Extreme rainfall events recorded in stalagmites from Oman during the last two millennia

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1. Motivation

- **Oman** is located at the crossroad of **monsoon systems** and **tropical cyclone** tracks.
- In recent decades, Oman has experienced **extreme rainfall** events like Cyclone Mekunu in 2018 and frequent flash floods. As a result, frequent damage in infrastructure is posing a major threat in both urban an rural communities.

Figure 1. Cyclone Mekunu hits Oman in 2018. Destroyed infrastructure in Salalah. Source: The Guardian. Photograph: Kamran Jebreili/AP

- **Future climate projections** from the recent IPCC Sixth Assessment Report predict i**ncreased precipitation** and **runoff** in the Arabian Peninsula.

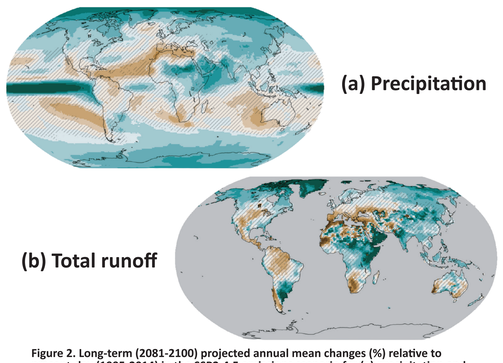


Figure 2. Long-term (2081-2100) projected annual mean changes (%) relative to present-day (1995-2014) in the SSP2-4.5 emissions scenario for (a) precipitation and (b) total runoff. Adapted from IPCC, 2021, Technical Summary Box TS.6, Figure 1.

- **Sparse instrumental and historical records** hinder long-term climate understanding – natural archives are key to identifying climate trends.

2. Why Stalagmites?

- Stalagmites are valuable climate archives by preserving geochemical signals that reflect past climate conditions spanning thousands of years.
- They capture evidence of **extreme rainfall** and **flood events** through detrital layers and trace element spikes.
- These features provide a natural archive of past monsoonal and cyclone activity over the past thousands of years.
- Especially valuable palaeoclimate records in data-scarse regions like Oman.

3. Cave settings

- Qunf Cave (southern Oman, 650 m asl) is influenced by the summer monsoon and receives 200-600 mm of rainfall annually, over 80% of which falls between July and September.
- Hoti Cave (northern Oman, 800 m asl) receives mainly winter rainfall from Mediterranean frontal systems, with an average annual rainfall of 55-255 mm.

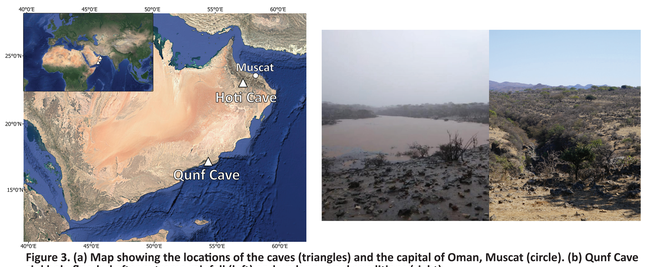
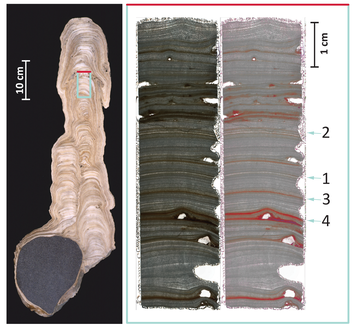


Figure 3. (a) Map showing the locations of the caves (triangles) and the capital of Oman, Muscat (circle). (b) Qunf Cave sinkhole flooded after extreme rainfall (left) and under normal conditions (right).

- Both caves are formed in limestone and experience episodic flooding, particularly during extreme rainfall events. In the case of Qunf Cave, these flood events introduce detrital particles and affect drip-water chemistry, which is captured in stalagmite trace element profiles. In contrast, Hoti Cave experiences more frequent sediment input during flooding, making it ideal for identifying flood layers using stalagmite thin sections.

4. Methods

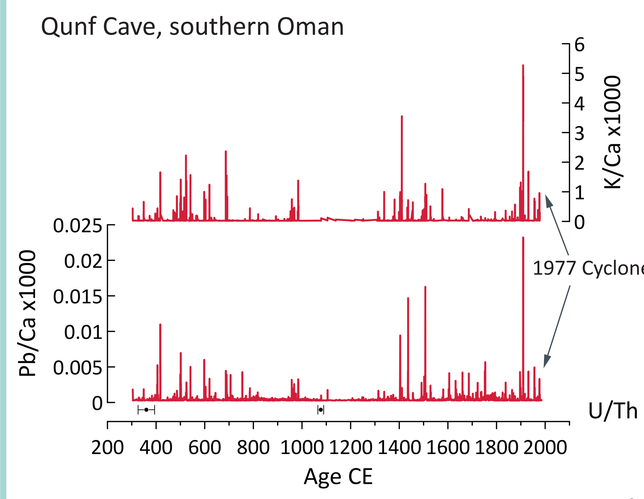


- Hoti Cave – Thin section analysis
  Flood layers were identified using high-resolution thin sections, where detrital horizons were enhanced by digitally isolating and highlighting reddish-brown particles.

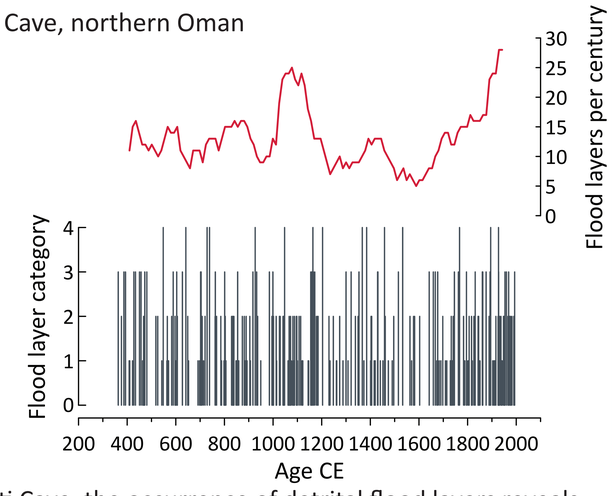
Category 1: discontinuous red layer
Category 2: continuous red layer
Category 3: thick red layer
Category 4: possibly more than one layers

- Qunf Cave – LA-ICP-MS trace element profiles
  K/Ca ratios reflect influx of clay-rich particles during flood events.
  Pb/Ca ratios are used as a tracer of fine-grained sediment input, linked to surface runoff and erosion during intense rainfall.

5. Preliminary Results



- Trace element ratios K/Ca and Pb/Ca from Qunf Cave reveal extreme rainfall events and possibly capture the deadly cyclone that hit Oman in 1977.



- At Hoti Cave, the occurrence of detrital flood layers reveals an increase between 1000 and 1200 CE, coinciding with the Medieval Climate Anomaly. In addition, there is a sharp increase in the beginning of the 20th century.

6. Outlook

- These findings contribute to a deeper understanding of how extreme rainfall and floods have varied in a region where long-term climate records are scarce.
- Further analysis is required to refine flood attribution and explore links to climate drivers.

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