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The whole story: Rumors and science communication in the aftermath of 2012 Emilia seismic sequence

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Controversies that stir the public debate on geological matters usually revolve around a few specific aspects, including the actual trigger of geological phenomena (i.e., natural vs. anthropogenic), their predictability, and the trustworthiness of the experts who provide information and advice on the phenomena. A typical example of such difficulties is the case of the 2012 Emilia, Italy, seismic sequence which struck an area of relatively moderate seismic hazard. In that period, geophysical prospecting was planned to assess the potential of a reservoir for gas storage, near the town of Rivara. The low frequency of important seismic events in the area, associated with the ongoing industrial planning prompted widespread rumors of an anthropogenic origin of the 2012 earthquakes. Controversy also arose about the actual size of the seismic events: earthquakes magnitude can be computed with different methods, and its value depends on the type, number, and geographical distribution of the available seismic stations. As a result, different institutions commonly release different estimates of the earthquake magnitude, casting doubts on the reliability of each estimate. Since 2012, public concern has also been caused by the repeated occurrence of unusual phenomena in the area, such as ground heating or bubbling well waters. Popular belief tends to establish a causal link between particular phenomena and seismic activity, reinforcing the false conviction that seismicity could be predicted. In this work we present and discuss some of the activities that INGV pursued through the years to contrast rumors and disseminate correct scientific information. In the aftermath of the 2012 seismic sequence, INGV worked in collaboration with the National Department of Civil Protection, the local administrations, the University Network of seismic engineering, the Regional Healthcare System and local volunteer organizations. The organization of public meetings, the collection and analysis of widespread rumors and the creation of *ad hoc* outreach materials all contributed to reinforce the mutual trust between our research institute and the local population.

KEYWORDS

earthquake, rumor, 2012 emilia earthquakes (Italy), science communication, risk perception

1 Introduction

On 20 May 2012 (02:03:53 UTC), a magnitude (Mw) 5.86 earthquake (Ml=5.9) hit the Po plain, in Italy, causing five casualties and damage in several towns, including Modena and Ferrara. Three hours earlier, a Mw 4.0 foreshock (Ml 4.1) struck the same area. These events initiated a seismic sequence that included six more shocks above magnitude 5.0, the greatest of which occurred on 29 May 2012 (07:00:03 UTC), had a magnitude Mw 5.7 (Ml 5.8) and was located 12 km to the west of the May 20 event (Figure 1). After this second mainshock, the death toll rose to 17 victims, while 13,000 people had to be evacuated. The economy of this wealthy, industrial area of Northern Italy was seriously impacted.

The occurrence of a strong earthquake increases the social awareness toward natural hazards, and commonly prompts a strong demand for information (Bossu et al., 2015). The need for a continuous flow of details becomes urgent, especially during prolonged seismic sequences. The availability of correct and exhaustive information affects people's capacity to cope with emergency situations, and may foster the resilience of single individuals and of the entire communities involved. On the contrary, the lack of timely and accurate information may favor the circulation of rumors and misinformation (Fallou et al., 2020). A good communication among different stakeholders during a crisis may improve the community response to the emergency and reduce the costs of the disaster. However, scientific communication also promotes a rational and transparent decisional process and facilitates the acceptance of the disaster consequences (Wendling et al., 2013).

However, science communication is not always straightforward in the aftermath of a natural disaster. In addition to the scientific complexity, which may hinder a proper understanding of the natural phenomenon, the scientific information provided may fail to address the specific fears and needs of the population at risk, adding to their frustration. The stressful circumstances emphasize the emotional reactions of the stakeholders involved, and the technical staff may be unprepared to cope with the irrational components of human interactions. Under these circumstances, fake news may grow and spread, and if not promptly addressed, may cause unwanted consequences (Lamontagne and Goulet, 2018; Fallou et al., 2020).

Nowadays, the need to fight earthquake rumors while ensuring a prompt and exhaustive flow of information is widely recongnized in the seismological community (Fallou et al., 2022). In this paper, we describe how our Institute (Istituto Nazionale di Geofisica e Vulcanologia, INGV) has worked to address this complex issue in particular after the 2012 seismic sequence, by promoting different kinds of actions. Proposed interventions were all aimed at engaging the local population in a fruitful knowledge exchange, and have been structured around three main principles: connect, listen, and share. The underlying concept is that knowledge transfer works when it is a

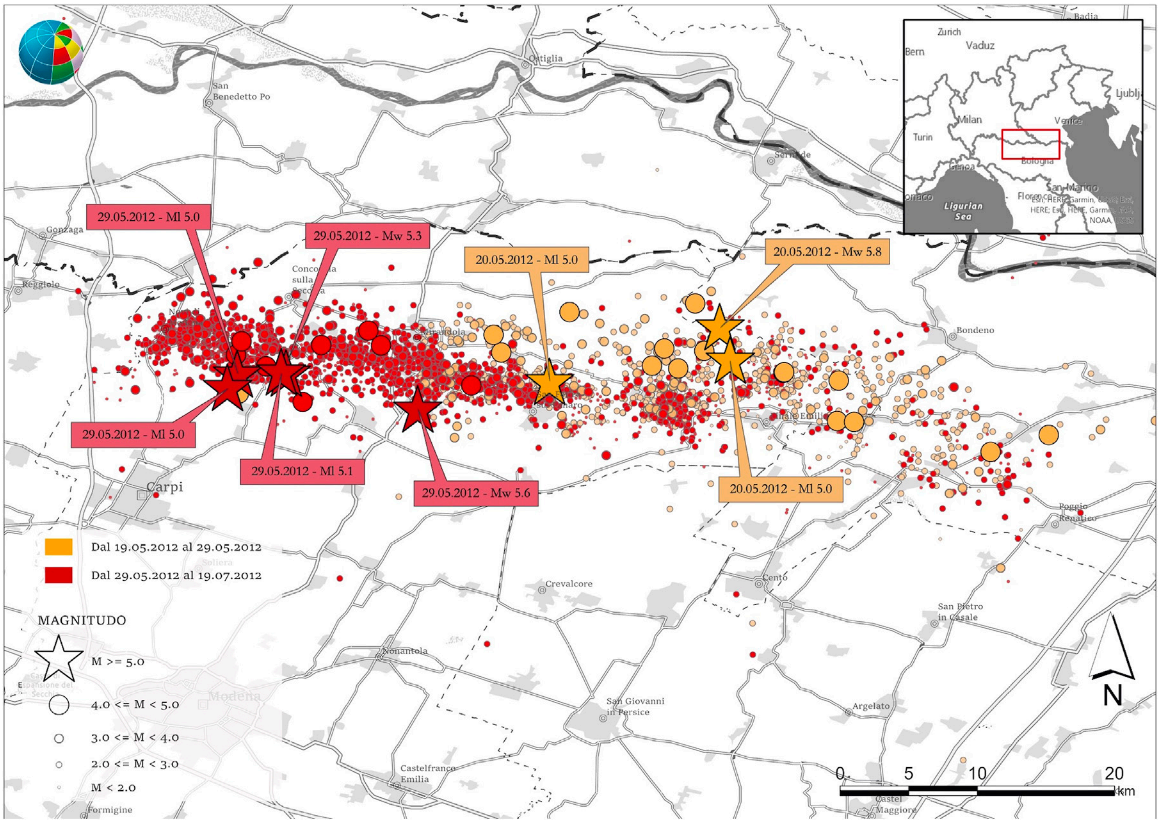

FIGURE 1
The main shocks of the 2012 Emilia Romagna seismic sequence. The size of the points reflects the magnitude, as shown in the legend. For the six greatest events (stars), the labels report the date (day.month.year) and the magnitude. The image is taken from a blog article published on the INGVterremoti blog on the 10th anniversary of the sequence (modified after https://ingvterremoti.com/2022/05/21/terremoti-in-pianura-padana-10-anni-dopo-i-numeri-della-sequenza-e-la-dashboard/).

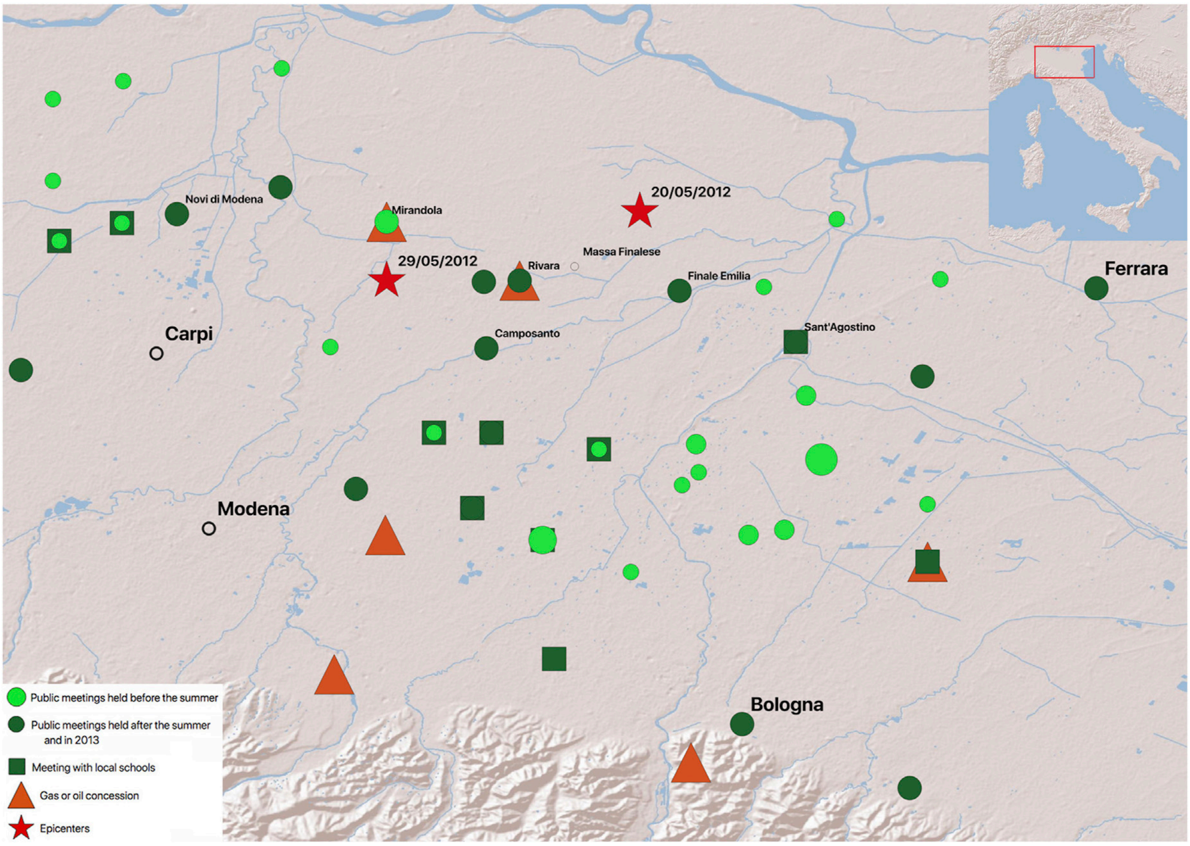

FIGURE 2
Locations of the public meetings organized in the region affected by the 2012 seismic sequence. The red stars indicate the two major events, on May 20 and 29, 2012. Orange triangles show the location of gas or oil concessions. Green symbols indicate the locations of the public meetings organized during and after the sequence. The size of the symbols reflects the number of meetings held at each location, with larger symbols corresponding to 5 encounters. Light green symbols indicate meetings held during the sequence (before the summer), while darker symbols show meetings organized after the summer. Square symbols refer to activities held in local schools, during the 2012/2013 school year.

mutual exchange, and where the scientific information that is released to the public is suited to address the public's questions and fears.

Accordingly, the first response to the seismic sequence was the organization of public meetings, which were held in different locations, upon request from local authorities, from May to September 2012 (Figure 2). These public encounters were realized thanks to the joint efforts of the Italian Civil Protection Department (DPC), INGV, and the regional administrative authority (Regione Emilia-Romagna), in collaboration with the Laboratory University Network of seismic engineering (RELUIS), the Regional Healthcare System and the organizations of civil protection volunteers. The meetings were announced locally with flyers and taking advantage of all channels available to the participating stakeholders (including announcements broadcasted on local radio or TV networks and institutional websites). Based on the fruitful experience carried out after the 2009 L'Aquila earthquake (Nostro et al., 2009; Moretti et al., 2011), the campaign was named "Earthquake: let's talk about it" and provided suitable spaces where citizens could meet the experts from the organizing institutions, receive information about the seismic sequence and its effects, and express their doubts and fears related to the earthquake. All these public meetings allowed ample space for open questions and informal discussion among the participants, providing a useful psychosocial support as the seismic sequence unfolded, accompanied by growing false information and urban legends.

Rumors about the ongoing sequence were then collected online, through various institutional websites, and analyzed to gain insights on the scientific information required to address common misconceptions or popular beliefs. Information on the rumor collection was provided during the public meetings, and advertised online. The collection of widespread rumors is a necessary step to counteract its effect, devising appropriate outreach material and providing authoritative and coordinate answers (Lamontagne and Goulet, 2018; Fallou et al., 2022).

On a longer term, the link established with the communities was maintained through different kinds of actions, including sharing of scientific results (through the institutional blog and social media, releasing interviews to traditional media), attending public meetings and cultural events, and participating in school activities. The scientific contents proposed during these outreach activities were tailored to address the specific needs that emerged in the public discourse about the earthquake.

In this paper, we describe the outcome of these combined actions and propose future steps to improve the communication of natural hazards.

2 Materials and methods

Our approach to the communication during the seismic sequence in 2012 was devised in collaboration with other national and local stakeholders, and was organized around three main pillars: connect, listen, and share. We sought a connection with the affected population by creating the conditions suited to allow a free exchange of information, thoughts and fears about the earthquakes. We listened to the questions that circulated among the people, and collected information on the widespread rumors and finally we produced outreach material suited to address those questions and rumors.

2.1 Connect: The psychosocial intervention

The traditional approach to emergency psychology has been primarily oriented toward clinical actions (aimed at both individuals or groups). In recent years, however, the guidelines released by international organizations of the field (Inter-Agency Standing Committee (IASC, 2007) and WHO, in particular) have emphasized more and more the psychosocial impact of the intervention, and its community and intercultural dimensions. Emergency psychology should not only take care of the clinic of single unrelated individuals, but also provide a systemic management of the psychosocial community scenario, where the emergency took place and whence it built its significance. Based on these indications, and taking advantage of the precious experience gathered in the aftermath of the 2009 L'Aquila earthquake (La Longa and Crescimbene, 2009), we organized a series of meetings with the local population. The meetings had different aims: to inform about the seismic sequence; to address people's anxieties and expectations; to promote resilience by increasing people's knowledge and self-consciousness (Lamontagne and Flynn, 2014). In particular, the psychosocial intervention was meant to.

- Share basic information about the geological setting of the area and available data about the ongoing seismic sequence.
- Provide basic knowledge about emotions, and individual and group reactions facing an emergency: psychological information was provided side by side with seismological information. The awareness of the state of arousal associated with the emergency allows to recognize the potential susceptibility to rumors, but also to acknowledge the individual and community capacity to cope with the emergency;
- Direct the population toward structures and practitioners capable of providing appropriate social and psychological support. The collaboration with the local public healthcare structures (AUSL) and institutions allowed to build a network of dedicated psychologists and psychotherapists for the population involved. Simple information on where to find these local services were provided during the meetings;
- Discuss and counter rumors and urban legend on the earthquake. A greater people awareness about these rumors contributed to lower the level of anxiety and to reduce the social tension within and between institutions;
- Encourage and promote open discussion where all stakeholders are present simultaneously. The availability of a space to discuss and exchange thoughts and fears has a strong "therapeutic" value and, when properly managed, it allows to ease tensions and conflicts, and represents an essential aid for those affected. Through this systemic approach, and thanks to appropriate listening skills, the emergency can be placed within its reference frame, and resources and responses can be oriented and calibrated according to the needs expressed by the communities affected;
- Favor the active participation of citizens and foster all the initiatives promoted by local communities.

This approach acknowledges the importance of a direct, continuous and empathetic contact with the population (Lamontagne and Flynn, 2014) and overturns a traditional perspective, according to which the authority needs to care for a sick or incapable population. In this case, the Civil Protection system stimulates curative effects toward objects that are damaged or destroyed, and toward responsible citizens: the people capable of taking care of themselves and up to take remedial actions. The community does not need to be rescued, but helped to get up again. An environment that promotes mutual exchange and that warrants timely and accurate information favors the population's engagement during the emergency and helps harmonize different stakeholders' perceptions (Wendling et al., 2013).

2.2 Listen: Rumors collection in 2012

Since the very beginning of our activities in the field, it was clear that we needed to address and counter the rumors about the seismic sequence that spread in a massive and uncontrolled way. Specific information on these rumors was considered of utmost importance in structuring the meetings of the campaign "Earthquake, let's talk about it".

Allport and Postman (1947) define rumors as faith propositions on specific (or current) topics, which pass from person to person, usually by word of mouth, with no clear evidence of their veracity. Media were shown (Ma, 2008; Dominick, 2010; Herriman, 2010; Doerr et al., 2012; Qin et al., 2015) to have a key role in their dissemination.

With the recent development of technology, especially mobile devices that have made social networks accessible 24/7, the spread of rumors has become faster than ever, regardless of the credibility of this information (Martin et al., 2021). This brings unprecedented challenges in ensuring the reliability of information. The spread of disinformation often occurs in the context of breaking news, where information released gradually often begins as unverified information. For these reasons, the automatic identification of rumors and fake news from online social media, especially microblogging sites, is a very important and current research topic (Zhao et al., 2015; Alzanin and Azmi, 2018; Fallou et al., 2022).

The scientific study of rumors began in America in 1940, when hearsay about the Second World War spread rising concerns about national security and social cohesion. The US government responded by appointing a committee meant to fight the rumors. Social scientists proposed the establishment of the so-called Rumor Clinic: operational facilities developed within the wider Rumor Project, involving several government agencies. Rumors were collected and cataloged throughout the country. Some newspapers, such as the Boston Herald, contributed to the effort, by publishing every week the most common rumor, together with a list of facts to counter it (Allport and Postman, 1947).

TABLE 1 Information requested when submitting a rumor report to characterize both the population sample and the collected rumor.

	Info about the reporting person		Info about the rumor	Indicator
P1	Name	Q1	Who told you?	Origin (O)
P2	Age	Q2	Did you tell anyone else?	Diffusion (D)
P3	Education	Q3	If so, how many people did you tell it to?	Diffusion (D)
P4	Sex	Q4	Do you believe it?	Trust (T1)
P5	Occupation	Q5	Did you check or verify it? If so, how did you check?	Trust (T2)
P6	Town of residence	Q6	How important is it to you?	Trust (T3)

TABLE 2 Descriptive information of the web users who reported rumors during the 2012 campaign.

Gender	
Males	112
Females	129
Age	
Range	da 15 a 72
Average age	42,77
Age class from 15 to 25	17
Age class from 26 to 35	39
Age class from 36 to 45	90
Age class from 46 to 55	64
Age class from 56 to 65	26
Age class from 66 to 75	5
Education	
Graduate	107
High school	114
Junior high school	18
Primary school	2
Geographic location	
Emilia-Romagna	178
Lombardia	27
Veneto	20
Altro	16

To gain information on the rumors spreading after the 2012 seismic events, a collection was carried out online, through the websites of the sponsoring institutions (the National Department of Civil Protection (DPC), the local administrative entity, Regione Emilia Romagna, our institute INGV, Edurisk, a long-term educational project on natural hazards). We devised an online form to acquire standard information about the rumors described by different participants. Web users were asked to report the rumor, together with some additional details on its origin, its perceived reliability and on its spreading patterns (Table 1). Some personal details on the users themselves completed the online survey (Table 2). From 16 June 2012 to 12 October 2012, we collected 241 rumors reports that could be subdivided into five main categories, as better described below.

2.3 Share: scientific contents to fight fears

The actions devised to contrast the rumors were designed to increase the critical sensitivity of the population involved. Critical sensitivity may indeed attenuate the rumor's strength (Chorus, 1953; Bordia and Difonzo, 2004). To reach this goal during the emergency, all the institutions involved in the public meetings with the population agreed on specific actions. Before each public meeting in a specific area, the strongest rumors at that location were discussed and analyzed to devise appropriate answers and information to be shared during the meeting. This approach meant to foster a healthy skepticism and the development of critical thinking by.

- Sharing seismological concepts and information on psycho-social aspects that influence rumors and their propagation (emotion, level of collective anxiety, uncertainty, social psychology mechanisms such as conformism);
- Promoting good practices such as careful checking on the source of information, instead of a blind trust on the news presented by traditional or new media;
- Suggesting that no institution should be considered authoritative *a priori* (not even those involved in the current information campaign).

After the emergency, the prosecution of outreach activity on themes that were perceived as relevant allowed to keep a strong and healthy relationship with the communities and their local institutions. Dissemination activities carried out in the affected area aimed at addressing the rumors described above. Ad hoc materials were prepared for display and discussed during public encounters of different kinds, including local fairs, public meetings organized by local authorities or cultural associations, science café, lessons in local schools (of all grades) and universities. We also published posts on institutional blogs INGVterremoti (Pignone et al., 2012) and gave interviews to local and national media (press, radio and television).

3 Results

3.1 Meeting with local communities

Based on the approach described above, during the 2012 seismic sequence we organized and held 44 public meetings, between June

FIGURE 3
Pictures taken during the public meetings at different locations, with the population **(A, D)** or with teachers **(B)** and personnel of the national health services **(C)**.

4 and 2 August 2012. Figure 2 shows the locations of these encounters that were attended by more than 6,300 people (Figures 3A, D). Eighteen more meetings were conducted in the following months, between September 2012 and April 2013, gathering another 700 people. This activity was flanked by more specific meetings targeting the schools since the opening of the school year, in September 2012: 800 teachers were engaged during 13 meetings (Figure 3B), together with healthcare professionals from the local structures (AUSL, hospitals, Figure 3C). Meeting duration was variable and depending on public response, ranging from 2 to over 3 h. Typically, two or three INGV researchers (both seismologists and psychologists) attended each meeting.

These meetings proved to be very useful to identify the issues that caused concern among the population. The most frequent questions were collected and updated after each meeting, and allowed to produce outreach materials specifically targeted to address people's worries. Table 3 reports some of these questions. The presence of different stakeholders allowed addressing very different but relevant topics during the same meeting, with the conversation easily spanning from the ongoing natural processes to the measure that can be taken to improve buildings' resistance to shaking. The availability of an open space with the presence of representatives of different institutions involved in the emergency allowed a public conversation that could address various causes of anxiety, related to both the ongoing seismic sequence and the efficacy of its management. Despite the tangible tension that often accompanied the opening of these encounters, the public discussion allowed expressing fears and doubts and most of the times granted the establishment of a positive bond of trust among various stakeholders involved.

3.2 Analysis and strength of the rumors

We classified the collected rumors into five categories, based on their contents: explanatory, conspiracy, catastrophic, paranoid (i.e. subject to persecution mania), and optimistic. Some of the rumors could fall in two or more categories (see Table 4), and in those cases we arbitrarily assigned the rumor to the first category listed. Figure 4A illustrates their relative proportions, with most of the rumors falling within the first three categories (explanatory, 35%, catastrophic, 29% and conspiracy, 26%), and a few exceptions grouped as "other effects". This prevalence of rumors with explanatory, catastrophic and conspiracy nature does not change even if rumors falling into more categories are assigned differently, to their second or third category. To classify and compare different rumors, we further analyzed the dataset assigning a score to the origin (O), diffusion (D) and trust (T) of each rumor. We identified three possible origins for the rumors: institutional sources and research institutes; national and local media; individuals and social media. To each source category we assigned a different degree of reliability, ranging from trustworthy (when the rumor originates from institutional sources, score O=1) to unreliable (single individuals, or social media, score O=3). Figure 4B shows how most of the rumors originate from untrustworthy sources. The diffusion of the rumor was assessed based on the number of people the rumor was repeated to, after being heard. We defined three levels of rumor spread (and associated scores): no diffusion (D=1), when the rumor was not reported to anyone else; sharing with a maximum of 6 people; and sharing with more than 6 people (score D=3). The threshold of 6 people stems from the theory of "six degrees of separation", according to which any person may be connected to any other person in the world through a chain of acquaintances with no more

TABLE 3 List of common questions raised during the public meetings organized during and after the 2012 Emilia seismic sequence.

n	Question
1	Is there a historical cyclicity in earthquakes occurrence?
2	Are there any links between the various earthquakes occurring in Italy?
3	What are the most dangerous areas in Italy from a seismic point of view?
4	Why did we hear a roar with the strong earthquakes?
5	What is the magnitude of an earthquake?
6	What is the difference between magnitude and intensity?
7	Why do other institutions attribute a different magnitude to this earthquake?
8	Why are there different types of magnitudes to measure an earthquake?
9	Are public funds for the reconstruction calculated on the basis of the recorded magnitude value?
10	According to the seismic hazard map of Italy, this area was not supposed to be dangerous. Is this true?
11	How was this area classified from a seismic point of view?
12	No one told us that our territory was seismic. Why? Whose responsibility, is it?
13	How do you define the seismic classification of a territory?
14	How much does the kind of subsurface rocks influence the effects of an earthquake?
15	Have the Po plain sediments cushioned the tremors?
16	Could this earthquake have changed the morphology of the Emilia region?
17	Where did the sand come from? (Referred to liquefaction episodes that drove underground sediment at the surface)
18	Is the underground now empty?
19	Can drilling cause an earthquake?
20	Does the subsidence of the land (associated with water and hydrocarbons extraction), contribute to the occurrence of the earthquake?
21	Is the Emilia sequence extraordinary, or is Italy exposed to close events?
22	Why did the second earthquake [of 5/29] do more damage than the first?
23	Why was the second quake stronger even though it was of a lower magnitude?
24	According to the communiqué of the Major Risks Commission [held on June 7], will there be a new earthquake in the province of Ferrara?
25	What are the rules of conduct to follow before, during and after the earthquake?
26	Why do reinforced concrete houses also collapse? When can a building be considered anti-seismic?
27	How can I verify the safety of my home?
28	If my house was badly built, what can I do to improve it?
	What can I do, alone, to make my home safer?
29	If seismic retrofitting is expensive, are there other low-cost interventions that I can implement to make my home safer?
30	What interventions can be made on a house that has suffered damage?
31	Are the ongoing safeness checks on buildings reliable?
32	Could the buildings that were found to be accessible for inspection after the two strong tremors have suffered damage with the seismic sequence in place?

(Continued in next column)

TABLE 3 (*Continued*) List of common questions raised during the public meetings organized during and after the 2012 Emilia seismic sequence.

n	Question
33	Following an inspection, my house was judged to be viable. After the numerous events that have taken place these days, can my home still be considered safe?
34	What is the procedure for checking the building in which a production activity is located, such as sheds?
35	Does the same procedure for safeness check for production activities, such as warehouses, also apply to schools and hospitals?

than five or 6 intermediaries (Milgram, 1977). While 33% of the rumors were repeated at least a few times, half of them were shared with more than 6 people (Figure 4C). The last three points of the survey (Table 1) were used to measure the confidence in the rumor. This was done combining three different indicators meant to: measure the degree of belief in the rumor, according to the rumor reporter (T1); check if the content of the rumor was verified by the reporter by consulting other trustworthy sources (T2); and the importance of the rumor content, according to the reporter (T3). The degree of belief T1 was assessed by asking the reporter "Do you believe it?". The five possible answers (not at all, very little, little, much, very much) were converted into a numeric value ranging from 1 (little, or no trust) to 3 (high degree of belief). The indicator T2 was established from the responses to the question "Did you check or verify the rumor content?", T2 values could range from 1, when the content was verified by consulting an authoritative source, to 3 if no check was made. The indicator T3 was computed by asking the questionnaire filler "How important is this content for you?", and ranged from 1 (not important at all) to 3 (very important).

The reporter's degree of belief in the rumor was then computed according as:

$$T = \frac{T1 * T2 + T3}{3}$$

Obtained T values range from 0.67 to 4 and were then classified into three levels of trust (low, medium and high), according to their T values within this range (Figure 4D). In most of the cases, the responders have a medium or high level of confidence in the rumor, while only 30% of the rumors are considered unreliable by the reporting person.

In order to identify the most frequent and dangerous topics, we used the indicators described above to compute the rumor strength (La Longa el al., 2014). According to Allport and Postman (1947), the strength of a rumor, $\boldsymbol{R}$, is the product of the subject relevance, $\boldsymbol{S}$, and its degree of ambiguity, $\boldsymbol{A}$. In our case, the subject of all rumors is always the earthquake and, given its major impact on people's lives at the time of the survey, we assigned $\boldsymbol{S} = \boldsymbol{1}$ to all rumors. More details about the limits and strengths of this approach are provided below, in the Discussion section. Rumor's ambiguity was computed as a sum of the scores attributed to the reliability of its source (O), its diffusion (D) and the confidence in the rumor itself (T):

$$R = O + D + T$$

Table 4 shows an excerpt of the collected rumors, together with their classification according to rumor type, origin, diffusion, trust and strength. The distribution of strength computed for all collected rumors is shown in Figure 5, while Figure 6 shows the distribution of rumors strength

TABLE 4 Excerpt from the list of collected rumors, classified according to their type (explanatory, catastrophic, conspiracy, positive, paranoid, other); their origin (O); diffusion (D), Trust (T) and strength (R). See text for discussion.

	Classification	Rumor description	O	D	T	R
1	Explanatory catastrophic	*The underground gas reservoir could easily explode with a new seismic event*	3	1	3	7
2	Conspiracy	*The strongest events had a magnitude larger than officially declared*	3	3	3	9
3	Explanatory	*The earthquake is due to fracking or to "seismic" exploration; the government lowers the magnitude to avoid refunds*	3	3	2	8
4	Catastrophic	*We expect another fault will generate similar events*	2	1	2	5
5	Catastrophic	*Mice, rats and moles are dying because of an underground temperature increment (up to 50 °C). This indicates that a volcano is forming in the Po Plain (just as in the 1997 LA movie)*	3	1	3	7
6	Explanatory	*Landslides (a few m deep) occurred last year near Sant'Agostino while explosions were heard, likely related to underground fracking*	3	2	3	8
7	Explanatory	*They say that the seismic swarm is due to the underground gas storage*	3	2	3	8
8	Other	*I've heard of a solar storm that will end in 2013, which could affect earthquakes*	2	2	3	7
9	Catastrophic	*Very likely, we'll have another strong earthquake due to a third fault that has not completely slipped yet*	3	2	3	8
10	Explanatory	*A lot of fishes died near Bondeno, after the May 20 event, because of the gas that were released and reached the water at the surface*	3	2	2	7
11	Explanatory	*An oil company exploded underground charges to create natural reservoirs for gas storage. They removed their installation overnight*	3	1	3	7
12	Other	*The earthquake is related to heat*	3	1	1	5
13	Catastrophic	*If it is very strong, it will last 3 years*	3	3	3	9
14	Other	*After the shocks, one could smell sulfur*	3	1	1	5
15	Explanatory	*Gas injected into groundwater causes earthquakes. There is not enough control on private companies*	2	1	2	5
16	Explanatory Conspiracy	*Earthquakes are due to the work carried out by "the Americans" at the Rivara gas storage site. They remove their equipment right before the event*	3	1	3	7
17	Explanatory	*The earthquake was caused or enhanced by gas extraction, which left void space underground*	3	1	1	5
18	Conspiracy	*The Emilia earthquake was not M 5.9 but 7.5, according to NASA and other international institutions*	3	1	2	6
19	Catastrophic	*It's getting closer and will be here soon*	3	1	1	5
20	Other	*A pigeon breeder reports that birds flew away the day before the earthquake and returned past mid-June*	3	3	3	9
21	Explanatory	*In Cremona earthquakes cannot happen because of the alluvial terrain. No strong earthquake ever struck here*	3	3	2	8
22	Explanatory Positive	*I've heard that the activity at the mud volcano in Nirano was stronger days before the earthquake. This could be a potential precursor*	3	2	3	8
23	Paranoid	*Too much badness in the world, God punished us*	3	1	1	5
24	Conspiracy	*The earthquake is caused by the HAARP antennas that the US government uses to study the atmosphere*	3	3	1	7
25	Catastrophic Paranoid	*An old lady dreams of her brother who says that between October 7 and 8 there will be another earthquake that will occur between Bologna and Ferrara, on the other fault. She was ready to leave before the first event thanks to her brother's warnings*	3	1	1	5

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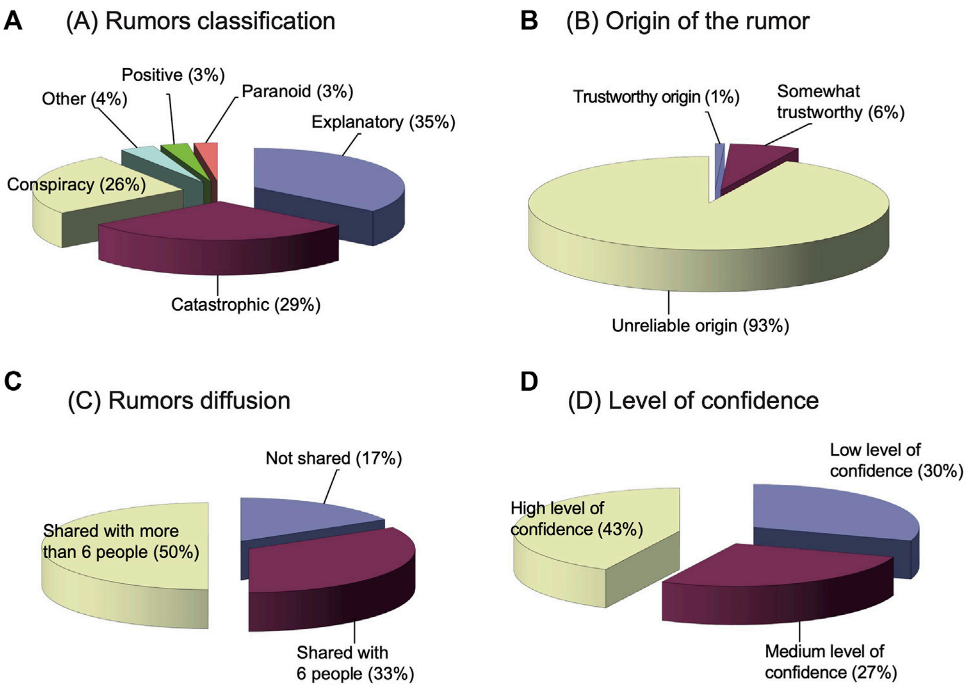

FIGURE 4
(A) Rumors classification. Collected rumors were classified in different categories based on their content. The most common are: explanatory (when the rumor focuses on the cause of the earthquake); catastrophic (when it suggests disruptive outcomes); conspiracy (when the emphasis is on alleged truth distortion by media or public institutions). **(B)**. Reliability of the rumor's source. We considered the institutions (such as the national Civil Protection Department) as trustworthy sources, while individuals and social media are considered unreliable. According to this classification, most rumors originated from unreliable sources. **(C)**. Rumor diffusion indicates if and how much the reported rumor was shared with other people. Most rumors had ample diffusion. **(D)**. The level of confidence, or trust, expresses how much the survey respondents believed in the reported rumor. Most rumors are accompanied by medium or high level of confidence.

for different rumor subjects. The main topics are better described below, and include: the occurrence of anomalous phenomena (often considered possible precursors); the anthropogenic nature of the seismic sequence (supposedly triggered by fluid injection or extraction); the actual forecasts of imminent seismic events; and the existence of a conspiracy to conceal the real magnitude of seismic events. The figure shows that most of the strongest rumors (R = 9) fall in the subject of an "anthropogenic triggering" of earthquake, but strong rumors are present in all subjects. Table 5 lists all the strongest rumors collected (R = 9) and the recurrent topics are described in the discussion. Specific outreach content was devised to debunk these rumors.

3.3 Sharing scientific knowledge

Scientific information was made available in the form of maps, geologic sections, images and pictures of present and past seismic events, sketches or diagrams, written text. These materials were displayed or distributed on site as posters, booklets, leaflets, bookmarks, or projected on screen. The topics included details on the seismic sequence: maps showing the distribution of epicenters and their magnitude were particularly appreciated, together with maps illustrating the temporal evolution of the seismicity. We found it important to provide information on the geology and tectonic setting of the region: geological sections and maps were used to describe the thrust and folds buried underneath the Po plain sediments, and to justify the occurrence and position of the seismic sequence. Historical seismicity completed this geological picture of the region: maps showing the location and magnitude of the historical events allowed a comparison with the most recent activity, while the temporal distribution of the main sequence helped to constrain the timescale of tectonic plate interactions. In some specific cases, even written explanations proved useful. By keeping the text simple and concise, we could provide clear definitions for some relevant concepts that easily enter the public discourse about seismicity without being fully explained: people showed appreciation for bookmarks describing the difference between magnitude and intensity, or reporting the different grades of the historical Mercalli scale. After the controversy about the alleged anthropic origin of the earthquake, we also provided simple definitions for terms like "fracking" and "gas storage", or explained the difference between "triggered seismicity" and "induced seismicity" (National Research Council 2013). These definitions were complemented by brief information on where (and since when) gas and oil are actually exploited or stored in the affected region. This kind of information gained a lot of attention during public events, despite their format (written explanations) apparently not appealing in a busy context. The short length of each body of text and the relevance of the topic at that time compensated for the little charm of the presentation.

Outreach efforts also focused on the phenomenon of shallow ground heating, commonly associated with diffuse degassing and bubbling well water (Capaccioni et al., 2015 and references therein). The occurrence of these phenomena captured the attention of a frightened population and has entered the local news several times

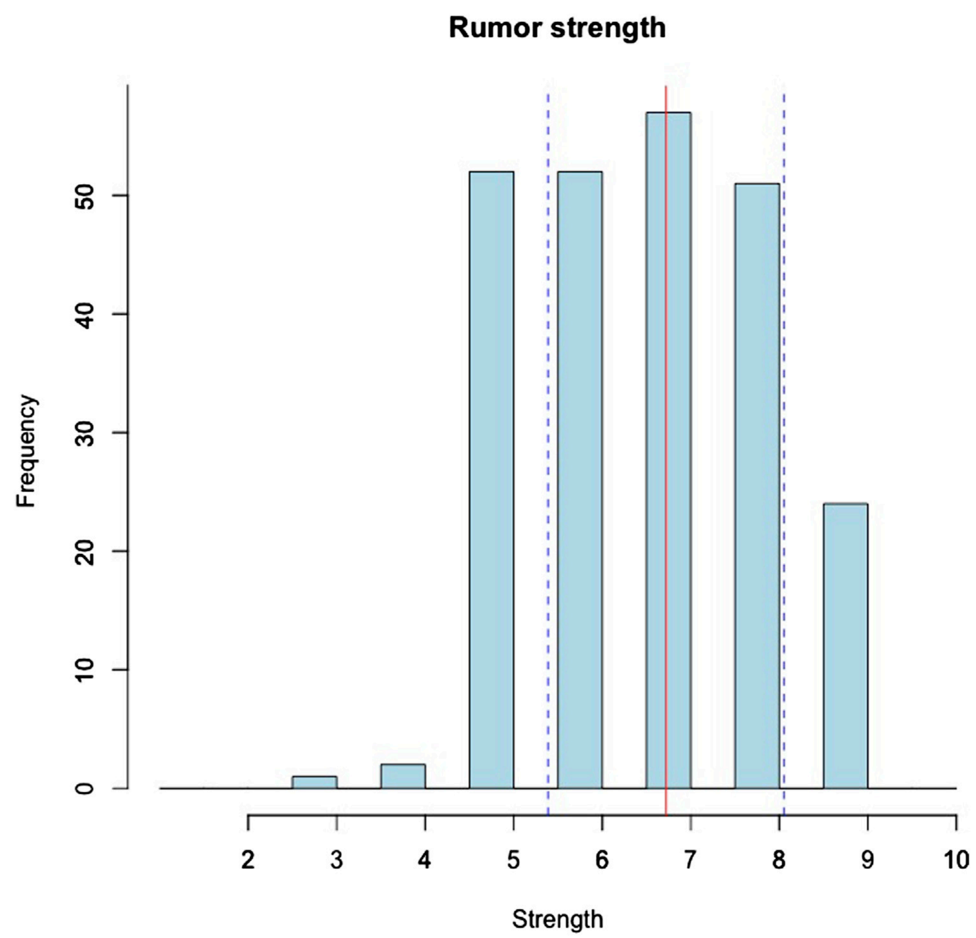

FIGURE 5
Rumor strength distribution. Vertical lines indicate the mean value (red) and standard deviation (blue, dashed). The strongest rumors (R = 9) are more than one standard deviation above the mean. They are listed in Table 5.

since the 2012 sequence. Repeated episodes, sometimes accompanied by the death of small animals, fed the rumors about their potential role of these anomalies as precursors of impending seismic activity. The phenomenon, and the public attention about it, motivated a scientific study that was carried out by the University of Bologna, in collaboration with INGV (Capaccioni et al., 2015; Nespoli et al., 2015). This study showed that observed changes in ground temperature and gas composition are well explained by an exothermic oxidation of biogenic methane, which is abundant in the soil of the Po plain. This explanation does not imply a direct connection with the seismicity in the area, as the phenomenon occurs any time ambient conditions are favorable to methane oxidation. These scientific results were shared during public meetings, and commented during interviews released to local media and were described in a post on the institutional blog INGVterremoti (https://ingvterremoti.wordpress.com/2015/11/18/cosa-sappiamo-delle-terre-calde-di-medolla/).

4 Discussion

During the emergency phase, direct contact with the population and local institutions (administrative and health institutions, cultural associations . . .) proved to be a strategic asset to ensure prompt and effective communication among the different stakeholders involved. These direct contacts had an important role in building mutual trust and dialog with the citizens.

The analysis of hearsay provides a special point of view on widespread fears and feelings about the earthquake. The relation proposed by Allport and Postman (1947) to compute the strength of rumors is certainly a good starting point for a preliminary assessment, even though this approach never went through a proper validation and critical analysis. One of the main criticisms risen about this approach regards the link between the topic of the rumor and its strength: according to some authors the importance and ambiguity of the theme cannot be considered a correct predictor of the rumor strength, as other features (such as the anxiety of the individuals involved) need to be considered. The criticism came primarily from the fact that the basic law of rumor postulated by Allport and Postman (1947) was not empirically grounded in any rumor research, but was adapted from the earlier work of McGregor (1938) on factors influencing predictive judgments (Rosnow, 1980). One difficulty with the basic law of rumor was that the factor of “importance” was elusive and not easy for researchers to operationalize. Also of concern was that the basic law of rumor ignored the emotional context of rumor. Based on subsequent research findings, Rosnow (1991, 2001) proposed a modified theory in which rumor-mongering is

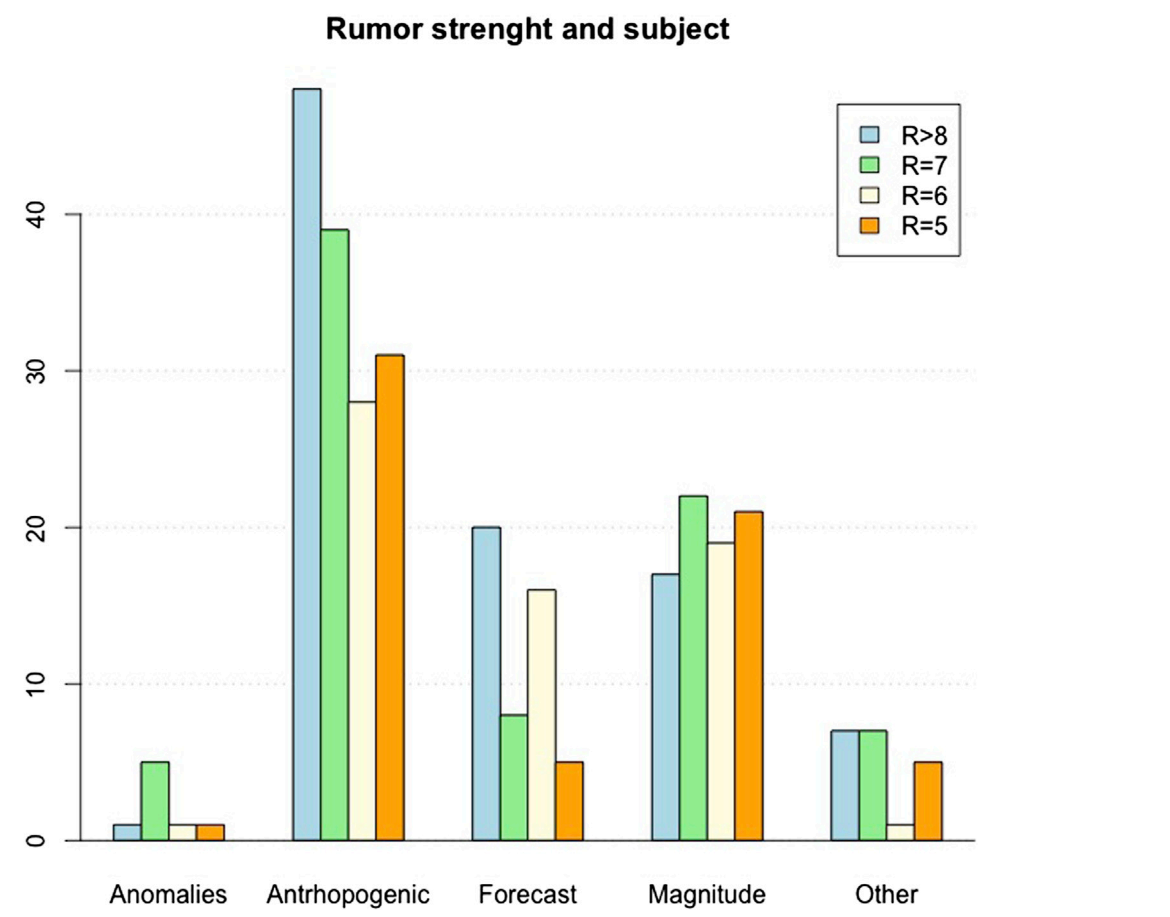

FIGURE 6
Distribution of rumors by strength and subject. Most of the rumors revolve around the anthropic nature (146 rumor reports, with an average strength of 7.0) and the supposedly hidden magnitude of the earthquakes (79 rumor reports, with average strength 6.7). Other rumors forecast future events (49 reports, average strength 7.3) or report the occurrence of anomalous phenomena, possibly related with the seismic sequence (8 reports, average strength 6.9). Twenty other rumors regard other topics (average strength 7.2).

viewed as an attempt to deal with anxieties and uncertainties by generating and passing stories and suppositions that can explain things, address anxieties, and provide a rationale for behavior. At a moral level, we can usually distinguish between two types of rumors (Rosnow et al., 1986), those invoking hoped-for consequences (wish rumors) and those invoking feared or disappointing consequences (dread rumors), but finer distinctions within each category have been described as well (e.g., Difonzo & Bordia, 2000). Another addendum is that people have a tendency to spread rumors that they perceive as credible (even the most ridiculous stories), although when anxieties are intense, rumormongers are less likely to monitor the logic or plausibility of what they pass on to others (Rosnow, 2001). More recently, the extensive use of social media allows to gather significant amounts of data on rumors' spreading. Large data sets are used to explore the rumors' propagation across the community using natural language processing and the mathematical characteristics of complex networks (Cheng et al., 2021).

In our case, however, we limit our analysis following the Allport and Postman approach. The theme of earthquake in the aftermath of the seismic sequence certainly had a strong societal importance in the impacted area, and the individuals involved collectively suffered a high level of anxiety. We therefore applied the Allport and Postman formula focusing on the degree of ambiguity of the theme, and we used three indicators (source, diffusion and trust) to compute the rumor's strength. This allowed us to identify and address the strongest rumors.

Most of the rumors that spread up immediately after the May 20 event focused on three main topics: the anthropogenic trigger of the seismic sequence, the prediction of forthcoming earthquakes, and the real (higher) magnitude of the events. The strongest rumors were carefully analyzed and debunked during public meetings and accompanied with sound scientific information.

4.1 The manmade earthquake

The theme of induced seismicity, in particular, stirred the public discussion for months, in a region where both the exploitation of geo-resources (mostly gas and minor oil) and gas storages within aquifers have been going on for decades. Not long before the seismic sequence started, a British corporation submitted a project to open a new gas storage facility near the town of Rivara, very close to the epicenter of the May 29 main shock. While the proposal was eventually rejected by local and regional authorities, the corporation could perform the

TABLE 5 List of the strongest rumors collected (R = 9).

Classification	Rumors
Conspiracy	*The strongest events had a magnitude larger than what officially declared*
Catastrophic, paranoid	*This sequence is just a precursor: the biggest event still has to come and will create a new mountain where now is the Po plain. Remember the date 21 December 2012: a millennial cycle closed then and people, things, animals from that cycle will be swiped away*
Explanatory	*Gas and oil extraction in the area, the emission of water at high pressure and drilling and storage of billions of cubic meters of gas in a huge underground storage. This intervention is called fracking and can be the cause of seismicity. This is well known and is why in the United Kingdom they are closing the reservoirs. These activities broke a natural equilibrium that was established in the past*
Explanatory	*The most common rumor about the earthquake is that fracking is responsible for it*
Explanatory	*They say the earthquakes were caused by underground explosions in natural caves underneath Rivara and Finale Emilia, triggered to study the effects with the aim of exploiting the caves for gas storage. According to the rumor, these explosions would have awakened our sleeping fault*
Conspiracy	*The May 20 event had a Magnitude 6.1 instead than 5.9 as mentioned by mass media and INGV. A web search shows that other institutions suggest magnitudes higher than 6. Why are Italian estimates always lower?*
Explanatory, conspiracy	*The cause of earthquakes are the obscure drillings related to gas storage in Rivara. Magnitude is supposed to be much higher than 5.9 (6.3 or 7.3). This information is not shared to prevent the State from repaying the damage*
Positive	*The sequence may last a year or more, with events of similar magnitude. In the 1,500 the lords of Ferrara lived in shelters for 4 years because of the earthquake*
Conspiracy	*The power of these shocks was stronger than what was declared. Otherwise, the State should have paid more than what is available. Who works in civil protection knows this*
Conspiracy	*all major shocks were officially under 6 but in reality, they were stronger, in fact at least one was lowered later. This is a strange case, as it happens, they do not pay us just for earthquakes below six; they say they were lowered on purpose*
Conspiracy Explanatory	*This earthquake is different from the others; we are in a non-seismic area and therefore its occurrence is strange; then all those shocks and they just happen to be where they're drilling. There are drilling exactly where the earthquake happened and they could have told us since they triggered it*
Catastrophic	*If it is very strong, it lasts 3 years*
Explanatory	*Drillings for gas storage stimulate earth crust movements*
Explanatory	*The shock in Ravenna was caused by drilling for gas and oil*
Conspiracy	*The rumor is that the magnitude of the 29 May event was much greater than reported (up to 6.8–7.4)*
Explanatory Conspiracy	*Fracking responsible for Emilia earthquakes, with approval of the Monti government. This technique is banned in several countries like France. The population was kept in the dark about the danger, even after the event on 17/07/11. Now the menace of a third fault about to break. But we live in the Po plain where the seismic hazard is zero. This is what they always told us. They will not pay us as they did in case of other earthquakes. It's time to stop it*
Other	*A pigeon breeder says that the day before the earthquake a group of birds went away and returned only in the middle of June*
Explanatory Conspiracy	*Shocks are probably caused by drilling in Rivara. Excavations are protected by the Army, also the American one. Who signed the project cannot be found. In Solara, near Modena, fire peaks spreader alternating with high water jets from the ground*
Positive	*I heard that the top manager of your organization is a P.E. sent there by the Minister of Education*
Conspiracy	*I've heard more than one person that the magnitude of the May 20 event was higher than that reported by INGV.*
Conspiracy	*With increasing insistence, we hear and read that the earthquake of 5/20 had a magnitude greater than 6 and that it was purposely "downsized" as the Italian government, in the first case, would have had to provide for the full compensation of all damage suffered*
Paranoid	*You're losers, what the fuck you wanna monitor? Everybody knows the secrets you hide,,,, Be ashamed to live*
Catastrophic	*Between 13 and 16 of July another earthquake will occur with magnitude between 4.5 and 6.1 in Emilia Romagna*
Explanatory	*Many different hypotheses about the causes of this earthquake ..... From the preliminary studies conducted on the ground for the construction of the rivara deposit ..... to fracking used to extract materials from the subsoil .... and in general from the extraction of gas or oil ..... up to "targeted" scientific experiments currently underway on our territory (they did not tell me what purpose) .... ah! also the famous underground Apennine ridge that moves to emerge and of which we are the summit ..... coincidentally ...*

required preliminary studies and geophysical prospecting. Sparse information on this industrial plan quickly merged with hearsay on the damage caused by fracking (which was never permitted in Italy), resulting in a confused picture where dangerous operations, involving gas and underground explosions, were carried out to benefit unspecified interests. Despite the lack of industrial activity at this specific site, the public concern was such that the regional authorities appointed a commission (ICHESE) to address the issue. The committee report concludes: "the Commission believes that it is highly unlikely that the activities of hydrocarbon exploitation at Mirandola and the geothermal activity at Casaglia have produced sufficient stress change to generate an 'induced' seismic event. While it cannot constitute proof, the current state of knowledge and all the processed and interpreted information does not allow ruling out the possibility that the actions involved in hydrocarbon exploitation in the Mirandola field may have contributed to 'trigger' the Emilia seismic activity". The Committee continues by stating: "The study does not indicate any evidence which can associate the Emilia 2012 seismic activity to the operation activities in Spilamberto, Recovato, Minerbio and Casaglia fields, whereas it cannot be ruled out that the activities carried out in the Mirandola License area have had a triggering effect". Finally, a brief note regards communication, suggesting that it is "critically important to implement an Outreach and Communication Program targeting local residents/administrative authorities so that they can gain confidence that operations are being managed optimally". (ICHESE, 2014).

4.2 The earthquake about to happen

The rumor about a forthcoming major earthquake, predicted by various individuals or institutions, was also very common and spread out quickly after the main shocks on May 20 and 29. Our survey allowed us to identify three different versions of this catastrophic rumor. The first version is simple: a major shock is forecasted at a certain time. The rumor started on 31 May 2012 and circulated by word of mouth (telephone calls, texting and social media) in various urban areas (Bologna, Modena, Reggio Emilia, Mantova). In some cases, it was intentionally spread to allow actual profiteering, with people pretending to be civil protection operators and inviting citizens to evacuate their houses. In one case, the rumor led to the evacuation of the National Bank (Banca d'Italia) offices in Bologna. The resonance of this episode, which involved an authoritative institution, contributed to increase the psychosis, leaving abundant tracks in local press and social media. The strength of the rumor was such that the National Department of Civil Protection, the local public authorities and INGV had to release official statements to counter it. These actions lowered the public's concerns and, together with the lack of seismicity at the predicted time, could finally downgrade the rumor to its actual nature. On 1 June 2012, the district attorney's office announced the possible opening of a legal procedure for false alarm.

A second version of this rumor was more sophisticated and malicious, and was triggered by the so-called Northern Independent Center for Seismology (CSIS). CSIS created a blog and published a video forecasting a strong event between July 13 and 16, 2012, roughly in the same area hit by the May sequence and with magnitude between 4.5 and 6.1. The video gained about 40,000 visualizations on YouTube. Furthermore, in an attempt to gain credibility, the rumor was also published on a faked copy of a very popular blog, and thanking the author (Beppe Grillo) for posting the rumor.

The third version was more articulated and refers to an alleged earthquake prediction attributed to a parish priest in Massa Finalese. According to the rumor, the Virgin Mary appeared to the priest in a dream, announcing a devastating earthquake due to occur on Saturday, September 22, before 9 a.m. The rumor spread out quickly, especially around Ferrara, Modena, Bologna and Mantova. Different accounts attribute the vision to other priests in the area, or to a parishioner, and indicate different sites (Ferrara) or timing (September 29) for the predicted earthquake. The rumor was accompanied by hearsay according to which the parish priest was about to be arrested or beaten by angry citizens, all baseless news. Fact checking on the site allowed to tie the rumor to a homily by the priest in Massa Finalese, during a mass at the end of June 2012. In the homily, the priest considered that the worst period for the people hit by the seismic sequence in May, was going to be in September, with the re-opening of the schools and the resumption of the customary habits, and with lesser attention from the rest of the country.

The theme of earthquake prediction is closely associated with the issue of precursory phenomena. Hearsay (sometimes reinforced by local media) often highlighted the occurrence of "clear" signs of a forthcoming earthquake that accountable institutions (scientists, civil protection) either fail to recognize or do not address properly. Popular precursors include strange animal behavior or particular weather conditions. A particular phenomenon that periodically raises public attention in this area is the increment of ground temperature, sometimes associated with heated well water, bubbling with gas (Bonzi et al., 2017). In some cases, the combination of heat and gas can cause the death of crops or small animals (fishes, in particular). These episodes are rather common in the area: they are found in historical chronicles and even entered the local toponyms (such as "Terre Calde", Hot lands). The long seismic sequence, however, promoted a renewed attention to the environment and its changes. Studies prompted by this renovated attention finally provided a scientific explanation for the phenomenon which is totally unrelated to the seismic sequence (Capaccioni et al., 2015; Nespoli et al., 2015). Nevertheless, these events are noted and still interpreted as potential precursors of future events.

4.3 The concealed magnitude of the events

The alleged falsification of the magnitude values by the institution in charge of seismic surveillance (INGV officials, in particular) is another persistent false news. This rumor had different versions, and stems from the observation that the magnitude values released by INGV may change with time or may not coincide with estimates performed by other, real or alleged, international agencies (from France, Poland, USA …). Magnitude values reported abroad tended to be higher than those officially released by INGV (5.9), with values ranging from 6 (according to USGS) and 6.1 (provided by the European Agency CSEM-EMSC) up to 7.3. A version of the rumor mentions an amateur seismologist living in Novi, near Modena (or a pharmacist from Carpi, or Mirandola) who could "record" magnitude values well above 7, with his own two instruments located on the second floor in his house. According to all these rumors, INGV conspired to keep the magnitude below 6, as this would be a threshold value above which the State would fully cover for the damage. According to another version of the rumor, the Civil Protection promoted a major reformation just 1 month before the earthquake (perhaps knowing it was about to happen) only to prevent any compensation of the damage caused by natural disasters (this position being eventually retracted after the event, for mere political expediency). This hoax is not new and is directly tied to the L'Aquila earthquake, in 2009. At that time, coverage of full damage was only granted for those towns where the macroseismic intensity was found above the VI grade of the MCS scale. The confusion between magnitude and macroseismic intensity raised malicious suspicions against the normal process of magnitude manual revision that is always carried out immediately after major events.

5 Conclusion

In the aftermath of the 2012 seismic sequence in Northern Italy, INGV carried out an extended outreach effort to address the need for information of the impacted population.

The impacted community and their administrative authorities received these diverse outreach activities with great favor. Even though we cannot provide a quantitative measure of the efficacy of these activities, the overall response of the public suggests that timely outreach was both appreciated and needed.

The organization of several public meetings were possible thanks to the fruitful collaboration between the Civil Protection, INGV, the representatives of the local communities, the regional network of healthcare assistance, and the involvement of local volunteering associations. The combined efforts of these stakeholders contributed to the establishment and formalization of a good practice that promotes effective communication during emergencies. Preliminary contacts with local representatives proved particularly useful to identify the specific themes or topics that were of interest for each community. This allowed us to prepare and share scientific or psycho-social contents that were both relevant and timely for those participants, at the time of that particular meeting. An informal structure of the public encounter, that leaves ample time for questions and open discussion, and where the presentation of scientific information is limited to a brief, initial overview, proved to be successful in building a positive relationship among all participants. The identification of fears and beliefs allowed to contain and counter uncontrolled rumors and prevent them from driving the public discussion. Future studies, encompassing a quantitative analysis of rumors diffusion and the comparison with other case studies, such as the recent SARS-COV2 pandemic, will provide further tools to counter misinformation.

The approach based on multiple meetings with the population has been followed in 2014 (Camassi et al., 2014), in the occasion of minor seismic sequences, as in the case of Gubbio, when about 400 events (mostly with magnitude below 3) were recorded between December 2013 and December 2014. The strongest event (Mw 3.9) was recorded on the 22nd of December 2013 (Marzorati et al., 2016).

More recently, the Amatrice seismic sequence taking place in 2016, has proven more difficult to address in terms of emergency communication, given its dramatic consequences over a very wide area in Central Italy. The sequence initiated on the 24 August 2016 with the Mw 6.0 Amatrice earthquake and was followed on 26 October 2016 by the Mw 5.9 Visso earthquake; the largest event, the Mw 6.5 Norcia earthquake, occurred on the 30th October. Each mainshock was followed by sustained aftershock activity. In that occasion, 24 meetings were organized with several schools in the area, involving almost 1,500 teachers and parents. Despite greater logistic difficulties, the 2016 experience confirms the positive outcome of the open interaction between scientists, civil protection and local communities.

Planning and participating in these public encounters favored mutual trust and reciprocal knowledge, improving the coordination among the different components of the civil protection system. The direct interaction with the communities affected provided important hints for the development of outreach strategies that go well beyond the emergency phase, and contributed to defining the scientific contents for awareness campaigns and educational activities.

These experiences affected the way in which we develop educational materials, promoting a transition from science-oriented contents, reflecting our interests and our results, to society-oriented contents, designed to address people's questions, accounting for their fears and understanding of geological processes.

Data availability statement

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent from the participants was not required to participate in this study in accordance with the national legislation and the institutional requirements.

Author contributions

MC and FL conceived and organized the rumors' collection and analysis. RC participated in the organization of the outreach campaign "Terremoto, parliamone insieme" and MT conceived and wrote the first draft of the manuscript. All authors participated in the public outreach campaign, attending some (MT) or many (MC, RC, EE, FL) meetings, collecting FAQs and elaborating outreach materials for the campaign. All authors were involved in the analysis of the rumors and contributed to writing the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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