



Bridging Technology and Tradition: A Review of IoT-Based and Local Wisdom-Based Early Warning Systems in Indonesia

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Received: 17-07-2026

Accepted: 18-08-2026

Published: 31-10-2026

Keywords:

early warning system, Internet of Things, indigenous knowledge, disaster-risk reduction, community preparedness, systematic literature review

ABSTRACT

Indonesia is highly vulnerable to geological and hydrometeorological hazards. The Early Warning System (EWS) has become a key strategy in disaster mitigation, which is now evolving towards the use of Internet of Things (IoT) technology as well as integration with local wisdom. This study aims to review the implementation, characteristics, and reported outcomes of IoT-based and local wisdom-based early warning systems for disaster risk reduction in Indonesia. A systematic literature review was conducted by analyzing 20 scientific articles published between 2020 and 2024. The reviewed studies indicate that IoT-based early warning systems commonly enable real-time monitoring, automated hazard detection, and rapid information transmission for measurable hazards such as floods and earthquakes. Meanwhile, EWS based on local wisdom is more contextual and sustainable, able to reach remote areas and strengthen socio-cultural resilience. The two approaches have complementary characteristics that may strengthen the effectiveness of disaster-risk reduction., thereby increasing the effectiveness of disaster risk mitigation holistically. This study recommends the integration of IoT-EWS and local wisdom in national policies and disaster education to strengthen community resilience in various regions.

1. INTRODUCTION

Indonesia's location along the Pacific Ring of Fire, combined with its complex geographic, geological, hydrological, and climatological conditions, makes it highly vulnerable to various natural disasters. These conditions place Indonesia at high risk of geological and hydrometeorological disasters, which can impact communities, the environment, and development (Rudyanto et al., 2024). Natural hazards, including earthquakes, tsunamis, floods, landslides, and volcanic eruptions, frequently threaten communities and can develop into disasters when they interact with exposed and vulnerable populations. These conditions require governments and communities to establish robust disaster risk management systems to minimize potential impacts (BNPB, 2023). One of the key components of disaster risk management is an Early Warning System (EWS), an integrated mechanism designed to monitor, detect, or forecast hazardous conditions before they escalate into disasters. By providing timely and reliable warning information, EWS enables authorities and at-risk

communities to undertake appropriate preparedness and response actions, thereby reducing disaster risks and potential losses (Heo et al., 2024; Huang et al., 2026). Early warning to the public about disasters is an action to provide information in language that is easily understood by the community. In critical situations, early warnings, which are the delivery of such information, generally take the form of sirens, gongs, audible, visual, and digital warning channels. (Syuryansyah & Habibi, 2024).

In the era of digitalization, EWS has evolved by integrating Internet of Things (IoT) technology, which enables real-time sensing, communication, and early warning deployment. IoT is a paradigm and concept that presents the widespread presence of various objects or devices that can interact and work together to create new services to achieve specific goals (Esposito et al., 2022). IoT connects these devices through a network, enabling more efficient and effective data exchange and control. The main supporting technologies in IoT implementation include network sensor, M2M (Machine-to-Machine communication), RFID (Radio

Frequency Identification), IPv6 (Internet Protocol version 6), mobile internet, semantic data integration, and semantic search. With the integration of these technologies, IoT can realize innovative solutions in various fields such as smart cities, smart healthcare, smart agriculture, and many more (Danu & Nugroho, 2024).

The Indonesian Meteorology, Climatology, and Geophysics Agency (BMKG) has implemented the Indonesia Tsunami Early Warning System (InaTEWS), a sensor-based tsunami early warning system that integrates seismic, sea-level, and geodetic monitoring networks for tsunami detection. The development of InaTEWS was driven by the devastating 2004 Indian Ocean Tsunami that affected Aceh and surrounding regions, as well as subsequent tsunami events in Indonesia. According to BMKG, the operational framework of InaTEWS utilizes the German-developed SeisComP system, which enables real-time seismic data processing and rapid tsunami warning dissemination. The system has been upgraded so that it is capable of calculating earthquake magnitudes comparable to moment magnitudes suitable for tsunami warnings (BMKG, 2010). In addition to InaTEWS, BMKG has been developing the Indonesia Earthquake Early Warning System (InaEEWS) since 2019. The system has been trialled in Banten and West Java and remains under development (BRIN, 2025; KOMPAS, 2019). Earthquake early warning can provide additional time for people to take protective action and provide sufficient time to seek protection before an earthquake occurs (Wood et al., 2025).

The implementation of EWS will certainly have successes and failures. However, these successes and failures depend on determining factors. According to the World Meteorological Organization (WMO), several factors that influence the success and failure of EWS are 1) hazard information; 2) monitoring and warning; 3) publication and communication; 4) response capabilities; 5) effectiveness of governance and institutional arrangements; 6) multi-hazard approach; 7) local community involvement; and 8) cultural diversity and gender perspectives (Golding, 2022). Furthermore, the failure of EWS is largely related to these factors and often results in suboptimal mass evacuations. However, the performance of EWS does not simply appear when there is a threat of disaster, but long before the disaster strikes. This is related to the accumulation of data from various sources such as weather forecasts, geospatial data, seismic data, and other related information. Failures in Early Warning Systems (EWS) are generally caused by inadequate integration of risk information, inaccurate data, limited monitoring and warning capacity, insufficient weather forecast validation and evaluation, weak information dissemination and communication systems, and low community preparedness, including a lack of disaster simulation exercises (Golding, 2022; Quansah et al., 2010).

The implementation of EWS that is known today mostly uses technologies such as IoT to support the accuracy, speed, and clarity of hazard information. Before the adoption of modern sensor technologies, many Indonesian communities relied on local knowledge and customary warning practices. Local wisdom mitigation is more associated with preventive measures to deal with natural disasters long before the disaster strikes. For example, in mitigating landslides and floods in Wonosobo Regency, the community participates in reforestation and river cleaning activities (Kusumadewi &

Suwarno, 2022), construction of houses with stone foundations and rigid connections using a system of beams and pegs in Nuwewang Village, Maluku, as an earthquake mitigation measure (Pakniy et al., 2022). In this review, Local Wisdom-EWS is defined as traditional community-based early warning practices that perform at least one core function of an Early Warning System, including hazard observation, warning generation or interpretation, warning dissemination, or response activation. Traditional practices that primarily aim to reduce hazard exposure or vulnerability, such as reforestation, terracing, or customary forest conservation, are classified as disaster mitigation or preparedness rather than Early Warning Systems.

Although local communities have taken preventive measures to mitigate natural disasters, in reality these mitigation efforts have not been evenly implemented across Indonesia. The success of EWS depends on various technical, social, and institutional factors. Although technological advances have improved hazard monitoring and warning dissemination, challenges remain in accessibility, last-mile communication, community trust, and cultural acceptance. Therefore, integrating IoT-based EWS with local wisdom may provide a more context-specific approach to strengthening disaster preparedness and community resilience. Therefore, the development of IoT technology combined with local wisdom is expected to increase the effectiveness and speed of providing warnings for various disasters, as well as helping communities to better mitigate disaster risks. This study has three main objectives, namely 1) to identify the types of disasters detected by IoT-EWS and Local Wisdom-EWS; 2) to identify how IoT-EWS and Local Wisdom-EWS are implemented; and 3) to identify the results of the implementation of IoT-EWS and local wisdom on community preparedness in facing disasters.

2. METHOD

This study employed a Systematic Literature Review (SLR) method to identify, evaluate, and synthesize previous studies related to IoT-based Early Warning Systems (EWS) and Local Wisdom-EWS for disaster management. The SLR process consisted of several stages, including literature identification, screening based on predefined inclusion and exclusion criteria, quality assessment of selected studies, and data extraction for comparative analysis. The selected articles were further analyzed to identify research trends, implementation approaches, advantages, limitations, and opportunities for integrating technological and community-based approaches in strengthening disaster preparedness. (Martiny et al., 2024; Syuryansyah & Habibi, 2024).

The literature used in Systematic Literature Review (SLR) obtained by searching the online electronic database of Google Scholar, which can be accessed at <https://scholar.google.com/>. The literature search was conducted using Google Scholar due to its broad interdisciplinary coverage. The retrieved articles were screened based on predefined relevance criteria, including their focus on IoT-based EWS, local wisdom in disaster management, and community preparedness. Screening was conducted sequentially through the search results until relevant studies were no longer identified (approximately the first 15 pages of results). The limitation of

using a single search engine, which may affect reproducibility and introduce selection bias, is acknowledged in this review.

The screening, data extraction, and quality assessment processes were conducted by a single reviewer based on predefined inclusion and exclusion criteria. The selected articles were evaluated according to their relevance to IoT-based EWS, Local Wisdom-EWS, and disaster preparedness. To maintain consistency, the extracted information and assessment results were reviewed iteratively throughout the analysis process. The absence of independent multiple reviewers represents a limitation of this study.

The details of this research method are as follows:

2.1 Research Question

A research question was formulated with the needs related to the research theme. There are three research questions that are the focus of this study, including:

RQ for Early Warning System Based on IoT

- RQ1: What disasters are mitigated by IoT-EWS?
- RQ2: How is IoT implemented as an Early Warning System?
- RQ3: What are the results of implementing an IoT-based Early Warning System on community preparedness for disasters?

RQ for Early Warning System Based on Local Wisdom

- RQ1: What disasters are mitigated by Local Wisdom-EWS?
- RQ2: How is Local Wisdom implemented as an Early Warning System?
- RQ3: What are the results of implementing a Local Wisdom-based Early Warning System on community preparedness for disasters?

2.2 Data Search Strategy

After formulating the research questions, a literature search was conducted to identify scientific sources relevant to the study topic. The search process was conducted through Google Scholar (<https://scholar.google.com/>) using the keywords "Early Warning System Based on IoT in Indonesia" and "Early Warning System Based on Local Wisdom in Indonesia". These keywords were used to obtain scientific publications discussing the implementation of early warning systems based on Internet of Things technology and local wisdom as the basis for the analysis in this study.

The literature review was limited to publications from 2020 to 2024 to capture recent advancements and current implementation trends of IoT-based EWS and Local Wisdom-EWS in disaster management. This timeframe was selected considering the rapid development of digital technologies and increasing application of IoT approaches in disaster risk reduction. Nevertheless, this limitation may exclude earlier foundational studies on indigenous knowledge and community-based disaster management, which is acknowledged as a limitation of this review.

2.3 Inclusion and Exclusion Criteria

Inclusion and exclusion criteria are intended to determine whether the collected data is suitable for use as a data source. The inclusion criteria for this study are 1) scientific journal

literature; 2) scientific journal sources from Google Scholar; 3) literature that is open access and available in full text; 4) literature written in Indonesian or English; 5) scientific journals published between 2020 and 2024; and 6) scientific journals that discuss the implementation of IoT-EWS and EWS-Local Wisdom for disaster mitigation in Indonesia.

The exclusion criteria included 1) duplicate records; 2) articles published outside the 2020–2024 period; 3) studies conducted outside Indonesia; 4) non-empirical publications (e.g., reviews, editorials, conference abstracts, and book chapters); 5) studies unrelated to early warning systems or disaster risk reduction; 6) articles without accessible full text; and 7) studies that did not report sufficient information on EWS implementation or outcomes.

2.4 Quality Assessment

The quality assessment stage is intended to ensure that the data collected for this study is of good quality. To determine whether the data collected is of good quality or not, the articles were evaluated using the following questions:

QA for Early Warning System Based on IoT

- QA1: Was the journal published between 2020 and 2024?
- QA2: Does the journal discuss specific types of disasters?
- QA3: Does the journal discuss the Internet of Things systems and types used?

QA for Early Warning System Based on Local Wisdom

- QA1: Was the journal published between 2020 and 2024?
- QA2: Does the journal discuss specific types of disasters?
- QA3: Does the journal discuss locally-based EWS systems and types used?

2.5 Data Collection

The literature search was conducted using Google Scholar on 18th February 2025, to identify studies related to IoT-based Early Warning Systems and Local Wisdom-based Early Warning Systems in Indonesia. The search employed the keywords "Early Warning System Based on IoT in Indonesia" and "Early Warning System Based on Local Wisdom in Indonesia". The search was limited to journal articles published between 2020 and 2024 in English and Indonesian. Retrieved articles were manually screened according to the predefined inclusion and exclusion criteria, and studies meeting the eligibility requirements were selected for data extraction and analysis. The search and screening processes were documented to ensure consistency throughout the review.

2.6 Data Analysis

The selected studies were analyzed using a comparative qualitative synthesis. Relevant information was extracted using predefined variables, including disaster type, Early Warning System approach (IoT-based or Local Wisdom-based), implementation characteristics, reported advantages, limitations, and key findings. The extracted data were systematically compared to identify similarities, differences,

implementation trends, and research gaps, which were then synthesized to answer the research questions.

3. RESULTS AND DISCUSSION

The literature selection process consisted of several stages, including article identification, screening based on title and abstract relevance, full-text evaluation, and final selection according to the inclusion and exclusion criteria. Articles were included if they were published between 2020 and 2024 and

specifically discussed the implementation of IoT-based EWS or Local Wisdom-EWS in disaster management. Articles that did not focus on disaster-related early warning systems, lacked sufficient methodological information, or were outside the research scope were excluded. The selected studies were subsequently analyzed through quality assessment and data synthesis. The results of the quality assessment can be seen in Table 1 and Table 2.

Table 1. Eligibility Assessment of Selected Studies on IoT-Based Early Warning Systems

No.	Authors	Study	Year	QA1	QA2	QA3	Result
1	Muhammad Syarif, Kevin Ardiyanto, Reza Maulana Akbar, Pramono	Prototype of Water Level Monitoring at Dams Using Internet of Things (IoT)-Based Ultrasonic Sensors	2024	Yes	Yes	Yes	Accepted
2	Asep Danu, Yohanes Anton Nugroho	Design and Construction of an Early Warning System for Landslides Using a NodeMCU Module with an Internet of Things-Based Microcontroller	2024	Yes	Yes	Yes	Accepted
3	Agung Eka Wardana, Moh. Noor Al Azam	Real-Time Monitoring and Early Warning System for IoT-Based Sea Level (Case Study: Tanjung Emas Port Semarang)	2024	Yes	Yes	Yes	Accepted
4	Panji Tegar Wikantama, Muammar Bahalwan, Muhammad Azzam Ghifary A	SIGEMPA: IoT-based Earthquake Early Warning System with ESP32	2024	Yes	Yes	Yes	Accepted
5	Edwin Tenda, Eric Alfonsius, Megastin Lumembang, Eliasta Ketaren	Early Warning System for Potential Landslide Disasters in Manado City based on the Internet of Things	2023	Yes	Yes	Yes	Accepted
6	Anshary Yudi	Development of an internet of things (IoT)-based flood disaster mitigation system in West Sumbawa Regency	2023	Yes	Yes	Yes	Accepted
7	Ivander Achmad Wandu, Ahmad Ashari	Monitoring Water Level and Rainfall in an IoT-Based Early Warning System for Flood Disasters	2023	Yes	Yes	Yes	Accepted
8	Gabriel Gracia Salindeho, Theophilus Wellem	Design and Implementation of IoT-Based Fire Detection and Warning Systems Using Nodemcu ESP8266 and Fire Sensors	2023	Yes	Yes	Yes	Accepted
9	Siswanto, Ngatono, Samidi Febri saputra	Prototype of Earthquake and Tsunami Disaster Early Warning System Based on the Internet of Things	2022	Yes	Yes	Yes	Accepted
10	Wahyu Sejati, Ning Adiasih, Tjhwa Endang Djuan	Utilization of IoT-Based Early Warning System Tools for Early Detection of Floods in Setu District, South Tangerang City	2021	Yes	Yes	Yes	Accepted

Table 2. Eligibility Assessment of Selected Studies on Local Wisdom Based Early Warning Systems

No.	Authors	Study	Year	QA1	QA2	QA3	Result
1	Hanifa Sekar Ayunda, Desy Safitri, Sujarwo	Disaster Mitigation Based on Local Wisdom <i>Nyabuk Gunung</i>	2024	Yes	Yes	Yes	Accepted
2	Jeremy Putra Pratama, Taqwa P. B. P. Sidi Hiram	Mitigation Management Based on Local Wisdom in the West Java Region	2024	Yes	Yes	Yes	Accepted
3	Akhmad Marhadia, La Inoa, Rahmat Sewa Surayaa, La Janua, Taufiq Said, Rahmat Gahoc	Understanding Local Wisdom as specific Knowledge in Natural Disaster Mitigation: An Empirical Lessons in Tiworo, Indonesia	2024	Yes	Yes	Yes	Accepted
4	Frischa Aulia, Abdul Muis, Fajar Rahma Az-Zahra, Nesya Auliya	Disaster Mitigation in Local Wisdom of Customary Forests in Guguk Village, Merangin Regency	2024	Yes	Yes	Yes	Accepted
5	Petrus Ana Andung, Ermenilda Putri, Leta Rafael Levis	The Utilization of Local Wisdom as Folk Media for Disaster Crisis Communication	2023	Yes	Yes	Yes	Accepted
6	Suci Ratika M.J, Haliadi, Exsa Putra, Faiz Urfan	Local Wisdom of the Tajio Tribe Community Based on Disaster Mitigation in Kaliburu Village, Kata Donggala Regency - Central Sulawesi	2023	Yes	Yes	Yes	Accepted
7	Yamres Pakniany, Weldemina Yudit Tiwery, Heinrich Rakuasa	Earthquake Disaster Mitigation Based on Local Wisdom in Nuwewang Village, Pulau Letti District, Southwest Maluku Regency	2023	Yes	Yes	Yes	Accepted

No.	Authors	Study	Year	QA1	QA2	QA3	Result
8	Zefanya Ginulur Rahmatullah, Saraswati	Disaster Mitigation Study Based on Local Cultural Wisdom in Naga Traditional Village, Neglasari Village, Salawu District, Tasikmalaya Regency	2023	Yes	Yes	Yes	Accepted
9	Kamasuta, Baiq Harly Widayanti, Sri Apriani Puji Lestari	Landslide and Flash Flood Disaster Mitigation Based on Local Wisdom of the Community of Bentek Village, Gangga District, North Lombok Regency	2022	Yes	Yes	Yes	Accepted
10	Yasinta Gekeng Mare, Ignasius Suban Angin, Arfita Rahmawati	Male Lewotobi Volcano Disaster Mitigation Based on Local Wisdom of the Nawokote Village Community in Wulanggitang District, East Flores Regency	2021	Yes	Yes	Yes	Accepted

Based on Table 1 and Table 2 regarding the quality assessment of articles used in this study, all articles taken as references related to early warning systems based on IoT and local wisdom have acceptable quality assessments. Thus, they

can be continued as a basis for literature review references in accordance with the Research Questions (RQ) in Table 3 and Table 4 below.

Table 3. Findings from a Systematic Literature Review of EWS Based on IoT

Study	Hazard Type	IoT-EWS implementation	Reported outcome
Prototype of Water Level Monitoring at Dams Using Internet of Things (IoT)-Based Ultrasonic Sensors (Syarif et al., 2024)	Flash Flood	Prototype monitoring of water levels in dams using ultrasonic sensors by calculating the reflection time of sound waves. If the water is below 2 meters, a green light turns on; between 2–4 meters, a yellow light turns on; and above 4 meters, a red light turns on accompanied by a buzzer. Water level data is sent in real time to a website to facilitate monitoring and prevent flooding.	The creation of a prototype water level monitoring system at dams using ultrasonic sensors effectively provides the information needed to take preventive measures in preparation for potential flooding disasters.
Design and Build Soil Movement Early Warning System Using NodeMCU Module with Internet of Things Based Microcontrollers (Danu & Nugroho, 2024)	Landslide	This device is equipped with vibration and humidity sensors to monitor soil conditions. Data from the sensors is processed by NodeMCU and sent to the Telegram application as an early notification if a potential landslide is detected.	The community can receive the latest information about potential landslides through Telegram notifications, enabling them to evacuate earlier.
Real-Time Monitoring and Early Warning System for IoT-Based Sea Level (Case Study: Tanjung Emas Port Semarang) (Wardana et al., 2024)	Flood	Real-time monitoring and early warning systems (EWS) can provide real-time information on water levels, pump status, weather conditions, and early warning messages about potential flooding to managers via email and SMS based on forecast data.	The implementation of EWS improves preparedness and response to potential flooding, resulting in highly accurate water level forecasting using the WMA method.
SIGEMPA: IoT-based Earthquake Early Warning System with ESP32 (Wikantama et al., 2024)	Earthquake	This device is equipped with a piezoelectric sensor that is sensitive to ground vibrations. When an earthquake occurs, the sensor will generate an electrical signal proportional to the strength of the vibrations. This signal is then processed by the ESP32 microcontroller to determine the severity of the earthquake. If the measured value exceeds the set threshold, the ESP32 will send a warning notification via Telegram.	The response speed of the IoT system in providing early earthquake warnings demonstrates its effectiveness, with a response time of around two to three seconds. The use of resources converted into renewable energy, such as solar energy, also increases the operational sustainability of the device.
Early Warning System for Potential Landslide Disasters in Manado City based on the Internet of Things (Tenda et al., 2023)	Landslide	The sensor will receive signals from vibrations detected by the <i>accelerometer</i> sensor, enabling it to detect the onset of a potential landslide.	Vibration information will be disseminated through the X application so that information related to disaster risks can be obtained, processed, and disseminated to the public quickly and easily.
Development of an Internet of Things (IoT)-Based Flood Disaster Mitigation System in West Sumbawa Regency (Anshary, 2023)	Flood	The use of IoT with <i>multi-flow</i> analysis, a data analysis system generated by ultrasonic sensors, to measure water levels in the Rea River Basin, West Sumbawa Regency. The sensor design consists of a series of components arranged in a buoyant tube, with HC-SR04 ultrasonic sensors and Arduino electronic board hardware.	Based on the validation results, the developed device achieved a feasibility rating of 94% from expert validators and 100% from practitioner validators. These scores demonstrate that the IoT-based flood mitigation system, which integrates multi-stream analysis, is capable of effectively monitoring

Study	Hazard Type	IoT-EWS implementation	Reported outcome
			environmental conditions, analyzing the acquired data, and providing rapid, real-time early warning information to the public as an effort to reduce flood disaster risk.
Monitoring Water Level and Rainfall in an IoT-Based Early Warning System for Flood Disasters (Wandi & Ashari, 2023)	Flood	The use of water level sensors and rainfall sensors is essential in the creation of an Early Warning System to effectively detect potential flooding. Notifications sent via Telegram have an average delay of 0.561 seconds. This value is smaller than when using SMS. The use of a database in the cloud helps with data analysis.	The final result of this research is that the HRC sensor can detect potential flooding and provide early notification via the Telegram app. This sensor can accurately read water levels and changes.
Design and Implementation of IoT-Based Fire Detection and Warning Systems Using NodeMCU ESP8266 and Fire Sensors (Salindeho & Wellem, 2023)	Fires	The IoT-based fire detection and warning system works using NodeMCU ESP8266 as the main controller and infrared sensors to detect the presence of fire. When fire is detected within an effective range of up to 50 cm, the system will activate a buzzer as a local alarm. In addition, the monitoring data will be sent to the Thingier.io platform, which automatically sends notifications in the form of emails and Telegram messages to users.	The fire detection system that was developed has successfully provided effective early warnings, thanks to the integration between NodeMCU ESP8266 and infrared sensors. Notifications sent through various digital platforms allow users to respond quickly to fire incidents.
Prototype of Earthquake and Tsunami Disaster Early Warning System Based on the Internet of Things (Siswanto et al., 2022)	Earthquake and Tsunami	This device utilizes an SW-420 sensor to detect vibrations that indicate an earthquake, as well as a Funduino water level sensor to measure changes in sea level. Analog data from both sensors is converted into digital data by an ESP8266 microcontroller, then sent to the Blynk server via the internet.	The prototype development successfully integrated hardware and software to accurately detect earthquakes and changes in sea level.
Utilization of IoT-Based Early Warning System Tools for Early Detection of Floods in Setu District, South Tangerang City (Sejati et al., 2021)	Flood	The EWS system is implemented using ultrasonic sensors to monitor river water levels in real time and detect the rate of water level rise at specific locations. The main technology in this system involves an Arduino Uno microcontroller as the main processor, an ESP8266 WiFi communication module for data transmission, and a Telegram bot application as a platform for providing real-time notifications to users.	The use of the Early Warning System (EWS) tool has successfully increased the understanding of the community and GEMALA members on how to operate and maintain the tool. With the support of the Telegram application, this tool is able to provide information on water levels.

Table 4. Findings from a Systematic Literature Review of EWS Based on Local Wisdom

Study	Hazard Type	IoT-EWS implementation	Reported outcome
Disaster Mitigation Based on Local Wisdom <i>Nyabuk Gunung</i> (Sekar Ayunda et al., 2024)	Flood, Landslide, Drought	Local wisdom called " <i>Nyabuk Gunung</i> " which means embracing the mountain in Central Java, is a natural disaster mitigation approach, especially on mountainous or sloping land. <i>Nyabuk Gunung</i> is done by creating terraces or rice fields along the contour lines.	<i>Nyabuk Gunung</i> can be used as a mitigation measure for natural disasters such as landslides, floods, and droughts due to its usefulness in soil conservation. Water flow velocity can be reduced, water absorption into the soil can be increased, and the direction of water flow can be controlled.
Mitigation Management Based on Local Wisdom in the West Java Region (Pratama & Hiram, 2024)	Earthquake, Landslide and Flood	Implementation of local wisdom disaster mitigation in West Java, such as traditional Sundanese stilt houses for development aspects, <i>Kasepuhan Cipta Gelar</i> (spatial planning and forest land use zoning system) for natural resource management aspects, and folk tales from <i>wayang golek</i> art as an appeal to preserve nature.	Improvements in understanding natural disaster mitigation have been effective in West Java, as the community still has cultural beliefs and upholds customs. These practices and knowledge continue to be transmitted from one generation to the next so that they are maintained and continued in the future.
Understanding Local Wisdom as specific Knowledge in Natural Disaster Mitigation: An Empirical Lessons in Tiworo, Indonesia (Marhadi et al., 2024)	Heavy Winds, High Waves, Coastal Damage	There are three things that the Bajo people do to mitigate disasters. The first is a prohibition called <i>Pamali</i> , a belief in not violating instructions in order to preserve the sea. The second is the <i>Maduai Ada</i> ritual, a ritual to ask for forgiveness for mistakes made against nature. The third is <i>Pakayuang Bangkau Karama</i> , a sacred mangrove forest protected by the Bajo people.	The disaster mitigation measures taken by the Bajo community are based more on religious beliefs and myths. This allows for a stronger bond between humans and nature, thereby raising awareness of nature conservation.
Disaster Mitigation in Local Wisdom of	Flood and Landslides	Disaster mitigation based on local wisdom is carried out in Guguk Village, Merangin Regency, Jambi, namely in	The division of swamp forests and protected forests in the customary forests

Study	Hazard Type	IoT-EWS implementation	Reported outcome
Customary Forests in Guguk Village, Merangin Regency (Aulia et al., 2024)		its customary forest management system, which is divided into <i>sesap</i> forests (secondary forests that can be utilized) and <i>rimbo larangan</i> (prohibited forests). Although <i>sesap</i> forests are utilized on a daily basis, there are rules regarding the distance between trees that can be cut down and <i>p</i> (planting of trees by individuals).	of Guguk Village is effectively controlled as a measure to mitigate flooding and landslides, given its location near the riverbank.
The Utilization of Local Wisdom as Folk Media for Disaster Crisis Communication (Andung et al., 2024)	Earthquakes, Flash Floods, Erosion, Crop Failure	The first form of local wisdom as an alternative means of communicating danger in Merbaun Village is <i>Koa "Pa Him Mui Tuaf,"</i> which is a way of communicating by shouting (Koa) when an earthquake occurs. Second, there is a tradition of planting a wooden pole tied with cloth called <i>Pao Urun</i> during the rainy season with high intensity for 3-4 days, which serves as a warning to evacuate immediately due to the possibility of flash floods. Third, there is <i>Ma'nun</i> or a slash-and-burn farming system to prevent soil erosion.	The form of local wisdom in Merbaun Village is very complex, ranging from preserving nature, creating danger signs, to communicating warnings when disasters occur. This proves that the capabilities of community media based on local wisdom can be used as instruments and tools for conveying messages about risk reduction and early warning of disasters.
Local Wisdom of the Tajio Tribe Community Based on Disaster Mitigation in Kaliburu Village, Kata Donggala Regency - Central Sulawesi (Ratika et al., 2023)	Flood and Landslides	The Tajio tribe's form of disaster mitigation is the <i>Vunja</i> and <i>Tula Bala</i> traditions. <i>Vunja</i> is an expression of gratitude to the Almighty for a good and abundant harvest, while <i>Tula Bala</i> is a tradition to ward off all kinds of disasters. In addition, the Tajio tribe also looks at signs in nature, such as the condition of plants and animals, to analyze upcoming disasters.	The Tajio tribe's culture, which is deeply rooted in mutual cooperation, encourages the community to play an effective social role in disaster mitigation, especially natural disasters that are prone to hit the village, such as floods and landslides.
Earthquake Disaster Mitigation Based on Local Wisdom in Nuwewang Village, Pulau Letti District, Southwest Maluku Regency (Pakniany et al., 2022)	Earthquake	Mitigation measures include the construction of houses with <i>umpak</i> stone foundations and rigid connections using a system of beams and pegs in Nuwewang Village, Maluku, as an earthquake mitigation effort. In addition to preventive measures, the EWS based on local wisdom also has communicative measures in conveying danger, such as the <i>Opruru Ampuapenu</i> shout from Maluku, which means that the shaking ground has come, and <i>Hnyoli Lieta</i> , which is a tradition of reminding and helping each other when a disaster occurs.	Disaster mitigation in Nuwewang Village is based on local knowledge passed down from ancestors, fostering community awareness and preparedness for potential disasters. The local wisdom applied in disaster mitigation also encompasses various preventive and communication efforts that contribute to increasing preparedness, strengthening adaptive capacity, and building community resilience to disaster risks.
Disaster Mitigation Study Based on Local Cultural Wisdom in Naga Traditional Village, Neglasari Village, Salawu District, Tasikmalaya Regency (Rahmatullah & Saraswati, 2021)	Earthquakes, Landslides, Floods, Erosion, Strong Winds, Fires	Local wisdom patterns in disaster mitigation efforts are based on the Tri Tangtu philosophy on Earth, which is manifested through three main aspects: mandate, testaments, and prohibitions (taboo). This wisdom includes guidelines for a simple, harmonious, and communal life (mandate); guidelines for building construction, farming, and forest conservation (testament); and prohibitions against certain actions and the use of certain objects that are considered to disturb the balance of nature (taboo).	The people of Kampung Naga lack knowledge in terms of structural disaster mitigation, but they have a foundation for preserving the environment and living in peace. Indirectly, this principle has become a form of mitigation for Kampung Naga.
Landslide and Flash Flood Disaster Mitigation Based on Local Wisdom of the Community of Bentek Village, Gangga District, North Lombok Regency (Kamasuta et al., 2021)	Landslide and Floods	The mitigation measures implemented by the Bentek Village community include: 1) Monitoring high rainfall for 7-9 hours and signs of water turbidity in river flows; 2) The customary laws of <i>Tapa Sila</i> and <i>Nir Gama</i> , which regulate community behavior and relationships with other people and the surrounding environment; 3) Land management using a terraced system to prevent landslides; 4) Forest reforestation; 5) Using <i>kentongan</i> as a means of communication to warn of disasters; and 6) Mutual assistance in helping others during and after disasters.	The disaster mitigation efforts of the Bentek Village community are considered quite complex and more advanced, because mitigation based on local wisdom begins before a disaster, during a disaster, and after a disaster. This enables an effective and systematic disaster management system.
Male Lewotobi Volcano Disaster Mitigation Based on Local Wisdom of the Nawokote Village Community in Wulanggitang District, East Flores Regency	Vulcanic Eruption	The local wisdom of the Nawokote Village community is interpreted using analytical and descriptive semiotics. Analytical semiotics takes the form of faunal, vegetal, and physical semiotics, which observe the behavior of animals, plants, and weather patterns when volcanic activity occurs. Meanwhile, descriptive/cultural semiotics is more focused on advice given verbally or through rituals. The <i>Tuba Ile</i> ritual is a ritual of	Local wisdom-based mitigation in Nawotoke Village is considered to be quite good to very good. The strengthening of local wisdom mitigation is also supported by the Flores Regency Government and combined with structural disaster mitigation.

Study	Hazard Type	IoT-EWS implementation	Reported outcome
(Mare et al., 2021)		“feeding” Lewotobi Mountain in order to maintain good relations with nature.	

3.1 Disasters Mitigated by IoT-EWS and Local Wisdom EWS (RQ-1)

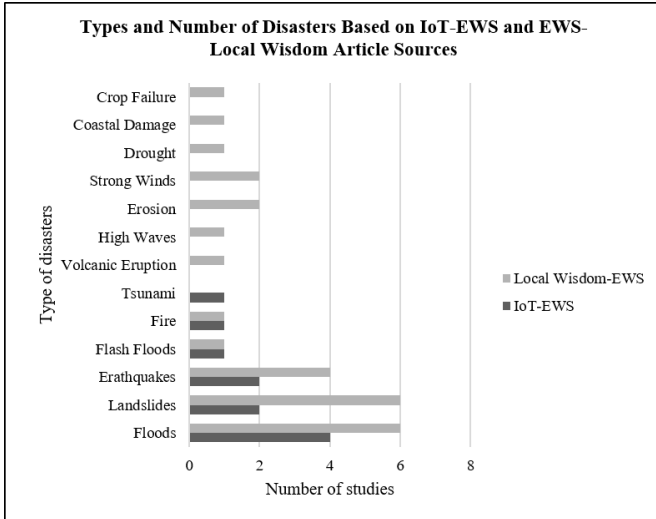


Figure 1. Frequency of hazard types addressed in the selected IoT-EWS and local wisdom based EWS studies

ased on the Systematic Literature Review (SLR), Figure 1 summarizes the diversity of disaster types reported in the ten selected studies for IoT-EWS and Local Wisdom-EWS. The reviewed IoT-EWS studies addressed six disaster categories, whereas the Local Wisdom-EWS studies covered twelve disaster categories. These findings reflect the scope of hazards discussed in the selected literature rather than the actual detection capability or performance of the respective Early Warning Systems. The most common types of disasters covered in the articles are floods and landslides. Based on BNPB data for 2024, there were 3,472 cases of natural disasters (99.34% hydro-meteorological disasters and 0.66% geological disasters), including: earthquakes (15 cases), volcanic eruptions (8 cases), floods (1,420 cases), forest fires (973 cases), extreme weather (733 cases), landslides (207 cases), drought (89 cases), and tidal waves/abrasion (27 cases) (BNPB, 2024). These statistics indicate that hydrometeorological hazards occurred frequently during the reported period, which is consistent with the greater research attention given to floods and landslides in the reviewed literature. .

Another urgency related to flooding as a disaster that constantly threatens Indonesia is that public panic will always

arise when the rainy season arrives. This is due to the lack of adequate information from upstream river-basin areas (Anshary, 2023). Therefore, IoT-EWS is suitable for use in disseminating information and early warnings of flooding in upstream areas (Anshary, 2023; Wandu & Ashari, 2023).

Figure 1 also shows that floods, flash floods, landslides, fires, and earthquakes can be detected by both Early Warning Systems. From these results, it can be seen that IoT-EWS only allows for the detection of natural disasters caused by geological and hydro-meteorological factors, as its data processing is based on meteorological, climatological, and geophysical data. Meanwhile, Local Wisdom-EWS has more preventive measures related to disasters caused by anthropological factors or human actions (Mare et al., 2021).

3.2 Implementation of IoT and Local Wisdom Based Early Warning System (RQ-2)

According to the SLR results, the implementation of IoT-EWS with EWS-Local Wisdom is very different. The Early Warning System focuses on early warning systems before a disaster occurs, long before the disaster strikes, until warnings are issued when a disaster is about to occur, so that the risk of disaster can be minimized (UNDRR, 2022). The implementation of IoT-EWS enables the use of the latest technology, such as sensors that are modified to detect natural conditions according to the type of disaster. Raw data from the sensors is then channeled to a database system, where it is processed to obtain conclusive data that can be distributed in real-time via the internet to web/application outputs (Anshary, 2023; Wikantama et al., 2024). Meanwhile, Local Wisdom-EWS emphasizes a social and natural approach, an intertwined bond that has traditionally been passed down from generation to generation, as well as the cultural values contained therein. EWS-Local Wisdom has many ways of application according to its implementation needs, namely implementation through communication, customs, rituals, ways of life, development, and reading the signs of nature (Kamasuta et al., 2021; Pakniany et al., 2022).

IoT-EWS and Local Wisdom-EWS certainly have their own applications, thus giving rise to fundamental differences between the two. Researchers attempted to analyze the differences between IoT-EWS and Local Wisdom-EWS from various aspects, as shown in Table 5 below.

Table 5. Comparison of IoT-based and local-wisdom-based early warning approaches

Aspect	IoT-EWS	Local Wisdom-EWS
Definition	An early warning system based on digital technology and sensors that are interconnected via the internet (IoT) (Esposito et al., 2022).	Early warning systems based on local knowledge passed down from generation to generation (Syuryansyah & Habibi, 2024).
Source Information	IoT sensors, real-time data (e.g., temperature, humidity, ground vibrations, rainfall), Artificial Intelligence (AI), and digital processing (Alphonsa A & Ravi G, 2016; Salindeho & Wellem, 2023; Syarif et al., 2024).	Signs from nature such as animal behavior, cloud formations, sounds of nature, or past experiences (Marhadi et al., 2024; Ratika et al., 2023; Sekar Ayunda et al., 2024).

Aspect	IoT-EWS	Local Wisdom-EWS
Detection Method	Automatic detection via digital sensors with instant data processing (Alphonsa A & Ravi G, 2016).	Manual observation based on collective experience and symbolic interpretation of the local community (Triastari et al., 2021).
Accuracy and Speed	Generally faster and more accurate because it uses real-time data and scientific calculations (Dini et al., 2024).	Relatively slow and qualitative in nature, depending on interpretation and experience.
Reliability	Highly reliable for measurable disaster conditions (floods, earthquakes, tsunamis). But vulnerable to technical or electrical disruptions.	Reliable in specific local and cultural contexts, especially if technology access is not available in certain areas.
Advantages	Rapid data transmission; real-time monitoring; broad spatial coverage; compatibility with emergency communication systems (Alphonsa A & Ravi G, 2016; Dini et al., 2024; Wikantama et al., 2024).	Inexpensive, easy to implement in remote areas, strengthens local cultural identity, more effective preventive measures for the long term.
Disadvantages	High investment costs, requiring infrastructure and technical training .	Subjective, not always accurate, and not standardized.

Differences in every aspect of IoT-EWS and EWS-Local Wisdom cannot be used as a reference for every region in Indonesia. This is influenced by the dynamic behavior of the community, namely factors related to the need for and access to Science, Technology, Engineering, and Mathematics (STEM). This is similar to the local wisdom mitigation efforts carried out by the community in the Semarang. According to Mulianingsih et al. (2020), STEM is key to the implementation of disaster mitigation, so the integration of disaster mitigation needs to be included in school subjects or curriculum. Mulianingsih combined local wisdom with disaster mitigation in Social Sciences learning to provide early disaster knowledge and optimize Disaster Resilient Schools (Mulianingsih et al., 2020).

In addition to community participation, the role of the government as a policymaker is crucial in supporting disaster risk reduction efforts. The development and implementation of IoT-based disaster mitigation technologies have been accommodated within Indonesia's legal framework, particularly as part of a science- and innovation-driven disaster management strategy. Law No. 24 of 2007 on Disaster Management emphasizes the importance of utilizing science and technology throughout all stages of disaster management. This is explicitly stated in Article 35(g), which mandates the "utilization of science and technology and the use of natural and artificial resources" in disaster management practices (Government of Indonesia, 2007). Government Regulation No. 21 of 2008 also reinforces this by stating that early warning systems must use scientific information, technical data, and the latest technology to detect potential hazards quickly and accurately (Government of Indonesia, 2008). Moreover, the 2025–2029 Disaster Management Master Plan (RIPB) issued by the National Disaster Management Agency (BNPB) emphasizes the integration of emerging digital technologies, such as the Internet of Things (IoT), Artificial Intelligence (AI), and Geospatial Information Systems (GIS), into multi-hazard early warning systems. This strategic direction aims to improve disaster monitoring, forecasting, and risk mitigation capabilities across Indonesia (BNPB, 2025).

The same applies to disaster mitigation based on local wisdom, which has been officially recognized in various laws and regulations in Indonesia. Law No. 24 of 2007 on Disaster Management states that communities have rights and roles in the entire disaster management process, including through the utilization of local knowledge (Pemerintah Indonesia, 2007). This acknowledgment is reinforced in Government

Regulation Number 21 of 2008 which emphasizes the importance of considering local social and cultural aspects in disaster risk reduction (Government of Indonesia, 2008). Not only the legal system in Indonesia, but the United Nations Office for Disaster Risk Reduction (UNDRR) has also issued a report on disaster management using traditional practices and indigenous knowledge to reduce disaster risk (UNDRR, 2022).

In reality, the implementations of IoT-EWS and Local Wisdom-EWS in Indonesia complement each other. IoT-EWS is more widely used in areas that already have adequate access to technology, networks, infrastructure, and human resources. Meanwhile, EWS-Local Wisdom is still widely used in remote areas that are far from technology and infrastructure access. Both have legal validity in legislation and work together to improve disaster risk reduction.

3.3 Results of the Implementation of an IoT-Based Early Warning System and Local Wisdom on Community Disaster Preparedness (RQ-3)

The review of 20 articles on Early Warning Systems (EWS) based on the Internet of Things (IoT) and Local Wisdom indicates that both approaches are effective in enhancing disaster preparedness and response, although each offers distinct advantages depending on the context and needs of the community. Rather than competing alternatives, these two approaches can be viewed as complementary strategies that address different dimensions of disaster risk reduction. The reviewed studies provide different types of evidence regarding the contribution of IoT-EWS and Local Wisdom-EWS. IoT-based studies primarily demonstrate technical performance, including monitoring capability, detection accuracy, and warning dissemination, whereas Local Wisdom-EWS studies mainly report qualitative evidence related to community engagement, environmental awareness, and culturally embedded preparedness. Consequently, the findings should be interpreted according to the type and strength of evidence rather than as equivalent measures of community preparedness.

Although IoT-based early warning systems (EWS) have been widely recognized as a promising approach to disaster management, the studies reviewed show that their effectiveness varies greatly depending on the context and cannot be universally applied. Most studies reported improvements in real-time monitoring, hazard detection, and alert deployment; However, these benefits are greatly

influenced by the availability of communication infrastructure, electricity supply, and technical capacity. Systems deployed in urban areas generally show higher reliability, while systems installed in remote or disaster-prone areas often face challenges related to unstable network connectivity, sensor maintenance, and operational sustainability. In addition, most of the existing evidence comes from the development of prototypes or short-term field trials; Few studies have evaluated long-term performance during an actual disaster event or assessed whether technological improvements actually have an impact on improving community preparedness and reducing disaster losses. The existing literature also places more emphasis on technical performance, such as detection accuracy and response time, than on social aspects, including public trust, adherence to warnings, and inter-agency coordination. These findings indicate that the effectiveness of IoT-based EWS depends not only on technological capabilities, but also on contextual factors and implementation conditions, thus underscoring the need for a more comprehensive and long-term evaluation that integrates both technical and social dimensions in disaster risk reduction efforts.

On the other hand, EWS based on local wisdom has also demonstrated significant contributions to disaster preparedness, particularly in remote and resource-limited areas where access to modern technology may be constrained. This approach relies on traditional knowledge, indigenous practices, environmental observations, and cultural norms that have been developed and refined through generations of experience with natural hazards. Examples include the interpretation of natural signs, customary rules governing settlement patterns, and community-based warning mechanisms that have historically enabled populations to anticipate and respond to disasters. The reviewed studies reveal that communities that maintain and apply such local knowledge often exhibit higher levels of awareness and preparedness, enabling them to respond more quickly and conduct earlier evacuations when warning signs emerge. Moreover, local wisdom-based EWS strengthens social cohesion, community participation, and cultural resilience, all of which are essential components of effective disaster risk reduction.

The findings further suggest that the effectiveness of an EWS is not determined solely by technological sophistication but also by the extent to which it is accepted, understood, and utilized by local communities. While IoT-EWS provides advanced technical capabilities, local wisdom-based systems offer contextual knowledge and strong community engagement. Therefore, integrating these two approaches may provide a more comprehensive and sustainable disaster management strategy. The combination of traditional values and active community participation makes this system relevant and sustainable at the community level (Mare et al., 2021).

4. CONCLUSION

The review results show that IoT-EWS and Local Wisdom-EWS are two different mitigation or early warning methods in terms of various aspects and implementation methods. However, both contribute to strengthening community resilience for disaster management. Hydro-meteorological disasters (such as floods, landslides, erosion)

still require measured and inclusive handling. This is because these disasters are not only caused by natural factors, but can also be accompanied by anthropogenic factors (human actions) that can exacerbate disaster risks, so that early warning systems such as IoT are considered to lack long-term mitigation capabilities because they only display real-time data. Therefore, integrating IoT-EWS and Local Wisdom-EWS is essential for effective disaster management across diverse regions of Indonesia. Local Wisdom-Based Early Warning Systems (EWS) contribute to disaster risk reduction through long-term community-based practices that have been passed down from generation to generation and implemented before disaster events occur, such as reforestation, traditional land management systems, and rituals that reinforce environmental awareness. However, the reviewed studies primarily describe these practices qualitatively, with limited quantitative evidence showing their direct impact on disaster risk reduction. As a result, instead of showing that Local Wisdom-EWS is more effective than IoT-EWS, the findings suggest that the two approaches perform different but complementary functions: Local Wisdom-EWS strengthens long-term readiness, environmental conservation, and community engagement, while IoT-EWS improves real-time monitoring, early detection, and rapid deployment of alerts.

The implementation of IoT-EWS and Local Wisdom-EWS also has similarities in terms of disaster risk reduction and its level of urgency in Indonesia's regulatory system. Although there are significant fundamental differences, the results of the implementation of both early warning systems are quite good in accordance with the conditions of each region. However, further optimization is needed for IoT-EWS in terms of equitable implementation across various regions, early enhancement of science and technology, and integration of disaster management knowledge based on local wisdom into the disaster education curriculum.

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