Assessment of Impact due to 2022 Floods on Mohenjo Daro UNESCO World Heritage Site based on Satellite Imagery and Derived Mapping Products

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Introduction

The Archaeological Ruins at Mohenjo Daro are among the six World Heritage Sites (WHS) in Pakistan, and are inscribed in the UNESCO List since 1980 as the best-preserved urban settlement in South Asia dating back to the beginning of the 3rd millennium BC, that exercised a considerable influence on development of urbanization (UNESCO, 2022). Located in today's Sindh Province on the right bank of the Indus River, 510 km north-east from Karachi, when it was discovered in 1922 the site revealed a 300 ha large city with a complex urban layout characterized by mudbrick and backed brick domestic, religious and secular buildings. According to McIntosh (2008), the complex interaction with the Indus River was already apparent in ancient Mohenjo Daro as confirmed by the presence of large flood defence platforms managed by a specific authority.

However, the proximity to the river may still nowadays represent a threat for conservation of and accessibility to the site, as experienced during the very disastrous floods that hit Pakistan in 2022. It is with regard to this event that the present paper aims to demonstrate how a multisciplinary collaboration between remote sensing and satellite image analysts, a geologist and an archaeologist using open satellite imagery and derived products can support the assessment of impacts on Mohenjo Daro due to floods and, in turn, inform conservation measures.

2022 Pakistan Floods and Analysed Data

From 14 June to October 2022 a series of floods devastated Pakistan, reaching the maximum observed floodwater extent between July and August of ~32,800 square miles countrywide (USAID, 2022). The catastrophic effects triggered multiple initiatives for mapping and monitoring the extent of the damage across Pakistan. While the Copernicus Emergency Management Services Rapid mapping products (Activation ID EMSR629; CEMS, 2022) did not include Mohenjo Daro within Larkana AOI, the report released by UNOSAT (2022) on 8 September about the satellite detected water extent in Sindh Province as of 31 August 2022 dedicated a focus on the WHS.

In addition, the full archive of cloud-free Copernicus Sentinel-2 images, in Level-2A Bottom Of Atmosphere format, collected between 12 July and 30 October 2022, was analysed according to the method by Tapete and Cigna (2018), with particular focus on the visible bands (10 m spatial resolution). The Sentinel-2 time series showing the temporal evolution of flooding was then integrated with the maps of flood water extent generated from Sentinel-1 imagery collected between 30 August and 2 October, using the CEMS Global Flood Monitoring (GFM) operational product (EODC, 2022). Local topography and natural factors predisposing to flooding were assessed using the Advanced Land Observing Satellite (ALOS) World 3D–30 m (AW3D30) global Digital Elevation Model (DEM; Tadono et al., 2014).

Results and Discussion

As the name suggests ("Mound of the Dead Men"), Mohenjo Daro is at higher elevation compared to the surrounding valley (Figure 1a). Therefore, even during catastrophic floods as the one occurred in 2022, the inner site is sheltered. However, as reported by several studies (UNOSAT 2022; Khan et al. 2023) and showed by flood water extent on 31 August (Figure 1b), Mohenjo Daro was fully surrounded by waters which, at least, impacted on site accessibility.

(Figure 1 around here)

The Sentinel-2 time-lapse highlights that river waters started raising since 1 August (Figure 2b), whereas the first nearly cloud-free view of the flood was captured on 26 August (Figure 2d). The peak inundation was documented on 31 August and 5 September (Figure 2e-f). Five days after, inundation was gradually decreasing, leaving deeply muddy terrain in the alluvial valley (Figure 2g). With a constant temporal sampling of five days (Figure 2h-k), Sentinel-2 shows the gradual retreat of waters which mostly evacuated by 30 October (Figure 2l).

(Figure 2 around here)

These visual observations are quantitatively corroborated by GFM spatial mapping of flood water extent (Figure 3). Sentinel-1 captured the peak inundation on 30 August and 3 September (Figure 3a-b). On 8 September a significant decrease of flood water extent was observed mainly in the fields on the left river bank (Figure 3e), whereas most of the waters retreated between 15 and 20 September (Figure 3i,k). However, large flooded areas persisted in the nearby of the site until the end of October (Figure 3l-p). In particular, the one south-west of Mohenjo Daro is located in a topographic depression (height of 48 m in AW3D30; Figure 1a). As stagnant water body, it may facilitate saline efflorescences and water capillarity, and thus in the short-term be hazardous for conservation of mudbrick structures in Mohenjo Daro. Satellite observations suggest that recovery actions should encompass not only the removal of muddy terrain from roads, but also drying of stagnant water bodies.
Finally, ground-truth validation by means of in-situ photographic documentation is exploited to complement satellite observations to locate, within the site, damages to brick structures due to rain and consequent water table rise.

(Figure 3 around here)

Conclusions

The analysis presented in this paper emphasizes how the 2022 summer floods had an impact on cultural heritage in the Indus valley region. In Mohenjo Daro WHS, floods nearly completely surrounded the site and created water bodies in local topographic depressions that could exacerbate the risk of saline efflorescences and water capillarity, in addition to the detrimental effect of abundant precipitation and water table rise on mud-brick structures.

From a methodological and operational point of view, this research shows how a multidisciplinary collaboration between remote sensing and satellite image analysts, a geologist and an archaeologist using multispectral and SAR imagery and derived products such as Copernicus data, alongside cartographic data and ground-truthing, represents a useful and feasible approach for assessing the impact of extreme climate change-related events, like floods. It is also important to stress the relevance of when assessing the condition of the archaeological remains and ancient monuments, flood damage in heritage properties also the impact on site accessibility should be taken in to account.

The proposed satellite-based methodology could be easily disseminated via capacity building projects in which established co-working teams, encompassing archaeologists, geologists, heritage experts and satellite image analysts, will train end-users from national heritage institutions, commercial archaeology companies and academia (Zaina and Tapete 2022). This activity would be particularly useful in those countries with limited access and funding to support on-purchase facilities, and where local personnel lacks advanced satellite remote sensing skills.

References

CEMS – Copernicus Emergency Management Service - Mapping, 2022. EMSR629: Floods in Pakistan. emergency.copernicus.eu/mapping/list-of-components/EMSR629 (Accessed: 1 June 2023).

EODC (2022). *GFM Product Output Layers*. extwiki.eodc.eu/GFM/PUM/Products (Accessed: 1 June 2023).

Khan, M. Y., Zaina, F., Muhammad, S., & Tapete, D. (2023). Integrating Copernicus Satellite Products and Ground-Truthing for Documenting and Monitoring the Impact of the 2022 Extreme Floods in Pakistan on Cultural Heritage. *Remote Sensing*, *15*(10), 2518. https://doi.org/10.3390/rs15102518

McIntosh, J. (2008). *The ancient Indus Valley: new perspectives*. ABC-CLIO.

Tadono, T., Ishida, H., Oda, F., Naito, S., Minakawa, K. and Iwamoto, H. (2014). Precise Global DEM Generation by ALOS PRISM. *ISPRS Ann. Photogramm. Remote Sens. Spat. Inf. Sci.*, II-4, 71–76. doi.org/10.5194/isprsannals-II-4-71-2014

Tapete, D., Cigna, F. (2018). Appraisal of Opportunities and Perspectives for the Systematic Condition Assessment of Heritage Sites with Copernicus Sentinel-2 High-Resolution Multispectral Imagery. *Remote Sensing*, 10(4), 561. doi.org/10.3390/rs10040561

UNESCO (2022). *Archaeological Ruins at Moenjodaro*. whc.unesco.org/en/list/138/ (Accessed: 1 June 2023).

UNOSAT (2022). Preliminary satellite-derived flood assessment, Islamic Republic of Pakistan - 08 Sep. 2022. unosat.org/products/3352 (Accessed: 1 June 2023).

USAID (2022). *Pakistan Floods, September 30, 2022, Fact Sheet #8*. www.usaid.gov/sites/default/files/2022-12/2022-09-30_USG_Pakistan_Floods_Fact_Sheet_8.pdf (Accessed: 1 June 2023).

Zaina, F.; Tapete, D. (2022). Satellite-Based Methodology for Purposes of Rescue Archaeology of Cultural Heritage Threatened by Dam Construction. Remote Sens. 2022, 14. doi:10.3390/rs14041009