Land Subsidence Linked to Evaporite Dissolution in Qatar: Insights from Ground-Truth Survey and PSI InSAR Analysis

Constantinos Loupasakis[1*], Antoniadis Nikolaos[1], Katerina Kavoura[1], Charalampos Kontoes[2], Stavroula Alatza[2], Martha Kokkalidou[2], Nikolaos Stasinos[2], Katerina-Argyri Paroni[2], Dimitris Valianatos[3], Dorothea Aifantopoulou[3], Ismat Sabri[4], Yassir Elhassan[4], Ali Feraish Al-Salem[5], Ali Anmashhadi[5], Elalim Abdelbaqi Ahmed[5], Umi Salmah Abdul Samad[5], Bilal Ilyas[5]

[1]National Technical University of Athens, School of Mining and Metallurgical Engineering, Laboratory of Engineering Geology and Hydrogeology, Athens, Greece
[2]National Observatory of Athens, Institute for Astronomy and Astrophysics, Space Applications and Remote Sensing, Center BEYOND for EO Research and Satellite Remote Sensing, Athens, Greece
[3]EDGE in Earth Observation Sciences, Athens, Greece
[4]STS Survey Technologies, Doha, Qatar
[5]Ministry of Municipality, Doha, Qatar

(*Corresponding E-mail: cloupasakis@metal.ntua.gr)

Abstract: Sinkholes and cavities resulting from evaporite dissolution pose a significant geotechnical hazard to infrastructure across Qatar. The collapse of these features is closely linked to the dissolution of evaporite layers within the Rus and Dammam formations. To monitor surface deformation nationwide, an extensive ground-truth survey was conducted, supplemented by the evaluation of thousands of geotechnical borehole logs. Data obtained through Persistent Scatterer Interferometry (PSI) applied to Sentinel-1 SAR imagery—covering the period from 2017 to 2024—were cross-evaluated. Based on the spatial correlation between PSI-derived deformation, known karst features, and geological formations, three distinct types of areas were identified and investigated across Qatar: (A) zones exhibiting deformation without a direct link to detected subsurface cavities or sinkholes, (B) zones where deformation coincides with mapped subsurface cavities, and (C) zones where deformation patterns are associated with the presence of sinkholes. These findings underscore the influence of geological conditions on land subsidence phenomena and demonstrate the effectiveness of PSI as a tool for regional-scale hazard assessment in evaporite-rich regions.

Keywords: ***Land subsidence, Sinkholes, Evaporites` dissolution, Cavities, InSAR.***

Introduction

Sinkholes and underground cavities constitute the main geohazards that affect infrastructure projects in Qatar. The phenomena that are strongly linked to those areas are long-term ground deformation observed on the surface due to land subsidence. Usually, most of them are related to the dissolution of gypsum interbedded in the lower subsurface geological layers. To identify and monitor the land subsidence phenomena in the State of Qatar, from 2017 to 2024, a PSI analysis on Sentinel-1 SLC images of both ascending and descending satellite passes was performed. The resulting deformation phenomena were verified by ground truth investigation.

Geology of Qatar

The geological formations exposed at the surface of Qatar consist of sedimentary rocks from the Paleogene Rus and Dammam Formations, the Neogene Dam and Hofuf Formations, and the Quaternary Fuwayrit Formation (Seltrust, 1980). Among these, the Dammam Formation covers the largest portion of the country's surface. These formations are primarily composed of carbonate rocks or calcareous formations, many of which include evaporitic layers, such as gypsum and anhydrite. Furthermore, extensive Quaternary deposits such as dunes and sabkhas are widespread in Qatar and reflect climatic and sea-level variations.

Land-Subsidence Due to Dissolution

Evaporite minerals such as gypsum and anhydrite, predominantly found in the Rus and Dammam formations, are highly soluble and susceptible to dissolution by percolating water or fluctuating groundwater. Over time, the dissolution of the prementioned formations leads to the formation of cavities, caves, sinkholes and other collapse features. The collapse of these features poses geotechnical risks, especially in urban or infrastructure-heavy areas. In north and central Qatar, where these formations are widely exposed or occur at shallow depths, sinkholes and cavity collapses have been reported to cause structural damage to buildings and road deformation. (Figure 1).

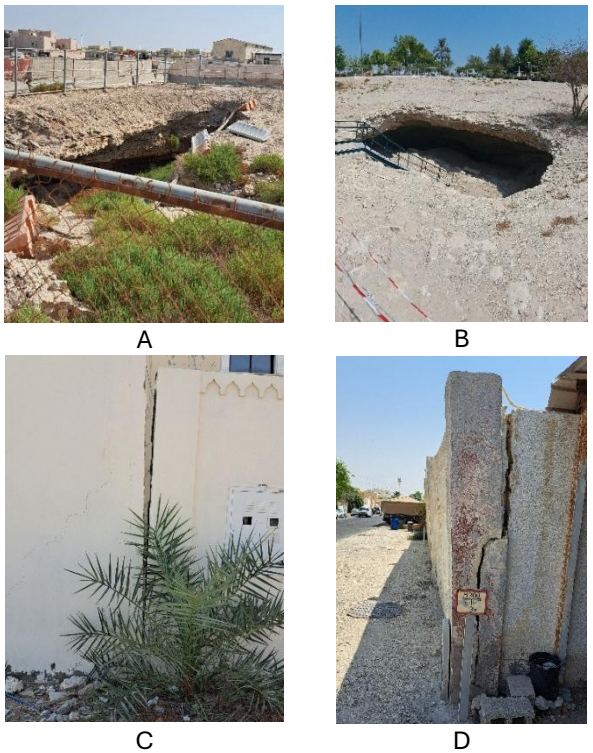
Ground truth survey for InSAR Validation

InSAR time-series analysis to estimate ground deformation in the AOI was performed with the P-PSI processing chain (Papoutsis et al., 2020) for the fully

automated assessment of LOS ground velocities through PSI. Considering the extremely large spatial sampling of PSs in Qatar, for visualization purposes, only LOS displacements lower than -2.5 mm/y, which can be considered as significant deformation, were selected for validation by means of ground truth survey.

To verify the recorded deformations, targeted locations were selected for field survey based on three criteria: (A) zones exhibiting deformation without a direct link to detected subsurface cavities or sinkholes (Figure 2, Area A), (B) zones where deformation coincides with mapped subsurface cavities (Figure 2, Area B), and (C) zones where deformation patterns are associated with the presence of sinkholes (Figure 2, Area C). The field inspections provided valuable data and photographic evidence from affected constructions, confirming that deformations detected through InSAR could be clearly identified and verified on site.

Figure 2 represents different cases of recorded deformation in the Northern part of Doha. In Area A, numerous permanent scatterers (PS) indicate deformations; however, no cavities or sinkholes have been identified in this region. In contrast, Area B contains both PS points and a dense cluster of detected underground cavities, which indicates that the occurring ground deformation can be directly associated with the subsurface cavities. Finally, in Area C, including the urban area surrounding the Dahl Duhail (Figure 1, A) and Dahl Al Hamam (Figure 1, B) Sinkholes, the ground deformation can be directly linked with detected cavities and sinkholes.



A B C D

Figure 1, The Dahl Duhail (A) and Dahl Al Hamam (B) Sinkholes. (C) and (D) present damages in contractions identified at the surmounting areas of the two sinkholes, respectively.

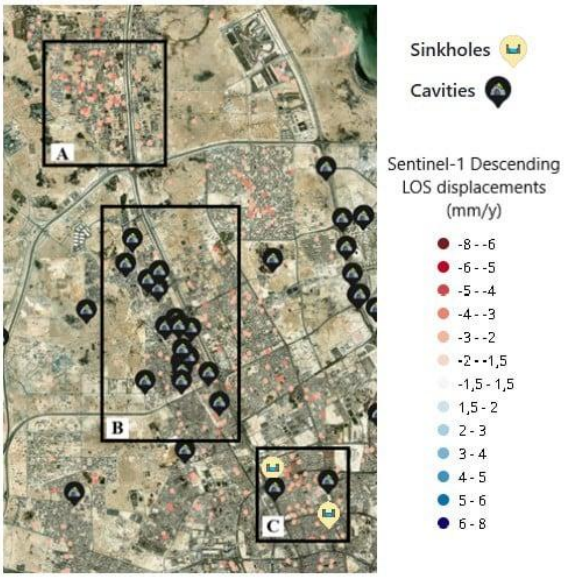


Figure 2, Filtered LOS displacements (< –2.5 mm/year) along the descending track in the area north of the Dahl Duhail and Dahl Al Hamam sinkholes, Doha. The locations of the identified cavities and sinkholes are clearly marked.

Conclusion

The land subsidence phenomena observed in Qatar are primarily driven by geological processes associated with the dissolution of evaporitic rocks, particularly gypsum, within the Rus and Dammam formations. These soluble layers are prone to chemical weathering and dissolution under the influence of percolating water or fluctuating groundwater, resulting in the formation of underground cavities and karst features. The collapse of these features causes surface deformation clearly identified by Persistent Scatterer Interferometry (PSI) analysis of Sentinel-1 data from 2017 to 2024.

Acknowledgement

The authors acknowledge the Qatar Geological Mapping Project Phase II.

References

Papoutsis, I., Kontoes, C., Alatza, S., Apostolakis, A., and Loupasakis, C. (2020). InSAR Greece with parallelized persistent scatterer interferometry: A national ground motion service for big Copernicus Sentinel-1 data. Remote Sensing, 12, 3207. https://doi.org/10.3390/rs12193207

Seltrust Engineering Limited. (1980). Qatar geological map (1980 edition): Explanatory booklet. Government of Qatar.