INVITED OPINION
doi:10.26443/seismica.v2i3.1012

A call from early-career Turkish scientists: seismic resilience is only feasible with "earthquake culture"

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Abstract Despite significant scientific advances in earthquake research and building codes, Türkiye remains vulnerable to earthquakes, as demonstrated by the tragic Kahramanmaraş earthquake in February 2023. In contrast, countries such as Chile and Japan have successfully reduced earthquake damage through strict enforcement of building codes and effective public awareness campaigns. This paper highlights the need for seismic resilience in Türkiye and proposes actionable guidelines to bridge the gap between science and society. These guidelines include comprehensive geoscience education, the establishment of local earthquake centers, effective science communication, preparation for future earthquakes through scenario modeling, and the development of an earthquake culture. Geoscience should be integrated into the education system, and opportunities for geoscientists should be increased. Local earthquake centers can improve seismic monitoring, research, and public outreach. Geoscientists, in collaboration with social scientists, should prioritize science communication training to engage the public and combat misinformation. Scenario modeling and annual preparedness exercises can improve earthquake preparedness across the country, and promoting earthquake memory and awareness initiatives would build a collective consciousness about earthquakes. By implementing these guidelines, Türkiye can build earthquake resilience and mitigate the impact of future earthquakes; however, the active engagement of scientists, institutions, and the public is essential to achieve earthquake resilience.

Özet (Turkish) Deprem araştırmaları ve bina yönetmeliklerindeki önemli bilimsel ilerlemelere rağmen, Şubat 2023'teki trajik Kahramanmaraş depreminin de gösterdiği gibi, Türkiye depremlere karşı savunmasız kalmaya devam etmektedir. Buna karşılık, Şili ve Japonya gibi ülkeler, bina yönetmeliklerinin sıkı bir şekilde uygulanması ve etkili kamuoyu bilinçlendirme kampanyaları yoluyla deprem hasarını başarılı bir şekilde azaltmıştır. Bu makale, Türkiye'de sismik dayanıklılığa duyulan ihtiyacı vurgulamakta ve bilim ile toplum arasındaki uçurumu kapatmak için uygulanabilir kılavuz ilkeler önermektedir. Bu ilkeler arasında kapsamlı yerbilimi eğitimi, yerel deprem merkezlerinin kurulması, etkili bilim iletişimi, senaryo modelleme yoluyla gelecekteki depremlere hazırlık ve deprem kültürünün geliştirilmesi yer almaktadır. Yerbilimi eğitim sistemine entegre edilmeli ve yerbilimciler için fırsatlar artırılmalıdır. Yerel deprem merkezleri sismik izleme, araştırma ve halka erişimi geliştirebilir. Yerbilimciler, sosyal bilimcilerle işbirliği içinde, halkın ilgisini çekmek ve yanlış bilgilerle mücadele etmek için bilim iletişimi eğitimine öncelik vermelidir. Senaryo modelleme ve yıllık hazırlık tatbikatları ülke çapında depreme hazırlığı geliştirebilir ve deprem hafızası ve farkındalık girişimlerinin teşvik edilmesi depremler hakkında kolektif bir bilinç oluşturabilir. Türkiye, bu kılavuz ilkeleri uygulayarak depreme karşı dayanıklılık oluşturabilir ve gelecekteki depremlerin etkisini azaltabilir; ancak depreme karşı dayanıklılığın sağlanması için bilim insanlarının, kurumların ve halkın aktif katılımı şarttır.

Production Editor: Stephen Hicks
Handling Editor: Danielle Sumy
Copy & Layout Editor: Anant Hariharan

Signed reviewer(s): Sara K. McBride

Received: May 25th, 2023
Accepted: September 7th, 2023
Published: September 28th, 2023

Living with earthquakes is possible, as demonstrated by Chile and Japan, but what went wrong in Türkiye? Despite significant scientific advances, Türkiye is still vulnerable to earthquakes, one latest example of which hit us tragically hard in February 2023. The consequences of the M_w 7.8 and M_w 7.6 doublet of the Kahramanmaraş earthquake sequence reveal issues in building code enforcement and earthquake awareness, and imply a severe lack of hazard and risk communication (Yeginsu et al., 2023). We, early-career Turkish scientists, were child witnesses of the catastrophic 1999 M_w 7.4 İzmit earthquake, and today, once again, we are shocked by the February 2023 tragedy. To prevent similar disasters in Türkiye and around the world, we call on all scientists to reflect on ways to fill the massive communication gap between science and society.

Geoscientists have been well-acquainted with the seismicity of Türkiye and its potential to generate large and damaging earthquakes during the past half-century (e.g., Barka and Kadinsky-Cade, 1988; Dewey, 1976) (Figure 1). The North Anatolian Fault, which hosted

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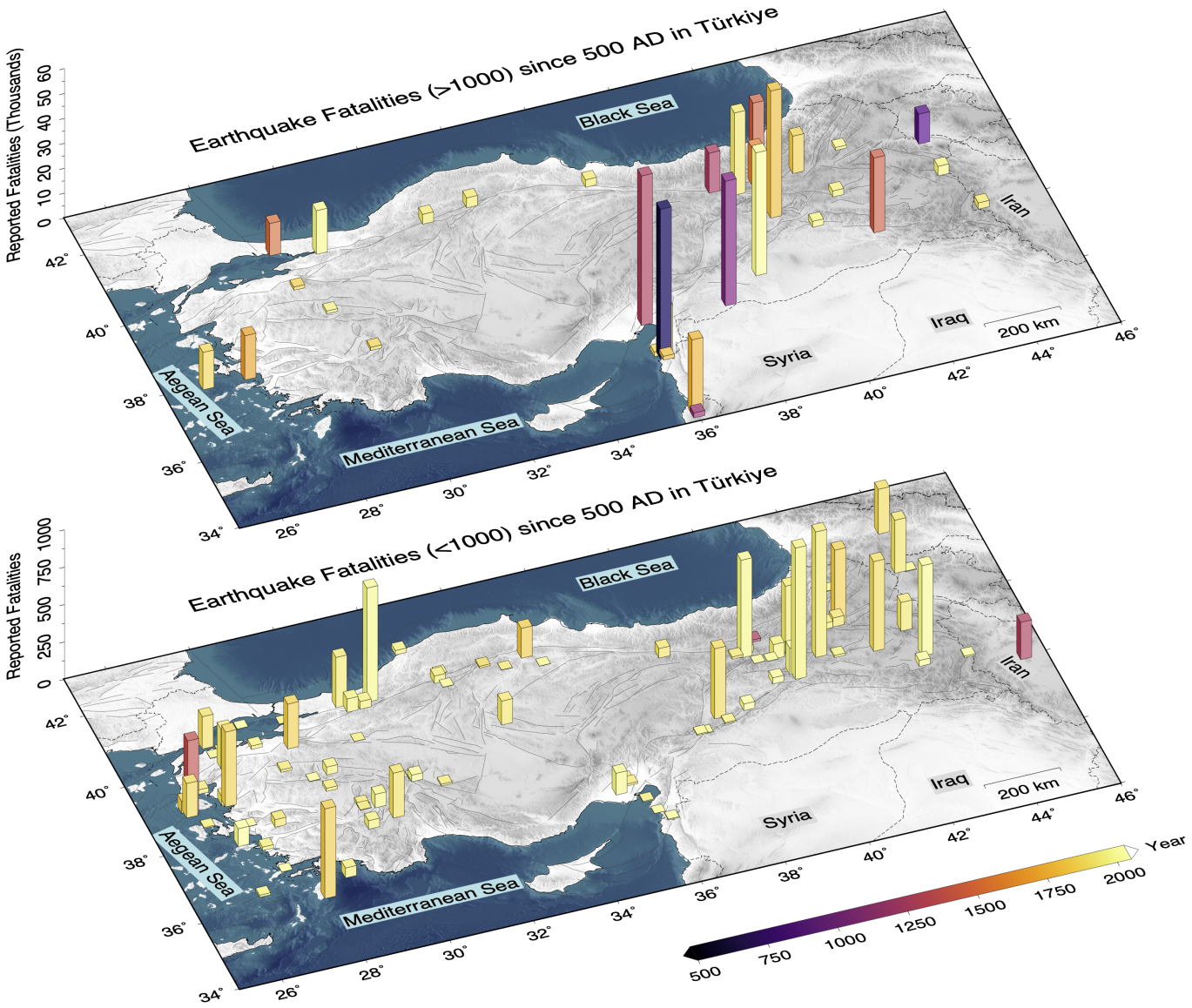

Figure 1 Earthquake fatalities since 500 AD in Türkiye. The top figure shows fatalities in thousands. The gray fault lines indicate the active faults.

the 1999 M_w 7.4 Izmit and M_w 7.2 Düzce earthquakes, spurred decades-long worldwide interest in the region, improving our understanding of continental strike-slip faults substantially (e.g., Stein et al., 1997; Bouchon et al., 2010). Similarly, the East Anatolian Fault, the other major strike-slip fault that produced the Kahramanmaraş earthquakes, is well documented and is well-known for its potential to generate large earthquakes (e.g., Ambraseys, 1989; Duman and Emre, 2013; Aktug et al., 2016; Petersen et al., 2023). Historical and current reported earthquake fatalities in this region are quite prominent (Figure 1). A long history of destructive earthquakes motivated Türkiye to build a dense seismic monitoring network and to continuously update seismic hazard maps and building codes (Cambaz et al., 2021; AFAD, 2023) while investing further in earthquake research (Inan et al., 2007). The 1999 disaster further accelerated the process of updating building codes in 2007. The most recent update of building codes was in 2018 (Akkar et al., 2018). Yet, updating building codes did not prevent the recent disaster.

Sadly, Türkiye was caught unprepared once again for the Kahramanmaraş earthquakes. Despite its world-class building codes, over 10,200 buildings collapsed in ten provinces, killing more than 50,000 people (Hussain et al., 2023). Among the 100,000 buildings that were heavily damaged (Çetin et al., 2023) were critical infrastructures and lifeline systems, such as hospitals, schools, and roads, which, based on seismic design criteria, are supposed to remain functional after earthquakes. The field reconnaissance reports point to various reasons for the structural collapses, including poor engineering design, low construction quality (e.g., labor and material shortage), and a lack of retrofitting for older buildings (Çetin et al., 2023). Once again, we find ourselves repeating N. Ambraseys: "The collapse of buildings in earthquakes are not acts of God. All too often nowadays, they are acts of criminal negligence" (e.g. Bilham, 2013).

Earthquake resilience is not a myth, as countries like Chile and Japan demonstrate (Figure 2a). These countries also suffered from damage after large earthquakes, but significantly less than in Türkiye (Ghosh and Cleland, 2012). How did they manage to reduce the damage caused by large earthquakes? What did Chile and Japan do right that Türkiye did not? The short answer is enforcing the building codes and raising public awareness by learning from each major earthquake (Esteban et al., 2013). Both countries strengthened their institutional management of disaster preparedness, response, and public awareness through strategic interaction plans between academia, state, and industry regardless of their differences in economic welfare (Figure 2b) (Gil and Rivera, 2023; Bolt and Van Zanden, 2020; Ritchie, 2023). In addition, performing regular evacuation drills is a strong component of community preparedness practices in Chile and Japan (Vásquez et al., 2018; Nakaya et al., 2018). California is another example of earthquake preparedness. It shares similar tectonic settings and design standards with Türkiye (Allen, 1982). However, this state has been preparing for a magnitude 7.8 San Andreas earthquake by organizing earthquake drills (Jones et al., 2008) annually and with long-term investment in advancing science with regional organizations (SCEC, 2023).

Contrastingly, in Türkiye, corruption has long been a major obstacle to enforcing the building codes, as in many countries (Ambraseys and Bilham, 2011; Dal Zilio and Ampuero, 2023). Construction amnesties — the last one accepted in 2018 — that legalize illegal construction worsen the situation (Burgaz, 2023). Concerning post-hazard management, in some cities, the assembly areas are insufficiently designed, as criticized by urban planners for many years (TMMOB, 2023). On the other hand, the Erzin district of Hatay, one of the most heavily damaged areas during the recent earthquakes, had no casualties or collapsed buildings simply because the mayor did not allow any illegal construction (Hurriyet, 2023). It is obvious from this example that to prevent earthquake damage in the future, Türkiye, first and foremost, needs sustainable law enforcement that eliminates illegal construction.

The absence of earthquake culture in Türkiye indeed aggravates the consequences of earthquakes. "Earthquake culture," originally defined by (Mileti and Darlington, 1997), describes the array of attitudes, behaviors, and traditions in societies regularly exposed to significant seismic activity. This concept encompasses the social and psychological adaptations that local communities undergo due to the persistent risks and effects of earthquakes (Mileti et al., 2002; Webb, 2018). Despite Türkiye's well-known susceptibility to earthquakes (Figure 1, 2), public earthquake preparedness remains insufficient regardless of education and income (Yildiz et al., 2020; Ozdemir et al., 2021). Natural hazard education is not a part of curricular activities (Milli Eğitim, 2018). Communications of the need for earthquake risk perception and preparedness are limited in the media (Tekeli-Yesil et al., 2019), often diminishing over time after a disaster. Unsurprisingly, the lack of public preparedness manifests itself in the mistakes made before and after earthquakes. For example, we observe post-construction errors, such as removing structural elements for interior design purposes without seeking consultancy and authorization (TMMOB, 2020). Social media videos show that people did not take necessary protective measures during shaking. In the aftermath of an earthquake, the countless scary scenarios that have been associated with future large earthquakes, i.e., apocalyptic scenarios for the expected Istanbul earthquake (Bashir et al., 2023), create the perception that people cannot do anything. Studies show that (e.g. Baytiyeh and Öcal, 2016; Joffe, 2012; Oral et al., 2015) fatalistic beliefs significantly impact earthquake preparedness in Türkiye, and thus, instead of preparing for the hazard, people often get scared and tend to forget.

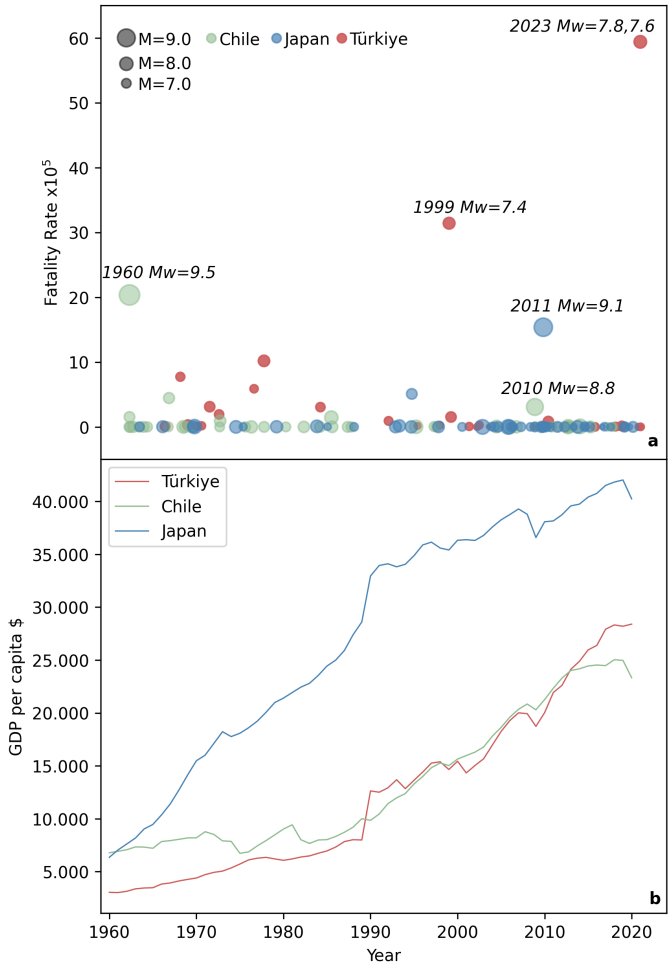

Figure 2 a) Fatality rates (the number of fatalities divided by past country population for each earthquake) in Chile, Japan, and Türkiye. Circles are scaled with earthquake magnitude. b) Gross domestic product (GDP) per capita in Chile, Japan, and Türkiye between 1960-2020.

It is obvious that earthquake resilience requires enforcing building codes interlinked with a solid country-wide earthquake culture, so what can we scientists do beyond research to contribute to the betterment of the situation? How can we fill this significant gap between science and society? Below we suggest five fundamental guidelines with action items as our solution. While our focus is Türkiye and earthquakes experienced in the

region, these action items also apply to other regions facing similar natural hazards and environmental challenges.

(i) We need comprehensive geoscience education and training. Geoscience education, undeniably, is the most crucial element in this gap. We should integrate geosciences into preschool education and maintain it at every level of the educational system. Elementary to high school curricula should include geoscience, similar to physics, chemistry, and biology (Geological Society of America, 2021). We should promote geoscience education to inspire future scientists, focusing on high-school students by demonstrating the field's relevance and career opportunities. Universities also need to enrich their geoscience programs through supportive and collaborative mentorship. Undergraduate and graduate students should have access to a wide range of work opportunities, both in industry and academia, and should be supported with local and international collaborations, internships, and scholarships. We also suggest installing additional requirements to become licensed professional engineers. These requirements should include adequate work experience and passing a qualifying exam, in addition to the current requirement of earning a four-year civil engineering degree. Additionally, we recommend providing local experts with earthquake risk training programs similar to the ones provided in the U.S. by FEMA (FEMA, 2022).

(ii) We need to build local earthquake centers. We need more geoscientists, but undergraduate geoscience enrollment is declining in Türkiye (Akçiğit and Özcan-Tok, 2020) (Figure 3). We see a comparable pattern in the U.S., with geosciences ranking among the least diverse STEM fields (Bernard and Cooperdock, 2018; Dutt, 2020; Keane, 2022). A major driving factor is the scarcity of job opportunities. Based on recent data (Presidency of the Republic of Türkiye, Human Resources Office, 2023), half of newly graduated geoscientists take a minimum of six months to secure employment, with only half of these jobs being in the geoscience field.

We can reverse this declining trend by building local networks and integrating them into the National Earthquake Center (AFAD), similar to the Advanced National Seismic System (USGS, 2023) in the U.S. These local networks should be responsible only for that region's resilience. Such centers should lead seismic monitoring, region-specific research, and public outreach. Geoscientists should take active roles at these centers, become regional experts and collaborate closely with engineers. Such centers will, in turn, solve the problem of job scarcity and redesign geoscientists' role in building country-wide earthquake resilience.

In addition, these centers, along with key agencies that contribute to earthquake mitigation efforts (e.g., AFAD, Kandilli), should be organized under one program responsible for maintaining

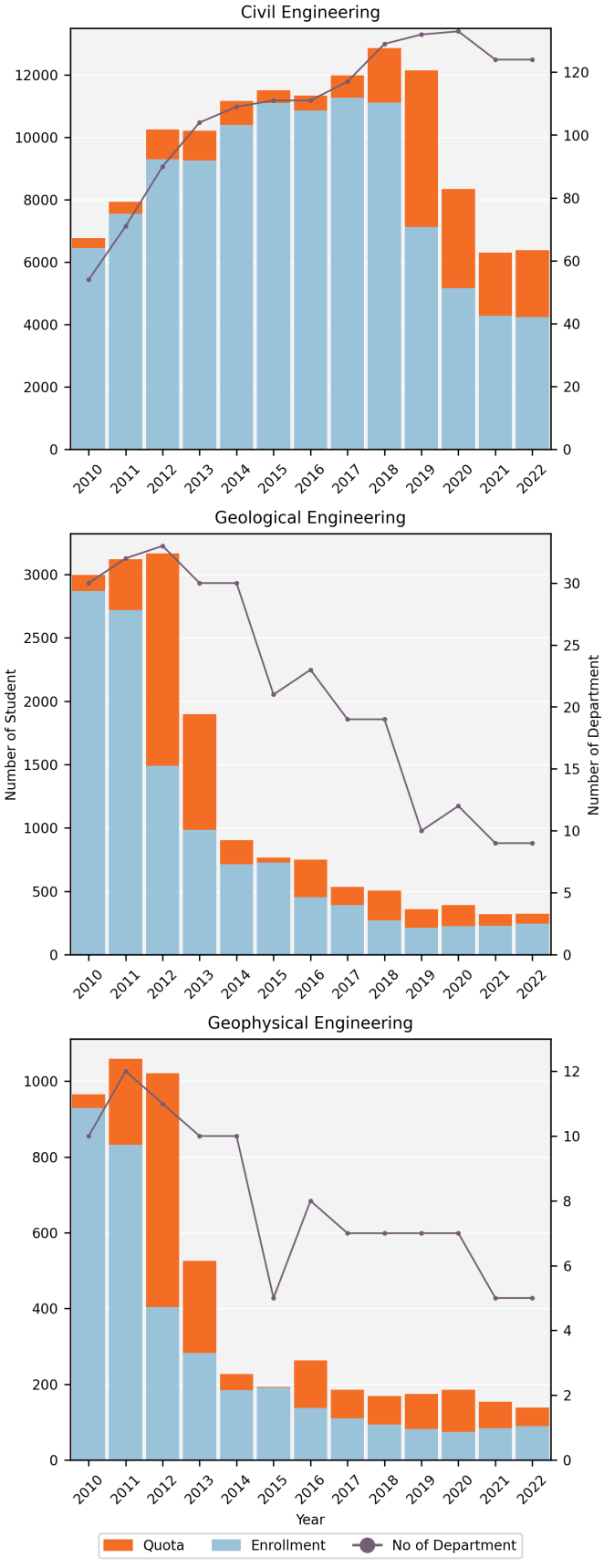

Figure 3 Undergraduate student quota and enrollment for earthquake science departments in Türkiye since 2010.

an effective earthquake hazard reduction program throughout the country. Such a program, similar to the National Earthquake Hazards Reduction Program (NEHRP, 2023) in the U.S., should be a nonpartisan organization and should remain above politics, focusing solely on improving earthquake hazard management in Türkiye.

(iii) We need to learn effective science communication. Geoscientists often face the public after earthquakes of any magnitude. Quite regularly, we find ourselves fighting against false earthquake predictions. However, most of us do this without proper science communication training. Ickert and Stewart (2016)'s study on earthquake risk communication in relation to the anticipated Istanbul earthquake underscores these existing challenges. Earthquake science will always have a public-facing aspect. For this reason, we should prioritize learning how to communicate our knowledge to a broader audience and adapt communication strategies as earthquake information evolves (e.g. Ickert and Stewart, 2016; McBride, 2018; Becker et al., 2019). We also need to revise hazard and risk communication and learn how to avoid the use of scary language. Social media is an emerging platform suitable for this purpose (Martin and MacDonald, 2020; Pearce et al., 2019). Studies show that social media can effectively communicate risks during crises as well as fight against misinformation (Huber et al., 2019; McBride et al., 2019; Malecki et al., 2021; Dryhurst et al., 2022; Gürer et al., 2023). Traditional media outlets are still a valuable channel to engage more directly with the public. For geoscientists to take active roles in such outlets, science communication should be treated as a necessary skill. University programs should also prioritize teaching these skills (e.g. Stewart et al., 2017). In turn, when equipped with such a skill set, more geoscientists can engage with the public more confidently, allow the public to access information from reliable sources, prevent misinformation, and help prepare the public for realistic scenarios. A strong collaboration between geoscientists and social scientists is crucial in this regard, as the intricate social nature of these challenges requires good acknowledgment and teamwork between different disciplines (e.g. Ickert and Stewart, 2016).

(iv) We need to prepare for the next earthquake in advance. The Southern San Andreas ShakeOut Scenario (Jones et al., 2008) is a highly effective way to prepare for an earthquake in Southern California. We should model similar earthquake scenarios across Türkiye, starting with the most risk-prone regions, such as the Istanbul metropolitan area, and examine the implications and aftermath of a potential major earthquake. Such an earthquake scenario would require close and ongoing collaborations between geoscientists, sociologists, engineers, and decision-makers to construct and model a likely earthquake scenario using all available research. By identifying the areas with higher risk, policymakers and emergency responders can take steps to mitigate the potential impact of the future earthquake. We can turn such scenarios into an annual emergency response and preparedness exercise, like the Great Southern California ShakeOut (ShakeOut, 2023). By updating the scenario and conducting exercises annually, we can improve our country-wide preparedness for future earthquakes and minimize human and infrastructure losses.

(v) We need to cultivate an earthquake culture. Societies that remember past earthquakes prepare better for future ones (Brondi et al., 2021). We need to keep Türkiye's earthquake memory alive. We should start by building a Kahramanmaraş earthquake museum and dedicate it to the victims of the recent tragedy as a promise for earthquake disaster prevention to the nation. Similar earthquake museums and exhibits are common worldwide (e.g., The Great East Japan Earthquake and Nuclear Disaster Memorial Museum (Japan Earthquake Museum, 2023), Shake: Earthquakes in Interior Alaska (Museum of the North, 2023)). Another effective way to keep the nation's earthquake memory alive is to symbolically expose selected ravages. Since the 1976 Fruli earthquake, the Church of San Giovanni Battista's ruin has been a stark reminder of the scale of devastation (personal communication with Floriana Marino, director of Tiere Motus of Venzone). Such free-choice learning environments have been proven more effective than traditional education in the US, offering locally relevant knowledge (Falk and Dierking, 2002; Falk, 2006; Sumy et al., 2022). Hence, figuring out ways to effectively communicate local earthquake information is highly important.

We should also make better use of the earthquake awareness week, designated as the first week of March in Türkiye, by practicing country-wide earthquake and tsunami evacuation drills (e.g. AFAD, 2021). During this week, people should be reminded to make their homes earthquake-ready (Mileti and Darlington, 1997), revisit their emergency plans, and revise their supply kits (Webb, 2018). These initiatives would help create a collective consciousness about earthquakes (Mileti et al., 2002).

Türkiye can indeed become earthquake-resilient, and as earthquake scientists, we play a crucial role here. We can connect with society and prepare for future earthquakes with the above-mentioned action items. To do so, scientists have a major duty to create public awareness about the earthquake risk in Türkiye. Türkiye will continue to experience earthquakes. Let's turn the Kahramanmaraş disaster into an exemplary turning point and encourage numerous governmental institutions, universities, and the public to work together toward an earthquake-resilient Türkiye.

Acknowledgements

This work was done as a private venture and not in the co-author's capacity as an employee of the Jet Propulsion Laboratory, California Institute of Technology. The content has not been approved or adopted by NASA, JPL, or the California Institute of Technology. Any views and opinions expressed herein do not necessarily state or reflect those of NASA, JPL, the University of Alaska Fairbanks, the University of Trieste, or the California Institute of Technology. P. B. is funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) - project number 407141557, and D.E. is funded by the Italian Department of Civil Protection—Presidency of the Council of Ministers (DPC) and Regional Civil Protection of Regione Autonoma Friuli Venezia Giulia. We are grateful to Harley Benz, Eric Bergman, Torsten Dahm, Edwin Nissen, Mohammadreza Jamalreyhani, Angela Carrillo Ponce, Gesa Maria Petersen, Fabrice Cotton, Stuart Sipkin, and Michael West for their valuable feedback. We are grateful to Danielle F. Sumy and Sara K. McBride for sharing their expertise and thoughtful reviews of this letter. We thank Nesrin Conker for proofreading. This work is dedicated to all those who passed away due to the earthquakes.

Data and code availability

The data of historical earthquakes and fatalities used in Figure 1 were combined from Disaster and Emergency Management Authority (AFAD; https://deprem.afad.gov.tr/event-historical), Kandilli Observatory and Earthquake Research Institute (KOERI; http://www.koeri.boun.edu.tr/sismo/2/deprem-bilgileri/tarihsel-depremler/), and Wikipedia. The fault data in Figure 1 was taken from the European Databases of Seismogenic Faults for Science and Engineering (https://seismofaults.eu/). The population data in Figure 2 were taken from Wikipedia and https://www.worldometers.info. Gross domestic product (GDP) data in Figure 2 is available at https://ourworldindata.org. The data in Figure 3 was taken from The Measuring, Selection, and Placement Center (OSYM, https://www.osym.gov.tr/). Figures were generated with GMT (Wessel et al., 2013), Python (http://www.python.org), and Matplotlib (https://matplotlib.org/) visualization packages.

Competing interests

The authors declare no conflicts of interest.

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