Assessing the Impact of the Türkiye February 2023 Earthquakes on Cultural Heritage Sites: A Multi-Disciplinary Approach Utilizing ARIA Maps and Social Media Collaboration

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Abstract

The earthquakes that occurred in our country on February 6, 2023, significantly damaged and destroyed cultural and historical assets. The Habib-i Nejjar Mosque in Antakya and other important historical sites suffered significant damage. This study provides a comprehensive account of the post-earthquake efforts carried out by volunteers from various disciplines, including archaeology, cartography, space sciences, and architecture, using social media platforms. The volunteers created an extensive database for cultural and archaeological sites in all 11 provinces that were declared disaster zones. This database made it easier to conduct a thorough evaluation of the damage. The database was augmented with surface displacement data, enabling an analysis of damage levels with the exactitude facilitated by the gathered information. The utilization of the Advanced Rapid Imaging and Analysis (ARIA) maps was pivotal in this study. The maps, created through partnerships between NASA and different space agencies, offer intricate satellite imagery and analysis of surface displacement. This is essential for evaluating the effects of earthquakes on cultural heritage sites. The utilization of ARIA maps in this study facilitated an accurate assessment of the seismic impact on cultural and historical resources. Additionally, Sentinel 1 images are used to generate displacement maps with the use of the LICSAR tool and the SBAS method. The study examined the state of about 1500 cultural heritage sites in 11 provinces in the aftermath of the earthquake. The report incorporated data from media coverage and input from relevant parties present at the scene, providing a thorough assessment of the situation following the disaster. For instance, the research revealed substantial shifts at prominent locations, like the UNESCO World Heritage site of Arslantepe in Malatya. This site experienced a displacement of over one meter towards the south and 75 cm towards the west, along with a subsidence of approximately 10 cm in the surrounding area. Furthermore, the study presented a visual representation that depicted the quantity of impaired cultural heritage sites in every province, providing a comprehensive evaluation of the impacted cultural and archaeological resources. This comprehensive strategy not only emphasized the magnitude of harm to cultural heritage but also emphasized the significance of interdisciplinary cooperation in disaster response and heritage preservation.

1. Introduction

Türkiye had a significant earthquake with a magnitude of 7.6 and, following this, 7.4, impacting 11 provinces and causing the collapse of several structures due to extensive damage. Besides the residential buildings, the area has a significant cultural heritage dating back to Palaeolithic Age. In relation to the evaluation of cultural assets, particularly in relation to the earthquakes that occurred in February 2023, a notable research study is on the assessment of damage and the formulation of restoration plans for the UNESCO World Heritage Site, Diyarbakır City Walls, located in Türkiye. This study highlights the importance of comprehending the causes and determinants of seismic-induced damage to cultural assets, with a specific focus on Diyarbakır, a region primarily characterized by basalt as the major construction material. The study emphasizes the dearth of data regarding the characteristics of mortar materials employed in the walls and seeks to provide guidance for restoration endeavours aimed at safeguarding the cultural and historical legacy of the location. The city walls of Diyarbakır are distinguished by their considerable length, diverse tower thickness, and historical importance, which serve as a testament to the architectural characteristics of several civilizations (Karataş and Bayhan, 2023). Boyoglu et al. (2023) conducted a study that specifically examines the visual interpretation of damages using high-resolution X-band synthetic aperture radar (SAR) images (Boyoğlu et al., 2023). This study highlights the difficulties associated with evaluating the economic and social consequences of earthquakes on cultural heritage monuments, extending beyond their financial worth. By utilizing high-resolution TerraSAR-X data obtained from the 2023 Türkiye earthquake, this study showcases the challenges associated with interpreting SAR photos to assess the extent of damage to cultural sites. Significant devastation is identifiable, but slight impairments are difficult to perceive. The study's findings indicate that relying just on single SAR scene interpretation is insufficient for evaluating the extent of damage to heritage sites in the absence of pre-event data.

This paper focuses on the damage caused by the February 2023 EQs to the cultural heritage. We use remote sensing-based datasets (ARIA) and InSAR-based displacement maps to assess the damage and support immediate recovery efforts and long-term preservation. The location of the cultural heritage of the affected region involves incorporating citizen science activities, allowing local communities to contribute to data collection. This approach not only deepens understanding of the disaster's impact, but also gathers crucial on-the-ground information from damaged areas. Volunteers gain a comprehensive and human-

centric perspective by documenting and sharing their observations, thereby providing valuable insights.

1.1 General Overview of the Cultural Heritage in the effected area

The earthquake region is a rich and diverse hotspot for archaeological and cultural heritage, with thousands of sites, some listed on the UNESCO World Heritage List and two more on the Tentative List. These sites include the Neolithic site of Göbeklitepe, the Bronze Age site of Arslantepe, the Hellenistic site of Mount Nemrud, the Medieval Diyarbakır Fortress, and the Hevsel Gardens Cultural Landscape (UNESCO, 2024). The region is also home to milestones in human history, such as the dispersal of early hominids from Africa to Eurasia (Dinçer, 2016), the domestication of plants and animals, and the invention of agriculture in Karacadağ in Şanlıurfa province (Heun et al., 1997). The region also has significant historical sites, such as early complex societies, Bronze and Iron Age kingdoms, major trade routes, antique and late antique cities, and the early development of Christianity, Judaism, Islam, and other religions and beliefs practiced by ethnic and religious minorities (Lowden, 1998).

Adana is the 4th largest city in Türkiye and we listed 149 cultural items in our database. In antiquity, the area was part of Cilicia, having both rugged mountainous areas as well as lush alluvial plains watered by the Seyhan and Ceyhan rivers. Our database lists 22 prehistoric and protohistoric settlement mounds. Hittite political interest in the area left traces of citadels and rock-cut monuments, such as in Sirkeli (Novak, 2020).

For Kahramanmaraş, the epicenter of the 6th of February EQ, the volunteers collected 144 cultural heritage items. Kahramanmaraş has many prehistoric and protohistoric sites. A few of these are currently under archaeological investigation. Caves and rock-cut features registered in our database count seven, while settlement mounds constitute 19 items. Also, 82 buildings of historical significance were recorded by the volunteers. The city itself goes back to the Iron Age, when Neo-Hittite kingdoms were established in the region after the demise of the kingdom in Central Anatolia. Neo-Hittite kingdoms established themselves in Kahramanmaraş (Hawkins, 1982).

Hatay boasts a rich history and an abundant cultural heritage, surpassing most other cities affected by the damage. Our team of volunteers collected data on archaeological and cultural heritage sites from across Hatay province (n = 232), with a main focus on the historical city center (n = 98). Hatay has been a place of importance from prehistoric eras into modern times with its unique atmosphere of cultural and ethnic diversity. Notably, the only Armenian village left in Türkiye is located here in Vakıflı, whose church has been unfortunately damaged by the EQ. Volunteers registered 126 buildings of historical and religious importance, 22 fortresses or citadels, and ten museums. The lush Amuq plain is home to over 300 settlement mounds, and the province contains at least 400 settlement mounds that have been documented by archaeological reconnaissance, of which we were able to document 49 better-known and excavated ones (Yener et al., 2000).

Gaziantep and Kilis, which are two neighbouring provinces on the border with Syria, have also been seriously affected. Both cities have highly significant heritage sites and museums. Volunteers registered 129 items from the major city of Gaziantep and 36 items from the smaller province of Kilis. Major mound settlements like Oylum Höyük in Kilis, the famous Hittite-era rock quarry Yesemek, and the and the Neo-Hittite sites of Carchemish and Sakçagözü are some of the sites of primary archaeological importance (Alkım, 1957).

Şanlıurfa is a city of extraordinary past and rich heritage. It is home to the UNESCO World Heritage Site of Göbeklitepe. It is also of utmost importance for Abrahamic religions as the place of birth of the prophet Abraham, who is considered to be the first prophet in Judaism, Christianity, and Islam. Thus, the old city centre houses a large number of pilgrimage sites of religious importance. Volunteers were able to register for a total of 200 items from Şanlıurfa. Besides, the medieval city of Harran, mentioned in the Holy Bible, with its roots dating back to the Bronze Age, includes well-preserved stone architecture and massive fortification walls (Lloyd et al., 1951).

Diyarbakır is yet another historically layered and lavish city, known for its extraordinary contribution to human history and being listed on the UNESCO World Heritage List. Volunteers registered 202 cultural assets from the whole province. The province, which is home to the largest Kurdish population in the world, is ethnically and religiously diverse, hosting Turks, Arabs, Armenians, and Syrian communities. Diyarbakır Medieval city, its gorgeous fortifications out of basalt and gardens on the outskirts of the inner citadel are part of the world heritage as unique cultural assets. The inner citadel, known as Sur, is home to many monuments and historic buildings, including the Behram Paşa Mosque, built by Architect Great Sinan in the 16th century. Armenian Orthodox, Armenian Catholic, Syriac Protestant, Syriac Catholic, and Roman Orthodox churches are also located inside the Sur neighbourhood (Soyukaya, 2017). Our volunteers noted 105 items from inside the citadel of Diyarbakır.

Adıyaman is one of the more significant provinces in the EQ region that suffered immense damage, with 132 items in our database. The province is home to UNESCO’s World Heritage Site of Mount Nemrud, a tumulus adorned with statues of divine figures. The site is part of the greater Commagene Kingdom territory that ruled the area between 160 BC and 72 AD (Doğan, 2021).

Malatya has been a commercial and political center at least since the 4th millennium BCE, when it was located to the north of the Taurus range in the Euphrates Basin. The province also contains earlier remains from the Neolithic and Chalcolithic periods (Frangipane, 2012). Our database documents 43 prehistoric and protohistoric sites.

Elazığ is located within the Upper Euphrates Basin, close to Malatya. The database contains information on 127 sites located in this province. Elazığ possesses a historical lineage that is traced back to the Palaeolithic era. Archaeological studies conducted during hydraulic dam construction previously examined prehistoric and protohistoric sites in the region. Researchers reported a total of 59 habitation mounds and features. The area is rich in Neolithic, Chalcolithic, Bronze, and Iron Age artifacts. The Palu Fortress, constructed by the Urartians, is a significant structure that houses a crucial cuneiform inscription dating back to the time of King Menua (ca. 810–786 BCE). Elazığ’s most prolific historical area is the town of Harput, with 23 extraordinary monuments and sites in the database. Harput has been a place of political and commercial significance since at least the Middle Bronze Age, when it appeared as an important kingdom (Demir et al., 2016).

Osmaniye, formerly part of Adana, is now a city with 71 cultural and historical sites, including 24 prehistoric and protohistoric settlement mounds, the Karatepe Arslantaş Open Air Museum, ten Hellenistic and Roman sites, nine Byzantine era items, and 15 Late Antique sites, including nine Ottoman era monuments and 19th-century train station buildings, according to the collected data by the volunteers.

2. Material and methods

2.1 Volunteering Data

The earthquake-affected region has numerous cultural heritage items, including buildings, museums, ancient sites, and tumuli. To investigate and analyse the extent of damage, precise data on these sites is essential. To gather this information, a social media post was distributed to the public, leading to fifty individuals participating in a WhatsApp group (Fig. 1).

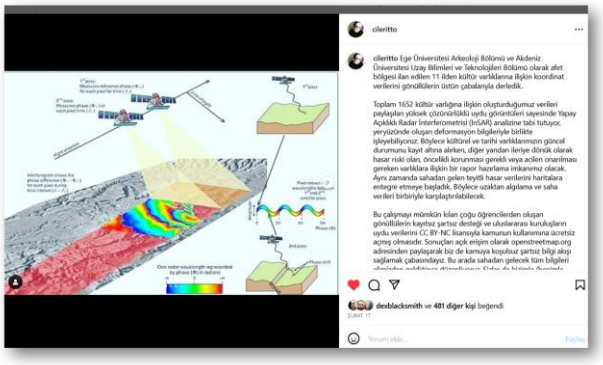

Figure 1. Contribution call posted on Instagram just after the EQ.

The participants' backgrounds ranged from archaeology to architecture and art history, and technical experts were involved in organizing geodatasets. The collected data includes attributes such as province, town, quarter, name of cultural heritage, latitude, longitude, comment, volunteer name, first entry time, and last edit time. The province field includes locations where the earthquake damaged cultural heritage, while the town attribute specifies the location within the province. The quarter name indicates the neighbourhood where the cultural heritage is located, and the name of the cultural heritage identifies the site. The Period field indicates when the cultural heritage was first built, and the Type field specifies the cultural heritage category. The Volunteer Name field records the individual who provided the data. Figure 2 shows the collected data on the map.

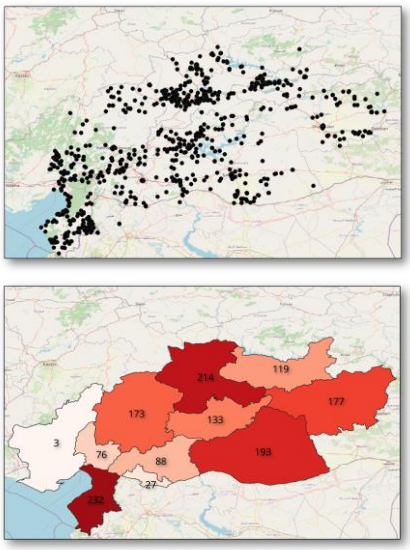

Figure 2. The collected data locations and their total numbers

2.2 Satellite Data

Satellite data has been used to identify damaged cultural heritage, including synthetic aperture radar images and optical satellite data. Sentinel 1, a radar satellite constellation consisting of two satellites, Sentinel 1A and 1B, is crucial for monitoring Earth surface features and is part of the Copernicus program, a European Union initiative providing free and open access to Earth observation data. Sentinel 1 has C-band wavelength capability with HH and VV polarization options and operates in a sun-synchronous orbit at an altitude of 693 km. The sensors have several acquisition modes, including Strip Map Mode, Interferometric Wide Swath Mode, Extra-Wide Swath Mode, and Wave Mode, with swath widths of 80 km, 250 km, and 20 km and spatial resolutions of 5 m, 5 m x 20 m, 20 m x 40 m, and 5 m x 20 m, respectively.

2.3 ARIA Damage Map

An ARIA damage proxy map is a satellite-based tool used to estimate the extent of damage caused by natural disasters. It compares coherence images from SAR datasets before and after the disaster, identifying areas that have been damaged. The ARIA team at NASA's Jet Propulsion Laboratory creates these maps using data from various satellite sensors. A sample of the map from the Hatay region is shown in Fig. 3.

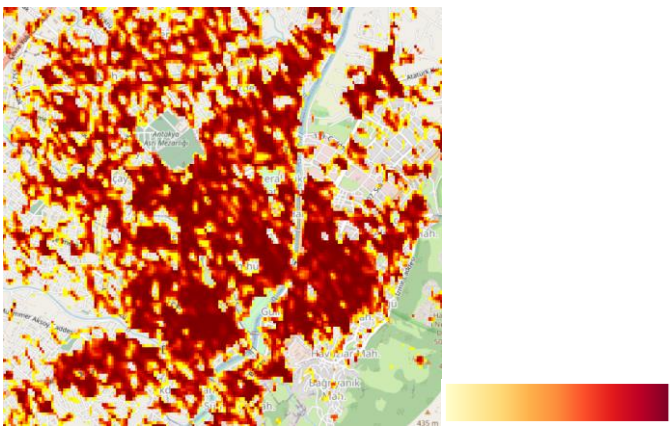

Figure 3. Damage level map (moderate : yellow, high: red)

2.4 Clustering of the damage level

To discrete the damage levels into 2 categories, the ARIA map has been clustered with the k-means clustering method, with the number of cluster parameters set to 3. The colours from yellow to red indicate the damage level according to the ARIA Map (Figure 4).

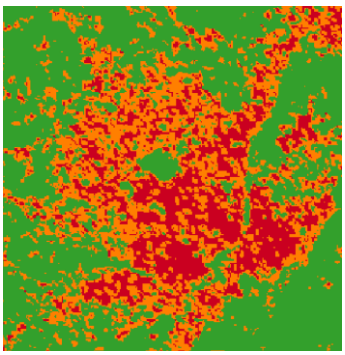

Figure 4. Extracted the damage levels from the ARIA Map (Red:High, Orange: Modarete damage)

2.5 Calculation of the displacement

The LICSAR tool has been used with the use of precalculated interferograms from the Comet Portal (Lazeckỳ et al., 2020). As part of the Looking into the Continents from Space initiative, the LICSAR package generates automated and synthetic aperture radar (SAR) interferograms from the Sentinel-1 satellites via an online platform. This technology plays an important role in producing extensive, accurate, and reliable InSAR data, which is so valuable for monitoring long-term deformation worldwide.

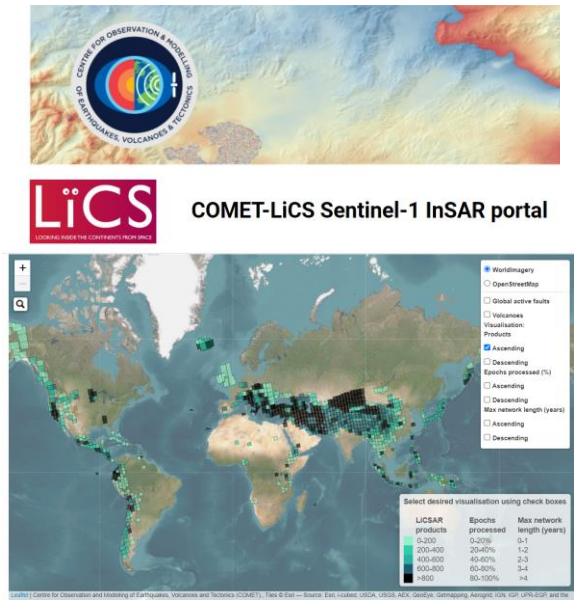

Figure 5. COMET Portal overview

Conversely, COMET InSAR, which is linked to the coordination of measurements of tectonic deformation, is a collaborative effort to employ InSAR technology to observe tectonic activities. This involves using a comprehensive dataset to analyse the movements of the earth's surface.

3. Results

The damage has been clustered into 3 classes: high-damaged, damaged, and none, with the application of k-means clustering of ARIA maps. The total number of cultural heritage sites that are damaged according to the ARIA maps is shown as follows:

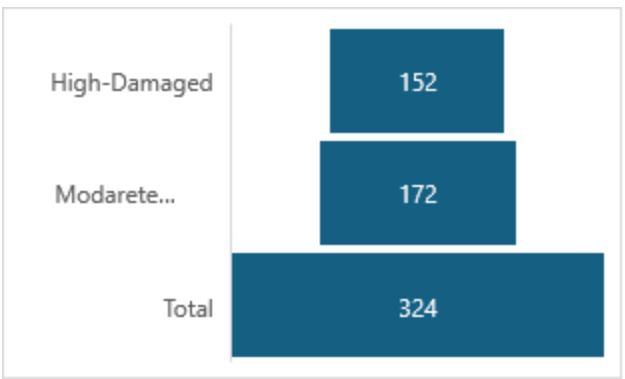

Figure 6. Total number of the damaged cultural heritage item

The damaged cultural heritage items per location is shown as following.

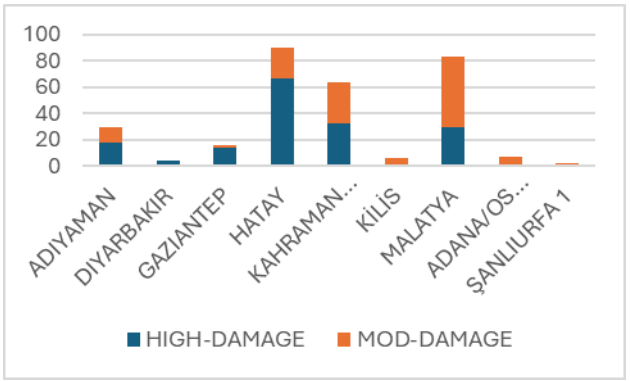

Figure 7. Number of damaged cultural heritage items per location

When considering the period of the damaged cultural heritage items, the following figure 8 shows the respective information.

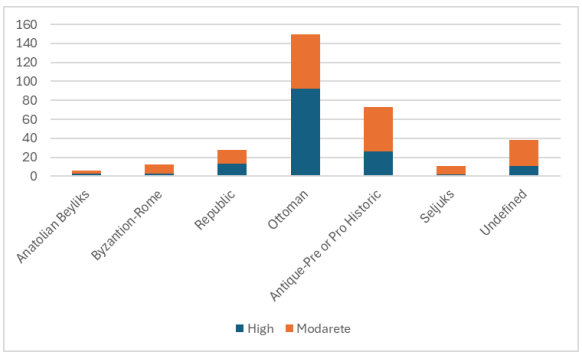

Figure 8. Damages regarding the period of the heritage

3.1.1 Some examples from the heritage

A historic structure in Antakya, the provincial capital of Hatay, is the Hatay State Parliament Building, also called the Hatay Republic Parliament Building. It is very important historically because, from 1938 to 1939, during the short life of the Hatay State, it housed the parliament. The Ottoman Empire and the French Mandate of Syria and Lebanon were overthrown, and the Hatay State was founded. Türkiye and Syria both claimed the area that was once known as Alexandretta, or Hatay. The Republic of Hatay was established in 1938 after talks and a referendum; it later gained some degree of independence but remained influenced by Türkiye. When the Hatay State briefly gained independence in 1939, it was united with Türkiye by a popular referendum, and the parliament building functioned as its political centre. During the February 2023 EQ, the building was significantly damaged, as shown in the following Figure 9. Our analysis shows that the east-west displacement is -0,476 m, the north-south displacement is 0.952 m, and the line of sight displacement of the ascending direction is -0.33 m.

Figure 9. Hatay State Parliament Building before and after (source :Kayiprihtim web page)

3.1.2 Habib-i Nejjar Mosque

The Habib-i Nejjar Mosque in Antakya, Türkiye, is a well-known ancient mosque that dates back to the seventh century. It is named after Habib the Carpenter, a Christian convert to Islam who was killed for his faith. The mosque is important to the region's religious and cultural fabric, and its architecture combines Islamic, Roman, and Byzantine influences. (Nabataea, 2024). The images from the pre-EQ and post-EQ periods can be found on the website: https://shorturl.at/uJVYZ. Our analysis shows high damage, and the NS displacement is -0,49 m, the EW displacement is -0,14 m, and the LOS displacement is -0.33 m on the grid data of the displacement results.

3.1.3 Arslantepe Mound

Arslantepe Mound is a UNESCO World Heritage Site with a 5,000-year history. It was inhabited from the sixth millennium BCE to the late Roman period, with a peak during the late Chalcolithic period (Frangipane, 2012).

Figure 10. Damage on Arslantepe Mound.

As shown in the above Figure 10, slight damage has been seen with the falling roof on the ground. Our analysis shows that there is moderate damage in the field with -0.48 m, 0.05 m, and -0.08 m NS, EW, and LOS displacements, respectively.

3.1.4 Arsemeia

Arsameia on the Nymphaios, located at the foot of Mount Nemrud in eastern Türkiye, served as the royal seat and summer capital of the ancient Kingdom of Commagene during the 1st century BCE. This historical site is not merely a burial place but a significant archaeological location that has revealed much about the cultural and religious practices of the time. The Kingdom of Commagene had three main cities, with Samosata being the primary capital. The discovery of Arsameia was somewhat serendipitous when, in 1951, Friedrich Karl Dörner, a German archaeologist, led to a relief depicting the god Mithras, sparking a series of archaeological excavations. Our analysis shows a high degree of damage with 1.02 m NS displacement, 0.63 m EW displacement, and -0.24 m LOS displacement that causes the column damage on the field, as shown in the figure at the link: https://shorturl.at/fvGHR

3.1.5 Diyarbakır Fortress

The Diyarbakır Fortress and Hevsel Gardens comprise an important cultural environment on an escarpment in the Upper Tigris River Basin. This location has served as an important centre throughout history, from the Hellenistic, Roman, Sassanid, and Byzantine periods to the Islamic and Ottoman periods and up to the present. The stronghold is notably notable for its spectacular city walls, which span 5.8 kilometres and include numerous towers, gates, buttresses, and 63 inscriptions from various historical periods. These walls, built of basalt, have undergone several modifications throughout the ages, reflecting the craftsmanship and architectural styles of their various times (UNESCO, 2024). Our analysis shows moderate damage to the site in the ARIA maps.

Figure 11. Damaged Fortress (Image source: Yesil Gazete)

In addition to these examples, there are things in our investigation that do not exhibit any damage degree, such as the significant sites like Göbeklitepe and Elazığ Ismetpaşa Mosque.

4. Conclusions

In this work, a volunteering-based data collection has been performed to identify the damaged cultural heritage items. The results shown here are only the derived results from what the ARIA map shows regarding the cultural heritage in the region along with the calculated displacement maps. This paper gives a brief information regarding the damages since the detailed paper is planned to be submitted, which is expected to be the extension version of this work.

Further investigation of the results using alternative data sources is necessary to ensure precise characterization of the extent of damage. Nevertheless, these findings are advantageous for the advancement of conservation and restoration efforts in the region affected by EQ. This study highlights the significance of social participation and the utilization of exploratory data (EO) in order to enhance the assessment of cultural asset damage and facilitate future planning efforts.

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LiCSAR contains modified Copernicus Sentinel data analysed by the Centre for the Observation and Modelling of Earthquakes, Volcanoes and Tectonics (COMET). LiCSAR uses JASMIN, the UK’s collaborative data analysis environment (http://jasmin.ac.uk).

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