UAV and geophysical approaches for the study and monitoring of sinkholes in evaporitic and alluvial environments

Alice Busetti[1], Michele Fernetti[1], Davide Martinucci[1,2], Emanuele Forte[1], Luca Zini[1] & Chiara Calligaris[1]

[1]University of Trieste, Department of Mathematics, Informatics and Geosciences, Via Weiss 2, Trieste.

[2]Esplora SRL.

AB, 0000-0002-2249-9178; DM, 0000-0001-8969-099X; LZ, 0000-0001-6564-1683; CC, 0000-0003-3164-5197.

Rend. Online Soc. Geol. It., Vol. 69 (2026), pp. ...-..., 8 figs. https://doi.org/10.3301/ROL.2026.15

Short Note

Corresponding author e-mail: calligar@units.it

Citation: Busetti A., Fernetti M., Martinucci D., Forte E., Zini L. & Calligaris C. (2026) - UAV and geophysical approaches for the study and monitoring of sinkholes in evaporitic and alluvial environments. Rend. Online Soc. Geol. It., 69, XX-XX, https://doi.org/10.3301/ROL.2026.15.

Guest Editor: Raffaele Viola

Submitted: 16 January 2026

Accepted: 23 April 2026

Published online: XX May 2026

SOCIETÀ GEOLOGICA ITALIANA ETS
FONDATA NEL 1881 · ENTE MORALE R. D. 17 OTTOBRE 1885

ABSTRACT

In Friuli Venezia Giulia region (NE Italy), sinkhole phenomena associated with evaporitic bedrock are particularly widespread and active, despite the fact that this bedrock is scarcely exposed. In this regard, the most recent event occurred in Esemon di Sopra, in the municipality of Raveo. The sinkhole suddenly opened on April 21st, 2022, on an alluvial terrace alongside the Degano River riverbed. The cylindrical collapse feature, has a diameter of 18 meters and a depth of 15 meters. It developed less than 200 meters from both the main road and the inhabited area of Esemon di Sopra. In the immediate vicinity of the sinkhole, a natural gas pipeline network is also present.

The paroxysmal phase developed due to the presence of a void within the loose detrital material, which was partially visible during the first surveys. Given the nature of the material involved, the sub-vertical walls immediately began to evolve with subsequent collapses. In this context, the use of drone-based photogrammetry proved to be of fundamental importance, allowing, in complete safety, a three-dimensional reconstruction of the sinkhole morphology and a detailed analysis of the depositional sequence. Integrated geophysical surveys have been conducted to improve our understanding of the spatial variability of sediments and bedrock.

In March 2024, a LiDAR survey was carried out, which highlighted the morphometric changes of the sinkhole's shape. The Esemon di Sopra event fits within a broader framework of instability affecting the valley areas of the Tagliamento River basin, where, however, no phenomena of such magnitude had been recorded for over eighty years. A similar historical case occurred in the early 1960s, south of the village of Quinis (Municipality of Enemonzo), on the alluvial terrace of the Tagliamento River, where two sinkholes opened with diameters of 45 meters and 15 meters, and a depth of 15 meters. The centre of this hamlet is still affected by subsidence, as evidenced by differential analyses of satellite images (D-INSAR) and geophysical investigations. Furthermore, to monitor ongoing movements, a robotic total station was recently installed as part of the PNRR GeosciencesIR Project.

KEYWORDS: sinkhole, evaporites, LiDAR, UAV, geophysical surveys.

INTRODUCTION

Sinkholes are among the most hazardous geomorphological phenomena in evaporitic environments, where the dissolution of highly soluble rocks such as gypsum and halite lead to karstification, which creates subsurface voids that can eventually cause the ground to collapse (Gutiérrez et al., 2014; Parise et al., 2018; Calligaris et al., 2024). These processes can result in severe damage to infrastructure, pose risks to human safety, and significantly alter the landscape (Williams, 2004; Carbonel et al., 2015). The study and monitoring of sinkholes are therefore essential for understanding their genesis, assessing related hazards, and supporting risk mitigation strategies (De Waele et al., 2011).

Traditional field surveys, although fundamental for direct geological and geomorphological observations, are often limited by accessibility constraints, spatial coverage, and temporal resolution (Cooper et al., 2011). In recent years, the integration of Unmanned Aerial Vehicles (UAVs) coupled with geological and geophysical investigations has revolutionised the geomorphological research, offering high-resolution spatial data of the surface and sub-surface, flexible acquisition schedules, and cost-effective monitoring capabilities (Colomina & Molina, 2014; Turner et al., 2012; Busetti et al., 2024). UAV-based photogrammetry, combined with digital elevation models (DEMs) and multispectral or thermal imagery, enables detailed mapping and temporal analysis of surface deformations associated with sinkhole activity (Lee et al., 2016; Guerrero et al., 2021). Geophysical investigations, such as electric tomography (ERT) and seismic refraction (RF) allowed instead a sub-surface definition of the in-depth structures (Calligaris et al., 2024).

This study aims to explore the potential of UAV technique for the identification, characterization, and monitoring of sinkholes in evaporitic and alluvial terrains by applying this approach to a test site area particularly prone to the occurrence of these phenomena. By integrating field data, geophysical data analyses, aerial imagery, and geospatial analysis, we demonstrate how these technologies can enhance the understanding of sinkhole evolution and provide a reliable basis for environmental management and hazard prevention in karst-prone areas (Gutiérrez, 2016; Kaufmann, 2014).

STUDY AREA

Friuli Venezia Giulia region (NE Italy) is characterised by the occurrence of more than one thousand sinkhole phenomena, which have developed both over carbonate and evaporitic bedrock. The evaporitic deposits—mainly distributed within the east–west oriented valleys of the north-western sector of the region—are responsible for the most significant impacts on existing infrastructure, since this bedrock is undergoing rapid evolution and shows a high propensity to collapse. Regional inventories and reviews have documented the widespread distribution and hazard posed by evaporite-related sinkholes (Calligaris et al., 2017).

Permian and Triassic evaporites in the area display elevated dissolution rates and low mechanical strength, which result in an intrinsically higher susceptibility to sinkholes compared to carbonate terrains; field dissolution experiments have quantitatively confirmed rapid evaporite weathering under local hydrogeological conditions (Busetti, 2024; Calligaris et al., 2019).

In the hamlet of Quinis significant collapses have been documented since the 1960s (Fig. 1A, B). This site has been the subject of several multidisciplinary investigations integrating geophysical, geomorphological and remote-sensing techniques. (Busetti et al., 2020; Zini et al., 2015). The lithological, geomorphological and hydrogeological conditions characterising the Quinis area are analogous to those of Esemon di Sopra (Municipality of Raveo), where a sudden collapse occurred on April 21st 2022 (Fig. 1C). Both areas correspond to fluvial terrace settings: the first is adjacent to the Tagliamento river bed and the second to the Degano Torrent.

They occurred immediately downstream of slopes where evaporites outcrop and mantled evaporites have been documented. These factors — proximity to the river/stream, unconsolidated terrace deposits, variable water-table dynamics and the presence of dissolvable evaporites/conglomerates — jointly favour the initiation and rapid development of collapse phenomena (Busetti et al., 2020). In such environment, also the presence of the structural lineaments can play a relevant role in the sinkhole formation (Jiao et al., 2025; Carulli, 2006).

MATERIAL & METHODS

The first survey was conducted on 29th April 2022 using a DJI Phantom 4 RTK drone. This UAV integrates a high-precision Real-Time Kinematic (RTK) positioning system, which substantially reduces positional errors compared to standard GNSS solutions. The RTK module ensures centimetre-level accuracy (Horizontal: ±1 cm + 1 ppm; Vertical: ±1.5 cm + 1 ppm) by receiving corrections from a ground-based GNSS station or a network service. The Phantom 4 RTK is equipped with a 1-inch CMOS sensor (20 MP) capable of capturing high-quality nadir and oblique images, and a fixed lens with an 8.8 mm focal length (35 mm equivalent: 24 mm), optimised for photogrammetric applications. The photogrammetric survey was conducted using waypoint mode for capturing images around the sinkhole perimeter, while manual flight mode was employed inside the sinkhole to ensure precise navigation in a confined and irregular environment where automated flight paths could not guarantee adequate coverage or safety. No ground control points (GCPs) were employed in this survey, as the integrated RTK system provided sufficient positional accuracy, eliminating the need for external georeferencing. The absence of GCPs may limit independent validation of absolute accuracy and could introduce minor discrepancies in areas with poor GNSS signal or complex terrain. Nevertheless, this approach significantly enhanced operational efficiency by reducing fieldwork time and simplifying the overall workflow of the first data acquisition.

On March 26th, 2024, a second data acquisition was performed, this time with Lidar support. It was used a DJI Matrice 300 RTK drone equipped with an L1 LiDAR sensor, which incorporates a Livox sensor, a high-precision IMU, and a one-inch 20MP CMOS visual camera with mechanical shutter, allowing the point cloud and RGB images to be acquired simultaneously for photogrammetric reconstruction. To achieve high accuracy in georeferencing the acquired data, in addition to the GNSS system integrated into the drone and connected to the differential correction network "Antonio Marussi" of the Friuli Venezia Giulia Region, 5 ground control points made of plastic panel were used. The geographical coordinates of each control point were acquired using a GNSS receiver Stonex S990a in NRTK mode connected to the "Antonio Marussi" network and used for the reconstruction of the photogrammetric and points cloud models. The survey was carried out using two different flight modes: (1) photogrammetric and LiDAR surveys of the area around the sinkhole using waypoints mode, and (2) photogrammetric and LiDAR surveys inside the sinkhole using manual mode. The obtained data were then processed by DJI Terra for the points cloud and Agisoft Metashape for the photogrammetric model.

Geophysical survey included electrical resistivity tomography (ERT) and seismic refraction (RF) conducted in the area surrounding the sinkhole to investigate the causes of its formation and determine the morphology of the bedrock. The surveys followed an East-West oriented profile. The ERT profile (188 m in length) was recorded using a Syscal Pro georesistivimeter connected with 48 metal electrodes spaced 4 meters with a mixed Wenner-Schlumberger electrodes configuration. Both

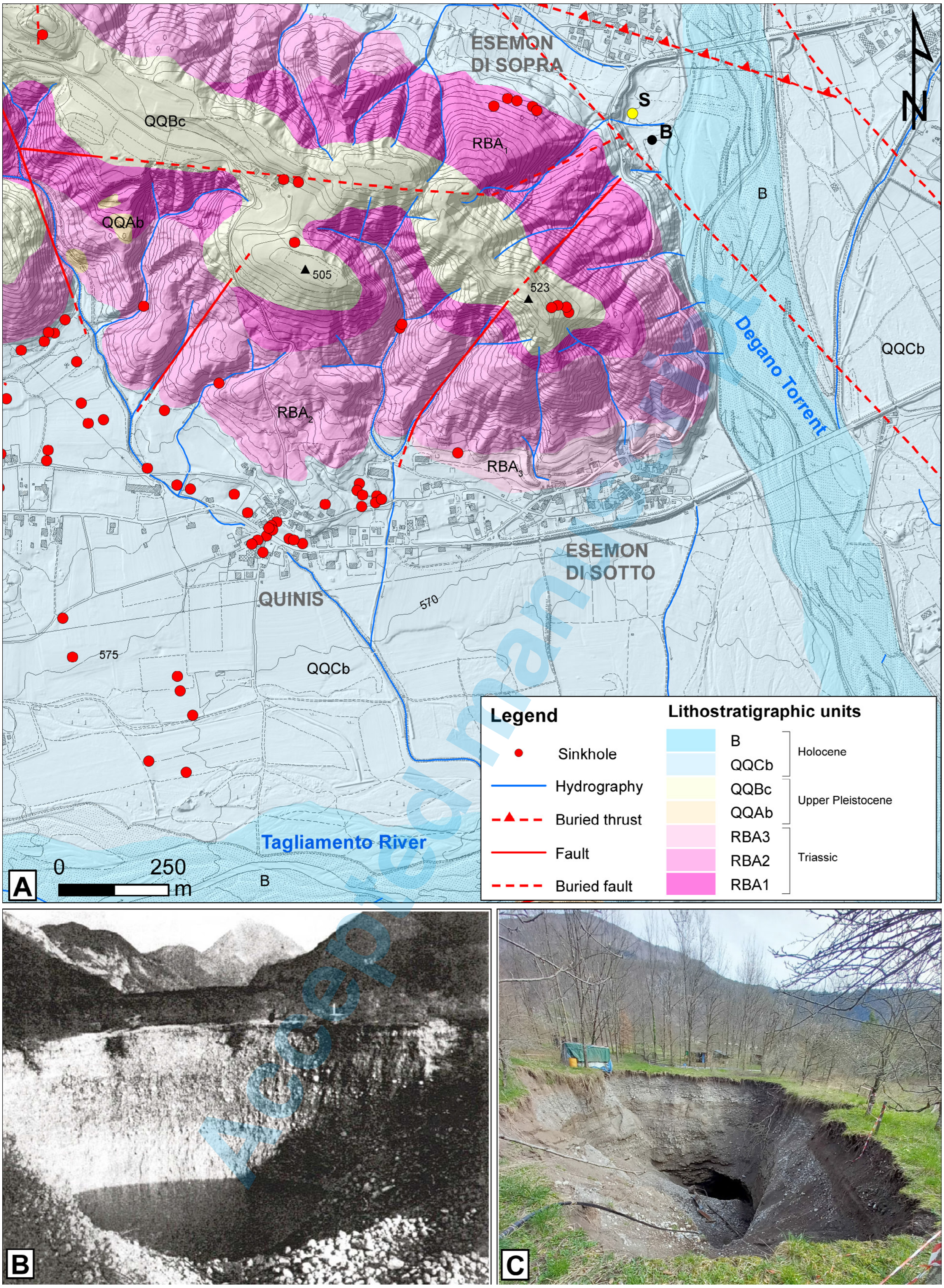

Fig. 1 - A) Geolithological map of Quinis, Esemon di Sotto and Esemon di Sopra hamlets. Lithostratigraphic units: B- recent alluvial deposits; QQCb - fluvial gravel and sand; QQBc - glacial deposits (diamicton); QQAb - fluvial conglomerates. All these units are Pleistocene-Holocene in age. RBA3 - marls and dolostones Member; RBA2 - gypsum and grey dolostones Member; RBA1 - red shales Member. RBA1, RBA2 and RBA3 are members of the Raibl Formation, Triassic in age. Red points represent subsidence sinkholes, yellow point indicates the sinkhole occurred on 21st April 2022 (marked with S); the black point corresponds to the borehole location (marked with B); red lines are structural features (dotted when buried); B) Cover collapse sinkhole occurred in Quinis hamlet in 1964 (Gortani, 1965) having a diameter of 45m and depth of 15m; C) Cover collapse sinkhole occurred in Esemon di Sopra hamlet on 21st April, 2022. The diameter was 18 m and the depth 15 m.

apparent and real resistivity data obtained using Res2DINV and ERTLab software were analysed. The RF profile was realised along a portion of the ERT profile, with 24 vertical geophones (fn=14 Hz) 4 m-spaced using a Geode Geometrics seismometer. A 5 kg sledgehammer shooting on a metal plate was used as a source of energy. For each energizing position (shot point) a vertical stack of 4 was made. A total of 28 shots were taken in 7 positions along the profile and at -10/+10 m from the first and last geophones, respectively. The total length of the profile was of 92 m. For the traveltime inversion, the software Plotrefa (OYO) was used to obtain the P-waves seismic velocity.

RESULTS AND DISCUSSION

The field surveys and drone flights realised on the site where the sinkhole occurred in 2022, enabled a detailed morphometric characterization and 3D reconstruction of the morpho-structure. The acquisition realised on 29th April 2022 using a DJI Phantom drone aimed to determine the 3D shape of the sinkhole, characterize the involved material, and compute the total volume.

The survey revealed a clear cylindrical shape (Fig. 2A) with impressive vertical slopes. The geometrical figure at the surface was sub-circular with an approximate diameter of 18 m. Thanks to the acquired internal images it has been possible to distinguish,

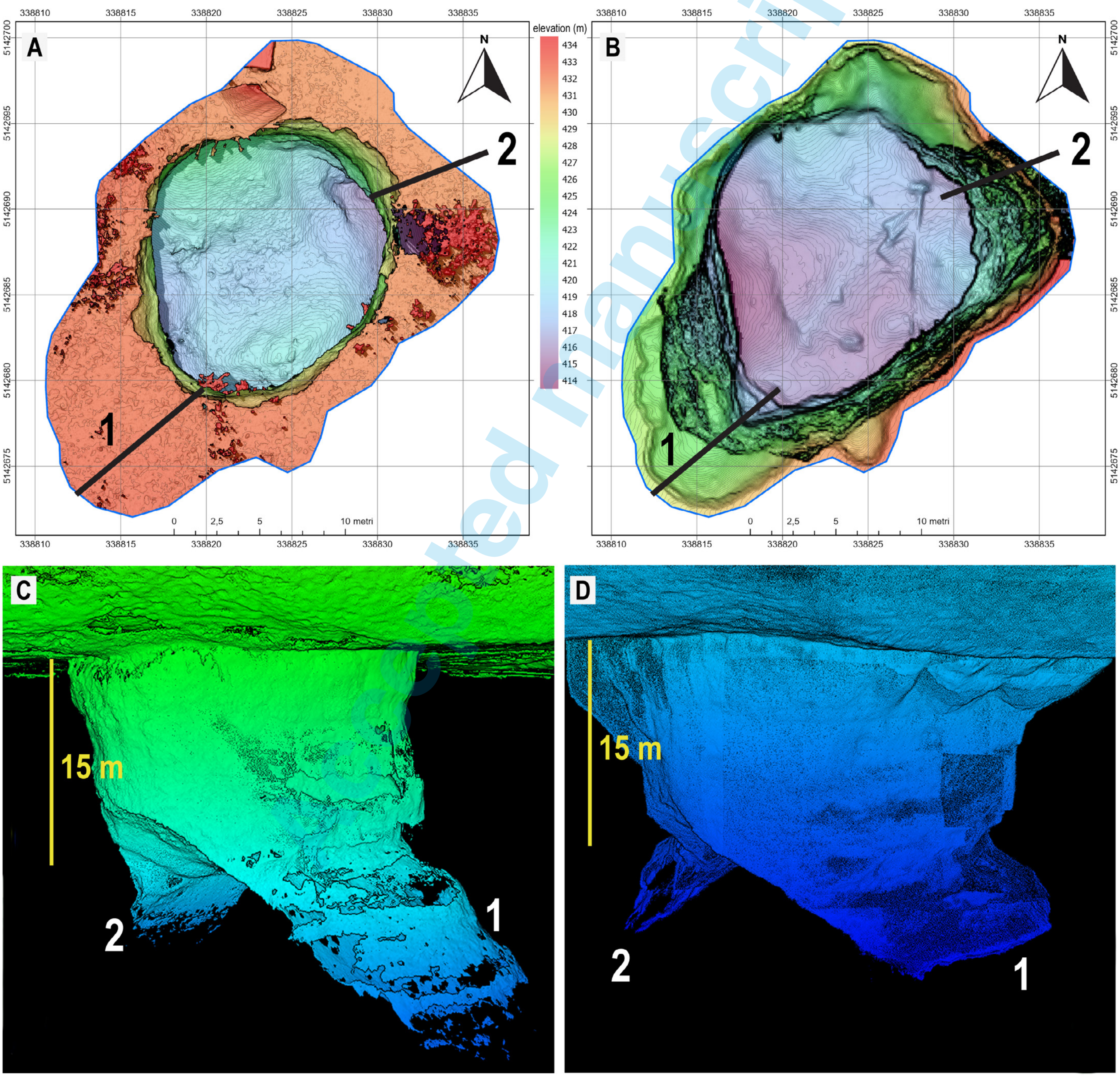

Fig. 2 - Comparison between the data acquisition by drone realised on 2022 and on 2024. Sinkhole aerial view with contour lines, acquisition of 2022 (A) and of 2024 (B), ellipsoidal heights; sinkhole 3D model reconstruction based on 2022 data (C) and 2024 data (D). 1 and 2 identify the oblique side conduits oriented according to the black lines drawn in (A) and (B).

in the shallower meters from the surface and on the cavity walls, an alternation of coarse granular and cohesive layers (Fig. 3), typical of alluvial deposits as the ones of the Degano Torrent are. This alternation continues all the way down to the visible bottom reached at -15 m from the ground surface. At the bottom, different zones were identified. Two of them, in the NW and SE sectors (light green in Fig. 2A) are characterised by collapsed material forming debris cones. The other two, located at the opposite corners, correspond to visible ceilings. The drone survey allowed to define the presence of two void extensions interpreted as conduits. This information revealed that, prior to the collapse, a void existed that was wider than the diameter of the collapsed cylinder. The underlying conduits are oriented SW-NE (Fig. 2, number 1) and WSW-ENE (Fig. 2, number 2) respectively. The calculated volume of the sinkhole in April 2022 was 1989 m^3.

The second drone survey realised with a DJI Matrice 300 RTK drone equipped with an L1 LiDAR sensor had as goal to study the evolution of the slopes, to delineate the new perimeter, and to estimate the volume of the sinkhole. In almost two years, the initial shape was only slightly modified and the slopes just started to evolve in the direction of the two conduits decreasing their steepness. The collapsed material deposited into the sinkhole decreased the initial volume of the void to 1296,45 m^3. The comparison of the two surface areas highlights an enlargement of 130% i.e. from 200 m^2 to 461 m^2.

Approximately 70 m away from the formed sinkhole, in 2022, a borehole (black point in Fig. 1) was drilled in order to identify the type of bedrock present in the area. From the core analyses (Fig. 3, simplified stratigraphic column), emerge a stratigraphy in which the first 13 meters consisted of loose deposits (alternating gravelly and clayey layers), followed by conglomerates (from 13 to 33 meters), loose deposits (from 33 to 39 meters), and more compact and fractured conglomerates with voids, locally up to 1 meter (from to 39 to 53 meters, end of the borehole). Even if the evaporitic bedrock crops out along the road connecting Esemon di Sopra with Esemon di Sotto, approximately 200 meters SW of the sinkhole, the evaporites were not detected by the borehole.

In order to understand the presence and geometrical trend of the bedrock, geophysical surveys integrating ERT and RF techniques have been performed. The ERT profile shows meaningful lateral variations. In the sinkhole area in the shallowest portion (down to about 5 m) there are present low resistive materials (values below 200 Ωm), while further East the values are above 500 Ωm. The approximate limit between the two zones is indicated by the black vertical dashed segment in Figure 4. This variation is probably linked both to finer materials in the sinkhole area and to the presence of water. Below, there is a lateral transition between materials with resistivity close to 1000 Ωm to the West, while to the East (i.e., in the riverbed area) resistivity decreases to approximately 200 Ωm, probably linked to the presence of water (Degano river-bed). These two levels are also present in the RF profile with a clear velocity increase between values of 400-500 m/s and more than 1000-1500 m/s at a depth of about 5 m. However, the ERT and RF data show a different behaviour. While the resistivity data show large lateral variations, in addition to the previously described vertical ones, the same is not true of the P-wave seismic velocities. This difference is not related to measurement or data processing/inversion errors, but is probably due to different saturation conditions at different locations within the investigated area. Based on the available data, and within the resolution limits of the methods employed, no cavities seem to be present in correspondence of the acquired profiles.

On the basis of the data exposed and the geological and geomorphological surveys carried out in the surrounding areas, there are elements of interest that can be directly or indirectly correlated with the sinkhole and that deserve further study and investigation.

In fact, several other elements of interest have been identified in the sinkhole area: the deformation of a retaining stone wall located about 100 m southwest of the sinkhole, suggesting past or ongoing ground movements; a depression approximately 80 m north of the sinkhole, currently artificially filled with water (northern minus red symbol in Fig. 4A), whose origin (natural or anthropogenic) is still unclear; and a generally lower morphological profile of the sinkhole area compared to the surrounding terrain (southern minus red symbol in Fig. 4A). Furthermore, the presence of an east-west-oriented methane pipeline located less than 50 metres north of the sinkhole represents a potential critical issue.

CONCLUSIONS

An exceptionally rapid development was observed in the present case study, where a cover-collapse sinkhole occurred on 21st April 2022. Although sinkholes are widespread and numerous in the Friuli Venezia Giulia Region (the number of items inventoried is currently 1,786, March 2026, https://sgi.isprambiente.it/sinkholeweb/database.html), it is necessary to go back to the early 1960s to identify an event comparable to the one here analysed. In fact, such phenomena are fortunately rare; however, they may occur under specific hydrogeological conditions, such as prolonged drought periods, which affected the Friuli Venezia Giulia region during late 2021 and the first months of 2022. Variations in water availability (Youssef et al., 2020; Watson et al. 2019), including both excess and scarcity, may in fact alter the hydrogeological equilibrium, thereby triggering abrupt collapses.

In such fragile settings, detailed subsurface investigations based on the integration of remote sensing, geophysical surveys and direct data lead to an improved understanding of the geological framework. In the present case, however, the borehole drilled did not intercept the evaporitic bedrock and therefore did not allow a definitive clarification of the lithological control governing sinkhole development. Within this geological context, the presence of supposed fault systems further contributes to the geotechnical weakness of the bedrock, creating favourable conditions for sinkhole occurrence. From the analysis of the sinkhole's slopes, it emerged that the presence of a small stream, apparently insignificant, played an important role in certain phases of loose material deposition, identifiable in the shallower meters of the stratigraphy (Fig. 3B).

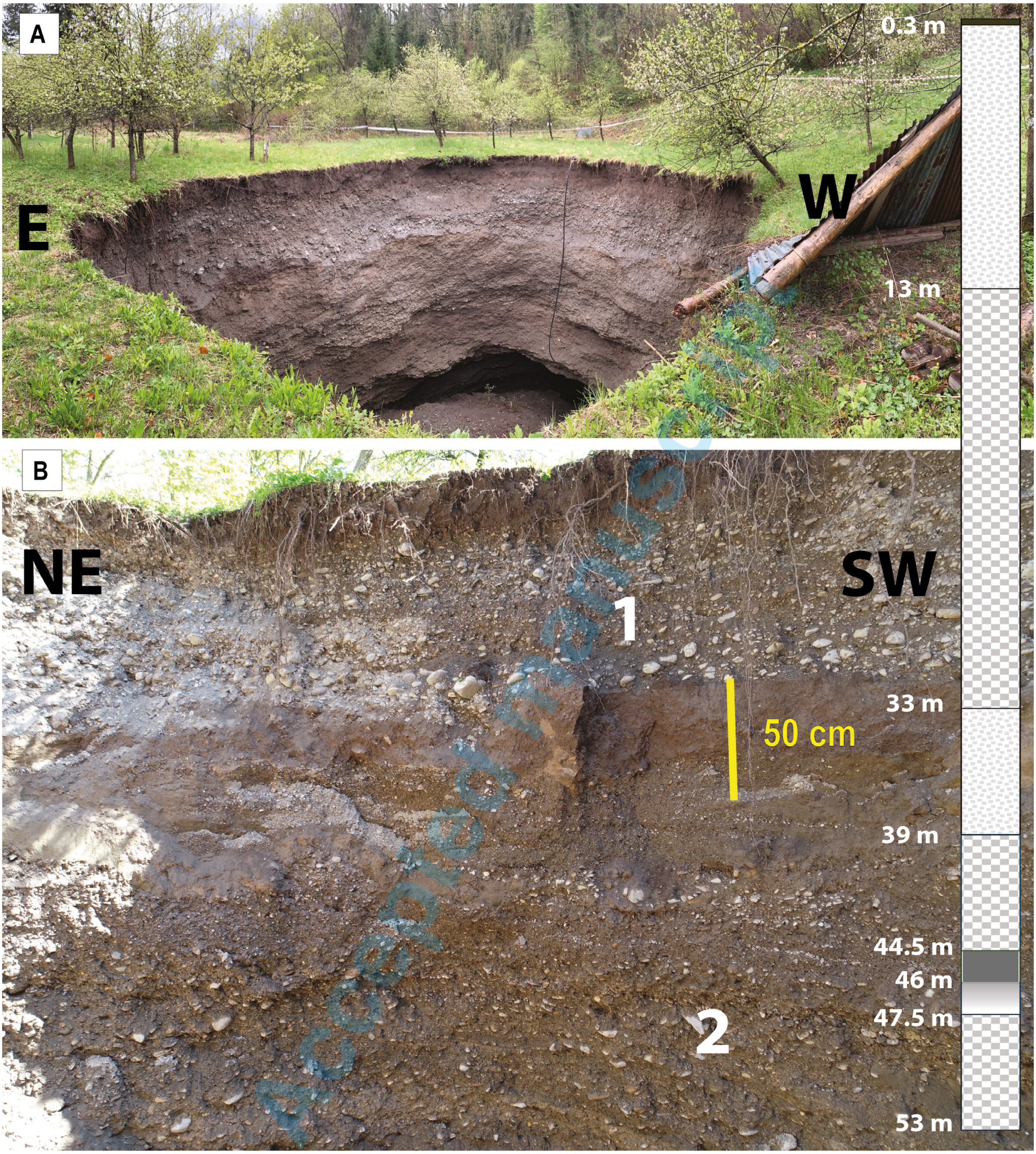

Fig. 3 - A) Panoramic view of the formed sinkhole with the ceiling over the conduit named as 1 in Figure 2; B) Detail of the steep slope with alternations of prevailing granular or/and cohesive layers: 1) cross-bedded gravels with foreset beds dipping to the left suggesting a sediment transport direction from SW to NE; 2) planar bedded gravels with imbricated clasts that suggests a flow direction from SW to NE. On the right side of the figure, a simplified stratigraphic column related to the drilled borehole. 0-0.3m soil; 0.3-13 loose alluvial deposit; 13-33m conglomerates; 33-39 m loose alluvial deposit; 39-44.5 m conglomerates; 44.5-46 m void; 46-47.5 alternation of conglomerates and voids; 47.5-53 conglomerates.

A thorough understanding of subsurface conditions and geological constraints is therefore essential not only to interpret the evolution of the phenomenon in the context of land-use planning, but also, in the short term, to define appropriate site stabilization and safety measures. In this framework, repeated UAV surveys represent an effective low-cost tool for monitoring the temporal evolution of the sinkhole, assessing ongoing ground deformation processes and define the relative set-back distances.

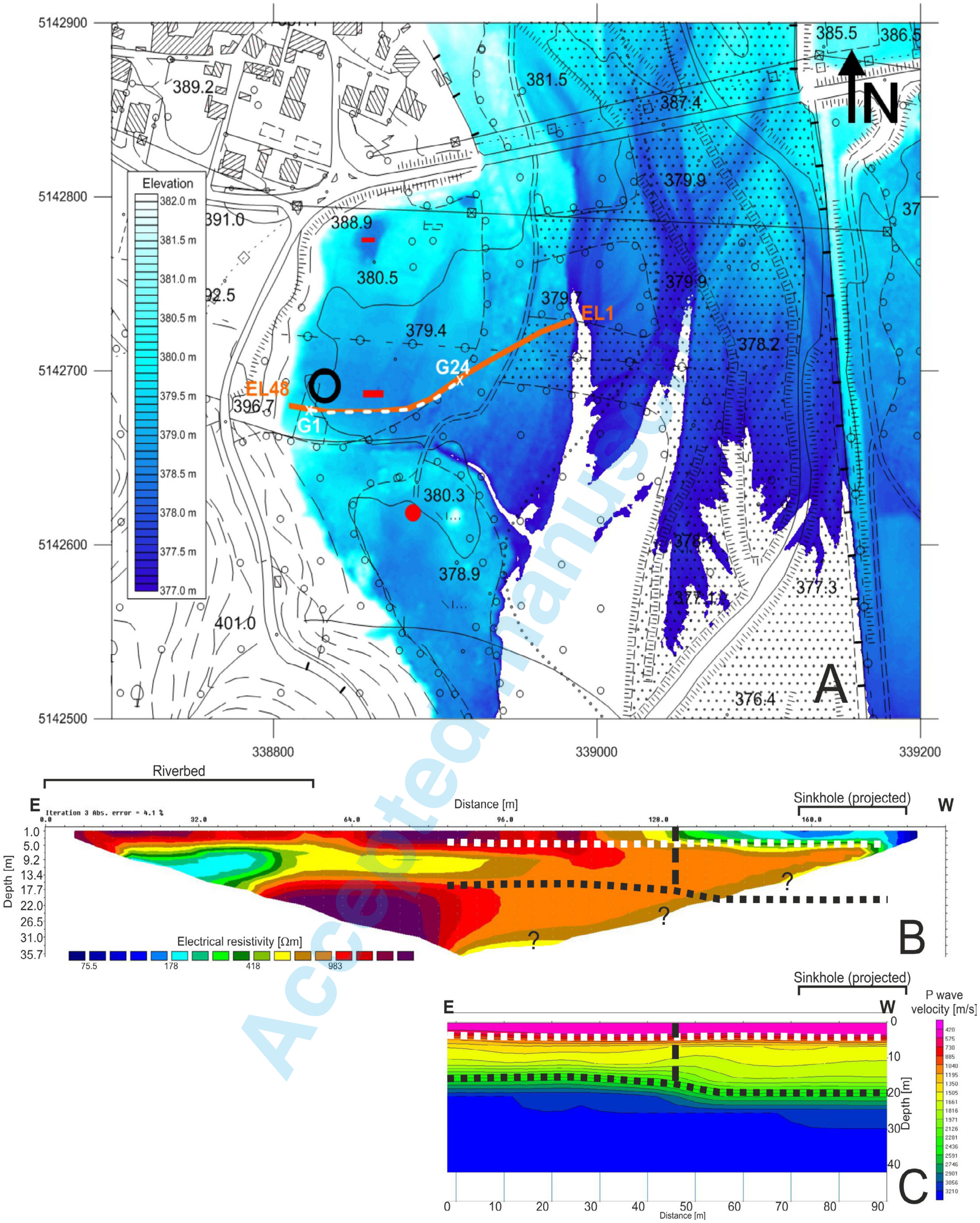

Fig. 4 - A) Location of the geophysical survey. The orange line represents the ERT profile and the white dashed line represents the RF profile. The black and red circles indicate the position of the sinkhole and the borehole, respectively. The red segments represent two depressed areas; B) ERT profile; C) RF profile. The white dotted line marks a clear variation in seismic velocity and it has also been reported on the ERT profile for comparison. The same applies to the black dotted line. The vertical dashed segment indicates a clear lateral discontinuity of resistivity, and it has been reported on the RF profile, where a deepening towards the West of the deepest seismic discontinuity is apparent.

ELECTRONIC SUPPLEMENTARY MATERIAL

This article contains electronic supplementary material, which is available to authorised users. The material consists in a video of the 3D sinkhole model realised by Fernetti M.

ACKNOWLEDGEMENTS

This research was partially funded by Servizio Geologico Friuli Venezia Giulia Region in the framework of the projects: 1) grant number ALP-B/10/AG—447 "Aggiornamento continuo del censimento e della pericolosità dei sinkhole del territorio regionale"; 2) grant number B/10/AG - 459 "definizione e quantificazione della pericolosità dei sinkhole insistenti sulle grotte del territorio regionale e la definizione di una metodologia standardizzata per il monitoraggio dei fenomeni di sinkhole in ambiti urbanizzati", scientific coordinator Prof. Chiara Calligaris.

REFERENCES

Busetti A., Calligaris C., Forte E., Areggi G., Mocnik A. & Zini L. (2020) - Integrated reflection seismics, PS-InSAR, leveling and 3D GPR to characterise sinkholes in FVG. Remote Sens., 12(22), 3814, https://doi.org/10.3390/rs12223814.

Busetti A. (2024) - Sinkhole of the Friuli Venezia Giulia region: characterization, data collection and hazard definition. PhD thesis, University of Trieste.

Busetti A., Leone C., Corradetti A., Fracaros S., Spadotto S., Rai P., Zini L. & Calligaris C. (2024) - Coastal storm-induced sinkholes: insights from unmanned aerial vehicle monitoring. Remote Sens., 16, 3681, https://doi.org/10.3390/rs16193681.

Calligaris C., Devoto S. & Zini L. (2017) - Evaporite sinkholes of the Friuli Venezia Giulia region (NE Italy). J. Maps, 13(2), 406-414, https://doi.org/10.1080/17445647.2017.1316321.

Calligaris C., Ghezzi L., Petrini R., Lenaz D. & Zini L. (2019) - Evaporite dissolution rate through an on-site experiment into piezometric tubes applied to the real case-study of Quinis (NE Italy). Geosciences, 97(7), 298, https://doi.org/10.3390/geosciences9070298.

Calligaris C., Busetti A., Forte E., Piano C. & Zini L. (2024) - Direct and indirect prospecting to detect and characterise sinkhole features in urban evaporitic environments. Ital. J. Eng. Geol. Environ., 47-55, https://doi.org/10.4408/IJEGE.2024-01.S-06.

Carbonel D., Rodríguez-Tribaldos V., Gutiérrez F., Galve J.P., Guerrero J., Zarroca M., Roqué C., Linares R., McCalpin J.P. & Acosta E. (2015) - Investigating a damaging buried sinkhole cluster in an urban area (Zaragoza city, NE Spain) integrating multiple techniques: Geomorphological surveys, DInSAR, DEMs, GPR, ERT, and trenching. Geomorphology, 229, 3-16, https://doi.org/10.1016/j.geomorph.2014.02.007.

Carulli G.B. (2006) - Carta geologica del Friuli-Venezia Giulia alla scala 1:150.000 e Note Illustrative; SELCA: Florence, Italy (In Italian).

Colomina I. & Molina P. (2014) - Unmanned aerial systems for photogrammetry and remote sensing: A review. ISPRS J. Photogramm. Remote Sens., 92, 79-97, https://doi.org/10.1016/j.isprsjprs.2014.02.013.

Cooper A.H., Farrant A.R. & Price S.J. (2011) - The use of karst geomorphology for planning, hazard avoidance and development in Great Britain. Geomorphology 134, 118-131, https://doi.org/10.1016/j.geomorph.2011.06.004.

De Waele J., Gutiérrez F., Parise M. & Plan L. (2011) - Geomorphology and natural hazards in karst areas: A review. Geomorphology, 134(1-2), 1-8, https://doi.org/10.1016/j.geomorph.2011.08.001.

Gortani M. (1965) - Le doline alluvionali. Natura e Montagna, 3, 120-128.

Guerrero J., Sevil J., Desir G., Gutiérrez F., Arnay A.G., Galve J.P. & Reyes-Carmona C. (2021) - The detection of active sinkholes by airborne differential LiDAR DEMs and InSAR cloud computing tools. Remote Sens., 13, 3261, https://doi.org/10.3390/rs13163261.

Gutiérrez F., Parise M., De Waele J. & Jourde H. (2014) - A review on natural and human-induced geohazards and impacts in karst. Earth-Science Reviews, 138, 61-88, https://doi.org/10.1016/j.earscirev.2014.08.002.

Gutiérrez F. (2016) - Sinkhole hazards. In: Gutiérrez F. (Ed) Oxford Research Encyclopedia of Natural Hazard Science. Oxford University Press, https://doi.org/10.1093/acrefore/9780199389407.013.40.

Jiao W., Dai Z., Song Q., Wang Y., Liu D., Tang J. & Yang L. (2025) - Influence of fault properties and fold structures on karst sinkholes formation and evolution: Insights from a multidisciplinary analysis. Geomorphology, 488, 109941, https://doi.org/10.1016/j.geomorph.2025.109941.

Kaufmann G. (2014) - Geophysical mapping of solution and collapse sinkholes. J. Appl. Geophys., 111, 271-288, https://doi.org/10.1016/j.jappgeo.2014.10.011.

Lee E.J., Shin S.Y., Ko B.C. & Chang C. (2016) - Early sinkhole detection using a drone-based thermal camera and image processing. Infrared Physics & Technology, 78, 223-232, https://doi.org/10.1016/j.infrared.2016.08.009.

Parise M., Gabrovsek F., Kaufmann G. & Ravbar N. (2018) - Advances in Karst Research: Theory, Fieldwork and Applications. Geological Society of London, Special Publications, 466, pp. 486, https://doi.org/10.1144/SP466.

Turner D., Lucieer A. & Watson C. (2012) - An automated technique for generating georectified mosaics from Ultra-High Resolution Unmanned Aerial Vehicle (UAV) Imagery, Based on Structure from Motion (SfM) Point Clouds. Remote Sensing, 4(5), 1392-1410, https://doi.org/10.3390/rs4051392.

Watson R.A., Holohan E.P., Al-Halbouni D., Saberi L., Sawarieh A., Closson D., Alrshdan H.,Karaki N.A.,Siebert C.,Walter T.R. & Dahm T. (2019) - Sinkholes and uvalas in evaporite karst: spatio-temporal development with links to base-level fall on the eastern shore of the Dead Sea. Solid Earth, 10(4), 1451-1468, https://doi.org/10.5194/se-10-1451-2019.

Williams P. (2004) - Dolines. In: Gunn J. (Ed.), Encyclopedia of Caves and Karst Science pp. 628-642, New York; Fitzroy Dearborn.

Youssef A.M., Zabramwi Y.A., Gutiérrez F., Bahamil A.M., Otaibi Z.A. & Zahrani A.J. (2020) - Sinkholes induced by uncontrolled groundwater withdrawal for agriculture in arid Saudi Arabia. Integration of remote-sensing and geophysical (ERT) techniques. J. Arid Environ., 177, 104132, https://doi.org/10.1016/j.jaridenv.2020.104132.

Zini L., Calligaris C., Forte E, Petronio L., Zavagno E., Boccali C. & Cucchi C. (2015) - A multidisciplinary approach in sinkhole analysis: The Quinis village case study (NE-Italy). Eng. Geol., 197, 132-144, https://doi.org/10.1016/j.enggeo.2015.07.004.