ADVANCING EARTHQUAKE PREPAREDNESS IN CROATIA: A SURVEY ON PUBLIC PERCEPTION OF EARTHQUAKE EARLY WARNING SYSTEMS AND THEIR POTENTIAL BENEFITS

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Abstract: *Earthquake Early Warning (EEW) systems represent a vital advancement in mitigating seismic risks in densely populated areas. By continuously monitoring seismic activity in real time, they send alerts to at-risk populations shortly before strong shaking reaches them, allowing for at least basic personal and automated protective measures. This study explores public perception of EEW systems and their potential implementation in Croatia through a survey. Due to the proximity of seismogenic faults to urban areas and financial constraints, Croatia currently lacks a functional EEW system. Nonetheless, the survey results indicate that most respondents, even when informed about the limitations of EEW systems, believe that early warnings would enhance their sense of safety, with 85% advocating for investments in EEW systems and related infrastructure. Additionally, 89% participants support earthquake-related education starting from school age. Even with extremely short warning times or providing post-earthquake information only, an EEW system, combined with trained responses to earthquakes, could reduce confusion and panic during and after an earthquake, thereby improving the overall seismic resilience.*
Keywords: *earthquake Early Warning Systems, earthquake hazard and risk, public perception of seismic preparedness, earthquake emergency response*

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1. INTRODUCTION

Earthquakes are rare and unpredictable events that strike suddenly, precluding the timely issuance of alerts common to other natural or anthropogenic hazards. While earthquake- resistant construction aligned with seismic hazard maps has become standard, ensuring that devastating structural damage and building collapses are minimized, even moderate-intensity earthquakes pose significant risks to human health and safety due to general unpreparedness and poor knowledge of how to behave in such situations.

Earthquake Early Warning (EEW) systems represent a new paradigm in reducing seismic risks, especially in densely populated areas. Instead of predicting the exact time, place, and magnitude of future earthquakes, EEW systems rely on real-time monitoring of local seismic activity and ongoing ground movements and on detecting the very first and weak primary seismic waves, often unnoticed by people. This enables warnings to be sent to endangered locations about slower but more devastating secondary waves' arrival, giving people a brief but crucial window to prepare for the impending strong shaking. Paired with earthquake- resistant construction, EEW systems have proven effective in many seismically active regions, such as the US West Coast and Japan, significantly reducing earthquake casualties (see for e.g. Allen and Melgar 2019; Cremen and Galasso 2020; Wald 2020).

Unfortunately, the feasibility of EEW in Europe faces many challenges, especially in its seismically most active Mediterranean region and Croatia itself. Due to the proximity of seismic faults to urban areas, and to the high speeds at which seismic waves travel (typically 4 to 5 km/s), the lead times between primary and secondary waves are extremely short. Even for the cities in Italy, Greece, and Turkey which are the best "candidates" and in the "best case" scenario, lead times do not exceed several seconds (Cremen et al. 2022; Galasso et al. 2023). Urban centers in Croatia are not an exception, as exemplified by the 2020 Zagreb earthquake. Scarcely two seconds passed from the first detection of seismic waves at the epicenter to their arrival to the Zagreb city center, only 7 km away (Atalić et al. 2020; Markušić et al. 2020).

Despite such constrained conditions, high hopes are being placed on implementation of efficient EEW systems in the Mediterranean basin and other parts of Europe (TURNkey 2019). Even a second or two can enable well-trained schoolchildren to "drop, cover, and hold on" to prevent injuries from flying objects. Moreover, less than a tenth of a second may be enough to activate automatic preventive actions that require no human intervention, such as disconnecting electricity or gas supply, opening evacuation exits, slowing down traffic, or deactivating sensitive medical processes. Even after-earthquake information, provided and distributed by the same systems, can aid in better organizing emergency responses.

However, building and maintaining EEW systems require substantial technical expertise and significant material investments, making also the financial factor a potential hindrance to their implementation. Therefore, the feasibility of an EEW system also depends on society's willingness to invest in the necessary infrastructure, particularly in less affluent countries.

The aim of the present contribution is to assess, via an online survey, a public perception of potential implementation of EEW systems, under limited Croatian conditions, and a general support to earthquake preparedness. A brief overview of the questionnaire and research methods is given in Chapter 2. In Chapter 3, the main survey results are presented and discussed in light of responders' socio-demographic factors and their experience and knowledge about earthquakes and earthquake self-protection. Chapter 4 discusses the EEW systems and related infrastructure in a broader context of Croatian earthquake emergency response. Concluding remarks are given in Section 5.

2. METHODS AND SURVEY ANALYSIS

The survey was conducted via a questionnaire created using Google Forms and distributed online. 121 responses were gathered over approximately one month. The questionnaire included a brief introduction to EEW systems and their working principles, as well as potential advantages and limitations in Croatia.

The questionnaire comprised 27 questions with two types of responses: categorical (e.g. socio-demographic categories or yes/no/not sure) and rating (on a scale from 1 to 5, where "1 = do not agree" and "5 = completely agree"). For representation clarity and to better identify statistical associations between responses, categories/ratings in the article are often grouped. Differences in score distributions between groups were quantified by comparing mean values. Associations between categorical variables were assessed using the chi-squared statistic. To determine statistical significance, *p*-values were obtained through permutation testing with n=106 permutations. Specifically, the p-value was calculated as the proportion of permuted datasets yielding a statistic greater than or equal to the observed value. A non-parametric approach was employed for *p*-value evaluation due to the often non-Gaussian distribution of the data and the uneven representation of categories. A significance level of $\alpha = 0.05$ was used throughout the study.

A complete questionnaire and responses are available upon request from the authors.

3. SURVEY RESULTS

3.1. Demographic and social data

Socio-demographic data cover gender, age, education, and work status. Age groups are categorized as 18-25, 26-35, 36-45, 46-55, 56-65, and 66+ years. Education refers to a completed level of education (from primary school to graduate study or higher). Among 119 respondents:

- Gender: 61% women, 39% men.
- Age Distribution: 56% younger than 35.
- Education: more than 50% have a diploma or higher education.
- Work status: 74% employed, 15% students.

While women, and young and educated participants, are somewhat overrepresented compared to the general population distribution (CBS, 2022), both genders and all age groups over 18 are included in the survey, ensuring diverse perspectives are captured. Similarly holds also for the working status.

3.2. Experience with earthquakes and obtaining after-event seismic information

Respondents were asked if they had experienced a "strong" earthquake and whether and how they searched for information about the event after having experienced it. For clarity, "strong" earthquake was defined as one of similar intensity as those that hit Zagreb, Petrinja, and the surrounding areas in 2020 (Markušić et al. 2020 2021). Those earthquakes claimed eight lives and caused significant damage and, while not everyone in Croatia felt them, the extensive media coverage made their consequences widely known. Results show that:

- 69% experienced the 2020 Zagreb and/or Petrinja earthquakes.
- 12% experienced an earthquake of similar magnitude elsewhere.
- 19% of responders had never experienced a strong earthquake.

After having experienced an earthquake, most respondents searched for information about its location, time, and magnitude (only 7% didn't). Most often, multiple sources were used, primarily through web searches (66%) and/or dedicated applications (18%), but also less reliable sources such as social networks or phone/SMS communication with friends (51%). It should be emphasized that as much as 20% of responders relied exclusively on the latest.

The stated percentages refer to the share of respondents who have experienced a strong earthquake. However, seismic information was sought also by 65% of respondents who have not felt an earthquake.

3.3. Earthquake response knowledge and education support

47% of respondents claim they are fully aware of the actions to take during an earthquake, while the others are only partially aware, and only one respondent admits to not knowing how to behave. A more detailed analysis reveals that those who have experienced a strong earthquake are more likely to know the appropriate reactions compared to those who haven't (**Table 1**, statistical significance *p*-value = 0.011).

Table 1 *Correlations of responses to the questions "Have you experienced a strong earthquake" and "Are you familiar with appropriate actions during an earthquake"*

Are you familiar with appropriate actions during an earthquake?	Have you experienced a strong earthquake?		
	No	Yes	
Yes, completely	5 (22% of 23)	52 (53% of 98)	57 (47% of 121)
Partially/Not at all	18	46	64 (53% of 121)
p-value = 0.011	23	98	121

A majority of respondents (85%) also believe that appropriate reactions to earthquakes could be improved through training. Accordingly, 88% of participants advocate for earthquake- related education starting from school age and support unannounced preparedness checks (**Figure 1**).

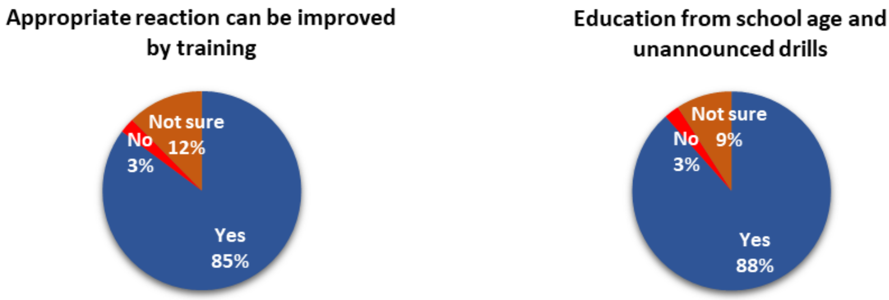

Figure 1 *Responses to the questions "Do you think the appropriate reaction can be improved with training for action in the case of an early warning" (left) and "Do you think primary school children should be taught appropriate actions and test reactions with unannounced preparedness checks" (right)*

As is shown in **Table 2** and **Table 3**, earthquake-education is supported regardless of respondents' earthquake experience or knowledge of earthquake-related measures (no significant correlations were found with neither of parameters: $p = 0.531$ and $p = 0.407$, respectively).

Table 2 *Responses to the question "Do you think primary school children should be taught appropriate actions and test reactions with unannounced preparedness checks" cross-tabulated with "Have you experienced a strong earthquake"*

Education in schools and unannounced checks	Have you experienced a strong earthquake?		
	No	Yes	
No/Not sure	3	11	14 (12% of 121)
Yes	20 (87% of 23)	87 (89% of 98)	107 (88% of 121)
p = 0.531 (no correlation)	23	98	121

3.4. Knowledge about earthquake prediction and early warnings

Due to the highly nonlinear nature of seismic processes, a prediction of exact time, location, and intensity of future earthquakes is considered impossible at present. The survey results show, however, that only 64% of the respondents are aware of this fact, the others do not know the answer (19%) or think earthquakes are predictable (17%).

Table 3 *Responses to the question "Are you familiar with appropriate actions during an earthquake" cross-tabulated with "Do you think primary school children should be taught appropriate actions and test reactions with unannounced preparedness checks"*

Education in schools and unannounced checks	Are you familiar with appropriate actions during an earthquake?		
	Partially/Not at all	Yes, completely	
No/Not sure	10	4	14 (12% of 121)
Yes	54 (84% of 64)	53 (93% of 57)	107 (88% of 121)
p = 0.407 (no correlation)	64	57	121

As shown in **Table 4**, the percentage of people knowing that earthquakes are unpredictable is significantly higher among people who have experienced an earthquake (statistical significance p-value = 0.046).

Table 4 *Correlations between earthquake experience and knowledge about its predictability*

Do you think earthquakes are predictable?	Have you experienced a strong earthquake?		
	No	Yes	
No, they are unpredictable	10	67	77 (64% of 121)
Yes/Not sure	13	31	44 (36% of 121)
p=0.046	23	98	121

It should be said, however, that we do not know what exactly participants do think by "predictable" and whether the early warning systems and their difference to earthquake prediction are clearly understood.

When asked about EEW systems, more than half of the respondents (58%) claimed they were familiar with them before the survey. Six participants even mentioned using at least one EEW application on their smartphones. However, an analysis of the "early warning" applications cited by participants revealed that most of these applications provide post-earthquake information rather than timely warnings, with the only two exceptions being Earthquake Network and MyShake. Additionally, no correlation was found between supposed EEW familiarity and earthquake experience, suggesting that awareness of EEW systems and their utility remains low in Croatia, even among those who have experienced earthquakes.

Nevertheless, individuals who claim familiarity with EEW applications advocate more strongly for school-age education on appropriate reactions to earthquakes (statistical significance p-value = 0.040), indicating their generally greater interest in earthquake preparedness.

3.5. A perception of EEW systems and their potential benefits in Croatia

Figure 2 shows that 76% of responders say they would use EEW systems if they were available in Croatia, and 41% even believe they would tolerate relatively frequent errors to which the EEW systems are prone. Yet, despite being warned about the short warning times, close to half (46%) responders consider them potentially useful in Croatia, believing they would make citizens feel safer (69%).

Responders were asked to rate their potential reaction to earthquake warnings, with ratings ranging from "1 completely disagree" to "5 completely agree" (**Table 5**). 63% of participants claim (agree or completely agree) they would not panic but would react appropriately (mean rating 3.64). Participants believe they could protect themselves physically (76%), prepare mentally (59%), search for seismic information even if the shaking is not felt (52%) or even help or save others (63%). Accordingly, 66% of participants express their support to investments in EEW system in Croatia (mean rating 3.78).

Only about 18% of participants admit (agree or completely agree) they would not know what to do in case of early warning. Traced to other questions, such insecurity is more pronounced if participants:

- have not experienced an earthquake (mean ratings for those who haven't experienced vs those who have experienced: 3.00 vs 2.17; statistical-significance p-value = 0.002),
- do not know the appropriate actions during an earthquake (mean ratings for those who do not know vs those who know 2.57 vs 2.05; statistical-significance p-value = 0.012), and
- are women (mean ratings women vs men: 2.49 vs 2.04, statistical-significance p-value = 0.039).

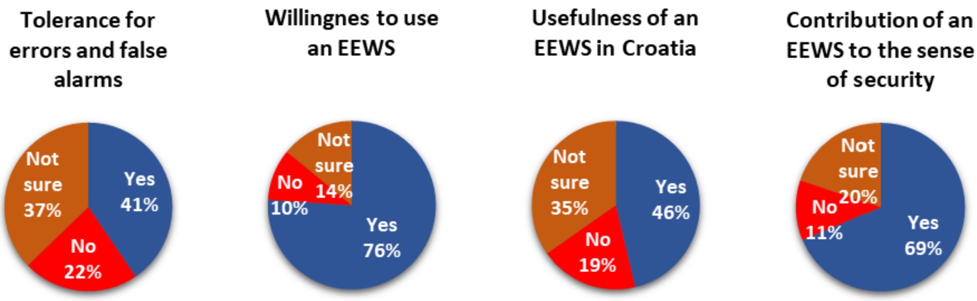

***Figure** 2 Responses to the questions "EEWSs are prone to errors and false alarms. Would you tolerate them?", "Would you be willing to use an EEW system if it were available in Croatia?", "Because urban centers are close to seismic sources, warning times in Croatia are estimated to be a few seconds. Do you think earthquake early warning system is still useful?", and "Do you think that, despite short warning times, implementation of an EEWS would contribute to the citizens' sense of security in Croatia?"*

***Table 5** Mean ratings and the percentage of respondents who agree or completely agree with various statements about their potential reactions in the case of an early warning*

In a case of an early warning…	Mean rating	Agree/ Completely agree
… I would not panic, but react appropriately	3.64	63%
… I could physically protect myself	3.91	76%
… I could mentally prepare for an incoming shaking	3.51	59%
… I would search for information, even if shaking isn't felt	3.33	52%
… I could help others	3.67	63%
… I wouldn't know what to do	2.33	18%
I think it is valuable to invest in EEWS in Croatia	3.78	66%

Different scenarios of earthquake early warnings were also rated by participants, with ratings ranging from "1 completely useless" to "5 completely useful" (**Table 6**).

***Table 6** Mean ratings and the percentage of respondents who find different scenarios of an EEW systems to be completely or mostly useful*

The EEW system…	Mean rating	Completely/ Mostly useful
… provides at least 20 seconds of warning with earthquake information (time and expected strength of the quake)	3.85	72%
… provides 2-3 seconds of warning without any earthquake information	2.88	37%
… gives less reliable seismic (location, time, and strength of the earthquake) information a few seconds after shaking	2.73	29%
… gives reliable seismic information only few minutes after shaking	2.91	39%

Predictably, the EEW systems are considered most useful if they provide warning more than 20 seconds before shaking and give also information about the expected shaking time and intensity (72% consider them useful or mostly useful in this case, mean rating 3.85). Ratings for such timely warnings are shown to be statistically higher for participants that (in other questions) admitted they wouldn't know what to do in case of an earthquake and/or are not sure about the personal protection measures (mean ratings 4.08 vs 3.54, statistical- significance p-value = 0.015).

As is expected (and is seen from **Table 6**), the observed usefulness decreases by decreasing warning time and reliability of seismic information, with a slightly higher mean rating for post-event information based on reliable seismological measurements. However, the proportion of participants that find such post-event information, even if reliable, useful or mostly useful (39%), is about the same as of those who consider it completely or partially useless.

4. DISCUSSION

The presented results indicate strong support among participants for enhancing general earthquake preparedness in Croatia. The vast majority of respondents agree that the correct response during an earthquake can be learned and should be taught in schools. Participants also show optimism for EEW systems and their potential use, stating that they would use them if available and would support investments in their implementation.

Importantly, these results are not related to participants' age nor education level. While the respondents are not entirely representative of Croatian society (there are more young and more high-educated participants compared to the Croatian average), the observed independence suggests, a posteriori, the findings' validity in a broader Croatian context.

The only significant difference in responses pertains to gender - women generally have a higher opinion of the utility of EEW systems. They rate the reliability of information provided by EEW systems higher than men, even if the information comes after an earthquake (mean ratings: 3.1 for women vs. 2.6 for men; $p = 0.036$). Additionally, women are more supportive of investments in EEW systems compared to men (mean ratings: 3.93 for women vs. 3.47 for men; $p = 0.050$). This difference may be linked to women's more pronounced (or more readily admitted) feelings of insecurity about what to do in an earthquake (mean "insecurity" ratings:
2.49 for women vs. 2.04 for men; $p = 0.039$). Due to the prevalence of women in the survey, the overall ratings of EEW systems may be slightly overestimated. However, this does not alter the generally positive public opinion about these systems and their potential utility in Croatia.

Unfortunately, a key limitation in complying with self-protection protocols, which challenges also potential EEW systems' feasibility in Croatia, is the proximity of seismic faults to urban centers. However, experiences from countries that have benefited from functional EEW systems for years somewhat justify the participants' optimism. Surveys show that people often do not react actively to the early warnings, rather, they prepare only mentally for an impending quake (Ahn 2021). This reaction, for which even an extremely short time may be enough, ensures more measured behavior during and after an earthquake and helps in avoiding unnecessary panic and additional casualties.

Numerous European research projects and initiatives aim to shorten earthquake warning times and develop functional EEW systems, especially in large cities in the Mediterranean seismic zones. Many of them have been conducted also in neighboring Italy, including the recently completed Real-time earthquake risk reduction for a resilient Europe (RISE, n.d.) and free and open-sourced software research platform PRESTo (Satriano 2011; PRESTo n.d.). It may be hoped that integration with European seismic networks could enhance also Croatia's earthquake real-time monitoring capabilities, enabling at least partial feasibility of EEW systems.

Currently, the most used EEW systems are regional ones, operating through extensive networks of instruments distributed throughout seismically active areas. Traditional ground- motion instruments are often supplemented by less accurate but more affordable small MEMS and IoT devices or even simple accelerometers within cell phones (ShakeAlert n.d.). However, while enhancing EEW systems' reliability, such systems become also more time- consuming, making their efficiency in the limited Croatian conditions unlikely.

Much simpler but faster on-site systems may be more appropriate under such conditions (Wu and Mittal, 2021). Low-cost instruments, installed in schools, hospitals or important public buildings monitor local ground-motion parameters and issue immediate warnings as soon as they exceed a threshold value. Local information is often collected (within Urban Seismic Networks e.g.), enabling also post-earthquake intensity estimations (D'Alessandro et al. 2019; Scudero et al. 2023; Vitale et al. 2022).

A pronounced problem for on-site based systems is distinguishing signal from noise and identifying the earthquake initial moment. There is a hope that deep neural networks may be trained to faster recognize seismic-activity patterns (Zhu and Beroza 2019; Datta et al. 2022). The artificial-intelligence powered systems are claimed recently to significantly outperform threshold-based methods in terms of accuracy and average leading time (Chiang et al. 2022).

5. CONCLUSION

Croatia is a seismologically active region with a pressing need to improve its overall seismic protection and preparedness. Besides unavoidable earthquake-proofed construction, earthquake early warning systems are considered one of the most promising options.

Currently, Croatia lacks a functional EEW system due to high costs and extremely short or even negative warning times in inhabited areas. Nevertheless, survey results indicate optimism among respondents about using these systems and a willingness to invest in them and in earthquake-related education. This support is consistent across different demographics.

Future approaches, like on-site systems or urban seismic networks integrated with advanced technologies and artificial intelligence, may reduce warning times, enabling at least automated preventive actions. Moreover, the same infrastructure meant to provide early warnings, can continue its activity also after an earthquake. Real-time data on the earthquake's impact may reduce reliance on rumors and aid in coordinated response and recovery efforts. The potentially high costs of such systems should be weighed against the benefits of improving seismic preparedness.

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