The Systematic Disaster Management Approach to Assessing Early Warning Systems in South Sulawesi: A Review

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ABSTRACT

Disaster risk in South Sulawesi, Indonesia, has increased owing to environmental degradation, population growth, and climate change. The employment of Early Warning Systems (EWSs) is fundamental to disaster risk reduction strategies aiming to provide timely and actionable information and thus minimize life loss and damage. This paper reviews EWS effectiveness in South Sulawesi, deploying a systematic disaster management approach that incorporates mitigation, preparedness, response, and recovery phases. Implementation gaps, community participation, technological infrastructure, institutional coordination, and local knowledge integration are analyzed through a literature-based review of academic articles, government documents, and case studies from 2015 to 2024. The review highlights the importance of multi-sector collaboration, proposing a more inclusive and localized approach to improve disaster resilience in

South Sulawesi. It is demonstrated that EWS competence relies on the integration of community involvement and technological innovation, while effective communication in fostering trust and preparedness to address flood hazards is also highlighted.

Keywords-floods; multi-layered EWS; hazard monitoring; community participation

I. INTRODUCTION

Disasters, whether sudden or prolonged, disrupt and threaten the lives and livelihoods of communities [1]. Natural disasters manifest in various forms, including floods, landslides, earthquakes, tsunamis, wildfires, and disease outbreaks [2, 3]. These hazards can result in significant destruction, life loss, and long-term economic setbacks. Located in Indonesia, one of the most disaster-prone countries, South Sulawesi is vulnerable to hydrometeorological events, such as floods and landslides. To mitigate these risks, EWS plays a vital role as a national disaster risk reduction strategy. However, in many areas of South Sulawesi, EWS remains underutilized and ineffective, hindered by technical limitations, institutional gaps, and socio-cultural factor barriers. A systematic approach to disaster management, including preparedness, response, recovery, and mitigation, offers a more holistic framework for evaluating and strengthening early warning mechanisms.

As climate change intensifies the frequency and severity of natural hazards, the need for an effective and responsive EWS has become more urgent [4, 5]. Flooding is one of the most frequent and destructive events, often triggered by intense rainfall and worsened by inadequate drainage systems [6-9]. Contributing factors include variability in rainfall, the morphology of river basins, soil characteristics, changes in land use, and the loss of green spaces due to rapid urban growth, all of which may result in increased surface runoff and a greater likelihood of flash floods. Climate change is exacerbating floods worldwide, causing life loss, property damage, and economic setbacks. In South Sulawesi, frequent flooding is driven by heavy rainfall, inadequate drainage, and geological vulnerabilities. Flash floods in Amman (2019 and 2020) and widespread flooding in South Sulawesi in May 2024 highlight the magnitude of the threat influencing six districts, displacing thousands, and causing multiple fatalities [10-12]. These recurring events stress the necessity for disaster management strategies and more resilient infrastructure to safeguard vulnerable communities from the growing frequency of extreme weather events.

Floods were the most common disaster in 2023, with 164 occurrences having been recorded. Indonesia documented 5,400 natural hazards that year, with floods ranking third in frequency [13, 14]. Every district in South Sulawesi faces a significant flooding risk, with water levels potentially exceeding 1.5 m [15]. EWS entails hazard monitoring, communication, and community preparedness [16, 17], being, thus, crucial for flood impact reduction. However, insufficient infrastructure remains a barrier in South Sulawesi. Effective forecasting models and community involvement are essential for EWS success. Empowering communities with accurate, timely warnings enables a quicker response and decreases vulnerability. Systems, like the Dynamic Flood Risk Model (DFRM), successfully tested in Bangladesh, demonstrate the potential of combining risk indicators with action plans to build resilience [18-21]. Strengthening EWS and raising public awareness are key contributors to sustainable disaster risk reduction.

The Emergency Water Information Network (EWIN) is a powerful tool for managing flood risks by integrating early warnings, real-time flood monitoring, and instant notifications [22]. Deployed in Colima, Mexico, the system integrates hydrological and meteorological stations, mobile "drifter" monitors, and data collection devices to provide timely and accurate information. EWIN ensures that decision-makers and the public receive crucial updates, facilitating swift evacuations during floods. As the latter become more frequent due to climate change and the growing energy in weather systems, real-time data have become more valuable than historical records for flood forecasting. While historical hydrological data help modify prediction models [19, 23], the rapid increase in water levels, often occurring within six hours of heavy rainfall, requires real-time data to predict and respond to floods [19, 24]. Effective flood management relies on an integrated approach that entails community involvement. Although few studies have focused on public opinions regarding Flood Risk Management (FRM) measures, existing research highlights the critical role communities play in decision-making [25, 26]. The Integrated Flood Risk Management and Adaptation Strategy (IFRMAS) helps uncover misconceptions, understand local flood risk perceptions, and develop better communication techniques. Engaging the community not only reduces risks against human lives and property, but also accelerates response times by influencing local networks, relationships, and innovative solutions. The present review evaluates the EWS efficiency in South Sulawesi, focusing on flood-related disasters.

II. MATERIALS AND METHODS

In the current work, a secondary research approach was deployed, drawing on a wide range of existing data, scholarly literature, and real-world case studies related to the implementation of EWS and disaster management practices within the broader disaster risk reduction framework. A comprehensive literature review was conducted to gather relevant information from academic journals, government publications, disaster management agency reports, and reputable international sources. Studies published from 2015 to 2024 were examined, focusing on topics, such as flood risk, EWS performance, and disaster preparedness in South Sulawesi. These sources provided the foundational data and context for the performed analysis. A structured analytical framework was applied to evaluate EWS performance based on certain key criteria: timeliness of alerts, communication effectiveness, stakeholder coordination, and the socio-economic impact of flooding events. This framework was established on the disaster risk management theory and was adapted to the local context of South Sulawesi, allowing for an evaluation of the system's strengths and areas for improvement. The proposed methodology is structured around several main components, as shown in Figure 1.

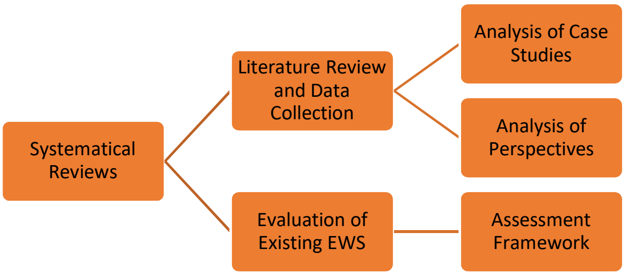

Fig. 1. Research methodology.

Combining the methodological elements presented in Figure 1 is essential for developing a thorough understanding of how EWSs function within the complex disaster context of South Sulawesi. This multi-dimensional approach extends beyond evaluating the technical EWS performance, since it also considers the human and institutional factors rendering it competent. By using this integrated perspective, the present research highlights systemic challenges and identifies opportunities to strengthen disaster resilience in vulnerable communities.

III. RESULT AND DISCUSSION

Various studies have investigated the design, implementation, and challenges of EWS for flood management across diverse contexts. Community-based approaches and institutional challenges were explained using both quantitative and qualitative methods to analyze community behaviors in Malawi [24]. Their findings revealed that while Civil Protection Committees, governmental departments, NGOs, and faith-based organizations are actively involved in community-based EWS, their effectiveness is limited by capacity constraints and bureaucratic issues. On the other hand, several studies have concluded that advanced technological innovations will be used in monitoring and prediction to improve flood warning accuracy [26-29]. A river water level monitoring system was developed using video cameras, computer vision, image processing, and IoT technologies. This system successfully identified river boundaries and water levels in both indoor and outdoor testing environments [27]. Similarly, a mobile-based early flood warning system that integrates communication technologies, Geographic Information Systems (GIS), Multi-Attribute Decision Making (MADM), and data mining can improve emergency response and evacuation planning through real-time risk assessment [28]. Additionally, a flood detection method using quantile estimation instead of Kendall's tau within the Copula-based Statistical Downscaling (CSD) framework successfully issued early warnings for 10 out of 12 recorded flood events, demonstrating high predictive capacity [29]. Furthermore, the calibration of rainfall-runoff models in Spain was enhanced by applying Hybrid Particle Swarm Optimization (HPSO), which proved to be faster and more accurate than other algorithms, with minimal parameter uncertainty validated through ANOVA [26].

Sustainability, system reliability, mobile applications, and forest accuracy have also been addressed. Energy harvesting can power flood sensors in vulnerable areas, enhancing monitoring capabilities and emergency response through solar-powered systems that integrate water level sensors, GSM modules, and LEDs [30-33]. Meanwhile, system reliability and cross-border cooperation have been highlighted to improve and address remaining system gaps [34-36]. These applications had similar outcomes, introducing *Raincell* to deliver early flash flood alerts based on rainfall data. Although global forecasting systems faced challenges in accurately predicting storm events, the app showed promising results in simulating realistic water levels, despite limitations in flow data verification.

EWS development primarily depends on advanced technologies to monitor conditions that could trigger disasters [37]. A review of the current literature reveals various innovative approaches to EWS design and implementation aimed at improving disaster prevention and response. In Tanzania's Kikuletwa region, a system has been developed that employs hydrological modeling for calibration and validation, utilizes ultrasonic sensors for continuous monitoring of river water levels, identifies critical thresholds for flood hazards, and incorporates flood forecasting techniques [38]. By comparing real-time river levels to historical data, the system determines flood severity. Similarly, authors in [27] introduced a computer vision-based system that integrates image processing with the Internet of Things (IoT). By employing edge detection on images captured by video cameras, the system precisely measured river height and water levels [27]. Subsequently, it advanced this approach by employing an ESP microcontroller with IoT support, vibration sensors, an automatic rain gauge, a fuzzy decision tree algorithm, and multi-channel disaster communication tools, such as WhatsApp, SMS, and radio. Sensor data are sent to a web server, allowing disaster mitigation teams to access them and deploy timely evacuation alerts [39]. Their system uses a network of Automatic Meteorological Stations (AMS) that continuously sends data to a central server, where the former are processed and displayed for authorized users, is utilized [24, 40]. A solar-powered flood EWS alerting residents via GSM messages has been also developed. This system features three LED indicators to show the water level status: safe, warning, and danger [41, 42]. Additionally, a Community-Based Early Warning System (CBEWS) has been implemented in Malawi, focusing on grassroot involvement. This system includes the installation of river gauges and other monitoring equipment, empowering local communities to monitor river levels and receive timely alerts about potential floods. These innovations showcase the growing role of technology and community participation in improving EWS effectiveness.

Local communities play a vital role in the effectiveness of EWS for natural disasters. In Kabbe, Namibia, there is a notable level of community readiness, self-reliance, and adaptability when responding to floods, supported by local knowledge, skills, and experience [43]. Community members actively monitor potential threats and alert others, illustrating the importance of grassroot engagement in disaster risk reduction. Nevertheless, the lack of community involvement in EWS planning and decision-making continues to be a significant obstacle in many areas. Yet, authors in [42] revealed a significant challenge, namely the public mistrust of government agencies. The latter reduces the likelihood that individuals will seek help or pay attention to early warnings, thereby diminishing system effectiveness [41]. When vulnerable groups are excluded and local stakeholders lack preparedness or awareness, EWS implementation becomes fragmented and ineffective. Additionally, response plans that ignore community input often fail to address local needs and are poorly executed.

EWS successful operation depends on the strength of all its components; even one single point of failure can undermine the entire system [31, 42]. Disaster risk studies stress that an efficient EWS should not only analyze and interpret data accurately, but also ensure that this information reaches the public in a clear and trustworthy manner. Additional technical and logistical challenges exist as well. Installing flood sensors in remote areas tends to be challenging due to a lack of reliable energy sources, which are essential for maintaining monitoring systems [34]. Furthermore, high-resolution flood modeling, while accurate, often demands lengthy computation times and incurs substantial costs, making it less practical for timely EWS. This is a common drawback that needs to be addressed to create cost-effective and responsive flood forecasting systems. Recent advancements have begun to tackle these limitations with important innovations. For instance, artificial intelligence and machine learning algorithms are increasingly integrated into EWS platforms to enhance real-time flood prediction and automate alert dissemination. Furthermore, community alerting has been improved by integrating crowd-sourced reports with rainfall and river monitoring, strengthening last-mile communication. Meanwhile, the use of Unmanned Aerial Vehicles (UAVs) has gained traction for real-time flood assessments and risk mapping, particularly in areas hard to reach. Innovations, such as low-cost wireless sensor networks and LoRaWAN-based communication infrastructures, have greatly enhanced data transmission in remote areas. Moreover, gamification and mobile-based learning tools have emerged to educate local populations about EWS protocols and increase community engagement, especially among young individuals. These advancements collectively reflect a shift toward smarter, more inclusive, and adaptive EWS capable of addressing both technological and socio-political challenges.

IV. CONCLUSION

This study highlights the importance of developing and strengthening Early Warning Systems (EWSs) as a central component of disaster risk reduction strategies in South Sulawesi, Indonesia, a region vulnerable to hydrometeorological hazards, such as floods and landslides. Based on scholarly literature, technical innovations, and case studies, the present research reveals both ongoing challenges and opportunities in EWS implementation, especially in flood-prone areas. EWS efficiency depends on the integration of four key elements: hazard detection and monitoring, accurate and timely communication of risks, robust institutional coordination, and active community involvement. In South Sulawesi, gaps persist in all these domains. Technological constraints, inadequate infrastructure in remote areas, lack of cross-sector collaboration, and socio-cultural barriers, such as public distrust of authorities, all contribute to the underperformance of existing systems. Moreover, climate change impacts, exemplified by more frequent and severe floods, have intensified the need for reliable early warning mechanisms.

However, this research also emphasizes important innovations and practices. Advancements in sensor technologies, Internet of Things (IoT) integration, computer vision, and real-time hydrological modeling have improved the technical capabilities of EWS to detect and predict flood events. Tools, such as mobile applications, cloud-connected monitoring systems, and data-driven decision-making frameworks (e.g., the Dynamic Flood Risk Model (DFRM) and EWIN) demonstrate that it is possible to create highly responsive systems tailored for both urban and rural areas. These technologies, when properly maintained and adapted to local conditions, can shorten lead times, enhance accuracy, and enable quick responses.

Equally important is the role of community participation. EWS success does not solely rely on technological sophistication, but also on the social infrastructure which ensures that warnings are trusted, understood, and acted upon. Case studies from Namibia, Malawi, and Nepal show how Community-Based Early Warning Systems (CBEWS) empower local populations, reinforce grassroot resilience, and build social capital, necessary for disaster preparedness and response. However, it is demonstrated that community engagement is not always prioritized in policy or practice. Many EWS initiatives in South Sulawesi fail to involve residents in designing or operating systems, leading to distrust and decreased effectiveness.

The performed analysis stresses the necessity for an integrated, multi-layered EWS framework that combines technological innovations with human-centered design. Such a system should integrate local knowledge, promote inclusive decision-making, and strengthen institutional capacities across multiple governance levels. Investing in renewable energy solutions, like solar-powered sensors, affordable low-power communication systems, and mobile connectivity, can help address the infrastructure challenges faced in remote areas. Furthermore, education and awareness campaigns, especially those employing digital tools and gamification, can increase public understanding and ownership of disaster protocols.

Finally, improving EWS in South Sulawesi, and by extension, in other disaster-prone regions, requires more than simple technological solutions. It demands a holistic approach that combines scientific excellence with community empowerment, institutional reform, and long-term sustainability planning. The future of disaster resilience in the region hinges on the ability of stakeholders to co-create adaptive, inclusive, and contextually grounded warning systems that are responsive to both current vulnerabilities and emerging climate threats. With the right blend of innovation, participation, and governance, EWS can evolve from reactive tools into proactive engines of resilience and safety for vulnerable populations.

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