Gypsum Dissolution Rate, New Data and Insights

A. Busetti, C. Calligaris, and L. Zini

Abstract

Sinkholes linked to covered evaporite karst in urban environments still represent a challenge in hazard and risk assessment. The Quinis hamlet, located in Friuli Venezia Giulia region (NE Italy), is heavily affected by sinkhole phenomena (linked to an evaporitic bedrock), which deeply interested infrastructures and houses. In order to understand the evolution of the sinking phenomena, a field experiment started on the dissolution rate of the gypsum. In 17 existing piezometers, at different depths, 51 evaporitic rock samples were exposed to the naturally occurring variation of relative humidity, air flow and hydrodynamics. The rock samples were placed respectively in the aeration, in the fluctuation and in the phreatic section of the piezometric tubes. Data related to groundwater level fluctuations, temperature and electrical conductivity were collected. After four months, rock samples were removed, weighted and the volume loss evaluated. The obtained results indicate that rock sample reduction is not only dependent on the groundwater level fluctuations and on the number of days during which the samples are immersed in the groundwaters but also on the mineralization of the latter. Some of the rock samples have been almost completely dissolved, with dissolution rate values almost eight times bigger than expected if compared to the available literature data. The proposed approach had as aim to evaluate the quickness of the dissolution process, which is dependant on several causes (groundwater level fluctuations, type of rocks, chemical characteristics of the groundwaters, etc.) and represents a novel contribution to the overall knowledge of karst processes with noticeable impacts on human-built construction.

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Keywords

Sinkhole • Evaporite karst • Dissolution rate • Risk assessment

1 Introduction

Sinkhole phenomena, linked to the presence of an evaporitic bedrock, developed in urban areas are very dangerous if considering the damage that they can cause on man-made structures. The results of recent investigations (Calligaris et al. 2020) have shown that Friuli Venezia Giulia region (here after noted as FVG) is one of the most affected areas in northern Italy with 1199 sinkholes inventoried.

In FVG, only 1% of the karstifiable lithologies are represented by evaporites (Calligaris et al. 2017), which can be identified mainly along two E–W alignments: one in correspondence with the Tagliamento valley to the south, and the other along Pesarina and Pontaiba valleys (Fig. 1) to the north.

The main problem with these phenomena is the occurrence speed with which they take place and develop over time due to the extremely high karstifiability and solution rate of the evaporites (0.68–1.14 mm/y, Klimchouk et al. 1996 and 0.4–1.0 mm/y, Cucchi et al. 1998). The latter is very high if compared for example to limestone one (0.009–0.14 mm/y, Furlani et al. 2009) allowing thus to understand the extreme vulnerability linked to territories where these lithologies are present.

The hazard assessment jointly with the presence of element at risk took Calligaris et al. (2019) to try to quantify, thanks to an on field experiment, the solution rate of the evaporite bedrock in the test site area of Quinis (Enemonzo—UD). The field experiment, carried out for the first time, consisted of installing core rock evaporitic samples, drawn from the drilled boreholes, in 7 piezometers at different depths for a period of one year. The aim was to recreate for

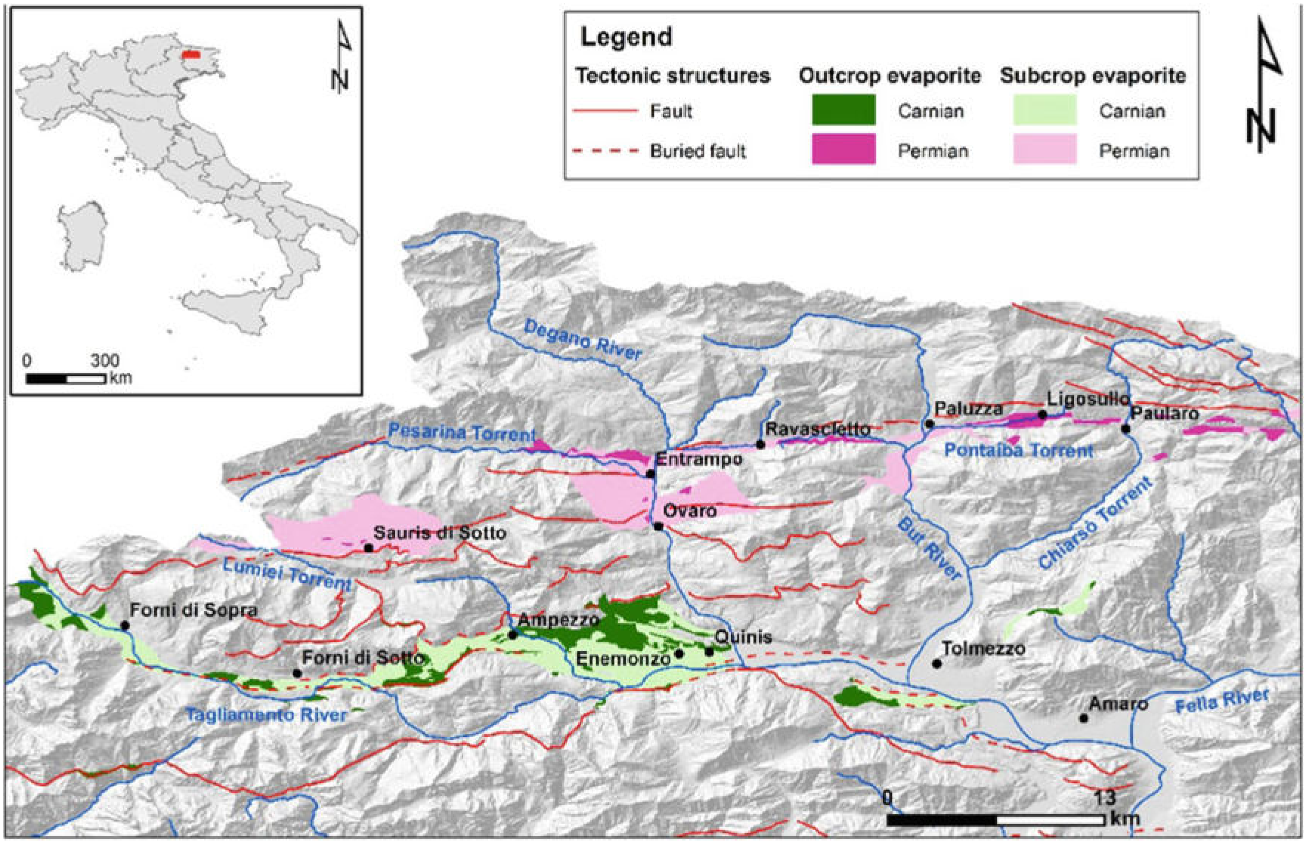

Fig. 1 Sketch of the evaporite outcrops (dark green and dark pink) and of the mantled or overlaid by a non-karst rock evaporites (light green and light pink) in the NW sector of the Friuli Venezia Giulia region

the rock samples the original conditions in order to assess their loss of weight and volume. The obtained results witnessed a range of solubility in between 0 and 8.1 mm/y with an average value of 2.1 mm/y, double the known maximum one. The high dissolution rate demonstrated and its spatial variability encouraged to investigate more in detail the particular situation in the inhabited area of Quinis.

In the present paper, we propose a new field experiment by placing rock samples in piezometric tubes at different depths to better understand the causes of the fast dissolution rate.

2 Study Area

The sinkhole evolution at Quinis is related to the presence of the Raibl Formation (RBA—Carnian in age) in the bedrock, which is subdivided into three different members (Venturini et al. 2009): red shales member (RBA1), gypsum and gray dolostones member (RBA2) and marls and dolostones member (RBA3). The RBA2 is the one present in the study area, and according to Venturini et al. (2009) is composed mainly by gray and white saccharoid gypsum with marl inclusions at the top, yellowish dolomitic marls, and to a lesser extent, blackish or greenish clays and dark limestone in thin layers.

The evaporitic bedrock is mantled by loose quaternary deposits such as glacial till, alluvial and colluvial deposits having a variable thickness, increasing from north to south, from a few meters up to more than 50 in correspondence of the Tagliamento riverbed. These materials are extremely heterogeneous due to complex and articulated depositional patterns conditioned by the tectonical setting, the alternation of glacial and interglacial periods, the recent depositional events due to the Tagliamento River and the overlapping alluvial fan present northern of Quinis.

In this framework, the high solubility of the gypsum and gray dolomites, scarcely outcropping in the investigated area, together with important oscillations of the groundwater level (Zini et al. 2015), has led over time to the formation of important sinkhole phenomena (Gutiérrez et al. 2008), which in turn caused extensive damages to local infrastructures and houses.

In the Enemonzo municipality, since the end of the nineteenth century, 208 sinkholes were inventoried, of which

46 are cover suffosion, 40 are cover collapse, and the remaining have an undefined typology. The latter was detected by desk activities and were not surveyed or not anymore identifiable in the field. In the Quinis village, actually 32 are the recognized sinkholes and most of them are active. Since the first time that these phenomena have been identified in the area (Marinelli 1898), some buildings have been demolished (Fig. 2) and others are actually damaged.

3 Materials and Methods

In the Quinis village, over time, 24 boreholes were drilled and later equipped with different instruments: 2 assestimeters, 2 Casagrande piezometers, 1 borehole drilled for geophysical proposes, and 19 piezometric tubes. 17 of the 19 piezometers (Fig. 2) have been used in the ongoing field experiment. The piezometers are well spread, covering the whole study area.

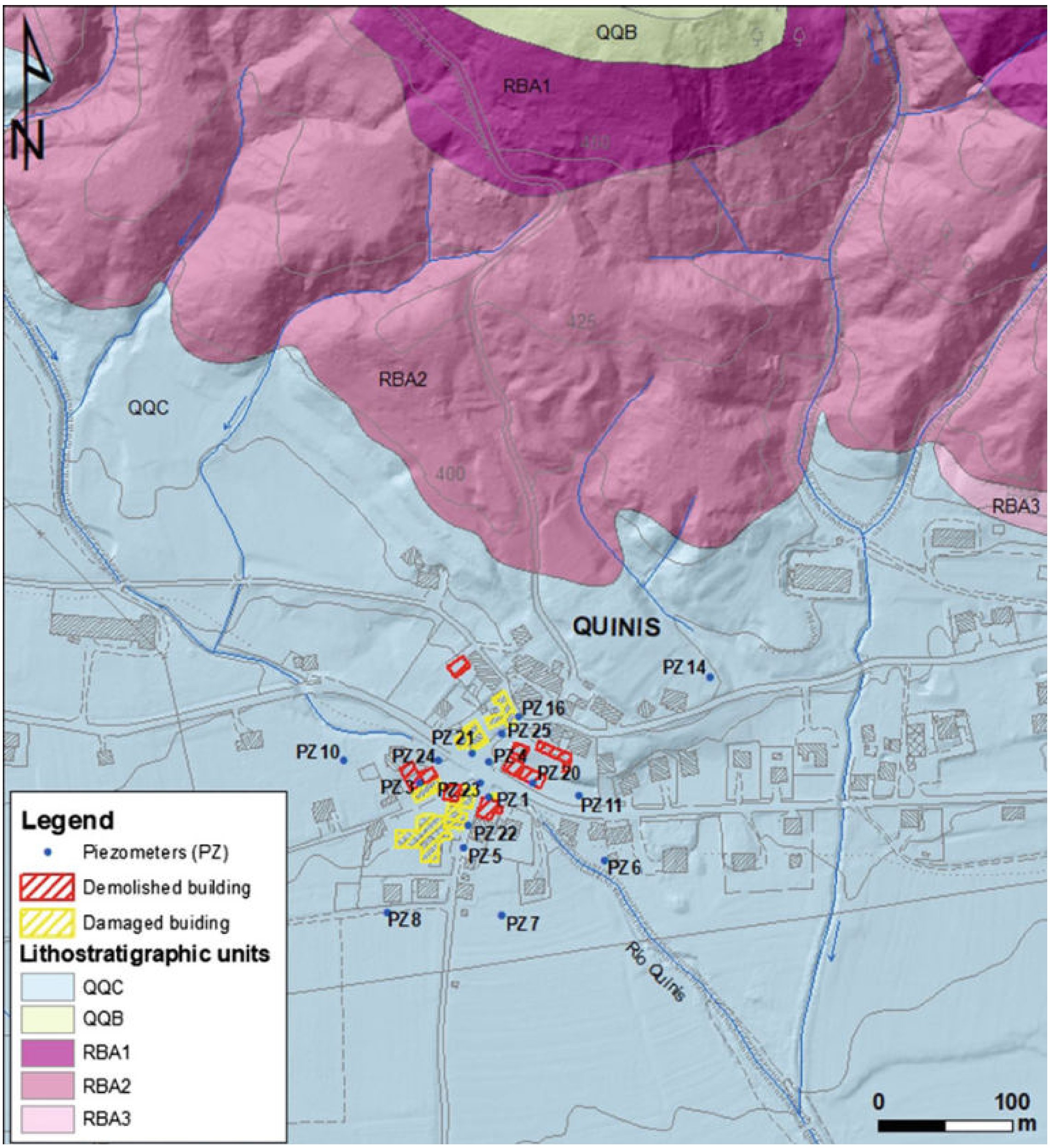

Fig. 2 Geological map of the study area with the evidence of the demolished and damaged building from 1800s to nowadays. Piezometers are identified as PZ. Lithostratigraphic units: (QQC) fluvial gravel and sand and (QQB) glacial till, Pleistocene-Holocene in age; (RBA1) red shales member, (RBA2) gypsum and gray dolostones member and (RBA3) marls and dolostone member belong to the Raibl Formation, Triassic in age (modified after Venturini et al. 2009)

In each piezometer, 3 rock samples have been installed placed at different depths:

- the shallower one at about 2 m below the ground level (in the vadose zone never reached by the groundwater);
- the middle one in the epiphreatic zone, where the groundwater level fluctuates;
- the third one in the phreatic zone (always immersed in the groundwater).

The positioning depth has been decided according to the level of the groundwater and the position of the screens.

Before the installation, a preparatory phase took place. In order to prepare rock samples as uniform as possible not only from a dimensional point of view, but also from a mineralogical one. 12 boulders were collected in the Entrampo (Ovaro) quarry and later shaped as 115 parallelepiped having 8 cm of height and a square base of 4 cm with an area (A) of 160 cm^2.

All samples were weighed and 78 of these were selected choosing the most similar in weight (range from 273.4 to 300 g) and dimension. Once over-dried in the oven at 50 °C for 48 h, a second weight (W_1) was done.

Before the installation, volume and density (ρ) were also measured. The first as volume difference by using a graduated cylinder containing water. Density was calculated as the quotient between dry weight and volume. The whole process is summarized in Fig. 3.

The 51 rock samples chosen were then installed in the piezometers wrapping each single parallelepiped in a plastic net and later fixed to a rope.

After the first 4 months (June 18, 2021–October 1, 2021), the samples were collected, over-dried for 48 h at 50 °C, weighted (W_2) and weight loss calculated ($W_1 - W_2$).

The weight loss is functional to the dissolution rate evaluation according to the formula proposed by Plan (2005):

$$R = \left[\frac{(W_1 - W_2)}{A\rho}\right] * 10(\text{mm}/4\ \text{month})$$

Data-logger devices, able to record in continuous groundwater level, temperature and electrical conductivity variations, were installed in 7 piezometers.

Two data-loggers WLT-Diver Eijekelkamp (pressure range 10 m, accuracy ± 0.5 cm, resolution 0.2 cm; temperature range −20 °C to +80 °C, accuracy ± 0.1 °C, resolution 0.01 °C) were installed in PZ10 and PZ11; five CTD-Diver Eijekelkamp (pressure range 10 m, accuracy ± 0.5 cm, resolution 0.2 cm; temperature range −20 °C to +80 °C, accuracy ± 0.1 °C, resolution 0.01 °C, Electrical Conductivity range 0–120 mS/cm, accuracy ± 1%, resolution ± 0.1%) were installed in PZ7, PZ22, PZ23, PZ24 and PZ25. The compensation of the atmospheric pressure variability was ensured by a Baro-Diver from Eijekelkamp (pressure range 150 cm, accuracy ± 0.5 cm, resolution 0.2 cm) installed in the PZ1, in the core of the study area. All instruments were synchronized and had a recording range interval of 30 min.

Rainfall data were downloaded from the OSMER FVG network (https://www.osmer.fvg.it/archivio.php?ln=&p=dati) for the Enemonzo rainfall station.

4 Results

Within the 1-year project, during the first check, after four months after the installation, data-logger devices were downloaded, and rock samples were collected. The monitored period coincided with a summer season characterized by a maximum daily precipitation of 60.5 mm (June 18, 2021–October 1, 2021). Six are the main rainfall events that had a meaningful response on the groundwater levels recorded by the data-logger devices (Fig. 4).

In accordance with the bedrock deepening from north of Quinis where it is seldom exposed to the south where it is mantled by even more than 50 m of deposits, the groundwater level fluctuation is lower in the northern part (PZ11 and PZ25, a few centimeters) and higher (PZ7 and PZ8, 13 m) in the southern of the study area.

During the four-month experiment, 27 rock samples always remained always above the groundwater level. Twenty-three of them recorded a weight loss of up to 6%; three (PZ1, PZ10 and PZ23) showed a weight loss of about 20%. The remaining PZ11 had a higher weight loss of about 42%.

The complete dissolution of the sample in PZ3 requires a separate explanation. In fact, a later inflow is present (at about 6.5 m b.g.l.) within the piezometer due to a local perched aquifer above the rock sample placed at 9.7 m b.g.l. The sample is thus always wet due to the water leaching from above.

Only 4 rock samples (PZ6, PZ7, PZ8, PZ23) in the epiphreatic zone got wet by the fluctuating groundwaters. They recorded a loss of weight between 15 and 25%.

Eighteen rock samples remained always immersed. PZ14, PZ16, PZ20, PZ21, and PZ25 recorded a loss of weight of less than 1%. PZ6, PZ8, PZ11, PZ23 and PZ24 are between 4 and 9%. PZ3, PZ4, PZ5, PZ7, PZ10 and PZ22 are between 30 and 50%. PZ1 had a loss of 96%.

In general, all the samples in the vadose zone never reached by the groundwater show a very low loss of weight. Instead, when the rock samples are occasionally or always immersed in the groundwater, the dissolution is higher. The dissolution rate strongly depends on the mineralization of the groundwaters and so on their saturation index. It comes out (Table 1) that when the groundwaters are characterized by low electrical conductivity values up to 2 mS/cm (PZ1, PZ3,

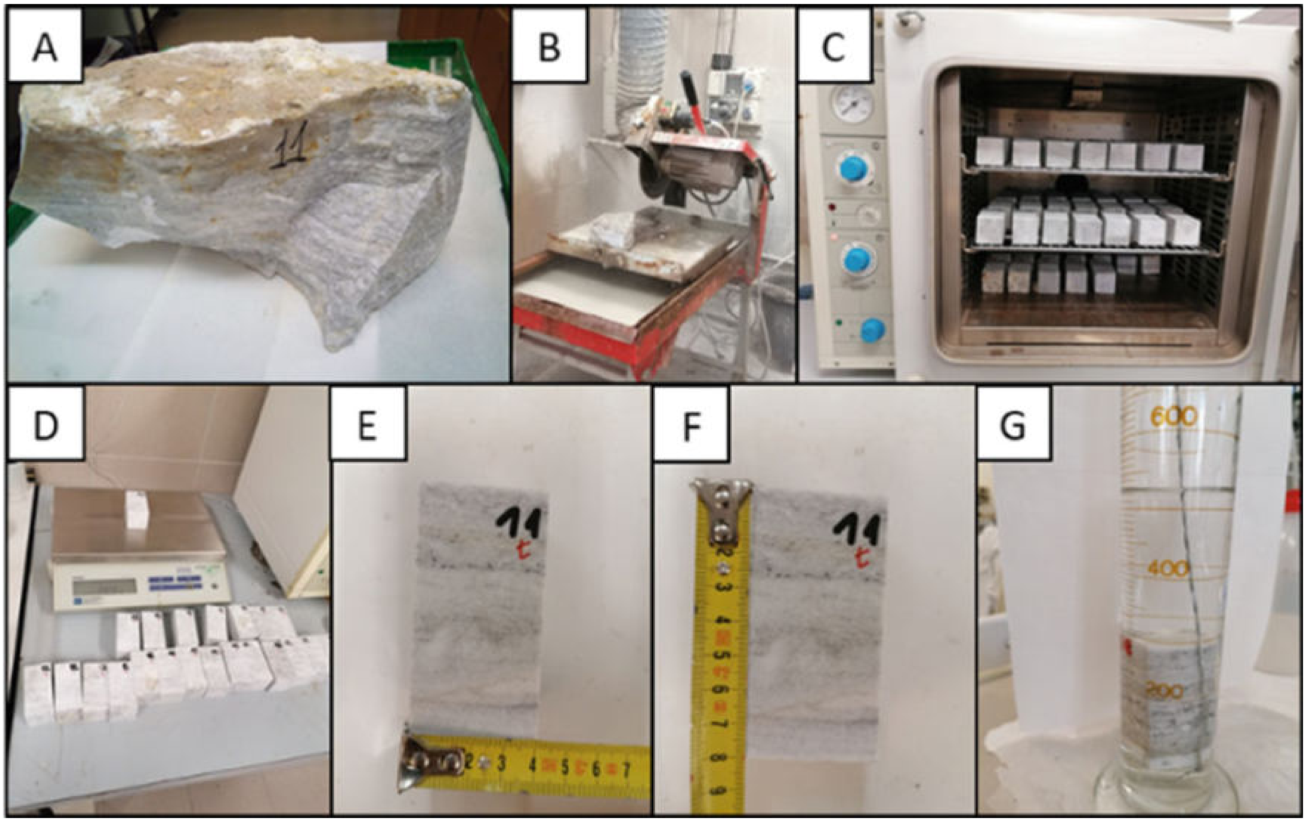

Fig. 3 Rock samples preparation process: **a** a boulder selected at the Entrampo quarry, **b** cutting and shaping phase, **c** over dried samples in the oven at 50 °C for 48 h, **d** weight procedure, **e**–**f** measurement of the dimensions **g** volume calculation

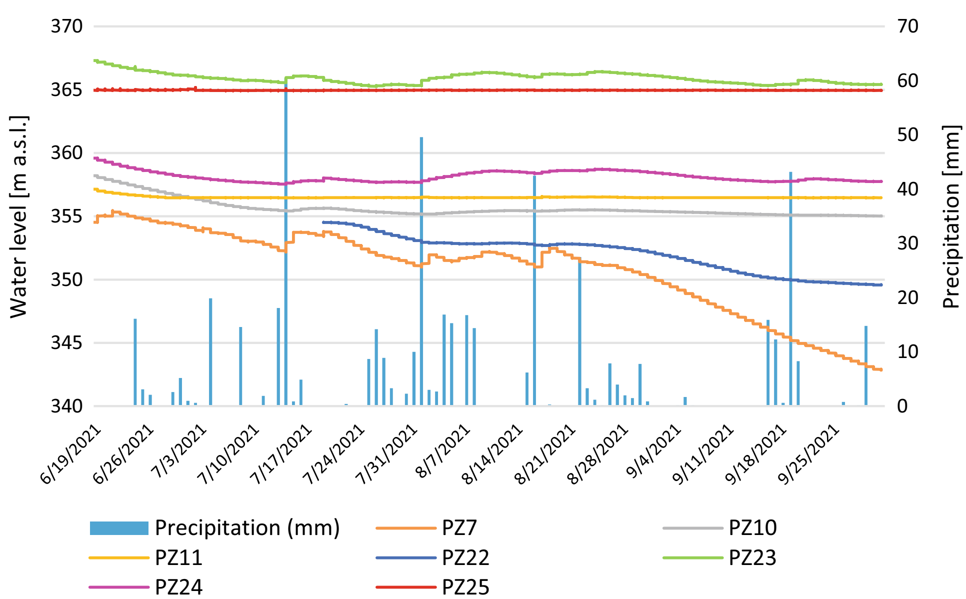

Fig. 4 Groundwater level fluctuations recorded in the piezometers of the Quinis village in the period June 18, 2021–October 1, 2021. Daily rainfall registered in Enemonzo station (OSMER FVG)

Table 1 Weight loss, dissolution rate (*R*) and electrical conductivity (EC) calculated for the rock samples used in the field experiment.

PZ	Depth (m b.g.l.)	Weight loss (%)	*R* (mm/4 months)	EC (mS/cm)	PZ	Depth (m b.g.l.)	Weight loss (%)	*R* (mm/4 months)	EC (mS/cm)
PZ1	−1.5	1.7	0.13	0.51	PZ14	−2	0.1	0.01	2.87
	−8	19.5	1.65			−12.7	0.1	0.01	
	−15*	95.9	7.68			−19.4*	0.2	0.02	
PZ3	−2	2.2	0.18	1.41	PZ16	−2	0.1	0.01	3.10
	−9.7**	100.0	> 8.125			−16.3*	0.2	0.01	
	−21.2*	49.4	3.77		PZ20	−2	1.3	0.10	10.70
PZ4	−2	2.1	0.16	1.75		−8.15	3.1	0.25	
	−7.7	0.9	0.07			−15.15*	0.3	0.02	
	−15.6*	49.7	3.85		PZ21	−2	0.5	0.03	3.28
PZ5	−0.5	0.9	0.07	1.40		−7.7	0.5	0.03	
	−13.7	6.1	0.50			−16.8*	0.7	0.05	
	−24.7*	40.1	3.21		PZ22	−2	0.2	0.02	2.18
PZ6	−2	0.2	0.01	1.80		−13	0.3	0.02	
	−15.6**	25.1	2.01			−28.1*	46.6	3.73	
	−36.7*	6.9	0.55		PZ23	−2	22.5	1.83	2.40
PZ7	−2	0.4	0.04			−10**	20.4	1.63	
	−19.6**	15.0	1.17	1.36		−30*	4.9	0.39	
	−37*	55.3	4.32	1.99	PZ24	−2	0.1	0.01	4.40
PZ8	−2	0.6	0.05			−11.6	0.2	0.01	
	−20**	20.6	1.65	1.60		−29*	4.2	0.34	
	−37.5*	4.5	0.35	2.50	PZ25	−2	0.4	0.03	
PZ10	−2	0.0	0.00	1.65		−12.6*	0.6	0.05	7.06
	−15	20.6	1.57			−17.4*	1.0	0.07	8.73
	−29*	32.0	2.50						
PZ11	−2	0.1	0.01	2.50					
	−11.6	42.0	3.20						
	−18.9*	8.8	0.69						

Depth (b.g.l.): rock samples depths
*when always inmmersed
**if inersed only occasionally

PZ4, PZ5, PZ7, PZ8, PZ10, and PZ22), the rock samples dissolve more (in the range between 30 and 50%).

In the piezometers, PZ14, PZ16, PZ20, PZ21, and PZ25 instead, it have been observed stability of the groundwater levels, which indicates a low water replacement and a consequent high mineralization (EC > 2.5 mS/cm). In this situation, the weight loss is quite low, less than 1%. The remaining (PZ6, PZ11, PZ23 ,and PZ24) showed a weight loss between 2 and 9%.

5 Conclusion

Quinis is one of the most prone areas to sinkhole phenomena in the FVG (NE Italy). Known since the 1800s, they are still active and involve built-up structures. Despite the intense activity developed over the years, researchers are still working in the area, trying to understand the evolution rate in order to assess the jointed risk.

During the summer of 2021, 51 evaporite rock samples were placed in 17 piezometers at different depths in order to evaluate the loss of weight and the relative dissolution rate. From data analysis emerged that the samples always above groundwater level have a minimum weight loss. The ones always immersed in the groundwaters have a weight loss related to the mineralization and the water replacement. The result is a non-homogenous dissolution within the area and depth mainly linked to the permeability and the groundwater circulation.

Regarding the dissolution rate, in the four months investigated, some values can reach rates of 8 mm, which if compared with literature (Cucchi et al. 1998; Klimchouk et al. 1996), yearly value is already much higher (at least eight times).

The experiment is still ongoing and future months will be used to evaluate the dissolution of rock samples according to seasonal variations.

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