



Participatory approaches promoting flood risk knowledge and self-protection behaviours in Liguria, northern Italy

Giuseppe Esposito¹, Rosa Maria Cavalli¹, Ginevra Chelli², Ivan Marchesini¹, Daniela Molinari⁴, Roberto Passarella³, Paola Salvati¹, Simone Sterlacchini², Debora Voltolina², Marco Zazzeri², Marco Milella³

¹Istituto di Geoscienze, Consiglio Nazionale delle Ricerche (CNR-GEO), Perugia, 06128, Italy

²Istituto di Geoscienze, Consiglio Nazionale delle Ricerche (CNR-GEO), Milano, 20126, Italy

³Dipartimento di Filosofia, Scienze Sociali, Umane e della Formazione, Università di Perugia, Perugia, 06123, Italy

⁴Dipartimento di Ingegneria Civile e Ambientale (DICA), Politecnico di Milano, Milano, 20133, Italy

Correspondence to: Rosa Maria Cavalli (rosamaria.cavalli@cnr.it)

Abstract. Participatory approaches are increasingly recognized as effective strategies for enhancing risk awareness and promoting inclusive decision-making processes in the context of natural hazards. Nevertheless, communicating risk to the general public remains a significant challenge, often facing indifference, low engagement, or resistance. This study investigates the potential of co-designed and participatory methodologies to strengthen flood-risk communication and awareness among young people in two towns in northern Italy. High-school students, including participants with disabilities, were actively engaged in the reconstruction of past flood events and evaluation of residential buildings' physical vulnerability through field surveys, data collection, and data analysis activities supported by web applications developed through co-design. In addition, the students took part in educational pathways integrating visual elements, colours, emotions, narratives, and sounds, thereby fostering a multisensory understanding of flood-related phenomena. Insights from student participation and interactive discussions, cognitive and emotional engagement, high-quality co-designed outputs suggest as these experiential and participatory approaches substantially contributed to students' understanding of flood dynamics, geo-hydrological risk, and the impacts of climate change. In addition, successful peer-to-peer dissemination experiences highlighted the emergence of students as effective intermediaries in risk-communication processes, facilitating peer-to-peer knowledge exchange and promoting dialogue with local communities and decision-makers. Overall, this work underscores as co-designed initiatives not only enhance knowledge and awareness of geo-hydrological risks but also encourage proactive behaviours and strengthen long-term resilience at both individual and community levels.

1 Introduction

Participatory approaches are increasingly recognised as a key strategy for engaging the public throughout the disaster management cycle (Newig et al. 2014; Challies et al. 2016). In particular, bottom-up citizen initiatives can foster adequate levels of awareness, strengthen risk perception, and promote self-protective behaviours, particularly within communities exposed to geo-hydrological hazards such as floods and landslides. For instance, Samansiri et al. (2023) highlighted that failures in existing flood-warning and response mechanisms are often associated with limited public understanding of warning information and insufficient use of participatory approaches to address community concerns. Similarly, Scolobig et al. (2012) identified a gap between flood-risk awareness and preparedness, limiting the effectiveness of disaster response. Comparable weaknesses have also been documented for landslide risk, particularly in countries with constrained financial and technical resources (Ramesh et al., 2023).



37 As exposure to geo-hydrological hazards is expected to increase across large regions worldwide (Winsemius et al., 2016;
38 Wood et al., 2020), resilience capacities based on adaptation, preparedness, and awareness are becoming increasingly
39 important for disaster risk reduction. Public authorities are responsible for ensuring safer environments for at-risk populations
40 and therefore require effective tools to prepare both individuals and communities for emergency situations (Minucci et al.,
41 2020). Within the field of geo-hydrological risk reduction, interdisciplinary research teams (Klein, 2014), integrating expertise
42 from both natural and social sciences, have successfully developed methodologies to assist this task (Acuña et al., 2021; Evers
43 et al., 2016; Smith et al., 2022; Lempert et al., 2023; Mezzacapo et al., 2025). Participatory approaches emerging from
44 interdisciplinary research are vital for supporting informed decision-making. They do this by providing communities with
45 accessible information on hazards, uncertainties, and risk-management options, as well as the distinct benefits of utilizing
46 such knowledge (Wong-Parodi et al., 2014; Wong-Parodi and Small, 2021). According to Lindell and Perry (1992), proactive
47 decision-making encompasses five stages: attention, comprehension, acceptance, retention, and action. While increasing risk
48 knowledge is a prerequisite for progressing through these stages, the effectiveness of this process strongly depends on the
49 adopted communication strategies. Additional factors influencing individual and collective decision-making include socio-
50 demographic and economic conditions, financial resources, preparedness levels, trust in public institutions, and previous
51 disaster experience. Among these, direct experience of disasters has been recognised as a particularly effective driver of
52 resilience-building worldwide (Hoffmann and Muttarak, 2017; Esposito et al., 2023).

53 The widespread diffusion of information and communication technologies (ICTs) has further expanded opportunities for
54 citizen participation in scientific activities and geo-hydrological disaster preparedness (Paul et al., 2018). ICTs facilitate the
55 rapid dissemination of information, including alerts and self-protection measures, while simultaneously enabling large-scale
56 data collection from communities. This latter aspect promotes both interaction between citizens and authorities and co-
57 production of risk knowledge (Lanfranchi et al., 2014). Numerous approaches have been proposed to enhance public
58 participation in flood-risk mitigation through the integration of ICT-based technologies and crowdsourcing techniques
59 (Frigerio et al., 2018; Ferri et al., 2020; Tran et al., 2024). In particular, Volunteered Geographic Information (VGI) approaches
60 (Goodchild, 2007) have benefited from the global expansion of smartphone use and the availability of free and open-source
61 technologies. Within this framework, web applications (hereafter referred to as web apps) have emerged as innovative tools
62 supporting the collection, storage, analysis, and sharing of structured geolocated information on hazards, exposure, and
63 vulnerability associated with geo-hydrological events.

64 Against this background, this study presents and critically evaluates a set of participatory approaches developed within the
65 HYRMA (HYdrogeological Risk assessment through collaborative MApping) research project, funded by the European
66 Union through the Next Generation programme, and implemented in northern Italy. A positive but hard-earned achievement
67 aspect of the project was the integration of collaborative geospatial data collection with educational and reflective pathways
68 aimed at strengthening both technical knowledge and social awareness of the risk. On the one hand, the project promoted the
69 acquisition, storage, analysis, and sharing of geolocated information on the physical vulnerability of buildings located in
70 selected areas prone to flash floods, as well as the structured reporting of flood events. On the other hand, it encouraged
71 collective reflection on the fragility of both territories and human experiences through original and innovative educational
72 activities. To achieve these objectives, the project relied on the interdisciplinary collaboration of natural and social scientists,
73 who co-developed inclusive and practice-oriented approaches to strengthen engagement with local communities. Following
74 a description of the study areas, the paper presents the developed methodologies, including public-engagement activities,



VGI-based data collection, and knowledge-transfer initiatives based on dedicated educational pathways and participatory experiences. The results illustrate both participants' responses to these activities and the scientific value of the obtained outputs, providing qualitative insights into the overall initiative success. Finally, the discussion addresses the main benefits, limitations, and challenges associated with the proposed approaches.

2 Study areas

The project was conducted in two municipalities of the Liguria region, northern Italy (Fig. 1). This region has experienced increasing trends in short-duration extreme precipitation events (Mazzoglio et al., 2022), confirming a growing frequency and intensity of heavy rainfall episodes that contribute significantly to flood risk. The selected municipalities share morphological and climatic characteristics common to many urban settlements along the Ligurian coastline (Fig. 1), a territory characterized by small and steep catchments that are highly susceptible to flash floods and rapid landslide processes triggered by intense rainfall.

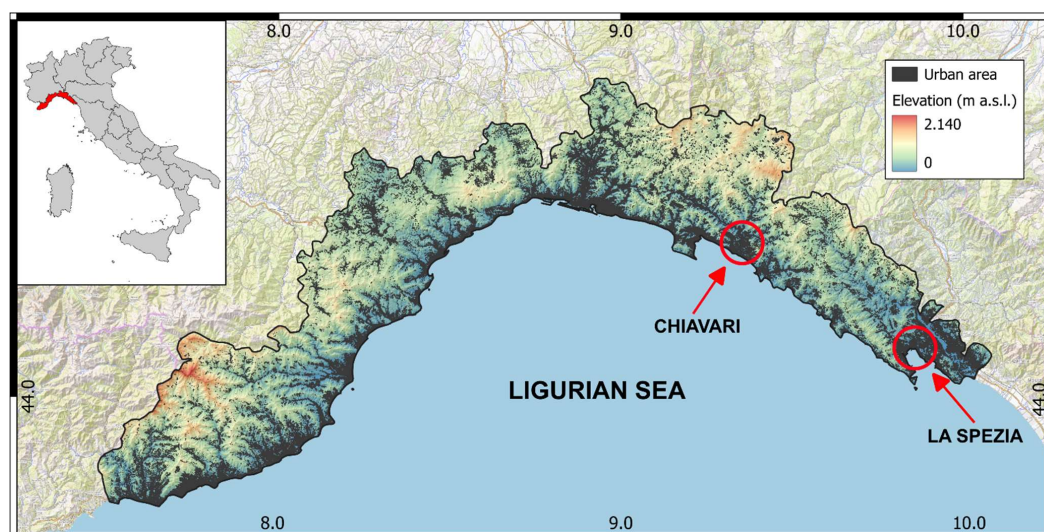


Figure 1: Elevation map of the Liguria region highlighted in the inset, and location of the Chiavari and La Spezia study areas. Basemap from: © OpenStreetMap contributors | DEM: SRTM, Sonny | map style: © OpenTopoMap (CC-BY-SA).

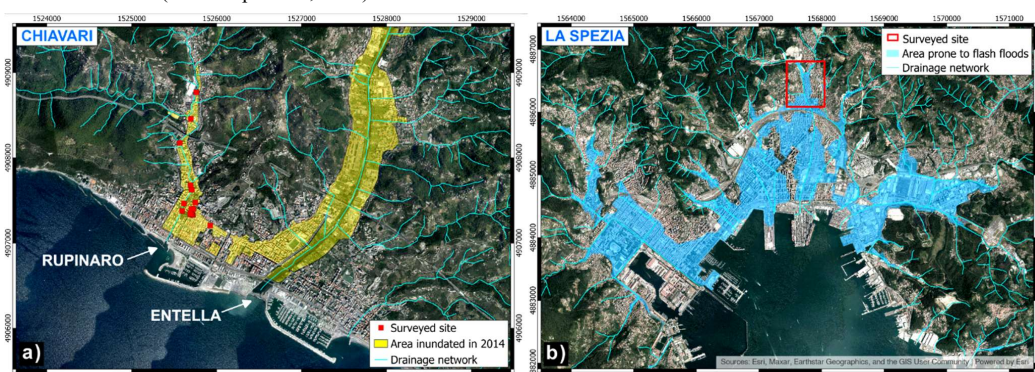
2.1 Chiavari

The municipality of Chiavari covers approximately 12.2 km² along the eastern Ligurian coast (Fig. 2a). Most of the urban area is located on the coastal plain surrounding the outlets of the Entella and Rupinaro River catchments. The Entella River drains one of the largest catchments in the region (375 km²), whereas the catchment of the Rupinaro is considerably smaller (11 km²) with a short main channel (4.5 km). The relatively high steepness of slopes in both catchments enhances rapid runoff generation and occurrence of shallow landslides.

The area is characterised by a sub-Mediterranean rainfall regime (Sacchini et al., 2012) with precipitation peaks occurring in autumn, and annual rainfall averaging approximately 1100 mm (Roccati et al., 2018). Intense rainfall is frequently associated



99 with convective systems developing over the Ligurian Sea and evolving into stationary self-regenerating storms capable of
 100 producing large rainfall accumulations over limited areas (e.g., Silvestro et al., 2012).
 101 The combination of geomorphological conditions, climatic forcing, and dense urbanisation (29.07% of the municipal territory)
 102 has historically exposed Chiavari to recurrent flooding, often causing severe impacts on people and assets (Sanguineti, 1953;
 103 Faccini et al., 2017; Roccati et al., 2018). A particularly significant event occurred in 2014, when floodwaters inundated large
 104 portions of the town centre, causing extensive damage to buildings and infrastructure (Fig. 2a). Floodwaters carrying fine
 105 sediments and vegetal debris affected underpasses, roads, ground floors, and basements, particularly in areas adjacent to the
 106 Rupinaro and Entella rivers, thereby complicating emergency response. Although no fatalities were recorded, the event caused
 107 economic losses estimated at approximately EUR 50 million, including substantial damage to commercial activities within
 108 the historic centre (Mezzacapo et al., 2025).



109 **Figure 2:** a) The town of Chiavari and the area inundated in 2014 within the Rupinaro and Entella River catchments; location of
 110 the sites (squares) surveyed with participatory VGI applications is also highlighted. b) The town of La Spezia and location of the
 111 site (rectangle) surveyed with participatory VGI applications; the area prone to flash floods is also highlighted. Basemap satellite
 112 images obtained from the World Imagery Esri layer: Esri, Maxar, Earthstar Geographics, and the GIS User Community. Copyright
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 114

115 2.2 La Spezia

116 The municipality of La Spezia extends over approximately 52 km² and is characterised by a narrow coastal plain of about 10
 117 km² bordered by mountainous reliefs reaching elevations of up to 745 m a.s.l. (Fig. 2b). The surrounding slopes are generally
 118 steep (>35% on average) and descend rapidly towards the coastline. The territory is drained by six main catchments flowing
 119 into the Ligurian Sea, all characterised by small drainage areas (<15 km²), steep topography, short concentration times, and
 120 limited alluvial plains. Hydraulic criticalities are mainly concentrated in downstream urban sectors, where human
 121 modifications have altered the natural drainage network and reduced conveyance capacity.

122 The city developed rapidly from the second half of the nineteenth century onwards, expanding from a small settlement of just
 123 over 3,000 inhabitants into a major urban centre currently hosting nearly 94,000 residents. Urban growth progressively
 124 occupied areas that historically served agricultural functions, while channelisation of streams, embankment construction, and
 125 the abandonment of traditional hydraulic and forestry management practices contributed to increasing geo-hydrological
 126 instability (Salvati et al., 2021).

127 Today, at least 17,500 residents live in areas classified as having high or very high flood hazard, while more than 5,000 people
 128 are exposed to landslide-prone conditions. The local climate is characterised by a bimodal precipitation regime, with a primary



129 maximum in November (~164 mm) and a secondary peak in April (~110 mm), whereas temperatures exhibit a typical
 130 unimodal annual pattern, with maximum values in July and minimum in February.
 131 The combination of high population density, widespread exposure to geo-hydrological hazards, and a long history of human-
 132 induced landscape modifications makes La Spezia a particularly relevant case study for investigating participatory approaches
 133 aimed at improving risk awareness, preparedness, and community resilience.

134

135 3. Overview of the Hyrma Project and scientific background

136 The HYRMA project was built upon a series of research activities conducted within previous projects aimed at improving the
 137 preparedness and response capacity of local communities, which, in turn, demonstrated, a strong willingness to engage with
 138 the scientific community.

139 In Chiavari, previous citizen science activities were carried out within the I-CHANGE project (2022–2025) financed by the
 140 European Green Deal, that emphasized the role of individual and collective behavioural change in achieving a sustainable and
 141 climate-resilient future (Parodi et al., 2022; Esbri et al., 2025; Mezzacapo et al., 2025). In La Spezia, the “Sentinelle del
 142 Territorio (Sentinels of territory)” project (Salvati et al., 2021) was part of the geo-hydrological risk reduction plan promoted
 143 by the local Municipality. This project was founded on the recognition, by local administrators and technicians, that
 144 monitoring the built environment and its critical aspects represents a preliminary step towards the implementation of any
 145 structural or non-structural mitigation strategy (Salvati et al., 2019). Moreover, in both towns, further scientific activities
 146 focused on geo-hydrological risk management were executed over the last decade by members of the research team under
 147 operational agreements with local authorities.

148 Based on this background, the HYRMA project intended to advance the participatory approaches in both towns, with the aim
 149 of enhancing citizens' understanding of geo-hydrological risk and their ability to actively contribute to risk assessment and
 150 mitigation, also through the support of new technologies. Accordingly, two approaches were proposed (Fig. 3): 1) the VGI, to
 151 address specific aspects of the flood risk on the base of local conditions and specific requirements of public authorities; 2)
 152 innovative educational pathways aimed at enhancing stakeholder engagement, deepening risk knowledge, and promoting self-
 153 protection behaviours (in Chiavari only). In order to foster the required synergy across the communities, both approaches
 154 involved people from the research team, government bodies, and young students, thereby empowering the new generations
 155 that are expected to face worse conditions in the future.

156

157 3.1 Stakeholders engagement and work plan

158 Initial efforts focused on engaging all stakeholders with a potential interest in joining the project (Fig. 3). Accordingly, a series
 159 of preliminary meetings were organised to present the project methodologies, research aims and expected outcomes in the
 160 two towns. Local civil protection authorities accepted to provide their contribution in terms of personnel, data, and connections
 161 with public and private secondary schools. Some meetings were thus carried out with teachers of the involved schools, leading
 162 to the engagement of a total of 150 students (10 classes) with ages ranging from 15 to 17 years. Students from all backgrounds
 163 were engaged without any restrictions to ensure the highest possible level of inclusion. This process also actively involved a
 164 private school for students with disabilities with their educators in Chiavari, in full alignment with the project principles.

165 Activities were carried out over the two-year project period (2024–2025) following the strategy illustrated in Fig. 3: the VGI
 166 approach was developed and applied with all the 150 engaged students in the first year of the project while innovative



educational paths were implemented in the second year only with student volunteers of Chiavari, who were also involved in the dissemination events, in the final part of the project. The dissemination was aimed at sharing their outcomes with peers and other stakeholders, thereby gaining valuable feedback on the impact of both proposed participatory approaches. Activities conducted in the VGI approach were structured with each class into three meetings. The first meeting consisted of a frontal lecture aimed at training students on the geo-hydrological risk, with specific reference to their territory, and at introducing the objectives and tasks of the VGI activity. The second meeting focused on a field experience aimed at co-creating and testing the web applications described below, representing a methodologically challenging step due to the need to ensure effective co-design, data reliability, and student engagement in real-world data collection. The third meeting was dedicated to the visualization and exploration of the collected datasets using the QGIS open-source software, accompanied by targeted explanations of their meaning and their potential applications in both scientific research and civil protection contexts. Within the educational activity, the research team promoted pathways based on a strong interaction among researchers, students, and educators to strengthen the role of citizens in geo-hydrological risk prevention. Details on the activities carried out in both approaches are described in the following sections.

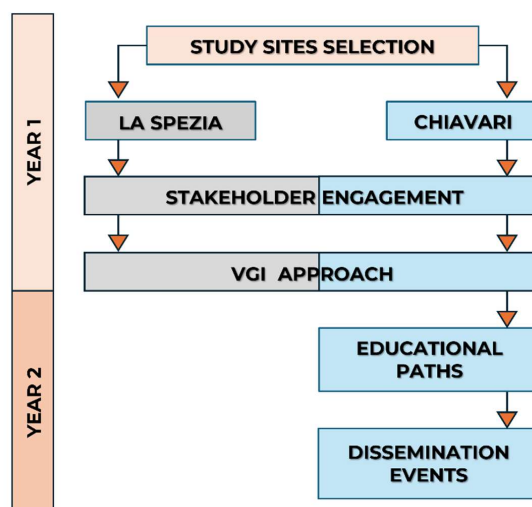


Figure 3: The HYRMA project workflow.

4. Methodologies

4.1 VGI data collection

The VGI approach was defined using a bottom-up strategy, involving the local civil protection authorities, in order to ensure alignment between newly and existing data collection procedures, project objectives, and end-user requirements. This consultation phase led to the identification of two distinct needs for the towns involved: i) in La Spezia, due to the high building density in the flood-prone areas, the project activities focused on the collection of data on residential buildings vulnerability; ii) in Chiavari, in line with the high frequency of recent floods, the activities focused on documenting the



190 occurrence and spatial distribution of damaging events. Accordingly, two structured forms for data collection were designed
191 and digitised into two corresponding web application versions, one for each study site.

192

193 **4.1.1 Implementation of the web applications with KoboToolbox**

194 The web applications were developed using the KoboToolbox digital platform (<https://www.kobotoolbox.org/>). KoboToolbox
195 is a versatile and robust tool specifically designed for use in difficult settings. Its features make it ideal for gathering field data
196 and implementing surveys in areas with limited resources and connectivity. The choice to adopt KoboToolbox was driven by
197 a limited, yet, key set of methodological requirements, namely user-friendliness, open accessibility, and the need to support a
198 collaborative and multi-stakeholder data collection process. Indeed, the platform enables multiple users to collect, store,
199 analyse, and share structured geolocated datasets in parallel, thereby supporting collaborative workflows. Users can design
200 forms incorporating a wide range of input types, including text, numerical values, dates, times, geographic locations, images,
201 videos, and additional multimedia content. In addition, KoboToolbox supports the collection, export, and integration of
202 geospatial data in compliance with OGC standards. This interoperability is ensured primarily through the acquisition of GPS
203 coordinates, support for standardised data formats, availability of APIs for system integration, and the possibility to export
204 datasets in formats compatible with OGC-compliant geospatial infrastructures. This compliance ensures that data collected
205 through KoboToolbox can be effectively integrated into broader geospatial analysis and mapping workflows, adhering to
206 established geospatial data standards. Collected data are accessible in real time, allowing for immediate inspection and
207 preliminary analysis, and can be exported into multiple formats, including CSV, Excel, and SPSS, hence facilitating
208 downstream statistical analysis and reporting. KoboToolbox can also be deployed either via its free public server or through
209 self-hosted installations, enabling greater control over data governance, security, and system configuration. Finally, API
210 services for integration with external systems and applications are available, supporting advanced data management,
211 automation, and interoperability across digital infrastructures.

212 To reduce data errors and user variability, the forms created for the VGI educational activities incorporated clear, unambiguous
213 questions, predefined response formats (checkboxes and radio buttons), and minimal open-ended text fields. This ensured
214 data standardization, simplified subsequent analysis, and maintained a user-friendly interface for students.

215

216 **4.1.2 Reporting flood events**

217 Documenting flood events provides substantial benefits for hazard and risk assessment. Spatio-temporal information on flood
218 dynamics, the effectiveness of protection measures, and damage documentation can be used by experts to support the
219 implementation of hydraulic and damage models, as well as the design of prevention and mitigation measures. This type of
220 information must be collected with high accuracy both during the emergency phase and in the post-event period. To this end,
221 crowdsourcing represents an effective approach for the collection of large volumes of timely flood-related data, as
222 demonstrated in several studies worldwide (e.g., Le Coz et al., 2016; Wang et al., 2018).

223 Accordingly, the web application developed for the Chiavari pilot site was designed to enable the reporting of flood-related
224 information either in real time or, alternatively, in the post-event phase. However, due to the absence of flood events during
225 the project timeframe, and in order to ensure safe conditions for all participants during their first experience with the activity,
226 the web application was tested in specific areas affected by the most recent flood event of 2014 (Fig. 2a). In each selected
227 site, participants were asked to visually compare the current environmental conditions with those observed during the 2014



228 flood event, using a set of archival georeferenced photographs or videos collected by local citizens from flooded buildings
229 and roads (Fig. 4). In this way, users were able to reconstruct and collect flood-related information under a simulated flood
230 scenario and in fully safe operational conditions. Even though data were collected by non-expert users, the related uncertainty
231 was limited by requiring simple measurements (e.g., the channel depth or height of protection walls measured with a laser
232 meter) or observations (the presence of levees, check dams, types of damage), thus gathering valuable data for scientists or
233 disaster managers. Accordingly, during the field activities, all participants were instructed on safety protocols and appropriate
234 behavioural guidelines to be followed during such activities, in order to avoid any risk to their own safety and to that of others
235 (e.g., emergency responders), particularly in contexts where flood processes may be ongoing.



236
237 **Figure 4:** Example of photographs provided to the students for assessing the 2014 flooding effects with the KoboToolbox web
238 application. The photograph of 2014 (on the left) was taken by a citizen during the event; the photograph of 2024 (on the right)
239 represents the same place during the survey. Circles in the photographs highlight the reference elements helping the students with
240 the comparison process. A map of the surveyed sites and a preview of the digital form included in the web app are highlighted below.
241 All contents reported in the screenshot of the custom survey form built using the KoboToolbox platform (kobotoolbox.org) not
242 authored or created by Kobo reflects solely the views and opinions of the authors thereof.

243

244 4.1.3 Residential building vulnerability data collection

245 A range of variables can be used to describe the physical vulnerability of residential structures to floods, including building
246 typology, structural features, and number of storeys, that must be collected through field surveys. Accurate, standardised, and
247 spatially distributed information can feed damage models aimed at estimating the monetary losses associated with exposed
248 assets, by relating the expected physical damage to recovery or reconstruction costs (Molinari and Scorzini, 2017). In this
249 way, damage scenarios useful for planning and prioritising relief operations can be generated, while carefully balancing the



trade-off between standardisation of survey design and the flexibility required to capture context-specific and often non-observable vulnerability indicators during rapid field assessments. Within this framework, the criteria adopted for collecting data on residential buildings in the La Spezia pilot site (Fig. 5) were defined according to two main requirements: (i) the possibility of conducting assessments exclusively through external visual inspection, without entering private properties; and (ii) the relevance of each vulnerability parameter for predicting building damage, also in the context of machine-learning-based modelling approaches. A particularly challenging aspect of the activity was the identification of a data-collection protocol capable of ensuring scientific robustness while remaining accessible to non-expert participants. Specifically, participants were asked to collect basic information through the careful observation of buildings and their surroundings (e.g., indicating multi-story or single-story buildings, the presence of a basement, the height of windows from the ground). While easily accessible even to non-experts, this information constitutes an essential input to inform damage models, thereby enabling meaningful citizen involvement in the generation of data suitable for advanced risk-modelling applications. Through this experience, students were not only introduced to the concepts of exposure, vulnerability, and flood risk, but also actively contributed to the creation of datasets that can support both research activities and operational risk-management practices. Therefore, this approach transformed a traditionally expert-driven assessment process into a participatory learning experience, fostering awareness of flood risk while simultaneously generating information of potential value for damage modelling and disaster-risk-reduction strategies.



Figure 5: Photograph taken during the field survey of residential buildings in La Spezia.

4.2 Educational paths

To improve knowledge of geo-hydrological risk and to promote self-protection behaviours, original and innovative educational pathways were designed, implemented, and continuously adapted to the specific contexts and evolving situations experienced in Chiavari. These pathways were characterised by their originality, as they combined the use of images, colours, emotions, and music, and by their innovative nature in leveraging the evocative and participatory roles of these elements within the learning process. The educational approach was inspired by a dialogical and reflective methodology, aligned with Morin's thinking (Morin 2023), and framed within the concept of "method as a journey". Basically, the approach is circular and integrates intrapersonal and interpersonal dimensions of all participants involved in such an "ad-ventura" (towards things that are about to come (Milella 2015). Education and relational processes are therefore interwoven in a continuous, shared,



278 and progressive discovery pathway. This process is essential and indispensable when considering the heterogeneity of abilities
279 among participants.

280 The educational pathway was offered to two secondary schools in Chiavari: one focusing on vocational training and social
281 inclusion programs - geared toward job readiness and hands-on community projects - for students with low intellectual
282 disabilities; the other being a technical institute for students without disabilities offering a specialized curriculum in
283 construction, environment, and land management to train future surveying professionals. Besides the students, the educational
284 pathways involved educators, teachers, Social Services representatives, and 4 project members including two research
285 geologists with expertise in geo-hydrological risk, one university professor expert in human relationships and communication,
286 and one expert in music composition with a PhD in education. Consequently, pathways for both schools resulted from a
287 process of convergence and negotiation among multiple perceptions and viewpoints of individuals exposed to geo-
288 hydrological risk, including both more vulnerable participants with disabilities and less vulnerable participants without
289 disabilities.

290

291 **4.2.1 The use of images, colours, emotions, and stories**

292 In the first phase of the educational pathway, particular emphasis was placed on the understanding of geo-hydrological risk
293 through the use of photographs. These were either collected directly by students in the field or via web or selected with the
294 support of educators, with the aim of depicting flooding events or risk situations occurring not only in Chiavari and
295 surrounding areas, but also in other global contexts. This strong focus on photographic material was motivated by the
296 recognition that individuals are increasingly “called upon” to observe and process a growing volume of images, both self-
297 produced and externally received. In general, the greater the number of images to which individuals are exposed, or voluntarily
298 expose themselves, the less time is devoted to their careful interpretation. This condition highlights a key cognitive and
299 pedagogical challenge related to attention scarcity and the risk of superficial visual processing in risk communication contexts.
300 Therefore, it becomes necessary to “train” individuals to develop a genuine “ecology of attention”, intended as enhanced
301 awareness of the interactions between living beings and their environment (Citton 2014).

302 For this purpose, each participant (particularly students) was asked to imagine themselves within the temporal and spatial
303 context depicted in the selected images. This exercise stimulated the formulation of numerous questions regarding the events,
304 associated risks, and appropriate behavioural responses in such situations. In addition, students were asked to associate each
305 image with a colour that best represented the emotions they experienced during image interpretation, as well as to anticipate
306 the emotions that potential “listeners” might experience when viewing the same images. The integration of emotional and
307 cognitive dimensions represents a central but methodologically complex aspect of the approach, requiring careful balance
308 between subjective emotional expression and structured learning outcomes in risk education. Emotion should thus be
309 considered a genuine cognitive capability that plays a fundamental role in decision-making processes (Damasio 2025). The
310 inclusion of this cognitive dimension can modify perspectives (Milella 1996) and consequently influence how geo-
311 hydrological risks are perceived and conceptualised. In this way, students were able to express perceptions of alertness and
312 danger through colour selection, sharing a wide spectrum of emotional nuances related to emergency conditions. Colour
313 functioned as an additional reflective tool, evoking internal experiences and facilitating processes of emotional awareness and
314 collective sharing.



315 To extend and share the outcomes of the educational pathway with other participants, each selected image was embedded in
316 a PowerPoint presentation, where the colour assigned to each image was used as the slide background. Some images were
317 also paired with photographs of the same sites prior to the flood event, highlighting how these locations were deeply
318 interconnected with the everyday lives of individuals, including squares, underpasses, commercial areas, parks, and other
319 urban spaces. Moreover, each slide included the name of the student who selected the image, the associated description and
320 emotion, as well as the reflections that emerged from the exercise of self-placement within the depicted scenario. All activities
321 were conducted during twelve remote sessions.

322

323 **4.2.2 The use of sound and music**

324 The second part of the educational pathway was dedicated to sound and music and focused on the development of a
325 “laboratory” aimed at constructing a collective sound experience. The main objective was to engage students in a creative and
326 participatory process combining music, sound (in its broadest sense), images, colours, emotions, and narratives, with the
327 purpose of exploring their interrelations with the environment and flood-related phenomena.

328 The connection between sound, music, and natural processes (or even self-protection behaviours in flood contexts) may
329 initially appear somewhat indirect. However, music should not be interpreted solely as an artistic language, but rather as a
330 primary form of human communication and expression, extending well beyond technical or aesthetic dimensions. It transcends
331 the sphere of art in a narrow sense and instead belongs to human communication in its broader meaning, encompassing the
332 full range of non-verbal communicative nuances that shape our relationship with the surrounding world. In this context,
333 musicality, understood as the capacity to perceive and modulate emotional and communicative “resonances” (Musaio 2025),
334 emerges as a potentially relevant resource for rethinking training practices and educational approaches.

335 Short musical sequences and sound effects, specifically designed to evoke natural scenarios or environmental phenomena,
336 were presented to the students. Listening to these sequences constituted the starting point for a shared reflective process:
337 students were invited to select the sounds they considered most representative of the phenomena described. Furthermore, they
338 were asked to justify their choices by explaining why a given sound was deemed particularly appropriate to represent the
339 previously selected images. This phase proved to be crucial in fostering a critical engagement with sound, encouraging
340 participants to interact with auditory dimensions through a playful yet structured musical experience capable of expressing
341 and narrating the relationship with the environment and its associated emotional experience.

342 Once individual sound preferences and reflections had been collected, the assembly phase was initiated. A form of “sound
343 puzzle” was constructed based on the ideas and suggestions emerging during the sessions. This collective composition
344 extended beyond a purely creative exercise and became the core of an actual soundtrack, designed to interact with the images
345 selected to represent flood events. Following a specific research perspective, each musical track was conceptualised as a true
346 “soundscape” (Schafer 2022), understood as a resonant environment in which individuals are continuously and inevitably
347 immersed. Moreover, during this experience, students were also guided in distinguishing between sounds intentionally
348 produced and those unintentionally perceived or passively experienced, highlighting a key interpretative challenge related to
349 auditory awareness and the subjective attribution of meaning to environmental soundscapes within educational settings.

350

351

352



4.3 Evaluation of the approaches

The performance of the used approaches was evaluated by the research team through a series of indicators focusing on proactive participation, risk understanding, and educational outcomes. The selected indicators, along with all evaluation criteria and methods, are summarised in Table 1. Given the qualitative nature of the students' cognitive and educational outcomes related to risk understanding and self-protection behaviours (e.g., data quality, depth of discussion, and multimedia content), the evaluation primarily relied on the continuous exchange among the research and teaching staff during both field and classroom activities. Furthermore, broader outreach capacity was integrated as an indirect evaluation method to measure whether participants actively assumed dissemination roles to communicate project outcomes and acquired knowledge to peers and external stakeholders. In this context, active willingness to present project outcomes was interpreted as a key reflection of knowledge internalisation, while hesitation denoted an ongoing process of concept consolidation.

Table 1: Evaluation indicators, criteria and methods.

INDICATOR	EVALUATION CRITERION	EVALUATION METHOD
Attendance to VGI activities	Number of digital forms completed	Ratio of completed forms to engaged students
Risk understanding through the VGI approach	Quality of VGI data and critical discussion on their usage for risk management	Expert assessment by the research team supported by GIS techniques
Risk understanding through educational paths	Number and relevance of the collected photographs and videos	Expert assessment by the research team, teachers, and educators
	Proactive involvement and degree of creativity in the development of multimedia products	
	Critical discussion on risk conditions and self-protection behaviours	
Proactive participation in risk assessment and mitigation	Critical discussion on citizen science and participatory approaches	Expert assessment by the research team, teachers, and educators
Speaker roles in dissemination events	Willingness to communicate project outcomes to peers and stakeholders	Binary metric (Yes/ No)

Overall, a cross-cutting dimension evaluated by the research team throughout the interaction with the students was the relational climate. To this end, both individual and group responses were assessed in terms of their degree of participation, curiosity, enthusiasm, and creativity. Specifically, curiosity and creativity were evaluated by analyzing the nature of the questions posed to the researchers, and the students' engagement in producing the co-created outputs (e.g., the accuracy of collected data, the relevance of photographs, and the depth of detail in reporting their experiences and feelings). Regarding the expert judgment for risk understanding, this evaluation focused on how students identified and assessed risk conditions in the field or through photographs and videos (e.g., improper human behaviors or the exposure of buildings in flood-prone areas) following initial discussions with the research team. Propensity to adopt self-protection behaviors during alerts or emergency scenarios was also evaluated.



375 **5 Outcomes and evaluation remarks**

376 **5.1 The VGI approach in Chiavari**

377 Response of the students and other stakeholders to the VGI approach in Chiavari provided interesting outcomes. Generally,
 378 the strategy of conducting three meetings was meaningful. The first meeting was necessary to recall the basic principles of
 379 the geo-hydrological risk and to introduce the web application. With the second meeting in the field (Fig. 6), based on the
 380 comparison between present-day field conditions and archival photographic/video material related to the 2014 flood event,
 381 the students were able to: (i) geolocate the survey points; (ii) estimate water levels at different locations using visual references
 382 from images and videos; (iii) derive flow velocity from video footage based on the travel distance of floating objects and
 383 corresponding time intervals (seconds); (iv) assess the presence, type, and approximate dimensions of transported materials;
 384 (v) estimate flow discharge by inputting measured channel depth and width into a predefined formula embedded in the web
 385 application; (vi) identify the presence of monitoring or early warning devices; (vii) verify whether temporary protective
 386 measures had been installed to safeguard private building entrances and windows; and (viii) conduct interviews with
 387 individuals involved in the 2014 flood event. The comparison between the reconstructed emergency conditions derived from
 388 2014 multimedia material and the current field situation proved particularly effective for fostering in-depth and interactive
 389 discussions. In this context, the interaction with researchers enabled students to be trained on flood dynamics and their
 390 potential rapid evolution in urban environments, as well as on structural and non-structural mitigation measures and
 391 appropriate behavioural responses during hazardous flood conditions. The link between climate change and the increasing
 392 frequency and intensity of extreme geo-hydrological events was also addressed. At the same time, the research team provided
 393 guidance on the risks associated with life-threatening situations during flood events, including the most common
 394 circumstances leading to injury or fatalities, as well as recommended self-protection behaviours in line with the Italian Civil
 395 Protection guidelines (<https://iononrischio.protezionecivile.it/en/get-ready/flood/what-do/>). The third classroom-based
 396 meeting further supported the consolidation of these concepts through the use of the QGIS software, while the involvement
 397 of volunteers and technicians of the civil protection facilitated the discussion of potential applications of the collected datasets,
 398 consisting of 130 completed forms from 98 participating students in Chiavari. This approach is consistent with the findings
 399 of Paul et al. (2018), highlighting the importance of joint data analysis and interpretation in enhancing citizen engagement in
 400 scientific research objectives. In particular, insights derived from the quality of the collected VGI data and critical discussions
 401 with students (Table 1) demonstrated: i) a strong interest in the understanding of geo-hydrological processes; ii) the capability
 402 of the used approach to promote fruitful information exchange with scientists and disaster managers; iii) the strength of
 403 practical activities to stimulate and raise the interest of young people in addition to in-class theoretical lectures. Overall, the
 404 proposed setup introduces a valuable methodological opportunity through the use of retrospective visual reconstruction as an
 405 effective proxy for real-time hazard understanding, while offering significant benefits for enhancing risk perception. In
 406 addition, to strengthen students' role as active mediators in risk communication processes, they were encouraged to share their
 407 experiences with peers, operationalising a peer-education approach that has been identified as a key strategy for improving
 408 risk communication among adolescents, leveraging social identification, shared language, and horizontal knowledge exchange
 409 (Hart, 2008; Asih et al., 2026).

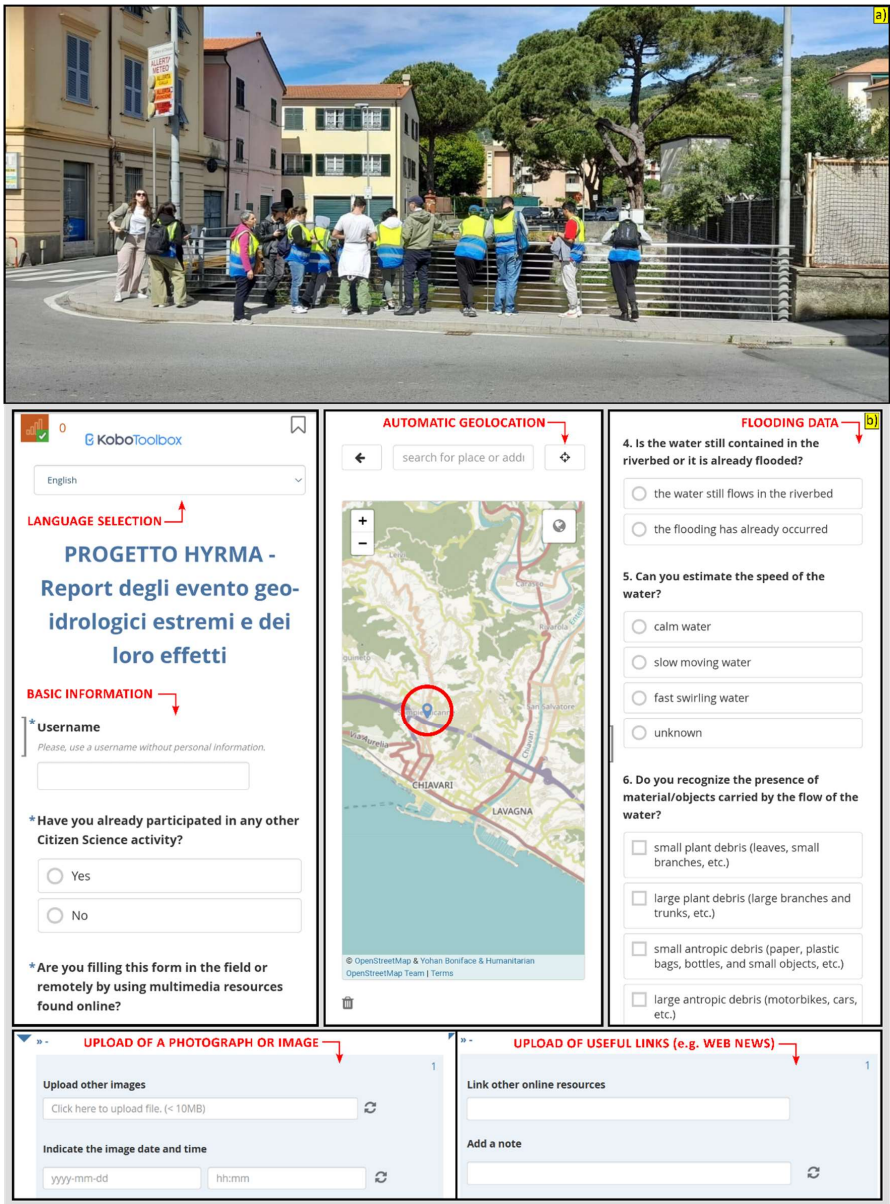
410

411

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413



414

415 Figure 6: a) Field survey in one of the sites struck by the flash flood in 2014 ([https://www.fondazionecef.it/sensibilizzazione-sul-](https://www.fondazionecef.it/sensibilizzazione-sul-rischio-idrogeologico-per-i-nostri-studenti/)
416 [rischio-idrogeologico-per-i-nostri-studenti/](https://www.fondazionecef.it/sensibilizzazione-sul-rischio-idrogeologico-per-i-nostri-studenti/)). (b) Overview of the main sections of the web app used by the students in Chiavari. All



417 contents reported in the screenshots of the custom survey form built using the KoboToolbox platform (kobotoolbox.org) not
 418 authored or created by Kobo reflects solely the views and opinions of the authors thereof.

419

420 5.2 The VGI approach in La Spezia

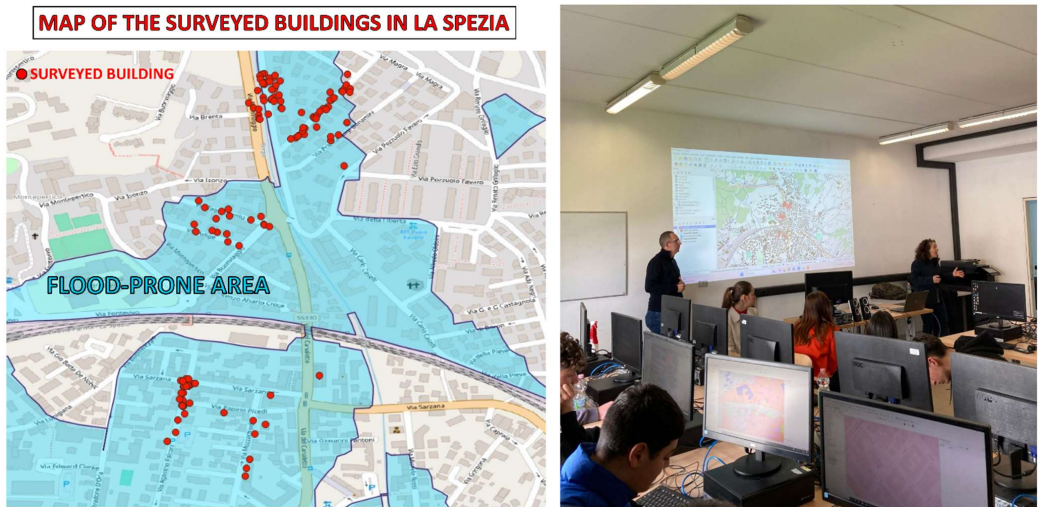
421 In the town of La Spezia, the VGI data collection resulted in 130 completed forms on buildings located within the selected
 422 flood-prone area, gathered from 52 participating students (Fig. 7). They were guided to an area located close to their school
 423 and currently classified as exposed to flood hazard according to the official hazard-planning framework of the Municipality
 424 of La Spezia (Fig. 2). Within this area, they analysed a series of residential buildings and, through the use of the web app,
 425 collected specific information on building's characteristics also relevant to the development of damage models. Even in this
 426 case, the first meeting was essential to prepare the students for the field survey and the use of the web application. With the
 427 support of the research team and volunteers of the civil protection, many students demonstrated particular understanding of
 428 the scientific meaning of the collected data, as well as of the correct methodological procedures required to perform accurate
 429 field surveys. Specifically, they were able to assess: the main structural characteristics influencing building vulnerability to
 430 flooding; the most critical uses of basement and ground-floor spaces that may increase risk to personal safety or economic
 431 losses in the event of flooding; and the types of mitigation measures that could be adopted to reduce building vulnerability
 432 and expected damage. The collection of this information in the field also represented an important opportunity to train students
 433 on the physical processes governing flood generation and associated risk conditions. Through this fieldwork, they were
 434 introduced to key concepts such as drainage basin dynamics, concentration time, return period, early warning systems, and
 435 urban planning. From a technological perspective, students had the opportunity to understand the potential of ICT and GIS-
 436 based systems in contributing to geo-hydrological risk mitigation. In particular, they explored the role that citizens can play
 437 by providing spatially distributed information through collaborative mapping and similar participatory initiatives. The
 438 comprehension of this aspect was further reinforced during the third classroom meeting (Fig. 7), when the research team,
 439 together with personnel of the civil protection, illustrated how the collected datasets could be used to generate maps and
 440 statistical outputs potentially supporting the risk management and scientific applications.

441 Overall, students found the web application intuitive and easy to use; however, they also provided constructive critical
 442 feedback suggesting modifications to improve its efficiency and robustness. For instance, they highlighted that external
 443 building inspection alone was insufficient to reliably assess certain structural characteristics, such as construction type, which
 444 was therefore removed from the initial form design. Conversely, the "notes" section proved particularly valuable, as it allowed
 445 participants to report relevant features not originally included in the structured fields, such as the number of steps at building
 446 entrances, which provided indirect information on the water depth potentially leading to building inundation. The possibility
 447 of offline data collection was also positively received.

448 As observed in Chiavari, these findings further demonstrate a deep involvement and willingness of the students in practical
 449 data collection, and notably their ability to comprehend the scientific meaning of datasets along with the important concepts
 450 of hazard, vulnerability, and exposure in urban settings like the surveyed one. Concrete evidence of this emerged from the
 451 critical discussions with researchers during the third meeting, when a solid grasp of these key concepts was successfully
 452 shown in the course of the final summary of the activity. As reported in Table 1, these discussions represented key moments
 453 to evaluate students' risk understanding, critical thinking ability, and active engagement in identifying both risk conditions
 454 and self-protection behaviours. Accordingly, both the research team and the teaching staff evaluated the outcomes very



455 positively, highlighting a high level of student responsiveness and an effective translation of theoretical concepts into practical
456 awareness.



457
458 **Figure 7: Map of the surveyed buildings in La Spezia discussed with the students during the third meeting, as shown in the**
459 **photograph.**

460
461 **5.3 Application of the educational paths to the geo-hydrological risk understanding**

462 It is not straightforward to anticipate the outcomes of an educational programme, as its effects may only become fully evident
463 in the longer term (Milella 2015). However, identifying the effects on the adult participants involved in the project was
464 comparatively more immediate. These participants sought to experience directly “the paradox of knowledge, which is only
465 profound and elevated when it is humble”, understood as humility in engaging with others who possess different skills,
466 experiences, perspectives, and epistemic trajectories, as well as humility in relation to the shared world inhabited with other
467 living beings, whether similar or different from ourselves (Moscati, 2024). This attitude contributed to the establishment of a
468 high-quality relational climate, in which all participants felt included regardless of fragilities, abilities, perspectives,
469 experiences, skills, and research backgrounds. This relational environment was reflected in the active engagement observed
470 across the four steps of the educational pathways.

471 **Step 1:** participants were encouraged to imagine themselves within the moments and situations depicted in the selected
472 images, responding with enthusiasm and creativity. The images were not perceived as a “view through a window”, but rather
473 as a threshold that participants crossed between observer and observed (Foerster 1987), thereby enhancing their understanding
474 of geo-hydrological risk and promoting self-protection behaviours. As outlined in Table 1, the research team evaluated this
475 outcome directly through active discussions during the activity. Some photographs depicted individuals directly involved in
476 the event or observing it (Fig. 8a). Imagining themselves in those situations or to experience them firsthand (Fig. 8b), triggered
477 a meaningful discussion on the behaviours required for self-protection. In particular, the need emerged to promote protective
478 attitudes not only towards oneself but also towards others, where “others” refers both to relatives or individuals in close



479 proximity and to emergency responders. Indeed, actions that place individuals at risk may also endanger rescuers and delay
480 assistance to those in more critical conditions. According to this reflection, guidance on appropriate self-protection behaviours
481 was provided with the support of experts, including recommendations such as remaining indoors, moving to upper floors, and
482 adopting cautious and responsible behaviours. Although simple, these indications were essential.



Sebastian

LOCATION: Emilia-Romagna (Italy) **a)**

SOURCE: WEB - Google search

DESCRIPTION: Cleaning up operations in a flooded town

COMMENT: Flood water and mud have damaged furnitures at ground floors. These have been transported along the road to be wasted. Cleaning operations are made by volunteers, so-called "Angels of mud"

FEELING: It's important caring for the common good. This concept can be summarised with: "We are angels of prevention"



Francesco

LOCATION: Rupinaro River, Chiavari (Italy) **b)**

SOURCE: Francesco (17 October 2024)

DESCRIPTION: It had rained heavily and the river level had risen considerably. The river was prone to overflow from one bank (about 1.5 meter). Fortunately, the river did not overflow, but the road was covered by about two centimeters of water. The color and power of the river were striking.

CHOSEN COLOR: a mix including the color of mud (brown) and that which commonly puts us on alert (orange)

EMOTION FELT IN CAPTURING THIS PHOTOGRAPH: Sadness, but also excitement in documenting the event as other people. Self-control and attention were also used, as recommended by volunteers of the Civil Protection who were monitoring the situation.

EMOTION FELT IN THE AFTERMATH
Curiosity and disorientation in seeing the territory so changed compared to ordinary days

483
484 **Figure 8:** a) Example of photograph found by students with disabilities on the web, with their original description, comments and
485 feelings on the right. The grey colour of the slide background was chosen by the students. b) An example of photograph captured
486 by a student of the technical institute; the associated colour and the evoked emotion and description are reported in the slide.

487
488 **Step 2:** the collective sound experience was received with considerable curiosity and enthusiasm, to the extent that students
489 expressed the desire to continue the activity beyond the project timeframe. Music was interpreted as another cognitive



490 dimension, alongside emotion, functioning as a “soundtrack” of individual perspectives and, consequently, of the ways in
 491 which geo-hydrological risk was perceived and conceptualised. Music becomes genuinely educational when it is transformed
 492 into a listening practice that stimulates the capacity to express emotions, motivations, and difficulties experienced by others,
 493 particularly those that are not verbally articulated. It is essential to emphasise that music should not be considered an
 494 “automatic antidote”: the mere act of listening to or producing music does not in itself guarantee educational or relational
 495 outcomes (Ball 2011). Rather, music can become an educational pathway capable of fostering listening, reflection, and
 496 understanding of emotional and social nuances, thereby promoting awareness of relational and societal complexity (Oliva
 497 2010). In this sense, when intentionally and critically integrated, music transcends its artistic dimension and becomes a tool
 498 for training observation, perception, and interpretation of the surrounding world, fostering curiosity, openness towards others,
 499 and relational care. These competencies are fundamental for individuals expected to navigate the complexities of
 500 contemporary social and cultural contexts, including the capacity to critically reflect on and dissent from social injustices.

501 **Step 3:** the integration of individual PowerPoint slides and associated sound materials resulted in the production of multimedia
 502 videos. These expressed the interaction between sound and environment from the perspective of young participants,
 503 highlighting their enthusiasm for the educational pathway and their willingness to share the experience. The montage also
 504 incorporated a narrative component consisting of texts written by the students themselves. In particular, three groups of
 505 students with disabilities, supported by educators, developed short narrative stories describing their identification with the
 506 selected images and the emotions they evoked. These narratives, inspired by visual stimuli and associated affective responses,
 507 combined with a collectively produced soundtrack, added an additional interpretative layer to the project, substantially
 508 enriching the multimedia output. This reflective process contributed to strengthening personal awareness and deepening
 509 understanding of risk-related concepts, as evaluated by the research team together with teachers and educators.

510 **Step 4:** an unexpected but highly significant outcome of the activity was the spontaneous expression by students of their
 511 desire and motivation to contribute to the improvement of knowledge on geo-hydrological risks, and to the promotion of self-
 512 protection attitudes. In this context, students defined themselves as “prevention angels”. This expression emerged from their
 513 interpretation of an image depicting the 2023 flood event in the Emilia-Romagna region, where individuals were engaged in
 514 clearing mud from urban streets (Fig. 8a). These scenes evoked associations with the so-called “mud angels” (Alexander,
 515 2010): thousands of young volunteers, both Italian and international, who travelled to Florence following the catastrophic
 516 flood of 4 November 1966. Inspired by this reference, participants chose to identify themselves as “prevention angels”. This
 517 demonstrated the development of a strong sense of responsibility to assume an active role as citizens in contributing to flood
 518 risk mitigation.

519

520 **5.4 Peer-to-peer dissemination events**

521 A series of dissemination events provided the students with the opportunity of sharing their experience with peers, teachers,
 522 educators, public authorities, and other citizens. In addition, these were occasions for the research team to gather valuable
 523 feedback on the participatory approaches proposed in the project. The most important event was a public conference focusing
 524 on the geo-hydrological risk affecting the town of Chiavari, organised by the local and national civil protection authorities
 525 (<https://www.abiliaproteggere.net/2025/04/02/a-chiavari-convegno-sul-rischio-idrogeologico-e-focus-sul-progetto-hyrma/>).

526 In this case, the students personally presented their project outcomes as speakers, confident in their deep understanding of the
 527 information transferred by the researchers and the hands-on activities they had carried out. This event was further enriched



528 by student speakers who had participated in previous projects with other research teams, and by experts of the National
529 Department of Civil Protection.

530 At the same time, other events were also organised in individual schools to promote a stronger interaction between students.
531 In this case, the activities were discussed between participant students and the other not involved in the project through the
532 screening and explanation of the multimedia video and PPT slides they had produced. In doing so, they enacted an authentic
533 form of peer education, supported by “digital aesthetics” (Manera 2022). This spontaneous willingness to participate and
534 share was neither expected nor taken for granted, particularly in the case of students with disabilities. Likewise, sustained
535 attention, active listening, and participation cannot be assumed even within formal educational settings, especially when
536 participation is not associated with formal assessment. This aspect represented a central outcome of the educational pathway:
537 the creation of a high-quality relational climate in which students, together with other participants, felt fully included beyond
538 their individual fragilities. With regard to the evaluation criteria highlighted in Table 1, both students with and without
539 disabilities thus responded positively to the opportunity to act as speakers in dissemination events, in some cases overcoming
540 their natural shyness and character traits.

541

542 **6 Discussion**

543 Participatory methods are essential for developing sustainable disaster mitigation strategies and for integrating local
544 communities into formal risk governance frameworks (Hicks et al., 2019; Stewart, 2024). Nevertheless, communicating the
545 risks associated with landslides and floods remains a major challenge, as target audiences often exhibit resistance, weak
546 motivations, or indifference towards risk-related messages (Salvati et al., 2015). This represents a well-established and
547 recurrent issue. O’Neill (2004) highlighted that public awareness is inherently difficult to achieve, noting that “it has been
548 apparent for some time that creating community awareness of floods and storms is not easy most of the time, people are not
549 particularly interested in them”. In this context, the NOAA Social Science Committee (2016) emphasised that effective risk
550 communication should be understood as a continuous process rather than a static product.

551 Within this framework, co-designed approaches and the active involvement of citizens provide a pathway towards more
552 inclusive and scientifically robust communication strategies, capable of strengthening both individual and collective
553 resilience. Participatory and collaborative governance of environmental risk explicitly requires not only that the public is
554 adequately informed (Newig et al. 2014; Challies et al. 2016), but also that children and adolescents are actively involved in
555 participating through school programs in shared decision-making processes alongside adult community members and local
556 authorities (Midtbust et al. 2018; Mort et al. 2020). For this reason, an increasing number of studies has focused on younger
557 populations, assessing risk awareness and perception (Bandecchi et al. 2019; Mezzacapo et al. 2025; Bosschaart et al. 2013;
558 Seddighi et al. 2020; Cvetković et al. 2019). Seddighi et al. (2020), for instance, reviewed approaches for preparing children
559 for climate-related disasters, analysing methods, outcomes, facilitators, and barriers to identify strengths and weaknesses of
560 school-based interventions. Schrot et al. (2021) implemented a two-year educational programme in North Tyrol (Austria) and
561 South Tyrol (Italy), including seven in-school workshops aimed at improving risk knowledge, while Song et al. (2023)
562 integrated GIS technologies and curriculum-based approaches to promote disaster risk reduction. Among the methods
563 analysed, those involving face-to-face interaction were identified as the most effective, although general daily attention levels
564 remained moderate (Song et al. 2023). Overall, only a limited number of studies have been designed to promote risk awareness
565 and self-protection behaviours among young people through genuinely participatory and collaborative approaches.



566 The participatory approaches developed in this study proved to be highly effective and engaging in transferring key concepts
567 related to geo-hydrological risk knowledge and perception. This was demonstrated by the exceptional response of both
568 students and teachers/educators during the activities, which exceeded expectations, as did the high quality of the collected
569 VGI datasets (Figs. 6 and 7) and the outputs produced within the educational pathways (Fig. 8), assessed by means of the
570 indicators reported in Table 1. A crucial role in the evaluation phase was played by critical discussions held both in the field
571 and in classrooms, through which the research team, teachers, and educators verified students' degree of participation,
572 curiosity, enthusiasm, and creativity, as well as their comprehension of key concepts. From a communication perspective, the
573 practical activities enabled the establishment of a preferential and informal communication channel between researchers and
574 participants, facilitating effective knowledge exchange. This outcome was supported by a high-quality relational climate
575 emerging from the continuous effort (requiring constant renewal) to listen to and recognise the diversity of skills,
576 competencies, experiences, perspectives, and research trajectories. In fact, genuine listening and inclusion do not imply
577 uncritical acceptance, but rather constructive dialogue with oneself and others, in which arrogance and coercion have no place
578 (Milella 2023). A key indicator of such a relational climate is the shared experience of well-being in group interaction, which
579 fosters continuous curiosity and creativity (Bateson 2000). In this sense, no participant perceives themselves as superior in
580 terms of ability, knowledge, or merit, but instead recognises every interaction as an opportunity for mutual learning and
581 growth.

582 These relational foundations were essential for effectively engaging young participants, although their practical
583 implementation also represented a significant operational challenge. The co-creation of web application content, PowerPoint
584 materials, and multimedia outputs further strengthened trust and relationships between the community and researchers.
585 Creativity emerged as an enabling factor for educational processes that combined collaboration with enhanced awareness of
586 geo-hydrological risk. On the one hand, informal exchanges with experts and the joint production of images, colours,
587 emotions, narratives, and sound materials stimulated deep reflection on environmental issues, vulnerability experiences, and
588 the emotional-perceptual sensitivity of young participants. On the other hand, the multimedia videos (both as an artefact and
589 as a co-produced narrative) and photographs collection/description enhanced attention and care towards territory and
590 otherness, supporting participatory communication and environmental risk prevention. Interestingly, although students with
591 disabilities often demonstrated higher enthusiasm and engagement during interactive activities, the overall outcomes were not
592 distinguishable across groups due to the consistently high quality of participation observed in all cases. This finding confirms
593 the important role of social sciences within the HYRMA project, in line with other interdisciplinary and transdisciplinary
594 initiatives that move beyond citizen science approaches based solely on crowdsourced data collection (Albagli and Iwama,
595 2022). Participants were not merely data collectors or mappers, but active contributors to the co-development of participatory
596 methodologies, developing autonomy in understanding, collecting, and using environmental and flood-related data. Their
597 willingness to challenge themselves by presenting the activities carried out to peers and other stakeholders is likely tangible
598 proof that participants deepened the concepts introduced by the research team regarding risk awareness and self-protection
599 measures, thus suggesting the overall effectiveness of the proposed approaches. Achieving deeper verification regarding this,
600 also with quantitative metrics, would require extended practical pathways repeated over time, a condition that is rarely
601 compatible with standard school curricula and students' availability constraints.

602 The outcomes presented in this study may therefore represent useful tools for supporting communities in responding to the
603 needs of civil protection authorities and for enhancing autonomy, resilience, and adaptive capacity in the context of climate



change (Albagli and Iwama, 2022). This potential should be further expanded through the inclusion of additional categories of citizens. Regarding implementation challenges, some difficulties emerged in conveying fundamental concepts related to flood and landslide processes, as these topics are not fully covered within the Italian school curriculum, despite the widespread exposure to related hazards and recurring disasters. These difficulties were particularly evident during frontal lectures in the training phase, where attention to theoretical content was sometimes lower compared to engagement observed during field-based practical activities. This suggests that interdisciplinary participatory approaches of this type should not be considered supplementary, but rather integrated more systematically within educational frameworks, moving beyond simple data collection exercises. In this perspective, it is important to note that geosciences and social sciences are characterised by different epistemological and methodological approaches, requiring careful planning of joint activities and continuous dialogue to ensure effective synergy. This was crucial to avoid divergences in objectives, which may arise from the absence of a shared language for discussing core concepts and from differences in methodological frameworks applied to the subject (Lowe et al., 2013).

7 Conclusions

A series of bottom-up initiatives was implemented directly with young students in two flood-prone cities in northern Italy. These activities were designed to actively involve local communities in data collection, interpretation, and analysis, while simultaneously functioning as effective tools for strengthening flood risk knowledge, perception, and awareness. The experience demonstrated that when students are directly engaged in the observation and interpretation of natural hazards, they tend to respond in a proactive and constructive manner, including the gradual development and internalisation of self-protection behaviours.

Within the framework of the HYRMA project, the implemented activities enabled the exploration of multiple complementary dimensions of participatory engagement with young people, integrating VGI, GIS-based analysis, educational pathways, and creative multimodal communication tools (images, colours, narratives, sound, and music) within a unified methodological framework. This integration represents a key novelty of the approach, as it moves beyond conventional citizen science paradigms based primarily on data collection, towards a fully co-designed and co-interpreted learning–research ecosystem.

First, the implemented experiences highlighted both the opportunities and the intrinsic challenges of participatory approaches for assessing and monitoring geo-hydrological risks. On the one hand, these approaches enabled students to engage in meaningful, context-based activities grounded in real events and familiar urban environments, thereby increasing relevance, motivation, and learning effectiveness. On the other hand, they revealed methodological, organisational, and technical constraints that must be carefully addressed when working with heterogeneous young participants, particularly in relation to communication dynamics, accessibility, and the maintenance of a consistent relational climate across different educational and social settings.

Second, the direct involvement of students in the collection, interpretation, and discussion of risk-related data contributed to a more informed and operational understanding of geo-hydrological processes and their potential impacts, as evidenced by the outcomes of both VGI field activities and structured educational pathways. In particular, the combination of field-based observation, digital data collection, and reflective learning activities fostered a transition from abstract knowledge acquisition to situated and experiential understanding of risk.



641 Third, these experiences indicate that such participatory and interdisciplinary activities can positively influence students'
 642 attitudes towards risk prevention, self-protection, and climate adaptation, promoting a stronger sense of responsibility and
 643 agency. Notably, the emergence of peer-led dissemination activities and autonomous communication initiatives (such as the
 644 voluntary presentation of results in public contexts) represents a significant added value, highlighting the capacity of the
 645 approach to generate self-sustaining processes of risk communication beyond the formal boundaries of the project.

646 An interdisciplinary research team proved essential for the success of this strategy, ensuring effective integration of diverse
 647 competencies and addressing critical aspects such as engagement design, risk communication, technological development,
 648 and educational mediation. The synergy between earth sciences, social sciences, communication, and educational expertise
 649 was fundamental in achieving coherent outcomes and in managing the complexity of participatory processes involving young
 650 citizens.

651 Beyond the student groups involved, the tested methodological framework demonstrates potential for transferability to other
 652 categories of citizens. While such extension may introduce additional challenges, these can be effectively managed through
 653 the robust and flexible structure of the proposed approaches, which integrates co-designed, field-based learning, and
 654 multimodal communication into a scalable model for participatory geo-hydrological risk education and awareness building.

655

656 **Data availability**

657 The datasets generated and/or analysed during the current study are available from the authors on reasonable requests.

658

659 **Author contribution**

660 Conceptualization: DM, GE; Data Curation: RMC, MM, RP, MZ, SS, GC; Investigation: GE, RMC, IM, GC, DM, RP, PS,
 661 SS, DV, MZ, MM; Software: GC, MZ, DV, SS; Visualization: GE, RMC, PS; Writing – Original Draft Preparation: GE, RMC,
 662 MM, RP; Writing – Review & Editing: DM, IM, PS, GC, DV, SS.

663

664 **Competing interests**

665 The authors declare that they have no conflict of interest.

666

667 **Ethical statement**

668 All participants in this research were fully informed about the study's purpose and procedures. No identifying information
 669 was retained or associated with the responses, since the survey could be conducted anonymously. Participants were not required
 670 for the evaluation at any time, nor were they passed on to third parties. Surveys were only conducted with individuals who
 671 were involved in or interested in the project. As for the class experiments, the study was conducted with the head of the school
 672 consent, adhering to ethical guidelines. No ethical committee approval is required for the type of information collected.

673

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681

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