

Article

Evaluating the Effectiveness of Early Warning Systems in Reducing Loss of Life in Natural Disasters: A Case Study of Greece

Stavros Kalogiannidis ^{1,*}, Dimitrios Kalfas ^{1,*}, Stamatis Kontsas ¹, Olympia Papaevangelou ¹ and Fotios Chatzitheodoridis ²

¹ Department of Business Administration, School of Economic Sciences, University of Western Macedonia, Grevena (51100), West Macedonia, Greece

² Department of Management Science and Technology, School of Economic Sciences, University of Western Macedonia, Kozani (50100), West Macedonia, Greece

* Correspondence: skalogiannidis@uowm.gr; Tel.: +302462061616 (S.K.); kalfdimi@otenet.gr; Tel.: +302462061616 (D.K.)

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Abstract: This paper assesses the impact of Early Warning Systems (EWS) on minimizing loss of life during calamities using Greece case. EWS are useful in disaster risk reduction due to their ability to issue alarm, offer early hazard forecast, educate the public and use technology to enhance the response action. This study aims at evaluating the effectiveness of these six components through a survey of 353 environmental professionals and specialists in Greece. The results show that the Greek EWS tends to offer early warning in most events, which assists in preparing the community. But still, there are critics who argue that the effectiveness of the system is still lacking in delivering urgency of threats. Though they admit that they have a high level of confidence in their hazard predictions, there remain issues with reliability, which need to be worked on constantly to retain the public's confidence. Although, increased public awareness and education activities have played a positive role in increasing understanding about the EWS, there are shortcomings existing in making sure that everyone realizes what steps they should take when they get a warning. Automated systems such as the IoT implemented to monitor hazardous events and AI integrated to forecast such events have made surveillance faster and more precise. However, access as a concept remains limited, especially for the sensitized population, and there is a need to adopt more inclusive methods of passing information. It also suggests the development of communication-Intensive EWS through the integration of mobile alerting, social media, and other community engagement programs. This study adds value to the existing body of knowledge and practice in disaster management by providing insights into factors that determine success of an EWS in reducing fatalities. Proposals include improving the communication of risks, improving the consistency of forecasts through the use of AI, focusing on more education among the public and spending on improved systems for monitoring. Better communication with relevant authorities and harmonizing of technology-enhanced solutions will provide more efficient and coherent disaster management in areas such as Greece and other high-risk regions.

Keywords: Early Warning Systems (EWS); Natural Disasters; Loss of Life; Timeliness; Accuracy of EWS; Public Awareness; Technological Advancements; Hazard Predictions; Greece

1. Introduction

1.1. Background to the Study

On global climate change and fast pace of urbanization, the utilization of early warning systems (EWS) to minimize impacts of natural disasters is a major factor acknowledged fundamental to disaster risk reduction [1]. Natural calamities, such as hurricanes, floods, tsunamis and earthquakes are dangerous to communities due to their propensity to cause extensive damages, long term and large scale disruption and high death tolls [2, 3]. The literature testifies that EWS have successfully mitigated on the above risks, revealing that timely alerting, accurate prediction of hazards, enhanced public awareness and advancement in technology are key approaches. Traditionally, EWSs were designed for monitoring and predicting various geological phenomena like earthquakes and climate conditions. However, modern EWS have expanded beyond the earlier definitions as they encompass capabilities for risk evaluation, communication, and response planning [4, 5]. This shift is more complex which calls for a more elaborate, people-centered intervention as opposed to hazard identification. Because of this, many international frameworks have recommended the development and incorporation of EWSs [6]. The Hyogo Framework for Action (2005–2015) for the first time recognized the imperative of the strengthening EWS as part of the international disaster risk reduction frameworks [7, 8]. Expanding on this, the Sendai Framework for Disaster Risk Reduction 2015-2030 extends the use of inclusive and technology based early warning systems for increasing community resilience [9, 10].

Research has shown that functional Early Warning Systems (EWS) contribute to the limitation of mortality and economic loss during disasters. This was evident in the 2004 Indian Ocean tsunami where over 230,000 people died in 14 countries [10]. On the Other hand, countries like Philippines and Japan that have had color-coded, multi-hazard EWS that incorporate the usage of modern technology, active involvement of the community and well-coordinated response frameworks [11, 12]. Nevertheless, there are remaining challenges with regard to the functionality of EWS as they relate to forecast accuracy, timeliness, perception, and incorporation of EWS into disaster management systems [13, 14]. The inconsistencies in EWS effectiveness make disaster management more challenging by worsening the situation through reflecting the difference in different dimensions of SES & geographic location. HICs on the other hand have structural and functional EWS that are technologically advance while LMICs are constrained by lack of infrastructure, inadequate resources and low level health literacy [15, 16]. The differences in EWS design and usage for different regions and political, economic, and environmental systems raise questions about the extent to which certain models and structures are internationally applicable or require more specific adaptations. Moreover, when climate change enhances the incidence and intensity of natural disasters, the need for EWS in protecting the vulnerable groups is paramount. For instance, in the last decades, the social frequency of climate-related disasters has increased significantly, whereas vulnerable groups particularly those living in cities have been most affected [17]. Therefore, there is need to work towards improving efficiency of EWS in delivering timely and accurate information to reduce loss of lives and other loses. Research reveals that EWS can help decrease disaster death toll by 60% as long as EWS are complemented by adequate governance, cooperation between various organizations, and community participation [18, 19].

Like many other countries in the Mediterranean region, Greece is vulnerable to various natural disasters, such as earthquakes, floods, wildfires, and hot summer waves. The country has recently been devastated by fires such as Attica in 2018, where over 100 lives were claimed and floods in Evia

in 2021 [20, 21]. However, issues have been raised on effectiveness by EWS via concern to do with the accuracy in forecasting, coordination in responding to disasters and how the warnings are issued to the public. It was found that timely warning and effective communication are a critical issue due to which the recent disasters in Greek areas have become worse [22, 23]. The country is vulnerable to natural disasters due to its geographical and climate profile and therefore requires a sound and flexible EWS. However, gaps still exist regarding predictive analytics, real-time monitoring, and participation of multiple stakeholders due to the current system prevailing within Greece. Interestingly, guidelines and strategies can be learned from nations with mature EWS frameworks, for instance; Japan, United States and Germany where; the application of innovative ICT based, community-focused measures have enhancing disaster mitigation [23, 24]. More so, the existing disaster risk reduction measures in Greece are in compliance with the EU regulations, but the strategies' implementation is a challenge. There is the lack of coordination between local, national and regional response agencies, and this coupled with weak advantageous risk communication strategies impacts the effectiveness of EWS in disaster risk reduction. This underlines the importance of the evaluation of Greece's EWS within the international context taking into account the existing positive experience but also the drawbacks.

However, although much has been written about EWS, the primary emphasis is usually provided to technical concerns, thus leaving little attention to the straight link between EWS efficiency and death outcome. Moreover, studies are scarce regarding the modularity and complexity of the relations among technological, social and governance factors for EWS effectiveness in real-life disaster situations [25, 26]. As in most countries, research based on practical experiences and improvements necessary to optimize the Greek EWS with respect to the international standards remains scarce. This paper seeks to meet this need through undertaking a comprehensive analysis of the Greek EWS with special focus on: the effectiveness and salience of EWS alerts and the extent to which they are facilitated to prevent mortality rates, a review on the reliability of hazard predictions and their effectiveness in preventing disaster-related deaths, a study on public education and awareness on disaster preparedness, and examining how technological interventions increase efficiencies in the operation of EWS. Therefore, identifying these facets of EWS will help develop improved disaster risk management policies, new technologies, and engagement frameworks to increase EWS effectiveness in Greece and other countries experiencing similar issues [27, 28].

1.2. Purpose of the Study

The study aims to empirically investigate the relationship between different aspects of EWS and their effectiveness in reducing mortality during natural disasters.

1.3. Study Objective

- (1) To examine the timeliness of EWS in providing early alerts to vulnerable communities and its impact on reducing mortality during natural disasters.
- (2) To assess the accuracy of hazard predictions and their effect in minimizing loss of life during natural disasters.
- (3) To examine the effectiveness of public awareness and education programs in EWS.
- (4) To find out the role of different technological advancements in improving the efficiency of EWS during natural disasters.

1.4. Research Questions

- What is the effect of the timeliness of early warnings on the reduction of mortality in natural disasters?
- What is the impact of the accuracy of hazard predictions on life preservation during natural disasters?
- How do public awareness and education initiatives within EWS contribute to saving lives?
- What is the role played by the different technological advancements in improving the effectiveness of EWS?

1.5. Research Hypothesis

- H1: Timely early warnings are significantly correlated with reduced mortality in natural disasters.
- H2: Accurate hazard predictions are critical in minimizing loss of life.
- H3: Effective public awareness and education programs within EWS significantly contribute to reducing fatalities.
- H4: Advanced technologies enhance the efficiency and effectiveness of EWS in minimizing loss of life.

1.6. Significance of the Study

This study offers valuable insights for policymakers, disaster management authorities, and stakeholders in enhancing the effectiveness of EWS, potentially leading to the saving of lives during natural disasters. Different policy makers can utilize the findings of this study to design and implement appropriate EWS to help in reducing the risk or negative outcomes of natural disasters. The findings of this study can act as a point of reference for future research in a similar or related area of study.

2. Literature Review

2.1. Historical overview of Early Warning Systems (EWS)

The evolution of disaster risk reduction and the role of technology and community involvement in lessening the effects of natural disasters are demonstrated by the historical development of EWS [29]. Over time, EWS have experienced a great deal of change, progressing from simple alarm systems to complex systems that include community engagement and technology improvements [13, 24, 30, 31]. In their discussion of this progression, Cazorzi et al. [23] highlight the move towards EWS that is more integrated and based around people whereby the systems put much focus on ensuring that those who are at risk get and comprehend the different EWS alerts that eventually act as early alerts in anticipation of natural disasters. Hammood et al. [32] noted that technology has been instrumental in enhancing the effectiveness of EWS most especially with the utilization of the Internet of Things (IoT) and cyber-physical systems. These developments have improved the ability to identify, track, and share hazards in real time, greatly enhancing EWS's reactivity. Meléndez-Landaverde and Sempere-Torres [33] draw attention to the shift in EWS methodology from top-down to community-centric. This change is indicative of a growing understanding of the value of local expertise and community involvement in guaranteeing the efficacy of EWS. This is further explained by Rangarirai

et al. [34], who look at the function of community participation in EWS and show how community involvement may enhance early warning comprehension and responsiveness.

The inadequacy of flood warning systems in Europe is discussed by Perdomo [30], highlighting the difficulty in guaranteeing efficient reaction and communication. This emphasizes how important it is for EWS design and implementation to keep evolving and adapting [35]. The creation of a multi-hazard EWS in India is covered by Sufri et al. [3], who offer a useful illustration of how such systems might be put into practice in a complicated and varied setting. Fofana et al. [36] examines several flood forecasting and warning system models and implementations in West Africa, emphasizing regional demands and specificities. Improving EWS's flexibility, dependability, and inclusion will be key to its future. Examining stakeholders' opinions of EWS efficacy, Agbehadji et al. [4] recommend that future systems be customized to fit the various demands and circumstances of various communities and areas. Incorporating cutting-edge technology with community-focused methodologies is probably going to continue to be a major area of emphasis for EWS development. A key component of EWS's development has been the incorporation of scientific discoveries into the formulation of public policy [12, 24, 37]. The design of EWS for systemic risk detection study by Budimir et al. [12] emphasizes how crucial it is to close the knowledge gap between science and real-world policy applications. According to Rangarirai et al. [34], and Yasmin et al. [38], this integration is crucial for the creation of EWS that are not only technically sound but also in line with the socioeconomic and political reality of the regions they serve.

The identification of infectious disease outbreaks has been included to the EWS in recent years [15, 22, 39]. The usefulness of EWS in identifying infectious illnesses was evaluated by Hermans et al. [40], underscoring the systems' increasing significance for the security of global health. This extension reflects the requirement for comprehensive systems that can handle a variety of dangers as well as the growing knowledge of what constitutes a "disaster" [41, 42]. In their reflection on the development of conflict EWS, Agbehadji et al. [4] highlight the systems' capacity to avert humanitarian disasters. The fact that EWS is being used in situations other than natural disasters shows how adaptable they are and how their worth is increasingly understood. There have also been notable developments in the realm of earthquake detection. Mustofa et al. [43] describe how IoT and cloud infrastructure are being used to identify earthquakes early, demonstrating how cutting-edge technology is being used to deliver timely warnings for seismic disasters [25, 44].

2.2. Effectiveness of EWS Components

Risk knowledge is utilized to become aware of potential threats and community vulnerabilities, and it is a crucial part of EWS [22]. According to Cazorzi et al. [23], Khankeh et al. [22], Rana et al. [24], and others, Early Warning System (EWS) components (Figure 1) are essential for disaster risk reduction because they provide early and useful information that enables people, communities, and organizations to plan for and lessen the impact of catastrophes.

Developing precise and thorough risk assessments is essential to developing EWS that work. According to Sufri et al. [3], these evaluations involve the identification of danger classes as well as their severity, frequency, and possible effect areas. Baudoin et al. [19], for example, stress the importance of risk awareness in warning the public and authorities about the particular dangers they confront in addition to anticipating disasters. This is especially crucial in areas where a variety of natural catastrophes are common, as risk awareness has to include a wide range of threats [23, 45, 46].

The integration of indigenous and local knowledge with scientific understanding is one of the emerging issues in the development of risk knowledge. By adding historical data, local knowledge, and conventional hazard detection and response techniques, this system enhances risk assessments [13]. Mustofa et al. [43] describe how disaster risk reduction may be greatly improved by community-centric techniques in EWS that use local knowledge. According to Khankeh et al. [22], these participatory techniques guarantee that EWS are not only scientifically sound but also culturally suitable and more easily accepted by the local inhabitants.

<p style="text-align: center;">Risk Knowledge</p> <p>Systematically gather comprehensive data and conduct detailed risk assessments to ensure a robust understanding of potential hazards and vulnerabilities.</p>	<p style="text-align: center;">Monitoring and Warning Service</p> <p>Establish advanced systems for continuous hazard monitoring and implement reliable early warning services to provide timely and actionable alerts, enhancing preparedness and response capabilities.</p>
<p style="text-align: center;">Dissemination and Communication</p> <p>Effectively convey risk information and early warning messages through clear, accessible, and timely channels, ensuring that all stakeholders, including vulnerable communities, are well-informed and prepared to take appropriate actions.</p>	<p style="text-align: center;">Response Capability</p> <p>Strengthen national and community-level response capacities by developing robust infrastructure, training programs, and resources to enable swift, coordinated, and effective action during emergencies. Empower communities through education, drills, and resilience-building initiatives to ensure readiness and self-reliance in the face of crises.</p>

Figure 1. The key components of EWS.

The accuracy and timeliness of hazard projections have greatly increased with the development and application of enhanced monitoring systems [47]. De Vasconcelos et al. [48] draw attention to the advancements in technology solutions for monitoring natural catastrophes, including the utilization of cyber-physical systems and the IoT. These developments have improved the capacity to identify and forecast natural catastrophes such as earthquakes and floods, which has led to the development of EWS that are more successful [12, 38]. In their additional discussion of the IoT and cloud infrastructure integration in earthquake detection, Zhang et al. [49] show how technology is transforming EWS.

EWS efficacy is largely dependent on how well alerts are communicated and efficiently distributed. In Canwat [50], the design of EWS for identifying systemic risks is discussed. It emphasizes the importance of communication that is both clear and intelligible in order to guarantee public comprehension and reaction. Sahana et al. [2] draw attention to the shortcomings of the flood warning systems in Europe and the difficulties in making sure that everyone who may be at danger receives and comprehends the warnings. For EWS to be effective, communities' and authorities' capacity for reaction is essential [40]. In their exploration of stakeholders' opinions about the efficacy of EWS for weather-related risks, Lumbroso et al. [51] emphasize the significance of preparation and response strategies. In his examination of the efficacy and dependability of EWS for natural disasters such as debris flows, Karakatsani [11] emphasizes the necessity of both efficient response systems and technological dependability.

In EWS, ESCAP [46] promotes a change from top-down to community-centric methods. This viewpoint is centered on enhancing catastrophe risk reduction by community involvement, guaranteeing that alerts are pertinent, comprehensible, and useful for those who are most vulnerable. In their systematic analysis of community participation in catastrophe EWS, Khankeh et al. [22] provide evidence in favor of this viewpoint, stressing the value of incorporating communities in the creation and execution of EWS.

2.3. *Technological Advancements in Early Warning Systems (EWS)*

The Internet of Things (IoT) has played a significant role in EWS by providing real data and hazard detection by the use of sensor networks, smart devices, and automated monitoring systems [12]. IoT-based EWS involves IoT devices which are networked and continuously collecting data on environmental conditions and are capable of alarming when an abnormality is detected. For example, Mustofa et al. [43] explain how to use IoT sensors to monitor the occurrence of earthquakes and flooding, severe weather patterns etc. This real-time data enhances the short-term hazard forecasting thus minimizing response time. Remote sensing technology is today proving advantageous in geographical regions where infrastructure for monitoring is not well developed [45]. These systems employ wireless sensor networks (WSN) and cloud-based interfaces for transferring hazard data to the disaster management centers for rapid response coordination. Zhang et al. [49] continue to point out that IoT is used in flood monitoring where there is flooding water level sensors installed where possible in river basins warn those affected of floods where they are likely to occur. Among the new fields that are expected to benefit from IoT is the area of urban disaster management and smart structures, weather stations and AI improved EWS in densely populated areas. Mobile-based early warning applications have been developed for implementation in China, Bangladesh, and Japan, which have provided considerable results in such disastrous events as typhoons and tsunamis, decreasing mortality rates [4, 40].

AI and especially machine learning algorithms have enhanced EWS capabilities through their ability to analyze big data sets and determine hazard patterns and real-time risk predictions [15, 22]. These technologies improve the way hazards are modeled and predicted, which in return helps in decision-making processes regarding disasters. ML models perform an analysis of past disaster data to predict future hazards as in earthquake outcome models and cyclone track models [3]. Current multi-hazard early-warning systems in the form of AI now incorporate live meteorological, geographical, and seismological data to provide instant prompting on the viable weather conditions [17]. For instance, Fearnley and Dixon [52] have reported the innovation of AI-driven deep learning avails in Japan's earthquake EWS and how the use of such systems enhanced prediction efficiency and reduced false positives. Likewise, Wadhawan [17] notes that integration of Artificial Intelligence has improved storm scoring and tracking to enable early warning to the affected coastal communities. Another advantage seen with the application of AI in EWS's is the evaluation of impacts from a disaster and the subsequent planning of the most effective approach in responding to the calamity [37]. They enable accurate decision making on use of resources, evacuation strategies, and number of potential victims in case of disaster, making it easier for governments and relief agencies to prepare for disasters. Furthermore, AI-based tools monitor social media for sentiment and necessary emergencies as per the disaster response team requirements in real time [19, 34].

The integration of big data analytics in EWS makes it possible to enhance information processing and real-time monitoring of disasters. Information from various big data sources like satellite images, social media, remote sensing data, and weather stations and more are incorporating into EWS platforms as cloud-based problems for accessing and analyzing [12, 38]. According to Meckawy et al., [53], big data analytics improve the accuracy of the monitoring of hazard events that may not be easily discernible through conventional approaches to forecasting. In the context of, for instance, a hurricane, big data from satellites as well as meteorological models are analyzed by machine learning models to determine storm strength and possible landfall places [15]. Furthermore, it is worth noting that cloud geospatial intelligence systems GIS have revolutionized flood risk mapping and early warning system [54]. Risk maps are the GIS operational maps that provide data about the areas of hazard occurrence in real time, helping authorities with the decision-making process concerning the evacuation and other mitigation measures [55].

2.4. *Public Education and Awareness in Early Warning Systems (EWS)*

According to Agbehadji et al. [4], public education and awareness are essential elements of successful EWS. The efficacy of EWS in mitigating the loss of life during natural catastrophes is contingent upon a community's capacity to comprehend, interpret, and respond to warnings. According to Zhang et al. [49], communities that have a greater knowledge and comprehension of catastrophes are more likely to react appropriately when warnings are issued. This emphasizes how important it is to have ongoing, focused education initiatives that help improve community readiness and response to natural catastrophes. According to Vengatesh and Abinaya [56], educational tactics frequently use multi-channel communication approaches, such as social media, mainstream media, community gatherings, and school activities. Research highlights the significance of disaster education in schools in cultivating a preparedness culture among youth [32]. Children frequently spread knowledge to their families and communities, thus these programs not only teach pupils but also have a cascading impact. There is growing recognition of the value of incorporating indigenous knowledge into public education initiatives for the underprivileged. Native American tribes have amassed a plethora of information regarding regional environmental dangers over many centuries of observation and experience [17, 57]. The NSW Treasury [58] argues that disaster education should take a more comprehensive approach that honors and takes into account this local knowledge. By recognizing local communities' customs and knowledge of natural occurrences, such integration not only increases EWS's relevance for them but also gives them a sense of empowerment [52].

According to Shah et al. [29], areas like some portions of Indonesia that have more public knowledge and comprehension of tsunamis have seen less deaths as a result of better responsiveness to warnings. This underscores the crucial influence of public education on the effectiveness of disaster response. Public education is clearly needed, yet there are still issues with its efficacy and reach. Language hurdles, cultural variations, and the disparities in risk perception across various populations can all be obstacles to the effectiveness of public education initiatives, according to Perdomo [30]. Maintaining public attention and knowledge over time is another difficulty, particularly in areas where natural catastrophes are not common [38].

Digital platforms and social media have become effective means of distributing disaster education and awareness in recent years [59]. According to Mavrouli et al. [60], social media sites like Facebook and Twitter have proven useful for quickly disseminating information in times of crisis.

Additionally, younger audiences can be engaged and given interactive learning experiences through disaster preparedness-focused educational applications and online games [43]. Public education for EWS that uses community-based techniques makes sure that the unique requirements and traits of various communities are taken into account [61]. The relevance and efficacy of disaster education programs may be greatly increased by community involvement in their design and implementation, as Cazorzi et al. [23] have shown. These kinds of participative initiatives strengthen community resilience and capacity in addition to educating. However, a research by Rana et al. [24] revealed that one of the biggest challenges is making sure public education and awareness campaigns are sustained over the long term. To keep these initiatives effective, ongoing participation and information update are required. According to Khankeh et al. [22], there are ways to maintain interest and awareness over time, such as including disaster education into national education curriculum and providing educators with ongoing professional development. Enhancing the efficacy of public education initiatives requires ongoing assessment and input. Insights from participant and stakeholder feedback can be very helpful in improving these programs [4, 62].

2.5. EWS in Reducing Loss of Life in Natural Disasters

One of the main objectives of EWS and disaster risk management is to minimize the number of fatalities after natural disasters [2, 63]. Creating methods that effectively reduce these losses requires an understanding of the elements that lead to mortality during such situations. It is well acknowledged that EWS plays a major role in lowering fatality rates during natural disasters. Sahana et al. [2] claim that early warning distribution may greatly lessen a population's susceptibility to natural disasters. According to Mavrouli et al. [60], the accuracy, timeliness, and public's capacity to comprehend and act upon these warnings are critical factors that determine their efficacy in averting fatalities. Communities' readiness and ability to react play a critical role in defining how natural catastrophes affect them. According to Budimir et al. [12], communities that have superior response systems and readiness suffer fewer casualties. This entails not only putting plans in place but also making sure that everyone in the community is aware of and comprehends them. The number of lives lost during catastrophes is largely determined by how resilient buildings and infrastructure are. Sättele et al. [14] state that upgrading old buildings and implementing rigorous building rules may significantly minimize earthquake mortality. According to research by Zhang et al. [49], the availability of shelters and the strength of vital infrastructure are also important for saving lives during cyclones and floods.

Disaster risk management requires strong institutional frameworks and effective governance. Potutan & Suzuki [16] contend that catastrophe mortality may be considerably decreased by governance frameworks that support stakeholder collaboration and guarantee the provision of sufficient resources for preparation and response. This include NGOs, community organizations, and international organizations in addition to government agencies [9]. In the wake of a catastrophe, the effectiveness of emergency medical responses and the capability of health systems are crucial. According to Karakatsani [11], in a well operating healthcare system, the rate of deaths may be considerably reduced if injured patients get quick and effective medical care. The promptness and efficacy of emergency services are also critical in this regard [2, 19, 54].

Yore et al. [6] define EWS as a complex set of protocols and instruments designed to recognize, evaluate, and disseminate information about possible hazards in order to enable timely and effective

response. The effectiveness of EWS is based on how quickly and precisely the warnings are given out. According to Wadhawan [17], the public's reaction time to warnings might significantly affect the number of lives saved. The accuracy of these notifications about the threat's location, intensity, and timing is equally crucial [64]. False alarms or disregarded warnings have the power to instill fear in the public, which might increase the likelihood of deaths during actual incidents, according to Rogers and Tsirkunow [65].

According to Hammood et al. [32], public reactions to catastrophe warnings are greatly influenced by awareness programs. These kinds of initiatives aid in the dissemination of knowledge on the types of hazards and the appropriate safety precautions. By analyzing how public awareness initiatives before to volcanic eruptions resulted in prompt evacuations and much fewer deaths, Sapena et al. [37] further demonstrate this argument. Education initiatives are essential to creating a resilient and safe culture. De Vasconcelos et al. [48] assert that educational programs emphasizing disaster risk reduction help adults and children alike become more knowledgeable and equipped for disasters. These initiatives, which are often carried out in community and educational contexts, provide participants with the skills and information they need to react appropriately in the case of a crisis. Furthermore, as noted by Lan Huong et al. [41], educational interventions are not only used in formal settings but also informally via community workshops and drills.

According to Golding [66], having resilient infrastructure may significantly lessen the effect of natural catastrophes and thus, the number of fatalities. Resilient infrastructure refers to more than just structural strength; it also includes a system's capacity to endure, adjust to, and quickly recover from catastrophic occurrences. According to Sufri et al. [3], important facilities including hospitals, emergency response units, and utility services are also included in the concept of infrastructure resilience, in addition to sturdy buildings and roadways. For these facilities to continue providing vital services both during and after catastrophes, they must stay operational, lowering the danger to human life. According to the Bahrainy and Bakhtiar [67], urban design is essential to reducing the risk of catastrophe. Urban regions and cities are especially sensitive to natural disasters since they are often inhabited densely and may be situated in disaster-prone locations [6, 68]. It is crucial to include risk reduction strategies in urban planning. This involves enforcing construction rules to guarantee that buildings can endure catastrophes and planning land use to minimize high-risk locations like fault lines and flood plains. Building rules that mandate seismic-resistant construction, for example, may prevent fatalities in earthquake-prone areas [55, 66, 69].

2.6. Global Comparisons in EWS Implementation and Effectiveness

The existence and efficiency of EWSs around the world remain varying due to geographical, socioeconomic, and policy contexts. Some of the countries have adopted AI, IoT, and big data analytics in their operations while other countries are constrained due to infrastructural challenges. Japan along with the United States and Germany have developed some of the most progressive EWS models which are embedded with multi-hazard EWS with Risk Assessment using AI [3, 12]. Earthquake Early Warning Systems include for example the Japanese EEWS that utilizes sensors and artificial intelligence algorithms to shed light on the occurrence of the quakes within seconds [52]. The flood warning system in Germany uses IoT sensors, hydrological models, and cloud-based Geographic Information system to forecast river floods with high accuracy [14]. The United States' National Oceanic and Atmospheric Administration (NOAA) utilizes predictions of weather

supercomputing models allowing for early detection and warning of hurricanes and tornadoes in areas prone to them [66].

However, the development of high-tech EWS for low-income and disaster-prone areas has its problems such as poor physical infrastructure, inadequate financial resources, and language issues [6, 64]. For instance, lack of timely data in Sub-Saharan Africa weakens flood and drought early warning initiatives [36]. Rana et al., [24] identified instabilities in data networks as a severely CRM limitation in Pakistan's flood warning system primarily due to the unavailability of real-time alerts to the effected but distant communities. In India, however, community-based EWS models have been successful in filling these gaps by integrating affordable mobile warning technologies and local knowledge [2].

As climate change becomes an ever-growing issue, developing countries are turning to other models of EWS which are more adaptable and operate with the use of mobile devices and peer-to-peer communication networks. The use of SMS, WhatsApp, and radio broadcasts has been more efficient in Kenya, Bangladesh and Indonesia especially since the early warning systems infrastructure is still immature in these regions [29]. Also, there is increased participation of Non-governmental Organizations working on disaster preparedness enhancing early warning systems within the Pacific Islands threatened with overflowing seas which are dangerous to the coastal dwellers. Another source of success in these areas is the combination of the concept of community-centered EWS with the help of innovative digital tools [22].

2.7. Summary of Literature Review and Identification of Research Gap

Literature review reveals how EWS among children have developed from simple alarm systems to multi-hazard, technologically advanced, and community-based systems. EWS have evolved from the top-down process models towards the community-based models that focus on risk knowledge, monitoring and response capacity. It has been pointed out that reliable EWS require specific technologies, awareness among the citizens, and government policies [12, 24, 37]. AI, IoT, big data analysis, and satellite monitoring have improved the precision and effectiveness of predicting disasters. AI integrated risk assessments, cloud computing and GIS mapping has enhanced disasters response capabilities [3, 49, 52]. Multi-hazard EWSs have been implemented and proved effective in Japan, Germany, US, whereas low income and disaster prone areas lack basic infrastructures and policy support [2, 6, 64].

However, some crucial gaps have been left open especially in the implementation of EWS across the globe. Second, as developed countries apply AI, IoT, and data-driven models for disaster management, many developing countries use conventional techniques, which make response time slow, and many lives lost. Second, despite the substantial promise of big data and predictive analytics in disaster preparedness, there is insufficient evidence on the application and impact of such tools in various socio-economic contexts. Furthermore, there is a lack of prior research focusing on how community engagement, social media, and behavioral interventions can enhance EWS efficiency [19, 38, 53]. This work intends to fill these gaps by assessing the efficiency of contemporary EW systems in minimizing the mortality and enhancing the mitigation of disasters internationally.

3. Materials and Methods

3.1. Research Design

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This study adopted cross-sectional survey research, which combined quantitative research method to assess the EWS to minimize loss of lives during natural disasters in Greece. The cross-sectional approach was adopted due to its effectiveness in ensuring the examination of patterns, perceptions, and relationships between the main components of EWS since the data is collected at a given point in time from a large number of individuals. Four parameters were selected to evaluate the effectiveness of EWS: the timeliness of alerts, the accuracy of the predicted hazards, the public awareness level of the issues it addresses, and the utilitarian function of technology in improving the strength of the system. SHARE also reflects other international frameworks for disaster risk reduction, especially the Sendai framework for disaster risk reduction 2015-2030 that focuses on multi-hazard early warning systems, risk assessment, and community-based disaster risk reduction. For this reason, the study designed a comprehensive research framework that sought to adopt quantitative data analysis from the fields of environment and disaster management in Greece. The survey developed and administered a questionnaire to the research participant which aimed at eliciting information concerning the WES performance, its reliability, and its effectiveness in mitigating disaster mortality. Furthermore, there was a comparative benchmarking exercise in that data was compared and contrasted with similar systems in comparable countries such as Japan, United States of America and Germany. Drawing on such methods as perceptual assessments, statistical models, and cross-national comparisons, the study delivered an overall evaluation of EWS effectiveness in Greece.

3.1.1. Criteria for Evaluating EWS Effectiveness

Since it is crucial to arrive at an elaborate and factual analysis, the study adopted four evaluation criteria based on the International Best Practices regarding disaster risk management. The overall evaluation of Greece's EWS was based on the following performance indicators:

1. The timeliness of Alerts focused on the extent to which early alerts were given before disaster occurrence. The respondents were also asked about the alerts that they have received, the time between the issuance of warnings and the disasters and whether the alerts granted time for effective decision making and evacuation. To determine the perceived timeliness, a Likert scale with 5-point scale ranging from 1= strongly disagree and 5= strongly agree was used.
2. Hazard Predictability: Forecast credibility was determined based on the perceptions of the respondents and the historical records of meteorological and disaster occurrences. The participants were asked whether past EWS alerts captured the intensity, location, and time of disasters appropriately. Such claims were then cross-checked with the previous disasters that happened in Greece such as wildfires, floods, and earthquakes in order to evaluate the accuracy of the hazard predictions. To determine the limitations of the forecast models, inconsistencies in the predictions were considered.
3. Knowledge of EWS alerts: The level of awareness in the community was assessed using the respondents' understanding of EWS alerts, their awareness of the evacuation procedures, participation in the disaster drills and overall confidence in decoding the early warning messages. In this case, the study question focused on whether social marketing campaigns put sufficient information into the public domain for the population to respond appropriately to disaster warning information. Focus was on demographic differences between awareness levels, such as urban and rural participants, different age and education

levels.4. Type of Technology: In this study, focus was on the impact of advancements in technology on EWS effectiveness. This revealed responses on factors such as the ease of access to mobile alerts, SMS alerts, GIS hazard map of disaster-prone areas, how timely data analytics was incorporated in the hazard forecasting, and credibility of the information dissemination platforms alerted via the internet. The assessment also included analyzing the use of AI, IoT sensors, and machine learning in hazard detection. Specifically, these four dimensions made it possible to carry out a broad analysis of Greece's EWS, assessing its merits and, at the same time, its weaknesses.

3.1.2. Benchmarks and Control Measures

Measures of control and comparison were implemented to ensure that comparison with benchmark and historical disaster records were used to establish Greece EWS performance. Greece's EWS was compared to the following internationally well-known EWS frameworks:

- Japan has developed a robust EWS system that employs artificial intelligence for earthquake surveillance, early warning of tsunamis, and a color-coded multiple-hazard warning system. The authors have contrasted the current systems in place in Greece with the system in Japan which incorporates several tiers.
- U.S.A National Oceanic and Atmospheric Administration NOAA: supercomputing models used for prediction with a combination of Artificial Intelligence storm chasing, information cartography, and geostationary satellite data for hurricanes and tornadoes. The study further examined whether Greece's hazard forecasting reflected the same levels of predictive analysis.
- Germany's IoT Based Flood Monitoring: In Germany, real-time hydrological models and IoT sensors are used to identify and prevent floods. Flood prediction capacities of Greece were then compared for relative analysis.

3.2. Study Population

The study targeted people or professionals who work actively in Greece's environmental sector. The study's target demographic consists of professionals and specialists in Greece's environmental sector, a varied and informed group of people who provide a wealth of knowledge and experience to the assessment of EWS efficiency in the face of natural catastrophes. Their opinions may have wider ramifications for comparable areas confronting environmental concerns globally. Their ideas are crucial for expanding our knowledge of catastrophe planning and response tactics within the Greek setting. Greece was a strategically chosen location for the research, considering the nation's susceptibility to a range of natural calamities, including earthquakes, tsunamis, and wildfires. Participants in this study would be appropriate since environmental professionals in Greece have extensive direct knowledge and experience with EWS and catastrophe management.

3.3. Sample

The research population consisted of 3,000 environmental specialists and professionals across Greece [70], from whom 353 professionals and experts in Greece's environment sector were chosen as the sample size. This was calculated using the following formula (Equation 1), which Yamane (1973) created [71, 72].

$$n = \frac{N}{1 + Ne^2} \quad (1)$$

Equation 1: Calculation of the minimum sample of respondents.

Where:

- n sample size sought,
- N population,
- e level of significance and
- 1 constant.

Based on a 5% (0.05) significance level, the preferred sample size was determined as:

$$n = \frac{3,000}{1 + 3,000 (0.05)^2} \Leftrightarrow n = 352.941$$

where $n = 353$.

The research used a systematic sampling technique to ensure that participants were chosen at random from the Greek environmental expert community. This strategy attempted to reduce the possibility of bias in the sample selection procedure and improve the study's results' generalizability to a wider Greek environment.

We used a technique known as stratified random sampling to ensure that our study produced the most pertinent findings. Although there is yet another method for defining the sample that yields a smaller sample, this method was not employed because there were a significant number of interested participants [73].

3.4. Data Collection

A structured questionnaire designed to meet the four study goals was utilized to collect data. Email was the main tool used by the questionnaire distribution method to communicate with the chosen experts. The questionnaire, which consisted of closed-ended questions, was sent via email to the chosen environmental sector specialists in Greece. The survey questionnaire had a one-week deadline for participants to complete. A link to the online questionnaire and comprehensive instructions on how to fill it out and submit it were sent to each participant via email. The email correspondence included further details on the goals of the research, the anticipated duration for filling out the questionnaire, and guarantees of data privacy. A one-week period was given to participants to complete the questionnaire, giving them enough time to provide accurate and meaningful answers. In order to ensure timely data collection and to accommodate respondents' schedules, a compromise has to be struck while setting this timetable. The researchers kept themselves available to participants throughout the data collecting time, prepared to answer any questions or concerns that could come up.

3.5. Data Analysis

Quantitative data analysis involved data editing, coding, and subsequent entry into Statistical Package for Social Sciences (SPSS) version 20.0 for analysis. Descriptive statistics, including frequencies and percentages, were employed to examine the data. Regression analysis, utilizing ANOVA statistics with adjusted R^2 and beta values, was conducted to explore the relationships between variables [74].

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \varepsilon \quad (2)$$

Equation 2: Multiple regression model to get the different anticipated values.

Where:

Y Reduction in loss of life in natural disasters,

β_0 constant (coefficient of intercept),

X_1 Timeliness of EWS in providing early alerts

X_2 Accuracy of hazard predictions,

X_3 Public awareness and education programs in EWS,

X_4 Technological advancements in enhancing the efficiency of EWS, and

ε Represents the error term in the multiple regression model.

$\beta_1 \dots \beta_4$ represents the three independent variables' regression coefficients.

Hypotheses were tested at a significance level of 5% ($\alpha = 0.05$), with the decision rule stating that if $p < 0.05$, the null hypothesis would be rejected, and if $p > 0.05$, the null hypothesis would be accepted. The analysis aimed to determine the predictive power of various independent factors on the dependent variable, "Reduction in loss of life in natural disasters".

4. Results

4.1. Demographic Characteristics

In terms of gender distribution, Figure 2 shows that 54.3% of the respondents are male, while 45.7% are female. This indicates a notable gender balance in this study, with a nearly balanced proportion of male participants compared to females.

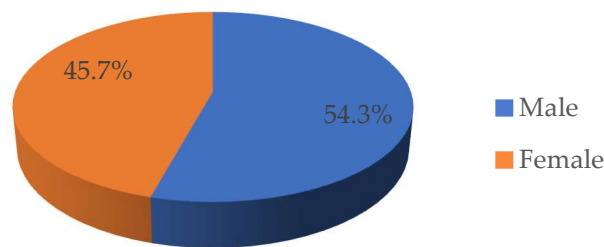


Figure 2. Gender distribution of respondents. Source: Survey (2024).

Among the age categories in Figure 3, the highest percentage of respondents falls into the age group of "41-50 years", accounting for 42.5% of the total. This suggests that a substantial portion of the respondents belong to the middle-aged demographic. The distribution indicates a relatively balanced representation across different age groups, with no single age group dominating the sample.

In terms of years spent working in the environment sector, the largest percentage of respondents, at 46.5%, reported having "6-10 years" of experience. This indicates that a significant proportion of the respondents have a moderate level of experience in the sector. It is noteworthy that a considerable percentage of respondents, 33.5%, reported having "1-5 years" of experience, while 17.7% had "More than 10 years" of experience as presented in Figure 4.

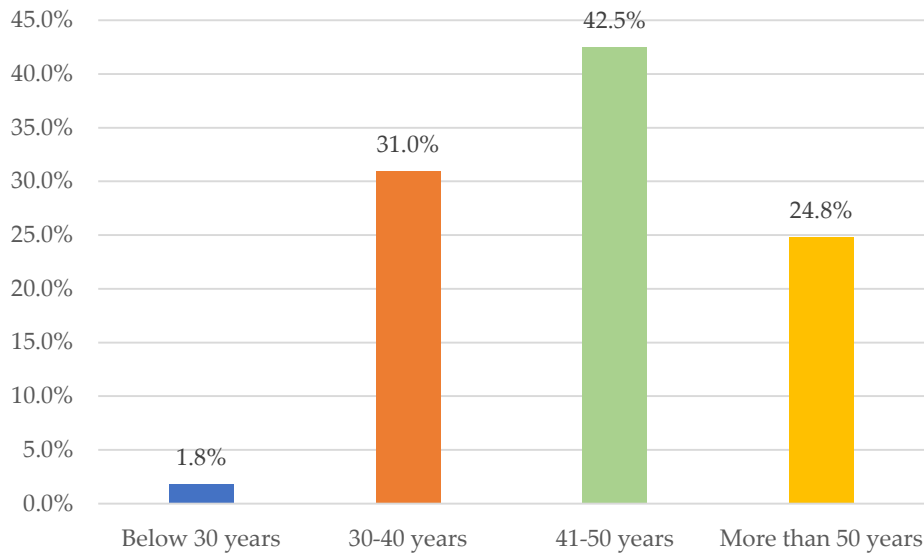


Figure 3. Age categories of respondents. Source: Survey (2024).

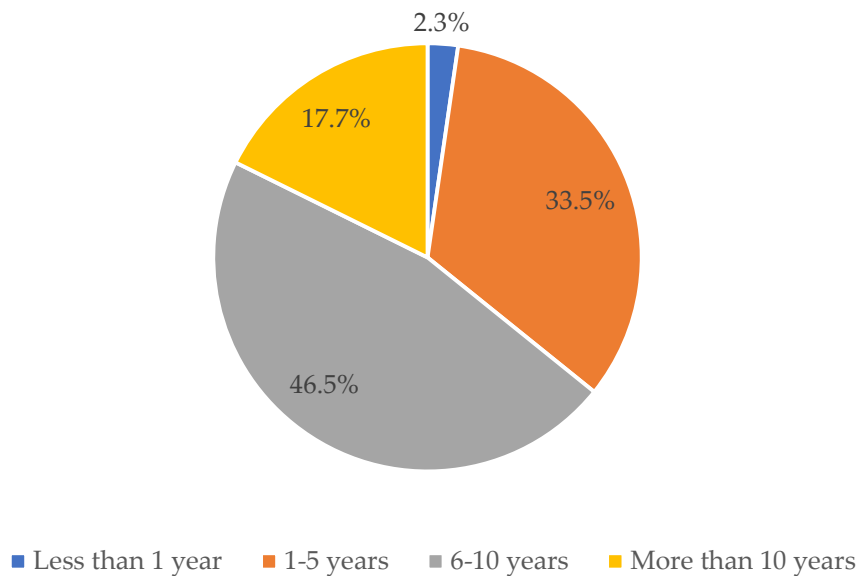


Figure 4. Experience of respondents. Source: Survey (2024).

4.2. Descriptive Results

The study established the effect of the timeliness of EWS in providing early alerts to vulnerable communities and the results are presented in Table 1.

From the results displayed in Table 1 above, it can be deduced that the EWS in Greece is generally effective in the provision of timely alerts but the following need to be addressed: The level of urgency of the disaster. The majority (74.4%) of the participants concurring/concurring with the statement that the early warning messages provided time to prepare. Also, 70.4% admitted to being informed well in advance of natural disasters. The results also highlighted that 70.4% of the respondents had received alerts well in advance of natural disasters. These findings confirm that the system is able to provide early warnings in order to aid the implementation of the Sendai Framework

for Disaster Risk Reduction that promotes prevention and mitigation of catastrophes. This way, the alerts are timely and help individuals and communities prepare and avoid catastrophic disasters thus supporting previous findings where timely warning helps in preventing the high number of deaths associated with disasters.

Table 1. Results on the timeliness of EWS in providing early alerts to vulnerable communities.

Statement	Responses (%)				
	SD	D	N	A	SA
-					
The early warning messages I received were timely and allowed for adequate preparation.	5.1	9.2	11.3	46.5	27.9
I received early alerts from the EWS system well in advance of the natural disaster.	4.8	11.1	13.7	42.3	28.1
The EWS provided timely information about the potential risks in my area.	10.3	15.7	17.5	34.2	22.3
The EWS system effectively communicated the urgency of the situation.	28.5	32.6	18.7	12.5	7.7
I felt well-informed and had sufficient time to take necessary precautions.	7.6	13.5	14.1	39.6	25.2
The EWS messages are very clear and easy to understand regarding the imminent threat.	2.4	3.9	5.6	45.2	42.9
The EWS system consistently provided timely alerts for various types of disasters.	12.7	18.4	15.2	33.7	20.0

Key: SD = strongly disagree, D = disagree, N = neutral, A = agree, and SA = strongly agree. Source: Survey (2024).

On the overall, most respondents indicated that the EWS offered timely alerts; nevertheless, only slightly over half agreed or strongly agreed that the EWS was timely in offering information on risks in their geographical regions. This means that while the system can communicate the existence of an alert, the manner in which it communicates additional details of the risk might not be ideal. The readability of the warnings was also positively received, as 88.1% of the respondents stated that EWS messages were easy to comprehend, implying the necessity of adequate structuring of the messages. This is particularly worrying, especially to the extent to which EWS was perceived to effectively communicate the severity of disasters; 20.2% of the respondents agreed with the statement, whereas 61.1% disagree or strongly disagreed. Here is a major drawback of the current system. Still, it is as important as timely alerting—the recipient can underestimate the threat and fail to perform any actions if the message is not clear.

However, a significant portion of the respondents, 53.7% affirmed that the EWS offered timely alerts across disasters but 29.6% reported the problem of unreliable alerts. This raises the probability of variability in the effectiveness of the system based on various disasters, justifications that call for enhancement of hazard prediction as well as integration of multi-hazards response. Despite the favorable results in terms of timeliness and clarity of Greece’s EWSs, there is a need to address the shortcomings of the warning messages, especially in the extent of urgency and the consolidation of delivering diverse disaster types.

From Table 2, majority of the respondents affirmed the belief that the EWS provides the approximation of hazards with reasonably good accuracy; however, some skepticism persists with regard to uniformity. In assessing the evaluate scale questions about the EWS, about the accuracy of

the provided hazard predictions, 64.6% of the respondents agreed or strongly agreed, with 16.8% remaining undecided. This means that although most people could trust that the system was a very accurate predictor of how long people would live, a significant minority doubted its precision. The responses to this question show that these efforts, particularly the intensity of hazard prediction accuracy, had the highest correlation to the level of preparedness with 79.4% of the respondents agreeing or strongly agreeing with the statement. This shows the importance of accurate hazard predictions to help people avoid disasters and where possible take protective measures. Furthermore, 67.5% of participants agreed that the predictions of the EWS system assisted in the minimization of the loss of life, as supported by prior research on the function of hazard forecasting.

Table 2. Results on the accuracy of hazard predictions and their impact on minimizing loss of life.

Statement	Responses (%)				
	SD	D	N	A	SA
-					
The hazard predictions made by the EWS system were accurate.	6.2	12.4	16.8	40.5	24.1
I relied on the EWS system's hazard predictions to make informed decisions.	7.4	14.6	18.2	38.1	21.7
The accuracy of hazard predictions influenced my level of preparedness.	3.8	7.2	9.6	44.5	34.9
The EWS system's predictions helped reduce the risk of loss of life.	9.5	15.3	7.7	36.2	31.3
The EWS system effectively predicted the severity of natural disasters.	5.9	11.7	5.5	49.8	27.1
The EWS system's accuracy in predicting hazards is consistent.	10.2	20.1	24.3	28.9	16.5
I trust the hazard predictions provided by the EWS system.	7.1	14.5	19.3	36.0	23.1

Key: SD = strongly disagree, D = disagree, N = neutral, A = agree, and SA = strongly agree. Source: Survey (2024).

However, 45.4% of the respondents agreed or strongly agreed that the EWS was consistent in their hazard predictions; 30.3% disagreed. This may be the reason why there is a fairly equal division of views as 19.3% of respondents remained non-committal on the reliability of the system, while 59.1% endorsed the ability of the system to predict hazards. Such variations may be due to differences in the accuracy of the forecast models, variations of the environment, and/or lack of research in these subjects or other areas. Therefore, it becomes crucial for EWS authorities to tackle these issues and work on making the forecasts better by updating technology, integrating real-time data, and developing better communication plans with the public. It would also enhance public confidence in the accuracy of such predictions, which will help in reducing loss of lives in cases of natural disasters.

Table 3. Results on the effectiveness of public awareness and education programs in EWS.

Statement	Responses (%)				
	SD	D	N	A	SA
-					
I am aware of the existence of the EWS and how to access it.	4.2	10.5	19.6	39.7	26.0
Public education programs have improved my understanding of EWS.	8.1	14.9	22.4	35.2	19.4
I actively seek out information about EWS and disaster preparedness.	0.0	11.6	8.9	38.8	40.7
Public awareness campaigns have increased my EWS knowledge.	1.3	2.5	4.6	43.5	48.1
I know what actions to take when I receive an EWS alert.	9.8	15.4	11.2	31.5	32.1
I feel confident in my ability to respond effectively to EWS alerts.	6.9	2.7	9.3	56.8	24.3

Key: SD = strongly disagree, D = disagree, N = neutral, A = agree, and SA = strongly agree. Source: Survey (2024).

From Table 3, it is clear that social awareness and educating the public in the Early Warning System (EWS) have been modestly successful but the lack of preparedness and confidence in actual response is still evident. Most of the respondents, or 65.7%, reported that they are aware of the EWS and know how to access it which show that the system has gained popularity among the clients. Still, close to 15 percent of respondents indicated they either disagreed or strongly disagreed, indicating that it is possible for there to be a lack of awareness regarding outreach efforts. Regarding public education programs, the perception of such programs does not seem to be overwhelmingly positive, but moderate, as 54.6% of the respondents expressed their agreement or strong agreeableness with the statement that such initiatives helped them enhance their understanding of EWS.

But 22.4% of the respondents were indifferent, while 23% disagreed, meaning that although education drives can certainly be effective, they can also be insufficiently informative or stimulating. Most positively, 79.5% of this population was found to have engaged in active search for information about EWS and disaster preparedness; therefore, illustrative of the population’s high interest and willingness to learn about disaster risk reduction. There was general support towards specific communication strategies with 91.6% of the respondents strongly agreeing or agreeing that with public awareness campaigns enhanced their level of knowledge about EWS. This shows how both voice call and text-message based campaigns are effective in directly getting through early warning alerts to the affected parties.

However, the respondents’ scores for perceived behavioral control demonstrated that knowledge does not guarantee preparedness; only 63.6% of the participants knew the concrete steps to take when receiving an EWS alert while 25.2% were not sure. This is a clear distinction between having knowledge of the event and being prepared for it—a gap that could be bridged by better training in responses to the event. Regarding the response capability of staff to EWS alerts, 81.1% of participants either agreed or strongly agreed that they felt they were ready to respond effectively to the alerts. However, 9.3% remained neutral, meaning that first aid drills, simulation and other preparedness programs should be continued to build confidence in the community and increase its resilience.

Table 4. Results on technological advancements’ role in enhancing the efficiency of EWS.

Statement	Responses (%)				
	SD	D	N	A	SA
-					
Technological advancements have improved the speed of EWS alerts.	2.3	4.2	10.5	40.8	42.2
New technologies have enhanced the accuracy of hazard monitoring.	6.8	12.1	18.7	34.2	28.2
The EWS system's use of modern technology has increased its reliability.	4.1	9.3	13.8	39.6	33.2
I am able to access the different EWS technologies without difficulty.	24.7	32.5	21.9	14.3	6.6
I find it easier to access EWS information due to technological advances.	9.6	14.8	19.5	33.7	22.4
Technological improvements have increased the coverage of EWS.	7.5	13.6	20.2	35.5	23.2
The use of technology in EWS has positively impacted disaster response.	1.9	2.5	6.3	42.1	47.2

Key: SD = strongly disagree, D = disagree, N = neutral, A = agree, and SA = strongly agree. Source: Survey (2024).

The findings as presented in Table 4 above show that there have been increased efficiency made through technological development encompassing the speed of alerts, accuracy of the Early Warning Systems (EWS) and even disaster response. The respondents’ agreement regarding the improvement

in the speed of EWS alerts by Technological advancement was substantial, with 83% of the respondents agreeing or strongly agreeing to the statement. Regarding improved precision, 62.4% of the participants expressed their agreement with the statement that new technologies have heightened the accuracy and efficiency of hazard monitoring while 18.7% of them were indecisive about the topic, meaning that while it may have improved, there is still room for new and better developing technologies regarding the precision of the predictions. Another advantage that was found highlighted is reliability, with 72.8% of participants considering that, due to modern technology, EWS has become more reliable.

But 13.8% were neutral, 13.4% disagreed, which means that though a majority of the users find technology reliable and useful, some may have issues with its reliability or trustworthiness. One problem concerns accessibility with 57.2% of the respondents disagreeing or strongly disagreeing with the statement that it asserts that they can easily access different EWS technologies. This may imply that some of our participants do not have adequate technological access or the necessary computer skills or the economic means. For instance, 24.4% of the respondents claimed that it was sometime challenging to obtain EWS information, although technology has helped develop better means to access such information. Technological improvements have expanded EWS coverage, with 58.7% agreeing or strongly agreeing, yet 20.2% remained neutral, suggesting that further efforts are needed to ensure comprehensive reach. Last, the positive influence of technology on disaster management was confirmed with 89.3% approval further emphasizing the role of technology in enhancing this sector.

The study examined the different outcomes resulting from loss of life in natural disasters and the results are presented in Figure 5.

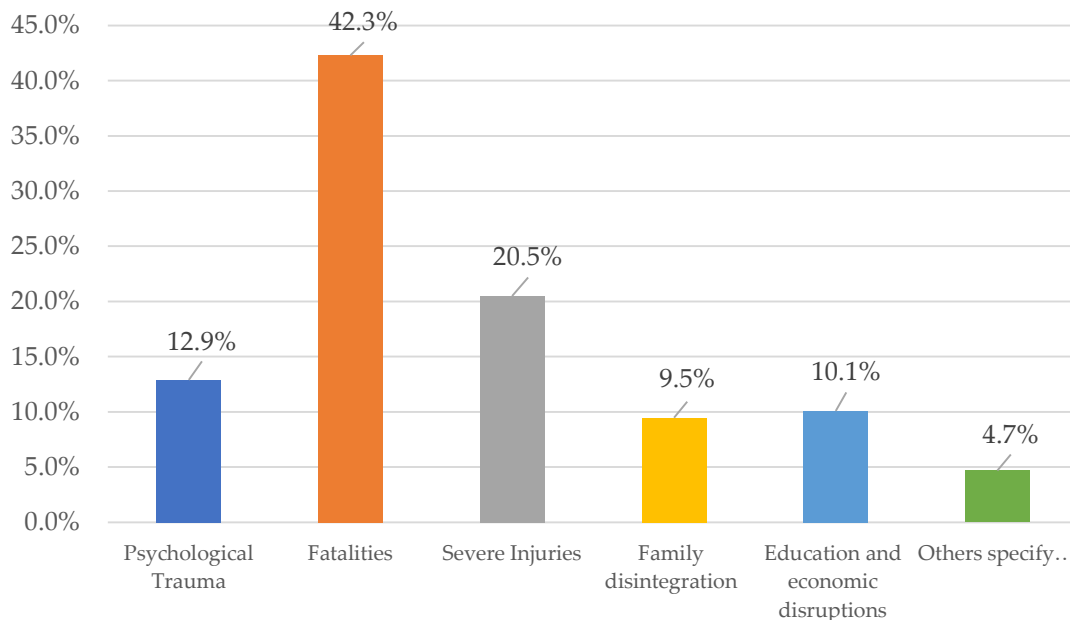


Figure 5. Outcomes resulting from loss of life in natural disasters. Source: Survey (2024).

Figure 5 shows that the highest percentage of outcomes, at 42.3%, is attributed to fatalities. This indicates that a significant majority of the respondents or data points in the study experienced the direct loss of human lives as the primary outcome of natural disasters. Fatalities represent the most immediate and tragic consequence of these events, leading to profound grief and trauma among

affected communities. Following fatalities, severe injuries account for a substantial portion, with 20.5% of the outcomes. This suggests that a significant number of individuals or communities not only experienced loss of life but also endured physical harm as a result of the disaster.

Severe injuries can result in long-term physical and psychological consequences for survivors, often requiring extended medical care and rehabilitation. Psychological trauma, at 12.9%, is another significant outcome. This indicates that a considerable proportion of respondents or individuals affected by natural disasters suffered from mental health issues such as post-traumatic stress disorder (PTSD), anxiety, and depression. Education and economic disruptions make up 10.1% of the outcomes. This suggests that a notable portion of respondents experienced disruptions in education and economic activities due to the loss of life in natural disasters. This can include school closures, loss of livelihoods, and economic setbacks for affected individuals and communities. Family disintegration, accounting for 9.5%, indicates that a significant proportion of respondents faced the breakdown of family units following the loss of life in disasters. This could result from the loss of breadwinners or caregivers, leaving families in vulnerable situations and facing challenges in maintaining their cohesion and stability. The least portion of respondents (4.7%) mentioned other additional consequences resulting from the loss of life in natural disasters. This includes issues such as depression among those who lost loved ones, increased vulnerability among affected populations, and reduced resilience among families dealing with the aftermath of the disaster.

4.3. Secondary Analysis

In this study, a longitudinal analysis is employed to assess the EWS efficiency for natural disasters in Greece, more specifically, floods and wildfires, for the past decades. The study relied on information from different national and international reports and databases to evaluate the frequency of disasters, related fatalities, and effects of EWS [75–77].

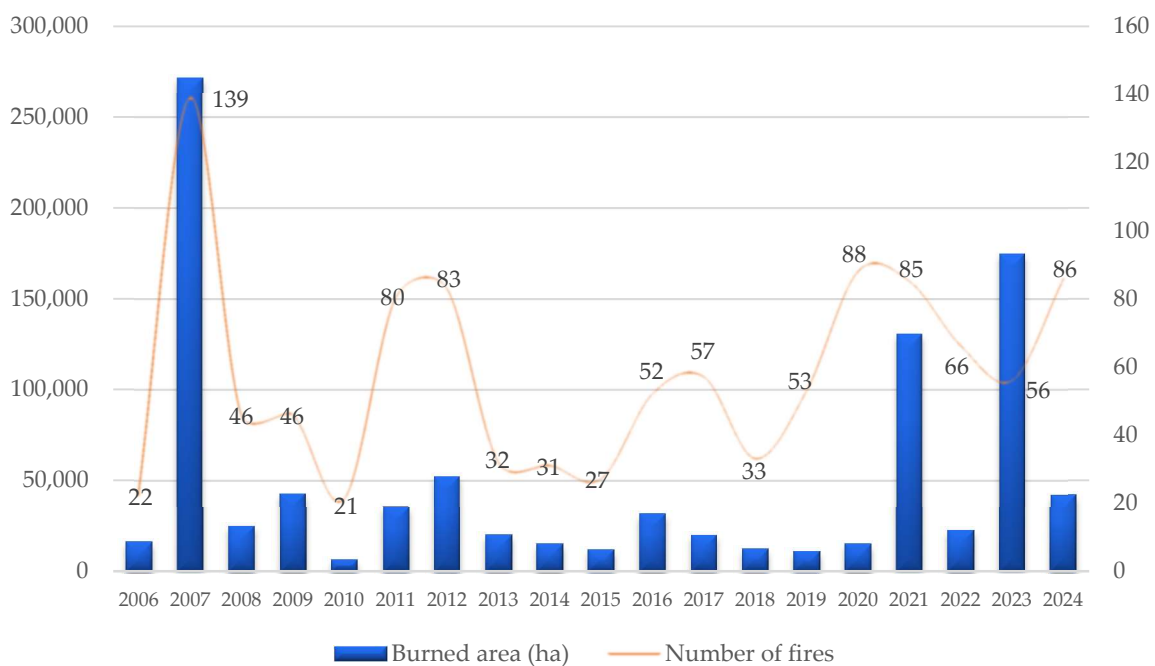


Figure 6. Wildfire Incidents and Burnt Areas (ha) in Greece (2006–2024). Fires mapped in EFFIS of approximately 30 ha or larger. Source: [75].

According to Figure 6, the assessment of the number of wildfires and the total burnt area from 2006 until 2015 revealed that Greece had been generally successful in preventing and mitigating wildfires. However, in 2007, 139 fires were recorded and they burnt 271,715 hectares (ha), making it the worst year in 13 years, in 2021, 85 fires were recorded, and they burnt over 130,744 ha. The increase was recorded in 2023 with 56 wildfires reported which affected about 174,723 ha of land (pointing, that fires mapped in EFFIS of approximately 30 ha or larger) [75, 77].

It is important to note other examples, including the Alexandroupolis fire that took place in 2023, became the largest ever in Europe and affected about 96,000 hectares. The increase of wildfire events has illustrated an increased threat level due to climate change and the constant changes in weather conditions like heat and dryness; Such challenges that have affected the normal operation of EWS need to be addressed by the implementation of new adaptive strategies [78, 79].

Moreover, about floods the study from Valavani et al. [80] shows the decrease of the number of flood related deaths per decade from 1980 to 2023. The steady decrease goes hand in hand with increasing utilization of high-quality EWS and raising awareness activities to advance disaster management and mitigation. Nevertheless, the increase of fatalities in 2023 as a result of Storm Daniel underlines the fact that it is not only overall trends that are making a positive shift, but extreme events still remain a threat.

4.4. Regression Test

4.4.1. Fitness of Model

Table 5 presents the fitness of model that was used in regression, and which helps in explaining the predictability of the dependent variable by the three independent variables. The independent variables (Timeliness of EWS in providing early alerts, Accuracy of hazard predictions, public awareness and education programs in EWS, and Technological advancements in enhancing the efficiency of EWS) were satisfactory in explaining the level of reduction in loss of life in natural disasters.

Table 5. Model Fitness.

R	R Square	Adjusted R-Square	Std. Error of the Estimate
0.791	0.693	0.641	0.275

Predictors: (Constant), Timeliness of EWS in providing early alerts, accuracy of hazard predictions, public awareness and education programs in EWS, Technological advancements in enhancing the efficiency of EWS.

The R value in Table 5 measures the strength and direction of the linear relationship between the dependent variable (Reduction in Loss of Life in Natural Disasters) and the combination of predictor variables (Timeliness of EWS in providing early alerts, Accuracy of hazard predictions, public awareness and education programs in EWS, Technological advancements in enhancing the efficiency of EWS). In this case, an R value of 0.791 indicates a strong positive correlation between the predictors and the reduction in loss of life. This suggests that these predictor variables are collectively influencing the reduction in loss of life in natural disasters.

Table 5 shows that R² is 0.693, which means that approximately 69.3% of the variance in the reduction of loss of life can be attributed to the predictors included in your model. This is a reasonably

strong value, indicating that the selected predictors are collectively explaining a significant portion of the variation in the reduction of loss of life.

4.4.2. Regression of Coefficients

Table 6 shows the different coefficients of regression that were obtained for each independent variable in the study.

Table 6. Regression results.

Predictive variables	Standardized	Significance
	Coefficients	
	Beta (β)	p-value
Timeliness of EWS in providing early alerts	0.231	0.002
Accuracy of hazard predictions	0.171	0.013
Public awareness and education programs in EWS	0.462	0.000
Technological advancements in enhancing the efficiency of EWS	0.371	0.001

Dependent Variable: Reduction in loss of life in natural disasters.

The standardized coefficient (Beta) for "Timeliness of EWS in providing early alerts" is 0.231, and the p-value is 0.002. The positive coefficient indicates that there is a positive relationship between timely early warnings and the reduction in loss of life. The low p-value (0.002) suggests that this relationship is statistically significant at conventional significance levels (e.g., $\alpha = 0.05$). Therefore, we can accept H1, as there is evidence to support the hypothesis that timely early warnings are significantly correlated with reduced mortality in natural disasters.

The standardized coefficient for "Accuracy of hazard predictions" is 0.171, and the p-value is 0.013. Similar to H1, the positive coefficient suggests a positive relationship between accurate hazard predictions and the reduction in loss of life. The p-value (0.013) is below the conventional significance level of 0.05, indicating statistical significance. Therefore, we can also accept H2, as accurate hazard predictions are statistically correlated with minimizing loss of life in natural disasters.

The standardized coefficient for "Public awareness and education programs in EWS" is 0.462, and the p-value is 0.000. The substantial positive coefficient and the very low p-value indicate a strong positive relationship between effective public awareness and education programs and the reduction in loss of life. The p-value is much lower than 0.05, indicating strong statistical significance. Therefore, we can confidently accept H3, as there is robust evidence to support the hypothesis that effective public awareness and education programs significantly contribute to reducing fatalities in natural disasters.

The standardized coefficient for "Technological advancements in enhancing the efficiency of EWS" is 0.371, and the p-value is 0.001. The positive coefficient suggests a positive relationship between technological advancements and the reduction in loss of life. The low p-value (0.001) indicates statistical significance. Therefore, we can accept H4, as there is evidence to support the hypothesis that advanced technologies enhance the efficiency and effectiveness of EWS in minimizing loss of life in natural disasters.

5. Discussion of the Study

This study focused on evaluating the effectiveness of EWS in reducing loss of life in natural disasters. The study findings suggest that overall, Greece's EWS effectively delivers timely warnings; still, there are issues concerning the communication of urgency. Even with the various types of alerts that are sent to recipients, sometimes the recipients do not feel the urgency to carry out measures that can prevent the attacks. This is consistent with another study we can draw from Sättele et al. [14] where they noted that, while the timing is critical in alerting the public, it is not the only factor that can affect the EWS as shown below. Comparing it with other nations' EWS frameworks, it emerges that some have initiated a more elaborate mechanism to ensure that the alerts are timely and actionable [7, 81].

For instance, the Japanese have developed a multiple-layered warning system that informs the populace not only of an impending disaster but also gives real-time information and recommended evacuation procedures via various means of communication [15]. Like it, Bangladesh utilizes a community-based early warning system that guarantees even the categories of people living in isolated regions receive the information on time which helps minimize the effects of cyclones and floods [52]. The current EWS of Greece can provide alert to risks but lacks structured and multi-channel risk communication system. The Sendai Framework for Disaster Risk Reduction lays emphasis on the aspect of early warnings that should lead to action on the ground [10].

One major drawback of Greece's EWS is that it still utilizes broadcast mode of disseminating information, which may not cover all the targeted members. The combination of mobile alerting, social media postings, and automated messaging may provide improved 'reach' and timeliness. Further, as discussed in the prior literature on behavior change, it is also found that people are more receptive to alerts that give directive instructions rather than only hazardous signals [17]. It is likely that the communication of structured messages with a focus on recommended action as opposed to the mere description of the hazard could be beneficial in bug reporting.

The results reveal that Greece's EWS affords fairly accurate forecasts; however, there are issues with the reliability of these predictions. Such discrepancies serve only to undermine public confidence in hazards' predictions and, consequently, citizens' willingness to heed warnings will be compromised [43]. When the accuracy of forecasts changes from one period to the other, the system loses credibility and thus, is not very useful. Several countries that have adopted and incorporated advanced forecasting models into their EWS have gained higher accuracy in the prediction of various hazards. Currently in the USA the National Weather Service employs AI based analytical models that aim to provide more accurate storm predictions based on meteorological and geographical data [49].

The Japan Meteorological Agency has a comprehensive earthquake and tsunami early warning system that involves using seismic switches, artificial neural networks and satellites to afford high precision [16]. To enhance the accuracy in future predictions, Greece's EWS could implement similar AI-based models and including real-time data analysis in determining the hazard levels. Another significant limitation of Greece's EWS is the lack of constant updating of forecast models that depicts the real occurrence in the environment. Recent studies showed that the application of machine learning techniques and big data processing can significantly improve the hazard forecasting due to the ability to solve patterns in disasters occurrences [43].

Integrating ML into the existing models used in Greece increases predictive accuracy, thus decreasing uncertainty and increasing citizens' confidence in EWS messages. One of the major weaknesses is that forecasting often fails to indicate the level of uncertainty. Such confusing and

conflicting signals can result in confusion or loss of trust by the public in the matters received. Research shows that probability-based approaches of supplying probability ranges of hazard forecasts enhance the credibility of EWSs among the public [3]. This approach can be applied to Greece's EWS: The inclusion of uncertainty indices in the warning messages would make the population more aware of the risk levels and the need for protective measures.

Awareness and education of the general public are crucial to making sure that when the EWS is triggered, the necessary action is taken. Overall, it can be inferred from the study that despite the knowledge of the existence of EWS in Greece, there are gaps in translating awareness to action and response. However, even after numerous awareness campaigns, people may not grasp the specific details needed when an alert is out [17]. Baudoin et al. [19] point out that raising awareness is not enough and that people should be trained in realistic paradigms. Benchmarks with other countries that receive high ratings for their public education show that Greece has some catching up to do. In Japan, the drills are incorporated in the school curriculum so children as from an early age are aware of how to act in case of a disaster and other emergencies [33].

Similarly in the Philippines, simulations are performed to provide an opportunity for people within the communities to understand EWS warnings and response plans [34]. Thus, with introduction of disaster preparedness in formal education program and organization of nationwide drills; Greece could further improve its public education methods. Digital platforms will ensure that public education initiatives are improved. Dailey and Cadigan (2007) also determined that the use of mobile applications, interactive simulations, and online training modules is effective in enhancing engagement and information retention in the disaster preparedness programs [56].

The Greek EWS could use the development of an educational platform that walks its users through potential scenarios and tutorials on how to approach each of them. Further, it has been documented that community-based awareness can help improve awareness through using the locally available knowledge and practices in the community, especially in the rural/remote and marginalized communities [17]. Enhancing the importance of community engagement in EWS education can also enhance this system even more.

The ability of EWS to issue alerts has evolved due to technological developments, where alerts are faster, more accurate, and more accessible now than they used to be. Specifically, it is argued that there is some flexibility in Greek EWS in integrating technology but there is more work that needs to be done to accommodate different population group in utilizing technological advancements. Some of the main barriers described by Hammood et al. [32] include the digital divide in that some populations, such as older people and rural residents, may not always access EWS technologies. China and Bangladesh have been among the countries that have been effective in utilizing the mobile technology to increase accessibility of EWS. Advanced technology in the form of message-based alert platforms, application interfaces and real-time hazard tracking interfaces have enhanced the delivery and effectiveness of the warning frameworks [52].

With such approaches, Greece could adopt solutions like utilizing mobile alerts and creating more multilingual and easily accessible digital platforms to help disseminate the warnings. Technological advancement has also improved the way different countries monitor and even predict hazards through the incorporation of environmental IoT sensors and cloud integration systems. For example, in Germany, smart sensors have been developed, which signal the onset of flooding as well as pass information about it to the rescue squads in real time [22]. Greeks could enhance the efficiency

of alerts used to detect potential hazards through incorporating the IoT sensors into the network. The two technologies of artificial intelligence and big data analysis could increase the effectiveness of early warning systems through increased accuracy and smoothed alerting. AI-based systems are capable of analyzing large amounts of data and providing alerts with better accuracy as compared to human intervention [49]. Thus, Greek EWS needs expanding by enhancing the AI-based hazard modeling capabilities and implementing some forms of automated decision support systems for the involved emergency management staff.

5.1. *Implications and Contributions of the Study*

The study bears important implications for practice, policy, and theory concerning the Early Warning System (EWS) for disaster management in Greece.

5.1.1. Practical Implications

The study provides critical insights into how EWS can be optimized to enhance disaster response efficiency. There is one more practical consequence that can be derived from the analysis of the overarching themes, namely the requirement for better risk communication practices [80]. The study also revealed that mere alerts are not effective; differently, the framing of the messages and how the warnings are disseminated influence their effectiveness. Based on the evidence from Japan, Bangladesh, and the United States, this research postulates that having a clear instruction from the message can increase the impact of the alert for the populace [15, 49]. Another practical implication pertains to the integration of advanced technological solutions in hazard monitoring and early warning dissemination. As such, this study reveals that the integration of AI-based predictive tools for data analysis, real-time sensors, and multiple-system alarm systems will enhance EWS capabilities. Like other countries that have applied AI in hazard prediction systems [43], the advancement in machine learning algorithms could increase the forecast accuracy and reduce the vagueness of the meteorological predictions.

Moreover, this study explores the involvement and education aspects of the disaster preparedness system. The study reveals that EWS is recognizable to the public but meaningful understanding about EWS is lacking. It has remained a proven fact that through integration of disaster preparedness training in school, societies become more resilient such as in Japan and the Philippines case [33, 34]. Therefore, the findings of the current study re-emphasize the importance of community-based education interventions that include practical handling and the demonstration of how to handle emergencies, not just in terms of providing information.

5.1.2. Policy Implications

This study has several key policy implications for disaster management authorities in Greece and other regions facing similar challenges. First, it overemphasizes policy leadership for multi-stakeholder collaboration. EWS depends not only on technology, but on meteorological organizations as well as emergency services and communication systems. Policy makers should also make sure that disaster risk reduction interventions are in line with international standards, most specifically the Sendai Framework for Disaster Risk Reduction [10] that emphasizes collaboration between sectors in regard to early warning systems. The third important lesson that comes out clearly is the importance of incorporating vulnerable groups in early disaster warning systems. Finite noted that due to the

digital divide, some population strata, such as the elderly and those living in rural areas, may not have equal access to such alerts [56]. It is therefore incumbent upon the policymakers to extend the alerts to all the demographics through SMS, radio, mobile apps and television [6].

The study also reveals the need for investment in technological infrastructure as another success factor. Governments need to allocate resources to fund the integration of cloud-based hazard monitoring platforms, IoT-based environmental sensors and AI-based forecast models in EWSs. Since the countries that make greater investments in disaster risk reduction have lower disaster mortality rates, Greek policymakers should work for permanent strategies for funding disaster prevention instead of response [49, 51].

5.1.3. Theoretical Implications

From a theoretical perspective, this research expands the knowledge of RRM and EWS models through evaluation findings on technology, populace reaction, and awareness methods. The study is based on frameworks of disaster preparedness as proposed by [22] and extends the literature on the role of trust and perception in response to early warning as discussed in [3]. In adopting features of risk communication theories and behavioral decision making, the study re-emphasizes the relevance of message framing and public confidence in EWS. Another important theoretical implication is the use of machine learning and AI theory with regards to hazard prediction. Similarly, studies have been conducted in the past on the application of AI in weather forecasting which indeed complement the focus of this study that examines AI-based EWS frameworks in line with the recent computational disaster modeling theories [43].

Current studies indicate that using analytics might revolutionize risk assessment approaches from mapping of hazardous areas to understanding real-time risk prediction systems. In addition, this study develops community-based disaster management theories by showing that people and localized information are essential components for disaster resistance. This supports the view that top-down approaches alone are inadequate and that bottom up, community-based approaches as seen in the frameworks used in South Asia and the Caribbean [19, 33] must be considered.

6. Conclusions and Recommendations

This study investigated the effectiveness of EWS in reducing loss of life in natural disasters. The findings offer significant perspectives on how to improve the effectiveness of EWS through timeliness, precision in danger forecasting, public awareness and education initiatives, and technology improvement. The results reveal that overall, Greece's EWS is reasonably accurate for providing timely alerts, but there are shortcomings in conveying the severity of the threats to the public. The study also shows that even though hazard predictions are generally fairly accurate, the variability in the reliability of models diminishes public trust. These are important observations that highlight the importance of experimenting with predictive models and the constant quest for emerging technologies like artificial intelligence and real-time data analysis to ensure that the accuracy and quality of forecast remain high.

One of the other findings highlighted is that awareness and educating the general public contribute to enhancing EWS efficiency. Despite a good understanding of EWS across the majority of the respondents, a knowledge implementation gap still exists. The work also focuses on the need for continued education campaigns and drills, which often saves the public not only awareness but also

instructions on what course of action to take. Such adaptations include including EWS education in school curricula and expanding its use of online platforms to enhance social learning. Technology has enhanced EWS efficiency, consistency, and effectiveness, but concerns are still raised concerning EWS accessibility for specific categories of people. It suggests broadening the use of multiple channel alerting such as the use of mobile applications, social platforms, and community warnings that accommodate all groups of people.

Also, building IoT sensors and developing AI-based predictive models can improve monitoring of hazards and communicating associated risks. Therefore, this study brings to light the necessity for comprehensive prevention of disasters: timely and accurate early warnings, public education, and the use of technologies. To address these limitations, more attention to risk communication should be paid, the data constancy in hazard predictions should be strengthened, and the further development of effective monitoring tools for the enhancement of EWS should be encouraged for policymakers. Enhancing Collaboration among agencies and increasing public trust in EWS can also help save lives and develop societies that are more resilient in high-risk areas, such as Greece. Future attempts to increase community resilience to natural disasters, not only in Greece but also in other places susceptible to similar calamities, might be guided by the significant insights this study adds to the field of disaster management and EWS efficacy.

Based on the findings of this study, different recommendations can be made:

- It is recommended that authorities make investments in cutting-edge monitoring technology and systems to improve the timeliness of EWS signals. This covers the utilization of satellite-based surveillance, automatic alarm distribution, and real-time data collection. EWS operators should also receive ongoing training and simulations to guarantee prompt warning distribution and response.
- Programs for education and public awareness must be maintained and extended in order to reach more people. These initiatives ought to aim to inform the public about EWS's presence as well as the precise steps they ought to follow in the event that they receive an alert. A variety of platforms, such as social media, smartphone apps, community seminars, and school curriculum, should be used to spread information.
- Multiple government entities, such as meteorological services, disaster management authorities, and communication agencies, must coordinate for effective EWS. For an effective and seamless response to disasters, a coordinated strategy to EWS planning, execution, and communication is essential.

Researchers could carry out longitudinal studies, which monitor the efficacy of EWS over a lengthy period of time, to gain an understanding of the long-term impact of the intervention. This would make it possible to evaluate how EWS effectiveness, public awareness, and disaster preparedness have changed over time while taking new innovations in policy and technology into account.

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