Earthquake early warning in Central America: The societal perspective

Journal Article

Author(s):
Orihuela, Benazir; Dallo, Irina; Clinton, John Francis; Strauch, Wilfried; Protti, Marino; Yani, Robin; Marroquín, Griselda; Sanchez, Jacqueline; Vega, Floribeth; Marti, Michèle; Massin, Frédérick; Böse, Maren; Wiemer, Stefan

Publication date:
2023-10-15

Permanent link:
https://doi.org/10.3929/ethz-b-000633084

Originally published in:
International Journal of Disaster Risk Reduction 97, https://doi.org/10.1016/j.ijdrr.2023.103982

Funding acknowledgement:
821115 - Real-time Earthquake Risk Reduction for Europe (EC)

International Journal of Disaster Risk Reduction 97 (2023) 103982

Contents lists available at ScienceDirect

International Journal of Disaster Risk Reduction

journal homepage: www.elsevier.com/locate/ijdrr

Earthquake early warning in Central America: The societal perspective

Benazir Orihuela [a,*], Irina Dallo [a], John Clinton [a], Wilfried Strauch [b], Marino Protti [c], Robin Yani [d], Griselda Marroquín [e], Jacqueline Sanchez [b], Floribeth Vega [c], Michèle Marti [a], Frédérick Massin [a], Maren Böse [a], Stefan Wiemer [a]

[a] *Swiss Seismological Service at ETH Zurich, Zurich, Switzerland*
[b] *Instituto Nicaragüense de Estudios Territoriales (INETER), Managua, Nicaragua*
[c] *Universidad Nacional, Observatorio Vulcanológico y Sismológico de Costa Rica (OVSICORI-UNA), Heredia, Costa Rica*
[d] *Instituto Nacional de Sismología, Vulcanología, Meteorología e Hidrología (INSIVUMEH), Guatemala, Guatemala*
[e] *Ministerio de Medio Ambiente y Recursos Naturales (MARN), San Salvador, El Salvador*

A R T I C L E I N F O

Keywords:
Earthquake early warning system
Protective action
Central America
International comparison
Social perspective

A B S T R A C T

Central America has an elevated seismic risk, resulting from the vulnerability of the building stock and steady population growth. Earthquake Early Warning (EEW) aims to provide warning in advance of imminent shaking, allowing recipients to take action and reduce casualties during damaging motions. The Swiss Seismological Service (SED) has been collaborating with local seismic agencies to develop national EEW systems across Central America, which can potentially benefit nearly 47 million inhabitants. We conducted a public survey to comprehend the desire for EEW, the preferences for EEW attributes, and the current behaviour of people during earthquakes and the driving factors behind it. We recruited participants from Nicaragua (N = 513), Costa Rica (N = 1350), Guatemala (N = 559), and El Salvador (N = 491). In all four countries, participants consider it necessary to have an EEW system, are tolerant of false alerts, and are likely to react promptly to alerts. The desirable alert threshold is for low felt intensities, ranging between MMI III to IV. We found that a significant number of respondents already take protective action when earthquakes strike, and appropriate reactions are expected to increase when EEW is available. Our survey is unique in providing insights into the social dimension of EEW systems in low-income regions with high earthquake risk and where no operational EEW system yet exists.

1. Introduction

Earthquakes are among the most dangerous hazards to human society as they can undo decades of development efforts and have severe repercussions on the living conditions of all social groups [1]. Compared to storms, floods or droughts, earthquakes are particularly devastating in Central America, as they have registered the highest death tolls [2]. The interaction of multiple tectonic plates drives the seismicity of the region; large magnitude subduction, as well as shallow crustal events, can cause strong ground shaking and produce extensive destruction, especially to 9 million dwellings built using adobe or unframed cement blocks that still prevail in both rural and urban zones [3]. In the past, shallow crustal earthquakes with moderate magnitude have occurred near densely populated areas resulting in heavy social losses [4]. Nearly 50 years ago, Nicaragua and Guatemala were devastated by two

* Corresponding author. ETH Zurich, Swiss Seismological Service, Sonneggstrasse 5, 8092, Zurich, Switzerland.
E-mail address: benazir.orihuela@sed.ethz.ch (B. Orihuela).

https://doi.org/10.1016/j.ijdrr.2023.103982
Received 31 January 2023; Received in revised form 1 September 2023; Accepted 2 September 2023
Available online 12 September 2023

major earthquakes that resulted in a combined death toll of 30,000 people, and property damage exceeded 7000 million dollars [5]. Seismic vulnerability can most effectively be reduced through strategies that improve the resilience of the building stock, including enforcing appropriate building codes or retrofitting existing structures. However, these are long-term, costly, and challenging solutions to implement. Meanwhile, the lack of urban planning is exacerbating the earthquake risk [6]. In comparison, Earthquake Early Warning (EEW) can be a cost-effective method to mitigate some of the losses that occur during earthquakes, and can be rapidly developed and implemented.

EEW relies on a dense network of sensors and takes advantage of the latest technological developments to detect and characterise earthquakes as they are beginning [7]. EEW aims to provide a warning before the destructive shaking begins, which will allow recipients to take protective actions that could reduce casualties, in many cases only a handful of seconds can be provided [8]. Hence, fundamental to a successful outcome is a well-educated public who knows how to respond in an appropriate manner. EEW can also provide early situational awareness for decision-makers, as strong shaking often causes cascading failures in key infrastructure systems (e.g., communication, power, transportation). Additionally, pre-programmed automated security actions such as the shut-down of nuclear reactors, deceleration of high-speed trains, bringing elevators to a stop at the nearest floor, can be implemented for engineering applications [9–11].

Since 2016, the Swiss Seismological Service (SED) at ETH Zurich, with the financial support of the Swiss Agency for Development and Cooperation (SDC), has been collaborating with national seismological agencies in Nicaragua (INETER), Costa Rica (OVSICORI-UNA), El Salvador (MARN), and Guatemala (INSIVUMEH) to develop national EEW systems across Central America. A moderate investment in instrumentation has enhanced the EEW capability of the seismic networks and at this stage, satisfactory performance in terms of accuracy and latency of alerts is being achieved [12,13]. Public EEW alerts have recently been made available via a mobile phone application in Costa Rica and Nicaragua. Considering the widespread nature of earthquakes across the region, EEW can potentially benefit the majority of the nearly 47 million inhabitants of Central America.

EEW systems are well established and provide public alerts in a number of regions [7]. These systems can vary significantly, for example they may be designed to target specific seismic sources, use different sensor types with variable network layouts, or depend on very different EEW algorithms. Nevertheless, EEW systems face common challenges concerning public expectations and acceptance. For example, in 2017 the Mexico City earthquake exposed a discrepancy between public expectations and actual performance of the EEW system, as the warning time provided was significantly less than people expected based on past experiences with alerts [14,15]. Similarly, in 2019, EEW alerts were not issued in California for the Ridgecrest earthquake due to the predicted shaking falling below the alert threshold which contradicted public expectations [16,17]. Furthermore, the Japan EEW system faced operational difficulties during the Tohoku earthquake in 2011, the magnitude and location were inaccurate, plus several missed and late alerts happened [18]. These examples highlight the importance of incorporating public expectations and preferences in the development of EEW systems.

An important amount of research has been devoted to the technical development and implementation of EEW by the science community. However, this process can be enhanced and refined by adding the perspective of users and stakeholders (e.g., political actors, governmental agencies, and local community) [19]. The United Nations Office for Disaster Risk Reduction (UNISDR) also emphasized that to be effective, any early warning system must be user-centred regardless of the hazard [20]. This requires identifying the needs and capacities of the target audience, determining drivers and restraints on how users can respond effectively to alerts and maximising public acceptance of the system [21]. In recent literature, social science surveys that document the behaviour, understanding and expectations of the public have been conducted in New Zealand [22–24], Switzerland [25], and the US [26]. In advance of the wide-scale roll-out of EEW in Central America, we aim to evaluate the level of desire for the system. We conducted public surveys in four countries - Nicaragua, Guatemala, Costa Rica, and El Salvador - with nearly 3000 participants in total. We conducted public surveys to evaluate the expectation for EEW systems, gather insights into preferences for EEW attributes and assess the current behaviour during earthquakes. The results are intended to inform and optimize the development of national EEW systems before they are introduced. We formulated three key research questions that shaped the content of the survey conducted:

(1) What is the perceived usefulness of a national EEW system?
(2) What are the public preferences for the attributes of an EEW system (e.g., what should the shaking threshold be for alerts, how would they like to receive alerts)?
(3) What are the current protective actions taken by the public and which factors influence these choices?

Section 2 describes the methodology and implementation of the survey. Section 3 presents the main results and includes a comparative analysis across nations within the region. Section 4 presents a global comparison of social surveys conducted in Japan, Mexico, the US-West Coast, New Zealand and Switzerland with our results obtained in Central America focused on the research questions. Section 5 presents the limitations of the study, followed by areas of future research and conclusions in Section 6.

2. Methodology

We assessed the expectations, attitudes and preferences of the public regarding EEW along with their behavioural response during earthquakes and the driving factors behind it. The survey evaluated in this work was conducted between May and July of 2022 and targeted the public in Nicaragua, Costa Rica, El Salvador, and Guatemala.

2.1. Survey development

Our questionnaire was adapted from prior studies performed in New Zealand [22], Japan [27], the US West Coast [26], and Switzerland [25]. Questions were formulated based on theoretical frameworks on how people respond to threats and hazards (e.g.

hurricanes, floods, volcanic eruptions) [28–31]. The questionnaire was structured into five question blocks (QB) consisting of a total of 27 questions. QB1 assessed the interaction, perception and planning of participants to various earthquake-related factors, including previous earthquake experiences, hazard perception, vulnerability perception, and preparedness planning (i.e, preparedness measure carried out, actions planned prior to the occurrence of earthquakes). Moreover, we asked participants what actions they took during the strongest earthquake they experienced. In QB2, we evaluated the perceived usefulness of the EEW system after presenting participants with a text describing the benefits and limitations of EEW. Additionally, we estimated the tolerance towards inevitable alert limitations (i.e., late, missed and false alerts). In QB3, participants were exposed to a hypothetical EEW alert for a strong earthquake and were asked to select a protective action. QB1 and QB3 allowed us to compare how past and intended protective actions may change with the implementation of an EEW system. Currently, no country in the region has official 'written' guidance on what is the recommended behaviour. Generally, individuals evacuate the premises during earthquake drills. Contradictory information can be found on web pages or brochures of Civil Protection Agencies that replicate the advice "Drop, cover and hold on" given by the USGS [32]. No guidance was given in this survey and it remains to be decided what official guidance will emerge in the future. In QB4, we explored the preferred system attributes (i.e, desirable alert threshold, acceptable warning times, dissemination channel). In QB5, we documented demographic information such as age, gender, location, highest educational degree, and occupation.

We used multiple or single choice questions and 5-point Likert-scale to evaluate the level of agreement with the statements proposed, with "1" representing a strong disagreement and "5" representing strong agreement. The most relevant parameters of the survey are presented in Section 3 and the Supplement S1 provides a detailed description of all parameters per country. The questionnaire was originally developed in Spanish and later translated to English for analysis. Both versions can be found in Supplement S2. It is important to mention that in Latin America, three terms are used to describe 'earthquakes' [33]: i) 'temblor' is applied to small and

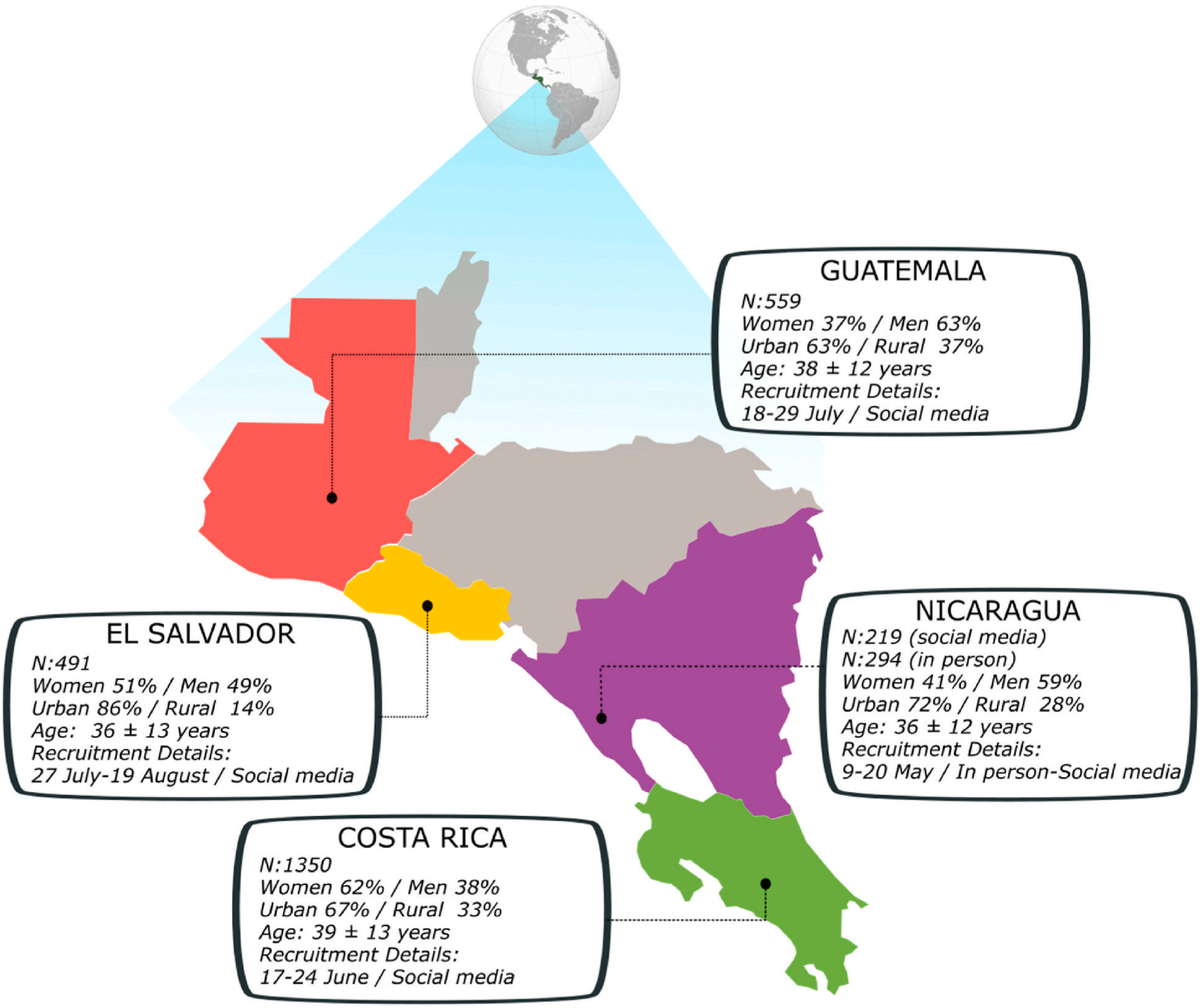

Fig. 1. Key demographic characteristics of the survey. Each of the four Central America nations are indicated in the map. The number of respondents (N) is indicated, as well as overview details.

medium size quakes with no severe repercussions; ii) 'terremoto' is reserved for earthquakes with strong shaking and potential for damage, and iii) 'sismo' is a scientific term that comprises both aforementioned terms. Questions pertaining to major earthquakes that required participants to envision potential damage were labelled as 'terremoto' and generic statements were categorized as 'sismo'.

2.2. Survey procedure, sample and analysis

The representative sample size was determined by a statistical power analysis using the software G*Power, the method used was stratified random sampling with quotas based on age, gender, and regional typology (i.e., urban, rural). The latest national Census of each country [34–37] was used to calculate the distributions of quotas and the criteria of classification can be found in Supplement S3. Across the four countries, nearly 3000 people participated in the survey and participants were at least 18 years of age. There was no financial compensation and the survey took an average of 15 min. Fig. 1 summarises the main survey characteristics for each country, including the sample size, key demographic information and recruitment procedure. Further details of demographics for each country can be found in Supplement S4. The survey was rigorously pre-tested to improve the clarity of the questions and UNIPARK software was used to create, conduct and archive the results.

The survey and a promotional video were posted on social media (e.g., Facebook, Instagram, and Twitter) by the national institutions of Costa Rica, Guatemala, and El Salvador. The survey generated public interest and positive feedback during the two-week response window. In Nicaragua the approach was different - in addition to the survey being openly available on the INETER web page, a team from INETER and ETH conducted in-person surveys during a two-week field trip to seven regions in the major cities of the Pacific Coast. We visited two universities, 12 municipalities, and 'early adopters' of the EEW system. The early adopters included

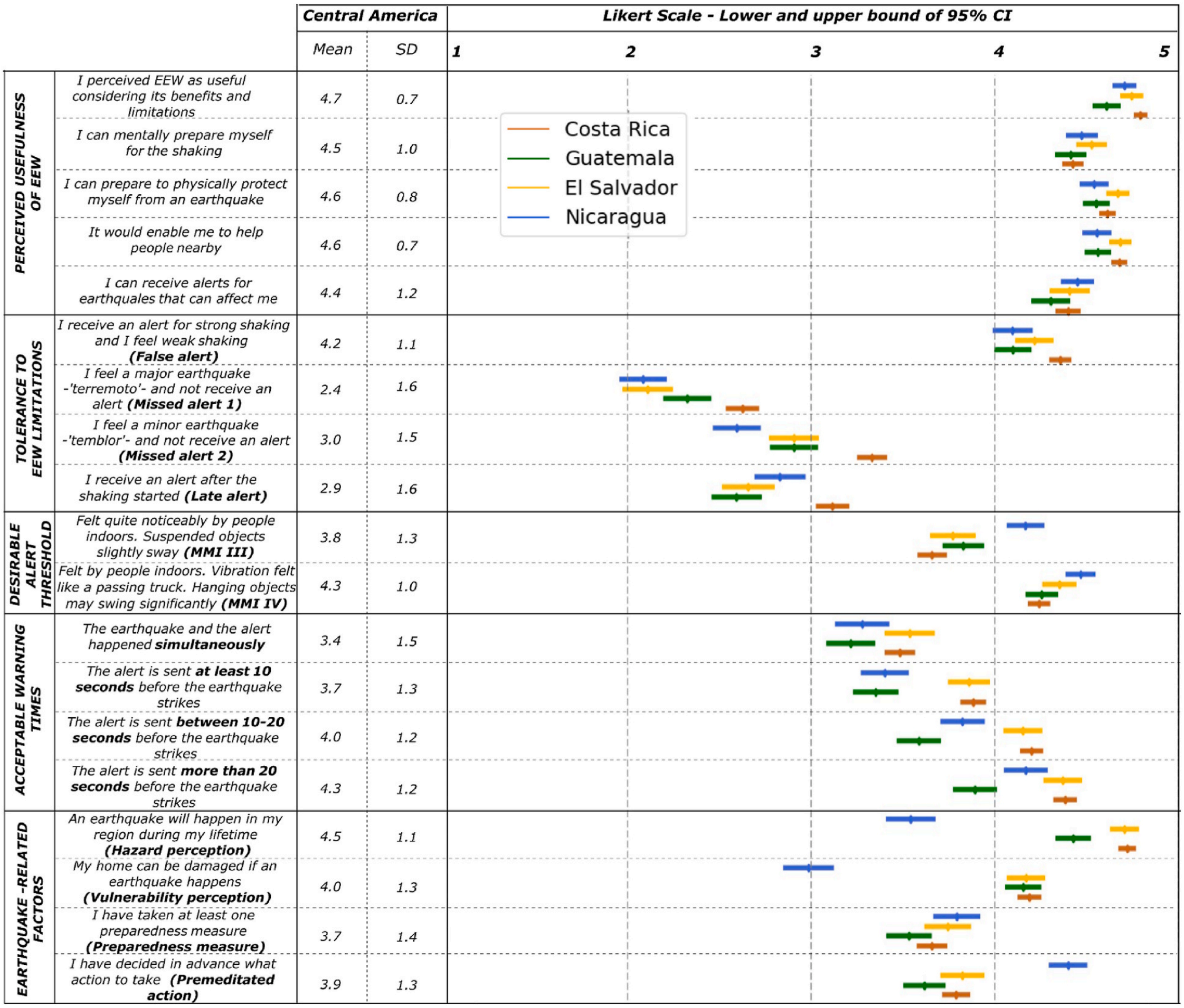

Fig. 2. Response to key questions from the survey. For each question, respondents could select answers on a 5-point Likert scale - 5 indicated strong agreement and 1 strong disagreement. Mean and standard deviation for the whole region are presented in Columns 3 and 4. The lower and upper bounds of the 95% Confidence interval are provided for each county: Nicaragua (blue), El Salvador (yellow), Guatemala (green) and Costa Rica (orange).

national stakeholders (i.e., civil protection, ministries, hospitals, universities, and schools) and private stakeholders (i.e., airport and shopping centres) located in Managua that have been receiving trial alerts since the beginning of 2022 through digital TV via the Emergency Warning Broadcast System. Due to the small sample size of early adopters (65 participants), we decided to merge the data. Supplement S5 presents the four additional questions that address the interaction of early adopters with EEW alerts. In Nicaragua, participants completed the survey on their mobile phones (via a QR code) or on paper (in this case completed information was subsequently manually entered in UNIPARK). Participants in all countries were encouraged to share the link with their colleagues, family and friends.

In addition to descriptive comparative analyses between countries, we employed several one-way analyses of variances (ANOVAs) and regression analyses. We used multinomial logistic regressions to examine the impact of earthquake-related factors on the behavioural response of participants, the perceived usefulness of EEW, tolerance to alert limitations, acceptable warning times, and preferable alert thresholds. The application of Bonferroni post-hoc tests provided a comprehensive understanding of specific group differences identified in our analysis and determined if these differences were significant [38]. We also considered demographic characteristics as driving factors however results were not statistically significant.

3. Analysis of the survey with a focus on inter-country comparison

Section 3 is structured according to the research questions, we analysed the expectation and preferences of the public towards EEW systems in addition to the current behavioural response during earthquakes in Central America. Fig. 2 provides a comprehensive overview showing how key questions using a Likert scale were answered at both the regional and country levels. Mean and standard deviation values are provided for the entire region in the 3rd and 4th columns, and the lower and upper bounds of the 95% confidence interval for each country are shown in the bars colour-coded for each nation. The interpretation of the Likert scale parameters is described in the following subsections. As a general guide, a rating of 5 indicates strong agreement, while a rating of 1 indicates strong disagreement. The remaining parameters of the survey and detailed results per country can be found in Supplement S1. The survey took place at least 1 year before the first alerts were available to the general public via a mobile application, although in Nicaragua a handful of early adopters were receiving alerts via digital TV signals for some months.

3.1. Exploring perspectives on the benefit and limitations of EEW

3.1.1. EEW understanding and expectations

We asked participants if they were familiar with the concept of EEW. We found that at least 75% of participants in Nicaragua, Costa Rica, and El Salvador knew about EEW, although this dropped to only 59% in Guatemala. Participants were subsequently asked to select all the options that they believed described how EEW functions (Fig. 3), before the system was explained to them. Overall participants showed a good understanding of EEW and there is little variation between the countries. Most participants agreed that EEW sends alerts for an expected earthquake (63–70%), provides a few seconds to take protective actions (55–84%), and the warning time depends on the distance to the source (44–49%); however, this last option was not available for the Costa Rican survey. However, we identified a few misconceptions that should be addressed with future educational campaigns. First, 20% across all countries thought that EEW systems predict earthquakes. A potential explanation is that participants might assume earthquakes only happen

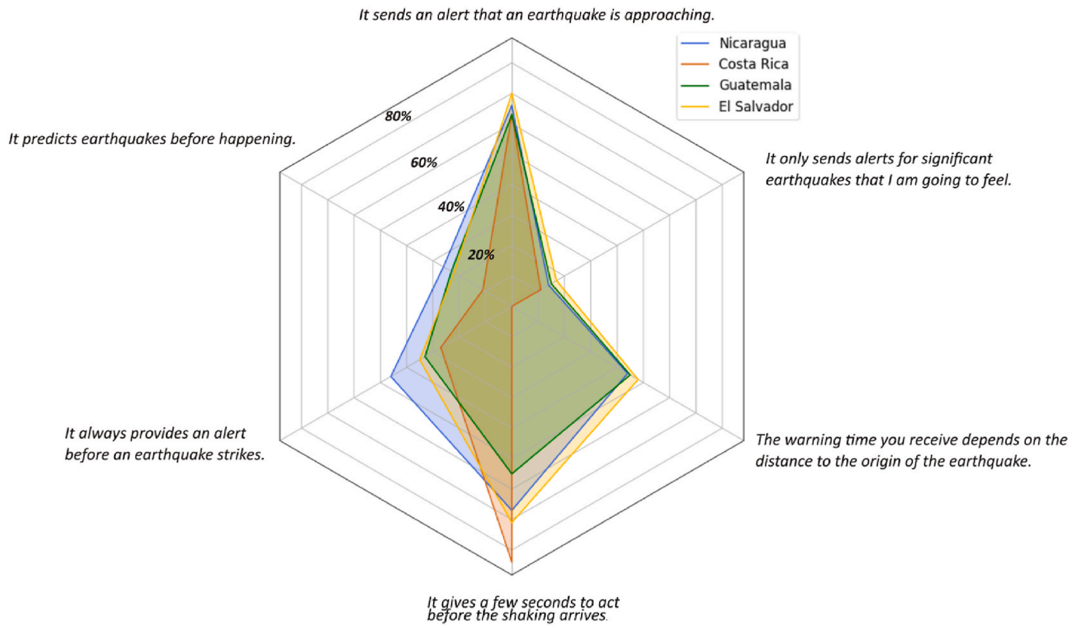

Fig. 3. Level of understanding of how an EEW system works. From a list of 6 statements shown above, participants selected all statements they thought were correct.

once shaking begins locally, without realising that shaking is the delayed result of fault rupture deep in the Earth. A large number of people also had unrealistic expectations, assuming alerts will never be missed or arrive after the shaking begins (27–46%). Additionally, only a small group of participants (11–17%) expected to receive alerts only for significant earthquakes, this suggests the public expects an EEW system should provide alerts also for non-damaging shaking. Detailed results are listed in Supplement S1.

3.1.2. Perceived usefulness of EEW

The participants were subsequently provided with a short text that describes the aim, benefits, and limitations of EEW (Supplement S1 pg.12) including the precautionary measures recipients can take, the capacity to enhance the emergency response of national institutions, the limited warning time provided, and the possibility of occurrence of false and missed alerts. Participants were asked to rate how useful they found the system. Fig. 2 shows that EEW was positively rated in all countries. Additionally, participants rated 'self-protect physically' and 'be able to assist individuals nearby' as the main benefits of EEW, followed by 'be able to mentally prepare for the shaking' and 'receive alerts for earthquakes that affect me'. Only 7% of participants of the whole sample perceived EEW as 'not useful'. These participants expressed concerns about their ability to respond if alerts are not timely enough ($M = 3.5$, $SD = 1.2$), if alerts go unnoticed ($M = 3.5$, $SD = 1.3$), or if they received alerts without experiencing shaking ($M = 3.4$, $SD = 1.3$). Supplement S6 shows the perceived usefulness of EEW by age group, education level, gender and region.

3.1.3. Tolerance to alert limitations

The participants were then asked to grade their level of tolerance towards late, missed and false alerts. The definitions of these alerts provided to the participants are shown in Fig. 2. The tolerance to alert limitations varied little across the countries. Notably, participants showed a high level of acceptance for false alerts. There is a decreasing tolerance for late alerts, missed alerts for moderate earthquakes ('sismo'), and missed alerts for strong earthquakes ('terremoto'), in that order. In the event of experiencing any alert errors, participants acknowledge that EEW has limitations ($M = 4.4$, $SD = 1.0$). Additionally, post-alert messaging is essential to develop trust and awareness about the functioning of EEW [25,26], highlighted by the observation that participants want to know immediately the reason for receiving incorrect information ($M = 4.0$, $SD = 1.2$). Overall, results suggested that, despite alert limitations, EEW was perceived as valuable. Loss of trust in EEW due to errors had a low effect ($M = 2.7$, $SD = 1.4$).

3.2. Towards an EEW system guided by user preferences

3.2.1. Desirable alert thresholds

The Modified Mercalli Intensity (MMI) scale describes the observed effects on people, buildings and the environment [39], and it was briefly introduced to participants. They were then shown pictograms of the MMI scale ranging from MMI III (felt) to VII (damaging) and were asked to choose the lowest level of shaking that they would want to be warned for. Fig. 2 summarises results for MMI III to IV, Supplement S1 shows detailed results for other intensities and Supplement S2 provides a detailed description of the MMI scale. In Nicaragua, participants chose to a large extent to receive alerts from MMI III+ ("Felt by several, vibration like the passing of truck, hanging objects may swing appreciably"). Similarly, across all countries the wish to receive alerts from MMI IV+ ("Felt by many, sensation like heavy body striking building, dishes and windows rattle") is very high.

Results suggested that participants desired to be alerted for any shaking they might feel, a possible explanation for this could be the novelty of the EEW system, as participants may be curious and interested in receiving alerts [22,26]. However, it is important to acknowledge that enforcement of building codes is lax in most countries [5] and participants might be worried about the performance of their houses during earthquakes. Nicaragua, Costa Rica and El Salvador implemented their building codes the following years after the devastating earthquake in Nicaragua (1972) and have re-evaluated the code at least twice [40]. In contrast, Guatemala only enforced its building code in 2019 [41]. Additionally, at least 20% of dwellings in El Salvador, Guatemala, and Nicaragua need rehabilitation to meet basic quality standards [5]. Consequently, these structures may not be capable of withstanding strong motions [42].

3.2.2. Acceptable warning times

We assessed the minimum warning time participants required to respond to earthquakes ('terremotos'). Participants were presented with different 'realistic' warning time scenarios and asked if they thought this provided sufficient time for them to take a precautionary action (Fig. 2). In general, the results suggested participants may have been overestimating the actions they could perform within the limited warning time provided. Respondents expressed being comfortable with short warning times, a potential explanation could be their confidence in their ability to respond due to their extensive earthquake experiences. The warning time a recipient will receive is highly variable and depends on the event location and the EEW systems [43]. In general, EEW alerts for offshore subduction earthquakes provide more warning time than for shallow crustal earthquakes. The latter results in late alarm zones for significant areas where the shaking is strongest [44]. The Guatemala earthquake in 1976 was an exception to this case, the rupture initiated on the Motagua fault, far from Guatemala City, and propagated towards it. In a repeat of this event, simulations show that an EEW system would provide tens of seconds of warning time for the capital before the strong shaking arrives [12].

3.2.3. Preferred dissemination channels

Respondents were provided with a list of technical options for how they may receive an EEW alert and asked to indicate which of them they preferred (Fig. 4). At 75%, the most popular option is push notification on a mobile device, followed by alerts sent via multiple technologies (50–68%). Next most popular were public announcements (40–55%), and mobile apps (39–52%). A small number of participants preferred TV and radio messages (23–40%). A promising option to deliver alerts in the region is via emerging Digital TV signals, though this would require the purchase of a small device for $10-$20. In El Salvador and Guatemala, only 12%

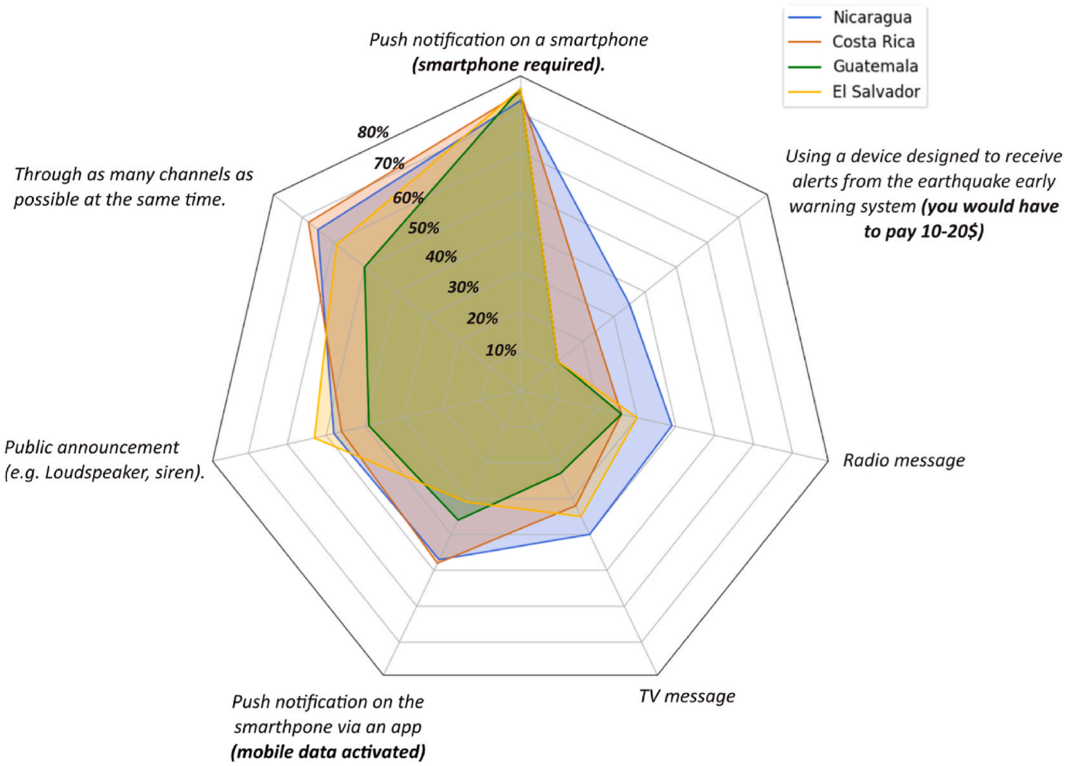

Fig. 4. Preferences for dissemination channels in all four countries for EEW alerts. 'Push notification on a smartphone' and 'through as many channels as possible at the same time' were most often selected.

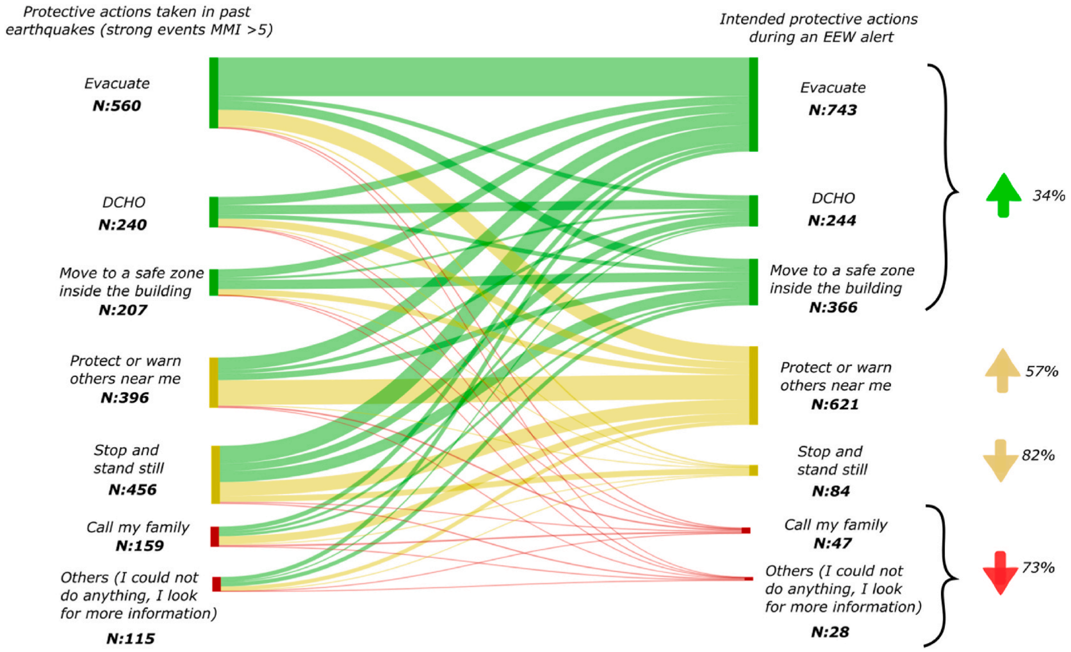

Fig. 5. Comparison between actions taken during a real past earthquake versus the action they would take when confronted with EEW alerts received seconds before strong shaking starts.

would consider such a purchase. These percentages are slightly higher in Nicaragua and Costa Rica (24–35%), although the costs were not provided in the Nicaraguan survey. Detailed results are listed in Supplement S1. Mobile phones were the preferred dissemination channel, although the average smartphone penetration ratio in the region is 54% [45]. In certain parts of Guatemala (Guatemala City) and Nicaragua (coastline), a network of public sirens exists that could be leveraged to disseminate the alert.

3.3. Patterns in protective actions

3.3.1. Comparison between real and hypothetical scenarios

The participants were provided with a list of possible actions to take during an earthquake and asked first to select which action they had taken during the strongest earthquake they had experienced and then to select the action they would take if they received an EEW alert seconds before a damaging earthquake ('terremoto') occurred. This survey was undertaken in the absence of official 'written' guidance on what is the recommended behaviour and no guidance was given during the survey. Detailed results are in Supplement S1. The list of actions is provided in Fig. 5 and tracks how actions would change in the event of an EEW alert. In this analysis, respondents from all countries are combined but we only included participants that report experiencing strong motions with intensity MMI V+ ("Felt by nearly all, some dishes and windows broken, unstable objects overturned"). In Fig. 5, actions are colour-coded according to how appropriate they are for protecting oneself. 'Green' indicates actions that can reduce casualties, although none are officially recommended today in Central America (i.e., evacuate, drop cover and hold on 'DCHO'; move to a safe zone). 'Yellow' indicates actions that can prepare the recipient or others for imminent shaking (i.e. stop and stand still; protect or warn others near me). Finally, 'Red' indicates actions that are not helpful in mitigating casualties and are not recommended (i.e., call my family; not take action; continue with my activities; look for further information). Fig. 5 demonstrates that once EEW is available, considerable improvements in behaviour can be expected. Recommended strategies are expected to increase by 34%, motionless reactions to decrease by 82%, and not-recommended actions to reduce by 73%. It is notable that the action 'Protect or warn others near me' would increase significantly if EEW is available. Numerous family members live in overcrowded conditions due to the high housing deficit in El Salvador, Guatemala, and Nicaragua [5], including children and the elderly with higher risks of suffering earthquake-related trauma [46,47]. 'Protect or warn others near me' is not a new action in Central America, experiences from Nicaragua (1972) and Guatemala (1976) earthquakes showed that protecting children was the first instinct of mothers [48], plus individuals tend to seek a familiar person during disasters [49,50].

3.3.2. Previous experiences with earthquakes

We wanted to assess the impact of historic earthquakes ('terremotos') on the social mindset. We asked participants about their previous earthquake experiences - what was the largest intensity shaking they have experienced, and what are the consequences of earthquakes they either directly or indirectly endured during their lifetime. The elevated seismic risk in Central America is clearly borne out by the previous earthquake experiences reported in Fig. 6a. Furthermore, Fig. 6b shows that at least 70% of participants have endured MMI VI+ (Felt by all, people move unsteadily, slight damage in poorly built structures). In Nicaragua, the question on intensity directly referred to the shaking experienced during the M6.7 earthquake that occurred two weeks prior to the survey (April 21st, 2022). Detailed results are listed in Supplement S1.

Each country has endured significant and deadly earthquakes in the recent past [4,51–53]. In order to understand the consequences of these earthquakes as perceived by those directly affected, we focus on participants who possess an appropriate age to recall these events, reside in close proximity to the epicentral region, and have experienced at least MMI VII+ ("Considerable damage in poorly built structures, slight to moderate damage in well-built ordinary structures, damage negligible in buildings of good design"). In Costa Rica, 70% of participants from the Limon region who are over 40 years old have felt MMI VII+, likely related to the M7.6 earthquake in 1991 [51]. In El Salvador, 64% of participants who are over 30 years and located near San Salvador and La Libertad reported having felt MMI VII+. These participants are likely to have lived through two consecutive earthquakes, the M7.7 and M6.6 that happened in 2001 [4]. Among them, 60% have observed local damage in their cities, and 34% have experienced personal injury, damage or loss. The M7.5 Guatemala earthquake in 1976 [52] and the M6.2 Managua earthquake in Nicaragua in 1972 [53] marked an entire generation and the effects are visible in our survey. In both countries, 70% of participants who are over 50 years old have felt MMI VII+. Additionally, 60% of them have observed earthquake-related damage in their cities, 43% have experienced personal injury, and 42% know someone who has suffered an injury.

3.3.3. Factors controlling protective actions

Behaviour during an earthquake can be strongly shaped by multiple factors, including the emotional impact of previous earthquake experiences, the level of preparedness planning, and the perception of hazard and vulnerability [50,54]. The high exposure to damaging motion in previous experiences was presented in Fig. 6 and discussed in the previous section, and the results from the other factors are explored in Fig. 2. With the exception of Nicaragua, there is a strong consensus that strong earthquakes ('terremotos') will occur in their region and they are aware that they live in vulnerable housing. The results in Nicaragua are unexpected, given the local history of earthquake events and the quality of housing, suggesting that the question was possibly misunderstood or the surveyed group has a high socio-economic status. Additionally, most participants in all countries indicated carrying out preparedness measures in the past. These measures include participating in earthquake drills or preparing emergency plans. The results confirm that a strong

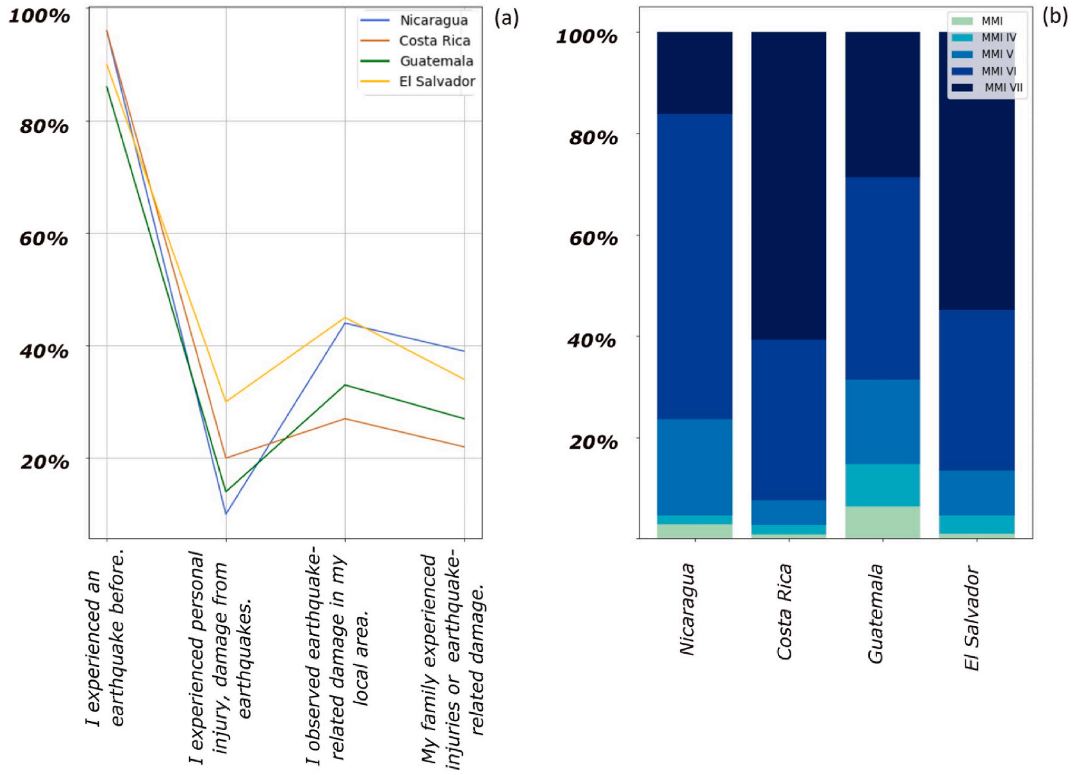

Fig. 6. (a) Summary of previous earthquake experiences. The majority of respondents in all countries reported experiencing an earthquake before, and between 25 and 45% reported directly observing earthquake damage. (b) The majority of participants in all four countries experienced at least MMI VI ("Strong shaking (Some objects fall, slight non-structural damage like cracks on the wall").

culture of earthquake preparedness exists. In fact, Civil Protection Agencies (SINAPRED,[1] CONRED,[2] CNE,[3] Proteccion Civil,[4]) organise at least one national earthquake drill each year, and the public is encouraged to prepare an emergency survival kit and create a family emergency plan. Lastly, the vast majority of participants in Nicaragua have already decided what action to take during the next earthquake. In contrast, lower values were found in Costa Rica, Guatemala, and El Salvador. Planning and promptly executing the action to take is crucial, given the limited warning time provided by EEW systems. Worryingly, most participants intend to make a decision on whether to take a protective action based on the shaking intensity ($M = 3.9$, $SD = 1.3$) and their surroundings or proximity to others ($M = 4.0$, $SD = 1.3$). Detailed results can be found in Supplement S1.

Table 1 explores whether there is any correlation between the aforementioned earthquake-related factors and the EEW behaviours labelled as 'green' and 'yellow' in Fig. 5. A multinomial logistic regression analysis was performed to determine the influence of these factors on the actions taken during earthquakes, Table 1 presents the standard error, odd ratio and significance level. Significant results ($p < .05$, $p < .001$) were only found for Costa Rica and Guatemala, hence El Salvador and Nicaragua are not included. Participants in Costa Rica and Guatemala who strongly agreed with any of these three criteria: "had previous earthquake experiences", "took preparedness measures", "had vulnerability perception", or "premeditated the action to take prior to the occurrence of earthquakes" were at least 2 times more likely to perform a recommended strategy (i.e., evacuate, DCHO, move away from furniture, move to a safe place inside the building) or 'protect and warn others' compared to someone that did not.

Furthermore, these factors also can influence the perceived usefulness of EEW, tolerance to alert limitations, and acceptable warning times. Participants in Guatemala who strongly agreed on the occurrence of future earthquakes in their region ($R2 = 0.036$, $F(2, 557) = 10.306$, $p = <.001$) rated EEW as significantly useful. Participants in Costa Rica ($R2 = 0.038$, $F(4, 1346) = 13.24$, $p < .001$) and El Salvador ($R2 = 0.050$, $F(4, 487) = 6.72$, $p < .001$) that took preparedness measure and strongly agreed on the occurrence of future earthquakes in their region were significantly more tolerant to any alert errors. Furthermore, participants in Costa Rica ($R2 = 0.024$, $F(2, 1348) = 16.21$, $p < .001$) who lived in vulnerable houses showed significantly lower tolerance to missed alerts. Participants in Costa Rica ($R2 = 0.029$, $F(1, 1349) = 40.245$, $p = <.001$) and El Salvador ($R2 = 0.060$, $F(2, 489) = 15.29$, $p = <.05$) that took preparedness measures or premeditated the action to take, tend to respond significantly faster.

[1] Sistema Nacional para la Prevencion, Mitigacion y Atencion de Desastres-Nicaragua.
[2] Coordinadora Nacional para la Reduccion de Desastres-Guatemala.
[3] Comision Nacional de Emergencias-Costa Rica.
[4] Direccion General de Proteccion Civil.

Table 1

Multinomial regression model predicting what action participants would take after receiving an EEW alert for a damaging earthquake. Significant effects are highlighted in bold, whereby the odd ratio (OR) indicates how many times people with a certain characteristic (e.g., high vulnerability perception) are more likely to take one of the protective actions compared to an action not recommended (actions coloured in 'red' in Fig. 4).

Action		Stop and stand still				Protect or warn others near me			
	Attribute	b	Std. Error	OR	Sig.	b	Std. Error	OR	Sig.
Costa Rica	Vulnerability perception	0.98	0.71	2.67	0.17	0.58	0.42	1.79	0.17
	Preparedness measure	0.16	0.42	1.18	0.70	**1.14**	**0.31**	**3.13**	**<0.001**
	Premeditated action	0.44	0.49	1.56	0.37	**0.64**	**0.34**	**1.90**	**<0.05**
Guatemala	Prior earthquake experience	0.21	0.43	1.23	0.63	0.46	0.35	1.58	0.18
	Vulnerability perception	0.04	0.53	1.04	0.95	**0.96**	**0.47**	**2.62**	**<0.05**
	Preparedness measure	-0.02	0.44	0.98	0.97	0.50	0.36	1.65	0.16
	Premeditated action	0.02	0.45	1.02	0.97	0.59	0.37	1.81	0.11
Action		**Evacuate**				**DCHO**			
	Attribute	b	Std. Error	OR	Sig.	b	Std. Error	OR	Sig.
Costa Rica	Vulnerability perception	***0.93***	***0.43***	***2.54***	***<0.05***	0.45	0.49	1.57	0.36
	Preparedness measure	**0.99**	**0.31**	**2.69**	**<0.001**	**0.72**	**0.36**	**2.05**	**<0.05**
	Premeditated action	**0.79**	**0.34**	**2.21**	**<0.05**	**0.77**	**0.41**	**2.16**	**<0.05**
Guatemala	Prior earthquake experience	0.14	0.33	1.15	0.68	**0.81**	**0.39**	**2.26**	**<0.05**
	Vulnerability perception	**0.86**	**0.44**	**2.35**	**<0.05**	0.57	0.52	1.77	0.27
	Preparedness measure	0.30	0.34	1.35	0.37	**1.00**	**0.44**	**2.73**	**<0.05**
	Premeditated action	**0.76**	**0.36**	**2.13**	**<0.05**	**0.94**	**0.46**	**2.56**	**<0.05**
Action		**Moved away from furniture**				**Move to a safe zone inside the building**			
	Attribute	b	Std. Error	OR	Sig.	b	Std. Error	OR	Sig.
Costa Rica	Vulnerability perception	0.34	0.34	1.40	0.61	0.57	0.44	1.76	0.20
	Preparedness measure	**1.11**	**0.52**	**3.02**	**<0.05**	**1.14**	**0.33**	**3.14**	**<.001**
	Premeditated action	0.21	0.52	1.24	0.68	0.40	0.35	1.49	0.26
Guatemala	Prior earthquake experience	0.18	0.79	1.20	0.82	0.64	0.37	1.90	0.08
	Vulnerability perception	0.54	1.13	1.71	0.63	0.56	0.49	1.76	0.25
	Preparedness measure	-0.10	0.79	0.91	0.90	0.22	0.38	1.24	0.56
	Premeditated action	0.32	0.87	1.37	0.72	0.28	0.39	1.33	0.47

4. Comparison of similar surveys from across the globe

In this section, we compare the survey results from Central America to similar social science surveys for either prospective or existing public EEW systems, the section is structured similarly to section 3. The perceived usefulness, preferences of attributes and responses to EEW alerts in New Zealand [22] and Switzerland [25] were hypothetically assessed without having an EEW system in place. The performance of the existing EEW system in Mexico was assessed following the M7.1, Puebla earthquake in 2017 [14,15]. Japan performed similar studies after the M9.1 Tohoku-Oki earthquake in 2011 [27], the M4.4 Gunma and M5.9 Chiba events in 2018 [55]. In both countries, surveys were only distributed to cities or prefectures that received EEW alerts. In the US, a study was conducted on the West Coast. At the time of the survey, ShakeAlert was available in California and the planned rollout to Oregon and Washington had been announced [26].

4.1. Views on usefulness of the EEW system and tolerance to alert limitations

EEW is a complex system with practical limitations and the expectations about its performance should be realistic and clearly communicated to the public [44]. Over time, issues with alerts are inevitable and can occur for a wide variety of reasons that include imprecise real-time information and the inherent ground-motion variabilities that can amplify or attenuate the shaking [7]. In this section, false, missed, and late alerts follow the definition described in Fig. 2. Scores relate to a common 5-point Likert scale.

Japan faced its biggest test so far during the Tohoku earthquake, the alert was promptly and successfully delivered to the Tohoku region, but the point-source algorithm significantly underestimated the seismic intensity in the adjoining region of Kanto and no alert was issued for areas that experienced severe shaking [18]. Further, over the following 50 days, in the midst of a vigorous aftershock sequence, the public received 17 false alerts and 20 missed alerts [56]. Despite these shortcomings, the EEW system received a positive evaluation (3.4/5) [27]. Tolerance of false alerts was positive, and the public took it as a chance to practise [7]. A possible component of this success was the powerful educational campaign by JMA before launching the EEW system that included educational brochures, national seminars, and broadcast videos explaining the technical principles of EEW [57]. The aim was to make the public aware of the possibility of inaccurate alerts, underestimation of magnitude, or any other unexpected technical limitations of the system [57]. Respondents stated that being aware of the EEW limitations increase the willingness to use it more positively in the future [18], possibly without this campaign EEW alerts may have caused confusion in the recipients [58].

A less positive experience occurred in Mexico City in 2017. The original purpose of SASMEX EEW system, developed over 3 decades ago, was to alert Mexico City of earthquakes in the Guerrero subduction zone, providing a long warning time for the capital. Currently, the system has been extended and covers more seismic sources and provides alerts to many cities nationwide. Experiences from the original system resulted in a misconception about the warning time being an average of 60 s [14]. Consequently, when the alert was not delivered on time for the Puebla earthquake due to the proximity of the epicentre [14,59], the trust in the system diminished, the public believed the system failed and rated it low (1.8/5).

All four countries in Central America include heavily populated regions with high seismic risk areas. Hence it was no surprise that EEW was very highly rated (4.6/5). New Zealand also received a high score (4.7/5) [22], and Switzerland ranked EEW slightly lower (4.2/5) [25]. In summary, surveys of prospective or nascent EEW systems achieved similar scores, but the two existing EEW systems showed a big difference. A successful EEW relies on science and technology but must be integrated with educated citizens, public outreach and educational campaigns [57,60]. A lack of integration of multidisciplinary elements can limit the effectiveness of EEW and reduce public trust in the system [61].

ShakeAlert was well-perceived despite the inevitable occurrence of false and missed alerts, especially to individuals with significant earthquake experience [26]. Respondents in Mexico reported a higher tolerance for over-alerting, since they considered false alerts as alerts for non-existent earthquakes rather than alerts for earthquakes with weak or no shaking [62]. Japan reported high levels of acceptance of false alerts, however missed alerts are considered unacceptable for MMI > VI [27]. Switzerland showed lower acceptance scores for false and late alerts and could be explained by the lack of familiarity of participants with major shaking [25]. In Central America, late alerts seem less accepted, false alerts received higher acceptance scores and acceptance levels for missed alerts were related to shaking intensity levels. Missed alerts can be reduced by lowering the alert threshold, but it comes with the trade-off of increasing false alerts. As a result, a “cry wolf” effect can happen [43], which could undermine the credibility of an EEW system [58]. The challenge lies in finding the appropriate alert threshold that could reduce the missed alerts and minimize false alerts.

4.2. Preferred EEW system attributes

4.2.1. Alert threshold and warning times

The 2019 Ridgecrest earthquake was successfully detected by the US West Coast ShakeAlert system, though alerts were not sent to the Los Angeles region because the predicted shaking was below the configured MMI IV threshold [16]. The public considered this a missed alert, as they expected alerts not only for damaging levels of ground motion but for any felt earthquake [17,63]. ShakeAlert sends alerts if a magnitude is reached, and the predicted intensity is above the configured MMI level. Different alert thresholds are available depending on the dissemination channel. The threshold for smartphone apps and the Android Operating System is M4.5+ with MMI III+, and for Wireless Emergency Alerts (WEA) is M5+ with MMI IV+ [64]. Public alerts in Japan are issued when the expected ground shaking exceeds MMI VI+ (Intensity 5-lower Shindo scale) [65], reports received after the Tohoku earthquake corroborate that respondents would prefer to maintain this threshold [27,65]. New Zealand also selected a similar threshold (MMI V+) [22]. Both countries had experienced significant and damaging earthquakes with long aftershock sequences, this may suggest that over time and with exposure to several earthquakes, individuals may prefer to receive alerts only for damaging earthquakes [24,26]. Central America and Switzerland chose to receive alerts for MMI III+, however the decision might be for different reasons. Switzerland has a moderate earthquake hazard and the public is mainly familiar with minor shaking [25]. Conversely, Central America has an elevated seismic hazard but constructions might present minor damage even for low intensities [5]. In contrast to ShakeAlert and JMA, SASMEX does not deliver alerts based on the expected felt intensity. Instead, SASMEX sends a single alert to cities based on a combined criterion of epicentral distance and moment magnitude (M5+ and $D < 250$ km, M5.5+ and $D < 350$ km; and M6+ and $D \geq 350$ km) [59,66].

The warning time provided by EEW ranges from seconds to tens of seconds and reacting effectively can be challenging, but even with short time windows casualties can be reduced [18]. Respondents in Costa Rica, El Salvador, and New Zealand [22] indicated they are likely to take protective action with a warning time of 10–20 s. In comparison, respondents in Nicaragua, Guatemala, the US West Coast [26], and Switzerland [25] would like to have at least 20 s. In practice, the available warning time for damaging motions will likely be much shorter than what recipients need to respond. Deciding the appropriate action - that can be realised fast - and practicing it prior to the occurrence of earthquakes can help individuals to be better prepared and to effectively benefit from the short available time. Participants in Costa Rica and El Salvador who have already decided what action to take report they can respond significantly faster to EEW alerts. In Japan, 50% of participants reported receiving less than 10 s of warning time before the shaking started and 70% were able to realise their planned protective action [27].

4.2.2. Dissemination channels and message content

The dissemination of EEW alerts requires data transmission and communication infrastructure to be fast and robust so the public receives alerts promptly and reliably [66]. Most public EEW systems use a multi-channel strategy to disseminate alerts. ShakeAlert sends alerts to the West Coast mainly through smartphone apps, WEA, and Google push messages [26]. JMA shares alerts via an emergency broadcast system (J-ALERT) to television channels, radio stations, mobile phones, and sirens [65]. Redundancy of channels was particularly important during the Tohoku earthquake due to subsequent power cuts [67]. SASMEX issues alerts through 12,600 loudspeakers, dedicated receivers, TV and radio station partners. However, cell-broadcast messaging is not available because mobile providers do not offer this service yet [66]. Participants in New Zealand, Switzerland, and Central America prefer to have redundancy and not rely solely on one technology. Push notification alerts via cell broadcasting or a dedicated app supported by other channels were chosen by the majority [22,25]. Other Global EEW initiatives, that take advantage of crowdsourcing and mobile phones accelerometers, such as the Android Earthquake Alert System by Google [68] and Earthquake Network (EQN) [69], are available today in many parts of the world, including in some of the Central American countries. These are also delivered solely via mobile phones. It is likely in the future that multiple alerts will be received from different independent sources. These global initiatives are likely to grow in importance in regions without resources to build and operate EEW systems.

In terms of what information to pass to alert recipients, users in Japan that are regularly exposed to alerts consider the approximate epicentre location and a map with the potentially affected areas as the most helpful information received [18,27]. In the US, participants familiar with ShakeAlert would prefer information about the shaking intensity and the warning times, however none of these variables are provided to the public because they are dynamic and uncertain [26]. Participants in Switzerland preferred messages that remind recipients of the recommended protective actions in the form of pictograms, as visual behavioural advice is simpler to understand and triggers people to take protective actions [25,70]. Similar results were found in New Zealand, where participants wanted guidance on how to behave, the shaking intensity, and information on additional hazards that might occur [22]. Although the message content was not the focus of the survey in Central America, we tested 3 mock-ups of mobile phone alerts ranging in complexity. The first alert provided the expected intensity and the approximate location was an extension of the first alert plus pictograms illustrating the actions to take. Nicaragua and Costa Rica were asked to rate them separately and all received high ratings. Guatemala and El Salvador, in comparison, were asked to choose the preferred message and the majority chose a message with pictograms similar to Switzerland. The mock-ups and detailed results can be found in Supplement S7.

4.3. Protective actions

There are two main but divergent recommended protective actions for individuals inside buildings: a) shelter in-place inside the structure, usually through "drop, cover and hold"; or b) evacuate the structure to an open area. The reason for this difference is related to the structure's performance during earthquakes and the threat it poses to occupants. Countries with strict building codes developed across decades are mainly concerned about flying debris or non-structural elements falling (e.g. furniture, electrical or mechanical components, etc.) in such cases "drop, cover and hold" is preferable [8,71], but in structures that may potentially collapse, evacuation is advised, especially if this can be achieved rapidly (occupants are on lower floors and close to exits). Table 2 summarises the top three protective actions reported in the surveys for each region. These include both hypothetical and real scenarios depending on the status

Table 2
Top-three actions participants would take during an earthquake when receiving an EEW alert in the various countries, except for the US where the question referred only to past earthquakes. Actions are colour-coded based on their appropriateness for protecting oneself.

		Protective actions		
	Country	Most mentioned	Second most	Third most
EEW Hypothetical Event	***Central America N=2985***	*Evacuated the building (34%)*	*Protected or warn others (26%)*	*Moved to a safe place inside the building (14%)*
	Switzerland N=596 Dallo etl al. (2022)	*Protected or warn others (23%)*	*Protected on the spot (DCHO) (21%)*	*Moved near to a safe place (16%)*
	New Zealand N=3084 (multiple option) Becker et al. (2020)	*Mentally prepared for the shaking (91%)*	*Moved nearby where it seems safe (89%)*	*Helped others or told others the earthquake is coming (89%)*
EEW Real events	***Japan N=450 Chiba earthquake Nakayachi et al. (2019)***	*Undertook no actions (56%)*	*Mentally prepared themselves for the shaking (25%)*	*Looked for further information about the warning (24%)*
	Japan N=299 Gumma earthquake Nakayachi et al. (2019)	*Undertook no actions (43%)*	*Stopped and stayed still, awaiting the shaking on the spot (21%)*	*Looked for further information about the warning (21%)*
	Japan National Survey N=5490 Post-Tohoku earthquake JMA (2012)	*Undertook no actions/I couldn't do anything (28%)*	*It was a safe place, I prepared for the shaking (21%)*	*Looked for further information about the warning (18%)*
	Mexico National Survey N=2400 Post-Puebla earthquake Vaiciulyte et al. (2022)	*Evacuated the building (53%)*	*Moved to a safe place inside the building (10%)*	*I contacted my family (7%)*
Not EEW Real event	***US N=3276 Bostrom et al. (2022)***	*Stopped what I was doing and stayed put (50%)*	*Stood in a doorway (14%)*	*Dropped, covered and held on (9%)*

of EEW in the region. The protective actions are colour-coded based on their appropriateness for protecting oneself.

Before the launching of the EEW system in Japan in 2007, JMA conducted educational campaigns and undertook a public outreach campaign to train the public on appropriate actions based on the time, place, and occasion of its issuance [57]. In the US, the appropriateness of protective actions has been assessed through an evaluation of more than a dozen actions based on FEMA[5] and GHI[6] reports [72], evidence-based guidelines were derived for the EEW context [8]. Surveys taken after the Ridgecrest [71], Puebla [15], and Tohoku [27,73] earthquakes showed self-protection was the dominant action inside the severest shaking region, but this percentage is drastically reduced after considering lower shaking intensities. The Chiba and Gunma earthquakes [55] had moderate shaking and most people performed non-active actions (i.e., seek additional information, do not act, or mentally prepare) as shown in Table 2. It seems many people are responding to the shaking intensity level rather than the alert, which was also suggested by our survey in Central America, and this is a challenge for EEW that needs to be further explored. Occasionally, people who regularly experience earthquakes without significant consequences tend to underestimate the likelihood of experiencing a major strike, this 'optimistic bias' can reduce the practice of protective actions [74].

In Mexico, a study analysed the protective actions taken by participants during past earthquakes in the states of Mexico and Guerrero, and Mexico City [75]. The study compared earthquake scenarios with and without EEW alerts. The results suggested that the additional warning time provided by EEW alerts had a minor impact on the effectiveness of actions that could enhance life safety [75]. A potential explanation for this result is the lack of stronger protocols that individuals can adhere to in the EEW context. After 30 years of SASMEX operations, authorities have not established protocols that include different building types, locations, or institutional requirements [66,75]. For example, during the Puebla earthquake many individuals residing in high-rise buildings decided to evacuate after receiving the EEW alert despite the short warning times and the threat that it posed to themselves [66]. The choice is likely learned from experiences from past earthquakes, many people were trapped under collapsed structures or partially collapsed and perished [66].

It is interesting to note that in Switzerland [25], and New Zealand [22], where EEW is not established yet, the survey revealed a strong intention to move to a safe place. Compared to Mexico, the results presented in section 3.3.1 suggest that there will be a significant increase in recommended actions practised when EEW is available in Central America. However, it should be a priority to establish protocols or guidelines of protective actions soon, otherwise the potential benefit of the system could be compromised [57,60,61].

5. Limitations

In this section, we outline the limitations encountered in the development of the survey and data analysis, and discuss their impact on the interpretation of our results. The colloquial terms 'temblor' and 'terremoto' are unique to the Spanish language and do not relate to a specific magnitude or intensity of an earthquake. The meaning of these terms is influenced by the previous experiences with earthquakes of individuals, as well as their cultural and regional context. Participants may have interpreted questions using these terms from their own perspective due to the lack of precision on the definition, leading to bias. In this study, participants who live in rural areas, have low education levels and are above 60 years old are underrepresented. The lack of social penetration in surveys can potentially produce sampling biases [76]. The results show a good comprehension of how EEW operates, this could be explained by the self-selection bias exhibited by participants who follow seismological institutions on social media, exhibit interest in earthquakes, have better education and access to technology. During the field trip in Nicaragua, we visited municipalities and early adopters, we observed that most participants were involved in disaster management, this could explain the high scores obtained in preparedness planning. Further, some questions of the survey in Nicaragua focused on a specific recent earthquake that was widely felt across the main cities, but was not damaging, which may account for the variability of results from Nicaragua compared to other countries. Moreover, besides the personal factors we considered in our surveys (e.g., gender, age, preparedness levels), the influence of other factors such as fear, uncertainty, or ability to respond appropriately to alerts needs to be assessed in the future [77]. The analyses of these factors are key to develop effective information campaigns and training for different societal groups with specific preferences and needs. Further research is also needed to better understand the needs of vulnerable groups, including ethnic minorities, those with low socioeconomic status, etc. since they are most affected by disasters [78].

6. Conclusion and future research

We conducted public surveys with nearly 3000 respondents from Nicaragua, Guatemala, Costa Rica, and El Salvador in order to understand the social perspective on EEW systems, before these systems become widely operational. This article is the first attempt to understand and incorporate the public needs in a third-world region where an EEW system is being built. The surveys allowed us to gain insights into the attitudes towards EEW systems, preferences for EEW attributes, the protective actions practised and the factors that influence them. In contrast to similar studies in other countries, a substantial percentage of respondents reported that they have previously suffered earthquake-related losses, and they are aware they live in vulnerable housing in a region with high seismic hazard. Thus, it is no surprise that the perceived usefulness of EEW is high in all four countries and participants are eager to receive alerts. Overall, the main perceived benefits of EEW alerts are 'be able to self-protect' and 'help others in close proximity'.

False, missed, and late alerts are an inevitable part of any EEW system, but despite these shortcomings, EEW was still perceived as

[5] Federal Emergency Management Agency.

[6] GeoHazards International.

valuable. Participants in all four countries are more tolerant of false alerts than late or missed alerts. We found that respondents who were aware of the seismic hazard; who have taken preparedness measures; or who premeditated the action to take prior to the occurrence of earthquakes, are significantly more tolerant to alert limitations, and are more likely to react in shorter warning times. Furthermore, participants who met the criteria of the last two factors, experienced earthquakes, and were acutely aware they live in vulnerable housing are more likely to perform a recommended strategy. The desirable alert threshold is generally low and participants prefer to receive alerts starting from light shaking, from MMI III-IV. Further, the preferred dissemination channel for receiving alerts is via mobile phones, although dissemination via multiple channels would be appreciated - this would be particularly important in rural areas where internet access is absent or unreliable and a network of public sirens already exists.

There is no official 'written' guidance on the recommended protective action individuals should take, and no guidance was provided in the survey. However, most of the participants reported that during past earthquakes they have either evacuated, protected or warned others nearby, or moved to a safe zone inside the building. Results suggested that safety actions will further increase when EEW is available. A challenge for EEW in this region is to address the behaviour of respondents who report seeking out loved ones rather than taking protective actions - a significant number since most of the public live in extended family units. Moving forward, we will attempt to establish consensus-based recommendations for how to respond to an EEW alert with our partners and other stakeholders in Central America. A single recommendation is not possible in this region since the building stock is a mixture of seismic-resistant and vulnerable structures. In Mexico, a country with a similar vulnerability and earthquake hazard, individuals in the first three floors are recommended to evacuate and individuals in the upper floors are recommended to stay inside and take shelter [68]. Similar recommendations should be considered across many parts of Central America, however warning times will often be very short so evacuation may be advised only for the ground floor.

The challenges faced by existing public EEW systems emphasize the importance of powerful educational campaigns and extensive public outreach in achieving a well-informed public. In Japan, where multiple problems in the EEW messaging arose during and after the Tohoku earthquake, public trust was not reduced because individuals were aware of the technical limitations of the EEW system. The institutions responsible for the implementation of EEW systems in Central America should prioritize educational campaigns to raise awareness of the capabilities and limitations of the system. In the survey, participants exhibit good comprehension of the main objective of EEW but it is important to address the misconceptions identified promptly.

The global comparison of social surveys highlights the importance of incorporating public preferences in the development of bespoke EEW systems. The survey gave us the opportunity to tailor the characteristics of the EEW system to the needs and preferences of the public in the smartphone app we developed. EEW alerts have been publicly available in Costa Rica and Nicaragua since June 2023. As more people begin to receive EEW alerts, we plan to conduct feedback surveys to assess users' reactions to the alerts. This will allow us to evaluate if people take the recommended (and intended) actions in real situations. Furthermore, the results are not only significant for the ATTAC project in Central America but are more generally significant as they expand the current knowledge on how the public behaves in low-income regions with high earthquake risk where there is a lack of such studies.

Author contributions

We use the CRediT Contributor Roles Taxonomy to categorise author contributions. Conceptualization: BO, ID, JC. Resources (developing survey): BO, ID, WS, JS, MP, FV. Methodology (method development and evaluation): BO, ID, JC. Investigation (data collection): BO, WS, JS, MP, FV, RY, GM. Formal Analysis (data analysis): BO. Writing (original draft): BO, ID, JC. Writing (review & editing): JC, WS, MP, RY, GM, JS, FV, MM, FM, MB, SW Supervision: JC.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgment

This study is a core component of the ATTAC (Alerta Temprana para Terremotos en América Central) project funded by the Swiss Agency for Development and Cooperation (SDC) and the Swiss Government Excellence Scholarship (Grant Reference: 2021.0509). Collaboration from ID, MM, and MB is possible thanks to the Real-time Earthquake Risk Reduction for a Resilient Europe 'RISE' project funded by the European Union's Horizon 2020 research and innovation program under grant agreement No. 821115. Opinions expressed in this paper solely reflect the authors' view; the EU is not responsible for any use that may be made of information it contains. This research was approved by the Ethics Committee of ETH Zurich (EK 2022-N-81).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijdrr.2023.103982.

References

[1] D.A. Aitsi-Selmi, V. Murray, Disaster Risk Reduction; a Cross-Cutting Necessity in the SDGs, 2015, p. 2.
[2] M.C. Hoyos, V. Silva, Exploring benefit cost analysis to support earthquake risk mitigation in Central America, Int. J. Disaster Risk Reduc. 80 (2022), 103162, https://doi.org/10.1016/j.ijdrr.2022.103162.
[3] D. Balzer, S. Jäger, D. Kuhn, Bundesanstalt für Geowissenschaften und Rohstoffe, in: El manual para la evaluación de la exposición al riesgo frente a amenazas naturales en Centroamérica - El Salvador, Guatemala, Honduras y Nicaragua: fue elaborado bajo el auspicio del proyecto de cooperación técnica mitigación de geo-riesgos en Centroamérica = Project of technical cooperation - mitigation of georisks in Central America = Guidebook for assessing risk exposure to natural hazards in Central America, San Salvador, 2010.
[4] J.J. Bommer, M.B. Benito, M. Ciudad-Real, A. Lemoine, M.A. López-Menívar, R. Madariaga, J. Mankelow, P. Méndez de Hasbun, W. Murphy, M. Nieto-Lovo, C. E. Rodríguez-Pineda, H. Rosa, The El Salvador earthquakes of January and February 2001: context, characteristics and implications for seismic risk, Soil Dynam. Earthq. Eng. 22 (2002) 389–418, https://doi.org/10.1016/S0267-7261(02)00024-6.
[5] A. Maria, J.L. Acero, Estudio de la urbanización en Centroamérica, 2018, p. 223.
[6] Crossley Juan Moreno, Déficit habitacional en América Latina y el Caribe: Una herramienta para el diagnóstico y el desarrollo de políticas efectivas en vivienda y hábitat, UN-Habitat, 2015. https://unhabitat.org/deficit-habitacional-en-america-latina-y-el-caribe.
[7] R.M. Allen, D. Melgar, Earthquake early warning: advances, scientific challenges, and societal needs, Annu. Rev. Earth Planet Sci. 47 (2019) 361–388, https://doi.org/10.1146/annurev-earth-053018-060457.
[8] S.K. McBride, H. Smith, M. Morgoch, D. Sumy, M. Jenkins, L. Peek, A. Bostrom, D. Baldwin, E. Reddy, R. de Groot, J. Becker, D. Johnston, M. Wood, Evidence-based guidelines for protective actions and earthquake early warning systems, Geophysics 87 (2022) WA77–WA102, https://doi.org/10.1190/geo2021-0222.1.
[9] S. Yamamoto, M. Tomori, Earthquake early warning system for railways and its performance, J. JSCE. 1 (2013) 322–328, https://doi.org/10.2208/journalofjsce.1.1_322.
[10] T. Kubo, Y. Hisada, M. Murakami, F. Kosuge, K. Hamano, Application of an earthquake early warning system and a real-time strong motion monitoring system in emergency response in a high-rise building, Soil Dynam. Earthq. Eng. 31 (2011) 231–239, https://doi.org/10.1016/j.soildyn.2010.07.009.
[11] G. Cremen, O. Velazquez, B. Orihuela, C. Galasso, Predicting approximate seismic responses in multistory buildings from real-time earthquake source information, for earthquake early warning applications, Bull. Earthq. Eng. 19 (2021) 4865–4885, https://doi.org/10.1007/s10518-021-01088-y.
[12] F. Massin, M. Boese, B. Burgoa, J. Clinton, C. Munoz, B. Orihuela, M. Protti, W. Strauch, R. Yani, in: Towards National Public Earthquake Early Warning Systems across Central America., 2022.
[13] J. Porras, F. Massin, M. Arroyo-Solórzano, I. Arroyo, L. Linkimer, M. Böse, J. Clinton, Preliminary results of an earthquake early warning system in Costa Rica, Front. Earth Sci. 9 (2021), 700843, https://doi.org/10.3389/feart.2021.700843.
[14] J. Santos-Reyes, How useful are earthquake early warnings? The case of the 2017 earthquakes in Mexico city, Int. J. Disaster Risk Reduc. 40 (2019), 101148, https://doi.org/10.1016/j.ijdrr.2019.101148.
[15] J. Santos-Reyes, T. Gouzeva, Mexico city's residents emotional and behavioural reactions to the 19 September 2017 earthquake, Environ. Res. 186 (2020), 109482, https://doi.org/10.1016/j.envres.2020.109482.
[16] A.I. Chung, M.-A. Meier, J. Andrews, M. Böse, B.W. Crowell, J.J. McGuire, D.E. Smith, ShakeAlert earthquake early warning system performance during the 2019 ridgecrest earthquake sequence, Bull. Seismol. Soc. Am. 110 (2020) 1904–1923, https://doi.org/10.1785/0120200032.
[17] E.S. Cochran, A.L. Husker, How low should we go when warning for earthquakes? Science 366 (2019) 957–958, https://doi.org/10.1126/science.aaz6601.
[18] Y. Fujinawa, Y. Noda, Japan's earthquake early warning system on 11 march 2011: performance, shortcomings, and changes, Earthq. Spectra 29 (2013) 341–368, https://doi.org/10.1193/1.4000127.
[19] Å. Knaggård, D. Slunge, A. Ekbom, M. Göthberg, U. Sahlin, Researchers' approaches to stakeholders: interaction or transfer of knowledge? Environ. Sci. Pol. 97 (2019) 25–35, https://doi.org/10.1016/j.envsci.2019.03.008.
[20] C. Garcia, C.J. Fearnley, Evaluating critical links in early warning systems for natural hazards, Environ. Hazards 11 (2012) 123–137, https://doi.org/10.1080/17477891.2011.609877.
[21] R. Basher, Global early warning systems for natural hazards: systematic and people-centred, Philos. Trans. R. Soc. Math. Phys. Eng. Sci. 364 (2006) 2167–2182, https://doi.org/10.1098/rsta.2006.1819.
[22] J.S. Becker, L.J. Vinnell, K. Nakayachi, S.K. McBride, Earthquake early warning in Aotearoa New Zealand: a survey of public perspectives to guide warning system development, Humanit. Soc. Sci. Commun. 7 (2020) 138, https://doi.org/10.1057/s41599-020-00613-9.
[23] J.S. Becker, S.H. Potter, R. Prasanna, M.L. Tan, B.A. Payne, C. Holden, N. Horspool, R. Smith, D.M. Johnston, Scoping the potential for earthquake early warning in Aotearoa New Zealand: a sectoral analysis of perceived benefits and challenges, Int. J. Disaster Risk Reduc. 51 (2020), 101765, https://doi.org/10.1016/j.ijdrr.2020.101765.
[24] J.S. Becker, L.J. Vinnell, S.K. McBride, K. Nakayachi, E.E.H. Doyle, S.H. Potter, A. Bostrom, The effects of earthquake experience on intentions to respond to earthquake early warnings, Front. Commun. 7 (2022), 857004, https://doi.org/10.3389/fcomm.2022.857004.
[25] I. Dallo, M. Marti, J. Clinton, M. Böse, F. Massin, S. Zaugg, Earthquake Early Warning in Countries where Damaging Earthquakes Only Occur Every 50 to 150 Years – the Societal Perspective, 2022, p. 27.
[26] A. Bostrom, S.K. McBride, J.S. Becker, J.D. Goltz, R.-M. de Groot, L. Peek, B. Terbush, Maximilian Dixon, Great expectations for earthquake early warnings on the United States West Coast, Int. J. Disaster Risk Reduc. 82 (2022), 103296, https://doi.org/10.1016/j.ijdrr.2022.103296.
[27] Japan Meteorological Agency (JMA), Survey Results on Utilization and Application of Earthquake Early Warning, 2012. https://www.jma.go.jp/jma/press/1203/22c/23manzokudo_data.pdf.
[28] M.K. Lindell, S. Arlikatti, C.S. Prater, Why people do what they do to protect against earthquake risk: perceptions of hazard adjustment attributes, Risk Anal. 29 (2009) 1072–1088, https://doi.org/10.1111/j.1539-6924.2009.01243.x.
[29] M.K. Lindell, R.W. Perry, The protective action decision model: theoretical modifications and additional evidence: the protective action decision model, Risk Anal. 32 (2012) 616–632, https://doi.org/10.1111/j.1539-6924.2011.01647.x.
[30] D.S. Mileti, J.H. Sorensen, Communication of Emergency Public Warnings: A Social Science Perspective and State-Of-The-Art Assessment, 1990, https://doi.org/10.2172/6137387.
[31] M.M. Wood, D.S. Mileti, H. Bean, B.F. Liu, J. Sutton, S. Madden, Milling and public warnings, Environ. Behav. 50 (2017) 535–566, https://doi.org/10.1177/0013916517709561.
[32] Sismos SINAPRED. https://www.sinapred.gob.ni/index.php?option=com_content&view=article&id=31&Itemid=151, 2023.
[33] Red Sismológica Nacional Costa Rica, ¿Cuál es la diferencia entre un sismo, un temblor y un terremoto?, (n.d.). https://rsn.ucr.ac.cr/documentos/educativos/sismologia/325-cual-es-la-diferencia-entre-un-sismo-un-temblor-y-un-terremot.
[34] Instituto Nacion de Informacion de Desarrollo (INIDE), Censo de Poblacion y Vivienda Nicaragua, 2005. https://www.inide.gob.ni/Estadisticas/censoCEPOV2005.
[35] Instituto Nacional de Estadistica de Guatemala, XII Censo Naciona de Poblacion y VII de Vivienda Guatemala, 2018. https://www.censopoblacion.gt/.
[36] Instituto Nacional de Estadistica y Censos, Censo Nacional Costa Rica. https://inec.cr/estadisticas-fuentes/censos/censo-2011, 2011.
[37] Oficina Nacion de Estadisticas y Censos De El Salvador, Cesno de Poblacion y Vivienda, 2007. https://onec.bcr.gob.sv/poblacion-y-estadisticas-demograficas/.
[38] S. Lee, D.K. Lee, What is the proper way to apply the multiple comparison test? Korean J. Anesthesiol. 71 (2018) 353–360, https://doi.org/10.4097/kja.d.18.00242.
[39] H.O. Wood, F. Neumann, Modified Mercalli intensity scale of 1931, Bull. Seismol. Soc. Am. 21 (1931) 277–283, https://doi.org/10.1785/BSSA0210040277.
[40] Colegio Federado de Ingenieros y Arquitectos de Costa Rica, Codigo Sismico de Costa RIca, 2018. https://www.codigosismico.or.cr/historia.htm.
[41] Asociacion Guatematelca de Ingenieria Estructural y Sismica, Historia de la norma sismica en Guatemala, 2017. https://www.agies.org/wp-content/uploads/2018/03/Historia-de-AGIES-2017.pdf.

[42] A.R.P. Guevara, Vivienda en Centro America, Cent. Latinoam. Para Compet. El Desarro. Sosten. (2018) 19.
[43] S.E. Minson, A.S. Baltay, E.S. Cochran, T.C. Hanks, M.T. Page, S.K. McBride, K.R. Milner, M.-A. Meier, The limits of earthquake early warning accuracy and best alerting strategy, Sci. Rep. 9 (2019) 2478, https://doi.org/10.1038/s41598-019-39384-y.
[44] D.J. Wald, Practical limitations of earthquake early warning, Earthq. Spectra 36 (2020) 1412–1447, https://doi.org/10.1177/8755293020911388.
[45] Hootsuite We Are Social, Centroamerica Perspectivas Digitales, 2018. https://www.thinkwithgoogle.com/_qs/documents/6512/Centroamerica_Perspectivas_Digitales_DGM_1.pdf.
[46] L.G.A.B. Lai, Understanding the Impacts of Natural Disasters on Children, 2020. https://www.srcd.org/research/understanding-impacts-natural-disasters-children.
[47] M. Ramirez, C. Peek-Asa, Epidemiology of traumatic injuries from earthquakes, Epidemiol. Rev. 27 (2005) 47–55, https://doi.org/10.1093/epirev/mxi005.
[48] R.I. Glass, J.J. Urrutia, S. Sibony, H. Smith, B. Garcia, L. Rizzo, Earthquake Injuries Related to Housing in a Guatemalan Village: aseismic construction techniques may diminish the toll of deaths and serious injuries, Science 197 (1977) 638–643, https://doi.org/10.1126/science.197.4304.638.
[49] A.R. Mawson, Understanding mass panic and other collective responses to threat and disaster, psychiatry interpers, Biol. Process. 68 (2005) 95–113, https://doi.org/10.1521/psyc.2005.68.2.95.
[50] S. Shapira, L. Aharonson-Daniel, Y. Bar-Dayan, Anticipated behavioral response patterns to an earthquake: the role of personal and household characteristics, risk perception, previous experience and preparedness, Int. J. Disaster Risk Reduc. 31 (2018) 1–8, https://doi.org/10.1016/j.ijdrr.2018.04.001.
[51] M. Protti, S.Y. Schwartz, Mechanics of back arc deformation in Costa Rica: evidence from an aftershock study of the April 22, 1991, Valle de la Estrella, Costa Rica, earthquake (M_w =7.7), Tectonics 13 (1994) 1093–1107, https://doi.org/10.1029/94TC01319.
[52] I. Espinosa, The Guatemalan Earthquake of February 4, 1976, a Preliminary Report, United States, 1002., Geological Survey. Professional paper, 1976.
[53] N.N. Ambraseys, The earthquake of Managua Nicaragua 1972, Nat 244 (1973). https://www.nature.com/articles/244427a0.pdf.
[54] G. Wu, Z. Han, W. Xu, Y. Gong, Mapping individuals' earthquake preparedness in China, Nat. Hazards Earth Syst. Sci. 18 (2018) 1315–1325, https://doi.org/10.5194/nhess-18-1315-2018.
[55] K. Nakayachi, J.S. Becker, S.H. Potter, M. Dixon, Residents' reactions to earthquake early warnings in Japan, Risk Anal. 39 (2019) 1723–1740, https://doi.org/10.1111/risa.13306.
[56] M. Hoshiba, T. Ozaki, Earthquake early warning and tsunami warning of the Japan meteorological agency, and their performance in the 2011 off the pacific Coast of Tohoku earthquake, in: F. Wenzel, J. Zschau (Eds.), Early Warn. Geol. Disasters, Springer Berlin Heidelberg, Berlin, Heidelberg, 2014, pp. 1–28, https://doi.org/10.1007/978-3-642-12233-0_1.
[57] Erika Yamasaki, What We Can Learn F e Can Learn From Japan om Japan's Early Ear s Early Earthquake Warning System, Momentum 1 (1) (2012) 28. Artic. 2.
[58] J.D. Goltz, Introducing Earthquake Early Warning in California: A Summary of Social Science and Public Policy Issues, A Report to OES and the Operational Areas, California Governor's Office for Emergency Services, 2002.
[59] G. Suarez, D. Novelo, E. Mansilla, Performance evaluation of the seismic alert system (SAS) in Mexico City: A seismological and a social perspective, Seismol Res. Lett. 80 (2009) 707–716, https://doi.org/10.1785/gssrl.80.5.707.
[60] D.F. Sumy, M.R. Jenkins, J. Crayne, S.E. Olds, M.L. Anderson, J. Johnson, B. Magura, C.L. Pridmore, R.-M. de Groot, Education initiatives to support earthquake early warning: a retrospective and a roadmap, Seismol Res. Lett. 93 (2022) 3498–3513, https://doi.org/10.1785/0220220159.
[61] O. Velazquez, G. Pescaroli, G. Cremen, C. Galasso, A review of the technical and socio-organizational components of earthquake early warning systems, Front. Earth Sci. 8 (2020), 533498, https://doi.org/10.3389/feart.2020.533498.
[62] R.M. Allen, EERI Reconnaissance Team, Quake warnings, seismic culture, Science 358 (2017), https://doi.org/10.1126/science.aar4640, 1111–1111.
[63] G.M.N. Del Rio, ShakeAlertLA Will Drop Threshold for Earthquake Alerts, amid Gripes People Not Alerted, Los Angeles Times., 2019. https://www.latimes.com/local/lanow/la-me-ln-local-shakealert-lowers-threshold-20190705-story.html.
[64] S.K. McBride, A. Bostrom, J. Sutton, R.M. de Groot, A.S. Baltay, B. Terbush, P. Bodin, M. Dixon, E. Holland, R. Arba, P. Laustsen, S. Liu, M. Vinci, Developing post-alert messaging for ShakeAlert, the earthquake early warning system for the West Coast of the United States of America, Int. J. Disaster Risk Reduc. 50 (2020), 101713, https://doi.org/10.1016/j.ijdrr.2020.101713.
[65] O. Kamigaichi, M. Saito, K. Doi, T. Matsumori, S. Tsukada, K. Takeda, T. Shimoyama, K. Nakamura, M. Kiyomoto, Y. Watanabe, Earthquake early warning in Japan: warning the general public and future prospects, Seismol Res. Lett. 80 (2009) 717–726, https://doi.org/10.1785/gssrl.80.5.717.
[66] G. Suárez, The seismic early warning system of Mexico (SASMEX): a retrospective view and future challenges, Front. Earth Sci. 10 (2022). https://www.frontiersin.org/article/10.3389/feart.2022.827236. (Accessed 1 March 2022).
[67] L. Appleby, THE ROLE OF COMMUNICATIONS IN THE GREAT EAST JAPAN EARTHQUAKE, 2013, p. 56.
[68] R.M. Allen, M. Stogaitis, Global growth of earthquake early warning, Science 375 (2022) 717–718, https://doi.org/10.1126/science.abl5435.
[69] L. Fallou, F. Finazzi, R. Bossu, Efficacy and usefulness of an independent public earthquake early warning system: a case study—the earthquake network initiative in Peru, Seismol Res. Lett. 93 (2022), https://doi.org/10.1785/0220220132, 2410–2410.
[70] J. Sutton, L. Fischer, L.E. James, S.E. Sheff, Earthquake early warning message testing: visual attention, behavioral responses, and message perceptions, Int. J. Disaster Risk Reduc. 49 (2020), 101664, https://doi.org/10.1016/j.ijdrr.2020.101664.
[71] J.D. Goltz, H. Park, V. Quitoriano, D.J. Wald, Human behavioral response in the 2019 ridgecrest, California, earthquakes: assessing immediate actions based on data from "did you feel it?,", Bull. Seismol. Soc. Am. (2020) https://doi.org/10.1785/0120200159.
[72] M.M. Wood, State-of-the-art Knowledge of Protective Actions Appropriate for Earthquake Early warning., Inc., Denver, Nusura, 2018, p. 38.
[73] M. Ohara, K. Meguro, A. Tanaka, A Study on People's Awareness of Earthquake Early Warning before and after the 2011off the Pacific Coast of Tohoku Earthquake, Japan, 2011, p. 7.
[74] M.J. Spittal, F.H. Walkey, J. McClure, R.J. Siegert, K.E. Ballantyne, The earthquake readiness scale: the development of a valid and reliable unifactorial measure, Nat. Hazards 39 (2006) 15–29, https://doi.org/10.1007/s11069-005-2369-9.
[75] S. Vaiciulyte, D.A. Novelo-Casanova, A.L. Husker, A.B. Garduño-González, Population response to earthquakes and earthquake early warnings in Mexico, Int. J. Disaster Risk Reduc. 72 (2022), 102854, https://doi.org/10.1016/j.ijdrr.2022.102854.
[76] A. Agresti, B. Finlay, Statistical Method for the Social Sciences, 1986.
[77] T.J. Huggins, L. Yang, J. Zhang, M.L. Tan, R. Prasanna, Psychological effects of dominant responses to early warning alerts, Int. J. Ambient Comput. Intell. (IJACI) 12 (2021) 1–15, https://doi.org/10.4018/IJACI.2021070101.
[78] M.R. Jenkins, S.K. McBride, M. Morgoch, H. Smith, Considerations for creating equitable and inclusive communication campaigns associated with ShakeAlert, the earthquake early warning system for the West Coast of the USA, Disaster Prev. Manag. Int. J. 31 (2022) 79–91, https://doi.org/10.1108/DPM-03-2021-0090.