studies of extreme rainfall and tropical cyclones | Co-produced forecasts effectively informed decisions in agriculture and disaster risk reduction | Future work should focus on sustained support for S2S datasets and improving forecast communication |
| (Adesina et al., 2024) | To deploy a shared low-cost flood monitoring system in Southeast Texas | Low-cost sensors, real-time data integration, web-based dashboard | Successful deployment of 73 sensor sites within 7 months, providing real-time flood alerts | Explore scalability and integration with other regional monitoring systems |
| (Mathew et al., 2021) | To assess flood impact in Kerala using post-flood surveys and in-situ measurements | Field survey, NCCR-Geo surveyor app for data collection | Identified severely affected regions and need for advanced warning systems | Focus on long-term solutions and community preparedness plans |
| (Khadka et al., 2024) | To assess risk and vulnerability of Nepalis to transboundary glacial lake outburst floods | Household surveys, analysis of risk perception and vulnerabilities | High risk perception and vulnerability in specific basins, need for improved public awareness | Enhance cross-border cooperation and resilient infrastructure development |
| (Kavitha et al., 2024b) | Develop an early flood monitoring and WhatsApp-based alert system | Integration of WhatsApp messaging with traditional SMS for flood alerts | Increased reach and efficiency of flood alerts, continuous monitoring of water levels | Explore broader applications and improvements in alert precision |

***Community Engagement and Participation in Flood Early Warning Systems***

Incorporating and engaging local communities in flood early warning systems (EWS) is essential for improving readiness and resilience. Active involvement of community members guarantees prompt and precise sharing of alerts, promoting proactive reactions and mitigating the consequences of flood calamities. This method capitalises on indigenous knowledge, fosters trust, and bolsters comprehensive DRR management.

The analysis of the primary discoveries in the examined articles indicates the relevance of co-design and stakeholder engagement in the creation of effective EWS is underscored in key discoveries, as evidenced by Miyamoto *et al.* (Miyamoto et al., 2022), in the Philippines. It is noted that the importance of public support and community involvement were discussed in the context of implementing the coastal flooding early warning systems as illustrated by Riama *et*

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*al.* (Riama et al., 2021), in Jakarta and Al-Mueed *et al.* (Al-mueed et al., 2021), in Bangladesh. In the circumstances, the argument proposed by Pandey and Basnet (Pandey & Basnet, 2023b), regarding the need for more international interaction to improve flood risk management is relevant in the development of these EWS. The technological progress indicates that the integration of monitoring, risk evaluation, and communication capabilities is possible, as shown by Haque *et al.* (Haque et al., 2024), in the creation of the Integrated Risk-based EWS for Bangladesh . Furthermore, the case of the adaptable EWS developed by Espejo *et al.* (Espejo et al., 2023) for Kiribati serves a similar purpose. Finally, studies by Jose Moises and Kunguma (Jose Moises & Kunguma, 2023) in Namibia and Langkulsen *et al.* (Langkulsen et al., 2022) in Thailand suggest that the consideration of socioeconomic and environmental aspects in the design of these EWS is paramount.

Moreover, enhancing resilience via multidimensional frameworks and exploring different aspects of resilience related to the community can be witnessed in the research in Malawi and Kabul City by Dewa, Makoka, and Ayo-Yusuf, (Dewa, Makoka & Ayo-Yusuf, 2023), as well as a study by Mushwani *et al.* (Mushwani et al., 2024). Such focuses reiterate the importance of infrastructure, local capacity, and special flood management policies for understanding flood resilience. In the Narayani Basin, the EWS was detected to be disconnected and low-performing. As such, the study suggests five significant elements of flood resilience enhancement, i.e. better technology in early warnings, community-oriented promotion of the EWS, timely warnings, tailored preparedness and response training, and flood-resilient housing, while analyzing case in the Pandey and Basnet (Pandey & Basnet, 2023b). As for the case in Kampung Jenagor, Malaysia, the research by Ghazali *et al.* (Ghazali et al., 2021) is concentrated on the development and deployment of an FEWS that would be capable of protecting the community from the risk of an overflow or the failure of Kenyir Dam. The main emphasis is placed on the ability of the systems to deliver the warning and ensure that people are always ready.

In conclusion, the necessity of the development of EWS that would be reliable and capable of ensuring flood resilience in the community is evident. Full deployment requires a combination of achievements in technology with a special community-oriented approach and improved cross-border and cross-sectoral cooperation. The continual enhancement and adjustment of EWS to harmonise with specific local requirements and circumstances are vital for the efficient management and reduction of flood risks.

**Table 4: Findings and Future Research on Community Engagement and Participation**

| Author's Name and Year | Objectives | Methodologies | Findings | Conclusion & Future Research |
|---|---|---|---|---|
| (Miyamoto et al., 2022) | Enhance flood resilience in Davao City, Philippines by social capacity and EWS | Co-design methodology, Online Synthesis System, Hydrological models | Developed real-time flood forecasting and climate change impact assessment; trained Facilitators | Integrating science-based knowledge with community practices |
| (Riama et al., 2021) | Measure public acceptance of | Survey, Cross-tabulation, Path analysis | High public acceptance with weak relationship | Increasing public awareness and |

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| | coastal flooding EWS in Jakarta | | between knowledge and community attitudes | engagement to enhance EWS effectiveness |
| (Pandey et al., 2023) | Explore transboundary flood resilience in Narayani and Mahakali Basins | Qualitative approach, State-centric and community cooperation analysis | Identified lack of state-to-state cooperation; emerging community cooperation and EWS | Encourage state and community cooperation to improve EWS and resilience |
| (Jose Moises & Kunguma, 2023) | Improve flood EWS in Kabbe, Namibia through socioeconomy | Situational analysis, Participatory approaches | Identified capacities for improved flood risk reduction through community engagement | Develop tailored EWS that address specific community needs |
| (Langkulsen et al., 2022) | Explore coping mechanisms for flooding and erosion in Southern Thailand | Summative content analysis | Effective surveillance systems, disaster preparedness, and risk mapping are essential | Implement modern technologies and pragmatic policies to enhance coping mechanisms |
| (Al-mueed et al., 2021) | Investigate the potential of volunteers in flood EWS dissemination in Bangladesh | Case study, Survey | Volunteers can effectively assist in EWS dissemination, enhancing community reach | Integrate volunteers into national policy for sustainable disaster management |
| (Haque et al., 2024) | Develop an IR-EWS to increase community resilience in Bangladesh | Dynamic Flood Risk Model, Community-based approaches | IR-EWS acceptable to the community with reasonable accuracy | Refine IR-EWS and enhance resilience through community |
| (Mushwani et al., 2024) | Assess resilience of Kabul City to flood hazards using AHP module | Mixed-methods, AHP analysis, GIS | Identified high social and physical resilience; lower institutional and technical resilience | Develop city-level flood management policies to enhance resilience |
| (Dewa et al., 2023) | Measure community flood resilience in rural Malawi | Multidimensional framework, Cluster analysis, Logistic regression | Identified infrastructure, EWS, and local human capacity as key resilience factors | Strengthen public health services to improve resilience |

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| (Espejo et al., 2023) | Develop an EWS for coastal inundation in Tarawa, Kiribati | Process-based forecasting, High-resolution wave model | Provided accurate water level predictions 7 days in advance, supporting informed decision-making | Improve baseline data for better coping with increased coastal hazards |
| (Pandey & Basnet, 2023b) | Analyze challenges of flood EWS in Narayani basin, Nepal | Qualitative approach | Identified fragmented and unreliable existing systems | Need for reliable technologies and community engagement, |
| (Ghazali et al., 2021) | EWS in Kampung Jenagor to increase flood resilience | Development and installation of a flood disaster EWS | Effective dissemination of warnings, improved community preparedness | Further improvements in warning dissemination techniques |

***Integration of Local Knowledge and Technological Solutions***

The integration of indigenous knowledge with technological innovations is imperative for the improvement of FEWS mechanisms. This collaboration capitalises on the advantages of community wisdom and cutting-edge technologies, leading to heightened precision, dependability, and situation-specific alerts. This unification nurtures robust communities that are more adept at pre-empting and addressing flood hazards proficiently.

The integration of renewable energy into FEWS presents a comprehensive strategy to bolster community resilience. Schismenos, Stevens, Georgeou, *et al.* (Schismenos, Stevens, Emmanouloudis, et al., 2022a) advocate for the amalgamation of these components to cater to both energy accessibility and flood response requirements. Furthermore, Bucherie *et al.* (Bucherie et al., 2022) illustrate the significance of fusing indigenous knowledge with empirical data in FEWS, thereby enhancing the precision and applicability of sudden flood alerts, especially in at-risk communities. These research works underscore the significance of all-encompassing, community-specific methodologies in fortifying resilience against flood hazards.

Assessing the efficacy of EWS in forecasting tsunami arrival times and flood extents is essential for enhancing evacuation strategies. Benazir and Oktari (Benazir & Oktari, 2024) stress the significance of conducting thorough investigations on the estimated time of arrival (ETA) along the Aceh coastline. In regions with limited data, characterised by Karst topography and mountainous terrain, Rozos *et al.* (Rozos et al., 2023) introduce a hybrid flood EWS that incorporates pre-simulated events and qualitative data. Torres-Freyermuth *et al.* (Torres-Freyermuth et al., 2022) point out the difficulties in predicting coastal hydrodynamic responses to hurricanes, underscoring the necessity of accounting for compound flooding and refining modelling techniques to improve EWS in coastal areas.

Affordable detectors and public research might play a notable part in boosting flood risk control in regions with limited data availability. Pandeya *et al.* (Pandeya et al., 2021) have proven the durability of sensors operated by the community in western Nepal, advocating for their assimilation into the current monitoring frameworks. Schismenos, *et al.,* .(Schismenos et a,

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2022) have underlined the potential of combined units for the production of hydropower and the issuance of flood alerts in communities situated along riverbanks. The participation of communities in the establishment of Flood Early Warning Systems (FEWS) is vital, especially in remote areas that are managing both energy shortages and exposure to flood hazards. Schismenos *et al.* (Schismenos et al., 2022) have deliberated on how engineering interventions with a humanitarian focus can aid in local risk mitigation and the advancement of socio-economic conditions. Yasmin *et al.,* (Yasmin et al., 2023) have suggested the use of a SMART approach, which supports a high level of involvement of the community at all levels of decision-making and, thus, supports grassroots efforts to increase the flood resistance.

To sum up, it must be stressed that the strategy must be comprehensive in support of using traditional knowledge in combination with technological developments to improve the FEWS. The means of increasing community resilience against flood may be linked to many different dimensions, including sustainable energy sources, local intelligence, reliable EWS, and participatory decision-making. If to consider ways to be taken to enhance the FEWS by overcoming the challenge of limited data, based on the reviewed studies, it is possible to say that improvements of predictive models, as well as usage of cheap sensors and participation in scientific research, allow communities to improve their preparedness and response to floods greatly. The results of the research reviewed in this paper prove the need to have a comprehensive situational strategy for resistance improvement, as well as prove the continuous need to keep searching for the ways to enhance the FEWS with creativity being brought to the top.

**Table 5: Findings and Future Research on Local Knowledge and Technological Solutions of EWS)**

| Author's Name and Year | Objectives | Methodologies | Findings | Conclusion & Future Research |
|---|---|---|---|---|
| (Schismenos, Stevens, Emmanouloudis, et al., 2022a) | To develop strategies for hydropower and flood response within a sustainable development framework. | Integrated systems approach | Demonstrated a community-centered approach that integrates renewable energy and FEWS. | Further exploration of combining renewable energy and flood resilience |
| (Bucherie et al., 2022) | To combine local knowledge with scientific data to improve flash flood warnings. | Social science methods, global datasets | Local knowledge and scientific data improve the understanding of flash flood. | Highlighted the potential for linking global datasets with local knowledge. |
| (Benazir & Oktari, 2024) | To assess tsunami risk and EWS efficacy for predicting flood extent | Nonlinear shallow water equation model, finite difference method | Highlighted critical ETA ranges and the need for optimized | Include comprehensive ETA investigations and wider |

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| | along the Aceh coast. | | evacuation plans. | observation areas. |
| (Rozos et al., 2023) | To develop a flood EWS for data-scarce, karstic, mountainous environments. | Hybrid (online-offline) FEWS | Effectiveness of a pre-simulated flooding events database and qualitative information. | Hybrid approach to other data-scarce locations. |
| (Torres-Freyermuth et al., 2022) | To assess hydrodynamic, morphodynamic, and hydrological responses to hurricanes on the Yucatan Peninsula. | Coastal flooding models, GPS measurements | Challenges in forecasting coastal hydrodynamic responses and the role of compound flooding. | Incorporating terrestrial processes and improving bathymetry and boundary conditions in future models. |
| (Pandeya et al., 2021) | To explore low-cost sensors and citizen science for flood risk management in western Nepal. | Citizen science-based hydrological monitoring | Feasibility of using low-cost sensors operated by non-scientists to collect reliable data. | Integrating sensing technology into existing monitoring practices. |
| (Schismenos, Stevens, Georgeou, et al., 2022) | Investigate flood response of communities in Greece and Nepal. | Community-led humanitarian engineering interventions | Hybrid unit for hydropower generation and flood warning is most preferred. | Prototype could be applied in different riparian areas. |
| (Yasmin et al., 2023) | To assess approaches in designing FEWS for mountainous river catchments. | SMART approach checklist for inclusiveness | Advocated for bottom-up initiatives and community engagement. | Focusing on local social and governance contexts. |
| (Schismenos, Stevens, Emmanouloudis, et al., 2022b) | Examine sustainability of renewable energy and flood EWS in remote communities | Scoping review of interventions in low and lower middle-income countries | Importance of institutional, social,economic, and technical indicators for successful EWS | Integrated renewable energy and flood warning systems |

**Discussions and Conclusions**

The integration of technological innovations within Flood Early Warning Systems (FEWS) represents a paradigmatic shift in community flood resilience enhancement, transitioning from traditional manual observation methodologies to sophisticated real-time monitoring frameworks. Contemporary FEWS leverage advanced sensor technologies, hydrological and meteorological modeling, and multi-channel communication platforms including SMS, mobile applications, and social media networks to deliver accurate, timely flood predictions, enabling proactive rather than reactive community responses. However, FEWS efficacy fundamentally depends on comprehensive integration approaches that synthesize advanced technology with

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community engagement, local knowledge incorporation, and broader socio-economic considerations. Community participation emerges as a critical determinant, with public acceptance, volunteer network optimization, and educational initiatives serving as essential implementation components. The research demonstrates that technological advancement alone is insufficient; sustainable flood resilience requires balanced approaches preserving human-centered elements while leveraging technological capabilities.

Technological innovations in FEWS have demonstrably strengthened community flood resilience through enhanced forecasting accuracy, real-time data provision, and improved communication mechanisms. The synthesis reveals that optimal flood resilience emerges from comprehensive approaches integrating technological advancement with community engagement, local knowledge systems, and inclusive decision-making processes. Successful FEWS implementation requires addressing socio-economic and environmental challenges while maintaining technological sophistication and community-centered methodologies. The evidence indicates that sustainable flood resilience cannot be achieved through technological solutions alone but necessitates holistic frameworks combining cutting-edge technology with community-based approaches and strategic partnerships. This integrated methodology ensures communities develop both preparedness capabilities and responsive capacities to address evolving flood hazards effectively.

Future research should prioritize several critical areas to advance community flood resilience. First, investigation into scalable low-cost sensor technologies and citizen science methodologies could address persistent data scarcity challenges in vulnerable regions globally. Second, comprehensive evaluation of hybrid flood Early Warning Systems across diverse geographical and socio-economic contexts would enhance understanding of their applicability and effectiveness. Research should examine optimal integration strategies for renewable energy systems within flood warning infrastructures, particularly in remote or resource-constrained communities. Additionally, longitudinal studies assessing the sustainability and long-term effectiveness of community-based FEWS implementation would provide crucial insights for policy development and resource allocation.

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