International Journal of Disaster Risk Reduction 52 (2021) 101969

Contents lists available at ScienceDirect

International Journal of Disaster Risk Reduction

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

A citizen science approach for supporting rapid earthquake impact assessments

D. Sandron [a,*], T. Tufaro [a,b], A. Scolobig [c], F. Di Bernardo [d], S. Parolai [a], A. Rebez [a]

[a] National Institute of Oceanography and Applied Geophysics - OGS, Italy
[b] University of Trieste, Italy
[c] University of Geneva, Switzerland
[d] Civil Protection - Friuli-Venezia Giulia, Italy

ARTICLE INFO

Keywords:
Seismic impact
Simplified questionnaires
Civil Protection's volunteers

ABSTRACT

After a strong earthquake, the rapid identification of the extent of the affected area is the most crucial task of civil protection authorities. The information provided by those directly affected by an event makes the difference since it offers the opportunity to take advantage of direct observations and, in the case alert systems are available, to verify if they worked properly. Thanks to the fruitful collaboration between the Regional Civil Protection of Friuli Venezia Giulia and the National Institute of Oceanography and Applied Geophysics – OGS in Italy, a procedure for collecting rapid information about the impact of an earthquake using an expert crowdsourcing approach has been in place for some years. The volunteers of the civil protection, appropriately trained, upon receipt of the seismic event notification, are asked to rapidly compile a specific questionnaire, describing the impact of the event. Data are rapidly coded, and the results are summarized in a seismic impact map showing the effect of the earthquake throughout the territory in a simplified way. This map complements the impact estimation provided by the analysis of recorded shaking data. This paper describes the results obtained by analyzing the "Trained Volunteers Seismic Evaluation" questionnaire (TVSE) completed by volunteers for some of the most significant events in recent years.

1. Introduction

What do civil protection authorities most need in the aftermath of an earthquake? Their primary need is to identify the most severely affected areas in order to optimize the rapid intervention of rescue teams to save as many lives as possible. To do so, reliable information about the impact of the event should be made available as quickly as possible [1]. Recently, the huge increase in the use of social media by the public, coupled with technological advances, has offered an opportunity for rapid data collection in case of natural disasters and for the rapid distribution of information to the public, for example, the products provided by the ShakeMap® online service [2].

The practice of collecting information or data from many people, usually, but not necessarily, through the internet, is defined as crowdsourcing. Crowdsourcing can be beneficial in emergency management because it allows end-users and authorities to access a quantity of data that was unthinkable only some years ago, for example, crowdsourced maps of a felt earthquake and/or damage scenarios (for example DYFI [3]). Information provided by those directly affected by an event can thus make the difference and can certainly contribute to providing relevant information for decision-making purposes in the aftermath of a local earthquake since such information is more reliable than that from predictions from numerical simulations. However, the actual integration of crowdsourced information into post-crisis decision-making has rarely happened [4].

This paper aims to address this research gap, by describing the development and testing of a citizen science approach for providing an impact scenario of a seismic event to civil protection authorities. This approach is part of a series of tools developed by the National Institute of Oceanography and Applied Geophysics (OGS) within the framework of its cooperation with the Civil Protection of the Friuli Venezia Giulia Region (PCFVG), and the Veneto Region (PCV) as a result of the Italian national law 828/1982, that determined the creation of the Center for Seismological Research (CRS) of the OGS, and the National law 399/

* Corresponding author.
E-mail addresses: dsandron@inogs.it (D. Sandron), Teresa.tufaro@phd.units.it (T. Tufaro), Anna.Scolobig@unige.ch (A. Scolobig), fabio.dibernardo@protezionecivile.fvg.it (F. Di Bernardo), sparolai@inogs.it (S. Parolai), arebez@inogs.it (A. Rebez).

https://doi.org/10.1016/j.ijdrr.2020.101969
Received 1 July 2020; Received in revised form 12 October 2020; Accepted 11 November 2020
Available online 18 November 2020
2212-4209/

1989 that assigned to the OGS the task of extending and developing the seismic network in Northeastern Italy also for civil protection purposes (Fig. 1). For this reason, the CRS is developing tools that are either based on the recordings of the seismological and strong motion network [5], or on the crowdsourcing/citizen-science approach that can provide in the first aftermath of an event a rapid damage distribution.

In this study, the approach proposed for expert crowdsourcing will be illustrated. An example of its application in the case of minor to light magnitude earthquakes will be provided. A description of the necessary training activities of the volunteers and the actions taken for stimulating their engagement will be presented. Finally, the complementarity of these results to those obtained by instrumental data analysis and non-expert crowdsourcing is shown.

2. The PCFVG-OGS "TVSE" method

For several years, a method for rapid assessment of the seismic impact within the territory of the Friuli Venezia Giulia region, based on an intermediate approach in between the "free" data collection via Social Network, that cannot (completely) be controlled, and the strictly supervised one carried out only by specialists sent in the field, has been tested. At first, the idea was to take advantage of one of the fundamental characteristics of the Civil Protection system in the FVG Region, which is the capillary distribution of a large number of volunteers all over the territory. In fact, each of the 215 municipalities has its own office (pale blue circles in Fig. 1), equipment, and radio devices for continuous communication with the headquarters' Operation Room (SOR), vehicle fleet, and above all, a group of volunteers ready for action. The number of Civil Protection volunteers in the FVG Region is around 8000. Second, as part of the fruitful and historic collaboration between PCFVG and

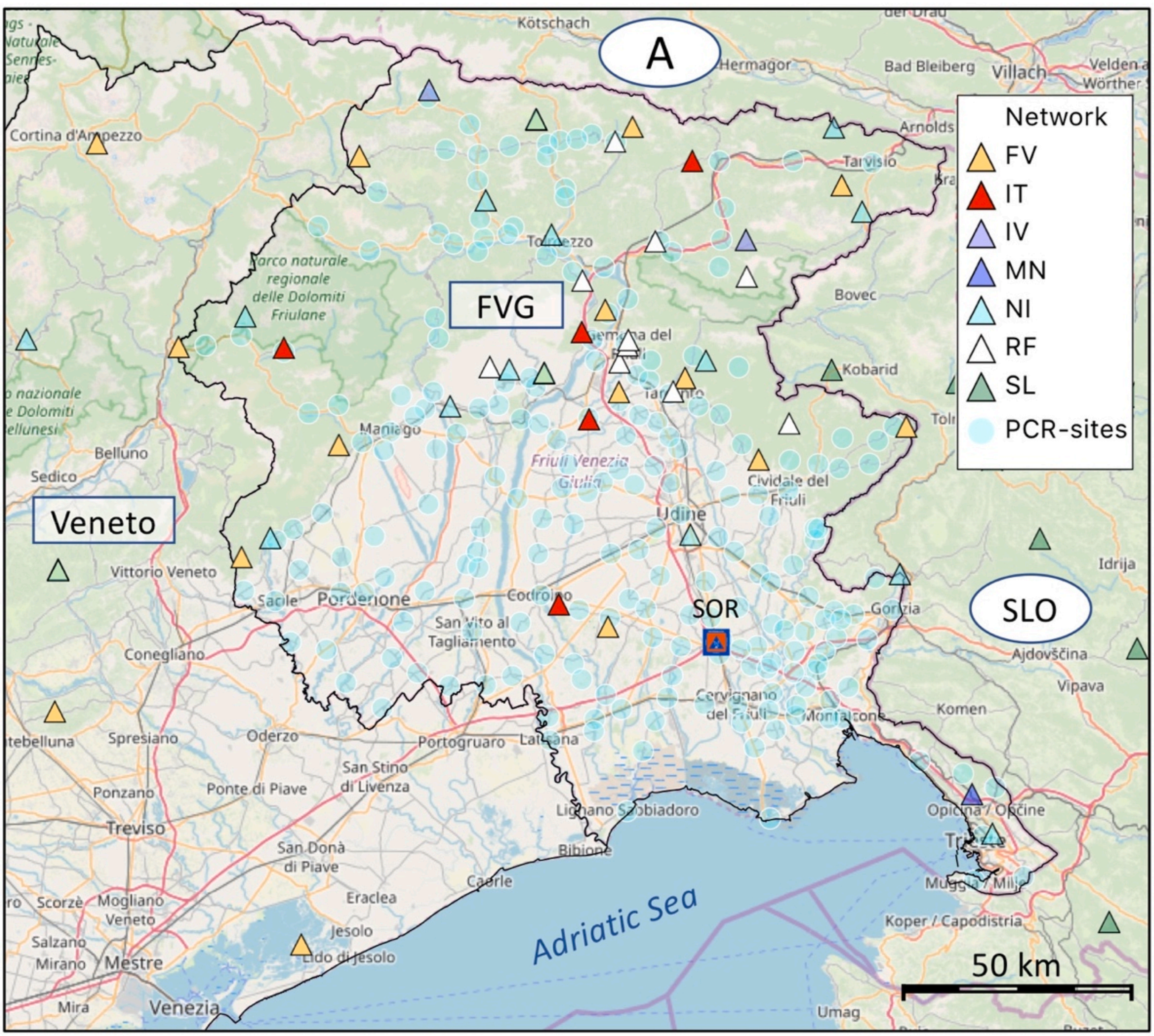

Fig. 1. Distribution of the municipal offices of the regional Civil Protection (PCR) volunteers (pale blue circles) in the Friuli Venezia Giulia (FVG) region. The PCR headquarters and the situation room (SOR) are sited in Palmanova. The colored triangles indicate the seismic stations spread over the regional territory. The stations belong to the following networks: Friuli Venezia Giulia (FV); Italian Strong Motion (IT); INGV (IV); MedNet (MN); Northeast Italy broadband (NI); Friuli Venezia Giulia accelerometer (RAF); Slovenia (SL). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

OGS, the procedures, described below, to be followed in case of earthquakes were defined together, and then they were included in the Civil Protection “Emergency Plan” [6].

Considering the magnitude and epicentral distance, three levels of alarm have been defined based on the expected level of shaking. These are coded as A, B, and C, to which the level corresponding to the absence of alarm has to be added (Fig. 2 [7]). To each level of alarm, there corresponds a procedure that has been identified and which is followed by all those involved in the emergency response (the mayor, the group of volunteers, the security managers in the relevant buildings, etc.) according to their assigned roles [7].

An integral part of this plan is the “Trained Volunteers Seismic Evaluation” questionnaire (TVSE), the tool purposely devised and entrusted to the volunteers for quick feedback from the affected places. It was conceived to be simple and easy to fill in [7]. The first section of the form (Fig. 3a) aims to describe the increasing levels of people’s awareness of the earthquake; the second section (Fig. 3b) is dedicated to the description of the damage. The form report is very concise so that, if communication via the Internet should fail, can be easily transmitted to the SOR via radio.

The general scheme foresees [7] that, upon receipt of the seismic event notification, a team of volunteers is always activated (within the limits of operations in potential emergency conditions) to quickly collect and transmit information on the seismic impact and possible damage obtained by a rapid post-event inspection across the territory and/or direct testimony of the people involved. Volunteers are invited to interview a reasonable number (10–20) of people in order to have a meaningful statistical sample. Each parameter indicated in the form is then expressed in terms of simple percentage terms: none (0%), few (0–20%), many (20–50%), most (50–100%). The TVSE data forwarded to the SOR are quickly analyzed and validated by OGS expert staff and then published on the PCFVG web portal (Fig. 4), generally in less than 1 hour from the occurrence of the earthquake. Currently, the data control activity, mainly outlier elimination, is still carried out manually, through a visual data screening (note relevant OGS staff operate on a 24-h service basis).

2.1. The experience so far

The last strong earthquake to hit the FVG region was the event of May 6, 1976 (Ms 6.5), which caused considerable destruction and a large number of deaths, and from whose experience the Italian Civil Protection was formed [8]. Since then, there have been no similar magnitude earthquakes in this region, except for a couple of events, several kilometers beyond the Slovenian border in Bovec (April 12, 1998, Ml = 5.6) and Kobarid (July 12, 2004, Ml = 5.1), with generally only earthquakes of magnitude around 4 occurring over the last two decades [9]. Thus, the testing of the proposed procedure so far has only covered aspects related to the “perception” of an earthquake by the general population, since even minimal damage has rarely been

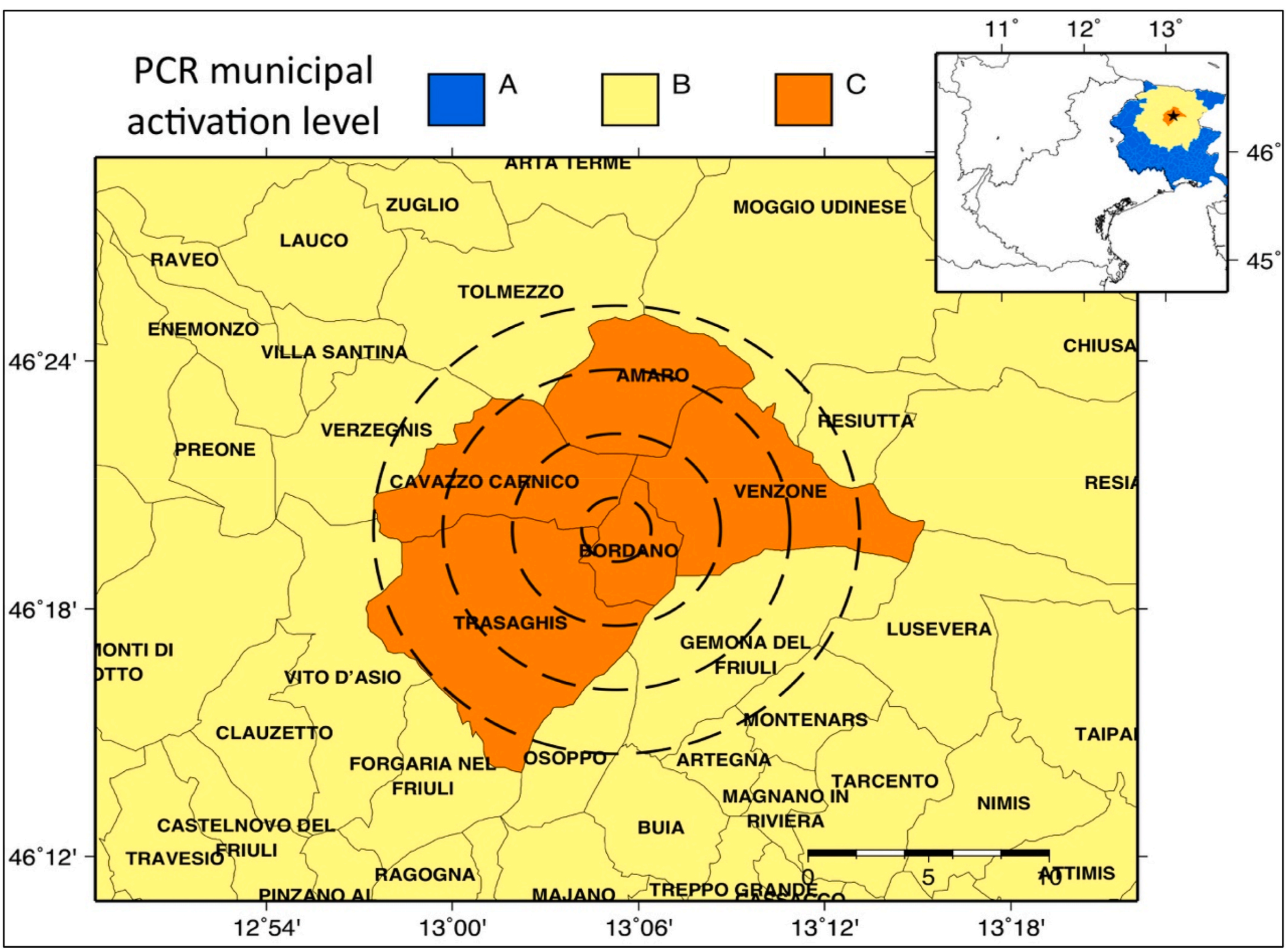

Fig. 2. Extract from the alert notification sent by OGS to PCR in case of a seismic event. In the map the municipalities are grouped according to the expected shaking level, basically obtained from the magnitude-distance couple. At each level of alarm (ABC), all those involved in the emergency (the mayor, the group of volunteers, the security managers in the relevant buildings, etc.) are required to follow the corresponding procedure according to their assigned roles.

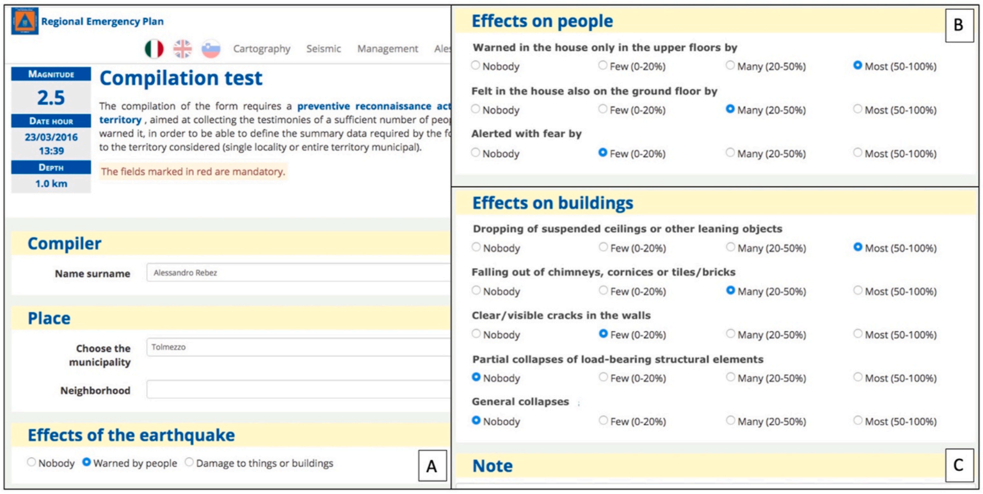

Fig. 3. FVG - PCR web portal screenshots where the TVSE questionnaire can be fulfilled. a) The earthquake is automatically loaded; the compiler has to log in and specifies his position (municipality and neighborhood). The first option regards the level of the earthquake alert: nobody (and the fulfilling is accomplished), warned by people (panel b), damage to things or buildings (panel c). b) this section describes the different increasing levels of people's feeling of the earthquake (warned in the house only in the upper floors by; felt in the house also on the ground floor by; alerted with fear by); c) this section describes the different increasing levels of damage (dropping of suspended ceilings or other leaning objects; falling out of chimneys, cornices or tiles/bricks; clear/visible cracks in the walls; partial collapses of load-bearing structural elements; general collapses). Volunteers are strictly invited to interview a reasonable number of people in order to have a meaningful statistical sample so that they can report their observations in simple percentage terms: nobody (0%), few (0–20%), many (20–50%), most (50–100%).

reported. However, how the territory reacts to a seismic event is also of great importance from the point of view of the civil protection authorities. In fact, the continuous testing of the procedure allows interest in the problem to be retained, and to improve preparation in the case of a larger event. In general, the Civil Protection is the public body that is first contacted by people to get information about the occurrence of natural disasters (floods, fires, landslides, earthquakes) or emergencies of various kinds. The threshold of perception of an earthquake, for example, is not an easy parameter to calibrate. It depends on multiple factors such as magnitude, depth, rupture mechanism, the distance of the receiver, and the foundation soil of the building where people are. In recent years, both earthquakes with low magnitude ($1.5 < Ml < 2.5$) have been felt by the population, and events with moderate magnitude ($2.5 < Ml < 3$) have poorly felt or alerted the population only very close to the epicenter.

Fig. 5 shows the seismic impact maps according to the completion of the questionnaires after two earthquakes on the regional territory: a) November 21, 2015 ($Ml = 3.5$), and b) September 22, 2019 ($Ml = 3.8$). The pale blue circles indicate municipalities that do not compile the questionnaires.

3. Training activities

The TVSE system takes advantage of the PCFVG volunteers' extensive coverage, where one of the most important components is the training activities that the volunteers must undergo. An extensive campaign was launched in 2015 by PCFVG-OGS aimed at volunteers with the aim of training them on how to effectively complete the simplified questionnaire. There are 215 municipalities in FVG, and the goal was to guarantee at least 2 or more trained volunteers for each municipality. The training activity (carried out through groups of 60/70 participants) is still ongoing and includes refresher courses for those who had been trained some time previously.

There are many aspects to be considered with regards to "training". The first is related to the fact that most of the volunteers, who have been highly trained and are competent to respond within the territory in case of events such as forest fires, falling trees, floods, landslides, and avalanches, but do not have a proper understanding of how to respond in the event of an earthquake. When joining the first time for the training, they do not have the knowledge of what is important to communicate after an earthquake. This is because major earthquakes are relatively rare events in this region and only very few volunteers still have in their minds their experience of the 1976 event. However, this experience is over 40 years old, when the technical capabilities were very different and the Civil Protection was not in existence.

The training, which consists of about 4/5 h of face-to-face lessons, is organized into two parts: the first aims to provide the volunteer with the main basic concepts of seismology; the second one is dedicated to describing the types of reconnaissance of the territory (public buildings, civil dwelling houses, production plants, roads, and bridges), how to fill in the form, the timing to follow, and last, but not least, the importance of transmitting this type of data to the SOR. Obviously, they are carefully instructed on the dangers they could be exposed to when entering a damaged building in the event of a second shock, and on all the precautions to be taken for their safety.

As a result of the training activities, we observed that the volunteers tend to underestimate the importance of communicating information related to an only "felt" event since they are accustomed to confronting real negative consequences and to assisting those in need. The training course also aims to convince the volunteers that even simply describing how the earthquake was felt by the population in their municipality is very useful for the Civil Protection authorities, which also has the task of disseminating proper information, and then with their help, can better understand the size and extent of the event, especially when combined with the analysis of the recordings collected by the seismological network operating in the region.

The whole training mechanism is also strongly focused on "motivational" aspects. This means ensuring the volunteers understand that all of the acquired information is not only useful to Civil Protection authorities, but also to the wider scientific community. It is also repeated that it is fundamental to the effective collaboration of all concerned parties, including municipal groups where the earthquake was not felt. The data "not felt" is, however, still valuable data to describe the earthquake as a whole, as is the reports from places that have not suffered damage. In summary, based on our experience, we can confirm that it is of major importance to ensure the continued training of the volunteer.

To summarize the results obtained so far, Fig. 6 shows a synoptic picture of earthquakes for which the TVSE forms have been filled in over the past few years (starting from 2015). The number within the circle

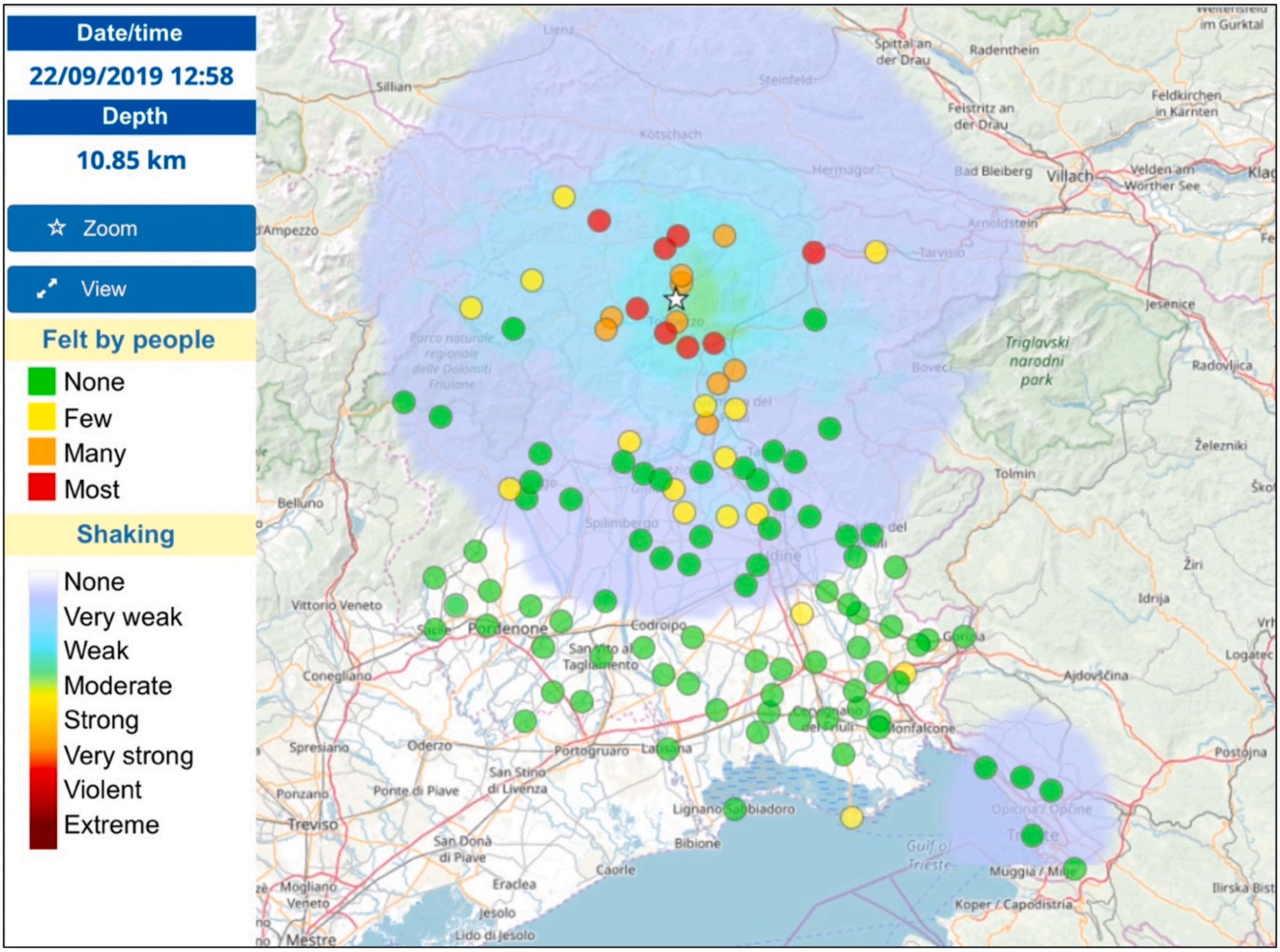

Fig. 4. Screenshot of the automatic seismic impact map of September 22, 2019, M = 3.8 earthquake on the PCR web page (www.pianiemergenza.protezionecivile.fvg.it). Colored circles stand for the level of seismic impact according to the compilation of the TVSE questionnaires for the individual municipalities. This map is automatically composed by the system without the evaluation of data by the experts. The additional layer shown reports the intensity ShakeMap®.

indicates the number of questionnaires received by the SOR for each earthquake and the color indicates the range of magnitudes. The blue curve indicates the total number of volunteers who have attended the training course over time. It is encouraging that a general increase in the number of trained people is followed by a greater number of compiled questionnaires (indicating the effectiveness of the training courses), as shown above (Fig. 5). Overall, since the beginning of the experimentation, 20 earthquakes have been surveyed, 2634 questionnaires have been completed, and 12 training courses have been held (with an average number of 65 people each time) involving a total of 770 volunteers.

Finally, from our experience so far, we have noticed that there is some evidence of systematic behavior in some zones where a greater sensitivity to earthquakes could be linked to local amplification phenomena (meaning the ground shaking is modified by the presence of softer sedimentary rocks covering stiffer layers), such around Cividale, on the moraine arch north of Udine, and near the coast. The challenge is to identify a model that can describe these very specific responses, also in the surroundings of Tolmezzo, that at present appear unpredictable. This is expected to be a mid-to long-term outcome, subject to the acquisition of an adequate data set.

4. Earthquake damage data collection in the field

The collection of data on damage to an area affected by a seismic event, while appearing outdated with the advent of new technologies, is of great interest not only to the scientific community, but also for local authorities and emergency managers. From a scientific point of view, the relevance of macroseismic surveys of a recent earthquake lies mainly in the comparison of the “intensity values” with those of a past earthquake in the same area [10]. In Italy, the national parametric catalog of earthquakes (CPTI15 [11]) and the related database (DBMI15 [12]) list earthquakes from the year 1000 to the present day. Thus, the seismic hazard assessment is mainly based on historical information, and therefore deriving from assessments of macroseismic intensity, up to 90%.

On the other hand, detailed surveys of the most severely affected areas carried out based on the European EMS98 scale (European Macroseismic Scale [13]), allow a statistical analysis of the different damage levels in relation to the seismic vulnerability of the buildings affected (the EMS scale indicates the final intensity value for each location, estimated based on the percentages of the different classes of building vulnerability in the location and the relative damage levels in relation to the total number of buildings). The official damage levels defined (in Mercalli degrees - MCS), carried out by a team of researchers and technical experts in macroseismic surveying, therefore, constitutes the

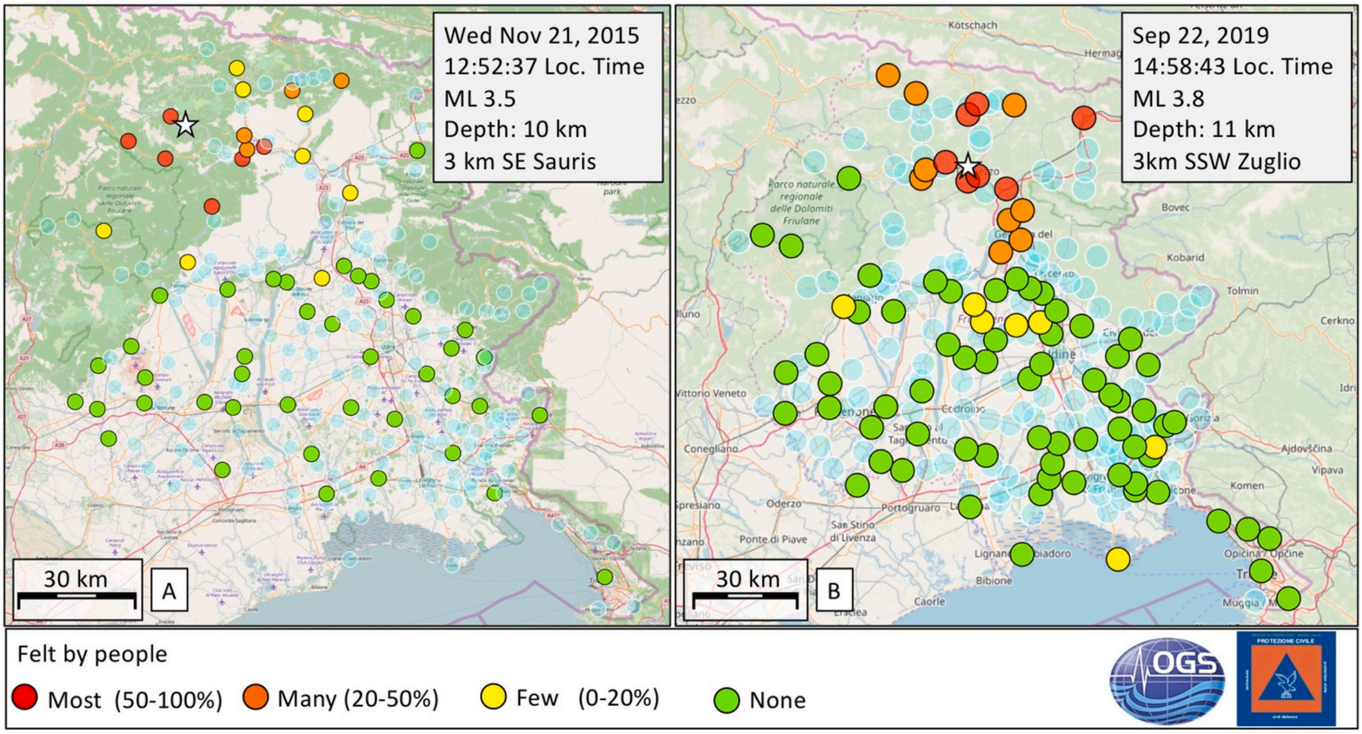

Fig. 5. Maps with the seismic impact values according to the completion of the questionnaires after the a) November 21, 2015 - Ml = 3.5, and b) September 22, 2019 - Ml = 3.8 earthquakes. The pale blue circles indicate municipalities that did not provide TVSE information. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

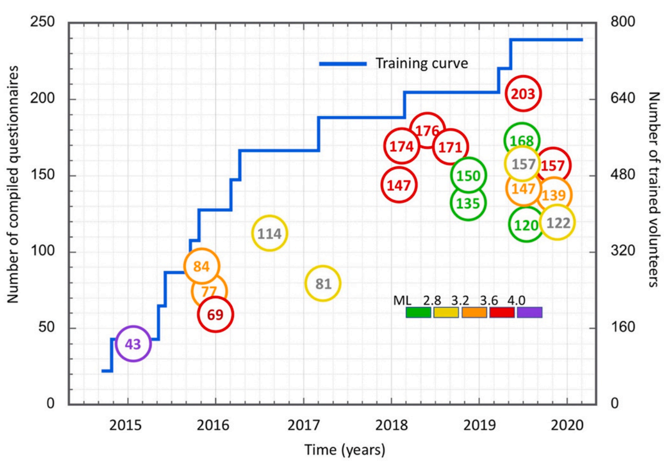

Fig. 6. Synoptic view of the earthquakes for which the TVSE forms have been filled in over the years. The number within the circle indicates the number of questionnaires received. The color of the circles indicates the magnitude class of the event. The blue curve indicates the number of volunteers who have attended the training course over time. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

basis on which individual citizens can ask the national or local authorities for damage reimbursement for the necessary repairs and restoration.

The TVSE method does not claim to replace the work of the experts, generally carried out in post-event and non-emergency situations, but rather to provide a reliable support tool for the PCFVG to support actions in the immediate aftermath of an earthquake. It, therefore, contributes to strengthening the decision-making and organizational skills of the staff involved.

4.1. Instrumental data and 'shake maps'

ShakeMap® is a tool developed by the U.S. Geological Survey (USGS), through the rapid mapping of instrumentally measured ground shaking, produces shake maps that paint an almost instantaneous picture of the effect of an earthquake in terms of the spatial distribution and severity of ground shaking. ShakeMap® represents the best possible description of shaking using a combination of recorded ground motion values, when available, and estimated ones through propagation models when instrumental coverage is scarce [2]. Since their introduction into Italy [14], these maps have been helpful in the initial post-seismic emergency phase, as after the L'Aquila earthquake (April 6, 2009, Mw = 6.3). Providing a snapshot of the shaking allows for the identification of those geographical areas where the emergency response should be concentrated [15]. The CRS produces real-time shake maps for earthquakes with Ml ≥ 2.5 occurring in Northeastern Italy (Bragato et al., 2020) for peak ground velocity, peak ground acceleration, 5% critically damped response spectra (at 0.3, 1.0, and 3.0 s), and for instrumental intensity. The shake maps are then immediately sent to the PCFVG and PCV and uploaded onto the Real-Time Seismology website [16], and then released to the public. At the regional level, by exploiting the high density of seismic stations (with spatial separations of a few kilometers, especially in the foothills, Fig. 1), ShakeMap® (Fig. 7a) can highlight more complex aspects of the ground motion, such as radiation patterns, source effects, propagation (such as directivity) effects, and local amplification [17].

The information that volunteers can collect in the field not only completes the picture of what happened, but at the same time allows the quick verification of the reliability of the distribution of ground motion implied by the seismograph recordings. For example, where the instruments have recorded acceleration values that would be expected to lead to damage, the rapid surveys undertaken by volunteers could confirm whether the actual situation is as expected. In the earthquake shown in Fig. 7 (May 9, 2018 Mll 3.6), it can be seen that in the

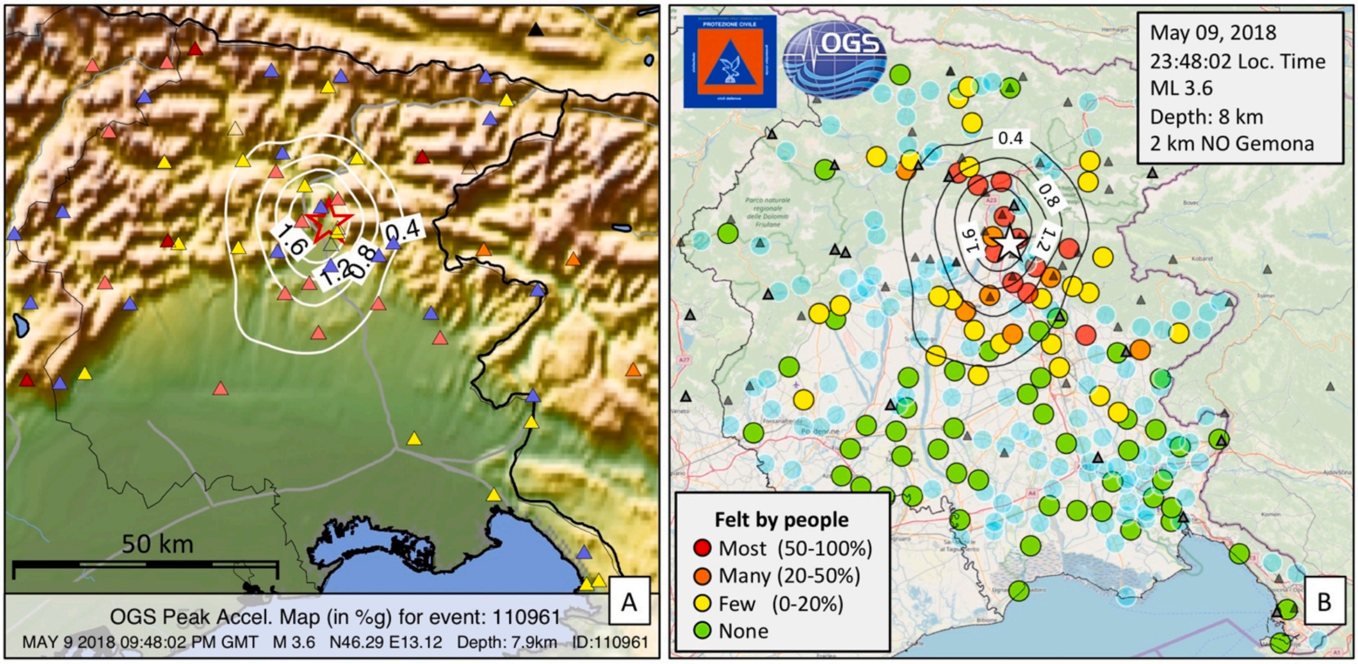

Fig. 7. 9 May 9, 2018 earthquake - Ml 3.6: a) ShakeMap®. The contour lines highlight the pattern of the maximum acceleration values (PGA, in %g). Image modified from http://rts.crs.inogs.it/event/44425/detail.html; b) seismic impact on the regional territory according to the compilation of the TVSE questionnaires for the individual municipalities (colored circles). The pale blue circles indicate municipalities that did not compile the TVSE questionnaire. The contour lines are as in a). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

epicentral area, the degree of perceived ground motion is not as homogeneous as the acceleration contours suggest, for example, there are areas where the earthquake was perceived by most people, while the ShakeMap® output indicates very low acceleration levels (Fig. 7b). Therefore, rapid feedback from in-situ surveys also becomes crucial for improving the prediction models used in the elaboration of the maps attached to the alert notification (Fig. 2). Once the data collected is fully operational, it will be possible to better describe the response over the territory as a whole, including, for example, incorporating commonly documented soil amplification effects.

4.2. Citizen science and crowdsourcing for disaster risk reduction

Citizen science, or "the participation of people from outside professional organizations in the gathering or analysis of data" [18] and information for scientific purposes, is now a well-established field of research [19,20]. Citizen science for disaster risk reduction (DRR) shows huge promise and has demonstrated success in advancing scientific knowledge, for example, by providing information for early warning hazard/risk assessment and the management of the impact of extreme events. As emphasized by Hicks and colleagues: "Not only can this information act as an early warning, which may help to save lives and livelihoods, it also has the potential to generate shared understandings of hazardous phenomena, improve communication and help communities at risk take actions to build their resilience during, after, and in preparation for future hazardous events" [18]. In their global mapping of citizen science approaches for DRR, the same authors provide an overview of the scientific-technological approaches followed in citizen science, including smartphone accelerometers and Global Positioning Systems that can detect earthquakes and potentially provide warnings, such as the proof-of-concept MyShake smartphone seismic network [21–23]. This network harnesses smartphone sensors to detect M 5 earthquakes and above at distances of 10 km or less. Moreover, games, apps, and online activities such as mapping (e.g., via OpenStreetMap) capable of recording observations, monitoring hazards, and providing early warnings [24–27], are becoming more popular with the public and researchers. Usually, web-enabled databases are also used by the public to submit observations directly about hazards, such as volcanic ash distribution [28], and about the resulting impact arising from an event on, for example, infrastructure [29]. Finally, social media data can be leveraged and transformed into useful and useable information for both the public at risk, emergency responders, and decision-makers.

The focus of this paper is on Italy, and for some years, in the wake of what was already being done at the international level (for example, DYFI [3], or LastQuake [30]), web portals have been made available for anyone to connect to and provide their observations about earthquake impacts and damage. More precisely, in Italy when major earthquakes occur, the "Hai Sentito Il Terremoto" (HSIT) system [31] allows the collection of data from the general population on a voluntary basis, leading to the production of maps describing the effects of the earthquake. This type of information depends on population density and is strongly conditioned by the accessibility to the internet, which is still more available in urban areas rather than in smaller towns and villages, especially in the mountains, such as the small settlements distributed throughout the Apennines or in the Alps. It is frequent that, in the case of an earthquake occurring in mountain areas, most of the reports come from cities or larger villages further from the epicenter, and not from nearer localities. Consequently, these are not the most suitable conditions to achieve optimal results for the DYFI/HSIT method. However, we are not seeking to have these very well-established procedures in competition with our TVSE methodology, as they involve two different approaches: DYFI/HSIT is based on the spontaneous participation of people who may feel more or less obliged to provide this information, regardless if it is important to the Civil Protection authorities or the scientific community. The TVSE, on the other hand, was founded on the assumption that the volunteers involved had carried out specific training, have a precise assignment by the PCR, and are therefore strongly encouraged, if not obliged, to complete the information forms.

As an example, Fig. 8 shows the earthquake that occurred in Tolmezzo on January 19, 2018 (Ml = 3.8). The information via TVSE (Fig. 8a) is much more distributed throughout the whole territory, with the epicentral area (located in the mountains) is better documented and

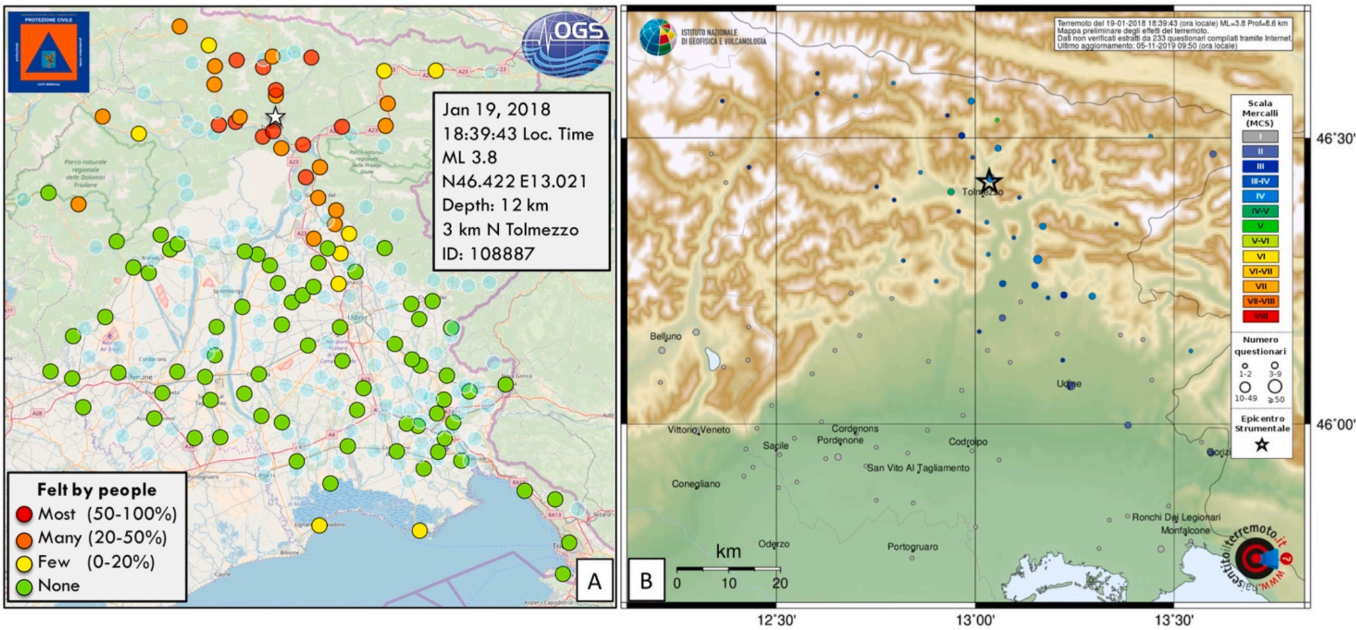

Fig. 8. January 19, 2019 earthquake - Ml = 3.8: a) seismic impact on the regional territory according to the filling in of the TVSE questionnaires for the individual municipalities (colored circles). The pale blue circles indicate municipalities that did not compile TVSE forms; b) seismic impact on the territory by HSIT procedure (from http://www.haisentitoilterremoto.it). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

the no-felt area (green circles) is well defined with respect to that of the HSIT (Fig. 8b). The TVSE system is much more oriented towards a specific target and to the requests of the Civil Protection authorities, which aims to have direct feedback from each municipality. The two yellow circles facing the Adriatic Sea are the municipalities of Lignano and Grado. The earthquake, which occurred far from these localities, was still felt by the population there, due to the influence of the foundation soils which, in this case, induced seismic amplification. However, the magnitude of the events is generally quite small and only some of the earthquakes documented by our experiment, like this one, are reported in the national HSIT portal.

5. Future prospects

Earthquakes do not recognize administrative divisions or national borders. Considering the case of Friuli Venezia Giulia, a border region in Northeast Italy, earthquakes occur in the border areas between Italy, Austria, and Slovenia. An exhaustive and homogeneous picture of the overall impact of the earthquake therefore requires the compilation of information from all the countries as uniformly as possible.

For example, there have recently been two earthquakes in Slovenia that have been felt by the population in FVG. The Slovenian Environment Agency (ARSO) adopts a well-calibrated and efficient system of data collection in the HSIT (or DYFI) style. Also, the ARSO system receives a great number of earthquake reports from the larger cities where the potential number of people who can easily access the internet and fill in an earthquake questionnaire is much higher than in the rest of the country (large pale red filled circles, Fig. 9). To homogenize the two datasets, we tried to normalize the Slovenian number of “felts” on the total number of inhabitants per location (colored squares, Fig. 9). Moreover, within the framework of a historic cross border collaboration among scientific institutions, there are plans to extend the TVSE method, via European research projects, to Slovenia and Austria, so as to obtain common maps. The Civil Protection of the Veneto Region, bordering the FVG region, and Emilia Romagna Region, have recently started to adopt the TVSE procedure.

Also, we are experimenting with alternative ways of filling in questionnaires in real-time on a smartphone application (for example, via Telegram®). With this system, it is possible not only to send the earthquake notice directly to the volunteers, but also the request and the direct link for filling in the form. In the notification message, it would be even possible to insert pre-configured keys with which the volunteer could provide preliminary answers to some questions (e.g., earthquake felt or not) and communicate the geographical position. A means of tracking in real-time the activity of the volunteers in the emergency area is also envisaged.

Finally, the TVSE system is only one component of a new broad-spectrum of monitoring activities that include widespread instrumentation on strategic buildings. In the European “ARMONIA” [32] project, developed in collaboration with PCR and Austria, the OGS is installing low-cost sensors in a large number of public buildings. In this way, it will be possible in the future to investigates a correlation between TVSE and accelerometric data in the monitored buildings, or the well-characterized buildings nearby the installed stations could become a reference point for the impact to be monitored by the volunteers.

6. Conclusion

The integration of crowdsourced information into warning and crisis decision-making is a promising field of research and practice. It is acknowledged that coupling early warning services and crowdsourcing activities could help with emergency management and assist in the required decision-making process. In this paper, we describe a citizen science approach for crowdsourcing with respect to seismic events. As indicated in the previous sections, the TVSE system is based on the training of volunteers spread over the 215 municipalities of the Friuli Venezia Giulia Region. The volunteers are at the center of the TVSE system, and they are trained to know the fundamentals of earthquake seismology, the relevant survey methodology, and the importance of collecting good quality data. This training and information campaign is of extreme importance for the civil protection system and crisis and post-crisis management. Its minimum objective is to keep the “awareness of the risk” of living in areas with a high seismic probability alive, especially where the memory of the last strong earthquake is gradually

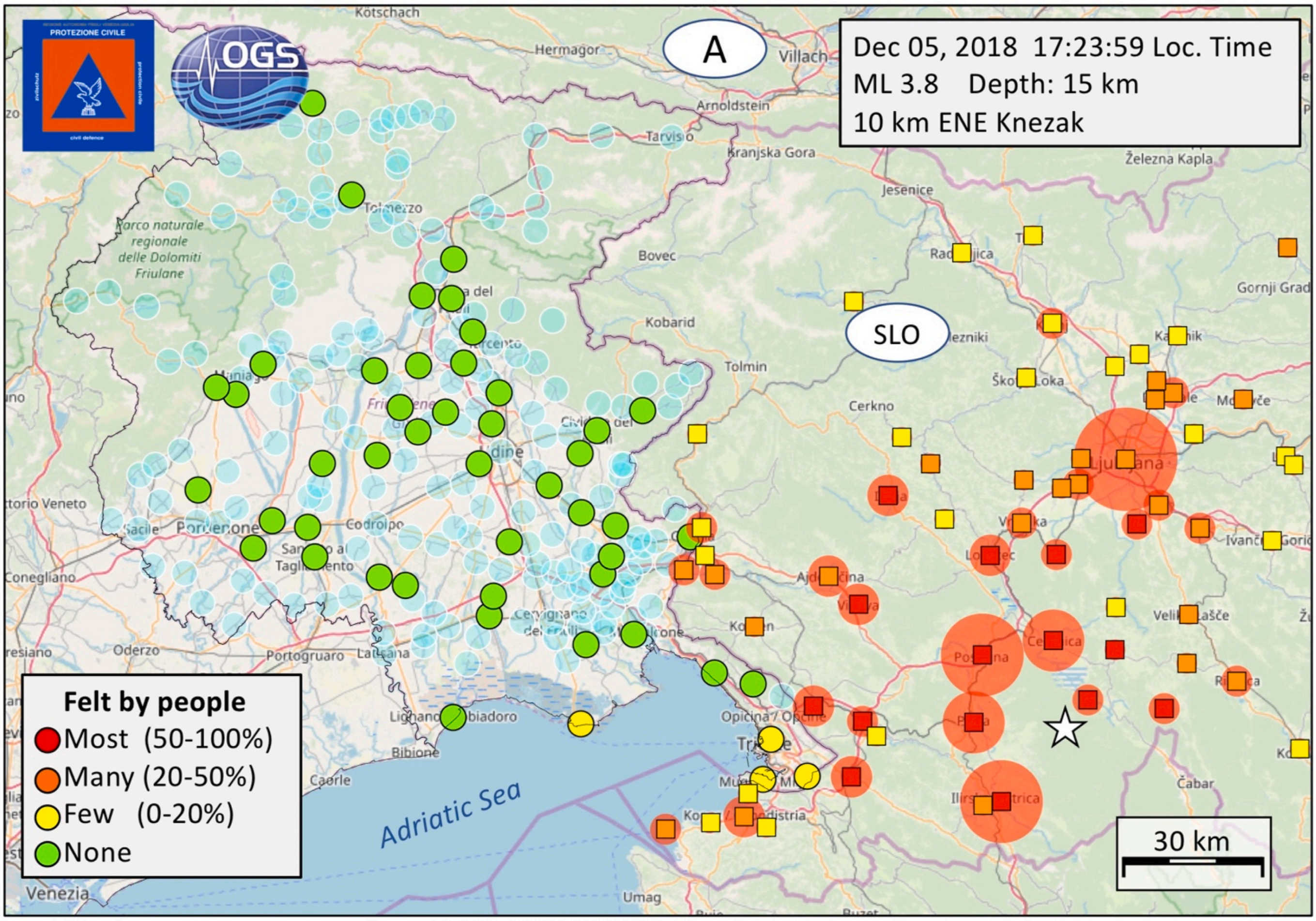

Fig. 9. December 05, 2018 earthquake with its epicenter in Slovenia (white star) - Ml = 3.8. The colored circles in the Italian territory indicate the seismic impact according to the filling in of the TVSE questionnaires for the individual municipalities. In Slovenia, data are collected by the Slovenian Environmental Agency ARSO (the pale red filled circles are proportional to the number of reports). The colored squares are the impact on localities normalized on the number of inhabitants. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

fading over time. The TVSE contributes not only to keeping the seismic risk awareness high among the volunteers and the wider population, but also to strengthening the collaboration between scientists, professionals, volunteers, and citizens. Thus, by generating better interconnections between a citizen science approach, and professionals on the various areas, it contributes to advancing the field of citizen science, particularly concerning the need for building stronger links between the scientific and practice domains.

There are already available web portals open for anyone to connect to and to deposit their observations about the effect of an earthquake, such as the system “Hai Sentito Il Terremoto” (HSIT) or “Did You Feel It” (DYFI) already mentioned above. Such systems allow the collection of data from the population on a voluntary basis, including the spontaneous participation of the member of the public who may feel more or less obliged to provide this information, regardless of its value for the Civil Protection authorities or the scientific community, as well as the completion of the above-described questionnaires by volunteers as part of the emergency procedures.

It is our belief, based on the previous years’ experience, that the information supplied by those directly affected by an event makes a difference, the undoubted added value of the TVSE system described in this paper is to rely upon, unprecedentedly, on the civil protection volunteers and therefore, in essence, on the organizational structure of the Civil Protection organization itself. This is what makes the method so attractive, such that other regions have also asked for assistance in adopting it.

Moreover, in the regional territory of the FVG, there is a continuous increase in the diffusion of accelerometric devices, very often installed in public buildings, which in turn are subject to the control of the Civil Protection authorities. The information collected by volunteers in situ allows a double control: where the instruments have recorded certain acceleration values, the rapid detection “de visu” can confirm, especially in case of expected damage, if the real situation is worse or better than expected.

At the end of the day, the TVSE method does not claim to replace the work of the experts, but rather it provides a reliable self-supporting tool for PCR in the immediate post-earthquake period.

Data and resources

All data used in this paper came from published sources listed in the references. Figs. 3 and 4 are taken from the FVG Civil Protection’s web portal: https://pianiemergenza.protezionecivile.fvg.it; Fig. 7a is taken from the OGS’s "Real Time Seismology" web page: http://rts.crs.inogs.it/; Fig. 8a is taken from the INGV’s web page: http://www.haisentitoilterremoto.it.

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.

Acknowledgements

This study is carried out was carried out in the framework of the cooperation "COLLABORAZIONE NELL'AMBITO DEL MONITORAGGIO SISMICO E METEOMARINO DI INTERESSE REGIONALE E PER IL SUPPORTO TECNICO-SCIENTIFICO NELLA PREVENZIONE E GESTIONE DI EMERGENZE SISMICHE, METEOMARINE E AMBIENTALI SUL TERRITORIO E LUNGO LE COSTE DELLA REGIONE FRIULI VENEZIA" between OGS and the Regione Autonoma Friuli Venezia Giulia Civil Protection. We thank our colleague Kevin Fleming for his help with the English.

References

[1] A. Frisiello, Q. Nhu Nguyen, C. Rossi, F. Dominici, Gamified. Crowdsourcing for disaster risk management, 2017, https://doi.org/10.5281/zenodo.1149042.
[2] C.B. Worden, D.J. Wald, ShakeMap Manual Online: technical manual, user's guide and software guide, U. S. Geol. Surv. (2016) 1–156, https://doi.org/10.5066/F7D21VPQ.
[3] D.J. Wald, V. Quitoriano, C.B. Worden, M. Hopper, J.W. Dewey, USGS "Did You Feel It?" internet-based macroseismic intensity maps, Ann. Geophys. 54 (6) (2011) 688–709.
[4] D. Alexander, Social media in disaster risk reduction and crisis management, Sci. Eng. Ethics 20 (2014) 717–733, https://doi.org/10.1007/s11948-013-9502-z.
[5] V. Poggi, C. Scaini, L. Moratto, G. Peressi, P. Comelli, P.L. Bragato, S. Parolai, Rapid damage scenario assessment for earthquake emergency management submitted to seismol, Res. Lett. (2020).
[6] D. Sandron, et al., Civil protection municipal emergency plans: earthquake procedures in the frame of the regional plan of emergencies in Friuli Venezia Giulia, in: D. Slejko, A. Rebez, D. Albarello, S. Grimaz, A. Masi, M. Mucciarelli, G. Naso, G. Valensise (Eds.), Atti 31° Convegno Nazionale, Tema 2: Caratterizzazione sismica del territorio, Mosetti Tecniche Grafiche, 2012, pp. 371–378.
[7] D. Sandron, et al., Rapid estimation of the seismic impact through the active contribution of the Civil Protection volunteers, Boll. Geofis. Teor. Appl. 57 (2) (2016) 183–193.
[8] A. Rebez, I. Cecić, G. Renner, D. Sandron, D. Slejko, Misunderstood "forecasts": two case histories from former Yugoslavia and Italy, Boll. Geofis. Teor. Appl. 59 (4) (2018) 481–504, https://doi.org/10.4430/bgta0244.
[9] OGS, Seismicity catalog available at: http://www.crs.inogs.it/bollettino/RSFVG/RSFVG.en.html (Accessed: 07-02-2020).
[10] D. Sandron, G. Renner, A. Rebez, D. Slejko, Early instrumental seismicity recorded in the eastern Alps, Boll. Geofis. Teor. Appl. 55 (4) (2014) 755–788.
[11] A. Rovida, M. Locati, R. Camassi, B. Lolli, P. Gasperini, Catalogo Parametrico dei Terremoti Italiani (CPTI15). Istituto Nazionale di Geofisica e Vulcanologia (INGV). https://doi.org/10.6092/INGV.IT-CPTI15, 2016.
[12] M. Locati, et al., Database Macrosismico Italiano (DBMI15), Istituto Nazionale di Geofisica e Vulcanologia (INGV), 2016, https://doi.org/10.6092/INGV.IT-DBMI15.
[13] G. Grünthal, European macroseismic scale 1998, Cah. Cent. Eur. Geodyn. Seismol. 15 (1–99) (1998).
[14] A. Michelini, L. Faenza, V. Lauciani, L. Malagnini, ShakeMap implementation in Italy, Seismol Res. Lett. 79 (2008) 688–697.
[15] F. Pettenati, L. Sirovich, D. Sandron, Rapid simulation of seismic intensities for civil protection purposes: two recent cases in Italy, Seismol Res. Lett. 82 (2011) 420–430, https://doi.org/10.1785/gssrl.82.3.420.
[16] A. Saraò, P.L. Bragato, P. Bernardi, Real time seismology of the OGS seismological research Centre. http://rts.crs.inogs.it, 2009.
[17] L. Sirovich, F. Pettenati, D. Sandron, Source- and site-effects in the intensities of the M5.4 29 July 2008 earthquake in South Los Angeles, Seismol Res. Lett. 80 (6) (2009) 967–976, https://doi.org/10.1785/gssrl.80.6.967.
[18] A. Hicks, et al., Global mapping of citizen science projects for disaster risk reduction, Front. Earth Sci. 7 (2019) 226, https://doi.org/10.3389/feart.2019.00226.
[19] R. Bonney, et al., Citizen science: a developing tool for expanding science knowledge and scientific literacy, BioOne 59 (2009) 977–984, https://doi.org/10.1525/bio.2009.59.11.9.
[20] M. Haklay, Citizen science and volunteered geographic information: overview and typology of participation, in: D. Sui, S. Elwood, M. Goodchild (Eds.), Crowdsourcing Geographic Knowledge: Volunteered Geographic Information (VGI) in Theory and Practice, Springer, Dordrecht, 2013.
[21] M. Ervasti, et al., iShake: mobile phones as seismic sensors – user study findings, in: Proceedings of the 10th International Conference on Mobile and Ubiquitous Multimedia, ACM, Beijing, 2011, https://doi.org/10.1002/9781118396599.ch1.
[22] S. Minson, et al., Crowdsourced earthquake early warning, Sci. Adv. 1 (2015), e1500036, https://doi.org/10.1126/sciadv.1500036.
[23] Q. Kong, R.M. Allen, L. Schreier, Y.W. Kwon, MyShake: a smartphone seismic network for earthquake early warning and beyond, Sci. Adv. 2 (2016), e1501055, https://doi.org/10.1126/sciadv.1501055.
[24] L. Palen, S. Hiltz, S. Liu, Online forums supporting grassroots participation in emergency preparedness and response, Commun. ACM 50 (2007) 54–58.
[25] L. Palen, R. Soden, T.J. Anderson, M. Barrenechea, Success & scale in a data-producing organization: the socio-technical evolution of OpenStreetMap in response to humanitarian events, in: Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems, ACM, Seoul, 2015.
[26] L. Mani, P.D. Cole, I. Stewart, Using video games for volcanic hazard education and communication: an assessment of the method and preliminary results, Nat. Hazards Earth Syst. Sci. 16 (2016) 1673–1689, https://doi.org/10.5194/nhess-16-1673-2016.
[27] S. Mossoux, et al., Hazagora: will you survive the next disaster? – a serious game to raise awareness about geohazards and disaster risk reduction, Nat. Hazards Earth Syst. Sci. 16 (2016) 135–147, https://doi.org/10.5194/nhess-16-135-2016.
[28] K. Wallace, S. Snedigar, C. Cameron, 'Is ash falling?', an online ashfall reporting tool in support of improved ashfall warnings and investigations of ashfall processes, J. Appl. Volcanol. 4 (2015) 8.
[29] R.L. Baum, et al., Report a landslide" A website to engage the public in identifying Geologic hazards, Cham: Springer Int. Publ. (2014) 95–100.
[30] R. Bossu, F. Roussel, L. Fallou, M. Landès, R. Steed, G. Mazet-Roux, A. Dupont, F. Frobert, L. Petersen, LastQuake: from rapid information to global seismic risk reduction, Int. J. Disaster Risk Reduc. 28 (2018) 32–4233.
[31] P. Tosi, P. Sbarra, V. De Rubeis, C. Ferrari, Macroseismic intensity assessment method for web questionnaires, Seismol Res. Lett. 86 (3) (2015) 985–990, https://doi.org/10.1785/0220140229.
[32] Armonia, Trans-frontier strategy in the management of natural disasters, Interreg Italia-Österreich V A, https://seisram.units.it/content/armonia# (Accessed: 02-17-2020).