Urban Geology: The Geological Instability of the Apulian Historical Centers

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Abstract. The tourist success of the Apulian region is certainly associated with the great landscape and architectural heritage. The union of these aspects is particularly evident in the territory and in the urban centers of Salento, Murgia and the surroundings in the coastal territory.

The conservation and sustainability of these places, however, often confronts the most invasive terms of hydrogeological instability (earthquakes, floods, landslides, etc.). It is true that sometimes in the Apulian urban centers geological phenomena of instability are observed much less evident than those mentioned but more subtle and equally invasive and harmful: for example subsidence, sink holes, karst.

In order to avoid the aforementioned effects, when planning and growing an urban environment, it is necessary for decision-makers, engineers, planners and managers to take into account the physical parameters of the urban area, as well as susceptibility to dangers natural.

The geology and geomorphology of an area are crucial to guarantee the sustainable management of the territory and consequently in the protection of human life in urban areas.

With this work we illustrate some examples of hydrogeological instabilities that have been observed in the historical centers of some Apulian cities and that can significantly affect strategies for preventing damage to things and people.

The cases of the hydrogeological subsidence in Acquaviva delle Fonti, in Castellana Grotte and Cutrofiano have been described and analyzed.

Keywords: Geological instability · Geological risk · Urban planning · Sustainable development

1 Introduction

Urban sustainability can be influenced by a wide range of economic, social and environmental factors (Fedeski and Gwilliam 2007; Thapa and Murayama 2010) such as economic development, socio-economic policy, population growth, physical environment and natural risks (Xiao et al. 2006; Rozos et al. 2011; De Lotto et al. 2018; Gazzola 2019). When planning, developing and managing an urban environment, usually only the economic and social parameters are taken into consideration.

Consequently, in vulnerable places, such as areas with steep slopes and/or degraded land, the natural hazards that often occur, such as landslides, earthquakes and floods,

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can cause serious damage, disruptions to the social and economic network and lead to loss of life and property.

The choice and use of risk management strategies strongly depend on the reference context and the scope of application. The United States Department of Defence has recognized four categories of risk management intervention. ACAT is an acronym for Avoid, Control, Accept, Transfer (www.defense.gov). The "Risk Elimination" strategy is desirable, for example, in cases where, both from a management and economic point of view, other measures are not suitable for reducing the conditions of the risk. On the other hand, this type of intervention also leads to the loss of potential benefits. Instead, "Acceptance of risk" interventions are used when the assumption of risk is not considered worrying for safety or when containment strategies are deemed excessively onerous. The definition of technical measures, traditional practices and public experiences to reduce the impacts of extreme natural events can also be recognized as a valid response to risk conditions.

The evolution of the concept of risk has seen a profound change in the risk reduction strategy itself. The minimization of the factors causing disasters was contemplated, providing for action on one or more variables that contribute to the definition of the risk such as Danger, Vulnerability, Exposure and Adaptation. In recent years, from an approach that dealt with the study of the hazard factor we have gone on to determine risk prediction and prevention. The forecast is aimed at understanding the dynamics and intensity of the expected phenomena. Prevention is that set of activities aimed at avoiding or minimizing the possibility of damage resulting from calamitous events. It is believed to be in line with the philosophy of recent years to underline the importance of adopting an approach to prevent, mitigate and prepare and not only to respond to disasters.

During the World Summit on Sustainable Development WSSD in Johannesburg (2002), disaster reduction is recognized as a fundamental prerequisite for achieving sustainable development. Of the 17 Sustainable Development Goals approved by the United Nations in 2015, ten concern the challenge of reducing natural hazards. It is believed that it is impossible to plan a sustainable and lasting development of cities and territories without taking into account the negative consequences of calamitous events that have proved critical for the development of urban and territorial settlements. When planning and growing an urban environment, it is necessary for decision makers, engineers, planners and managers to take into account the physical parameters of the urban area, as well as the susceptibility.

The geology and geomorphology of an area are crucial to guarantee the sustainable management of the territory and consequently in the protection of human life in urban areas.

The conservation and sustainability of these places, however, often confronts the more invasive terms of hydrogeological instability (earthquakes, floods, landslides, etc.). It is true that sometimes in the Apulian urban centers geological phenomena of instability are observed much less evident than those mentioned but more subtle and equally invasive and harmful. For example subsidence, sink holes, karst. There is a need to convert short-term non-structural interventions which are generally characterized by post-disaster emergency periods with long-term and permanent structural prevention interventions (Mejri et al. 2017; Esteban et al. 2011).

The contribution of this work is aimed at the possibility of activating an urban functional redefinition (Gazzola V. 2019) policy as the best answer to the need for urban improvement and redevelopment in relation to safety.

The cases of the hydrogeological subsidence in Acquaviva delle Fonti, in Castellana Grotte and in Cutrofiano have been described and analysed (Fig. 1).

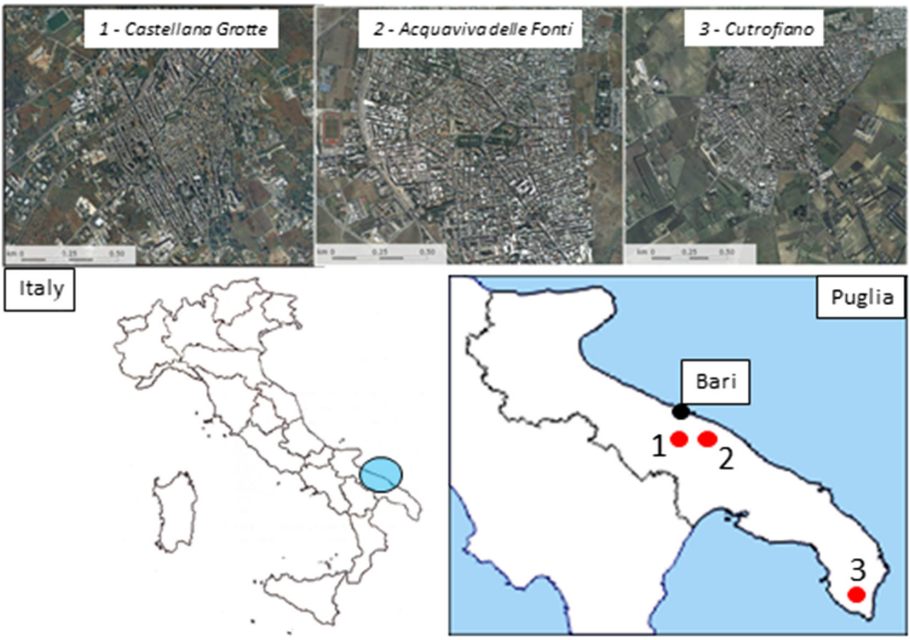

Fig. 1. Location of the historical centres of Puglia studied

2 Study Cases

2.1 Castellana Grotte

The city of Castellana Grotte is located at an altitude of about 300 m above sea level in the Murge of the south-east of Bari, about 20 km the Adriatic coast. From geological point of view, the territory is characterized by the presence in the outcrop and in the subsoil of layers of fractured and karst limestones dating back to the Upper Cretaceous.

A particularly serious event occurred in Largo Porta Grande in 1968 (Fig. 2), where following a phenomenon of subsidence, which also involved an overlying building, a pre-existing karst cavity 55 m deep was identified which in the ancient quaternary, following the collapse of the vault it was filled with red earth and continued to function as a way to dispose of rainwater. The phenomenon of opening of the cavity that it was triggered by the massive presence of water which lubricated the filling soil making it plastic and plastic-fluid consistency. Consequently, the removal of the finer particles

through the joints of the limestone has led the progressive settlement of the imposing mass of earth, creating the cavity.



Fig. 2. The collapse in Largo Porta Grande in 1968

To date, 22 natural caves are known in the area of Castellana Grotte; among these, the Castellana Caves (total length over 3500 m) and the Pozzo Cucù Caves system (total length of 1200 m) stand out for their planimetric development. Some important cavities are known below the town, such as Torre del Mastro, Abate Eustasio and Voragine del Canalone (Fig. 3).

In the case of cavities, their collapse is a real calamitous event, induced by natural but also anthropic causes. In general, the natural causes that can cause collapses of karst voids are earthquakes and the same evolution of the dissolution phenomena.

The change in the use of a territory is one of the factors triggering the collapse of the cavities: the vibrations induced by vehicular traffic, the expansion of the rooms in the subsoil, the increase in the load on the ground due to the need to raise old buildings, water leaks from sewage water networks, both public and private, are anthropogenic causes of the phenomenon.



Fig. 3. Location planimetric extension of the main cavities in the urban area: *1) Grotta di Torre di Mastro, 2) Voragine del Canalone; 3) Grotte dell'Abate Eustasio; 4) Grotte di Castellana*

The main problem is due to the fact that for the city area, a specific study has never been carried out to systematically verify any other cavities present, but only emergency intervention has been carried out on the occasion of a failure.

There is a situation of difficult management of prevention as there is a practical difficulty of preventive investigation that can be carried out on the whole territory. The underground cavities determined in a karst context present an objective difficulty due to their anisotropic development and often not accompanied by evident signals on the surface of the soil. The economic commitment of a possible plan of geognostic investigations of a direct or indirect type for the entire city area is also not negligible.

2.2 Acquaviva delle Fonti

The original nucleus and consequently the name of the city are due to the easy availability of fresh water in the subsoil. Geological and hydrogeological structure is made up of quaternary sandy deposits that rest on stratified and karst limestones of the Cretaceous age (Fig. 4). Interposed between the two sedimentary terms, silty clays and red earth are observed, according to the scheme in the figure.



Fig. 4. Geological schematic section of the city of Acquaviva delle Fonti: 1) Cretaceous limestones; 2) Pleistocene sands and silts; 3) Pleistocene clays; 4) peat; 5) red soils (from Maggiore et al. 1995, modified) (Color figure online)

With the ban on the use of surface water, what was once a resource in the past is proving to be a failure factor. Due to the high degree of pollution, the use of the surface stratum was prohibited. The historic center currently complains about a series of failures in buildings such as cracks and rising damp, in relation to the change in the level of the water table with rainfall. The relief of the recognizable damages in the buildings of the historical center are shown in the Fig. 5.

Monitoring of groundwater levels in observation wells found that indicated the hydrogeological regime of the aquifer which is connected with the rainfall. the level of the aquifer rises almost simultaneously to coincide with rainy events. During periods of low or no rainfall (summer) there are phenomena of land subsidence probably connected with the compaction of the sands. With the rain there is an increase in the volume more clayey lithological terms.

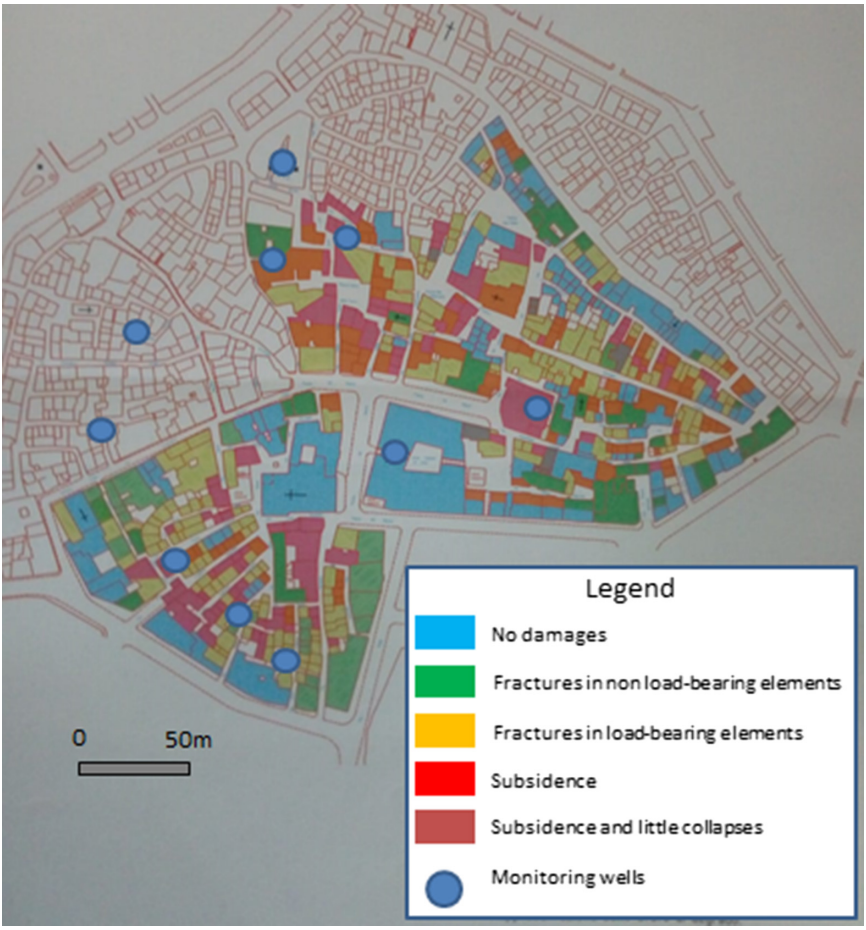

Fig. 5. Map of the distribution of the type of damage in the buildings analysed in Acquaviva delle Fonti

The sands also have a certain degree of particle size uniformity ($D_{60}/D_{10} = 3 - 3{,}3$) and therefore may be susceptible to liquefaction in the event of earthquakes.

The forecast of phenomena is not accompanied by an adequate prevention policy.

2.3 Cutrofiano

The municipality of Cutrofiano rises in central-southern Salento and is about 30 km from Lecce. It occupies a territorial surface of 55.72 km^2 and is located at an average altitude of about 80 m a.s.l.

In consideration of the peculiar geological-stratigraphic constitution and for the intense anthropic activity, the territory of Cutrofiano is characterized by the diffusion of a series of phenomena about instability of the soil which cause subsidence, even of

considerable entity, which can affect the functionality and the stability of infrastructure and buildings (Fig. 6).



Fig. 6. A building damaged by subsidence

The hydrogeological risk is linked to the presence of tunnels built for the underground cultivation of calcarenite (Fig. 7), a material widely used in local construction, and subsequently abandoned, from the early 1990s, due to the unsustainable increase in extraction costs.

The underground mining, which began at the time of the unification of Italy and lasted almost to the end of the last century, started from the area immediately south of the inhabited center, where the deposit was more superficial (about 6 ÷ 8 m), and it pushed southwards into the countryside at increasingly greater depths and with consequent greater costs and risks.

The underground quarries represent a particular type of quarry that is adopted when the deposits are positioned at a depth that makes the open-pit uneconomical, as long as the rock masses have good self-bearing characteristics and that are in the absence of substantial aquifers. The quarry is therefore made up of a series of underground tunnels and rooms of considerable size oriented in the direction of the bench to be quarried. The wells were used for access from the surface and for the transfer of the extracted material (Fig. 8).

Over time the tunnels and descending wells have given rise to sinkhole phenomena (sinking and subsidence of the soil) in some places, also affecting some existing buildings. The calcarenitic bank, which constitutes the cultivable field, was reached through descending wells (160 in total) that crossed the various superficial layers of the soil.

Different types of causes (stress, mechanical, geometric, karst) contribute to the manifestation of the instabilities:

– poor strength and/or reduced thickness of the reservoir roof - the low degree of compactness of the calcarenitic material is certainly one of the causes of the collapses.



Fig. 7. Images of some underground galleries. Lithostratigraphic succession with location of underground tunnels.

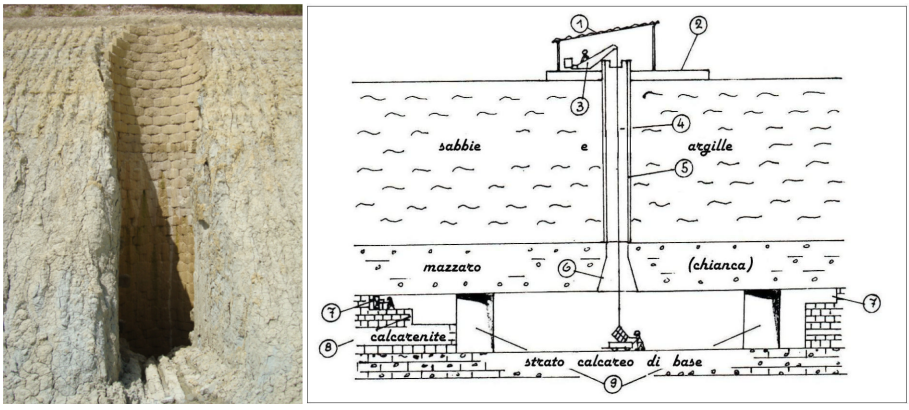

Fig. 8. Example of a well and typical section of an underground quarry (from Toni and Quartulli 1986). Sabbie = sands; argille = clays; mazzaro = hard calcarenite; strato calcareo di base = limestone

- poor strength and/or small dimensions of the pillars - the mechanical characteristics of the calcarenite to be extracted, constituting the quarry pillars and their dimensions, are fundamental for the stability of the same 5 × 5 m of the first deposits, to those of 20 × 20 m or 25 × 25 m of the more deposits recent and profound.
- tunnel size - the width and height of the tunnels affect stability
- depth of the quarry - the bank of the calcarenite deposit is at depths progressing further south towards the inhabited center.
- presence of wells - the extraction well has always been considered as the weak element of the system. The causes of collapse can be determined by various factors such as: depth of the well, with the concentric forces acting on the rings gradually increasing with depth; the development of the roots of the trees, which with time could expel segments; rainwater runoff and groundwater infiltration phenomena.

The stability conditions of the wells were analyzed. The boundary conditions can be quite variable in correspondence with the 160 wells present, therefore, for the purposes of this study, a single case has been considered in which the realization of the collapse conditions is hypothesized, in order to be able to carry out what are the induced effects on the ground following the loss of load-bearing capacity of the coating layer of the well.

The stability of the wells was investigated under axial symmetry conditions. The boundary conditions of the analyses were defined essentially on the basis of the hydro-geological structure of the modelled area. The hydro-mechanical behaviour of the materials was simulated through the use of an elastic-perfectly plastic constitutive model with a Mohr-Coulomb breakage criterion. The geometry adopted for the well is that typical of the descents used to lift the material, with a diameter of 3 m. At the mouth of the well, in the surface layer of sand, an inclined excavation profile equal to the effective friction angle of the material ($\varphi' = 28°$) was considered.

In the hypothesis of axial symmetry, the study was carried out considering a section identified by a radial abscissa of the well originating from its axis (Fig. 9).

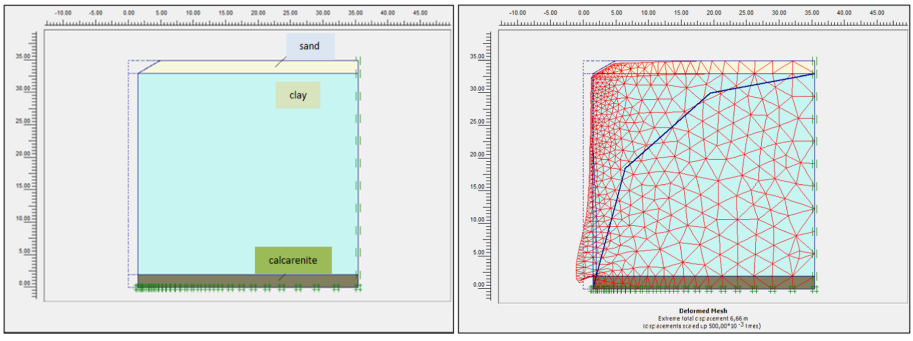

Fig. 9. Deformation associated with the collapse of the well

The analyzes highlighted the presence of subsidence in the area surrounding the well, which increase significantly when the condition of collapse of the vertical walls is reached (Fig. 9).

At the foot of the well, in contact with the reservoir, the deformations reached in the clay layer are of the order of 6 m (Fig. 9) which, in consideration of the axisymmetric condition of the model, show how, following the collapse, the well is occluded by the layers of clay, triggering a sinking of the area adjacent to the mouth of the well (surface sinkhole), as described in the analysis of the collapse phenomenon.

For the purposes of a correct risk mitigation policy for citizens, the results highlighted with this research indicate that the hydrogeological instabilities observed in the Cutrofiano area are attributable to different causes. These failures, which entail different types of phenomenology and damage to the structures (Fig. 10), cannot be attributed exclusively to sinking in correspondence with the presence of underground tunnels (De Pascalis et al. 2009), as shown by the commented analyses. The analyses have in fact shown how subsidence phenomena can also be associated in correspondence with vertical wells, in which potential collapse phenomena develop.

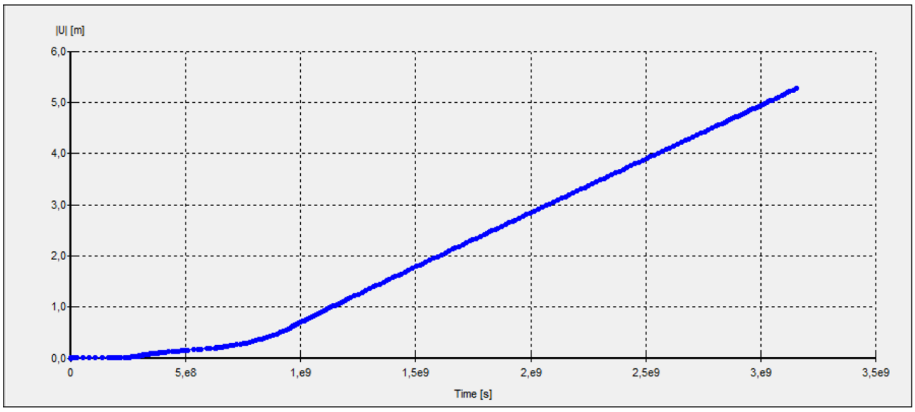

Fig. 10. Diagram of the horizontal displacements observed at the base of the well (the extent of which is limited to a few centimeters until the collapse of the vertical walls occurs).

3 Results and Discussion

The critical points of the geological instabilities that characterize some historical centers of Puglia have been illustrated. These studies aim to contribute to the evaluation of the urban recovery and enhancement capacity of Castellana Grotte, Acquaviva delle Fonti and Cutrofiano.

Due to the growing demand in the tourism sector, it is necessary to adopt mitigation intervention measures that must be targeted and adapted for a better conservation of buildings and for the safety of citizens.

It is clear that the discrepancy between the forecast of failures and prevention actions is still strong with respect to the evident increase in demand for populations in historic centers.

The historical centers of Puglia represent strategic and identity places with a difficult proposition of functional redefinition. Therefore, providing a knowledge base on geological hazards, preventive intervention policies are desirable, which above all safeguard the historical building heritage, while maintaining the destination and function.

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