Artificial caves as a possible danger: sinkholes and other effects at the surface

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Abstract

Artificial caves may represent a possible danger, threatening the public and private properties. Presence of underground cavities beneath built-up areas implies situations of potential risk for all the man-made infrastructures and constructions above. Nevertheless, such a risk remains unknown until an effective knowledge about the real extension, the typology, and the stability conditions of the caves has been reached.
Cavers must be well aware of such a risk, and be ready to provide a contribution in facing the problems that might occur. In many occasions, development of deformations at the surface, up to subsidence and eventually formation of sinkholes, has caused severe direct damage, and produced a number of related problems, from inconveniences to circulation for the local population, to decreased value of properties, and so on. The conditions possibly leading to occurrence of sinkholes must be therefore object of study by cavers, since they are the only "eyes" that have a direct possibility of inspection and monitoring of the underground.
Artificial cavities, once abandoned, are subject to degradation of the rock mass, which may also be favored by water infiltration, presence of wastes, or other anthropogenic actions (i.e., overcharge, vibrations due to traffic, etc.). Identification of the first signs of instability underground, in the form of tension cracks, deformations along the wall of the cavities, and first detachment of volumes of rocks, is crucial to assess the instability conditions at the site, and to plan the necessary interventions.
All the above issues will be dealt with in this contribution, by means of some examples from Apulia region (southern Italy) where in recent years several episodes have occurred, mostly related to underground quarries. This latter typology of artificial caves has been identified by far as the most dangerous typology of artificial cavity concerning instability phenomena and the likely effects to the human society.

KEY WORDS: artificial cavities, hazard, sinkholes, civil protection.

Riassunto

CAVITÀ ARTIFICIALI COME UN POSSIBILE PERICOLO: SPROFONDAMENTI ED ALTRI EFFETTI IN SUPERFICIE

Le cavità di origine antropica possono costituire un potenziale pericolo, e mettere a repentaglio la pubblica e privata incolumità. La presenza di cavità sotterranee al di sotto di zone urbanizzate implica situazioni di rischio potenziale per tutte le sovrastanti infrastrutture, nonché per le costruzioni esistenti. Ciò nonostante, tale rischio resta ignoto sino a che una effettiva conoscenza della reale estensione e tipologia delle cavità, e delle loro condizioni di stabilità, siano state raggiunte.
Gli speleologi sono ben consapevoli di tali rischi, e possono fornire un significativo contributo per affrontare correttamente e nei tempi più opportuni i problemi connessi a cavità ipogee. In più di una occasione, lo sviluppo di deformazioni in superficie, sino a fenomeni di subsidenza e, infine, alla formazione di sprofondamenti, ha causato seri danni diretti, e prodotto numerosi problemi ad essi collegati, quali ad esempio difficoltà nella circolazione del traffico per le popolazioni locali, diminuito valore delle proprietà, e così via. Le condizioni potenzialmente in grado di condurre alla occorrenza di sprofondamenti devono pertanto essere oggetto di studio da parte degli speleologi, in quanto questi costituiscono gli unici "occhi" che hanno una possibilità diretta di ispezione e monitoraggio degli ambienti sotterranei.
Le cavità artificiali, una volta abbandonate, sono soggette a fenomeni di degrado dell'ammasso roccioso, che possono anche essere favoriti da infiltrazioni d'acqua, presenza di rifiuti, o da altre attività antropiche (i.e., sovraccarichi, vibrazioni per il traffico, etc.). L'identificazione dei primi segni di instabilità nel sottosuolo, sotto forma di fratture da tensione, deformazioni lungo le pareti delle cavità, e primi distacchi di volumi di

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roccia, è cruciale per valutare le condizioni di instabilità al sito, e per pianificare le necessarie operazioni di intervento.
Gli argomenti su citati sono trattati nel presente contributo, per mezzo di alcuni esempi dalla Puglia (Italia meridionale), una regione dove nel corso degli ultimi anni si sono verificati numerosi eventi di sprofondamento, la maggior parte dei quali risulta connessa a cave sotterranee. Questa tipologia di cavità artificiali è stata pertanto identificata come la più pericolosa per quello che riguarda la possibilità di occorrenza di fenomeni di instabilità, e i possibili effetti negativi derivanti alla società.

Parole chiave: cavità artificiali, pericolosità, sprofondamenti, protezione civile.

Introduction

Sinkholes are among the main types of hazards that affect karst environments (Ford & Williams, 2007; Parise & Gunn, 2007; Waltham & Lu, 2007; Parise, 2010a; Gutierrez, 2010; Zhou & Beck, 2011). They occur as natural events, deriving from karst processes in soluble rocks, either cropping out at the surface or covered by other materials (Waltham et al., 2005; Parise, 2008), or can be related to presence of underground cavities realized by man. Especially in countries where the underground space has been historically used by man for several purposes, occurrence of subsidence or sinkholes related to old, often abandoned, man-made cavities is quite frequent. This may become a significant problem in built-up areas, and in particular in those sectors where expansion of the urban areas included those sectors of land affected by man-made cavities.
Cavers may play a very important role in the identification of the sites possibly interested by subsidence and sinkholes, since they are the only category of people that have the opportunity, and the technical skills, to move safely underground. Their survey, and the observation of likely instability features affecting the rock masses, may be of crucial importance to timely identifying unstable sites, and might help in carrying out studies to ascertain the effective possibility of collapse, and consequently the sinkhole occurrence at the surface.
As an example to highlight the hazards related to the presence of man-made cavities, the Apulia region, the heel of the Italian boot, is considered in this article. Due to the almost exclusively presence of soluble rocks at the outcrop, Apulia is heavily affected by sinkholes, related to both the natural caves produced by karst processes, and the artificial cavities widely characterizing the region. As a matter of fact, Apulian land hosts some thousands of artificial caves, encompassing practically all the typologies of man-made cavities, and realized during the different time epochs.

Sinkhole occurrence in Apulia

Since the beginning of last century, sinkholes in Apulia are being frequently caused by anthropogenic activity, and particularly by quarrying which, among the human activities, is certainly one of those producing the worst impacts on the natural Apulian landscape. When quarries are realized underground, they become potential dangers when, once abandoned, are affected by instability processes which upward stoping may eventually lead to sinkhole development at the surface.
In Apulia several rock types have been interested by underground quarrying activity. In particular, the Plio-Pleistocene calcarenites, widely used for construction purposes, have been extensively extracted through subterranean excavations (Parise, 2010b, 2012). Underground quarrying historically developed due to a number of reasons, namely the presence of the rocks with the best characteristics at a certain depth, and the need to preserve surface land to be used for agriculture. The latter point is particularly important for the local economy, which is based on agricultural production, with some products of remarkable quality such as olive oil and wines. Due to the above reasons, subterranean galleries and passages were excavated in order to reach the rock levels to be cultivated for extraction. This occurred mostly at low depth (that is, not greater than 10 meters), but in some cases, depending upon the local geological and topographical settings, it was necessary to dig shafts over 30-40 m-deep. Most of these activities had to be recorded during the XIX century, and typically lasted for a few decades, before being abandoned, as a combination of some accidents related to the difficult working conditions, and to high expenses of the extraction works. Once abandoned, the underground sites rapidly were forgotten, and such a loss of memory played a crucial role in increasing the sinkhole hazard. With time, the expansion of the urban areas that occurred during the XX century often resulted in construction of buildings and communication routes just above the underground galleries. At the same time, weathering processes due to water circulation and/or to illegal discharge of liquid and solid wastes underground, caused a progressive decrease in the strength properties of the materials (Andriani & Walsh, 2003), a factor which undoubtedly is favorable to the degradation of the rock mass in the underground quarries and may promote development of failures (Parise & Lollino, 2011).
Apart from underground quarries, many other typologies of man-made caves in Apulia have originated subsidence and/or sinkhole problems: from underground oil mills, to storage houses, cisterns and rupestrian settlements, there is record of several cases where the presence of an artificial caves, and the failure processes occurring therein, with progressive stoping toward the surface, resulted in sinkhole formations, with severe

damage to the society in terms of economic losses, and (luckily, in a limited number of events) casualties.

A chronological research about sinkhole events related to anthropogenic caves in Apulia has been recently carried out by Fiore & Parise (2013): the main outcomes are summarized in Table 1. It has to be noted that the 45 sinkhole events listed in the table under-estimate the real occurrence of sinkholes. The table includes only those cases for which a documentation has been found, which includes a specific temporal reference, even though limited only to the year of occurrence (Fig. 1). Other events, for which no information about date of occurrence was found, were not considered in the study, and therefore do not appear in Table 1.

Many sinkhole events go unreported, or the related documentation is lost with time. In other situations, sinkholes are not recorded since land owners prefer to keep them secret, to avoid loss of value of the land. This is in particular true as concerns the sinkholes in rural areas: in the chronology shown in Table 1, only 5 even-

[12/02/2008] condividi questo articolo

LEQUILE: FRANA IL TERRENO E INGHIOTTE TRE AUTOMOBILI

Una piccola voragine larga circa 7 metri, lunga 5 e profonda 50 centimetri si è improvvisamente aperta in via Solano, nel riore "Dragoni", alla periferia del paese. Inghiottiti un furgone e due auto

Ripresa dall'alto di Via Solano con i tre mezzi sprofondati nel terreno

Un tonfo. Semplicemente un tonfo, nemmeno tanto rumoroso. I muratori che stanno lavorando nella palazzina di via Solano a Lequile, rione "Dragoni", alla periferia del paese, si voltano e vedono che il terreno ha ceduto inghiottendo in parte due auto e un furgone, mezzi che poco prima il cedimento si trovavano parcheggiati dall'altra parte della strada, alle loro spalle. Ore 10.30: tre mezzi sprofondano in un fosso apertosi improvvisamente nella terra: è largo circa 7 metri, lungo 5 e profondo una cinquantina di centimetri. Tutto è accaduto senza che alcun segnale avesse potuto in qualche modo far presagire l'avvenimento. Una sequenza che riporta inevitabilmente ai fatti di Gallipoli, in via Firenze, alle voragini d'altro tipo e allo sfollamento dei residenti. Le cose, fortunatamente, in fondo via Solano, a due passi dalla cappella intitolata proprio alla Madonna di Solano, sembrano subito meno gravi, ma la preoccupazione per gli abitanti della zona inizia a serpeggiare. Anche perché, circa un mese fa, un altro cedimento del terreno, più circoscritto di quello verificatosi questa mattina, c'è stato. I residenti hanno segnalato l'evento al Comune, che ha poi provveduto a inviare i propri tecnici. Ricoperta la buca, tutto è tornato nella normalità, si fa per dire.

Sono stati proprio gli abitanti della zona ad avvertire questa mattina i vigili del fuoco del comando provinciale di Lecce, i quali sono giunti sul luogo per rendersi conto della portata dell'evento. Ma come è possibile che il terreno possa cedere in quel modo? Stando a quanto risaputo, fino ad un paio di secoli addietro nel sottosuolo vi era la presenza di numerosi frantoi ipogei, molti dei quali sono stati col tempo ricoperti per consentire poi l'edificazione delle abitazioni. Un po' come è accaduto in quel di Gallipoli. Ora toccherà ai tecnici comunali capire se il cedimento del terreno in via Solano può ritenersi un episodio isolato, oppure se quella piccola voragine è un fatto che va preso seriamente in esame, essendosi verificato a una manciata di metri dalle abitazioni dislocate lungo tutta la strada.

La Redazione

Fig. 1 - Example of newspaper clip about occurrence of sinkhole: the events at Lequile (no. 32 in Table 1; source: www.LecceP-rima.it).

Fig. 1 - Esempio di notizia tratta da giornali su eventi di sprofondamento: il caso del sinkhole a Lequile (evento n. 32 in Tabella 1; fonte: www.LeccePrima.it).

ts occurred in rural areas (Fig. 2). In any case, we feel that the events listed in Table 1 may provide an overall framework, even though not comprehensive, about frequency and distribution in the Apulian territory of anthropogenic sinkholes. This well highlights the existence of the problem in the region, a danger which has been for long times ignored by the local Authorities, and only recently gained the due attention (Barnaba et al., 2010), in the aftermath of the impressive sequence of events occurred in the last decade.

The cases of occurrence of anthropogenic sinkholes for which a date is known are listed in Table 1. Overall, 24 cases of sinkholes due to underground quarries have been found (Figs. 3 and 4), whilst in 9 other cases the occurrence of sinkholes attributed to subterranean quarries is likely, but not sure. As concerns the most ancient documented events, two towns deserve particular attention: Canosa di Puglia, where in the first

no.	*date*	*location*	*province*	*source*	*type of cavity*
1	1925	Canosa di Puglia	BAT	Soc. It. Cond. Acqua, 1989	quarry
2	1947	Altamura	BA	Martimucci *et al.*, 2010	quarry
3	March 8, 1955	Canosa di Puglia	BAT	Soc. It. Cond. Acqua, 1989	quarry
4	July 1956	Cutrofiano	LE	Parise *et al.*, 2008	quarry
5	April 8, 1957	Canosa di Puglia	BAT	Soc. It. Cond. Acqua, 1989	quarry
6	May-June 1957	Cutrofiano	LE	Parise *et al.*, 2008	quarry
7	November 27, 1959	Andria	BAT	AdB Puglia	?
8	February 3, 1972	Andria	BAT	AdB Puglia	quarry (?)
9	October 13-14, 1972	Andria	BAT	AdB Puglia	quarry (?)
10	December 11, 1972	Andria	BAT	AdB Puglia	quarry (?)
11	January 3, 1973	Andria	BAT	AdB Puglia	quarry (?)
12	July 21, 1973	Andria	BAT	AdB Puglia	?
13	May 5, 1974	Andria	BAT	AdB Puglia	?
14	February 5 (?), 1979	Andria	BAT	AdB Puglia	quarry (?)
15	February 20, 1980	Andria	BAT	AdB Puglia	?
16	before April 1985	Cutrofiano	LE	Cutrofiano Municipality	quarry
17	1986	Canosa di Puglia	BAT	Soc. It. Cond. Acqua, 1989	quarry
18	May 4, 1990	Canosa di Puglia	BAT	AdB Puglia	quarry
19	December 20, 1992	S. Marco La Catola	FG	AdB Puglia	storage site
20	November 11, 1995	Grottaglie	TA	Grottaglie Municipality	oil mill
21	February 1996	Cutrofiano	LE	Cutrofiano Municipality	quarry
22	January 24, 1997	Capurso	BA	Andriani *et al.*, 1998	silos
23	1998	S. Marco La Catola	FG	AdB Puglia	storage site
24	September 5, 1999	Canosa di Puglia	BAT	AdB Puglia	quarry
25	June 16, 2000	Sant'Agata di Puglia	FG	Parise & Wasowski, 2002	storage site
26	October 3, 2000	Sant'Agata di Puglia	FG	Parise & Wasowski, 2002	storage site
27	March 2006	Altamura	BA	Martimucci *et al.*, 2010	quarry
28	April 2006	Candela	FG	AdB Puglia	storage site
29	March 29, 2007	Gallipoli	LE	Delle Rose, 2007	quarry
30	May 5, 2007	Gallipoli	LE	CNR-IRPI surveys	quarry
31	May 7, 2007	Altamura	BA	Spilotro *et al.*, 2010	quarry
32	February 12, 2008	Lequile	LE	newspaper clip	oil mill (?)
33	July 15, 2008	Cutrofiano	LE	CNR-IRPI surveys	quarry
34	December 3, 2008	Altamura	BA	newspaper clip	quarry
35	2008-2009	Gravina in Puglia	BA	AdB Puglia	cellar, storage site (?)
36	February 2009	Ginosa in Puglia	TA	CNR-IRPI surveys	quarry
37	February 18, 2010	Trani	BAT	newspaper clip	?
38	March 2010	Cutrofiano	LE	CNR-IRPI surveys	quarry
39	May 3, 2010	Barletta	BAT	De Giovanni *et al.*, 2011	quarry
40	May 2010	Cutrofiano	LE	CNR-IRPI surveys	quarry
41	October 2010	Cutrofiano	LE	CNR-IRPI surveys	quarry
42	November 2010	Gallipoli	LE	newspaper clip	quarry
43	December 20, 2010	Gallipoli	LE	CNR-IRPI surveys	quarry
44	February 19, 2011	Andria	BAT	newspaper clip	water channel
45	February 11, 2012	Taranto	TA	newspaper clip	storage site

Tab. 1 - List of the documented sinkholes in Apulia, related to anthropogenic cavities.

Tab. 1 - Elenco dei casi di sprofondamento connessi a cavità antropiche in Puglia, per i quali è stata reperita documentazione relativa alla data di occorrenza.

Fig. 2 - A sinkhole in rural areas: the May 2010 event at Barletta (no. 39 in Table 1).
Fig. 2 - Uno sprofondamento in zona rurale: l'evento del Maggio 2010 a Barletta (n. 39 in Tabella 1).

Fig. 3 - A sinkhole at Altamura, and an example of the failures in the underground system of quarries (photos by Centro Altamurano Ricerche Speleologiche).
Fig. 3 - Uno sprofondamento ad Altamura, e esempio di evidenze dei dissesti nelle cave sotterranee (fotografie del Centro Altamurano Ricerche Speleologiche).

decades of the XX century a series of sinkholes occurred, which were at the origin later on of a crisis during the '90s with subsequent reclamation works in the town (Società Italiana per Condotte d'Acqua, 1989); and Andria (Fig. 5), where at least 9 events were recorded, showing lower impact than at Canosa di Puglia as regards the damage produced, but nevertheless producing great alarm in the town. The main difference among the sinkholes registered at these two sites is that, based upon the available documents, the events at Canosa di Puglia are all attributable to underground quarries, whilst this link is less clear at Andria, where also other categories of man-made cavities may had been responsible of the sinkholes.

Fig. 4 - Sinkhole at Cutrofiano, related to presence of underground calcarenite quarries (event no. 38 in Table 1; photo G. Quarta).
Fig. 4 - Sprofondamento a Cutrofiano, per presenza di cave sotterranee in calcarenite (evento n. 38 in Tabella 1; foto G. Quarta.

Apart from these two towns, the chronology reported in Table 1 points out to a very high frequency of sinkhole events related to underground quarries in the last years. Since 2006, as a matter of fact, several towns in Apulia have been affected by collapse events that in many cases repeatedly threatened or directly involved the urban areas.
Sinkhole occurrence in urban areas causes the greatest concerns in terms of civil protection issues, and safeguard of the public safety, due to likely direct involvement of buildings and people (Figs. 6 and 7). Ideally, any expansion of built-up areas should be preceded by geological-engineering surveys, also addressed to recognize the possibility of presence of underground voids in the area. In practice, however, in many Apulian towns the memory of the excavations realized in the past centuries has been lost, or, when location of underground cavities is known, a detailed map is lacking, as well as any information about degradation of the rock mass and occurrence of failures in the subterranean system. In some cases, the underground spaces have become working sites, potentially representing a threat to the workers, as had to be registered on the occasion of the event in a subterranean oil mill at Grottaglie (no. 20 in Table 1; Fig. 8).
Even outside of the towns, and in particular at their outskirts, the possibility of sinkhole occurrence has to be

taken into serious consideration, since they pose a serious threat to the communication routes, threatening the safety of vehicles. At several locations, sinkholes are only few meters apart from the roads, which have repeatedly been inhibited to heavy traffic, thus creating several economic damage to the local activities, consisting essentially of working in the surface quarries of clays, used for the pottery industry and artcrafts.

Fig. 5 - Sinkhole events in the urban area of Andria (photos dating back to the early '70; source: Basin Authority of Apulia): above, via Federico II di Svevia; below, via Pietro I Normanno and via C. Colombo.

Fig. 5 - Eventi di sprofondamento nell'area urbana di Andria (foto dei primi anni '70; fonte: Autorità di Bacino della Puglia): in alto, via Federico II di Svevia; in basso, via Pietro I Normanno e via C. Colombo.

Fig. 6 - Sinkhole at Capurso (event no. 22 in Table 1; source: Capurso Municipality).

Fig. 6 - Sprofondamento a Capurso (evento n. 22 in Tabella 1; fonte: Comune di Capurso).

Fig. 7 - The sinkhole at Taranto (event no. 45 in Table 1).

Fig. 7 - Lo sprofondamento di Taranto (evento n. 45 in Tab. 1).

Fig. 8 - Within the underground oil mill at Grottaglie, where sinkhole no. 20 in Table 1 occurred.

Fig. 8 - Interno del frantoio ipogeo a Grottaglie, sede dell'evento n. 20 in Tabella 1.

The presence of man-made underground caves that were originally located not directly below the built-up areas, but at a certain distance from this, once again may refer to underground quarry (which location had to be not too far from the inhabited areas, in order to avoid long transport of the building materials; Fig. 9), as well as to working places such as oil mills (particularly frequent in the Apulian countryside), in order to be at close contact with the key source, that is the oli-

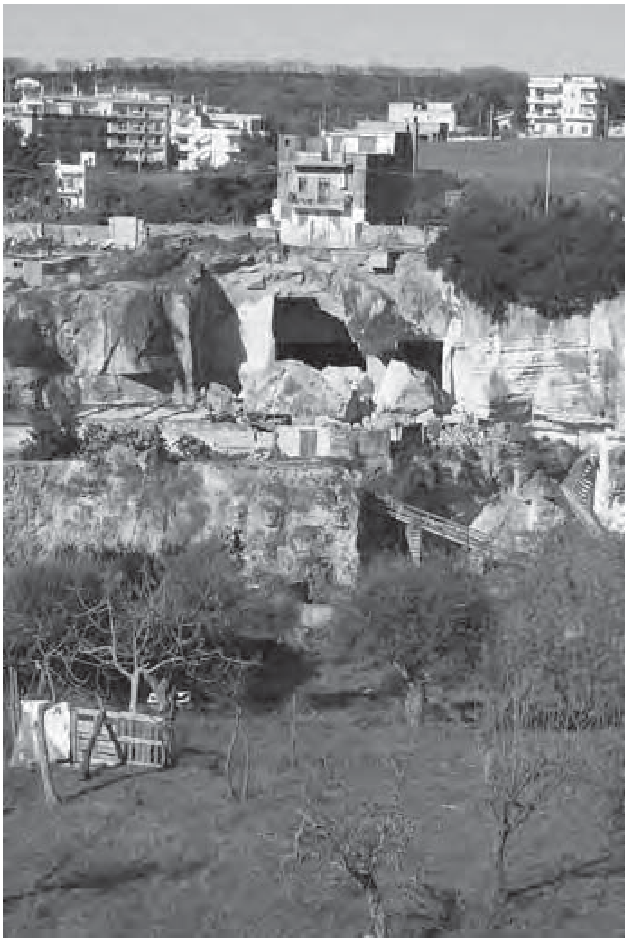

Fig. 9 - The fallen access to the underground quarry at Ginosa in Puglia (event no. 36 in Table 1). Note the proximity of the three-stories building to the sinkhole.

Fig. 9 - L'accesso crollato alla cava sotterranea di Ginosa in Puglia (evento n. 36 in Tabella 1). Da notare la prossimità della palazzina a tre piani all'area crollata.

ve field. Further, religious sites too, may be located at the outskirts of town, in order to celebrate some episodes in the life of saints, and/or promote processions by the pilgrims. With time, expansion of the urban areas brought the buildings at the borders of towns to be located more and more closer to those sectors where the underground cavities were originally excavated.

Conclusions

The high number of sinkholes related to underground man-made caves that have occurred in the last years in Apulia highlights the need to face a hazard that until recent times was greatly underestimated. Direct involvement of inhabited areas and important communication routes and infrastructures makes clear that numerous elements at risk can be threatened by sinkholes, which therefore should deserve greater attention and be object of thorough studies. The latter should ideally deal with:

- historical research, aimed at identifying the sites interested by presence of man-made caves;
- ascertaining the availability of plan and sections of the underground sites, and, when these are not available, carrying out dedicated surveys to have a precise understanding of the real development of the cave, and of the built-up areas likely to be involved in the case of sinkhole occurrence;
- recognition of the mechanisms of failures occurring in the underground sites (Szwedzicki, 2001; Parise & Lollino, 2011; Parise, 2013);
- evaluation of the decrease in the mechanical properties, related to degradation of the rock mass underground, as a consequence of water infiltration or any anthropogenic activity (Andriani & Walsh, 2003);
- analysis of premonitory signs of the catastrophic phase of collapse, in order to understand whether or not the collapse is preceded by signs that could be used for forecasting purposes.

In countries as Italy, as well as in many other regions of the Mediterranean Basin and the Middle East, historical research should play a very important role in the process of recovering old information about location of abandoned artificial cavities. Further, the several warnings about stability conditions of the subterranean quarries pointed out by cavers should be more seriously taken into consideration by the local authorities, instead of being neglected (as for instance occurred at Gallipoli; see Fiorito & Onorato, 2004).

The actual number of events is certainly underestimated, due to difficulty in finding informative accounts, and, when these are available, in their frequent fragmentation and/or inconsistency. As observed in many cases dealing with different types of natural and anthropogenic hazards, availability of historical information is not an easy issue, and the use of such information should take into account the need to critically evaluate all the different sources analyzed, in order to establish a degree of reliability for each source (Calcaterra & Parise, 2001; Glade et al., 2001). Notwithstanding these drawbacks, historical information is extremely useful to identify the most vulnerable areas, and, when properly considered and used by local land planners and managers, may significantly contribute to reduce the possible negative effects of future events.

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