International Journal of Disaster Risk Reduction 15 (2016) 80–93

Contents lists available at ScienceDirect

International Journal of Disaster Risk Reduction

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

# Assessing the safety of schools affected by geo-hydrologic hazards: The geohazard safety classification (GSC)

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ARTICLE INFO

*Article history:*
Received 27 August 2015
Received in revised form
23 November 2015
Accepted 26 November 2015
Available online 30 November 2015

*Keywords:*
Geological risk
Coping capacities
Resilience
Human behavior
Safety school

ABSTRACT

Three-quarters of the world population suffered natural disasters at least once between 1980 and 2000. Furthermore, last years' chronicles showed us several geological events that repededly affected urban landscapes. As a consequence beside the loss of human lives and environmental degradation, lots of students were excluded from school, many of whom never to return. Natural hazards have physical, educational, economic and psychosocial impacts. Nowadays it is well ascertained that to decrease this impact by means of structural interventions requires considerable economic resources. Nevertheless, the comparision consequences of similar events in different contexts, it emerges that risk awareness of the population and education to emergency procedures have a positive impact on the occurrence of victims. It follows that the ability of school occupants exposed to hazards to resist and recover from the effects of a hazard in a timely and efficient manner plays a key role to reduce risk, moreover resulting in a cheaper and faster strategy of intervention.

This paper presents a new cost-effective methodology and procedure to rapidly assess the geohazard safety classification (GSC) of schools and provides useful information to local decision makers. The GSC, based on the concepts of hazard, vulnerability and resilience, can be calculated integrating ancillary data by means of rapid and not invasive field surveys and questionnaires distributed to the schools employees. Moreover, it can be easily read and understand since it uses the same type of scale as energy efficiency, to indicate the occupants' safety in case of adverse events related to geo-hydrologic hazards.

This new rapid assessment methodology have been tested on 10 schools in Tuscany (Italy) and the present paper shows how the GSC can be strongly affected by the lack of ancillary information or the incompleteness of the Risk Assessment Document as well as the school occupants poor perception of geo-hydrologic risk. However, this limitation is at the same time one of the strengths of the GSC: investing in education is a cost-effective way to increase substantially the GSC.

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## 1. Introduction

The impacts of adverse events related to geological hazards are unevenly distributed among communities and groups of individuals concentrated in restricted workplaces. Their consequent safety level is the result of differential exposures to these events and of diversified levels of preparation to them [1,2]. These two aspects, combined with different percentage depending on the places and communities living there, contribute to characterize the weakness of such anthropic environments. For instance, a United Nation study has demonstrated that while in Bangladesh the number of disastrous events between 1990 and 1999 was three times less than in the United States, the number of deaths in Bangladesh was 34 times higher because of the poor coping capacity of the people [3].

Nowadays, the exposure and coping ability as co-determinants of people's safety are of particular interest for local and national institutions managing the school system, that are also increasingly concerned in the comprehension of the causal chain between a hazardous event and the downstream human consequences [4]. Such awareness is slowly spreading because the proper information and knowledge are taking root firmly in the decision-making administrations [5]. In fact, it is now widely accepted that in order to have a completely safe school is not enough to deal only with

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http://dx.doi.org/10.1016/j.ijdrr.2015.11.006
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**Table 1**
Victims, injures and psychological consequences of the most damaging geo-hydrologic occurrences worldwide on schools in the last twelve years (2004–2015) [10–14].

| Year | Location | Main geo-hydrologic occurrences | Damages |
|---|---|---|---|
| 2015 | Nepal | Earthquake | 334,000 students have had their classrooms destroyed, and an additional 137,000 students have had majorly damaged classrooms and 260,000 students with minorly damaged classrooms. Schools will likely combine classes and use other methods to ensure that schooling goes on in affected locations. In total, 377 students were killed, with counting still to be finished with some school age deaths not accounted for in the death statistics currently as students. (Update 20.05.2015) |
| | India, Jammu and Kashmir | Landslide | After 13 days from the beginning of a considerable precipitation 14 government school buildings have been damaged by landslides triggered by the rainwater infiltration. |
| | Malawi | Flood | Hundreds of schools destroyed or badly damaged and dozens of others being used as temporary shelters. About 350,000 children could not getting an education. A total of 415 schools have been affected by the flooding and 181 of them have been turned into camps for those fleeing the rising waters. A total of 40 schools were not accessible. The rest were either accessible but without standing structures or destroyed structures that pose danger to students or without sanitary facilities and school feeding shelters. |
| 2014 | India, Jammu and Kashmir | Flood | The worst-ever floods in the Valley of Kashmir has fully destroyed thousands of school buildings while thousands others have been partially damaged, rendering them unfit for schooling. According to official figures, out of 11,526 primary and middle school buildings, 1986 have collapsed while 2685 were partially damaged. Besides, 525 school buildings have been converted into shelters for flood affected people. The devastating floods left 17 schools submerged in central Kashmir's Ganderbal district of which one school building has been declared unsafe while two primary schools have been partially damaged. In South Kashmir's Pulwama district, 12 schools were left unsafe for schooling while 157 are partially damaged. 99 school buildings have been damaged in Kulgam district. 30 schools in Anantnag education zone and 11 in Bijbehara education zone have been declared unfit for schooling as well. This assessment is of the primary and middle schools only. As per the departmental survey, 2397 students enrolled in different primary and middle schools have been left without buildings. |
| | Guatemala | Earthquake | A magnitude 6.4 earthquake with its epicenter in Mexico had here minor damages at the school system but it released most of the energy in Guatemala. A school was heavily damaged in Comitancillo. Schools were damaged in Retalhuleu. 26 schools were damaged in Chicacao, 14 schools were damaged in San Antonio Suchitepéquez and 4 schools were also damaged in Totonicapan. |
| 2013 | Taiwan | Earthquake | 174 schools were damaged. At least 37 students were injured by trying to escape from the school building. |
| | India, Jammu and Kashmir | Earthquake | As consequence of 6 aftershocks 3 school buildings were damaged in Doda, Gandoh and Bhaderwah wherein 7 students and 2 teachers sustained injuries. Across this belt 25 more students and 2 teachers were at least injured. While the roof of a school building collapsed in Baderwah injuring eight girl student, four students were injured when the building of their school collapsed in Kishtwar district. In another incident two school kids and one of their teachers were seriously injured in Putinag village of district Kistwar. |
| 2012 | China | Earthquake and Landslide | (September)-Multiple earthquakes struck Yiliang County and its neighboring areas in Yunnan and Guizhou provinces, killing 81 people and injuring 800 others. The earthquakes in Yiliang county caused 257 schools to become damaged (containing 98,000 students). Economic losses of up to 582.26 million yuan (about 90 million USD) have occurred with schools needing at least 270 million yuan of funds.<br>(October)-Nineteen people, including 18 students who followed classes during a China festival week to make up for lost days during the Yunnan earthquake in September, were buried in a landslide that occurred in southwest China's Yunnan Province. The landslide, of about 160,000 m$^3$, was triggered by heavy rains and engulfed a primary school building, fatally trapping 18 students. |
| | Thailand | Floods | 2600 schools and 700,000 students/teachers were affected by *Bangkok*'s floods. The estimated economic damage to educational facilities amounted to $ 224 million. |
| 2011 | Japan | Earthquake and Tsunami | 733 school students/teachers died or missing, 193 schools were destroyed, 747 schools significantly damaged, 5064 schools suffered minor damage. |
| 2010 | Philippines | Typhoon/flood | The *Super Typhoon Megi* damaged 28 schools and other 63 school buildings were used as evacuation centers. |
| | Chile | Earthquake | Earthquake impacted 2 million people, but struck on a Saturday, outside of school hours. In the most affected areas 80% of the students resumed the school just one week late. The school damage is estimated of about $2.1 billion out of $30 billion total for all damages. |
| | Haiti | Earthquake | 4000 students and 700 teachers are estimated to have died in schools in the 7.0 M earthquake. About 4800 schools were damaged or destroyed, including 1300 schools and all three universities in Port-au-Prince. About half of the nation's 15,000 primary and 1500 secondary schools were affected. The overall impact collapsed the school system. Two years later, 6,000,000 children remained out of school. |
| 2009 | Sumatra, Indonesia | Earthquake | Earthquake struck after then end of the school day. It caused collapse of many schools. 1100 schools (3200 classrooms) damaged. Thirty-four were reconstructed with support from USAID and AUSAID. |
| | Philippines | Tropical Storm | The *Tropical Storm Ketsana* ruined 78 schools. The estimated economic damage amounted to $ 13 million. 122 schools were used as evacuation centers. |
| | Taiwan | Typhoon/flood | The *Typhoon Morakot* destroyed 682 schools. The estimated damage amounted to $ 6 million. |
| 2008 | Myanmar | Cyclone | During the Cyclone Nargis 2460 schools were completely destroyed (the 50% of schools in the affected area). Another 750 schools were severely damaged. |
| | Sichuan, China | Earthquake | More than 10,000 children died in their schools. About 7000 classrooms were destroyed. |
| 2007 | Pisco, Peru | Earthquake | The earthquake damaged schools not built according to the new codes. New codes require combination frames and 3-foot shear walls every 15 feet. Infill walls have self-supporting frame and are separated by "1" elastic materials and no stucco over the joint. These performed very well. |
| | Sumatra, Indonesia | Earthquake | The seismic swarm destroyed 260 educational facilities and severely damaged more than 450 schools. |
| | Bangladesh | Monsoon floods and Cyclone | (August)-Monsoon-related floodings occurred and consequently 44 Schools washed away by river erosion, 4603 Primary schools affected, 4444 Primary schools closed and, 292 Primary schools being used as flood shelters. In the initial aftermath of the 2007 floods, an estimated 1.5 million children, or around 10% of the country's 80,000 primary schools had been affected.<br>(November)-The *Cyclone Sidyr* destroyed 496 school buildings and damaged about 2110 schools. |

**Table 1** (*continued* )

| Year | Location | Main geo-hydrologic occurrences | Damages |
|---|---|---|---|
| | Assam, India | Floods | 150,000 evacuated to public school buildings. |
| 2006 | Philippines | Typhoon | The *Super Typhoon Durian* caused an estimated economic damage of about $20 million to thousands of primary and secondary school buildings and day care centers, including 90–100% of school buildings in three cities and 50–60% of school buildings in two other cities. The schooling of hundreds of thousands of children was severely affected. |
| | Leyte Island, Philippines | Landslide | 248 children and 7 teachers died in a landslide that buried the Guinsaugon Elementary School. It occurred after 5 days the rain ceased. To date in the whole area approximately 980 persons are still missing and 139 are officially death. |
| 2005 | Kashmir, Pakistan | Earthquake | 17,000 students and 900 teachers died at school, 50,000 were seriously injured and many became disabled. 10,000 school buildings were destroyed. A total of 300,000 children was affected. In some districts 80% of schools were destroyed. |
| | Gulf States, USA | Hurricane and floods | The *Hurricane Katrina* and subsequent flooding destroyed 56 schools and 1162 were damaged. 700 schools were closed and 372,000 children WERE displaced. 73,000 college students were displaced. $2.8 billion was spent to educate displaced students for the first year. |
| 2004 | Indian Ocean | Tsunami | A large tsunami destroyed 750 schools in Indonesia and damaged 2,135 more. 150,000 students remained without schools. 51 schools were destroyed in Sri Lanka, 44 in Maldives, and 30 in Thailand. |
| | Cambodia | Floods | Between 500,000 and 1 million of students in hundreds of schools of 8 provinces were directly affected. |
| | Bangladesh | Floods | 1259 school buildings were lost and 24,236 were damaged. |

possible anthropogenic dangers (such as fires, accidents or criminal attacks) or natural menaces limiting to earthquakes.

Other types of geo-hydrologic processes (e.g. floods, landslides, eruptions and tsunamis) can be equally problematic in terms of victims, injuries or psychological consequences (shocks or discourages for the future) (Table 1). Most of them are not occasional phenomena with unfortunate consequences [6,7], on the contrary they are quite frequent. According to the disaster risk reduction experts, these geo-hydrologic processes can be mitigated with knowledge and planning, physical and environmental protection measures, and response preparedness [8,9,5]. Consequently, more governmental authorities are promoting interest in such themes within the educational community.

Worldwide, approximately 1.2 billion students are enrolled in primary and secondary schools. About 875 million of them live in high seismic zones and hundreds of millions are exposed to regular floods and landslides [15]. Among them, the most vulnerable group is who are likely to suffer a disproportionate share of the effects of these hazardous events. Schools that are not constructed nor maintained to be disaster resilient can result in lifelong injuries and death for millions of children and adults, causing irreplaceable loss to families, communities and countries.

An emblematic case of this type is the burial of an elementary school in the Guinsaugon village (Philippine) in 2006, which represents the worst recent tragedy associated to a landslide. On February 17, after ten days of heavy rainfall, a large rockslide-debris avalanche hit a school when it was in session and full of children (see Table 1). Several residents had left the area during the previous rainy days but most of them returned when the rains had eased, believing they had already avoided the most critical moment [11,12].

Moreover, the disruption of functions and related services arising from damage can similarly have medium to long-term negative effects for the life of communities [16] which can hardly return to normal in a short time. For example, following the eruption of Mount Pinatubo in 1991, about 700 school buildings (4700 classrooms) were destroyed in the Philippines, displacing about 236,700 pupils and 7009 teachers. Disruption of schooling was compounded by the use of undamaged school buildings as evacuation centers, which forced delays in the opening of classes and caused further disruptions of the school calendar [17].

On the other hand, the 30-years effort of the interested administrations to improve the safety of school buildings was able to oppose the destructive force of the 2010 earthquake ($M_w$=7.1) that affected the South Island of New Zealand. In fact, very few edifices sustained significant damages and 75% of them required minor repairs (rearranging toppled contents, repairing broken windows, replacing ceiling tiles). Therefore, most schools (226) in all districts opened one week after the event while only nine schools remained closed beyond one week, for further structural evaluations and repairs. This was possible because the newer schools were built with timber-frame single-story structures with unreinforced slab-on-grade foundations [18].

UNISDR is promoting a global culture of safety and resilience through the integration of disaster risk reduction in school curricula and the continuous involvement of children and youth in the decision-making process for disaster risk reduction. The Comprehensive School Safety (CSS) framework is intended to advance the goals of the Worldwide Initiative for Safe Schools and the Global Alliance for Disaster Risk Reduction and Resilience in the Education Sector, and to promote school safety as a priority area of post-2015 frameworks for sustainable development, risk reduction and resilience. Multi-hazard risk assessment is the foundation for planning CSS and its three pillars are: (i) safe learning facilities, (ii) school disaster management and (iii) risk reduction and resilience education.

In Italy, according the latest ministerial survey [19], there are 41,902 school buildings. Their alarming condition in terms of safety for their daily occupants is reflected by 39 fatalities ascribable to structural failures in the last 21 years [20]. In 95% of these cases victims are a sad tribute due to natural phenomena, which have struck very weak buildings. The widespread diffusion of schools throughout the Italian peninsula implies that a large part of them is directly exposed to geo-hydrologic criticalities.

The whole national territory is, in fact, a young geological area subjected to endogenous phenomena (volcanoes, earthquakes) and exogenous phenomena, which determine land evolution and natural hazard (landslides, coastal erosion, floods, slope instabilities, sinkholes). Recent studies have pointed out that 24,073 schools are located in areas with no negligible seismic potential and 6251 in areas affected by exogenous hazards [21]. In addition, more than the 50% of the structures were built before 1974, when specific technical rules for seismic design of structures were established for the first time, and costs for adaptation to standards are now estimated in 13 billion of Euros [22]. Furthermore, some analyses based on polls involving teachers, students and their parents have showed that awareness of geological risks and knowledge of correct emergency procedures are inadequate in most cases [23].

Currently, according to Legislative Decree no. 81/2008 (and updated with the Legislative Decree no. 106/2009) every Italian workplace, including schools, is requested to draft the global and documented assessment of all risks for the health and safety of workers present in the facility. This evaluation aims to identify appropriate prevention and protection measures, and to develop a plan of measures useful to ensure the improvement of the level of health and safety. The document that collects such information is called Risk Assessment Document and it is also known as DVR (Italian acronym).

In almost every DVR document prepared until today the natural hazards considered are only earthquakes and, more rarely, flooding from large rivers. Unfortunately, other geological phenomena equally important and widespread throughout the country (though more localized) are neglected, even if they are similarly dangerous. Among these, the slope instability, sinkhole, tsunami or problems resulting from excessive surface water circulation related to the urban drainage or to the minor rivers system can have important effects on school buildings.

Following the international and national framework, we have developed a pilot of an operative method able to assess the level of safety of schools for these natural events that can provide specific and useful information for the improvement of the DVR or similar documents. The level of safety is expresses by class (Geohazard Safety Classification or GSC), which does not imply structural measure or engineering calculations but is the result of a multidisciplinary and cost-effective analysis that takes into account only the degree of interaction of the aforementioned geo-hydrologic phenomena with the buildings and the school population. This implies that the proposed methodology, according to all the three pilasters of CSS, is aimed at conveying useful tools to the school administrators in order to effectually enhance the coping capacity and not at evaluating the structural stability of buildings, which cannot be achieved on large scales in reasonable times and costs.

## 2. General concepts and rationale for the study

The scientific literature provides various notions of risk [24,25]. According to several authors [25–28] risk is a complex concept since it refers to something that has not happened yet and that is related to random chance and possibility. Moreover, action and decision are implicit in the risk definition that requires the establishment of interactions between subjective risk perception and scientific need for objective measurement.

Nowadays it is widely accepted that risks, and damages associated with them, are not only due to the entity of natural phenomena, but also to the vulnerability of the exposed elements [29]. Total risk is the potential loss of exposed subject or system (i.e. the expected number of lives lost, injured persons, damages to property or disruption of economic activities) expressed as the probability of surpassing a determined level of economic, social or environmental consequence at a certain site and during a certain period of time [26,28]. Considering that risk is an objective variable that may be quantified, mathematical approaches have been established [25] that link two or more of the following variables: damage, probability, intensity, hazard, vulnerability and element at risk. From the point of view of the physical science, risk is mainly related to hazard, vulnerability and element at risk. Hazard ($H$) is defined as the probability of occurrence, within a specific period of time and area, of a potentially damaging phenomenon. It is nowadays used to refer to a latent danger or an external risk factor of a system or exposed subject. Vulnerability ($V$) is defined as the degree of loss of a given set of elements at risk resulting from the occurrence of a natural phenomenon of a certain magnitude. It is an internal risk factor of the subjects or systems exposed to hazard and corresponds to the intrinsic predisposition to be affected, or to be susceptible to damage. According to UNISDR [16], a school is considered vulnerable or at risk when it is exposed to known hazards and is likely to be adversely affected by the impact of those hazards if and when they occur. Elements at risk ($E$) are defined as the population, properties, economic activities, public services, etc., at risk in a given area [3,16,24–26,28].

Taking into account the three mentioned variables, the total risk ($R_t$) may be expressed by the following equation:

$$R_t = H \text{ x } V \text{ x } E \tag{1}$$

A rigorous evaluation of the total risk of a school building would require a complete probability density function describing the exposure to specific types of events of all the pupils and personnel in the school. In addition, the probability that the inhabitants are present in the school during an event should be estimated depending on the time of day, day of week, or month of the year, as well as on local holiday schedules [30]. Furthermore, the economic value of the people is priceless. Taking into account these considerations and that hazard and vulnerability are concomitant, mutually conditioned and neither can exist on its own, it is easier to evaluate and calculate their convolution, called specific risk ($R_s$), that represents the expected degree of loss due to a particular natural phenomenon:

$$R_s = H \text{ x } V \tag{2}$$

In order to reduce the risk of natural hazards becoming disasters, it is necessary to intervene on one or more of the three components mentioned in Eq. (1). According to UNISDR [16,31], disaster risk reduction is the concept and practice of reducing disaster risks through systematic efforts to analyze and manage the causal factors of disasters. The latter may include reduced exposure to hazards, lessened vulnerability of people and property, wise management of land and environment, and improved preparedness for adverse events. Nevertheless, in order to reduce the risk, in many cases the intervention on the exposure value is hardly practicable and modifying the hazard is not possible or is costly in terms of money and time. Sometimes there is nothing to do except modify the conditions of vulnerability of the exposed elements. This is why in technical literature emphasis is commonly placed on the study of vulnerability and on the vulnerability reduction as a measure of prevention/mitigation. However, a significant structural intervention on vulnerability may also be costly and vulnerability is not only related to the exposure of the material context or to the physical susceptibility of the exposed elements, but also to the social frailties and lack of resilience of the prone communities [32]. Vulnerability and resilience are related and express the features of systems or victims potentially at risk. Waiting for new and effective non-structural measures (such as laws, restrictions or surveillance and early warning systems) by the local government, we can do something to increase the coping capacity of communities, investing in the preparedness and the consciousness of the community about the risks insisting on a specific area [33,34].

It is difficult to have a common and widely accepted definition of resilience [25,35]. In our work we refer to resilience according to UNISDR [35]: it is *"the ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions. […] [It is] determined by the degree to which the community has the necessary resources and is capable of organizing itself both prior and during times of need"*. Resilience should not be confused with coping capacity [35] that is "*the ability of people, organizations and systems, using available skills and resources, to face and manage adverse conditions, emergencies or* *disasters. The capacity to cope requires continuous awareness, resources and good management, both in normal times as well as during crises or adverse conditions".*

## 3. Test site

For this project, ten school buildings were selected in the Tuscany Region (central Italy) considering a representative set of different geo-morphological contexts and related exogenous phenomena, structural typologies and age of occupants. Eight of these schools are located in the north mountainous belt of the Apennines (1–6 and 9–10 in Fig. 1) while the remaining two are located in a wide flat basin of alluvial origin (7 and 8 in Fig. 1). We considered the geo-morphological phenomena that are most widespread in the studied territory: (i) the seismic behavior of the ground on which the building foundations lay according to the official national classification; (ii) the slope instabilities as recorded by the dedicated agencies and (iii) all the dangerous hydraulic effects (e.g. floods, excessive surface runoff) as indicated by the authorized local entities.

All the Italian municipalities are classified into four seismic zone according to their Peak Ground Acceleration (PGA) value [36] (Department of Civil Protection, 2014): 43.06% of them are classified as seismic zone 4 ($PGA > 0.05$ g), 19.25% as zone 3 ($0.05\ g < PGA < 0.15$ g), 28.9% as zone 2 ($0.15\ g < PGA < 0.25$ g) and 8.74% as zone 1 ($PGA > 0.25$ g). In Tuscany there are no areas classified as seismic zone 1 and the 33.10% of municipalities are in seismic zone 2, 58.54% in zone 3 and 8.36% in zone 4 (http://www.rete.toscana.it/sett/pta/sismica/03normativa/classificazione/classificazione_toscana/). Therefore eight of the selected schools are located within the seismic zone 2 and two schools within the seismic zone 3 (Fig. 1).

According to the national inventory of the landslides (also known as IFFI project, available online at: http://193.206.192.136/cartanetiffi/#) realized by ISPRA (Italian acronym for *Istituto Superiore per la Protezione e la Ricerca Ambientale* i.e. National Institute for Environmental Protection and Research) in Italy there are about 500,000 landslides. With reference to this inventory two of the selected ten buildings fall in areas mapped as active landslides, three are located on quiescent landslides, three are not too far (less than 300 m) from recognized instable slopes and two are enough distant from any slope movement (Fig. 1).

There is not a unique national zonation for the hydraulic hazard. In fact, the existing classification maps are edited by each River Basin Authorities according to the executive directive of national law 183/1989 which officially designed such institutional entities to the management of the river basins. Therefore, the requested information can be found in different documents called "Piano Stralcio di Assetto Idrogeologico" (PAI), which are characterized by a hazard mapping based on an immediate classification of the territory in different areas from "no hazard" to "very high hazard". In the test area the schools exposed to the hydraulic hazard are just three and are all located in very high hazard zones (Fig. 1).

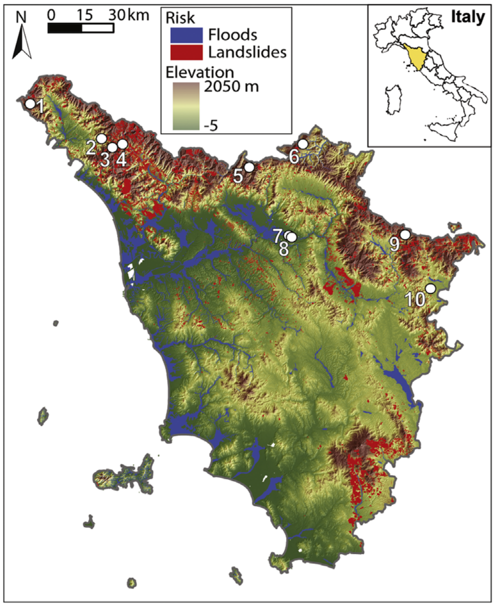
Four schools with masonry structures (MAS in Fig. 1) and six schools with concrete frame structures (CLS in Fig. 1) effectively depict the variety of structural typologies that characterize national territory. The selected sample includes buildings with both regular and irregular distribution of masses as different plant shapes, including linear and compact geometries, and different floor distributions, from single level to 5 levels, are included. It is also important to note that five buildings were built before 1974, confirming the national distribution of ages illustrated in Section 1. Moreover, the volume of buildings is reasonably allied with the number of occupants (Fig. 1), both in buildings expressly constructed as schools and in historic buildings modified and converted over time.

Finally, it is important to point out that the age of students is well distributed over the entire sample and they range from small children (3 year old) up to teenagers (18 years old).

## 4. Methodology

### 4.1. GSC definition

According to Lucini [25] risk is the product of four factors: probability, intensity, vulnerability and resilience. The inclusion of



| | Municipality | PGA [g] | Landslide risk | Flood risk | Structures | Period of years | Gross volume [m$^3$] | Students age range |
|---|---|---|---|---|---|---|---|---|
| 1 | Coloretta | 0.200 | ☑ | | MAS | 2012 | 2880 | 6-14 |
| 2 | Minucciano | 0.195 | ☑ | ☑ | CLS | 2002 | 8790 | 3-14 |
| 3 | Piazza al Serchio | 0.203 | ☑ | | CLS | 1970 | 14000 | 3-14 |
| 4 | Casola in Lunigiana | 0.198 | ☑ | | CLS | 1961-75 | 3000 | 3-11 |
| 5 | Treppio | 0.195 | ☑ | | MAS | 1961-75 | 981 | 3-11 |
| 6 | Pietramala | 0.201 | ☑ | | MAS | 1946-60 | 1293 | 6-11 |
| 7 | Firenze | 0.131 | | ☑ | MAS | 1800-95 | 21550 | 14-18 |
| 8 | Firenze | 0.131 | | ☑ | CLS | 2000 | 10000 | 11-14 |
| 9 | Corezzo | 0.210 | ☑ | | CLS | 1995 | 1219 | 3-11 |
| 10 | Anghiari | 0.212 | ☑ | | CLS | 2010 | 5199 | 3-11 |

**Fig. 1.** (on left) Localization of the studied schools over an elevation map of Tuscany: in red the areas affected by landslides hazards and in blue the valleys prone to floods. (on right) Summary table of the school characteristics: municipality, PGA value for a return time of 475 years (http://esse1-gis.mi.ingv.it), landslides and flood risk areas, structure typology (MAS stands masonry and CLS for concrete frame), period of construction, gross volume and student age range.(For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

resilience as a component of risk allows us to refine the risk awareness, focusing attention on the cultural and social meaning of risk as a shared practice among communities that are potentially at risk.

Following this approach, and taking into account Eq. (2), the new specific risk equation is:

$$r_s = \frac{H*V}{\rho} \tag{3}$$

where $\rho$ is resilience. Consequently the building Index of Geohazard Impact (IGI) can be defined as the maximum of the considered specific risks:

$$IGI = \max r_{si} \tag{4}$$

where *i*, in our case study, stands for earthquake, flood, and landslide.

The Geohazard Safety Classification (GSC) is here defined as the complementary to one of the IGI, and since school-resilience is not a function of each considered risk (see Section 4.2.2), Eq. (4) assumes the following form:

$$GSC = 1 - IGI = 1 - \frac{\max(H_i*V_i)}{\rho} \tag{5}$$

Both the IGI and GSC are divided into five classes and their value ranges from zero to one (Table 2), similar to the energy consumption labeling scheme established by the EU Directive 92/75/EC. A different level of safety and specific risk is defined for each class: from class A, very low risk, to class E very high risk (see Table 2). According to the definitions of hazards (H) and vulnerability (*V*) stated in Section 2, their convolution ranges from zero to one and we divide it again into the same IGI five classes (Fig. 2). As the resilience ( $\rho$) is inversely proportional to the specific risk (Eqs. (1) and (2)) it is still divided into five classes but it ranges from 1.2 (good condition) to 0.8 (worst condition) (Fig. 2). Therefore, resilience could be a damper, if greater than one, an invariant, if equal to one, or an amplifier, if less than one, of the specific risk.

Fig. 2 shows in a schematic way the results of the Eqs. (4) and (5).

## 4.2. GSC estimation

In this work, we used three main steps, to obtain the GSC value, as concisely sketched in Fig. 2: (i) data collection; (ii) data processing and (iii) IGI and GSC calculation (results).

### 4.2.1. Data collection

First, we collected the available cartographic information of the study area (e.g. topographical arrangement, geological phenomena, natural risks and susceptibility, seismic microzonation, distribution of infrastructures, urban plans), together with the building's structural and not-structural information, and integrated them with field surveys. The latters were mainly aimed at integrating the base maps with updated and detailed data connected to the geo-hydrologic hazards and vulnerabilities and sometimes obtained with cost-effective devices. For example, some of the main on-site activities consisted in verifying the existence of effective retaining works on unstable slopes and the preservation status of the hydraulic works for controlling the surface circulating waters, as well as for the protection against river flooding and landslides.

**Table 2**
The five Geohazard Safety Classification (GSC). The values range from one (GSC equal to A that means very high security level and therefore very low specific risk) to zero (GSC equal to E that means very low security level and therefore very high specific risk). The reference values of each class are calculated according to the Eq. (5).

| Geohazard safety classes (GSC) | Security level | Reference values of the specific safety class | Index of geohazard impact (ICI) | Specific risk ($R_s$) | Reference values of the specific risk |
|---|---|---|---|---|---|
| A | Very High | 1.0–0.8 | a | Very low | 0.0–0.2 |
| B | High | 0.8–0.6 | b | Low | 0.2–0.4 |
| C | Medium | 0.6–0.4 | c | Medium | 0.4–0.6 |
| D | Low | 0.4–0.2 | d | High | 0.6–0.8 |
| E | Very low | 0.2–0.0 | e | Very High | 0.8–1.0 |

All these data are summarized in four sheets (Fig. 2): School Building General Information (SBGI-sheet), Hydraulic Risk (HR-sheet), Landslide Risk (LR-sheet) and Seismic Risk (SR-sheet). These check lists are essentially based on a heuristic direct observation activity, similar to the Italian AeDES sheets (http://www.protezionecivile.gov.it/cms/view.php?dir_pk=188&cms_pk=17654) for the building post-seismic assessment. This approach aims to quickly collect and organically structure the information needed to obtain an assessment of hazards, vulnerability and response capacity of the building itself.

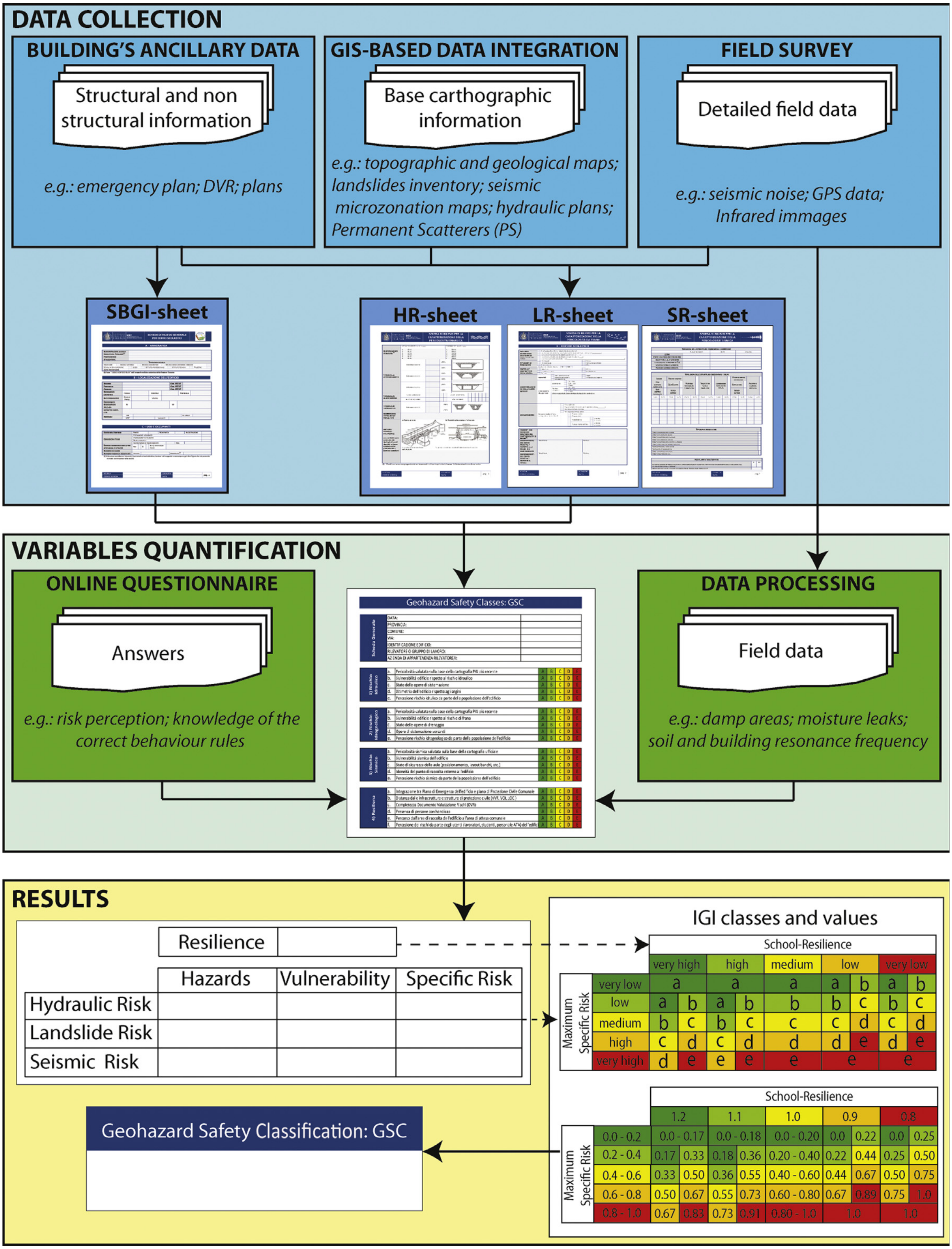
The compilation of the SGBI-sheet is preliminary to the others, since it contains general information about the building, such as the geographical and urbanistic localization, the type of school and the use of its spaces, the number of people who work and study inside and the list of the available documents (planimetric layouts, DVR, emergency plan). The HR- and the LR-sheets allow to characterize and classify the area in which the school is located from a hydraulic (water circulation) and geomorphological (slope instabilities) point of view, according to the current legislation and the scientific state of the art. In conclusion, these sheets allow us to summarize the building hazard and vulnerability to floods and landslides. Finally, according to the Italian law (Order of the President of the Council of Ministers 3519/06 and Ministerial Decree 14/01/2008), the SR-sheet summarizes the seismic hazard of the area and the seismic vulnerability of the school building.

### 4.2.2. Variables quantification and GSC calculation: the IGI sheet

The next step aims at quantifying the variables of Eq. (3), and therefore calculate the IGI. A sheet that summarizes and quantifies all the information and data collected during the field survey was created in the framework of the project. This summarizing document (Fig. 2) is divided into four parts: three devoted to each analyzed risk and one exclusively reserved to the school-resilience. Each of the three sections regarding the risks is subsequently divided into five questions. Each question has five possible answers with five different weights, from 0.2 (A, optimal condition) to 1 (E, bad condition) as shown in Table 3.

The first question of each section concerns the hazard ($H_i$): it is derived by the national seismic classification and the PAIs and it ranges from “not a risk area” (A, $H_i=0.2$ optimal condition) to “$PGA_{max}=0.35$ g” or “P4_very high hazards” (E, $H_i=1$ worst condition). The other four questions deal with the vulnerability ($V_i$) and, for each risk, the value $V_i$ is the arithmetic mean of the four answers. The last question of each section concerns the hazard perception (hydraulic, landslide and seismic, respectively) of the school-population, evaluate using the correspondence between the mapped hazards and the answers to the on-line questionnaire (A, $V_i=0.2$ optimal condition: correspondence greater than 85%; E, $V_i=1$ worst condition: correspondence lower than 35%).

The hydraulic building vulnerability is evaluated taking into account: (i) floor numbers and dimension of the rooms (A, $V_i=0.2$ optimal condition: more than one floor above-ground that can hold all the people present in the building; E, $V_i=1$ worst condition: the escape routes are in the basement); (ii) building height compared with the dam height (A, $V_i=0.2$ optimal condition: the building is higher of at least 3 m; E, $V_i=1$ worst condition: the



| Maximum Specific Risk | School-Resilience: very high | | high | | medium | | low | | very low | |
|---|---|---|---|---|---|---|---|---|---|---|
| very low | a | | a | | a | | a | b | a | b |
| low | a | b | a | b | b | | b | c | b | c |
| medium | b | c | b | c | c | | c | d | c | d |
| high | c | d | c | d | d | | d | e | d | e |
| very high | d | e | e | e | e | | e | | e | |

| Maximum Specific Risk | School-Resilience: 1.2 | | 1.1 | | 1.0 | | 0.9 | | 0.8 | |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.0 - 0.2 | 0.0 - 0.17 | | 0.0 - 0.18 | | 0.0 - 0.20 | | 0.0 | 0.22 | 0.0 | 0.25 |
| 0.2 - 0.4 | 0.17 | 0.33 | 0.18 | 0.36 | 0.20 - 0.40 | | 0.22 | 0.44 | 0.25 | 0.50 |
| 0.4 - 0.6 | 0.33 | 0.50 | 0.36 | 0.55 | 0.40 - 0.60 | | 0.44 | 0.67 | 0.50 | 0.75 |
| 0.6 - 0.8 | 0.50 | 0.67 | 0.55 | 0.73 | 0.60 - 0.80 | | 0.67 | 0.89 | 0.75 | 1.0 |
| 0.8 - 1.0 | 0.67 | 0.83 | 0.73 | 0.91 | 0.80 - 1.0 | | 1.0 | | 1.0 | |

**Fig. 2.** Flow chart for the Geohazard Safety Classification (GSC) definition: data collection (blue box), variables quantification (green box) and results (yellow box). In the latter the IGI classes and the respective numeric values and convolution are also shown.(For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

building is lower than the dam); (iii) state of hydraulic works (A, $V_i=0.2$ optimal condition: there are hydraulic works; E, $V_i=1$ worst condition: poor or no maintenance of the hydraulic network). The landslide building vulnerability is evaluated taking into account: (i) where the building is located with respect to landslide (A, $V_i=0.2$ optimal condition: there is not mapped landslide or the building is far enough from it; E, $V_i=1$ worst condition: the building is located on a landslide); (ii) presence and maintenance of the drainage slope system (A, $V_i=0.2$ optimal condition: operated and maintained drainage; E, $V_i=1$ worst condition: drainages absent); (iii) state of retaining works (A, $V_i=0.2$ optimal condition: there are retaining works; E, $V_i=1$ worst condition: absence of retaining works). The seismic building vulnerability is evaluated taking into account: (i) the building resonance frequency

**Table 3**
Weights of the answers in the GSC summary sheet. The answers in the three risk sections (hydraulic, landslide and seismic) range from 0.2 (A, optimal condition, minimum risk) to 1 (E, bad condition, maximum risk), while the answer in the resilience section range from 1.2 (A, good condition that dampen the specific risk according to Eq. (3)) to 0.8 (E, bad condition that amplify the specific risk according to Eq. (3)).

| Answer | Values in risk section | Values in resilience section |
|---|---|---|
| A | 0.2 | 1.2 |
| B | 0.4 | 1.1 |
| C | 0.6 | 1 |
| D | 0.8 | 0.9 |
| E | 1.0 | 0.8 |

(A, $V_i=0.2$ optimal condition: building frequency less than free-field frequency and area classified as stable; E, $V_i=1$ worst condition: building frequency equal to free-field frequency and/or area classified as unstable); (ii) classrooms equipment and the status of the emergency ways(A, $V_i=0.2$ optimal condition: adequate height and form of the desks; E, $V_i=1$ worst condition: inadequate height and form of the desks); (iii) suitability of the waiting area (A, $V_i=0.2$ optimal condition: close to the school and corresponding to the municipal waiting area; E, $V_i=1$ worst condition: absence of a waiting area or the way to reach is not safe).

The forth section of the IGI sheet is devoted to the school-resilience and is divided into six questions whose answers have different weights, from 0.8 (A, optimal condition) to 1.1 (E, bad condition) as shown in Table 3 and the $\rho$ value in Eq. (5) is the arithmetic mean of the six answers. We defined this variable school-resilience since it is not related to specific hazards and vulnerabilities but it take into account: (i) DVR completeness (A, $R_i=0.8$ optimal condition: all the geo-hydrologic risk are examined; E, $R_i=1.2$ worst condition: no one of the geo-hydrologic risks are examined); (ii) integration between the building

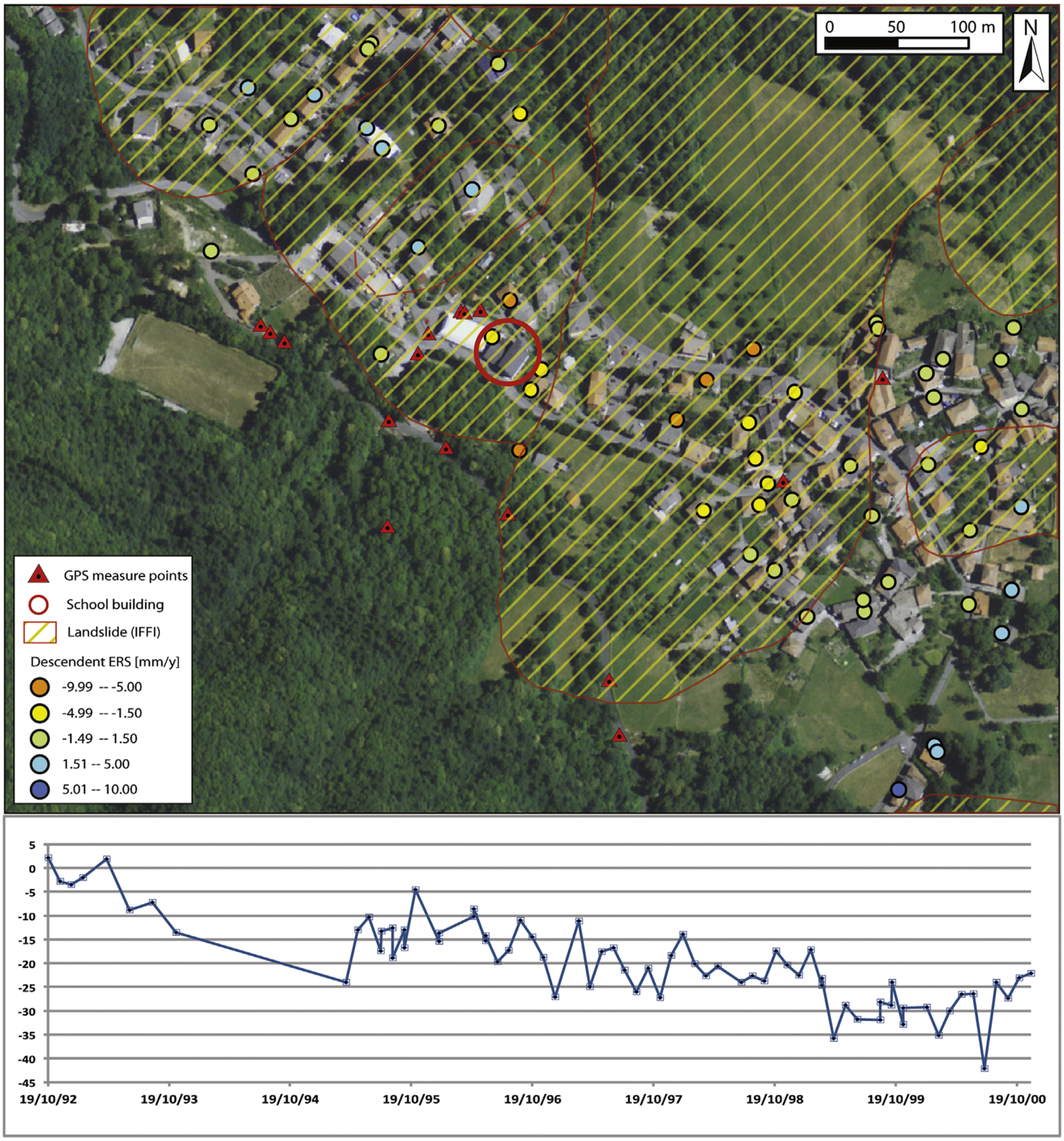


**Fig. 3.** Overview map of the site 1 (see Fig. 1) with the position of the available permanent scatterers (colored dots) and the measured GPS points (red triangles). The underlying blue chart shows the displacement time series of the permanent scatterer within the red circle centered on the school.(For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

emergency plan and the municipality civil protection plan (A, $R_i = 0.8$ optimal condition: all the geo-hydrologic risk are considered and there is well integrated with the municipality civil protection plan; E, $R_i = 1.2$ worst condition: absence of the building emergency plan); (iii) distance between the school and strategic buildings such as hospitals or fire stations (A, $R_i = 0.8$ optimal condition: distance less than 5 km; E, $R_i = 1.2$ worst condition: distance higher than 30 km); (iv) state of the path from the school waiting area to the municipal one (A, $R_i = 0.8$ optimal condition: the path is safe concerning the geo-hydrological risks; E, $R_i = 1.2$ worst condition: the path is not safe concerning the geo-hydrological risks); (v) presence of people with handicap (A, $R_i = 0.8$ optimal condition: there are not architectural barriers, presence of trained staff and there are not people with handicap; E, $R_i = 1.2$ worst condition: there are architectural barriers, no staff and there are people with handicap). The sixth question of this section takes into account the answers to the on-line questionnaire that had to be filled in by the students and personnel of the school.

The multiple response on-line questionnaire was distributed through a link to an Internet page and consisted of fifteen questions about: (a) what is in the opinion of the interviewed on the hydraulic, landslide or seismic mapped hazard class of the area; (b) what does the interviewed thinks about the geo-hydrological safety of the school; (c) what are, according to the interviewed, the correct behaviors -among those listed- to adopt during an earthquake, food or landslide; (d) how often there are evacuation drills; (e) what is the knowledge of the interviewed about the School Emergency Plans (does he/she knows it, did he/she read it, does he/she think that it is exhaustive…).

The last step of the GSC definition is the calculation of the IGI and therefore of the GSC (Fig. 2), according to its definition and Eq. (5).

### 4.3. Working line for the data integration

All the cartographic data collected during the first phases of the work (see Section 4.1) were georeferenced in the same coordinate system (UTM-WGS84) within a GIS project in order to allow a general overview of the risks. In addition to this overlap, that pictures the current situation, we integrated the ERS1/2

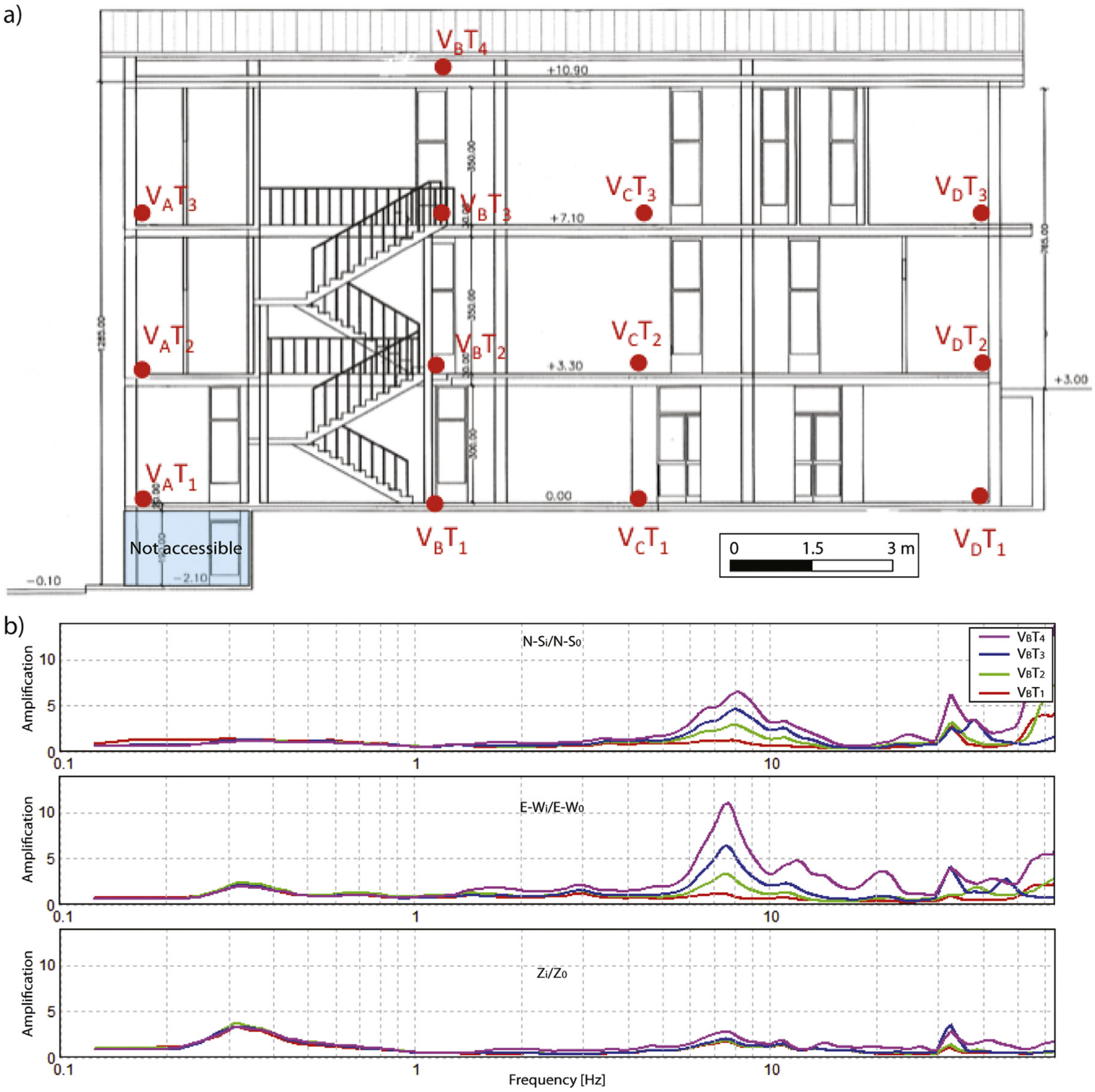


**Fig. 4.** (a) Location of seismic noise measurements along four verticals ($V_iT_i$ indicate the installation sites of the instruments for the i measure) at the site 1; (b) ratios $H_i/H_0$ along the vertical $V_B$. In these graphs it is possible to identify the first flexural mode at 7.9 Hz along the E–W component and the second flexural mode at 8.18 Hz along the N–S component.

(monitoring period 1992–2000) and ENVISAT (monitoring period 2002–2010) permanent scatterers (PS) datasets (http://www.pcn.minambiente.it/GN/progetto_pcn.php?lan=it, Fig. 3) for the instable areas, in order to assess the soil and building movements in the past decades [37–39] and therefor evaluate point (i) of the landslide vulnerability.

Afterwards, during the supplementary field surveys, detailed terrestrial topographic surveys were carried out around the schools to map the most relevant geomorphological features [33,40,41] (Fig. 3) that are pertinent with the aim of the work. To do this, we used a Leica 1200 differential GPS (mean 3D coordinate quality of 3.0 cm) in real time kinematic mode [42,43]. Such instrument was employed as rover device which received, from time to time, the real-time correction message (NRT) from the nearest reference station (i.e. Nearest Correction) belonging to a national network fully managed by Leica Geosystems Italia and named Smart-Net ItalPoS [44–46]. These information lead to evaluate: points (ii) and (iii) of he hydraulic vulnerability, points (i), (ii) and (iii) of the landslide vulnerability and point (iii) of the seismic one.

Complementarily to these measures, a series of free field and on buildings seismic noise measurements (Fig. 4) were carried out to detect the soil-structure interaction and the building fundamental modes and resonance frequency. These were obtained by means of the $H_i/H_0$ ratio, where $H_i$ is the measure tacked at the $i$th floor and $H_0$ is the reference measure, usually the free field one [33,47], according to the Horizontal to Vertical Spectral Ratio (HVSR or $H/V$) technique [48–53] and the SESAME project (2004) indication. These measures were carried out by means of five Tromino®, the all-in-one compact 3-directional 24-bit digital tromometer by Micromed (maximum portability: 1 dm$^3$ volume and 1 kg weight). Even thought it is well known that landslide areas have to be considered as unstable sites, especially during an earthquake, the buildings seismic noise measurements have been carried out anyway since the majority of the landslides were classified as non-active. Knowing the building and free-field soil frequencies lead us to evaluate the point (i) of the seismic vulnerability.

In addition, thermographic images (Fig. 5) of interior and exterior surfaces of the buildings were taken to: (i) reveal the presence of water on the foundation soil; (ii) locate moisture leaks and damp areas; (iii) disclose any substrate features; (iv) assess the condition of structural elements [54–60]. These measures were carried out by means of a Flir SC620 thermal camera, characterized by a focal plane array microbolometer sensor [61] and where used to evaluate the point (iii) of the seismic vulnerability.

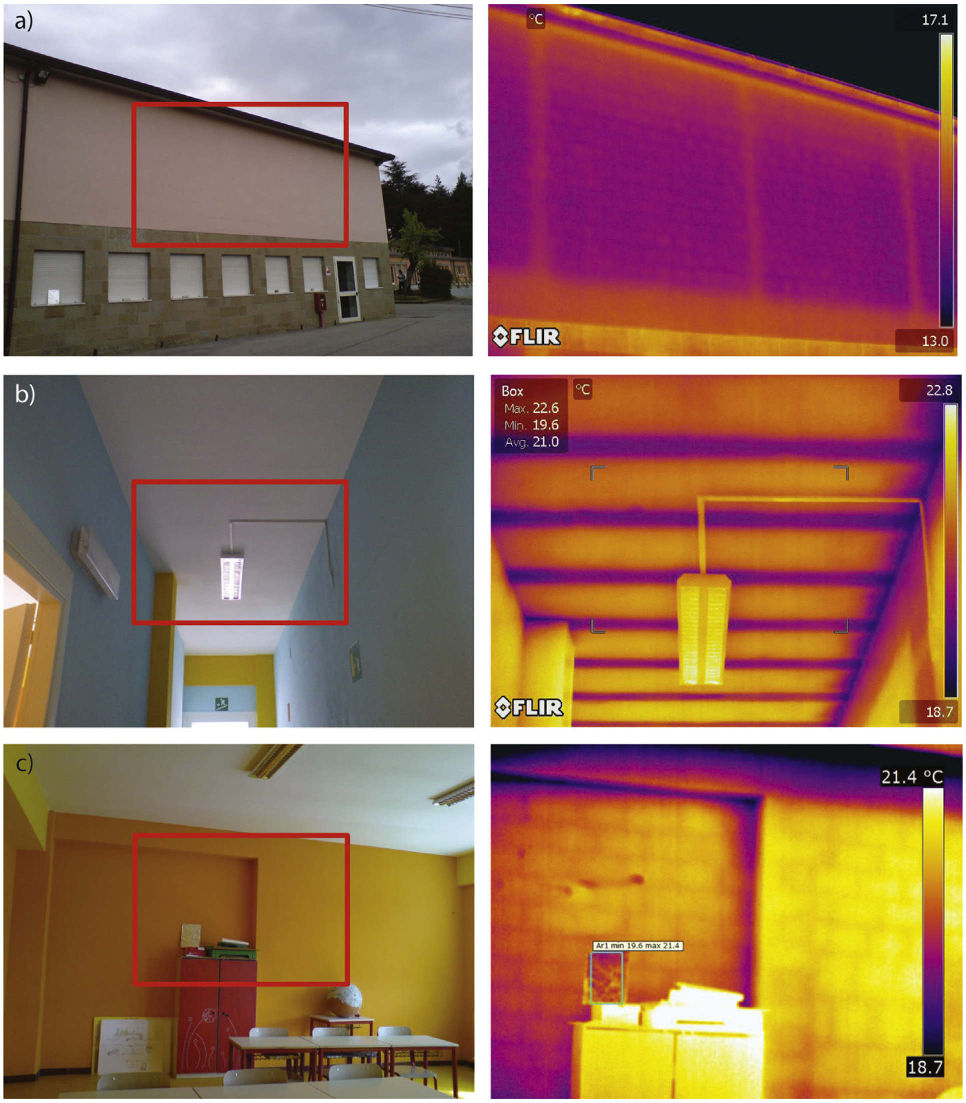


**Fig. 5.** Examples of couples of optic and thermal images focused on the wall structures of three different sites. (a) façade, (b) ceiling and (c) interior wall. The thermal images refer to the inside part of the red rectangles in the optical image.(For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

## 5. Results

Collecting existing documents on structural features, safety procedures and hazards of the surrounding environment of each school building, took the first 2 months of this research (17% of the total project time) including making data uniform and putting them in a standard format. Official projects and structural analyses, owner institutions are in charge of conserving them, were only 27% of the requests. Such a low percentage, which represents a significant limitation for assessing the safety of a structure, is due to changes in ownership throughout building history and to a nonexistent policy of data conservation and accessibility. Official documents on analysis of risks connected to the work activity in schools and safety procedures were instead 50% of the requests. This alarming small fraction is unrelated to the nonexistence of those documents, which owners were asked to provide recently, but to their loss or unavailability. Background data on the analysis of natural hazards at regional scale and related council-scale safety procedures, of which specific public organizations are in charge of and freely accessible to the population, were 75% of the research. Therefore this initial phase shows that the completeness, accessibility and knowledge of the documents can be improved only by standardizing procedures and identifying institutions in charge of school facility management.

In relation to the fieldwork, a team of five experts of environmental risks was employed for one day in each school. Such short time, to better suit school necessities, was the result of a detailed planning of activities and selection of appropriate and non-invasive survey technologies. The standard configuration consisting of two thermographic acquisition and GPS surveys technicians while the rest of the team was arranging the five Tromino®, surveying structures and interviewing school employees. Given peculiar facility dimensions and weather conditions, the work plan was properly modified to guarantee an effective use of time and resources.

As for instrumental measurements, in Table 4 we summarize the number of the seismic noise single station measures and the number of the thermographic images for each school. All these measurements have been carried out according to the standard methods described in the available references. We also juxtaposed this information to the satellite dataset available for the PS analysis. The seismic noise data processing showed that in 50% of the school the frequency of the first vibrating mode of the structure is similar to the main vibrating frequency of the surrounding soil, which means the building is prone to the soil-structure resonance effects according to Clinton et al. [49]. These results, as expected, were obtained especially from one-floor buildings. In 30% of the schools, the building frequency is higher than the soil one, meaning that the soil-structure resonance effects are not possible in this moment, but they cannot be excluded in the next years due to mainshocks. Finally, the remaining 20% of the schools were evaluated as not prone to resonance effects since the building first mode frequency is lower than the soil one [33].

**Table 4**
Number of seismic noise single station measures, number of thermographic images and PS dataset available at each school. The ten schools are numbered according to Fig. 2. In the V-column of the seismic noise measure the numbers of the verticals of measure (the first number) and measure taken at each vertical (the second number) are reported; in the M-column the single station measures are reported; in the FF-column the number of the free field measures are reported. In the PS dataset column, _desc stands for descending and _asc for ascending acquisition geometry of the satellite.

| ID school | Seismic noise measures | | | Thermographic images | PS data |
|---|---|---|---|---|---|
| | *V* | *M* | FF | | |
| 1 | 3 × 3<br>1 × 4 | 3 | 1 | 34 | ERS_desc |
| 2 | 3 × 2 | 6 | 1 | 50 | ERS_desc |
| 3 | 3 × 2 | 2 | 1 | 30 | ERS_desc |
| 4 | 3 × 2 | | 1 | 40 | ERS_desc |
| 5 | 1 × 2 | 3 | 1 | 35 | ERS_desc<br>ENVISAT_asc<br>ENVISAT_des |
| 6 | | 3 | 1 | 30 | ERS_desc<br>ENVISAT_asc |
| 7 | 1 × 5 | | | 50 | ERS_desc<br>ENVISAT_asc<br>ENVISAT_des |
| 8 | 3 × 2 | 5 | 1 | 45 | ERS_desc<br>ENVISAT_asc<br>ENVISAT_des |
| 9 | 3 × 2 | | 1 | 40 | ENVISAT_des |
| 10 | 3 × 2 | 4 | 1 | 35 | ERS_desc<br>ENVISAT_dec |

The thermographic images did not emphasize structural criticalities over the entire school sample. Only in 40% of the buildings no moisture leaks and damp areas were detected. Moreover, in about 16% of this group (10% of the school), the damp areas were much more widespread than it was perceived by the visual inspections. However, their distribution over the structures allowed us to exclude serious infiltration issues.

Among the dataset of PS at disposal, we focused on the ones that are in a radius of about 250 m from the school facilities. Only in 30% of the test sites there is at least one PS in correspondence of the school building and in two-thirds of these cases they show movements. In addition, in 60% of the entire studied areas no significant displacements were measured in the period 1992–2000 (ERS dataset) and 2002–2010 (ENVISAT dataset), while displacements higher than 5 mm/yr in the period 1994–2000 and in the period 2003–2010 were detected in 30% and in 10% of the cases, respectively.

The direct observation of the buildings and their surrounding landscape did not show evidences of ground instabilities or inefficiencies in the surface water channeling throughout the surveys. Nevertheless, this activity was useful to identify negligence by the local administration in charge of the maintenance of these systems and to map them with the GPS device.

## 6. Discussion

For each of the ten selected schools, we calculated the values of hazard ($H_i$) and vulnerability ($V_i$) for flood, landslides and seismic risk respectively, the resilience value ($\rho$) and the quality of the school emergency plans and DVR, on the basis of retrieved literature, field survey observations and answers to the online questionnaire. A brief overview of these results is illustrated in Fig. 6.

After data were made uniform, it was possible to assign a value to each of the three considered hazards. With respect to the flood occurrence, 70% of the schools is in class A (very low hazard), 20% in class D (high hazard) and 10% in class C (medium hazard). In relation to the landslide occurrence, 40% is in class A, 30% in class D, 20% in class B (high hazard) and 10% in class E (very high). Finally, with regards to the seismic occurrence, 80% of the studied buildings is in class D and 20% in class C. On the other hand, as for vulnerabilities factors, no school is in class A or B: 80% of the buildings are in class C and 20% in class D in relation to the flood vulnerability, 40% are in class C and D and 20% in class E as regards to the landslide vulnerability. Finally 30% is in class C, 60% in class D and the last 10% in class E in relation to the seismic vulnerability.

Because of a problem occurred with the Italian education system (students could not fill the questionnaire because it was not included in school programs) only school staff filled it. The results

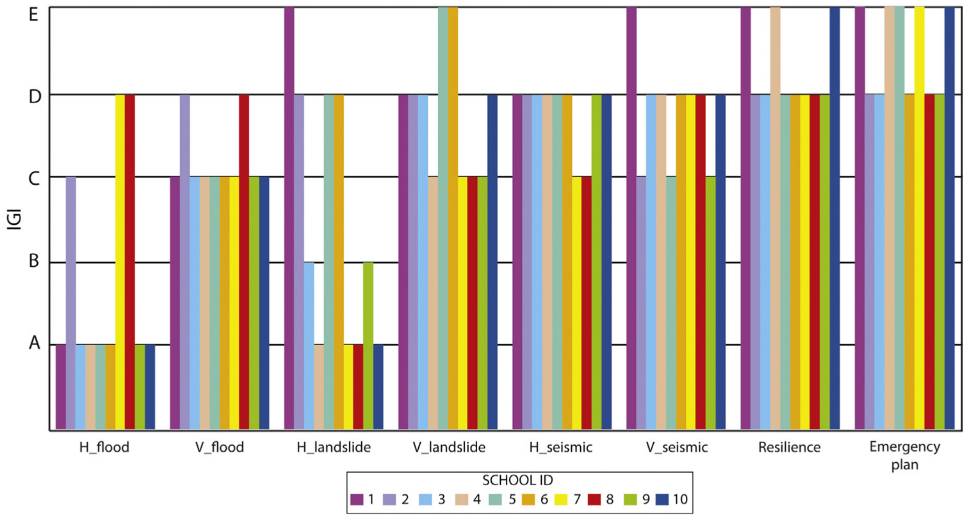


**Fig. 6.** Hazard and vulnerability classification in relation to the three analyzed geo-hydrologic risks and codification of the resilience and the quality of the emergency plans for each school. Considering the vertical axis, the letter A means "very low risk" or "well done", while the letter E means "very high risk" or "very bad" (see Tables 2–3).

of the online questionnaires (response rate 80% approximately) revealed that more than 70% have a poor perception of flood and landslide hazards for the area where the school is located, while in the same place the seismic hazard is well perceived. Moreover, they have only a partial knowledge of the proper behavior rules in case of geo-hydrologic emergency and. The rules in case of landslide emergency are the least known. In addition, more than 50% do not know the waiting area established (by law) by the Municipal Civil Protection Plan. As for resilience, quantified on the basis of the collected answers, the research shows that 70% of the school have a low resilience (class D) and 30% a very low resilience (see Fig. 6) that implies, according to the Table 3, the resilience value in Eq. (5) is a specific risk amplifier.

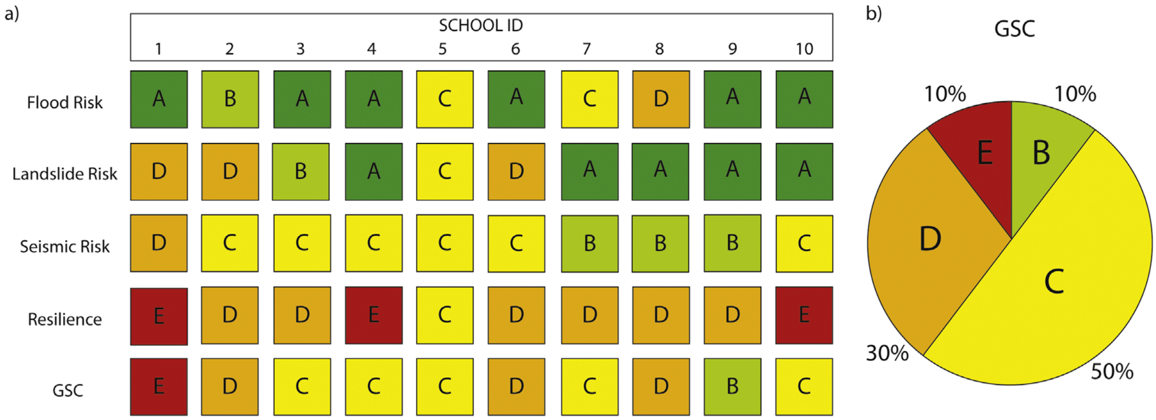
Moreover, the DVRs and/or the emergency plans of each school were also deeply analyzed to verify their completeness with respect to the three considered geological hazards. In half of the schools these documents are missing or they do not treat the geological risk, so they were classified in class E, while in the other cases they deal at most with the geo-hydrologic risk, so they were classified in class D (Fig. 6). Other specific outcomes are listed below:

- in all the analyzed documents an accurate description of the type and arrangement of the school can be found, but only in one document the building surface area is specified;
- in most of the documents there are only general indications about risks, their origin and rules in case of emergency;
- among the geological risks, only the seismic risk is analyzed;
- there is not a single and unambiguous definition of the risk classes since the used risk equations are different or the result matrices are grouped into different classes;
- the exact location of the waiting area is rarely specified outside of the school; sometimes a general descriptions of the qualities of a suitable waiting area are indicated, as though the people in charged of the evacuation procedures could identify the most suitable area from time to time, according to their perceptions.

In conclusion, Fig. 7 shows the GSC of the ten studied schools: no school is in class A (very low specific risk), 10% are in class B (low specific risk) and E (very high specific risk), 40% are in class C (medium specific risk) and D (high specific risk). It is important to underline how the resilience, even if it is a risk amplifier, according to the table in Fig. 2, does not imply a jump into a worst class.

## 7. Conclusion

All over the world about 875 million of school users live in high seismic zones and hundreds of millions are exposed to regular floods and landslides. In many cases, schools neither are constructed, nor maintained to be disaster-resilient. These geo-hydrologic occurrences can cause medium to long-term negative


a)

| | SCHOOL ID | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Flood Risk | A | B | A | A | C | A | C | D | A | A |
| Landslide Risk | D | D | B | A | C | D | A | A | A | A |
| Seismic Risk | D | C | C | C | C | C | B | B | B | C |
| Resilience | E | D | D | E | C | D | D | D | D | E |
| GSC | E | D | C | C | C | D | C | D | B | C |

b)

**Fig. 7.** Specific risks and GSC of the ten studied schools (for the school ID see Fig. 1).

effects, irreplaceable losses, lifelong injuries and death of several students and school staff. Starting from this social context, a quick tool for the rapid assessment of the land-induced risks in schools was developed with a pilot project in Tuscany (Italy). The project developed a method for assessing school hazard exposure (landslide, seismic, flood) and structural fragility/safe learning facilities (seismic response, dampness, plan configuration) which is non-invasive, fairly quick, and appropriate to the Italian school context. This tool, which is based on the GSC definition, was optimized for a very wide variety of situations, so that it may be exported and tested in schools (or in similar working places) of other geographical areas.

The GSC was obtained as the complementary to one of the IGI, calculated modifying the equation of the specific risk, taking into account also the resilience as a damper, amplifier or invariant of the specific risk itself. The variables of this new equation (hazard, vulnerability and resilience) can be quantified on the basis of ancillary data (thematic maps), results of the data processing of field surveys (seismic noise measure according to the $H/V$ technique, thermographic images, GPS surveys) and the answers to an online questionnaire implemented on purpose. The key features emerging from the study area and identifying this operative part of the work are summarized as follows: (i) simple analytic procedure; (ii) high speed (iii) objectivity in all the processing steps; (iv) reliability of the procedures and used devices and (v) unambiguous comprehension of results.

The reason why determining results is immediate and relatively straightforward, is mainly related to the use of a system based on indexes and classes. This allowed us to identify effectively what critical aspects are worth of dealing with. Furthermore, the immediacy results from economic resources that may be limited, field surveys requiring a minimal time, measurements of the school structures, as well as of the soil features, are not invasive and use innovative technologies (e.g. Tromino or GPS) and areas that are not physically accessible can be monitored with remote devices (e.g. thermographic camera). However; all these positive aspects are counterpoised by critical issues that highlight the administration's unrealistic appraisal of these threats: lack of sufficient data, huge variation among buildings and the long time needed to collect all of the available ancillary data (thematic maps, plans and documents) and to make them uniform. As shown in Section 4, this work has occupied 17% of the total project time, in our study, because of the poor systematic distribution of the required material for each situation. In other circumstances, the timing of this phase could vary case by case and it remains a hardly predictable factor on which the public administrations should reflect in their public governance and begin to intervene making the assessment procedure here proposed even faster.

Lastly it is of great value developing a rapid assessment methodology for school safety, appropriate for local contexts, the GSC has to take into account all the geo-hydrologic threats and has to be done in every school as well as buildings energy efficiency classification.

## Acknowledgments

This work was funded by *INAIL – Direzione Regionale per la Toscana* (Grant no. 2254/2013) and the project was signed off by the *Dipartimeto di Scienze della Terra – Università di Firenze, INAIL*, the *Area Coordinamento Istruzione, Educazione, Università e Ricerca* of the Tuscany Region and the *Ufficio Scolastico Regionale* of Tuscany. The authors are grateful to all the people who collaborated to the project, especially to the headmasters and to all the school staff who actively cooperated during the field surveys. The authors also thank the anonymous reviewers whose comments allowed improving the scientific quality of the work.

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