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# ASSESSMENT AND MANAGEMENT OF GEOHAZARDS RELATED TO KARST, STATE OF QATAR

J. Perrin[1], R. Couëffé[1], G. Noury[1], A. Ortiz[1], C. Allanic[1], B. Lemaire[2], O. Higgins[2], B. Matti[2], C. Lerevenu[2], R. Pillai[2], S. Al-Yafei[3], E. Ahmed[3], U.S. Samad[3]N.T. Mahmood[3]

[1] BRGM (French Geological Survey), 3 Av. Claude Guillemin 45060 Orléans, France
E-mail: j.perrin@brgm.fr
[2] EGIS group, 15 Av. du Centre CS50238 – Guyancourt 78286 Saint-Quentin-en-Yvelines Cedex, France
E-mail: bastien.lemaire@egis-group.com
[3] Ministry of Municipality, Infrastructure Planning Department, Doha, Qatar
E-mail: saalyafei@mm.gov.qa ; eahmed@mm.gov.qa

The State of Qatar is underlain by carbonate and evaporitic rocks with abundant karst features. Currently, Qatar does not have adequate geological and hydrogeological maps at regional and local scales with proper geodatabases to appropriately support future planning and development. It is important for the State to develop a dedicated infrastructure to inform on the hydrogeological conditions across the country and the related geohazards such as subsidence, presence of karst or flooding caused by rising groundwater. Therefore, the Ministry of Municipalitylaunched the "Qatar Hydrogeological Assessment Project" with the aim to develop detailed hydrogeological models, geohazards maps, reports and related products for the entire country as well as for major existing urban areas and future development areas.

In this project, the assessment of karst geohazards in Qatar entails:

1) a karst inventory built from existing information in the literature and unpublished reports, information in boreholes data, historical aerial photographs, satellite imagery, and a depressionmapping based on the processing of a high-resolution LiDAR bare ground digital terrain model. A ground-truthing is then performed for validation of this karst inventory.
2) Geological field work androck/sediments labanalyses to determine the nature, origin, and timing of karst: evaporitic vs carbonate karst, epigenic vs hypogenic karst, typical karst features and karst features dimensions, depth of karstification, temporal evolution of karst features, etc.
3) Karst geohazard mapping using a multicriteria approach combining geological, hydrogeological and groundwater chemistry data to determine several classes of hazard.

Based on this assessment, karst geohazard risk mitigation and management plans are developed: the role of human activitieswill be looked at with special care as it is known to be a main triggering mechanism of ground subsidence.

The geohazards and risk maps as well as the guidelines and operational recommendations will be made accessible through a web portal.

*Keywords*: Karst, Geohazards mapping, Geohazards management, Qatar, Sinkholes, Multicriteria analysis.

## 1. Introduction, Context, and Objectives

The State of Qatar, located in the Middle East, is a peninsula surrounded on three sides by the Arabian Gulf and its surface area (11,586 km$^2$) is largely covered by dolostone and limestone rocks of Tertiary age (Figure 1). Although it has an arid climate with average annual rainfall of 75 mm, its karst topography is well developed withmorethan 9,700 large and small depressions (Sadiq and Nasir,2002). To date few published karst studies are available:Embabi & Ali (1990) carried out a thorough analysis of the Peninsula karst geomorphology, a work partly summarized by Sadiq & Nasir (2002) who present the main karst features existing in Qatar with sketches of seven of them. They discuss the most likely period for karstification (humid Middle Pleistocene) and mechanisms of karstification based on morphological observations.Cuttler & Al Naimi (2013) present Holocene Qatar landscape evolution with impacts on human settlements and archaeological artefacts. They describe karst features, particularly mentioning the presence of water at the bottom of Dahl Al Misfir(Dahl means cave in Arabic) until the 1980' and the fact that Dahl Al Mudhlem had collapsed near the entrance when visited in 2002. Duggan (2014) carried out an inventory of karst depressions across Qatar using a DEM dataset (10 m cell size). The northern depressions tend to be hierarchically integrated low-lying depressions with gentle slopes, while depressions in the south are larger,

more isolated, with well-defined ridges and terraces. Howari et al. (2016) carried out a geophysical investigation (micro-gravimetry measurements) around Dahl Al Hamam (within Doha urban area). At depth of ~15m, this cave is water filled (saline water) and they indicate that it is hydraulically connected to the Arabian Gulf at a distance of 4 km.Orndorff et al. (2018) summarize the geological context of the Qatar peninsula and provide recommendations for future karst studies in Qatar.Emil et al. (2021) used InSAR time series in conjunction with ALOS Palsar-1 and Sentinel-1 SAR datasets to assess ground deformation within the Qatar peninsula. Whereas significant uplift is observed in sabkha and subsidence under landfills, the deformation rates over areas surrounding known karst feature locations were low (+/-2 mm/yr). Ross (2010) shows an application of historical aerial photography of Duhail area (1947) as a way to detect karst features (depressions) in a presently densely urbanised sector.Recent publications by Abdelbaky et al. (2022) and Akbar et al. (2023) highlight the importance of karst in subsurface infrastructure projects in Qatar, and more specifically in Doha capital city area. The role of karst on shallow groundwater resource and associated hydraulic conductivities is described by Baalousha (2024) and Eid et al. (2024).

The low relief of the Qatar peninsula is coincident with a broad, north-trending fold called the Qatar arch with the axis of the arch being nearly equidistant from east and west coastlines (Figure 1). The surface and near subsurface stratigraphy includes Tertiary carbonate and evaporite rocks with some interbedded clastic units (Figure 1): the dominant formation at outcrop is the Dammam limestone, and more specifically the Umm Bab member, and that could be silicified in some places. It is separated from the underlying Rus formation by the Midra shale. The underlying Eocene Rus formation exhibits thick sequences of gypsum in its lower part (Traina member) in south Qatar, but not in the north where both depositional conditions and secondary dissolution may explain its absence (Eccleston et al., 1981). The Paleocene and lower Eocene Umm er Radhuma formation constitutes a regional fractured/karstic carbonate aquifer present across the entire Qatar subsurface; it is an important unit for injection of treated sewage effluent and waste fluid disposal in oil and gas production areas.

In addition to the geotechnical rock mass characteristicsof subsurface materials, particularly with respectto building foundation design and buried infrastructure,owners, engineers, developers, and planners are alsovery interested in understanding the behavior of karstfeatures and the potential geological hazards they maycause. With carbonate and evaporite rocks at and nearthe surface, cavity collapse and settlement associatedwith the presence of shallow solution cavities cause significantgeotechnical and other engineering problemsacross the country. This context encouraged the Ministry of Municipality (MM), and particularly its Infrastructure Planning Department (IPD) to elaborate a thorough assessment of karst geohazards across Qatar. This ongoing project includes an inventory of karst features, a 3D geological modeling of the entire Qatar peninsula, geological fieldwork to assess karstification processes and mechanism of karst subsidence/collapse, and the mapping of karst geohazard and risk across the entire country. One objective of the geohazard risk map will be to enable identification and delineation of areas prone to subsidence/collapse geohazard to ensure a more stringent and informed engineering design and construction practice. The policy would improve the zoning regulation on geohazard risk areas including buffer zones and construction permit controls and reporting of cavity encountered. In parallel, an educational program on karst and groundwater rise geohazards is elaborated for different stakeholders: the general public, the technical community, and decision-makers. This program will feature a dedicated module focused on a media awareness campaign, along with preparation of comprehensive guidelines and policies aimed at effectively assessing and mitigating groundwater rise, as well as addressing geological hazards (karst) and associated risks. The guidelines and policies will provide developers with a framework within which due diligence obligations can be met and properties damage can be avoided. In addition, a comprehensive long-term monitoring plan, including groundwater monitoring and continuous monitoring and inspection of the conditions of potential hazard areas will be developed.

This paper presents the preliminary results of this project and highlights the outcome of the field surveys. It also discussesthe way forward and next steps towards the mapping of karst geohazard. The presented approach may be replicated to similar karstic contexts in arid and semi-arid regions.

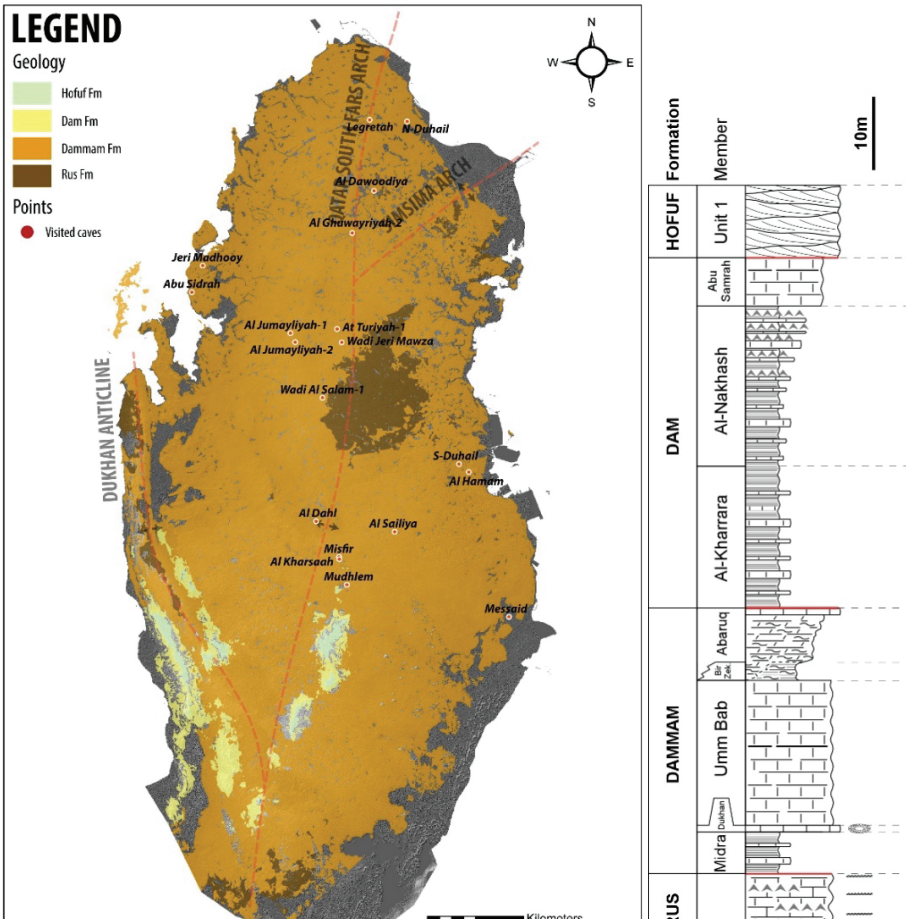



Fig. 1.Simplified geological map of Qatar with explored caves and stratigraphic column of the shallow subsurface.

## 2. Methodological approach

A literature review together with a compilation of existing databases at MM and LiDAR DTM depression mapping in a GIS environment were performed to define targets for field investigations. In parallel, a first 3D geological model was built on the basis of validated geological borehole logs (n=506).A one-week reconnaissance survey was followed by a two weeks field survey by three teams (structural geology, sedimentary geology & karstification, cave and depression survey & geohazard). The field survey objectives were to acquire additional geological information for the 3D geological model, to obtain observations on karst features and karst fillings as well as samples that should enable a better understanding of karstification processes and age, and observation of accessible cavities main characteristics as well as ground-truthing of the LiDAR DTM depression mapping.

The upcoming steps will encompass the update of the geological model and karst features (caves & depressions) database, possible records of recent ground subsidence related to karst using InSAR data (Emil et al. 2021) and historical accounts by locals, and the incorporation of information obtained on karstification from samples analyses. On this basis, a robust karst conceptual model will be developed and geohazards maps produced together with practical recommendations on managing such geohazard.

## 3. Results

### 3.1. Field observations

The caves and depressions visited during the field missions are summarized in the Table 1. All the caves are developed in the Umm Bab member of the Dammam formation, the only exception being the bottom part of

Misfir cave, which penetrates the upper member of the Rus formation. Two mechanisms of cave formation could be identified: 1)roof collapse (9-10 cases) and 2) carbonate dissolution (8-9 cases). We observed that most collapses occurred on the edge of much larger depressions.

Epigenic karstification process appears to be no longer active. Only some caves testify of recent hydrological activity as they receive local runoff during rare high intensity rainfall.

Table 1. List of karst caves surveyed during a recent field mission and summarizing main characteristics

| Cave/sinkhole name | Dimensions(1) (m) | Geology | Hydrology | Formation process |
|---|---|---|---|---|
| Misfir | E: 13.3x6.2, L: 78, D: 36 | Umm Bab, upper Rus at bottom | Runoff during heavy rain | Roof collapse |
| Al Hamam | E: 14.5x8.2, L: ~30, D: ~15(2) | Umm Bab | Groundwater table at bottom | Roof collapse |
| Duhail (S) | E: 22.5x4.5, L: 22 D: 5 | Umm Bab | | Roof collapse |
| Mudhlem | E: 9.4x4.4, L: 19, D: 7 | Umm Bab | Runoff and swallow-hole 45m NW of main cave | Roof collapse |
| Al Sailiya | E: 5.3x4.3, L: 28, D: 8 | Umm Bab | Runoff during heavy rain | Roof collapse |
| Al Dahl | E: 1.0x0.8, L: 3, D: 1.6 | Umm Bab | | Dissolution likely |
| Al Kharsaah | E: 16x1.5, L: 2, D: 2 | Umm Bab | | Roof collapse likely (anthropic backfilling) |
| Messaid | E: 50x49, L: 5, D: 5 (continues under water) | Umm Bab | Groundwater table at bottom with tidal fluctuations | Collapse likely |
| Wadi Al Salam-1 | E: 0.5x0.5, L: 6, D: 3.5 | Umm Bab | | Dissolution likely |
| Al Jumayliyah-2 | E: 1.4x1.3, L: 114, D: 9 | Umm Bab | Runoff during heavy rain | Dissolution |
| Abu Sidrah | E: 2.6x1.5, L: 5, D: 1 | Umm Bab | | Roof collapse |
| Jeri Madhooy | E: 4.1x2.4, L: 12, D: 3 | Umm Bab | | Roof collapse |
| Al Dawoodiya | E: 4.3x3.4, L: 27, D: 9 | Umm Bab | Groundwater table at bottom | Dissolution likely |
| Al Ghuwayriyah-2 | E: 0.9x0.9(3), L: 10, D: 3 | Umm Bab | Two entrances | Dissolution likely |
| Legretah | E: 1.4x1.3(3), L: 75(4), D: 5.5 | Umm Bab | Five entrances | Dissolution |
| Duhail (N) | E: 3.3x2.3, L: 6, D: 3 | Umm Bab | | Dissolution likely |
| Wadi Jeri Mawza | E: 3.2x1, L: 3.5, D: 1.5 | Umm Bab | | Collapse? |
| Al Jumayliyah-1 | E: 1.5x1.4(3), L: 61, D: 5 | Umm Bab | Two entrances | Dissolution |
| At Turiyah-1 | E: 0.6x0.6(3), L: 9, D: 4 | Umm Bab | Two entrances | Dissolution likely |

(1) E=Entrance (length x width), L: cave extension, D: cave depth; (2) no detailed survey yet, (3) largest entrance, (4) cumulated length of the five caves

A number of depression identified via the processing of LiDAR DTM data acquired in 2017 constitute internal drainage basins. However, they do not seem to act as naturally active infiltration points (like dissolution sinkholes do) as they accumulate water after heavy rainfall and their bottom part may be flooded. To overcome this flooding hazard, and as these depressions are often used for agriculture because of the presence of soils, recharge wells were dug since historical times. These wells are also beneficial for the groundwater balance as they contribute to augment the recharge (166 recharge wells according to Al-Muraikhi & Shamrukh, 2016).

### 3.2. Preliminary interpretation

The most sensitive geological contexts for karst geohazard are mantled karst and hydrologically active feather-edge karst (contact karst) (e.g., Waltham et al. 2005). Such contexts do not exist presently in Qatar and barren karst conditions prevail. Two types of potential processes leading to karst hazard can be inferred so far: 1) roof collapse sinkhole in the Umm Bab member of the Dammam formation, 2) subsidence in developed areas where barren karst have been covered by unconsolidated material.

The main observed karst features during the fieldwork seem to be related to collapse-karst mechanisms (quarries in Dammam limestone (Figure 2), Misfir, Al Hamam, Mudhlem, Duhail caves). The inception mechanism may be due to dissolution of gypsum of the Rus formation (intrastratal karst). Relatively recent ground movement in this context is documented around Mudhlem cave (about 40m diameter depression with observable tensile cracks at some locations), and Duhail cave (fissures in nearby houses mentioned by MM, however karst subsidence origin is not confirmed), and Al Sailiya cave.In contrast, cavities developed by dissolution in the Umm Bab limestone seem to be of much smaller size (Table 1) and related geohazards are likely minimal. This needs to be confirmed by additional field observations.

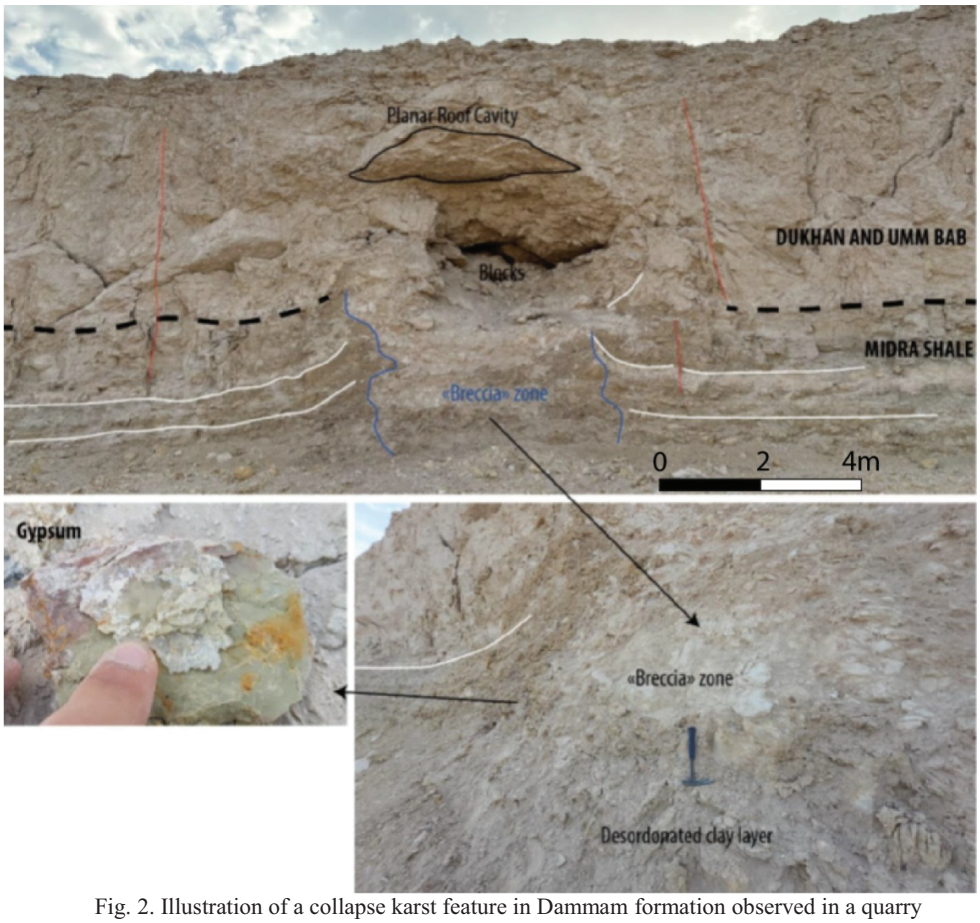



Fig. 2. Illustration of a collapse karst feature in Dammam formation observed in a quarry

## 4. Outlook and Conclusion

This paper presents the outcome of the literature review together with preliminary results from field investigations. This ongoing work confirms the widespread presence of karst features across the Qatar peninsula and the occurrence of caves formed by dissolution where shallow subsurface is constituted by the Umm Bab member (Dammam formation) and cave collapse features of deeper origin, potentially originating from dissolution ofthe underlying evaporitic Rus formation (Traina member), i.e., intrastratal karst. Due to the large outcropping areas of Umm Bab, the dissolution karst featuresseem to be extensive; in contrast expression of intrastratal karst at the surface remains limited to very specific areas. Our field observations seem to indicate a relatively low geohazard related to the Umm Bab karstification due to its massive nature and small size of caves; the intrastratal karst potentially constitutes a higher geohazard, with occurrence of large collapse sinkholes, however it remains limited to specific locations. The age and frequency of such collapse remain unknown. As such information is crucial for a thorough hazard assessment, potential recent ground subsidence due to karst will be analysed by InSAR interferometry together with historical accounts that may be accessible (interviews of local inhabitants, "grey" literature).

On this basis, the surface karst geohazard mapping at Qatar scale will be performed via a multicriteria analysis (e.g., Perrin et al. 2015) considering the following criteria among others: geology at outcrop, presence of backfilling material on top of barren carbonate rocks, areas where surface water may be present in excess of natural conditions.

The final map will be accompanied by an explanatory notes as well as operational recommendations for developers.

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