2022 Pakistan Flood: Report on the Damage Assessment of Cultural Heritage in Sindh Province

February 2024
Japan Consortium for International Cooperation in Cultural Heritage

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This report, "Pakistan Floods of 2022: Report on Damage to Cultural Properties in Sindh Province," was researched and edited by the Japan Consortium for International Cooperation in Cultural Heritage as part of a FY 2023 project commissioned by the Agency for Cultural Affairs.

1. Background/ Introduction

The monsoon rains that severely hit Pakistan from June to October 2022 have caused one of the worst flooding in decades across the country, submerging a third of the country. While many lives were lost and many residents are still forced to live in evacuation, the country's proud cultural heritage has also been severely damaged. Still, details are not widely investigated or shared. The Japan Consortium for International Cooperation in Cultural Heritage embarked on collecting information on the damage to cultural heritage in Pakistan in 2022. It sought ways to cooperate with local heritage stakeholders, starting with a report by the National Committee for ICOMOS Pakistan at the Southeast Asia and South Asia Regional Committee meeting in February of the same year. After contacting the authorities in the provinces of Pakistan and discussing the situation with local officials, it was agreed that we conduct the assessment of the damage to cultural heritage in Sindh, one of the areas particularly hard hit by the floods.

2. Aim of mission

To assess of the cultural heritage sites in Sindh province in Pakistan affected by the floods and to identify needs for their rehabilitation and restoration.

3. Date

Islamabad (20 – 22/ December/ 2023)
Sindh province (22 – 30/ December/ 2023)

4. Delegation of Japan in the mission

Name	Position	Expertise/role
Atsushi NOGUCHI	Special Commissioned Associate Professor, Research Center for Next Generation Archaeological Studies, Komatsu University.	Archaeology
Takayoshi AOKI	Professor, Graduate School of Design and Architecture Architecture and Urban Design, Nagoya City University	Architecture
Mitsuhiro MIYAMOTO	Associate Professor, Faculty of Engineering, Department of Safety Systems Construction Engineering, Kagawa University	Architecture
Yohsei KOHDZUMA	Director, Director, Cultural Heritage Disaster Risk Management Center, Japan	Conservation Science
Abdul Wahid Mohamed RASMY	Senior Researcher, International Center for Water Hazards and Risk Management (ICHARM),	Civil Engineering
Koki MAEDA	Secretariat, Japan Consortium for International Cooperation in Cultural Heritage Tokyo National Research Institute for Cultural Properties	Project Coordination/ Architecture

5. Itinerary

Date (2023)	Departure	Destination	Location of visit	Accommodation
20.12	Narita Airport/ Suvarnabhumi Airport (Bangkok)	Islamabad International Airport	-	
21.12	Islamabad	-	・Department of Archaeology & Museums (DOAM) ・Islamabad Museum ・Embassy of Japan in Pakistan	
22.12	Islamabad International Airport	Karachi Airport		
	Karachi Airport	Karachi City	・DG Antiquities Sindh ・National Museum of Pakistan	Ramada Plaza Karachi Airport Hotel (Karachi)
23.12	Karachi City	Karachi Airport		Sambara Inn
	Karachi Airport	Larkana		
24.12	Larkana	Moenjodaro	Moenjodaro	
	Moenjodaro	Gambat		Royal Inn Hotel Gambat
25.12	Gambat	Kot Diji Fort	Kot Diji Fort	
	Kot Diji Fort	Nawabshah		Nawabshah Rest house
26.12	Nawabshah	Mian Noor Muhammad Kalhoro Graveyard	Mian Noor Muhammad Kalhoro Graveyard	
	Mian Noor Muhammad Kalhoro Graveyard	Nawabshah		Nawabshah Rest house
27.12	Nawabshah	Quba Mir Shahdad	Quba Mir Shahdad	
	Quba Mir Shahdad	Ranikot		Ranikot Rest House
28.12	Jamshoro	Ranikot	Ranikot fort	
	Ranikot	Bhambore		Bhambore Rest House
29.12	Bhambore	Makli Necropolis	Makli Necropolis	
	Makli Necropolis	Karachi		Ramada Plaza Karachi Airport Hotel (Karachi)
30.12	Ramada Plaza Karachi Airport Hotel (Karachi)	Karachi Airport		
	Karachi Airport			
31.12		Suvarnabhumi Airport (Bangkok)/ Narita Airport		

6. List of personnel

Date (2023)	Name		Position
12/21	Dr, Abdul Azeem	Department of Archaeology and Museums Islamabad.	Director General
	Dr. Tahir Saeed	Department of Archaeology and Museums Islamabad.	Director
	Arshad Ullah	Department of Archaeology and Museums Islamabad.	Deputy Director
	Muhammad Azeem	Department of Archaeology and Museums Islamabad.	Archaeological Engineer
	Mitsuhiro Wada	Embassy of Japan in Pakistan	Ambassador
	Kazumasa Takane	Embassy of Japan in Pakistan	Councillor
	Moeto Fukuda	Embassy of Japan in Pakistan	Second Secretary
12/22	Manzoor Ahmed Kanasro	Directorate General of Antiquities & Archaeology, Culture, Tourism, Antiquities & Archives Department, Government of Sindh	Director General
	Zahida Quadri (Local Coordinator of the mission)	Directorate General of Antiquities & Archaeology, Culture, Tourism, Antiquities & Archives Department, Government of Sindh	Assistant Director
	Abdul Fatah Shaikh	Directorate General of Antiquities & Archaeology, Culture, Tourism, Antiquities & Archives Department, Government of Sindh	Director Archaeology & Museums
12/24	Syed Shakir Ali Shah	Directorate General of Antiquities & Archaeology, Culture, Tourism, Antiquities & Archives Department, Government of Sindh	Director Conservation Mohen jo Daro
12/25	Mr. Tanweer	Site Office Kot Diji Fort Directorate General of Antiquities & Archaeology, Culture, Tourism, Antiquities & Archives Department, Government of Sindh	Site Incharge Kot Diji Fort
12/26	Mr. Naqash Ali	Directorate General of Antiquities & Archaeology, Culture, Tourism, Antiquities & Archives Department, Government of Sindh	Architect and Conservator in-charge at Mir Shahdad Ja Quba
12/27	Mr. Zahoor Dahiri	Directorate General of Antiquities & Archaeology, Culture, Tourism, Antiquities & Archives Department, Government of Sindh	Assistant for Conservation at Mian Noor Mohammad Kalhora Tomb in Dulatpur
12/28	Mr. Mohsin Soomro	Directorate General of Antiquities & Archaeology, Culture, Tourism, Antiquities & Archives Department, Government of Sindh	Field Officer/Site manager of Ranikot
12/29	Mr. Zaheer Jokhio	Directorate General of Antiquities & Archaeology, Culture, Tourism, Antiquities & Archives Department, Government of Sindh	Site manager of Makli
	Mr. Sarfraz Nawaz	Directorate General of Antiquities & Archaeology, Culture, Tourism, Antiquities & Archives Department, Government of Sindh	Chief conservator of Makli

7.Assistance in Disaster Risk Reduction & Disaster Management Plan

Requests were also received for assistance in the development of disaster risk management plans for cultural heritage, which will require a long-term commitment. This study aims to collect information on the existing framework for disaster risk reduction in Sindh and Sindh Province, and to gather information on perspectives that should be included in future cultural heritage disaster risk reduction plans, such as restoration of damaged cultural heritage, medium to long-term conservation, and the systems required for disaster management. In addition, meetings were held with the Federal Department of Archaeology and Museums, the Embassy of Japan, and the Department of Archaeology of Sindh Province to exchange views on future cooperation between Japan and Pakistan.

8.Documentation / Drone Photogrammetry

Due to time and technical constraints, detailed surveying was difficult, so the main focus was on photographic documentation. A drone was used to record panoramic views of the ruins and high locations, and 3D data of the ruins was created and provided to the Sindh Provincial Archaeological Department based on the photos collected after returning to Japan. Assessments were made mainly by visual inspection, and attempts were made to identify the cause and extent of damage to damaged areas and the medium- to long-term conservation measures required, in terms of structural and non-structural damage, material deterioration, flood control and drainage conditions, flood risk, and other factors. In particular, the stability of the structures was assessed through measurements of the Microtremors at each site. In addition to the four archaeological sites in the Indus River basin requested by the Department of Archaeology of Sindh Province, the World Heritage sites of Moenjodaro and Makli at Tatter were selected for the survey (see Chapter 3 for details).

Result of Site Documentation and Damage Assessment
Drone photogrammetry

Drone photogrammetry is a sort of airborne remote sensing. Small and lightweight drones are effective to achieve quick field documentation with a minimum of equipment. This time, we use DJI mini2 and mini3. Source data for photogrammetry are acquired by still photography with program flight, or video capturing with manual flight.

For covering a certain range of survey areas, program flight by DroneLink is highly effective, because of stable operation with fixed overlap of source photos. Flight courses are arranged and input prior to flights on web map. Drone flight is assisted by GNSS location data. The operation is simple and easy. Prices of certain small and lightweight drones are more reasonable than high-end models. Therefore, this method is applicable to quick-emergency field documentation.

Fig.1 is the result of alignment of source photos on Moenjodaro-HR area. 87 photos taken from 30m above the ground covers about 175 by 100m (1.75ha). A flight time is within 15 minutes. Fig.2 is the orthographic output of a color-texture model. The present condition of site is well-represented. Fig.3 is the step-colorized DEM. Fig.4 is hill-shade added to Fig.3. Ground features are more visible, and surface water flow marks are also visible as well as other ancient structures. Fig.5 is the visualization of surface slope. Upright structures, such as brick walls, are represented in red, while flat areas are represented in blue. This makes outlines of structures more visible.

It should be noted that all these different types of output are based on a single documentation data.

This means that the minimum field documentation can provide multiple results. Because of this characteristic, we can obtain more information and can share more resources to further restoration and reconstruction works.

Figs. 6a and b are results of drone photogrammetry on the main complex of Mian Noor Muhammad Kalhoro Graveyard. In cases of documentation of buildings, manual flight is required for the effective operation due to the lack of enough GNSS assistance. When a drone flies closer place to the target building, the building itself shuts out GNSS signals from satellites and the control of drone position is deteriorated. For ensuring enough overlap for better alignment, video capturing is selected. But trajectories are instable than manual flight. (Figs. 7a and b). 1252 frames are cropped out from 3 different video footages covering about 14.5m square in plane and 15 min height. Total amount of flight time is about 15 minutes.

Figs.8a-e are orthographic images of the main tomb from NEWS direction and the top. The color-texture model represents both structures and exteriors well. This could be the best documentation of present condition of the site/ building, the source for architectural/ structural analyses, as well as the platform of multiple records of conservation and restoration works (e.g. for recording positions of sampling, conservation works and installation of reconstructed materials, etc.).

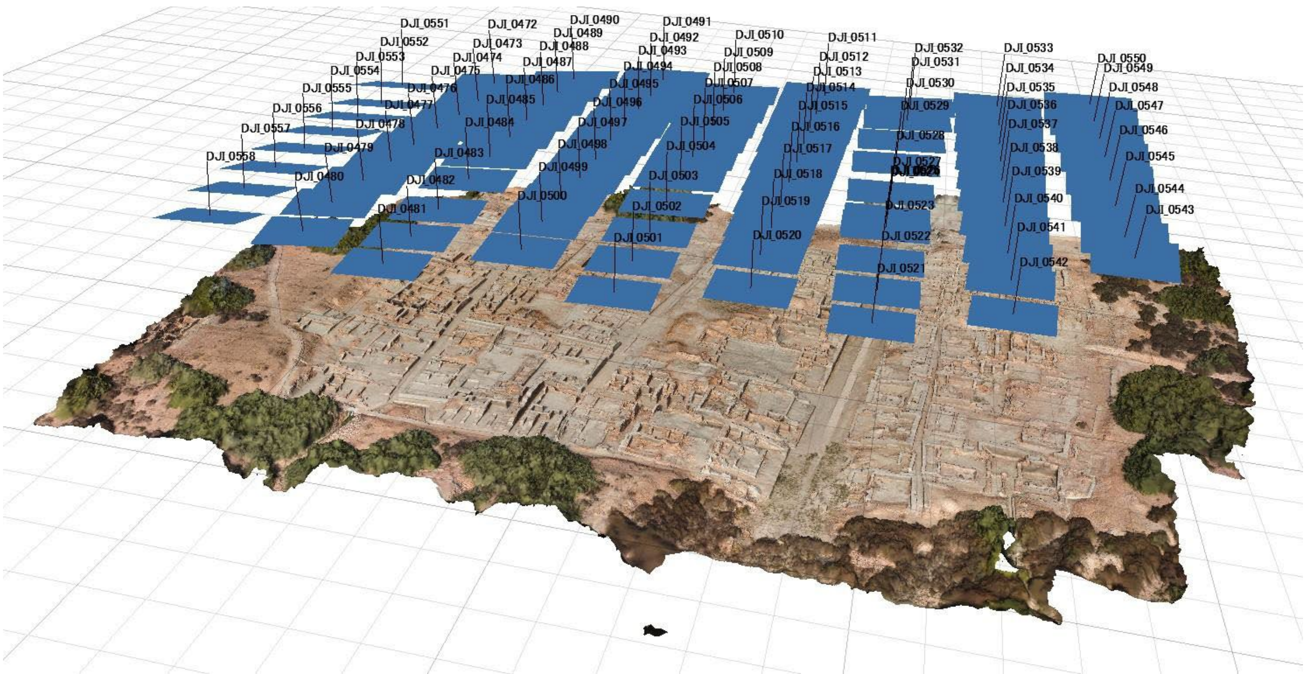


Fig 1.The result of alignment of source photos on Moenjodaro-HR area.

Fig 2. The orthographic output of a color-texture model.

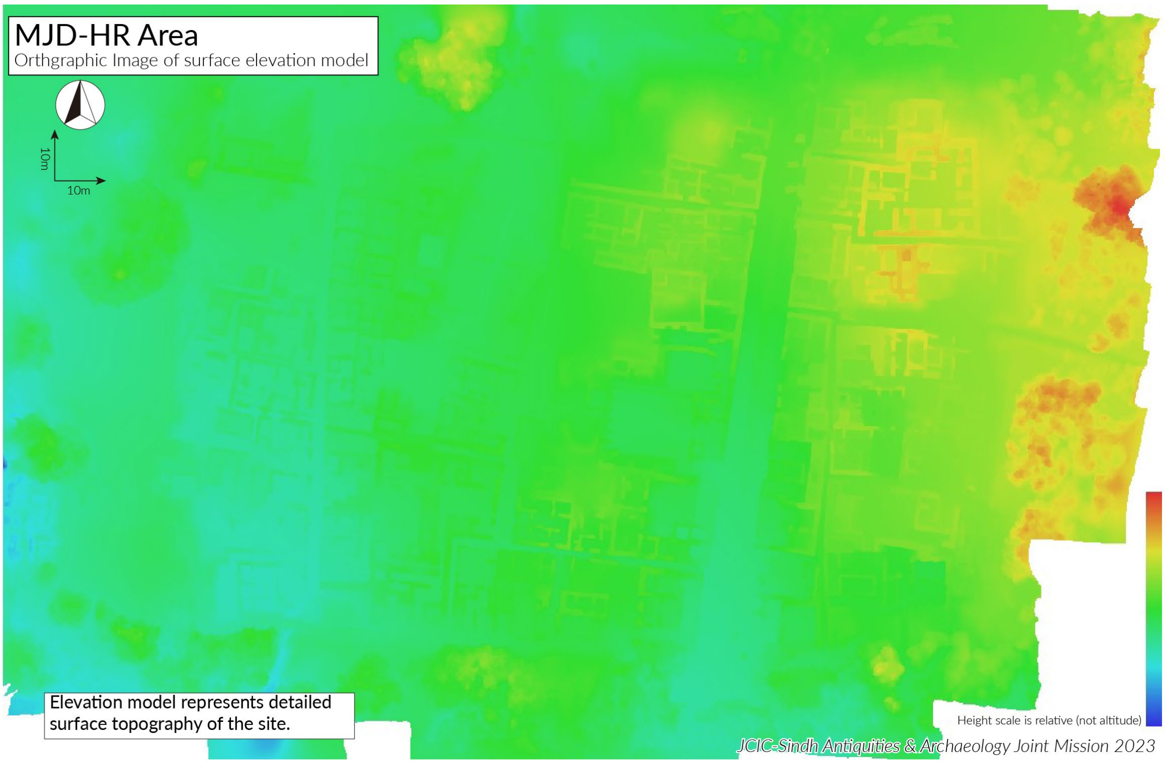


Fig 3. The step-colorized DEM

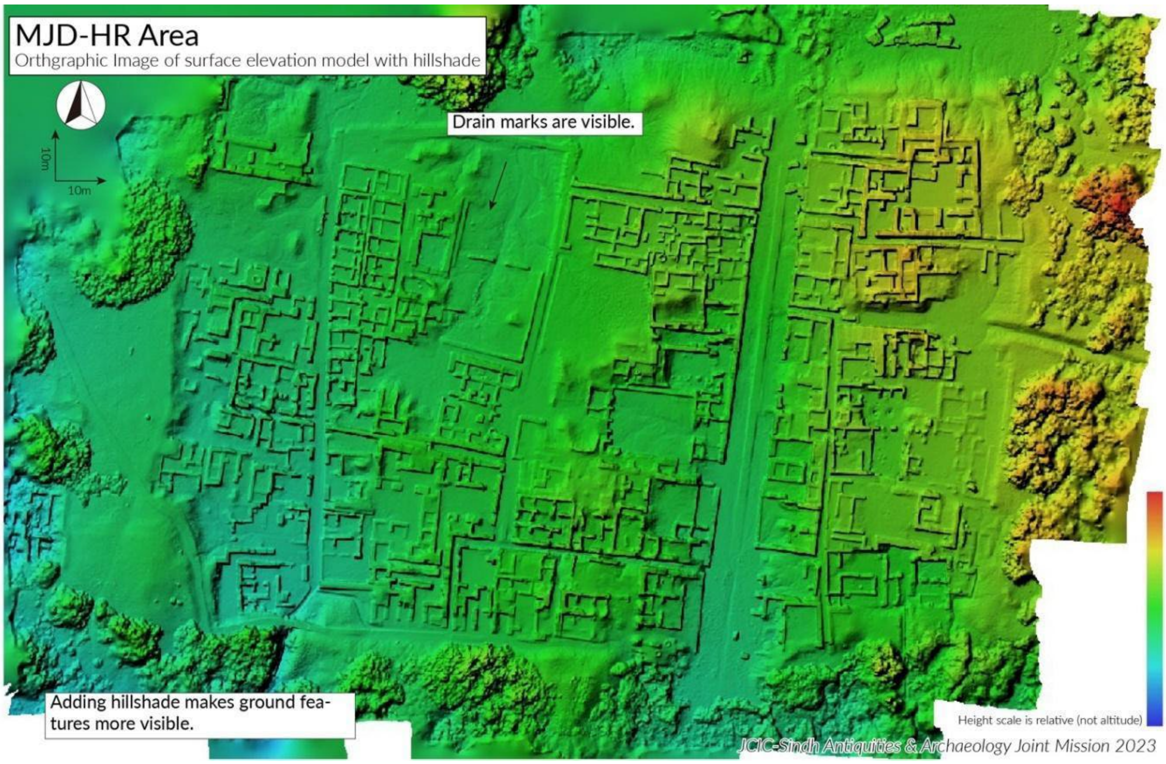


Fig 4 The hill-shade added to Fig.3

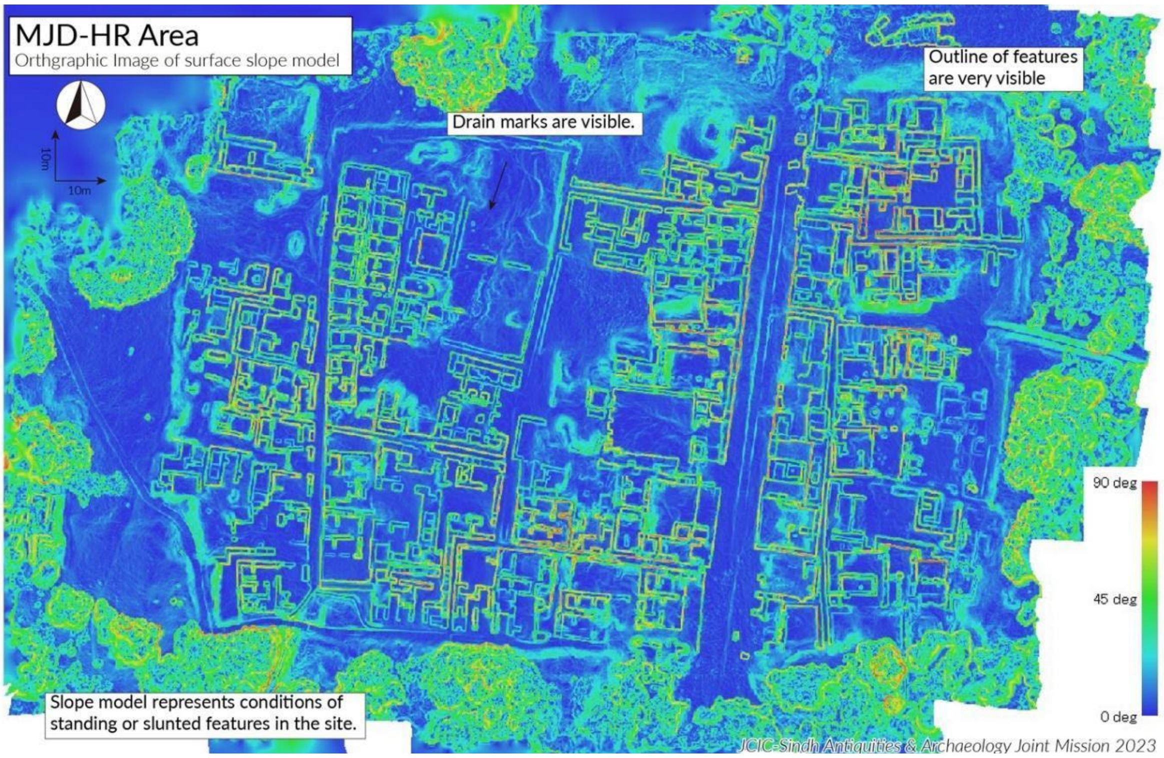


Fig 5 The visualization of surface slope

Fig 6a(above) and 6b(below). Results of drone photogrammetry on the main complex of Mian Noor Muhammad Kalhoro Graveyard.

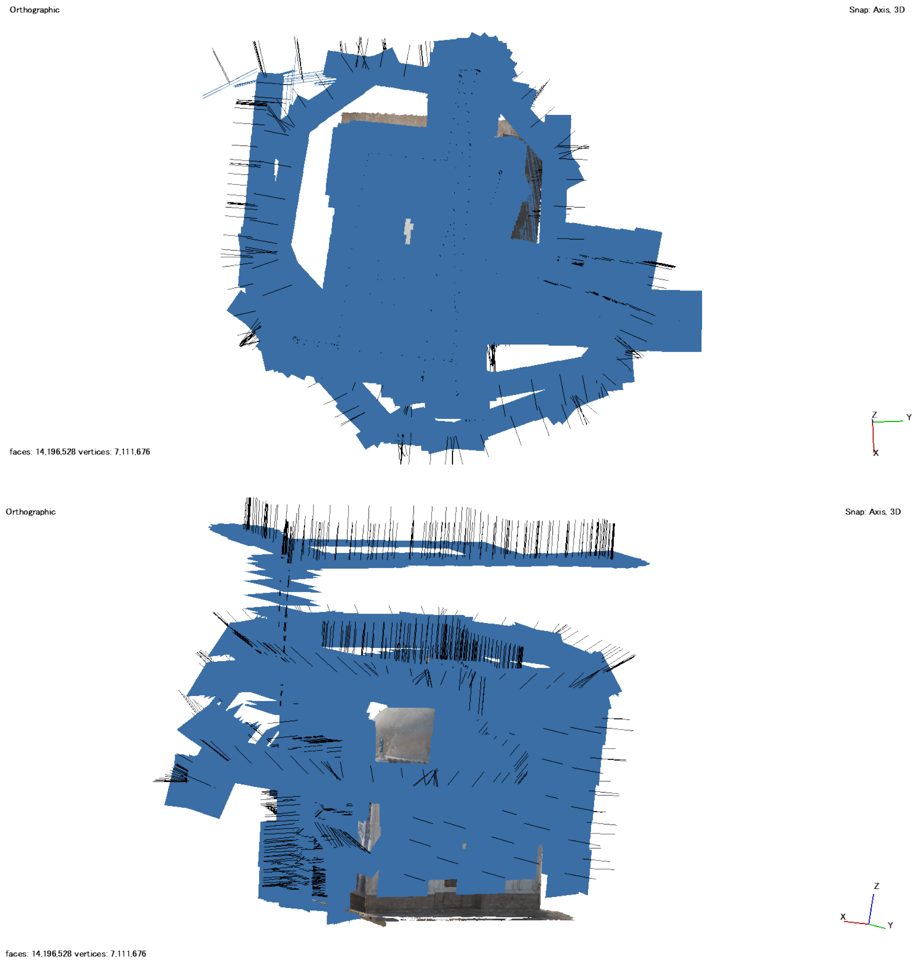


Fig. 7a (above) and 7b (below). Trajectories of the video capturing.

Fig. 8a Orthographic images of the main tomb from NEWS direction and the top.

Fig. 8b~8e Orthographic images of the main tomb from NEWS direction and the top.

9. Structural Damage Assessment

Aim of Measurement

Microtremor measurements were conducted with the aim of obtaining basic data for determining the vibration characteristics of the building. From the measurement results, the basic vibration characteristics of the building, such as natural frequencies and vibration modes, are determined. Since the natural frequency correlates with the rigidity of the building and the vibration mode identifies the points where the building tends to sway easily, the measurement results provide important information for understanding the characteristics of building vibration and for considering areas that require special attention during future repairs. The results of these measurements are also useful in studying the effects of external factors other than earthquakes, such as windstorms and heavy rain, and partial damage due to aging on the stability of buildings.

Measurement Method

Microtremors is a micro vibration of a building caused by an unidentifiable input propagated from a vibration source. By measuring and analyzing the time history waveforms of the microtremors, the vibration characteristics of a building can be evaluated. The advantage of the microtremor measurement is that it is non-destructive, and data can be obtained from the actual building. A portable high-sensitivity vibrometer (SPC52) shown in Fig.1 and five servo velocity sensors (VSE-15D) as sensors were used for the measurements. Each of the five VSE-15Ds was connected to the SPC52, which was connected to a laptop computer. In each building, several patterns of simultaneous measurements were performed by changing the installation position and direction.

In each case, measurements were made at a sampling frequency of 100 Hz for 300 seconds until two or more data were recorded. The measured records were filtered with a low cut of 0.1 Hz (1 Hz only for Moenjodaro) and a high cut of 20 Hz (50 Hz only for Moenjodaro), then divided into 40.96 seconds (4096 data) and overlapped by 50% (2048 data) to create tens of data sets in each case. The data sets were then divided by 40.96 seconds (4096 data) and overlapped by 50% (2048 data) to create tens of data sets in each case. A Fast Fourier Transformation (FFT) was applied to each record obtained to calculate the Fourier amplitude spectrum, and an ensemble average was performed after 50 smoothing operations with a Hanning window. Natural frequencies and vibration modes were estimated from the Fourier spectral ratios of each measurement point in the building relative to the ground surface.

(A)Portable High Sensitivity Vibrometer

(b)Servo type velocity sensor

Fig.1 Measuring Equipment

Measurement Results (Moenjodaro)

The target structures are the remains of the HR area shown in Fig. 2. Across the passage, the brick wall on the north side is less damaged and the brick wall on the south side is more damaged. The locations of the velocity meters in each case are shown in Fig. 3: Ch1 was placed on the ground surface, Ch2 and Ch4 were placed on the south brick wall, which is more damaged, and Ch6 was placed on the north brick wall, which is less damaged, and the north and south directions were measured in CASE1 and CASE2 and in CASE3, respectively.

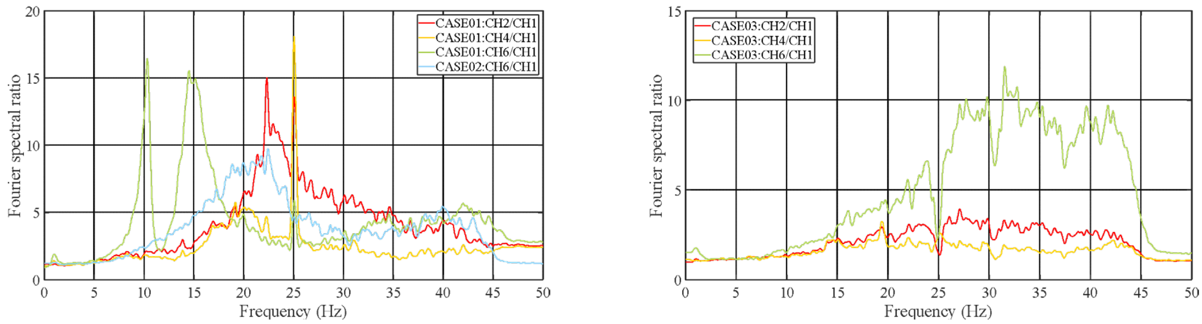
The Fourier spectral ratios are shown in Fig. 4 for each measurement case. In the north-south direction, a peak was observed around 22 Hz for the south brick wall with large damage and around 10 Hz for the north brick wall with small damage, while no clear peak was observed in the east-west direction. The peak frequency was lower for the brick wall on the north side, which was less damaged, but this may be due to the support condition of the brick wall rather than the size of the damage, since there was no brick wall orthogonal to the edge of the brick wall where the sensor was placed in Ch6 of CASE 1. This indicates that the stability of a brick wall depends not only on the size of the damage, but also on the existence of a brick wall orthogonal to the wall.

(a)From the East (b)From the north

Fig.2 Target structure (Moenjodaro)

(a) CASE1, 2 (b) CASE3

Fig.3 Measuring position (Moenjodaro)



(a) CASE1, 2 (b) CASE3

Fig.4 Measurement results (Moenjodaro)

Measurement Results (Kot Diji Fort)

The target structure is the castle wall in the top area shown in Fig. 5, with a similar structural form, the east brick wall with less damage and the west brick wall with more damage. The locations of the velocity meters in each case are shown in Fig. 6: Ch1 was placed on the ground surface, Ch2 and Ch4 were placed on the west brick wall, which is more damaged, and Ch3 and Ch6 were placed on the east brick wall, which is less damaged, and the north-south direction was measured in CASE 1 and the east-west direction in CASE 2, respectively.

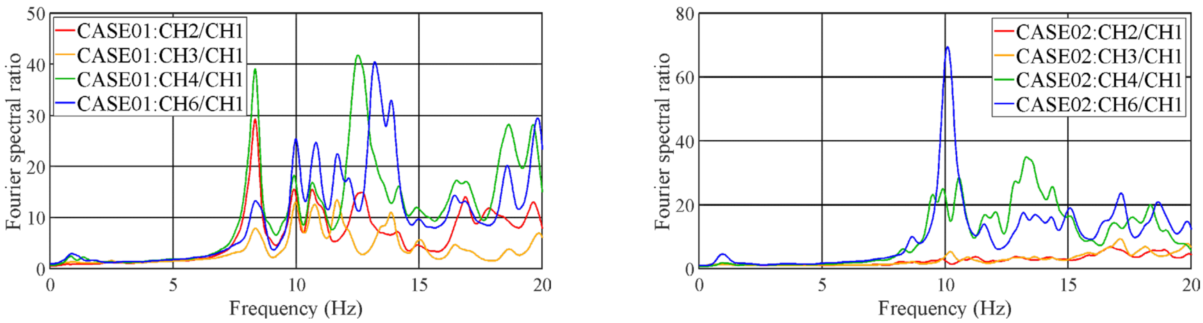
The Fourier spectral ratios are shown in Fig. 7 for each measurement case. In the north-south direction, both brick walls have a common peak around 8.3 Hz, indicating that they are vibrating in unison, but the amplitude is larger on the west brick wall, which is more damaged. In the east-west direction, the east brick wall, which was less damaged, showed a common peak at around 10 Hz, indicating that the brick wall was vibrating as one unit, but the west brick wall, which was more damaged, showed no common peak. This may be due to the fact that the edge of the brick wall where Ch4 was installed was cut off by the damage. In the case of a continuous brick wall such as a castle wall, if the edge of the wall is cut off due to damage, the wall loses stability, and it is important to take countermeasures against this.

(a)West side (Major damage) (b)East side (slightly damaged)

Fig.5 Target structure(Kot Diji Fort)

(a) CASE1 (b) CASE2

Fig.6 Measuring position(Kot Diji Fort)



(a) CASE1 (b) CASE2

Fig.7 Measurement results(Kot Diji Fort)

Measurement Results (Mian Noor Muhammad Kalhoro Graveyard)

The target structure is the dome-shaped building of Mian Noor Muhammad Kalhoro Graveyard shown in Fig.8, with the exterior walls restored but with cracks remaining in the interior. The locations of the velocity meters in each case are shown in Fig. 9: Ch1 was placed at ground level, and Ch2, 3, 4, and 6 were placed at the center of each of the four sides of the rooftop floor, and the north-south and east-west directions were measured in CASE 1 and CASE 2, respectively.

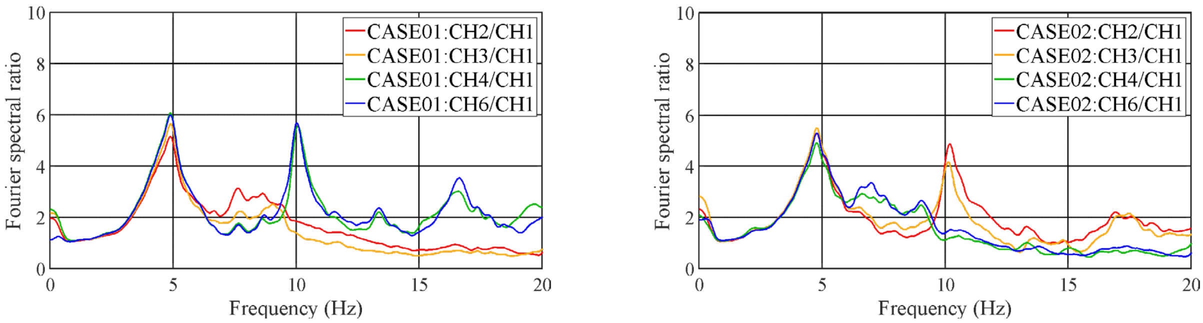
The Fourier spectral ratios are shown in Fig. 10 for each measurement case. The peaks in both the north-south and east-west directions are around 4.9 Hz and 10 Hz, respectively, and it is inferred that the former is the natural frequency of the in-plane direction of the wall and the latter is the natural frequency of the out-of-plane direction of the wall. Normally, the natural frequencies of out-of-plane walls are lower than those of in-plane walls, but in this building, the relationship is reversed. This may be due to the fact that the out-of-plane vibration is restrained by the arch effect of the dome. The above indicates that the stability of the walls of a building with a dome-shaped rooftop is greatly affected by damage to the dome section.

(a)Exterior (b) Interior

Fig.8 Target structure(Mian Noor Muhammad Kalhoro Graveyard)

(a) CASE1 (b) CASE2

Fig.9 Measuring position(Mian Noor Muhammad Kalhoro Graveyard)



(a) CASE1 (b) CASE2

Fig.10 Measurement results (Mian Noor Muhammad Kalhoro Graveyard)

Measurement Results (Quba Mir Shahdad Talpur)

The target structure is the eight-pillared domed building of Quba Mir Shahdad Talpur shown in Fig. 11, with a similar structural form with more damage to the east side stone structure and less damage to the west side stone structure. The locations of the velocity meters in each case are shown in Fig. 12. In the east side stone structure, where damage was greater, Ch 1 and Ch 2 were installed at ground level, and Ch 3, 4, and 6 were installed at diagonal positions at the corner of the rooftop, and measurements were made in the north-south direction in CASE 1 and in the east-west direction in CASE 2. Similar measurements were made on the west side of the stone structure, which was less damaged, in the north-south direction in CASE 3 and in the east-west direction in CASE 4.

The Fourier spectral ratios are shown in Fig. 13 for each measurement case. In both the north-south and east-west directions, peaks are observed around 4.9 Hz for the east stone structure with large damage and around 5.9 Hz for the west stone structure with small damage, respectively. The peak frequency was higher for the less damaged stone structure on the west side, and the fact that no significant damage was observed at the columns suggests that the loss of the integrity of the building due to the loss of the dome section may have had an effect. From the above, the stability of a stone structure with a domed rooftop is greatly affected by damage to the dome section.

(a) East side(Major damage)

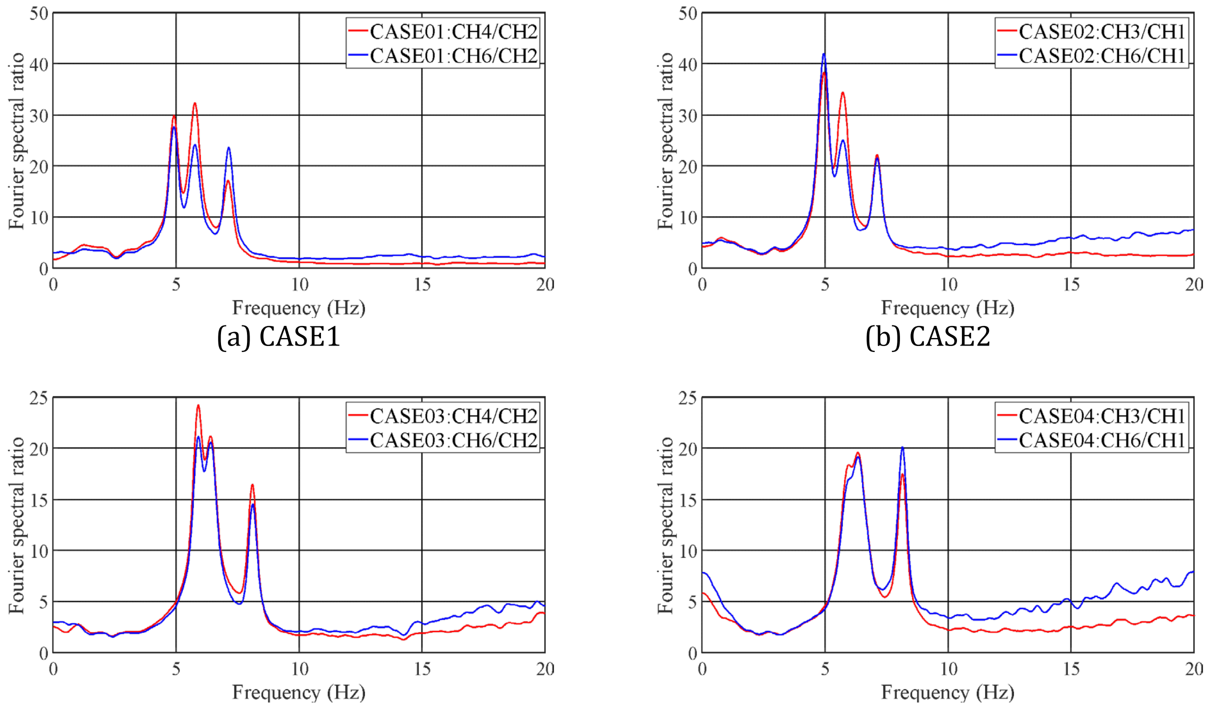
(b) West side (slightly damaged)

Fig.11 Target structure(Quba Mir Shahdad Talpur)

(a) CASE1, 2

(b) CASE3, 4

Fig.12 Measuring position(Quba Mir Shahdad Talpur)



(a) CASE1 (b) CASE2

(c) CASE3 (d) CASE4

Fig.13 Measurement results(Quba Mir Shahdad Talpur)

Measurement Results (Ranikot)

The subject structure is a part of the castle wall shown in Fig. 14, with a similar structural form, the east stone wall having been plastered by later restoration, and the west stone wall in its original condition. The locations of the velocity meters are shown in Fig. 15: Ch1 was placed on the ground surface, Ch2 on the east stone wall after restoration, and Ch3 and Ch4 on the original west stone wall, and the north-south direction was measured.

The Fourier spectral ratios are shown in Fig. 16. A common peak is seen around 14 Hz for the east stone wall after restoration and around 11 Hz for the original stone wall. Although the peak frequency is higher for the restored stone wall, it appears to vibrate separately from the original stone wall, possibly due to the loss of unity as a castle wall. The above indicates that it is important to unify the restoration methods used for the continuous stone walls such as castle walls, because they lose their integrity if different restoration methods are used at different locations.

Fig.14 Target structure (Ranikot)

Fig.15 Measuring position (Ranikot)

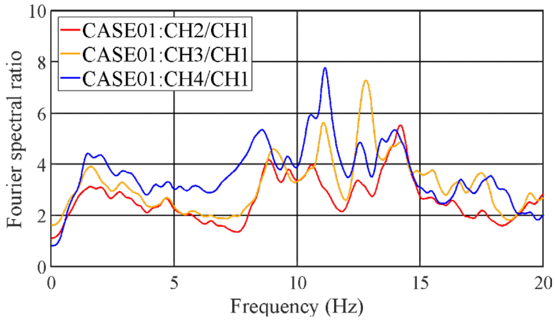


Fig.16 Measurement results(Ranikot)

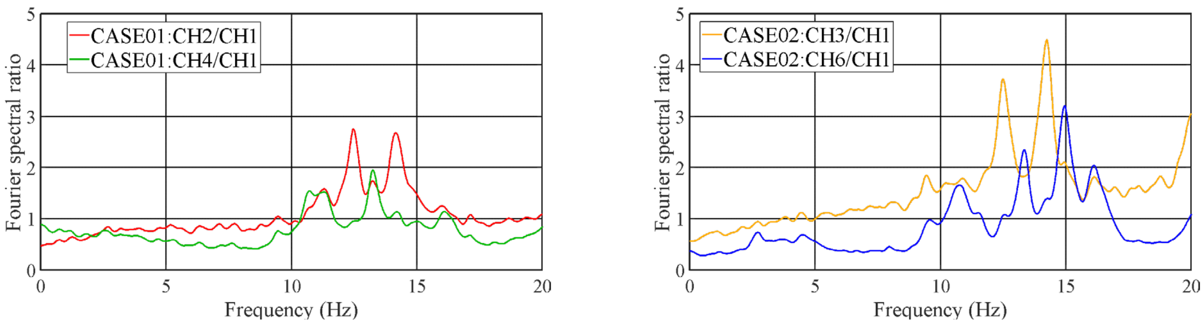
Measurement Results (Makli)

The target structure is the stone structure of Makli shown in Fig. 17, with the dome portion missing and some walls collapsed. The locations of the velocity meters in each case are shown in Fig. 18: Ch 1 was placed on the ground surface, and Ch 2, 3, 4, and 6 were placed at the diagonal positions of the rooftop corners, and the north-south direction was measured in CASE 1 and the east-west direction in CASE 2, respectively.

The Fourier spectral ratios are shown in Fig.19 for each measurement case, with peaks around 12 Hz for Ch 2 and Ch 3, and around 11 Hz for Ch 4 and Ch 6, indicating that the peak frequencies differ between the structures in both the east-west and north-south directions. This is thought to be due to the loss of the integrity of the building due to the loss of the dome section. From the above, the stability of a masonry structure with a domed rooftop is greatly affected by damage to the dome section.


Fig.17 Target structure (Makli)


Fig.18 Measuring position(Makli)



(a) CASE1 (b) CASE2

Fig.19 Measurement results(Makli)

10.Training staff in Scientific documentation/ Damage assessment

On-site lectures were given to the staff of the local conservation office of the Sindh province on the method of heritage documentation and assessment, such as photogrammetry techniques using drones and smart phones, the use of constant micro-motion measurements for historical buildings, and points of focus in diagnosing material deterioration. Due to the insufficient information on the detailed objectives and needs of the audience, training for the local communities in First Aid for natural disaster responses was not conveyed.

Methods

Based on a request from the Culture, Tourism, Antiquities & Archives Department, Government of Sindh, a survey was conducted from three perspectives: documentation and assessment of damaged cultural heritage sites in Sindh, assistance in disaster risk management planning, and training of local personnel.

11. Result of Site Documentation and Damage Assessment

【Moenjodaro】

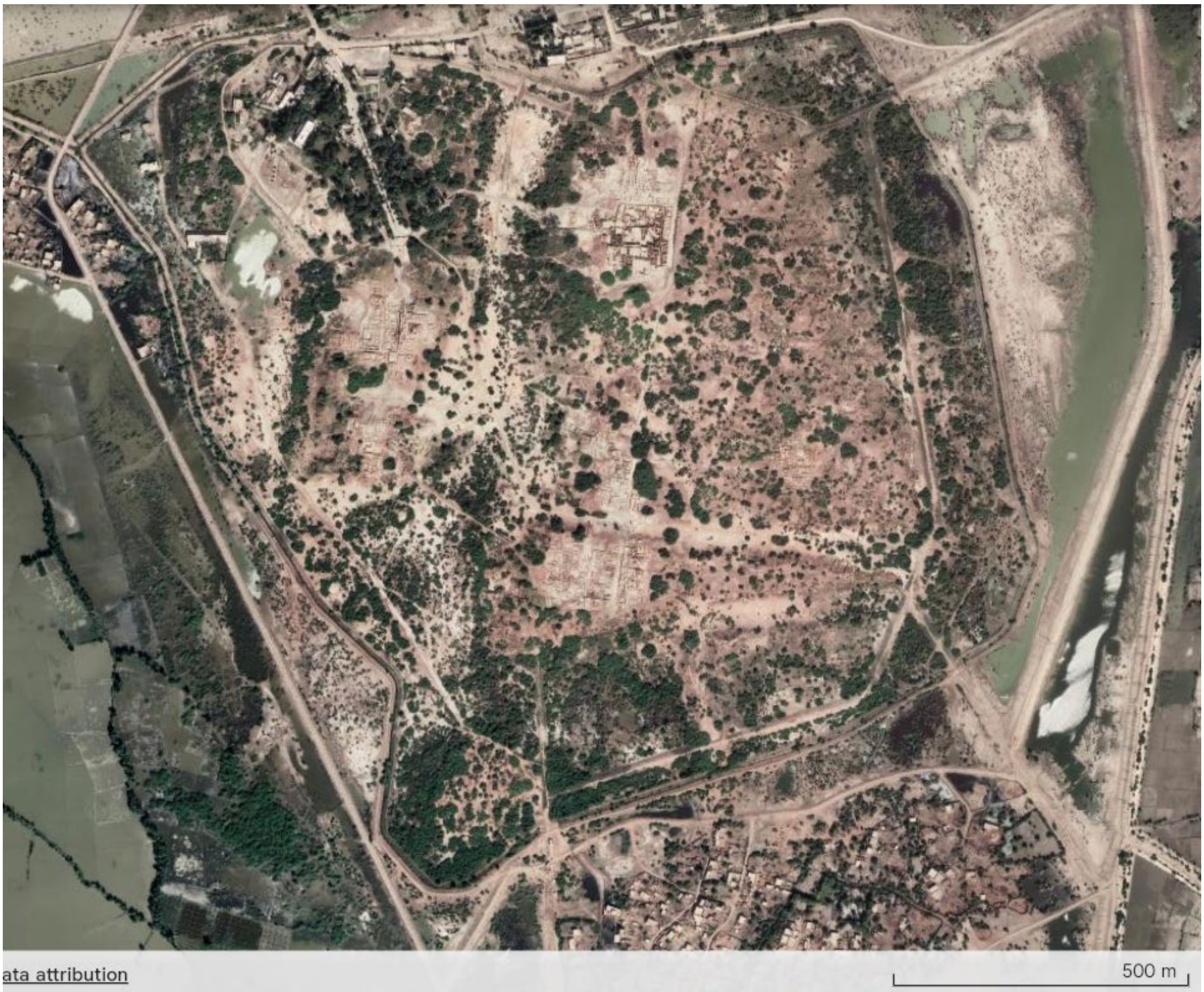


Fig. 1 Layout of Moenjodaro and location of selected structures

Basic information from the survey

Name of the site	Moenjodaro
Address of the site	84FP+P78, Moenjodaro, Larkana, Sindh, Pakistan/ 27.324188404045, 68.13565681030738
Date of assessment	24/12/2023
Site access	Two routes
Inspected location(s) (Geo-coordinates)	SD(Citadel) Area 1 Stupa 27.3253425098571 68.1333935347123 2 Great Bath 27.3253032886213 68.1326219407432
	HR Area 1 27.3216687831884 68.1364497985514 2 27.3221231051681 68.1370902050629
	Surrounding Area (including Indus River Bed) 27.3176126310433 68.1481348120951
	Burned bricks/ Mud bricks/ Mud mortar

Overall degree of damage to the building	moderate structural damage, heavy non-structural damage heavy material decay
Past activities for assessment/ conservation.	1. Threatened for many years by salt weathering caused by groundwater, an international campaign by UNESCO in the 1970s conducted the restoration of mud bricks 2. UNESCO's mission for damage assessment was conducted in October 2022. Restoration work has been underway since early 2023. 3. The restoration of the SD area was conducted by renewing the wall cap with mud mortar with straws, replacing decayed bricks with new burnt bricks or mud bricks 4. The new drainage channels and pipes were installed

1.Overall condition of the site

- Water/flood management system (risk evaluation of water-related disaster…)

Moenjodaro is located near the right bank of the lower Indus river in Larkana District, Sindh, Pakistan. It was built on relatively elevated land or a small mount compared to the surrounding areas to keep the site safe from flooding. The archaeological remains have a sophisticated drainage/sewage system to move the water away from the main buildings. The site is encompassed by a circular drain, new drains are built from time to time and existing drains are cleaned regularly. Barriers of brick and soil are also constructed within the built-up area as well as the edge of the ancient site to divert water away from the structures. The site is protected from Indus river flooding by rock spurs as well as massive inner and outer embankments/bunds, which were made of mud and reinforced with stone pitching, which protects the embankment from erosion and slumping.

2.Causes of Damage

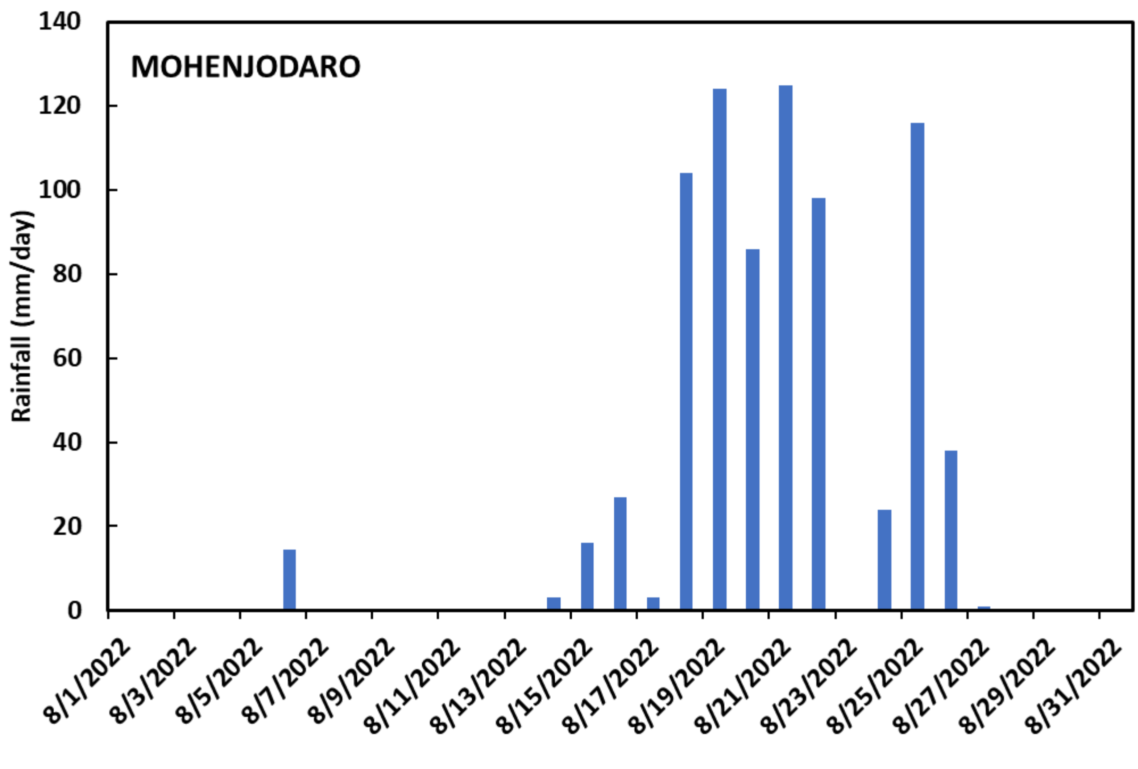


Fig. 2 Rainfall intensity during August 2022 (Source: Pakistan Meteorological Agency)

Between August 16 and 26, 2022, Moenjodaro World Heritage Site received unprecedented extreme rainfall (~ 760 mm). It is reported that though the Indus river was discharging record breaking river flows, the riverine water did not directly hit Moenjodaro, as the site located on a relatively high mount and protected by massive embankments/bunds. On the other hand, the record-breaking high intensity rainfall which exceeded 100 mm/day for 5 or more consecutive days has inflicted severe damage on the ruins (Fig. 2) due to rainfall droplet impact force, loss of mud and bricks, and accumulation of water within the structures and chambers.

The specific damages were;

1. Collapse/damage to the protection wall of the stupa dome
2. Collapse of walls, and creation of cavities and holes in structures due to loss of mud and bricks
3. Erosion of slopes and mud slurry that weakened foundations of structures and walls
4. Choked drainage system: the extreme rainfall caused the drainage system to be choked with high volume of water, sand, silt, and other materials causing an accumulation of water into the site up to one to two feet in height inflicting further damage to the remains.

3.Conditions before/after the flood

The three main causes of the long-term decay at Moenjodaro have been identified as:

a) Superficial drainage

b) pre-existing weaknesses in the wall structures

c) Salt crystallization and hydration/dampness inside mortar and bricks.

In order to deal with the long-term problems, the following conservation measures have been adopted by the Government of Sindh such as application of mud slurry and mud capping, re-pointing and under-pinning of structures, construction of embankments and spurs to protect against riverine flood, and maintaining ancient and newly constructed drains and build new drains. Barriers of brick and soil are also constructed within the built-up area as well as the edge of the ancient site to divert water away from the structures.

It was reported that some of the pathways constructed for visitors have been reported to obstruct the flow of water during the Aug. 2022 event, while some pathways have slopes leaning towards the archaeological ruins which lead to weakening the base of the walls due to water flow. During the event, the absorption capacity of the wall capping or protective covering over the walls to minimize rainwater flow into the walls) and flooring was saturated, and water seeped through. In some rooms, gaps in the backfilling under the flooring resulted in formation of depressions (Joffroy, 2023).

At the time of our visit to the site, almost all of the collapsed debris and bricks were cleared out and restoration and preservation works are progressing.

Fig. 3 Left image depicts the status of the ruins and conservation of wall basements using mud and straw and right image depicts the collapse of the structure and wall which need to be restored later with proper care.

Fig. 4 These photographs were taken at the S.D. and HR area, which depicts the new and old paved/concrete pathway for deep and shallow drainage systems to ease the water flow away from the main structures.

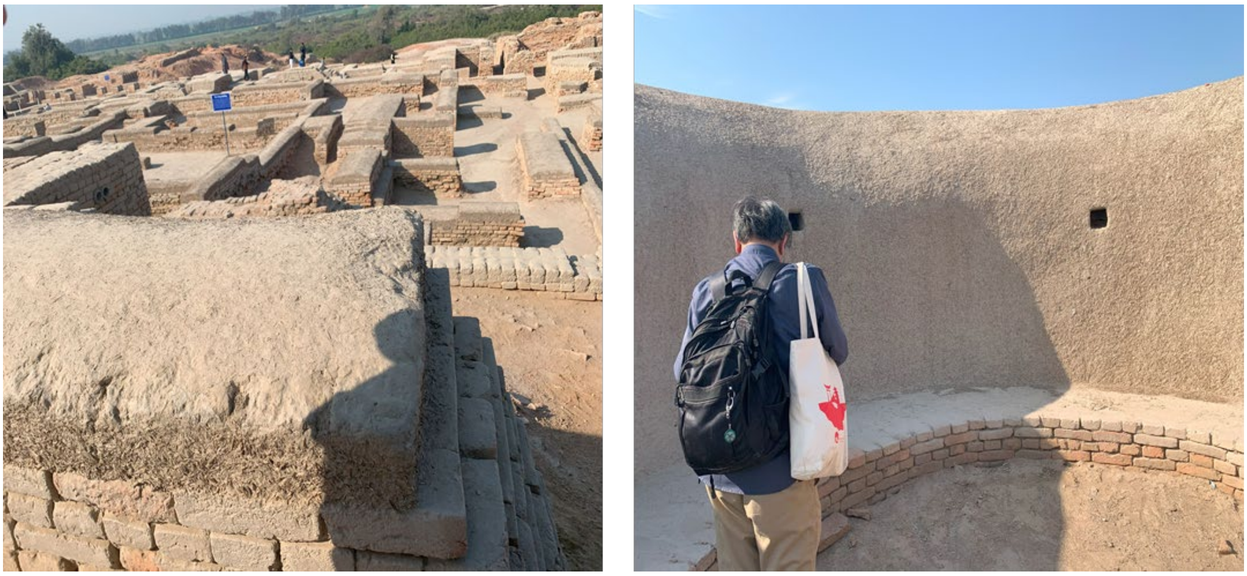


Fig.5 Mud slurry and mud capping works to protect the ruins (i.e. wall and stupa dome) from extreme climatic/weather conditions.

4.Necessary measures

The Government of Sindh (GoS, 2023) undertook the following steps to prevent future rainfall damage:

1. Removal of debris and mud slush from drains
2. Renewal of mud capping, resetting of loose bricks and filling of voids in walls
3. Buttressing of leaning walls using steel frame shoring and building of shallow drains
4. Filling in of gullies that had developed after the heavy rains

The UNESCO mission (Joffroy, 2023) made the following suggestions for improved preparedness:

1. Revision of flooring method by making changes to the slope and layers of the floors
2. Improvement of drainage design by including increased number of channels and larger collection areas for water
3. Ensuring water run-off exit and putting ancient drainage channels into service
4. Preparation of colour-coded plans identifying drainage and vulnerable areas for launching future conservation work
5. An overall site drainage plan to be prepared which would identify transportation of water to the Indus River on the east and Dadu Canal on the west
6. Improved methods for dealing with salinity damage to the ruins
7. Some contents in the Conservation Manual of 1997 and Master Plan need to be revised in order to cater to climate change induced higher intensity rainfall
8. Increased number of personnel for rehabilitation work (Joffroy, 2023)

Further measures to be taken into account.

<u>Site specific measures</u>

- Testing the strength of mud capping to the intensive rainfall observed in 2010 and 2022
- Flood/flow simulation/estimation to quantify the flow rate and drainage capacity during peak rainfall period

- Provide additional drainage pathways to drain the water from the site into the outer ring drainage channel

<u>General measures (for all the sites)</u>

- installing and monitoring rainfall and river monitoring network and setting up threshold and alert levels incorporation with relevant agencies
- As global warming will intensify the extreme rainfall and its frequency in the future climate, further research is needed to quantify the Impact of Climate Change (i.e. rainfall and temperature) and associated damages to the ruins.
- Providing capacity building and training workshops for experts and local people on flood disaster mitigation and adaptation methods.
- Forming a national platform on water- related disaster resilience and mitigation incorporating state agencies and stakeholders to ease the pathways for information sharing and dialogues on mitigation and adaptation measures of heritage buildings.

[GoS] Government of Sindh. 2023. State of conservation report: archaeological ruins of Mohen Jo Daro, Larkana, Sindh, Pakistan. Culture, Tourism, Antiquities & Archaeology Department, Government of Sindh. Retrieved December 26, 2023 from https://whc.unesco.org/document/198758

Joffroy, T. 2023. Moenjodaro UNESCO emergency mission following disastrous rainfall in 2022. Retrieved December 26, 2023 from https://hal.science/hal-04111785/document#:~:text=21%20-%2029%20October%202022&text=The%20intensity%20of%20heavy%20rainfall,and%20structures%20at%20Moenjodaro%20Site

5.Remarks on the primary source of damage

Moenjodaro is located 1 km west of the Indus River, and although the 2022 flood inundated the low-lying area where the office is located, the entire sites were spared from flooding. The damage caused by the 2022 flood in Moenjodaro consisted of collapsed and washed away remains due to prolonged rainfall.

a Structural Damage

The site had previously maintained drainage channels and other facilities to prepare for rainfall (Fig. 1), but these failed to function adequately in the 2022 flood. One of the reasons for this was that the drainage system was not adequately maintained and managed due to the vastness of the ruins. However, when looking at the entire site, drainage channels are not necessarily the only pathways for torrents of runoff caused by rainfall (Fig. 2), in the HR area, there are dwelling remains with structures that easily accumulate water and have difficulty in drainage,and these remains were also severely damaged.

b Material decay

One of the problems in the preservation of Moenjodaro has been the destruction of the remains due to salt precipitation. The method used to mitigate this so-called salt weathering the surface of the remains. The problem in the recent flooding was that extremely heavy rainfall caused a large amount of water to flow through the cracks between the geotextile and the mud curing inside the capping structure, resulting in soil washout that caused the collapse (Fig. 3). A similar problem occurred in Japan when a rammed earth wall collapsed at Kinojo site in Soja City, Okayama Prefecture, and there is a common issue regarding the method of curing and preserving the remains.

c Water / flood management system

At Moenjodaro, two issues have been identified for the 2022 flood. One is to improve the drainage plan for the entire site, and the other is to improve the so-called capping that is curing the remains.

d Further measures to be taken into account

Since it is fully expected that climate change will cause more rainfall than expected in a short period of time in the future, it is necessary to reconsider the drainage plan for the entire site. In formulating a drainage plan, it is necessary to fully understand the topography of the ruins, confirm the risks by simulation analysis of rainfall and runoff pathways, and study methods to solve the risks. As for the drainage system, it is assumed that it may be necessary to intervene in the remains themselves, so the method of construction must be thoroughly examined. However, it is also necessary to take emergency measures in the short term to cope with the heavy rains that are expected to occur frequently in the future.

The issues include curing the original remains to protect them and giving them a structure that can withstand the intensity of precipitation. In addition, these capping should not be permanent, but should be replaced on a regular basis. Furthermore, it is necessary to continue research on new materials and methods of capping in order to realize a longer service life and more stable preservation of the remains.

The issues identified by the 2022 flood in Moenjodaro have been discussed above, but one of the underlying factors that is increasing the damage caused by this flood is the problem of salt weathering. Even today, the measures taken against salt weathering at Moenjodaro are not sufficient (Fig. 4). It can be said that the collapse of the remains is greatly accelerated by the action of strong rainfall on the remains, which are routinely weakened by salt weathering. A laboratory has been set up at Moenjodaro to continue testing materials for capping (Fig. 5). The problem of salt weathering at Moenjodaro, a vast ruin, is an issue that has attracted worldwide attention. Salt weathering at Moenjodaro, which appears to be uniform at first glance, actually varies from place to place due to various factors such as sunlight, groundwater level, temperature, humidity, and topography (Fig. 6 and 7).

To solve a single problem, it is necessary to investigate the cause of the problem, consider countermeasures, construct conservation measures, verify the implemented conservation measures, and, of course, continue monitoring. It is highly expected that further enhancement of the current on-site laboratory at Moenjodaro and training of human resources will help to overcome salt weathering at Moenjodaro and, in turn, increase the resilience of the site itself against water damage.

Fig.1 Drainage channel maintained in Moenjodaro HR area, which was blocked by garbage and other debris at the time of the 2022 flood.

Fig.2 Moenjodaro HR area. There are complex undulations and the remains of dwellings with difficult drainage exist.

Fig.3 Curing of the upper part of Stupa in the Citadel area. The front from the area where the finger is pointing is where the collapsed area was repaired.

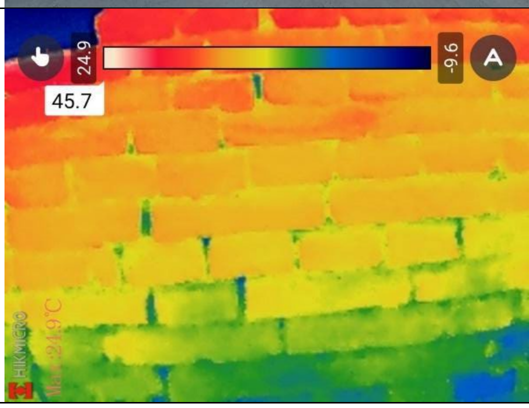
Fig.4 Brick wall with progressive salt weathering. Salt weathering is in progress throughout the entire site, and research on countermeasures is needed.

Fig.5 Water and soil research laboratory. Soil is analyzed to make bricks for restoration.

Fig.6 Burned bricks for restoration. Replacing bricks in areas that have collapsed due to salt weathering with bricks for restoration.

Fig.7 Salt weathering on the north face of the wall. Salt precipitation is observed below the fifth level from the bottom.

Fig.8 Thermal image of Fig. 7. The areas where salts are deposited tend to have lower temperatures. It is unclear if this is due to the latent heat of evaporation of water. Measurement of water content ratio is necessary.



3D images made by photogrammetry

Fig. 9 MJD-HR	
Fig. 10 MJD- HR_oblique	

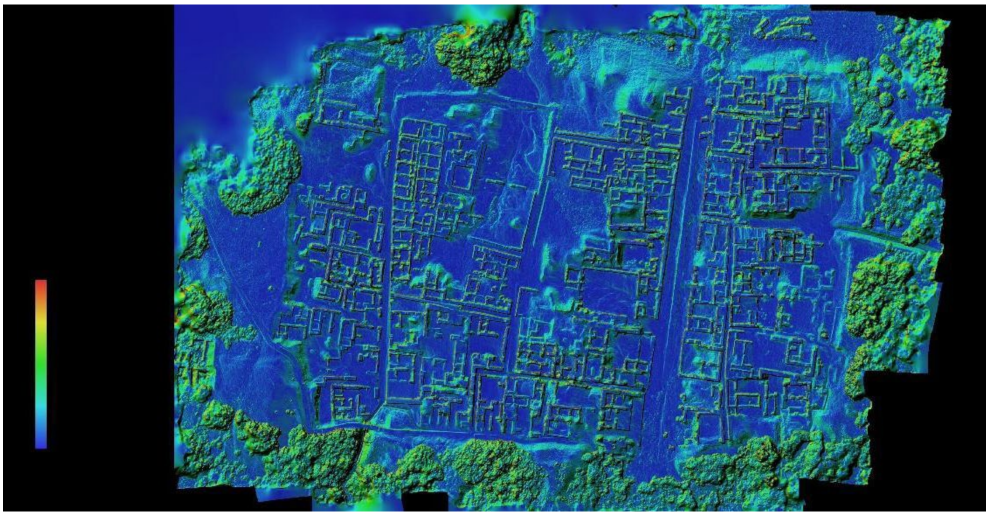
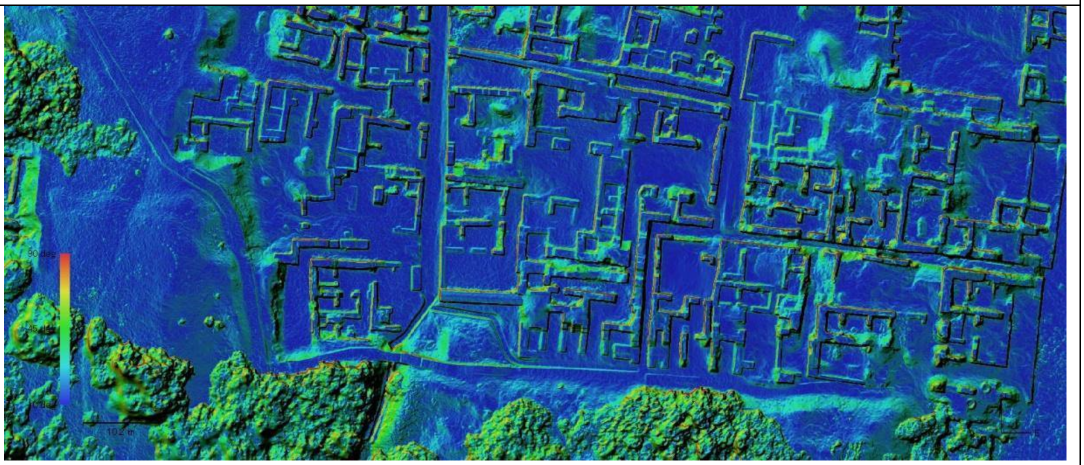
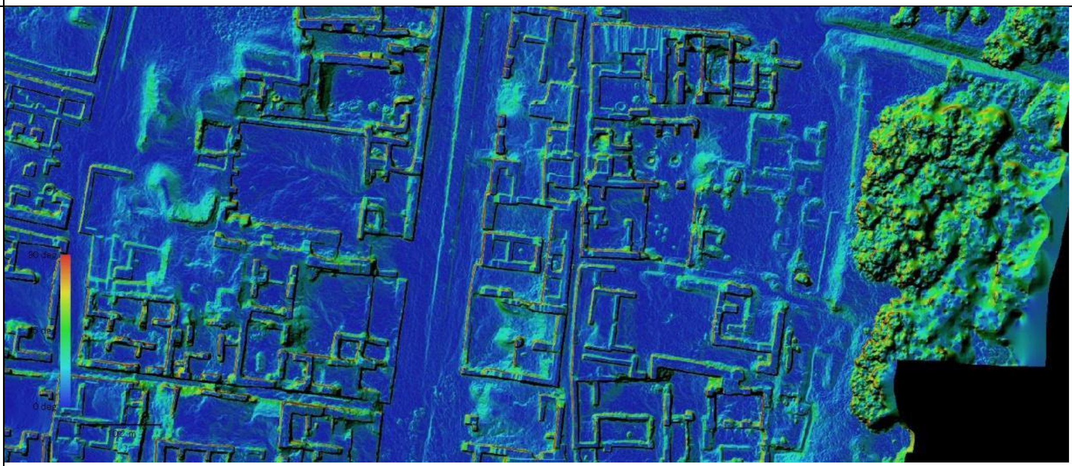
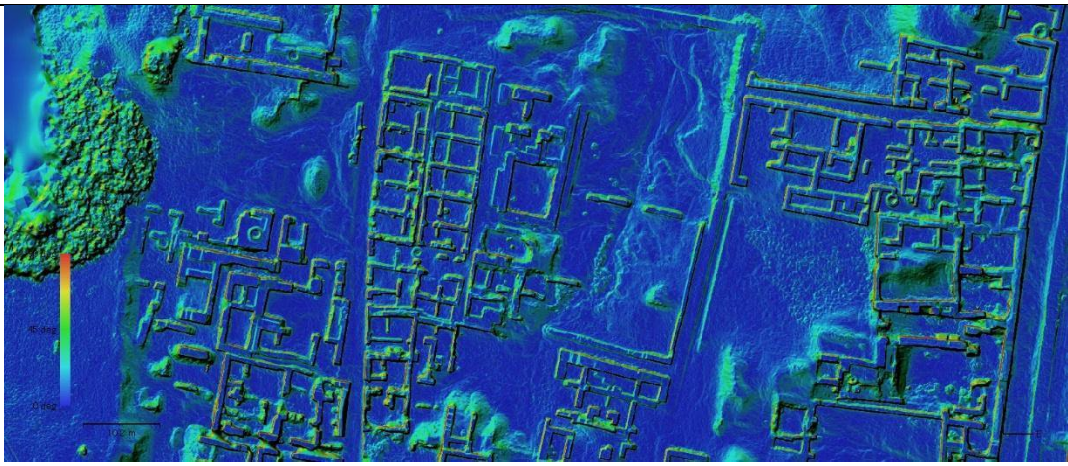
Fig.11 MJD-HR_hillslope	
Fig. 12 MJD-HR_hillslope02	
Fig. 13 MJD-HR_hillslope03	

Fig. 14 MJD-HR_hillslope04	

【Kot Diji Fort】

Name of the site	Kot Diji Fort
Address of the site	Taluka, Kot Diji, Khairpur, Sindh 66020, Pakistan
Date of assessment	25/12/2023
Site access	Two routes
Inspected location(s) (Geo-coordinates)	North west wall at the top level (27.3466856157518 68.7081267123357)
	Fresco ceiling inside the Mosque at the top level (27.3453616646178 68.7068196748037)
	Gate Arch at the top level (27.3445242021560 68.7061675623204)
	Retaining wall at the entrance level (27.3436904905693 68.7068220967830)
Building materials	Lime stones, Burned Bricks
Overall degree of damage to the building	moderate structural damage, heavy non-structural damage heavy material decay

1.Overall condition of the site

- Water/flood management system (risk evaluation of water-related disaster…)

Historic fort of Kot Diji Fort located about 45 km south of Khairpur and situated on the east bank of the Indus at the foot of the Rohri Hills opposite Moenjodaro. The fort overlooks the city, which is situated at a lower elevation than the fort. As the city is situated at lower elevated ground, the city was surrounded by stagnant water up to six feet or more for nearly two to three months during the August 2022 flood. A temporary embankment between northern and southern ends of the city was raised to divert water flows from the eastern side to take the old path on gravity instead of heading towards the city's western part. Water was moving along this dyke towards disposal point and ending up in Khairpur Feeder East eventually. In addition, a pumping machine was installed outside taluka hospital, around one kilometre away from the city area, which was draining out water from the western side of Kot Diji Fort(https://www.dawn.com/news/1713187 accessed on 15 Jan. 2023).

2.Causes of Damage

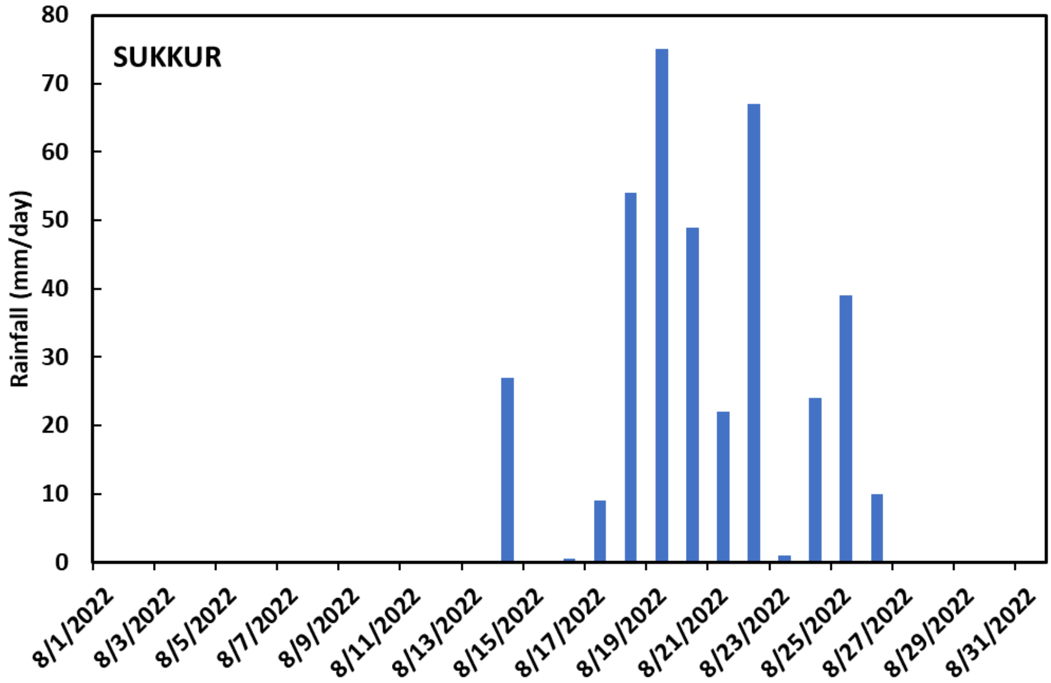


Fig. 1 Rainfall intensity during August 2022 (Source: Pakistan Meteorological Agency)

As there was no rainfall monitoring station near Kot Diji Fort, the data from Sukker station was used to understand the rainfall condition at the site. Between August 16 and 26, 2022, the Sukker Site received extreme rainfall of about 350 mm. It is also reported that though the city was inundated up to six feet or more water for nearly two to three months during August 2022 flood, the fort was not affected by the flood and the inundation water reached the foothill of the fort and the water height was about one to two feet at the entrance of the fort. Similar to Moendojaro, the record-breaking high intensity rainfall which exceeded 40 mm/day for consecutive days inflicted severe damage on the ruins (Fig. 1).

The specific damages were;

1. Collapse/damage to the inner boundary wall
2. Collapse of walls as well as pathways/decks, and creation of cavities and holes in structures due to saturation and loss of mud/mortar and bricks
3. Erosion of slopes and mud/mortar that weakened structures and walls

3.Conditions before/after the flood

The main causes long-term decay at Kot Diji Fort are

1. pre-existing weaknesses in the wall and structures due to aging and previous climatic conditions
2. Poor surface drainage and strong rain drop impact force and rainwater splash has resulted in hollowing out of masonry, loss of bonding mortar, and weakening the base of the walls due to water flow along the pathways.
3. Hydration/dampness in walls.

Fig. 2 Left image depicts the entrance to fort and right image depicts the status of the boundary wall near of the entrance

Fig. 3 Left image depicts the previous condition of the boundary wall (source: Bilawal) right image is after the collapse of the wall entrance to fort and right image depicts the status of the boundary wall near of the entrance

Fig. 4 Status of the walls and structures after the damage

Fig. 5 On-going restoration works of pathways/decks and walls

Fig. 6 Left image shows the water level near the fort entrance and right depicts the water level in the city area during Aug. 2022 flooding pointed out by a fort stuff previous

Fig. 7 The existing conditions of the drainage system

4.Necessary measures

Site specific measures

- Removal of debris and mud slush from existing drains and building of additional drains
- Resetting of loose bricks and filling of voids in walls
- Buttressing of tall vertical inner and boundary walls
- Filling in of gullies that had developed in walls and domes after the heavy rains
- Maintaining slope for water flow along the pathways and at the top floor or build additional shallow water drainage
- Improved methods for dealing with hydration/dampness damage to the inner and outer walls
- Investigate the drainage system and draining routes to design proper flood mitigation structures to protect the city from future flooding.

5. Remarks on the primary source of damage

During the flood of 2022, the water level at Kot Diji Fort only rose to the third step of the stairs at the main entrance, and the entire site was not inundated. The damage to Kot Diji Fort was caused by a torrent of water generated by extremely strong precipitation over a long period of time, which destroyed the castle walls and other structures. Based on our observation of the current situation at Kot Diji Fort, we believe that there are three issues that need to be addressed. The first is to review the drainage plan for the entire site, the second is to review the restoration method, and the last is to examine the maintenance method to increase the resilience of the site against disasters.

a Structural damage

Kot Diji Fort has many crenellations on its walls, and it is thought that these parts served as a drainage function to some extent at the time of the 2022 flood, however on the slope leading to the middle gate, the water that eventually flowed out of the crenelation collected on the slope, resulting in a large volume of water flowing down the slope as a torrent, As a result, a large amount of water flowed down the slope as a torrent, destroying the castle walls (Figure 1). However, since this crenellation was not originally built as a drainage facility, it was not plastered or otherwise waterproofed, and when flooded, the mud used to join the bricks flowed out, damaging the crenellation itself (Fig. 2).

The part of the wall that collapsed due to the flood in 2022 was not the original part of the wall when it was first built but was mostly a part of the restoration work that was done in 1955. Cracks had already appeared in the restored wall before the flood, and the lower part of the wall collapsed first, starting from these cracks, and then the upper part collapsed. The newly restored part was not built with bricks as in the original, but with limestone gravel the size of a human head, hardened with mud and soil to form the wall, and limestone blocks piled up on the surface (Fig. 3). The wall that collapsed may not have escaped collapse even if the original brickwork had been used, since it was also part of a steep slope. However, if the original brickwork with mud joints and the limestone blockwork with mortar joints coexisted, the imbalance between structure and materials would have created an imbalance in strength, resulting in a risk of failure. The fact that the lower side collapsed before the cracked area suggests that water intrusion into the cracks may have washed out the internal mud and soil. Although the restoration of Kot Diji Fort, including previous restorations, has been carried out in a manner completely different from the original materials and structure (Fig. 4), close examination of the original materials and structure should be considered, and as much as possible the same methods should be used to restore the castle.

b Material decay

The roofs of some of the rooms at the top of Kot Diji Fort have collapsed (Fig. 5). In many cases, it is assumed that the plaster layer that had a waterproof function in the roof area was broken or lost (Fig. 6), allowing water to penetrate inside and lead to the collapse. First of all, measures against rainfall should be considered, such as reinstalling plaster that originally had a waterproof function. Rainwater infiltration into the interior of the building can be adequately maintained by daily inspections and minor repairs as necessary.

c Water/flood management system

The provision of resilience to disasters is also highly relevant to a review of drainage planning and restoration methods for the entire site. At the time of its construction, Kot Diji Fort was built using materials and construction methods appropriate to the climate of the time, with no expectation of frequent heavy rains. If we are to anticipate the heavy rainfall disasters that are likely to occur more frequently in the future, we must consider the development of a more resilient structure against disasters. Naturally, it may become necessary to intervene in the original remains or to apply new restoration methods. Authenticity and modification to improve resilience against disasters must be thoroughly discussed. Based on this, when altering the original structure, record keeping through excavation or other means must be done.

d Further measures to be taken into account

Since it is easily predicted that heavy rains due to climate change will occur frequently in the future, it is necessary to formulate a drainage plan for the entire site by analyzing simulations of water movement throughout the site during rainfall and examining methods to disperse drainage and countermeasures for areas where water flow is concentrated.

Fig.1 The collapsed part of the wall of Kot Diji Fort due to flood damage in 2022.	
Fig.2 A crenellation. The water runoff from this area served the function of drainage to some extent, but at the same time it was damaged.	
Fig.3 Structure of the wall after the restoration in 1955. The wall is made of limestone gravel and mud the size of a human head, with limestone blocks piled up on the surface.	
Fig.4 Restoration that is proceeding by a method that differs from the original materials and construction.	

Fig.5 A Bathhouse with collapsed roof.	
Fig.6 The plaster layer in the roof area at the back of the figure is fragmented and has lost its waterproofing function.	

3D image made by photogrammetry

Fig. 7 KDJ- entrance_close	

【Mian Noor Muhammad Kalhoro Graveyard】

Photos of inspected area

Name of the site	Mian Noor Muhammad Kalhoro Graveyard (MNMK)
Address of the site	H327+2P9, Abdul Rahman Dahri, Shaheed Benazirabad, Sindh, Pakistan
Date of assessment	26/12/2023
Site manager/ custodian (e.g, local NGOs)	
Site access	Two routes
Inspected location(s) (Geo-coordinates)	MNMK tomb (26.5500087088081 68.0643157586334)
	Subsidiary tombs 1 (26.5501097977555 68.0645799446524)
	Subsidiary tombs 2 (26.5498960260789 68.0646728784512)
	Surrounding wall (26.5501614355593 68.0643290444591)
	Graveyard (26.5499946804551 68.0639374419518)
	Surrounding area (26.5500087088081 68.0643157586334)
Building materials	Burned bricks, Sand stones
Overall degree of damage to the building	moderate structural damage, heavy non-structural damage heavy material decay

1.Overall condition of the site

- Water/flood management system (risk evaluation of water-related disaster…)

Mian Noor Muhammad Kalhoro Graveyard in Moro has lost several graves during the August 2022 flood. The site is surrounded by irrigated land, agricultural fields, and a small water pond.

2.Causes of Damage

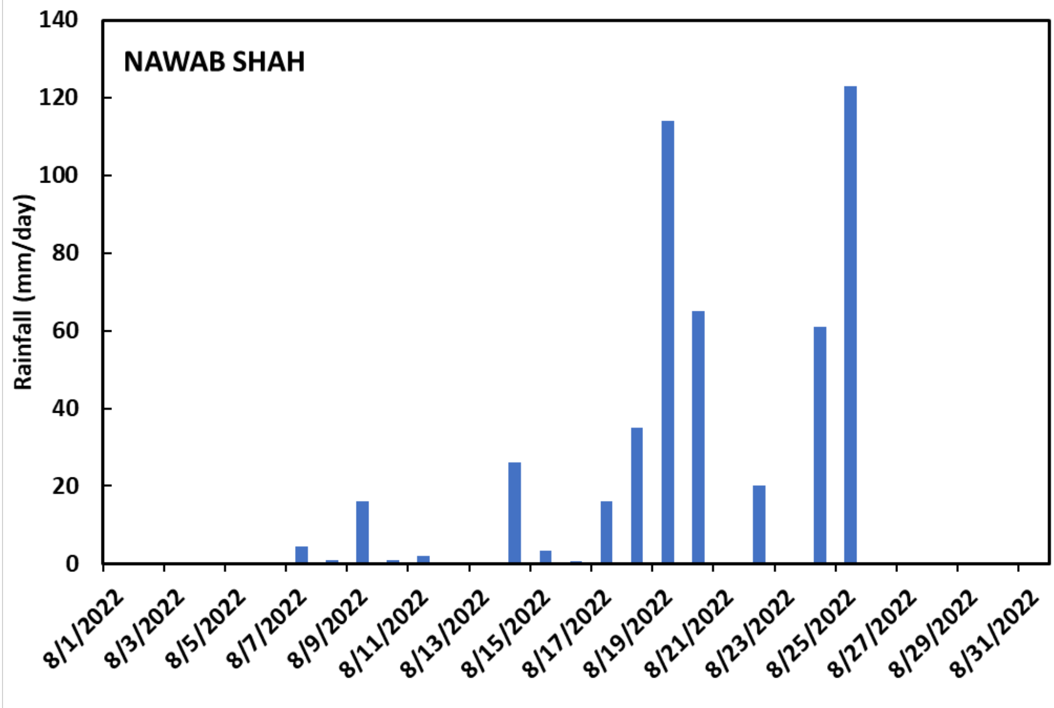


Fig. 1 Rainfall intensity during August 2022 (Source: Pakistan Meteorological Agency)

The rainfall data from Nawabshah station was used to understand the rainfall condition at the site. Between August 16 and 25, 2022, the Nawabsha Site recorded extreme rainfall of about 460 mm. Similar to other places, the record-breaking continuous high intensity rainfall which exceeded 100 mm/day for some days might have inflicted severe damage on the fort structures (Fig. 1). The graveyard is located about ~ 10 km away from the main Indus river and therefore probably not affected by Indus river water, directly. It is also reported that the graveyard except the main compound (protected by a perimeter wall) was inundated about two feet for nearly two to three months during the August 2022 flood. Similar to other sites, the record-breaking high intensity rainfall for consecutive days might have inflicted severe damage on the Quba/tombs and other masonry graves.

The specific damages were;

1. Damage to the main gate and domes
2. Collapse of masonry grave structures
3. Creation of cavities and holes in structures due to saturation and loss of lime mortar and bricks

3.Conditions before/after the flood

The main causes long-term decay at the sites are

1. Pre-existing weaknesses in the gate, dome, and wall due to aging
2. Heavy Rainwater splash and other climatic conditions has resulted in hollowing out of masonry, loss of bonding mortar, and weakening the walls due.
3. Hydration/dampness in walls due to surrounding climatic conditions that is continuously weakening the walls and structures.

Fig. 2 Status of the walls and structures after the damage

Fig. 3 Cracking on the main dome and damages to the surrounding graves

Fig. 4 Damage status of the domed structures/tombs

4.Necessary measures

Site specific measures

- Resetting of loose bricks and filling of voids in walls
- Rehabilitation/conservation of the dome structures
- Filling in of gullies that had developed in walls and domes after the heavy rains
- As there is no drainage facility in the site, investigate the draining routes to make a new drainage system to drain out the water from the graveyard.
- Improved methods for dealing with hydration/dampness damage

5.Remarks on the primary source of damage

Mian Noor Muhammad Kalhoro Graveyard has a gate on the east side and is surrounded by plastered brick walls on all four sides, with the mausoleum, six attached buildings, and a brick tomb. The mausoleum is built on a platform with brick foundation decorated by limestone blocks (Fig. 1). Outside the area of the mausoleum are many Islamic tombs built of brickwork, as well as many tombs without headstones, some of which are relatively new with plastered surfaces (Fig. 2).

Currently, of the four perimeter walls, part of the western side has collapsed due to external forces moving inward from the outside, and the southern wall is almost completely collapsed. A portion of the north wall is open, but Google Maps images of the area after the flood damage show that this portion of the wall has not collapsed (Fig. 3), suggesting that it probably did not collapse due to flood damage, but was partially demolished for the convenience of restoration work and other purposes. The area of the mausoleum is approximately less than 1 m higher than the surrounding area, and the area was not inundated during the 2022 flood. The flooding of the surrounding area continued for five months, suggesting that the walls, buildings, and tombs contained a significant amount of water. In addition, the field to the east is still submerged, and the soil is considered to be in a very high-water content state (Fig. 4).

a Structural damage

The wall construction consists of brickwork to create the wall body, which is coated with mud and then plastered with a plaster finish (Fig. 5). In some parts, plaster mortar is placed directly on the brickwork, and the final plaster finish is applied (Fig. 6). In addition, some parts of the gate still have wall paintings as decoration, and it was observed that in past restoration, new wall paintings were painted on top of the original paintings that were plastered on top of the original paintings. The areas where plaster mortar was applied directly to the brickwork remain in the upper part of the remaining walls, but most of the areas where mud was applied have been lost.

The roof of the building within the area of the mausoleum collapsed due to rainfall during the flooding, which may have been caused by a week of intense rainfall, which allowed a large amount of rainwater to percolate into the roof area, resulting in the roof structure being unable to support the weight and collapsing. The collapse of a portion of the western side of the mausoleum platform (Fig. 1) is also thought to have been caused by the same rainwater penetration.

b Material decay

Salt precipitation was partially observed in areas where the brickwork, the main body of the wall, was exposed. One phenomenon observed on the north wall was the collapse of the south face (Fig. 7), while salt precipitation was observed on the north face, which corresponds to the opposite side of the same location (Fig. 8). The ground surface is in a high-water content state and the wall is constantly supplied with water, but on the south face, the surface may be rapidly drying out due to solar radiation during the day and becoming wet again at night, which is repeated. On the other hand, on the opposite side of the same location, water is constantly evaporating on the surface, causing salt to concentrate and crystallize when the temperature and humidity meet the conditions for salt deposition, possibly resulting in salt weathering.The temperature distribution on the north face of a brick tomb in the mausoleum area (Fig. 9) was measured using thermal imaging and a radiation thermometer, showing that the temperature was higher in the upper part of the tomb and also in the lower part where there was sunlight (Fig. 10). The upper part of the tomb is always dry, while the lower part is always wet. In the lower part, the same deterioration phenomenon may have occurred as in the north wall described above. The brick tombs outside of the mausoleum area are also considered to be deteriorating in a similar manner. The reason for the more advanced deterioration outside the mausoleum area than inside the mausoleum area could not be determined enough to be discussed in this survey.

c Water/flood management system

Mian Noor Muhammad Kalhoro Graveyard is located in a vast plain, and in the event of a prolonged period of strong rainfall, such as the 2022 flood, the area could easily be submerged. Since there are also cemeteries spread out around the area, it is necessary to consider not only disaster prevention as a cultural heritage, but also disaster prevention for the entire area. For this purpose, it is necessary to grasp the broad topography of the area and consider the establishment of drainage channels and water catchment ponds.

d Further measures to be taken into account

Basic research on the deterioration of brick walls and structures is also needed to accurately identify the causes of deterioration and to control it. Both groundwater and salinity are undoubtedly extremely important and difficult problems to solve in the preservation of the ruins in the Indus River basin. It is an urgent issue to actively promote organization and human resource development to tackle these problems.

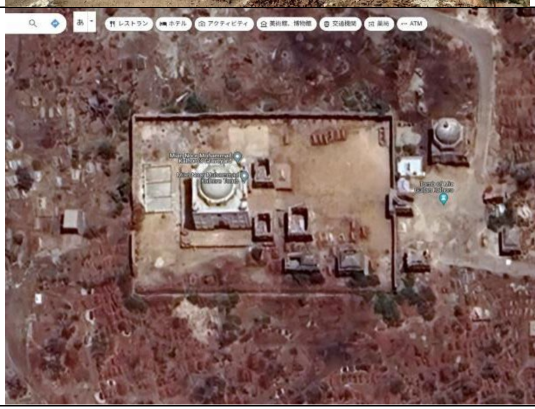
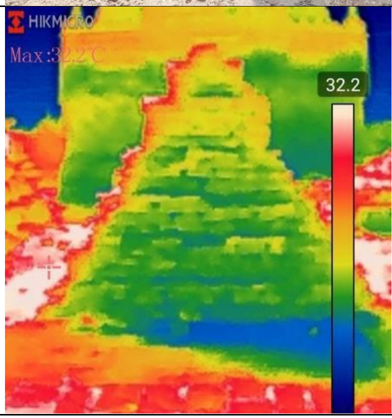
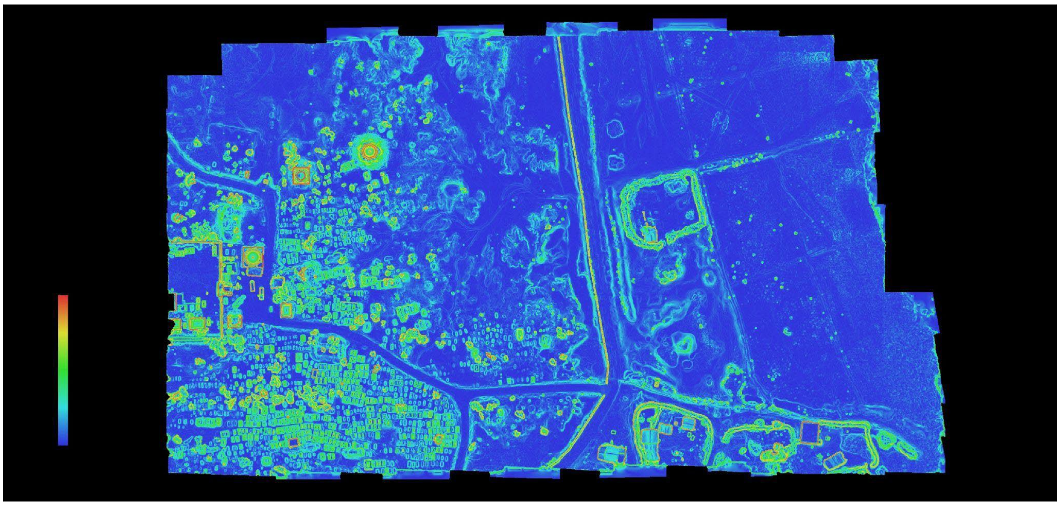
Fig.1 The mausoleum is built on a brick platform decorated with limestone blocks. The platform partially collapsed.	
Fig.2 Islamic tombs spread out outside the area of the mausoleum. In addition to the brick tombs, there are also relatively new tombs painted with plaster.	
Fig.3 Post-flood 2022 conditions according to Google Maps. The north wall is confirmed to be undamaged.	

Fig.4 Originally, the eastern side of Mian Noor Muhammad Kalhoro Graveyard was a field area, but it is still submerged.	
Fig.5 Basic wall structure. The brick wall body is coated with mud and then plastered over.	
Fig.6 Some parts have plaster mortar directly applied to the brick wall body. The new and old with the part with the mud plaster coating is unknown.	
Fig.7 Partial brickwork collapse is observed on the south face of the north wall.	

Fig.8 On the north face of the north wall (opposite side of Fig. 7), salt weathering is observed.	
Fig.9 Brick tomb. The condition of the north face is not as severely deteriorated as the east, south, and west faces.	
Fig.10 Thermal image of the brick tomb in Fig. 9. A trend toward higher temperatures at the top is observed. The influence of solar radiation and moisture content is considered.	

3D images made by photogrammetry

Fig.11 MNMK_area	
Fig.12 MNMK_area_slope	
Fig.13 MNMK_area_obrique	

【Quba Mir Shahdad Talpur】

Name of the site	Quba Mir Shahdad Talpur
Address of the site	5JPM+VFJ, Shahpur Chakar, Shaheed Benazirabad, Sindh, Pakistan
Date of assessment	27/12/2023
Site manager/ custodian (e.g, local NGOs)	
Site access	Two routes
Inspected location(s) (Geo-coordinates)	Mir Shahdad tomb (26.1872212135428 68.6335809617797)
	Tomb of sons of Mir Shahdad (26.1872569922975 68.6337611799411)
	Tajar (a tomb of princes) (26.1893413069973 68.6353270944595)
	Surrounding area (26.1872212135428 68.6335809617797)
Building materials	Burned bricks, Sand stones
Overall degree of damage to the building	moderate structural damage, heavy non-structural damage heavy material decay

1.Overall condition of the site

- Water/flood management system (risk evaluation of water-related disaster…)

Quba Mir Shahdad is located in Shahpur Chakar (city) of the Sanghar District, in Sindh Province of southern Pakistan. It is surrounded by irrigated land used for wheat and other cultivation and nearby irrigation channels supply water to the field.

2.Causes of Damage

As Quba Mir Shahdad is also closer to Nawabshah city, the rainfall data from Nawabshah station was used to understand the rainfall condition at the site. Similar to Mian Noor Mohammad Kalhoro graveyard, the record-breaking continuous high intensity rainfall which exceeded 100 mm/day for several days inflicted severe damage on the structures and graves. The graveyard is located about ~ 50 km away from the main Indus river and therefore not affected by Indus river water. It is also reported that the graveyard except the main compound (protected by a perimeter wall) was inundated about one or two feet for nearly two to three months during the August 2022 flood. The flood water is mainly from infiltration excess water that collected at low land areas and irrigated fields. As similar to other sites, the record-breaking high intensity rainfall for consecutive days might have inflicted severe damage on the Quba/tombs and other masonry graves.

The specific damages were;

1. Collapse/damage to the Quba
2. Collapse of masonry grave structures
3. Creation of cavities and holes in structures due to saturation and loss of lime mortar and bricks

3.Conditions before/after the flood

The main causes long-term decay at Quba Mir Shahdad Talpur are

1. Pre-existing weaknesses in the Quba dome and wall due to aging
2. Heavy Rainwater splash and strong rain drop impact force as well as other climatic conditions has resulted in hollowing out of masonry, loss of bonding mortar, and weakening the walls due.
3. Pre-existing high degree of hydration/dampness in walls due to surrounding climatic conditions weakening the walls and structures.

Fig. 2 Status of the walls and structures after the damage

Fig. 3 Outer renovation and restoration works and damages to the grave structures due to dampness

4.Necessary measures

Site specific measures

- Improved methods for dealing with hydration/dampness damage to the inner and outer walls
- Resetting of loose bricks and filling of voids in walls
- Filling in of gullies that had developed in walls and domes after the heavy rains
- As there is no drainage facility in the site, investigate the draining routes to make a new drainage system to drain out the water from the graveyard.

5.Remarks on the primary source of damage

Quba Mir Shahdad Talpur is located on a slightly elevated area and was barely submerged during the 2022 flood. The damage was the collapse of the dome roof of the mausoleum. The buildings at the site, including the mausoleum with the collapsed dome roof, are constructed of bricks piled with an adhesive mixture of clay and gypsum, and sandstone is used for the base, pillars, and beams finishing (Fig.1 and 2). For those with domes, the surface of the domes is plastered, and prior to the 2022 flood, the plaster of the domes had cracks (Fig.3), and water from heavy rainfall penetrated through these cracks, loosening the adhesive layer and increasing the weight of the sandstone due to water absorption, resulting in the roof not being able to support the structure. The roof could not support the structure and collapsed as a result. This is not the first time this phenomenon has occurred; some of the dome roofs had also collapsed during the 2010 flood, and some had already been restored (Fig.3).

a Structural damage

The mausoleum has a two-tiered platform, with the tomb placed on the second tier. Of the sandstone used for the basement decoration, the lower part of the lower basement decoration is severely weathered by salt. Salt weathering is also observed on the upper basement, but it is less severe than that on the lower basement. The foundation of the building is brickwork, and it can be imagined that this structure has a kind of capillary barrier effect. Some of the missing parts of the openwork fence around the upper basement were replaced with bricks that are different from the original sandstone.

b Material decay

On the other hand, there are many tombs in this ruins area, and their collapse is remarkable (Fig. 4). They were not destroyed by the flood of 2022, but are continuously being destroyed, but the lack of budget and the sheer number of tombs make restoration impossible. The destruction of the surrounding tombs is very similar to that of the tombs surrounding Mian Noor Muhammad Kalhoro Graveyard. Quba Mir Shahdad Talpur is located on a slightly elevated area, but in an agricultural area, where the level of groundwater is quite high, and the soil is highly hydrous. Salt weathering and other weathering processes are occurring on a daily basis, and it is necessary to conduct basic research on the deterioration phenomena, causes of deterioration, and methods to deal with these problems.

In the mausoleum on the left side of Fig. 5, repair work was in progress, but the tombs inside the mausoleum were significantly salt weathering on the south side (Fig. 6). This is most likely due to the entrance to the mausoleum being located on the south face, and the solar radiation and wind accelerate water evaporation from that part of the mausoleum. Similarly, on the north face, there is a window, which is thought to be contributing to salt weathering due to wind effects. The site manager was aware of the same problem and said that although it is not possible to completely screen the windows, he would consider using an openwork design for the windows and shading the entrance on the south face.

c Water/flood management

According to the current site manager, since the 2022 flood, restoration has been prioritized. The restoration policy is to use traditional materials and methods, which makes sense in terms of authenticity and effectiveness as mentioned above. The mausoleum whose dome collapsed due to the 2022 flood (right side of Fig. 5) was repaired according to this policy, but the upper surface of the basement was not plastered. When we asked about this point, we were told that measures were being considered because it would soon be damaged by salt weathering. One idea is to form a capillary barrier by digging in around the basement and building and spreading sand and gravel, but considerable research and study is needed to demonstrate the effectiveness of such a barrier.

d Further measures to be taken into account

The southern mausoleum, which has been restored in the past, uses different materials for bonding and filling than the original, and its construction is not as elaborate as it should be. The use of different materials and methods for restoration from the originals should be thoroughly discussed with regard to authenticity and effectiveness. Inexperienced restoration can lead to faults and further deterioration. Basic research on deterioration phenomena, causes of deterioration, and restoration methods is needed.

The meteorological data for this area is only available from a distant location, which cannot be used as a reference due to the administrative division of the area. In order to solve the problem of salt weathering, which is constantly progressing, it is necessary to establish a meteorological observation station at this site and also to investigate the behavior of soil moisture.

Fig.1 The basic structure of the mausoleum, with a two-tiered platform. The basement decoration, pillars, beams, and dome are made of sandstone.	
Fig.2 The basement is brickwork, as evidenced by the collapsed sections.	
Fig.3 The restored mausoleum which had collapsed in the 2010 flood.	
Fig.4 Brick tombs spread out around it. The collapse is remarkable.	

Fig.5 The mausoleum on the right side of the photo was restored after the dome collapsed due to the 2022 flood.

Fig.6 Fig. 5 Lower part of the tomb enshrined in the mausoleum on the left. Salt weathering is significant.

【Ranikot】

Name of the site	Ranikot
Address of the site	Ranikot fort Wall, Karchat, Jamshoro, Sindh, Pakistan
Date of assessment	28/12/2023
Site manager/ custodian (e.g, local NGOs)	
Site access	Two routes
Inspected location(s) (Geo-coordinates)	Southern Wall (25.8635539611670 67.9053826728581)
	Southern Wall gate (25.8629913992733 67.9070923531152)
	Surrounding area (25.8629913992733 67.9070923531152)
	Sann Gate (25.8838348187883 67.9323848116988)
Building materials	Burned bricks, Lime stone, Sand stones
Overall degree of damage to the building	moderate structural damage, heavy non-structural damage heavy material decay

1.Overall condition of the site

- Water/flood management system (risk evaluation of water-related disaster…)

Ranikot is a vast fortress complex in the Kirthar Mountains in southern Pakistan. The defensive walls have a total length of 35 kilometres and were built under the rule of Quba Mir Shahdad Talpur dynasty. The fortification walls, which have solid semi-circular bastions at intervals run on three sides of the mountain ridges, while on the northern side the higher hillocks serve as a wall. The whole architecture of the fort is restricted to stone and lime (https://whc.unesco.org/en/tentativelists/1284/). One of the tributaries of the Indus river (Sann River ?) originates in the Kirthar Mountains inside the fort area and passes through Sann gate and reaching Indus river at Town Sann.

2.Causes of Damage

Nawabshah station was the closest station that has rainfall records for August 2022 flood. Between August 16 and 25, 2022, the Nawabsha Site recorded extreme rainfall of about 460 mm. Similar to other places, the record-breaking continuous high intensity rainfall which exceeded 100 mm/day for some days might have inflicted severe damage on the fort wall and gates. It is also reported that water flow through Sann gate was very heavy and flooding water obstructed the route for the fort guesthouse and local residency for about two to three months.

The specific damages were;

1. Collapse/damage to old and recently restored boundary walls. Wall structure has weak inner mud/clay mortar and relatively stronger outer lime mortar to hold the rocks. Cracks in lime-mortar protection layers due to previous climatic conditions allow water to intrude to the mud core of wall and resulting to collasing of the walls due to its own weight and strong rain impact force as well as heavy rainwater splash.
2. Collapse of pathways/decks, creation of cavities and holes in structures due to saturation and loss of mud/mortar and stones
3. Erosion of basements due to poor drainage facilities that weakened structures and walls
4. Collapse of the Shah-Pere Gate: Poor surface drainage resulted in continuous water flow along the deck to reach the gates which are located at the lowest point of the mountain ridges, infiltrate to the core of the wall through cracks, and then weakened the base of the gate wall and lead to collapse completely.

3.Conditions before/after the flood

The main causes decay at Ranikot

1. pre-existing weaknesses in the wall and structures due to aging
2. Cracking of the lime-mortar protection layer and allowing water to intrude to the wall core that was made of mud and stones.
3. Poor surface drainage and rainwater splash has resulted in hollowing out of the stone wall and weakening the base of the walls due to water flow along the pathways.

Fig. 1 Damages to walls and basements

Fig. 2 Collapse of the Shah-Pere Gate and status of reconstruction

Fig. 3 Flow path of Sann river near the main gate and the eroded condition of the wall foundation and supported by sand bags

4.Necessary measures

- Resetting of loose rocks and filling of voids in walls to provide protection layers
- Filling in of gullies that had developed after the heavy rains
- Maintaining/build drains for water flow along the pathways
- As the foundation wall of Ranikot was shallow and standing on the cliffs, they are vulnerable to heavy downpours and landslides. The weakening points to be identified and rectified.

5. Remarks on the primary source of damage

Ranikot was built in a mountainous area on the west side of the Indus River. As far as we were able to observe in the collapsed area, the wall seems to have been constructed by piling sandstone flat stones on the ridge as a foundation and sandstone blocks as a wall (Fig.1). In addition, the passageways for human traffic were paved with plaster mortar (Fig. 2).

Most of the collapsed walls are parts which had been newly restored (Fig. 3). There are two methods of conventional restoration: piling up limestone blocks only (Fig. 4) or building a new wall with limestone gravel (the size of a human head) and mud, and then piling up limestone blocks as a decoration on the surface (Figure 5). The latter method is similar to the one used at Kot Diji Fort.

a Structural damage

According to the site manager, the construction method of this wall is the same as that currently used in urban areas. While maintenance is easy in urban areas, it is difficult in mountainous areas such as Ranikot, where the castle walls ruins are long and extensive. The cause of the collapse is thought to be the cracks in the plaster mortar at the joints of the walls and in the passageways, where rainwater flowed in and loosened the wall structure.

b Material decay

Observing the sandstone layers that make up the ground around the walls, we see many of them broken into sheets (Fig. 6). Considering the presence of plants such as tamarisk, which is common in Gobi, it is assumed that there is some moisture in the soil. The climate is inland, and the daily temperature range is extremely large. It is also important to understand how the sandstone responds to large changes in wet-and-dry during the day and night, or to large changes in temperature.

c Water/flood management

To prevent the collapse, the following measures should be considered: (1) introduction of a structure that prevents the restoration area from slipping by anchoring or geotextile method, (2) improvement of waterproofing on the surface of the passage, and (3) daily maintenance to check for cracks. In terms of restoration methods, a construction method that does not allow water intrusion to loosen the structure should be considered but considering that the original wall structure is still in existence, it is necessary to first investigate the original construction method and verify its durability. For the missing wall sections, the wall should be strengthened, and the stones for using decoration should be bonded to the wall so that there are no gaps.

d Further measures to be taken into account

Based on the above, it is likely that the cause of the collapse of Ranikot is the loosening of the wall structure due to water intrusion into the wall, but age-related deterioration, including weathering over time, must also be considered. Temperature and moisture play a major role in the deterioration of man-made stone structures. It is not appropriate to use data from nearby weather stations to determine the weather at Ranikot, a long wall. It is necessary to establish a weather station to observe temperature, humidity, sunlight, and moisture content in the wall in areas where collapse has occurred or where deterioration has been observed over time. It is also necessary to determine the physical properties of the materials used in the original walls as well as those used in the new restoration, with respect to changes in temperature and moisture content. The restoration methods, including re-examination of the original wall construction methods, should be reexamined to devise a restoration method that will enhance the resilience of the wall while paying sufficient attention to its authenticity.

Fig.1 Structure of the wall. Lamination of flat sandstones and blocky sandstone piles are recognized.	
Fig.2 Plaster mortar applied to the passageway. Slits are cut here and there for drainage.	
Fig.3 Collapsed condition of the castle wall. Scattered white limestone from the collapsed area indicates that the area had been restored.	
Fig.4 The part of the wall body constructed by piling up only limestone.	

Fig.5 A section where the wall body is constructed of limestone or other gravel and mud, and limestone is used for decorating purposes.	
Fig.6 Sandstone layers that make up the ground. It is fractured into plates.	

3D images made by photogrammetry

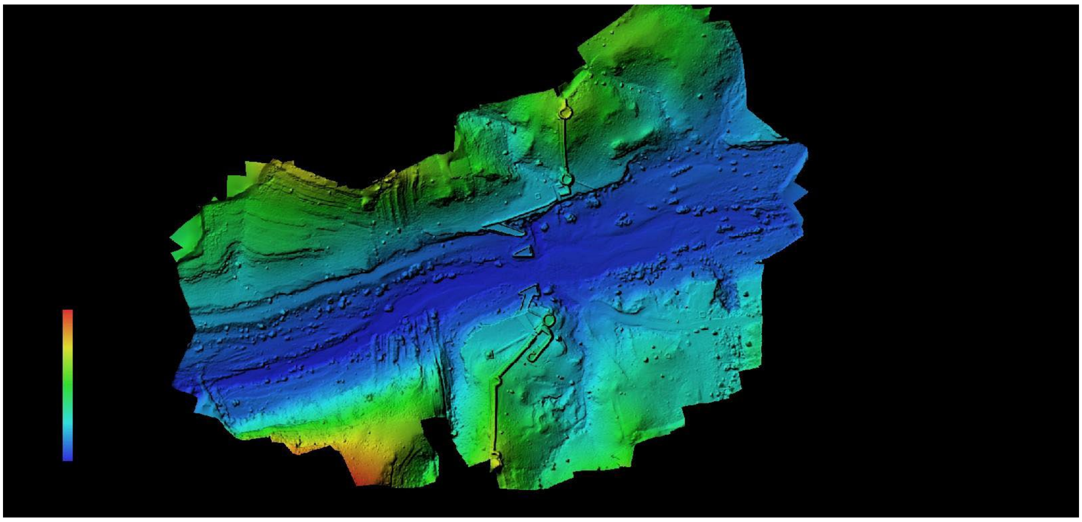
Fig.7 RKT_SannGate_elevation_hillshade	
Fig.8 RKT_SannGate	

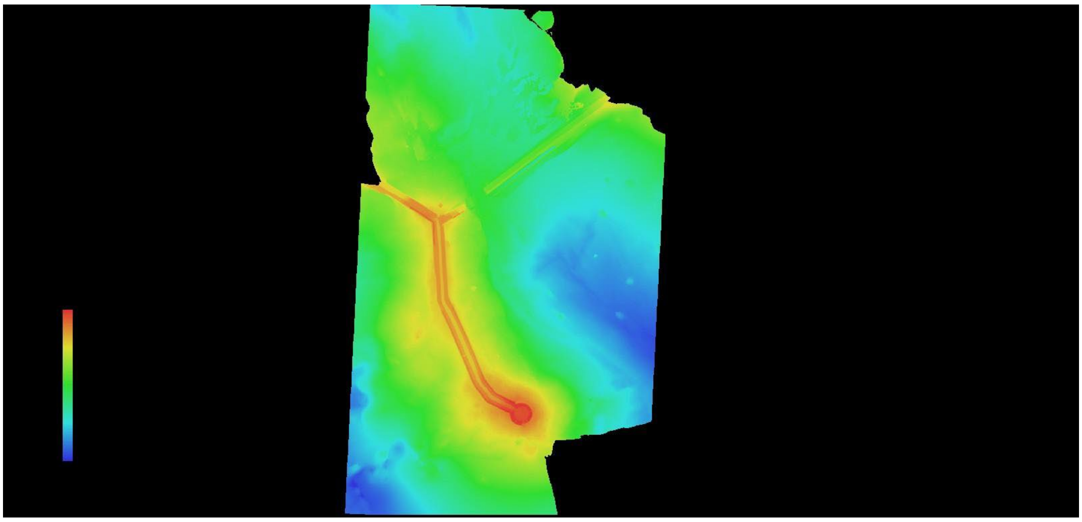
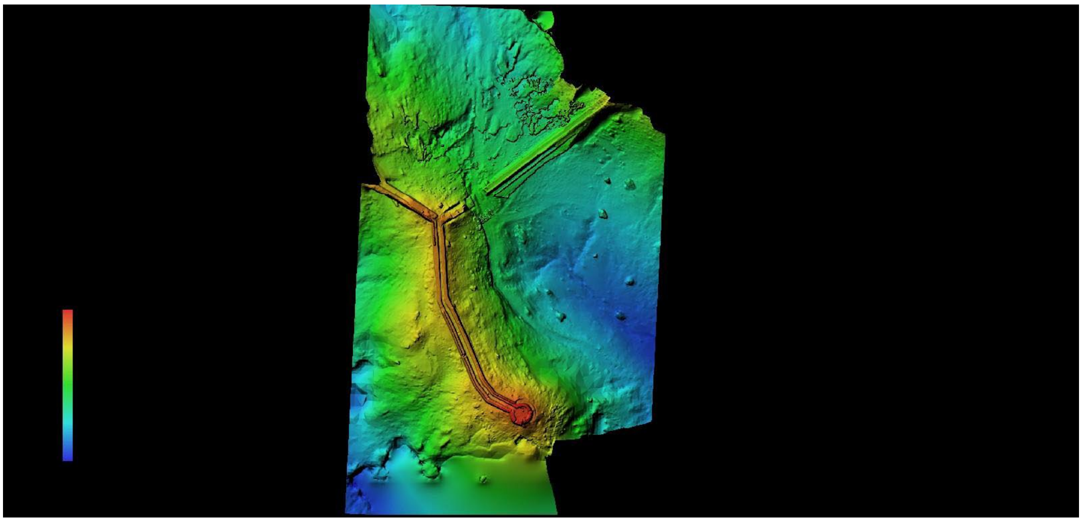
Fig.9 SWallGate_elevation	
Fig.10 SWallGate_elevation+hillshade	

Fig.11 SWallGate	

【Makli】

Name of the site	Makli (Historical Monuments at Makli, Thatta (UNESCO))
Address of the site	QV2X+P6R, Makli, Thatta, Sindh, Pakistan
Date of assessment	29/12/2023
Site manager/ custodian (e.g, local NGOs)	
Site access	Two routes
Inspected location(s) (Geo-coordinates)	Shaikh Jiyo (24.7650178395252 67.9044173314194)
	Amir Muhammad Yar (24.7662777451679 67.9048046564244)
Building materials	Burned bricks, Sand stones
Overall degree of damage to the building	moderate structural damage, heavy non-structural damage heavy material decay

1. Remarks on the primary source of damage

The World Heritage Site of Makli, a vast ruins site, was located on higher ground than its surroundings, so it was not flooded during the 2022 floods. However, strong rainfall caused some buildings to collapse. Secondary damage included a fire in which a large amount of overgrown weeds burned after the rainfall.

a Structural damage

Two types of Makli structures were identified: those that are mainly brickwork and those that are mainly stonework. The brickwork structure shown in Figure 1 is still cherished by local residents as a place of worship and is maintained to a certain extent. The brickwork of the semi-circular domes at the four corners of the upper part of the building is piled in a complex manner to form the dome structure (Fig. 2). According to the repairman, when building with brickwork, the bricks need to be glued together quickly, which is why gypsum is used. A mixture of gypsum and sand is used as the adhesive. Although the solubility of gypsum in water is not high at 0.21 g per 100 g of water, it is thought to gradually dissolve and lose its function as an adhesive when exposed to rainfall for a long period of time. The plaster-based adhesives found in Mian Noor Muhammad Kalhoro Graveyard,Quba Mir Shahdad Talpur and Ranikot are considered to be similar to this gypsum-based adhesive. Buildings constructed with brickwork have their surfaces finished with plaster mortar. Plaster mortar takes a long time to cure, but once cured, it is extremely waterproof. This is due to the fact that the solubility of calcium carbonate, the main ingredient of plaster, in water after curing is extremely small at 0.0013 g per 100 g of water.

The other structure (Fig.3), which is mainly built of stonework, is based on a pile of rectangular cut sandstone measuring 15 cm x 30 cm x 40 cm (Fig.4). The wall structure consists of a layer of gypsum as the adhesive, a layer of crushed sandstone, a layer of sandstone gravels of which the size is a fist or human head, and a layer of crushed sandstone, and it is thought that four units of this structure were stacked together to form a wall, which was then covered with cut sandstones (Fig.5). The building collapsed in part during the flood of 2022, probably due to the loss of adhesive strength between the stacked wall structure and the sandstone quarry attached to the outside of the building over a long period of time due to rainfall.

b Material decay

While the damage caused by prolonged heavy rainfall and its causes have been discussed above, salt weathering is observed in the lower portions of many buildings (Fig.6). This salt weathering makes the structures vulnerable and is one of the factors that cause rapid collapse of these vulnerable structures when they are hit by heavy rainfall, such as in the 2022 floods. Salt weathering is a problem not only throughout Pakistan, but also all over the world.

d Further measures to be taken into account

Restorations are currently being carried out in Makli using a variety of methods, and it seems that some of the appropriate methods are not being applied. The repair personnel at the World Heritage Center in Makris were very aware of the importance of the original structure and said that they would like to consider putting in further reinforcement as needed, while taking advantage of the strengths of the original structure, rather than simply repairing it neatly. A lab for repairs has been set up in the World Heritage Center in Makris. In the lab, they were working on researching adhesive formulations using various types of soil (Fig.7), and testing the strength of materials (Fig.8), and so on. They wanted to know the composition of the original adhesive using gypsum, so we received the original materials and decided to analyze them. In addition, there are many other issues to be addressed in this laboratory, such as the composition of the plaster mortar and the strength required for actual repair work. As in the case of Moenjodaro, further development of this laboratory and human resource development based here is highly expected not only for the development of repair techniques for Makli, but also for the development of repair techniques throughout Pakistan. In addition, a meteorological observation station, provided free of charge by Japan, has been installed on Makri site, and it is hoped that the data from this station will be put to good use in the future.

Fig.1 A mausoleum located in Makli. It is still used by local residents as a place of worship.	
Fig.2 Brickwork in the dome section of the building, which is primarily brickwork.	
Fig.3 The building is mainly constructed of stonework; strong rainfall during the flood of 2022 caused the building to collapse.	
Fig.4 Stonework structure.	

Fig.5 Structure of the stonework. The structure was revealed when a collapse exposed the inner of the walls.	
Fig.6 Salt weathering observed in the lower part of stonework structures.	
Fig.7 Mixing tests of adhesives with gypsum as the main ingredient. Experiments with various soils.	
Fig.8 Strength tester for measuring the strength of adhesives. Compressive strength is used as an indicator.	

[GoS] Government of Sindh. 2023. State of conservation report: archaeological ruins of Mohen Jo Daro, Larkana, Sindh, Pakistan. Culture, Tourism, Antiquities & Archaeology Department, Government of Sindh. Retrieved December 26, 2023 from https://whc.unesco.org/document/198758

Joffroy, T. 2023. Moenjodaro UNESCO emergency mission following disastrous rainfall in 2022. Retrieved December 26, 2023 from https://hal.science/hal-04111785/document#:~:text=21%20-%2029%20October%202022&text=The%20intensity%20of%20heavy%20rainfall,and%20structures%20at%20Moenjodaro%20Site

		Author
1	Background/ Introduction	Koki MAEDA
2	Aim of mission	Koki MAEDA
3	Date	Koki MAEDA
4	Delegation of Japan in the mission	Koki MAEDA
5	Itinerary	Koki MAEDA
6	List of personnel	Koki MAEDA
7	Assistance in Disaster Risk Reduction & Disaster Management Plan	Koki MAEDA
8	Documentation/ Drone Photogrammetry	Koki MAEDA
	Result of Site Documentation and Damage Assessment Drone photogrammetry	Atsushi NOGUCHI
9	Structural Damage Assessment	Takayoshi AOKI/ Mitsuhiro MIYAMOTO
10	Training staff in Scientific documentation/ Damage assessment	Koki MAEDA
11	Result of Site Documentation and Damage Assessment	
	【Moenjodaro】	
	1-4	Abdul Wahid Mohamed RASMY
	5 a - d	Yohsei KOHDZUMA
	【Kot Diji Fort】	
	1-4	Abdul Wahid Mohamed RASMY
	5 a - d	Yohsei KOHDZUMA
	【Mian Noor Muhammad Kalhoro Graveyard】	
	1-4	Abdul Wahid Mohamed RASMY
	5 a - d	Yohsei KOHDZUMA
	【Quba Mir Shahdad Talpur】	
	1-4	Abdul Wahid Mohamed RASMY
	5 a - d	Yohsei KOHDZUMA
	【Ranikot】	
	1-4	Abdul Wahid Mohamed RASMY
	5 a - d	Yohsei KOHDZUMA
	【Makli】	
	1 a, b, d	Yohsei KOHDZUMA

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