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Acta Sci. Pol.
Architectura 21 (4) 2022, 11–20
ISSN 1644-0633 eISSN 2544-1760 DOI: 10.22630/ASPA.2022.21.4.26

REVIEW PAPER

Received: 12.11.2022
Accepted: 18.12.2022

# EARTHQUAKE EARLY WARNING SYSTEMS (EEWSs) AND THEIR APPLICABILITY IN MODERN RESEARCH – A REVIEW

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**ABSTRACT**

Sending alerts or warnings about ground tremors is known as an earthquake early warning system (EEWS). It is issued after the earthquake has already started to cause observable ground motion, setting it apart from the forecast. The interval between detection and the moment a user feels ground motion is known as the available warning time. Therefore, the potential warning window can be anywhere between seconds and minutes. Similarly to this, users must be able to act quickly because only seconds to minutes are available to collect, interpret, and transmit seismological data and warning signals. By reviewing previously published, high-quality literature, the review article offers clear insight into EEWSs and how they operate. This will support researchers in understanding the current technologies used to send signals to save lives from earthquakes at the appropriate time. The effects of earthquakes and how they have been tracked using EEWSs are also covered in the article.

**Key words:** EWS, EEWS, earthquake, natural disasters

## INTRODUCTION

Early warning systems (EWSs) have played a critical role in decreasing the risk of death and injury from natural catastrophes caused by weather, climate, and water. This improvement has been aided by better natural hazard evaluation, as well as improved forecasting and warning systems. People are also becoming more aware of the dangers presented by natural disasters and the precautions they should take to safeguard themselves and their families. Peng, Zhu, Yang, Xue and Chen (2013) characterised the enhancements of test distribution on-site at a consolidated earthquake in Zhoatong (China) resulting from the implementation of EDAS-MAS and EEWS depicted in Figure 1. To monitor the optimal effect of these systems with S-wave velocities less than P-wave velocities and hypocentre distances, two types of magnitudes were calculated using value calculations. It also provides the capability of reducing the "blind zone" range and extending the warning period when the measurement threshold is exceeded. In this study, EDAS-MAS has been equipped with three types of alarms, seismological processing, a data acquisition unit, and a three-channel microelectromechanical system (MEMS) accelerometer. Lin, Chan and Tagawa (2020) summarised the perceptual-based segregation method that authorised the EEWS, as shown in Figure 2. The earthquake early warning system utilised the various seismic S-waves and P-waves of varying travel speeds to achieve the intended public warnings. In susceptible cities and areas, earthquakes have caused not just human and material destruction, but also significant economic disruption. The significance of the economic difficulties and the

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effects of earthquakes drew the attention of engineers and created new research and employment prospects for engineers, who had previously been concerned exclusively with risk mitigation measures. The new smart base isolation is designed to increase the standard time duration of vibration and decouple the structure from its natural base. In the event that the EEWS failed, additional vibration sensors were utilised to detect incoming earthquake waves. This system is particularly effective for reducing earthquake retaliation on the structure within the context of earthquake-risk mitigation. Sutton, Fischer, Lori and Sheff (2020) examined some laboratory tests by observing the visual response and behaviour of subjects in response to an artificial earthquake early warning message. The success of the EEWS was marginally influenced by the presence of informational icons describing the appropriate protective action along with the message. Also, reducing the harmful effects of hold-on practices is more crucial.

Schaefer, Di Traglia, Chaussard, Nolesini and Casagli (2019) monitored the assessment of volcano slope instability challenges utilising smart synthetic aperture radar (SAR) techniques, observing behaviour and collecting data from Stromboli (Italy) and Pacaya (Guatemala) volcanoes. The synthetic aperture radar images are the best tool for mapping zones of geomorphological change, as they provide special information on the development of slope failure. This is accomplished by combining the interpreting SAR (InSAR) and ground-based InSAR (GBInSAR) to create multi-temporal deformation maps and frequent SAR images in the EWS. In order to identify potentially hazardous slope instabilities with the aid of SAR imagery, these two cities' volcanoes, demonstrated the case study, ground truth constraints, persistent volcanic activity, and recent instability events. Mohanty, Hussain, Mishra, Kattel and Pal (2019) presented how the adaptability of traversing communities and early warning features for landslides, debris flow, and flash floods in disruption-prone villages Badakhshan, Afghanistan, enchance the Sendai structure's emphasis on the resilience of groups vulnerable to real risks. The primary objective of this analysis is to implement the EWS framework for flooding, mudslides, and landslides using the calculated examination method. The Climate-related Disaster Community Resilience Framework (CDCRF) and a new structure proposed greater participation in emergency planning and disaster management in communities with decreasing flexibility.

Chaintoutis et al. (2014) discussed the instituted observation procedure rooted in makeshift pigeon serological trials. They were dealing with cELISA conducted by serum sampling experiments. In 2010, a transition of the West Nile virus (WNV) happened in Greece, with 197 West Nile virus neuro-invasive disease (WNND) cases. The WNV seroprevalence point


**Fig. 1.** Tested area: a – the location of the EDAS-MAS test bed (The bubbles represent the 5.7 magnitude mainshock and aftershocks of the 2012 Yiliang earthquake); b – the locations of 12 EDAS-MAS test stations

Source: Peng et al. (2013).

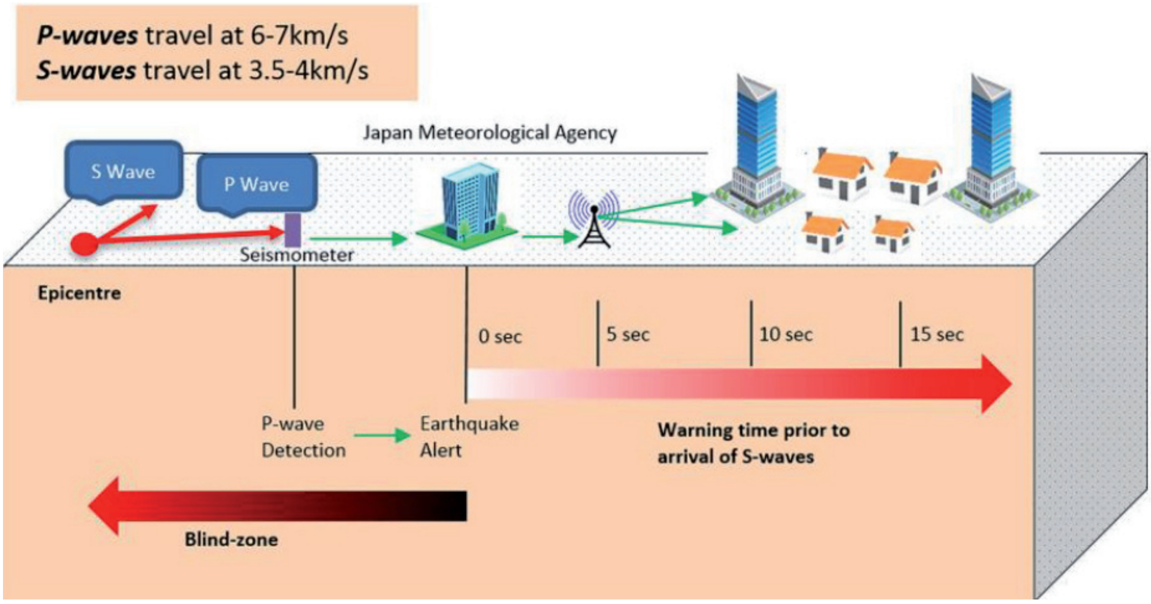


**Fig. 2.** Schematic diagram of an earthquake early warning system (EEWS)

Source: Lin et al. (2020).

in domestic pigeons and WNND cases in men for 2011 were decreased similitude to the 2010 data and hints at a lesser level of virus discursiveness at the beginning. Punctual prevalence of knowledge to well-being mastery makes smooth the execution of plans to safeguard humankind's well-being. Jin and Lin (2011) addressed the research conducted to identify the primary factors that will have a significant impact on the evolution of a tsunami warning structure in which uncivilised engineering and scientific investigation can be productively integrated into riparian uncivilised danger preparation. The effective tsunami alert process must include ocean technology for newly discovered swell tsunamis and an infusion method so that the provincial government and other authorities can alert the public in a timely manner. The results indicate that funding a tsunami warning system in the south pacific region may lead to significant financial returns. Perera, Agnihotri, Seidou and Djalante (2020) explored the work created by a survey and published literary texts to identify and debate gaps in movement, alacrity, and impediment stages to the flood early warning system (FEWS) alerts. The work also discusses the role of civil society institutions in resolving the recognised defiance and in strengthening FEWS regionally. Increase the FEWS machinists' and speculators' awareness of the non-technical and social aspects of FEWS and focus more on these areas.

## EARTHQUAKE

When two sections of the ground abruptly move past one another, an earthquake occurs. The surface where the slippage occurs is known as the fault or fault plane. The area under the Earth's surface where the earthquake begins is known as the hypocenter, and the area just above it on the Earth's surface is known as the epicentre. Asgary, Levy and Mehregan (2007) estimated the total impact of an earthquake on Tehran Metropolitan residents. They developed the contingent valuation method (CVM) in order to determine the efficacy of a hypothetical EEWS. The public's willingness to pay and the CVM of inspection were the most important factors in mitigating the impact of disaster-related losses, such as an earthquake. It was determined that the optimal investment to reduce earthquake risk through an EWS is proportional to the willingness of households to pay for an EEWS. Fabozzi, Bilotta, Picozzi and Zollo (2018) evaluated the rapid response system and the viability of a loss-driven EEWS for the

Italian high-speed railway network. High-capacity, high-speed rail networks carry a high seismic risk for earthquake-related damage. The real-time mitigation analysis evaluated the availability of time and the possibility of seismic risk to the tunnel constructions in order to reduce the tunnel lining in both conditions. This method is easily configurable to achieve the various objectives of designing an early earthquake warning system to maintain, manage, and control the high-speed railway network for tunnel structures.

Santos-Reyes (2019) presents the importance of early earthquake warning systems and provides a case study of the 2017 Mexico City earthquake. It was believed that the Mexican EEW and seismic alert system (SAS) called SASMEX would make people aware of the seismic emergency sooner by measuring the time between the warning bell and the actual ground vibration. These systems can be followed by having knowledge of seismic risk management's response capability, dissemination and communication, warning and monitoring, and risk knowledge, and they should be human-centred. In Japan, Fujita, Minagawa, Tanaka and Shimosaka (2011) came to the conclusion that using an EEW and air bearings was an intelligent seismic isolation technique. This kind of technique successfully achieves enough isolation. In this study, the air bearings were used to support the high-rise building during its natural period by floating them during the

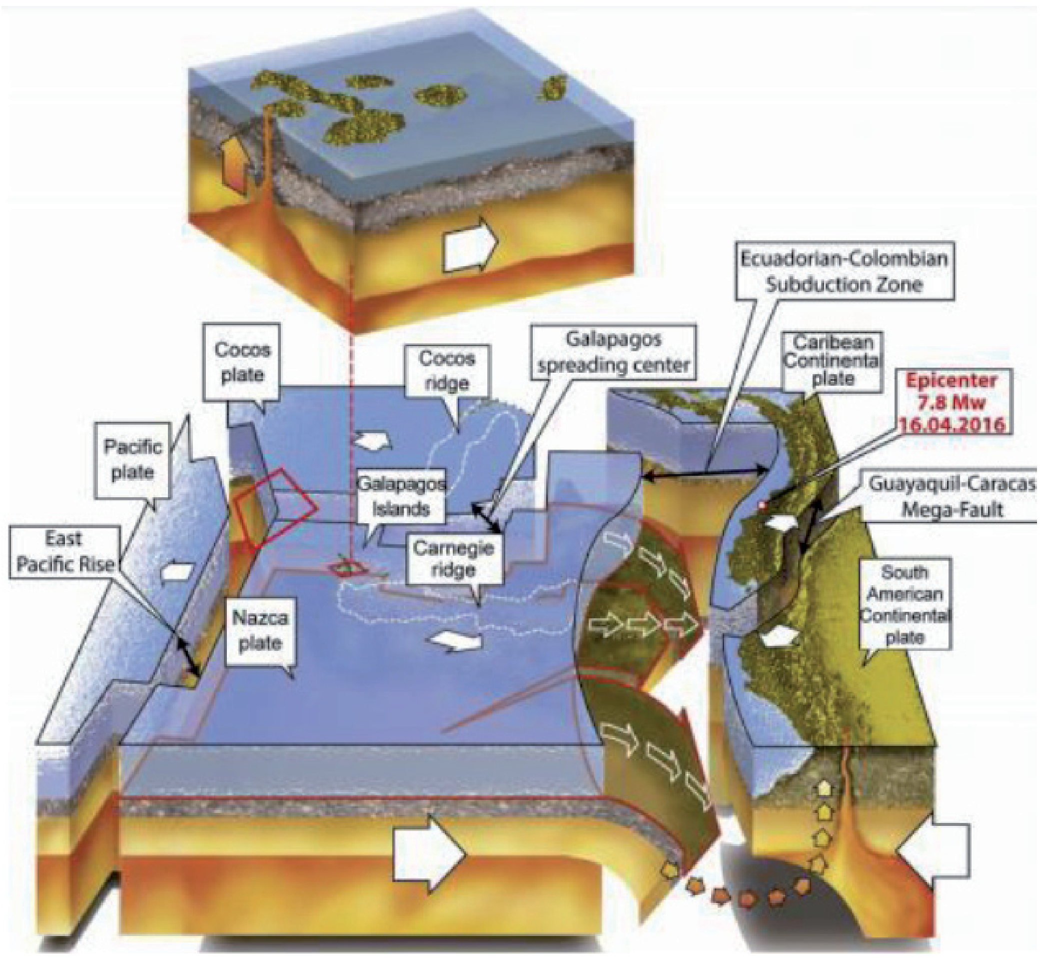


**Fig. 3.** Continental and oceanic plates along with plate boundaries of the plates surrounding Ecuador, the Galapagos Islands and the Carnegie Ridge

Source: Toulkeridis et al. (2019).

isolation process. In general, these seismic isolation systems need to be improved by taking into account the characteristics of seismic waves and controlling the system with the necessary time duration, predominant periods, and ground acceleration. Figure 3 shows plate boundaries as well as the Carnegie Ridge and the Galapagos Islands' continental and oceanic plates.

## Effects of earthquakes

An advanced early earthquake warning system was discussed by Gresnigt, Kole and Franses (2015) for long-term destructions brought on by earthquakes and the financial crisis. The EWS on S&P 500 statistics throughout the current financial market crash is taken into consideration to assess the positive Hanssen and Kuiper skill scores (KSS). Additionally, the observed configuration was achieved by using data from applied volatility models in the preferred series, which were uncommon and well-known for forecasting the most significant price movements with the least amount of forecasting time. Neural earthquake early warning system (NEEWS) is a technique described by Rafiei and Adeli (2017) shown in Figure 4. The main goal is to preserve critical lifeline infrastructure and save human lives while also maintaining vital facilities. According to the machine learning concept EEWS model, a combination of a classification algorithm (CA) and optimisation algorithm (OA) is used to predict the significant earthquake location and its magnitude within a time form of weeks. The integration

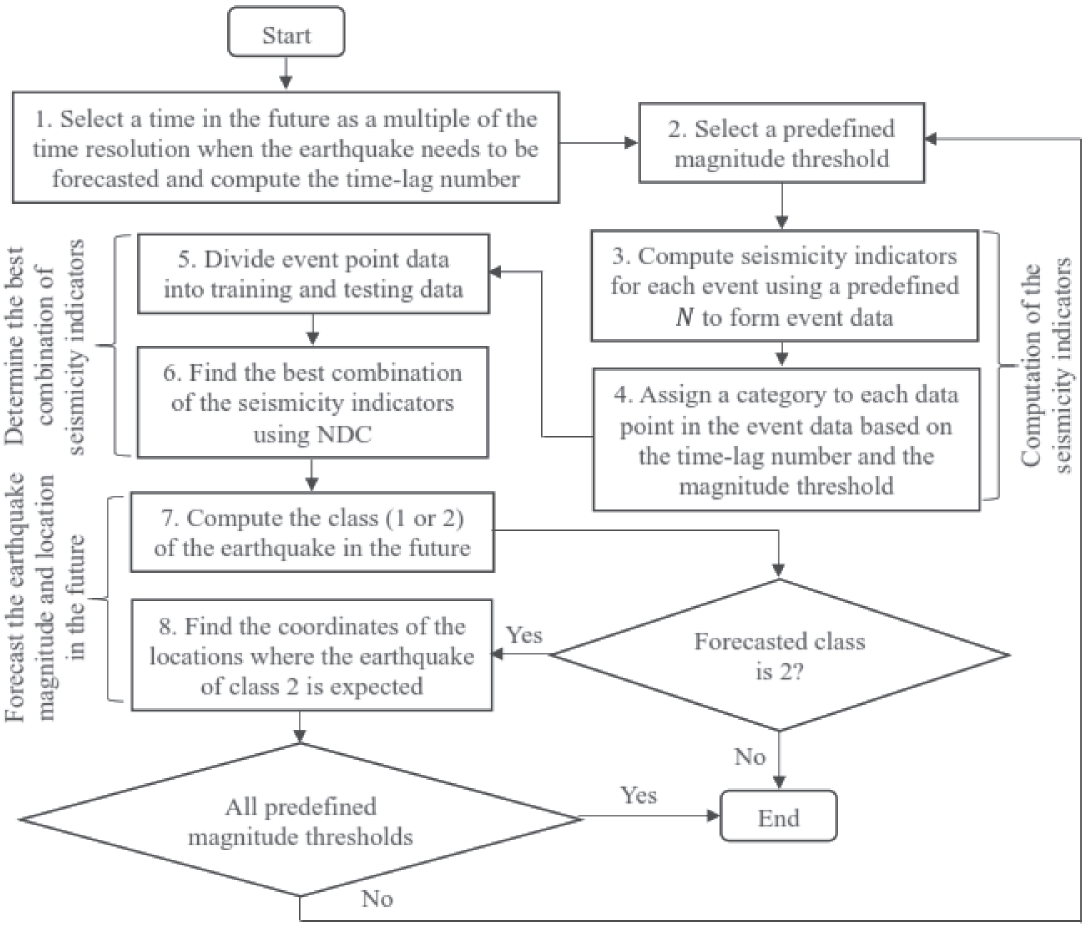


**Fig. 4.** The neural earthquake early warning system (NEEWS) general flowchart

Source: Rafiei and Adeli (2017).

of the machine learning CA method and the dynamics OA of Rafiei's and Adeli's problems were successfully solved by the observation of the early warning system.

The value of the EEW system against an earthquake's powerful motion was expressed by Nakamura, Saita and Sato (2011). To reduce the risk of earthquakes and other seismological events, EEWSs must be properly implemented. The study's findings revealed that the development of an EEW ultimately results in an improvement in Japan's Urgent Earthquake Detection and Alarm System (UrEDAS) of P-wave seismology. Dunn, Ahn, Bostrom and Vidale (2016) used three rounds of Google paywall interrupt surveys to gather information about how people felt about the EEWS performance in the context of a disaster on the US West Coast. The local government and the federal government were in charge of funding the EEW system and installing an ShakeAlert application on their personal computers and Android or smartphones to lessen the impact of the earthquake. Aside from that, highly visible mass media content, such as movies and articles, raised awareness of the risk of earthquakes, which helped the EWS develop better and receive excellent support.

The Irpinia Seismic Network (ISNet), which can identify the anticipated upcoming earthquake risk of the seismogenic area within the next 20 years (Satriano et al., 2011), introduced the future interpretation, potentiality, and central concept of the EEWS in Southern Italy. In order to address the magnitude and real-time data output and input in various seismogenic regions and networks, the probabilistic and evolutionary EWS (PRESTo) software is used. Additionally, the location and size of the earthquake were estimated, and both small and large earthquakes were tracked using the simulation model ISNet.

## Prediction of earthquakes

The capabilities and scope of the EEW system in Aotearoa, New Zealand, were briefly described by Becker et al. (2020). The benefits of reducing the aid response, impacts, and recovery in the case of site-specific and organisational actions, situational assessment and emergency plans, activation, psychological preparedness, and life safety were benefits of the earthquake early warning method. Additionally, the EEW system should be implemented by every household in the community, including the actions taken with the message and con-

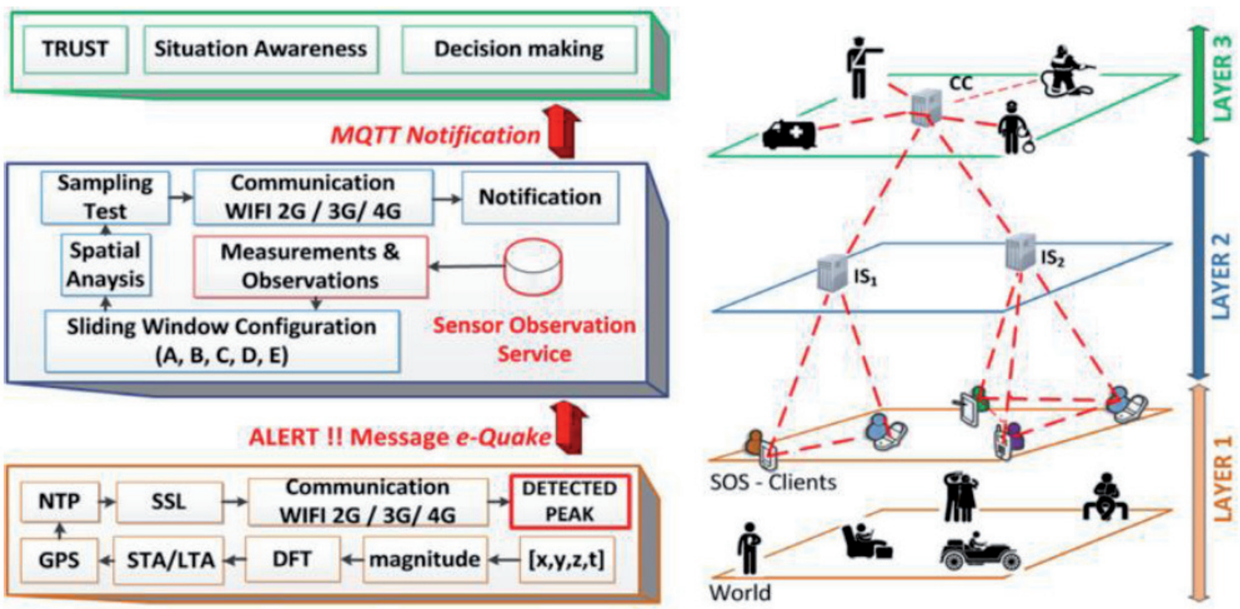


**Fig. 5.** Three-layered hierarchical architecture for an earthquake early warning system (EEWS)

Source: Zambrano, Perez, Palau and Esteve (2017).

tent of EEW, the threshold for sending warnings, and user confidence in EEW technology. Future research is also necessary for the advanced EEWS and their functional zonal supplication. Zambrano et al. (2017) connected and described the Internet of Things (IoT) mechanisation used in the EEWS. Nowadays, most citizens use smart appliances with so many advanced technologies of IoT, such as Message Queue Telemetry Transport (MQTT) and Sensor Web Enablement (SWE) framework, as illustrated in Figure 5 to detect the epicentre zone through the wireless advanced Android smartphones within the highest seismic peak up to 12 s and time seismic information and implementation to handle the information from contrasting sensors.

Wang, Wu, Lin and Brant (2012) discussed the minimisation of damage and loss of life from catastrophic earthquakes with the aid of advanced EEWSs. During the prediction process, the unpredictability of the peak ground acceleration (PGV), excess probability (PE), and their interconnection through the established analytical relationship. The proposed method for estimating the ground acceleration (PGV) by increasing the precursor measurement (Pd3), as well as future development, is required to avoid early warning notification problems. Theofilos et al. (2019) discussed the two most common EEWS appliances. One of these two precursors is used to identify the radiation of earthquake position hourly before and after the main earthquake, and the actual time is recorded; the other is used prior to a few minutes before the main earthquake, and the actual and accurate position is determined by taking readings from 24 GPS stations every second. The main 7.8 Mw earthquake was deemed an optimal standard for the other seismic activities, which were not monitored, and these two independent measurement tools in the EWS based on the geodetic and radioactive procedure.

Mărmureanu, Ionescu and Cioflan (2011) studied the newly developed real-time access to the European EWS for Vrancea earthquakes. Bucharest is the city most frequently affected by the high-energy Vrancea intermediate-depth earthquakes. P-wave in the epicentre is used to estimate magnitude errors and set real-time software to send earthquake warnings to the city of Bucharest within 4–5 s of detecting the earthquake in the epicentre for the warning signs facility. Alcik, Ozel, Wu, Ozel and Erdik (2011), approached a second Istanbul-based earthquake early warning system. In 1999, two devastating earthquakes occurred in the Marmara Region, prompting the development of essential treatment for future tremors. The observed relationship between moment magnitude and tc and between peak ground velocity (PGV) and vertical displacement amplitude parameters (pd) was used to identify the destructive earthquake within seconds of the arrival of P-waves. It may permit site-based warnings in the Marmara Region.

## Earthquake monitoring using an EWS

An earthquake early warning system for seaside areas and their functionality during the earthquake risk were observed by Cervone, Kafatos, Napoletani and Singh (2006). It has been developed to perform a time-related data mining inspection in real-time using an impulsive system known as CQuake from remote sensing data obtained via satellite. Instead of using another geophysical specification, the CQuake executes projections for previously defined sectors based on the surface latent heat flux (SLHF) analysis. Kubo, Hisada, Murakami, Kosuge and Hamano (2011) adapted the association of the real-time strong motion monitoring system (RSMS) and EEWS for the superstructure to immediate response using the Plan-Do-Check-Action (PDCA) method. In addition, an uninterruptible power supply system (UPS) was installed and used to power the RSMS and the EEWS on each floor of the high-rise buildings, as well as emergency IP telephones to the security control centre for the main floors, as the UPS works for approximately 30 min after a major earthquake, which is sufficient time to collect all destruction information during the initial response. Following the PDCA method correctly, the manual of emergency response and systems, as well as people's utilisation of these systems, were enhanced.

Based on mechanical and electronic properties, Chan, Lin and Tagawa (2019) investigated an advanced isolation system for early earthquake warnings. During the arrival of S- and P-waves in Japan, the intelligent EWS is used to protect the populace from natural disasters such as earthquakes. In addition, passive and active and semi-activated shaking control processes and strategies have evolved. The EEWS was controlled by the mechatronics system, which is fully automated and proposed independently. The Internet of Things (IoT) was also discussed. Wagener, Goda, Erdik, Daniell and Wenzel (2016) measured pseudo--spectral acceleration (PSA) and peak ground acceleration (PGA) because these two sites were experiencing a similar seismic event and were also interconnected. In urban areas, the Istanbul Earthquake Rapid Response and Early Warning System (IERREWS) provides an array with a two-kilometre spacing between stations. The co-connected mode of Monte Carlo reflection is used to assess the economic loss caused by a 7.2 Mw framework earthwork.

In the study entitled "Two independent real-time precursors of the 7.8 Mw earthquake in Ecuador based on radioactive and geodetic processes – Powerful tools for an EWS", no deviation in the GPS time series was found, and the method is not considered to be a reliable predictor of earthquakes (Yepes et al., 2020). The InSAR and GPS analyses conducted were inconsistent and implausible. Prior to the 7.8 Mw earthquake, only one radiation deviation was recorded, and the actual rate of predicting earthquakes using radiation deviations is 2.5%. In addition, these forecasting systems for short- and medium-term earthquakes in operational margins around the world are imperfect. McBride et al. (2020) invented a shake-alert for the post-alert messaging system for the public EEWS on the West Coast of the United States. The six steps are taken to evaluate the uses of the messaging alert system, which may disseminate unfavourable information to the public, and to address these issues. These six steps included the development of a typology of earthquake alert, the elaboration of message templates for various communication programmes (Arvindan & Vijayan, 2022; Dallo et al., 2022), the structure of an analytical set of post-alert messaging framework, the presentation of a decision tree for providing the post-alert message, the evaluation of shake-alert performance to date for the eventual development of the system, and the evaluation of human behaviour.

## CONCLUSIONS

The current paper has provided a critical analysis of methodologies used to improve EEWSs that alert people in advance of the event. The literature's most important guideline refinements were used to improve the early warning systems by discussing best practices strategies. The following list of key findings from this review article:

- When carrying out the operational evaluation of EEWSs, the review has concentrated on a wide variety of approaches that have been applied in the relevant body of research.
- The fundamental performance of EEWSs was a pivotal factor that influenced the techniques that were applied in each individual case study.
- The article discusses EEWSs and their current state of development in civil engineering in an effort to improve the research findings in this field.
- The article discussed a variety of cutting-edge early warning systems that can forecast natural disasters as far in advance as possible so that people can take appropriate safety measures.
- The application of an EWS to earthquakes has been analysed in depth with the benefit of prior research.

**Acknowledgements**

The research in the manuscript was supported by Aarupadai Veedu Institute of Technology, Chennai. We would like to extend thanks to the authors from Aarupadai Veedu Institute of Technology, Chennai, for providing the needed technical support.

**Authors' contributions**

Conceptualisation: A.S. and D.S.V.; methodology: A.S. validation: D.S.V. and A.S.; formal analysis: P.D. and D.S.V.; investigation: A.S.; resources: A.S.; data curation: P.D.; writing – original draft preparation: A.S.; writing – review and editing: A.S. and D.S.V.; visualisation: P.D.; supervision: A.S. and D.S.V.

All authors have read and agreed to the published version of the manuscript.

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## SYSTEM WCZESNEGO OSTRZEGANIA PRZED TRZĘSIENIEM ZIEMI (EEWS) I JEGO ZASTOSOWANIE WE WSPÓŁCZESNYCH BADANIACH – PRZEGLĄD

### STRESZCZENIE

System wysyłania alarmów albo ostrzeżeń przed wstrząsami terenu jest znany jako system wczesnego ostrzegania przed trzęsieniem ziemi (ang. *earthquake early warning system* – EEWS). W odróżnieniu od systemu prognozującego EEWS jest aktywowany po rozpoczęciu się trzęsienia ziemi w celu umożliwienia obserwacji ruchu gruntu. Przedział czasowy między wykryciem ruchów gruntu a wyczuciem ich przez użytkownika jest określany jako osiągalny czas ostrzegania. Potencjalne okno czasowe ostrzegania może zawierać się między sekundami a minutami. W związku z tym użytkownicy muszą mieć możliwość szybkiego zadziałania, gdyż na zebranie, zinterpretowanie oraz przesłanie danych sejsmologicznych i sygnałów ostrzegawczych mają do dyspozycji tylko sekundy lub minuty. Niniejszy artykuł przeglądowy, będący wynikiem przejrzenia wydanych dotychczas wysoko punktowanych publikacji, prezentuje w celach dydaktycznych zagadnienia specyfiki działania współczesnych technologii wykorzystywanych w EEWS. Opisano w nim także skutki trzęsień ziemi oraz sposób, w jaki były one śledzone z użyciem EEWS.

**Słowa kluczowe:** EWS, EEWS, trzęsienie ziemi, katastrofy naturalne