

# Article Satellite Imagery-Based Damage Assessment on Nineveh and Nebi Yunus Archaeological Site in Iraq

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Abstract: During the last decades, archaeological site looting throughout Iraq has increased significantly up to a point where some of the most famous and relevant ancient Mesopotamian cities are currently threatened in their integrity. Several important archaeological monuments and artifacts have been destroyed, due to ISIL attacks and associated looting. Since 2016, the policies of the European Union have been increasingly harsh to condemn these atrocious acts of destruction. In such a scenario, the European Union Satellite Centre can be an invaluable instrument for the identification and assessment of the damage in areas occupied by ISIL. A detailed view of the damage suffered by the Nineveh and Nebi Yunus ancient sites, in Iraq, was assessed via visual inspection. The analysis was conducted considering the main events that occurred in the city of Mosul, between November 2013 and March 2018. More than 25 satellite images, new acquisitions and archived, supported by collateral data, allowed the detection and classification of the damage occurred over time. A description of the methodology and the classification of category and type of damage is presented. The results of the analysis confirm the dramatic levels of destruction that these two ancient sites have been suffering since 2013. The analysis reported in this paper is part of a wider study that the SatCen conducted in cooperation with the EU Counter-Terrorism Office and PRISM Office. The whole activity aimed at confirming to EU institutions the massive looting and trafficking operated in the area. The results have been provided to archaeologists in the field as well in support of local authorities who are trying to evaluate the current situation in the area.

**Keywords:** cultural heritage; damage assessment; looting; remote sensing; very high resolution; Iraq; Niniveh; Nebi Yunus

# 1. Introduction

In summer 2014, the military conflict and the political upheaval that were affecting the surrounding regions of the Middle East swept across Iraq, exposing the rich cultural heritage to unprecedented threats from looting, direct conflict-related damage, and ideologically-driven destruction of sites and monuments [1–5]. Due to the impossibility of archaeologists or heritage officials to access most parts of the war-ravaged country, only scarce and inaccurate information on the status and the destruction of archaeological sites and monuments could be available. In such a scenario, Very-High Resolution (VHR) satellite data (optical) represent an invaluable asset to support the evaluation of the level of damage to archaeological sites and to estimate looting activities in all those areas. The use and analysis of this type of data can also provide the possibility to cross-check information against ground observations of the damages reported by civilians, media, and government reports [6–8].



Even if there is some criticism on the use of image-based analyses, e.g., inherent limitations in terms of spatial and temporal resolution [9], satellite data investigations can reveal forms of damage much more effectively than other means (e.g., in-situ measurement) [10–15]. Indeed, ground observations focus mainly on damage to historic buildings and monuments (usually located in urban areas), because these are most evident, but rarely recognize wide-area looting, especially at remote archaeological sites. Satellite data, instead, can be effective at revealing earth-moving, destruction, and looting, particularly outside urban areas, thanks to the capacity of such sensors to acquire information on vast areas, with detail of less than 1 m. In many cases, the evaluation of damage to archaeological sites to large and recent datasets, that would allow characterizing their evolution during the time. The use of images provided through Google Earth, Bing Maps, and other free access web mapping platforms can reveal damage to heritage, but these data are only updated infrequently while buying commercially available images can be very expensive [16,17].

This paper presents the results of a wide analysis of two important archaeological sites located in Mosul city, in Iraq. These sites are Nineveh, the ruins of the former capital of the Neo-Assyrian Empire, and Nebi Yunus, the Mosque of the Prophet Jonah. The analysis demonstrates the massive damage that the cultural heritage in these areas suffered during the period 2013–2018, while controlled by the Islamic State of Iraq and the Levant (ISIL). More than 25 VHR satellite images were used and the analysis was conducted by visual inspection from a team of expert Image Analysts of the European Union Satellite Centre.

#### 2. Cultural Heritage in EU Policies

Cultural heritage has always been subject to destruction, looting, and illicit trafficking, but nowadays the protection and preservation of such patrimony imply challenges that are more complex than ever. In the Middle East and North Africa, the destruction and looting of archaeological sites have become a systematic activity managed and carried out by well-organized armed groups. It is hard to provide an assessment of the global extent of the illicit trafficking in cultural property, but it has been estimated that this phenomenon has a value of between \$6 billion and \$8 billion per year [18].

The United Nations Educational, Scientific and Cultural Organization (UNESCO) defined cultural heritage broadly as "the legacy of physical artifacts and intangible attributes of a group or society that are inherited from past generations, maintained in the present and bestowed for the benefit of future generations". The vision of cultural heritage has constantly evolved since the adoption of the 1972 Convention Concerning the Protection of the World Cultural and Natural Heritage (the World Heritage Convention). This vision covers architectural works, sculptures, paintings, archaeological structures and inscriptions, cave dwellings, groups of buildings, and sites comprised of the works of humans, or humans and nature, of outstanding universal artistic, historic, scientific, anthropological, ethnological or aesthetic value [19].

In acknowledging the importance of cultural heritage as an integral part of its values, the European Union (EU) strongly committed to promoting a global order based on peace, rule of law, freedom of expression, mutual understanding, and respect for fundamental rights. As a key partner of the United Nations (UN), the EU cooperates closely with UNESCO to safeguard the world's cultural heritage. As a party to the 2005 UNESCO Convention on the protection and promotion of the diversity of cultural expressions, the EU is committed to promoting the diversity of cultural expression as part of its international cultural relations [20].

On 8 June 2016, the EU High Representative and Vice-President Federica Mogherini and Commissioner Tibor Navracsics put forward a proposal to develop an EU strategy to international cultural relations. In a joint communication, it is reported that "the EU has adopted restrictive measures towards Syria and transposed UN sanctions against Daesh/ISIL and Al-Qaida, as well as the UN sanctions regime for Iraq: these include a ban on illegal trade in cultural and archaeological artefacts" [21].

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In June 2016 as well, the European Union published its Global Strategy for the Foreign and Security Policy, establishing Societal Resilience as one of the priorities of the European Union Global Strategy. "We will nurture societal resilience also by deepening work on education, culture, and youth to foster pluralism, coexistence, and respect.", thus underlining the importance of culture as a vector for the construction of resilient societies [22].

The UN Security Council, in March 2017, unanimously adopted Resolution 2347, the first Resolution dedicated exclusively to the destruction and trafficking of cultural heritage in situations of armed conflict in general and at the hands of terrorist groups in particular [23]. On May of the same year, the Council of Europe, with its 47 European member countries, ratified an international treaty specifically dealing with the criminalization of the illicit trafficking of cultural property, establishing several criminal offences, including theft; unlawful excavation, importation and exportation; and illegal acquisition and placing on the market [24]. Finally, in January 2019, the European Parliament "Underlines that the looting of works of art and other cultural goods, during armed conflicts and wars, as well as in times of peace, is a major shared concern that needs to be addressed in terms of both prevention and restitution of looted cultural property in order to protect and ensure the integrity" [25].

#### European Union Satellite Centre

The European Union Satellite Centre (SatCen) is a decentralized agency of the Council of the European Union working under the political supervision of the Political and Security Committee and the operational direction of the High Representative of the Union for Foreign Affairs and Security Policy. It is located near Madrid and it supports the decision making and actions of the European Union in the field of Common Foreign and Security Policy (CFSP), in particular, Common Security and Defence Policy (CSDP), including European Union crisis management missions and operations, by providing products and services resulting from the exploitation of relevant space assets and collateral data, including satellite and aerial images, and related services (more details at https://www.satcen.europa.eu). During crises, or to evaluate the situation in zones of conflict, the SatCen can be requested to monitor an area or identify specific activities. For cultural heritage site,s the request could be related to:

- the analysis of destruction;
- the identification of destruction due to fundamentalist motivation;
- the evaluation of damages directly due to conflict; and
- the estimation and quantification of looting activities.

Since 2016, the SatCen has also been entrusted by the European Commission (that coordinate and manage the Copernicus Programme (more details at https://www.copernicus.eu)) to operate the Copernicus Security Service in Support to EU External Action (SEA) (more details at https://sea. security.copernicus.eu). This considerably improved the capacities of the Centre, in terms of resources and access to data.

#### 3. Case Study

The cultural heritage of Iraq is one of the richest and oldest in the world. It has been in constant danger since 2003 due to the instability of the country and the Middle East [26]. For the last decade, the presence of the ISIL has been a direct threat to this cultural heritage; ISIL has declared many religious places and monuments to be idolatrous and blasphemous. Consequently, these places have been subject to vandalism, looting, and destruction. Since ISIL made its appearance in 2014, several important archaeological monuments and artifacts have been destroyed, e.g., the tomb of the biblical prophet Jonah in Mosul or ancient sites in the ancient Assyrian capital of Nimrud [27,28]. This type of attacks captures the attention of the world and is aimed at supporting ISIL's claims of invincibility, as well as representing a convenient way to facilitate the financing of its activities, through

the underground markets of antiquity. ISIL destroyed many archaeological sites as it expanded across Iraq, looting some of them for profit and damaging others to attract attention. Several videos and pictures made available by propaganda Islamist media apparently show ISIL militants destroying ancient artifacts smuggled, looted or even within museums [29,30].

However, some archaeology specialists claim ISIL fraudsters were taking jackhammers to "artistic copies", rather than the actual monuments. In other words, likely, ISIL is not destroying ancient but artistic copies [31]. Some of the most precious artifacts were probably stolen and sold on the black market by ISIL to raise needed funds. Although these cultural objects were probably fake, the danger of ISIL destroying genuine treasures from ancient cities is almost certain [32]. There have been several proofs of ISIL's illicit trafficking in antiquities. In July 2016, the United States Ambassador to Iraq, Mr. Stuart Jones, returned to the National Museum in Baghdad 700 objects and fragments, all of them stolen after 2003. These artifacts were recovered during a US Delta Force commando raid on the Syrian compound of Daesh senior leader Abu Sayyaf on 15 May 2015 [33]. Ambassador Jones said that these artifacts were indisputable evidence that ISIL—beyond its terrorism, brutality, and destruction—was also a criminal gang that was looting and smuggling part of the Iraqi heritage and culture. The illegal trade of stolen archaeological objects was an ISIL attempt to finance its terrorist organization [34]. Those stolen antiquities by ISIL also arrived in the European market. In March 2018, Spanish police arrested Jaume Bagot, a renowned antiquities dealer in Barcelona (Spain), who was accused of years-long involvement in a smuggling ring that trafficked antiquities looted from Libya (Cyrenaic and Tripolitan regions) to finance the Islamic State group. Police alleged he was part of a network, based in Catalonia, that sourced, restored and resold archaeological works from sites that were controlled by jihadists linked to ISIL [35]. According to the Center for the Analysis of Terrorism, in 2015, ISIL generated around \$30 million through the trafficking of antiquities, around 1% of its total revenue [36]. It has been estimated that the revenues of the Islamic State deriving from the looting and trafficking of manufactured goods could be second only to oil traffic [37].

In February 2018, SatCen received the request to analyze and quantify the massive damage and looting suffered by several ancient sites in Iraq, which had been under the control of ISIL for several years. The analysis was part of the activity that SatCen created in close cooperation with the EU Counter-Terrorism Office and PRISM (Prevention of conflict, Rule of law, Integrated approach, Stabilization, and Mediation) Office. It was intended to be used by the new EU Advisory Mission in supporting civilian security sector reform in Iraq (EUAM-Iraq), whose mandate includes the protection of cultural heritage and the fight against organized crime, such as the looting, smuggling, and selling of cultural artifacts. This type of illicit trafficking is highly likely related to the financing of international terrorism. Considering the presence of ISIL in Iraq before 2018 [38], as reported in Figure 1, the request referred to six archaeological sites; five areas are situated in the Northern part of Iraq, two of these within the Mosul city (Nineveh and Nebi Yunus), and the remaining three (Khorsabad, Tepe Gawra, and Nimroud) in the city's close vicinity. The sixth site, Samarra, is located in the central part of Iraq, approximately 100 km north from Bagdad, Iraq's capital.

The analysis provided in this paper focuses on two out of these six sites: Nineveh and Nebi Yunus. Each of the archaeological sites has been carefully analyzed over time (2013–2018) to assess the possible site damage related to war events and the presence of ISIL forces. The SatCen identified the damage suffered from each site by undertaking a comparative analysis between archived and new satellite images, complemented by collateral data. The analysis assessed the status of these sites before and after the arrival of ISIL in the area, and its overall impact over time.



Figure 1. ISIL territory control between 2015 and 2018 [38].

#### 3.1. Archaeological Context

Nineveh is the oldest and most populous city of the ancient Assyrian empire. It is located on the east shore of the Tigris River and surrounded by the modern city of Mosul, Iraq. Nineveh was situated at the intersection of important north–south and east–west trade routes, and its proximity to a branch of the Tigris, the Khawsar River, added to the value of the fertile agricultural and pastoral lands in the district [39]. First mentioned in ancient texts around 1800 B.C., Nineveh became an important trade and religious center and was Assyria's capital city from the ninth through the seventh century B.C. It was destroyed when the Assyrian Empire collapsed, around 612 B.C. In the Bible, it was considered the site of Jonah's famous preaching after escaping the belly of a great fish [40].

After the city's destruction, the site remained uninhabited for centuries until the Sassanian period. The city is mentioned again in the Battle of Nineveh in 627 A.D., which was fought between the Eastern Roman Empire and the Sassanian Empire of Persia near the ancient city. From the Arab conquest 637 A.D. until the modern time the city of Mosul on the opposite bank of the Tigris River became the successor of ancient Nineveh. Before the excavations in the 1800s, historical knowledge of the great Assyrian Empire and its magnificent capital was almost completely unknown [41]. Other cities that disappeared in the past, such as Thebes, Palmyra, and Persepolis, left ruins as a demonstration of their existence and their past magnificence; whoever, of the imperial Nineveh there did not seem to be a single trace, and even the place where it was located became almost a conjecture.

Nineveh archaeological site covers an area of 750 ha and is 12 km long. Two prominent mounds, i.e., the hill of Kuyunjik and the one of Nebi Yunus, lie within its perimeter, surrounded by a large city wall with several gates (Figure 2). The Neo-Assyrian levels of Kouyunjik have been extensively explored, while the Nebi Yunus ones not, due to the presence of a Muslim shrine on the site. However, excavations in 1990 revealed a monumental entryway consisting of several large Neo-Assyrian sculptures [42].

#### 3.1.1. Kuyunjik

The ruins mound of Kuyunjik rises about 20 m above the ancient city surrounding plain. It is quite a large area and measures approximately  $800 \times 500$  m. Its upper layers have been extensively excavated and several Neo-Assyrian palaces and temples have been discovered. In the nineteenth century, several explorations led to the discovery of the glorious edifice of Sennacherib (the "Palace

without Rival") and the famous library of Ashurbanipal, with 22,000 cuneiform clay tablets [42]. Since 1990, the palace chambers have received significant damage by looters. Pictures of the chambers made in 2003 show that many of the fine relief sculptures of these palaces have been reduced to piles of rubble [43].

## 3.1.2. Nebi Yunus

Nebi Yunus is the secondary ruins mound at Nineveh, located about one kilometer south of Kuyunjik. Based on texts left by Sennacherib, the site has traditionally been identified as the "armoury" of Nineveh. In 1990, the excavations revealed a monumental entryway consisting of several large inscribed orthostats and "bull-man" sculptures, some unfinished [44].



**Figure 2.** Overview of the walls and gates of Nineveh, with Nebi Yunus and Kouyunjik mounds location—WorldView-2, 13 November 2013 ©DigitalGlobe.

# 3.1.3. City Wall and Gates

The ruins of Nineveh are surrounded by the remains of a large stone and mud-brick wall dating from about 700 B.C. The wall system consisted of a stone retaining wall about 6 m high, surmounted by a mud-brick wall about 10 m high and 15 m thick. The retaining wall had projecting stone towers spaced about every 18 m. The stone wall and towers were topped by three-step battlements [45]. The entrance through the wall was guaranteed by 15 monumental gateways. They served as checkpoints on entering and exiting the city and were probably used as barracks and armories. With their inner and outer doors closed, the gateways were virtual fortresses. Within each gate structure, a stairway led from

one of its interior chambers to the top of the city wall. Five of the gateways have been explored by archaeologists [46]:

- Mashki Gate, translated as the "Gate of the Watering Places", was probably the entrance used to take livestock to water from the Tigris River, which currently flows about 1.5 km to the west. It has been reconstructed in fortified mud-brick to the height of the top of the vaulted passageway and seems accurate as far as it goes. The Assyrian original may have been plastered and ornamented.
- Nergal Gate, named for the god Nergal and excavated in the nineteenth century, was the gate that may have been used for some ceremonial purpose, being the only known gate flanked by stone sculptures of winged bull-men.
- Adad Gate, named for the god Adad, is the gate partly reconstructed in the 1960s by Iraqis. The result is an uneasy mixture of concrete and eroding mud-brick, which nonetheless does give one some idea of the original structure. The original brickwork of the outer vaulted passageway is well exposed, as is the entrance of the vaulted stairway to the upper levels.
- Shamash Gate, named for the Sun god Shamash, was the first gate excavated in the nineteenth century and partly reconstructed in the 1960s. Its structure projects outward about 20 m from the line of the main wall, the only gate with such a significant projection. Its size and design suggest it was the most important gate in Neo-Assyrian times.
- Halzi Gate is located near the south end of the eastern city wall; exploratory excavations were undertaken on this gate by the University of California expedition of 1989–1990. It features an outward projection from the main city wall, although not as pronounced as at the Shamash Gate. Human remains from the final battle of Nineveh were found in the passageway.

# 3.2. Current Situation

Since 2003, the area of Nineveh and its reliefs were endangered by the lack of proper protective roofing, vandalism, and looting [47]. Its preservation gets further complicated by the proximity of the expanding suburbs. The Mosul Dam is also a constant threat to Nineveh as well as to the entire city of Mosul. This is due to years of decay, the abandonment of a second dam project (around 1980), and occupation by ISIL in 2014 resulting in fleeing workers and stolen equipment. If the dam fails, the entire site could be under as much as 14 m of water [48]. In October 2010, the Global Heritage Fund mentioned Nineveh among the 12 sites most "on the verge" of irreparable destruction and loss, citing looting as one of the primary causes [49]. However, the greatest threat to Nineveh in recent times has been the deliberate actions by ISIL, which first occupied the area in the mid-2010s. In early 2015, ISIL announced the intention to destroy the walls of Nineveh if the Iraqis attempted to liberate Mosul. On 26 February, ISIL destroyed several items and statues in the Mosul Museum and are believed to have plundered others to sell overseas. The items were mostly from the Assyrian exhibit, which ISIL declared blasphemous and idolatrous [50].

The study requested to SatCen was focused specifically on assessing ISIL activity in the area. Thus, the analysis reported in this paper focuses on the period from 2014 to 2017. The period covers the recent years of the conflict, i.e., starting from 2014 up to the setting-up of the new governmental coalition, in 2017. In Table 1, the most important dates and events of this period are listed [51].

Period	Event
June 2014	ISIL takes the control of Mosul
June 2014–February 2015	First reports of ISIL inflicted damage to cultural heritage
16 October 2016	Battle of Mosul begins
03 November 2016	Iraqi forces enter Mosul from the East
January 2017	Entire eastern side of Mosul taken by Iraqi forces
19 February 2017	Beginning of clashes in western Mosul
09 July 2017	Entire Mosul city cleared of ISIL and taken by Iraqi forces

Table 1. Main event during the period 2013–2018 related to the city of Mosul.

#### 4. Materials and Methods

Satellite images provide an objective view of the Earth at a given moment in time; they can, therefore, help in clarifying and understanding the situation on the ground. The big advantages of remote sensing include the ability to collect information over large areas, in some cases unreachable (e.g., due to violent conflict); to characterize natural features or physical objects on the ground; and to observe surface areas and objects on a systematic basis and monitor their changes over time [52]. Nowadays, the use of remote sensing for archaeology and cultural heritage exploration is a well-known discipline. Several manuscripts, articles, and books (e.g., [53–62]) have been published, highlighting the capability of remote sensing for the discovery of new archaeological sites, cultural heritage assessment, and monitoring of the effects caused by natural- or human-induced threats. Users such as image analysts, archaeologists, and heritage conservators use satellite image analysis as a powerful instrument for their activities.

In [63,64], Tapete highlighted the lack of common standardized methods for data processing. Remote sensing is commonly used in archaeology in combination with other types of data, such as geophysical surveys, ground-truth and historical data collection. The way in which remote sensing and other sources of information are combined, mainly depends on the expertise of the analyst or researcher. Thus, workflows (from data collection to analysis) are mainly designed by each research team to fit for the purpose they need to address. In [5,65], Danti et al. and Rayne et al., respectively, described how archaeologists with skills in remote sensing (or supported by image analysts) can exploit large volumes of VHR images for damage mapping and assessment on a regional scale. Both studies produced geospatial databases for spatial and temporal analysis. The analysis in [5] is based on the combination of satellite-data analysis with ground-based observations and open-source information. The study was conducted on the area of Nimrud and the Old City of Mosul, in northern Iraq, and Palmyra in Syria. The defined methodology demonstrated its utility in addressing cultural heritage assessment in conflict zones. The work in [65] instead focused on the combination of multi-temporal satellite images with open-source data to create a detailed database on a specific site.

Chyla [66] and Parcak et al. [67], with different methodologies, showed how the expansion of agriculture and urbanization impacts on Egyptian archaeological heritage, and how satellite-based assessments can support decision-making in a timely manner. Finally, in [68], Agapiou et al. proposed a methodology for the detection of looting activities in archaeological sites based on a combination of indices (e.g., vegetation) and data processing (e.g., data fusion and object-oriented classification) on VHR multispectral satellite data (WorldView-2) and RGB high-resolution aerial orthorectified images.

However, satellite optical data can present some limitations. In particular, cloudy weather can completely obscure the view from satellite, causing the usage of such data to be useless. Another limitation can be related to the spatial resolution of the data. Each pixel of a VHR image usually corresponds to areas with approximately from 50 cm  $\times$  50 cm to 70 cm  $\times$  70 cm size on the ground. Therefore, not all the details related to damage can be fully observed, identified, and recognized.

Some of the damage or changes cannot be identified solely based on imagery. For example, the damage inflicted inside a building or below a roofed structure cannot be detected with satellite images. Thus, in this study, the analysis with satellite data was complemented by collateral information. The joint use of satellite images and collateral data (e.g., ground-based images or measures) provided further information about the status of a site at the time of the acquisition and causes of such a situation. However, given these limitations, the damage assessment herein has to be considered an estimate.

#### 4.1. Dataset

The whole task requested by the EU organization required the analysis of 117 images and the publication of a report in less than two months. For the two sites described in this paper, 27 of the 117 VHR satellite images were considered. All the images were delivered in RAW mode and then orthorectified and pansharpened internally. These two methodologies were used to correct acquisition issues and improve image resolution before proceeding with the analysis of the images.

Raw satellite images contain distortions (due to sensor orientation, topographical variation and Earth curvature). When an image is collected, it needs to be processed to correct inaccuracies; this process is called orthorectification. Distortion effects change throughout the image, thus a ground control point adjustment cannot compensate these errors. The correction process considers topographical variations and sensor orientation to re-arrange pixels to their correct position. Once orthorectified, images can be used for direct measurement, feature extraction, and other applications requiring measurement-ready data [69]. For this step, the orthorectification tool included in ArcMap was used. Pansharpening is an image-fusion methodology that combines the high resolution of panchromatic images with the lower resolution of multispectral ones. The result of such method is a colored image with a higher resolution. This step is required since the images have different geometric resolution, and this does not allow their direct overlay [70]. The type of pahsharpeing used is the Gram–Schmidt one [71], included in ArcMap.

Due to the urgency to provide timely manned results and to the availability of satellite data at the time of the analysis, there was no possibility to provide further type of analysis (e.g., Stereo-Pair Imagery Processing [70]). In one case, i.e., Worldview-1 image, only panchromatic band was available. The remaining 26 images (i.e., QuickBird, Pléiades-1, GeoEye-1, WorldView-2, and WorldView-3) were available in four bands (i.e., panchromatic and RGB). In Table 2, the list of images used with their acquisition date and the reference to the related event is reported.

	Acquisition Date Satellite		Spatial Resolution	Number of Images	Related Event
	15 November 2013	Worldview-2	0.5 m	1	Before ISIL presence
-	21 June 2014 19 July 2014 30 July 2014 21 August 2014	QuickBird QuickBird QuickBird GeoEve-1	0.6 m 0.6 m 0.6 m 0.5 m	4	ISIL takes control of Mosul (June)
-	10 February 2015 6 August 2015 19 December 2015	Pléiades-1 Pléiades-1 Pléiades-1	0.5 m 0.5 m 0.5 m	3	First reports on ISIL inflicted damages to cultural heritage
_	1 April 2016 02 May 2016 21 May 2016 16 June 2016 17 July 2016 29 July 2016 5 August 2016 11 August 2016 23 August 2016 19 September 2016 9 October 2016 20 November 2016	GeoEye-1 Worldview-2 Worldview-3 Worldview-3 Worldview-3 Worldview-3 Worldview-3 Worldview-2 Worldview-2 Pléiades-1 Pléiades-1	0.5 m 0.5 m 0.3 m 0.3 m 0.3 m 0.3 m 0.3 m 0.3 m 0.5 m 0.5 m 0.5 m	12	Battle of Mosul (October), Iraqui forces enter Mosul (November)
-	1 February 2017 12 March 2017 16 April 2017 11 June 2017 18 August 2017 14 November 2017	Pléiades-1 Pléiades-1 Pléiades-1 Pléiades-1 Worldview-3 Worldview-1	0.5 m 0.5 m 0.5 m 0.5 m 0.5 m 0.5 m	6	Clashes between ISIL and Iraqui forces (until July)
	12 March 2018	Worldview-2	0.5 m	1	Iraq forces present (from July 2017)

**Table 2.** Summary of satellite imagery used for the Nineveh and Nebi Yunus archaeological sites, related to Mosul recent event timeline.

Note: All images have four bands (panchromatic and RGB), except the Worldview-1 one (only panchromatic).

#### 4.2. Methodology

As introduced above, the analysis reported herein is part of a wider study and emerged out of an initial urgent need (i.e., two months to finalize the study) to evaluate the extent and severity of damage on the requested sites in the context of the Iraqi war. In particular, the final aim of the whole study was:

• to demonstrate the massive looting and trafficking operated in the areas that were controlled by DAESH to some EU institutions;

- to increase the efficiency of the new EU Advisory Mission in support of Security Sector Reform in Iraq (EUAM Iraq), whose mandate was modified to include cultural heritage; and
- to help archaeologist to return to work to those places.

Therefore, many of the decisions made in the design and implementation of the study were driven by this exigency. A strategy to survey systematically samples for each of the sites was quickly sought. Observations were recorded in a manner that would facilitate spatial and temporal queries. Specifically, the data were organized to easily determine how many sites were damaged and how severely, what type of damage they suffered, and when it occurred.

The database was designed considering all the information available via collateral sources. Primarily loci of the ancient settlement, including mounded sites, architectural ruins, and dense artifact scatters were considered. Other features such as ancient cemeteries, ritual installations, or monuments as well as main roads, waterways, etc. were taken into consideration (Figure 3) as well. The possibility to access a vast archive of VHR satellite imagery dating back to 2013 offered a unique opportunity to institute a large time-scale monitoring effort on the areas considered.



**Figure 3.** Overview of the main roads and waterways overlapped on walls and gates of Nineveh area—QuickBird, 19 July 2014 ©DigitalGlobe.

#### Damage Assessment Protocols

Thanks to more than 25 years of experience in the domain of geospatial intelligence, the SatCen owns a clear understanding of all the types of damage that can be detected by imagery-based assessment (e.g., looting, earth-moving, construction, militarization, or other issues). As introduced previously, the areas considered are the Nineveh and Nebi Yunus archaeological sites and correspond to approximately five square kilometers. The boundaries and specific areas of the archaeological sites have been delimited on the oldest available image with the support of collateral archaeological sources (e.g., maps and reports) [72,73]. All the images were uploaded into the ArcGIS suite. Analysts access the site database in ArcMap and then turn on and off individual satellite images while logging observations. For each site, the comparison of the images was conducted within the considered time-frame (2013–2017). Any type of change observed was logged into a damage assessment table. To facilitate the use by multiple analysts, each user first accesses a central database, creates a copy locally, proceeds to save observations, and then synchronizes the results with the central database. Each satellite image was then carefully examined looking for signs of damage to the archaeological site and its close surroundings. Each observed instance of damage was cross-checked against all available images and classified accordingly.

The classification of the observed damage was grouped into three main categories (damage driver), while five possible types of damage were identified. Within each category, one or more types of damage were associated (Table 3).

Damage							
Category	Possible Looting	Fundamentalist	Military				
Туре	Destruction Partial destruction Earth movement	Destruction Partial destruction Earth movement Construction	Destruction Partial destruction Earth movement Construction Weapon impact				

Table 3. Classification of damage observed by category and type.

The analysis and classification of the damage were defined based on three main categories and qualified according to the type of damage detected. The characterization of the damage is based on the SatCen analysts experience in battle-damage assessment. This information was then cross-checked with collateral data. Information coming from news, social media, and other web content was investigated and used to refine the analysis. Collateral data were used to get an overview of the situation in the area (e.g., political and military) at different times and correlated with the observations detected on the corresponding images to categorize the damage. Damage definition and characterization were conducted in line with different NATO standards (to consult the different standards, please refer to https://nso.nato.int/nso/nsdd/listpromulg.html; some of the standards could have limited access), such as:

- STANAG 3596: Air Reconnaissance Requesting And Target Reporting Guide, published 26 November 2007
- ATP-26(A): Air Reconnaissance Intelligence Reporting Nomenclature, published on 1 January 1989
- AAP-06: Nato Glossary of Terms and Definitions, published on 8 November 2018

## 4.3. Damage Category

Damage category refers to the driver of the damage. The damage identified in a region was then associated with one of three distinct categories, which represent the "reason" behind the damage of the cultural heritage site.

- Looting is defined as the illegal excavation and plundering of an archaeological site, done to gain profit (e.g., by selling what has been plundered). A typical sign of looting on satellite images is the presence of numerous, amorphous, dark holes in the ground (diameter of 1–3 m), caused by manual digging. However, looting can also be carried out by using types of machinery, such as bulldozers and excavators, and in such cases it is difficult (sometimes impossible) to distinguish between construction work and deliberate destruction. For this reason, the corresponding category of damage was named "Possible looting". Removing reliefs from walls or stealing artifacts from buildings or ruins (e.g., temples and palaces) is also classified as looting, but this type of activity cannot be observed or tracked using satellite images. What has been observed during the analysis of these archaeological sites is that possible looting holes were often already present onsite before the arrival of ISIL forces. This suggests that, during periods of instability (e.g., war and conflict), archaeological sites lack proper protection and therefore looting can take place. Within the analysis results, the most prevailing types of damage observed in combination with looting are "partial destruction", which covers damage such as holes in the ground, and (to a lesser extent) "earth movement", which covers damage such as large quantities of the ground being moved.
- **Fundamentalist** damage is defined as all types of site damage (especially "destruction" and "partial destruction") that correspond with the ISIL presence in the area. Damage in this category was driven by ISIL's belief that many monuments and places of cult (even very old ones) include images idolatrous and blasphemous to their beliefs, namely cult locations to gods other than Allah, or figurative representations of humans, animals, or plants. This type of damage can be identified in satellite images due to the extent and the clear intentional damage applied to cultural heritage. Among all types of observed damage, the ones associated with fundamentalist are "construction", "destruction", "earth movement", and "partial destruction".
- Military damage is defined as all types of actions related to military activity, e.g., defence
  positions, construction of perimeters, revetments, or trenches located on an archaeological site,
  as well as damages due to weapon impact or explosion. Within the analysis results, the most
  prevailing damage type associated with looting are "construction", "earth movement", and
  "weapon impact".

# 4.4. Type of Damage

Damage type refers to the action directly causing the damage. This taxonomy of damage refers to the morphology and extent of the damage. Even if the causes attributable to observed damage are often due to a combination of different factors (or types) of damage, it may be useful to understand the most prevalent one to facilitate the analysis and the assessment. The types of damage identified in the images considered are as follows.

- **Partial Destruction**: Damage directly applied to a structure that results in a partial destruction.
- **Destruction**: Complete destruction of a cultural heritage element.
- **Construction**: Characterized by the presence of new infrastructure built in the area. The process of construction may affect cultural heritage by destroying directly or by looting of construction materials.
- **Earth movements**: Removal of objects using construction vehicles affecting directly cultural heritage.
- **Weapon Impact**: Characterized by the presence of craters or localized destruction on buildings with the associated presence of expelled debris.

A list of examples of damage types are reported in Figures 4–9.



(**a**) GeoEye-1, 21 August 2014

(b) WorldViev-2, 12 March 2018

**Figure 4.** Destruction damage type related to demolition. The northwest palace of Nimrud had an interpretation center and protective structures that have been demolished ©DigitalGlobe.



(a) GeoEye-1, 21 August 2014

(**b**) WorldViev-2, 12 March 2018

**Figure 5.** Partial destruction and construction damage types due to large infrastructure, such as highways passing through the area, have damaged ancient walls©DigitalGlobe.



(a) QuickBird, 30 July 2014

(**b**) WorldViev-2, 12 March 2018

**Figure 6.** Construction damage type related to uncontrolled construction activities. Trenches affecting buried heritage have been opened and new buildings have been constructed over cultural heritage site (highlighted in yellow)©DigitalGlobe.



(**a**) GeoEye-1, 12 February 2016

(b) WorldView-2, 6 December 2016

**Figure 7.** Construction damage type related to new defence position including strongholds, revetments and trenches directly over cultural heritage sites (highlighted in yellow) ©DigitalGlobe.



(a) WorldView-3, 2 December 2015

(b) WorldView-3, 25 October 2017

**Figure 8.** Earth movement damage type. The Ziggurat of Nimrud was bulldozed to the ground. The marks of the bulldoze are clearly visible in the image, as well as posterior looting in the form of small excavations (highlighted in yellow) ©DigitalGlobe.



(a) WorldView-2, 21 August 2015

(**b**) GeoEye-1, 12 February 2016

**Figure 9.** Weapon impact damage type, where impact craters can be identified in the imagery (highlighted in yellow) ©DigitalGlobe.

# 5. Results

In the areas of interest corresponding to the Nineveh and Nebi Yunus sites (around five square kilometers), a total of 268 points have been identified and classified (Figure 10). Each point of damage or change observed has been encoded into a geodatabase with its corresponding category, type, and date of the image associated.

As reported in Figure 11, the damage observed over the entire period (November 2013–March 2018) has been assessed as mostly falling under the fundamentalist category (55%), followed by military-related damage (30%) and possible looting (15%). As regards the type of damage, construction-related damage predominated (49% of all cases), followed by partial destruction (22%), weapon impact (12%), earth movement (10%), and destruction (7%). The predominance of construction-related damage reflects the expansion of housing and farms (the area of Nineveh was already occupied with dwellings), as well as temporary military checkpoints and booths erected and dismantled along the site perimeter during the monitoring period.



Figure 10. Distribution of damage by category (top-half) and type (bottom-half) per year (2013-2018).



Figure 11. Distribution of damage in the overall period (November 2013–March 2018).

The yearly breakdown (by category and type) is reported in Tables 4 and 5 and represented graphically in Figures 12 and 13. As highlighted in Table 4, the highest volume of damage has been observed in 2016. The majority of the events identified in this year is ascribable to fundamentals activity. The corresponding types of damage are: construction, partial destruction, earth movement, and destruction (Table 5).

Category of Damage	Total	2013	2014	2015	2016	2017
Possible Looting	39	26	-	1	12	-
Fundamentalist	148	2	8	22	82	34
Military	79	-	-	36	4	39
Total	266	28	8	59	<b>98</b>	73

**Table 4.** Distribution of the damage (total and per year) grouped by category.

Table 5. Distribution of the damage (total and per year) grouped by type.

Type of Damage	Total	2013	2014	2015	2016	2017
Partial destruction	59	26	-	3	30	-
Destruction	19	-	1	2	9	7
Construction	131	2	7	39	49	34
Earth movement	25	-	-	15	10	-
Weapon impact	32	-	-	-	-	32
Total	266	28	8	59	98	73



**Figure 12.** Distribution of damage by category observed over the entire period (November 2013–March 2018).

Figure 12 shows that, during 2013–2016, the fundamentalist component of the damage to cultural heritage grew exponentially. This trend follows the sequence of events reported in Table 1 and is directly related to the escalation of ISIL activities in the area. ISIL's cultural heritage devastation started in 2014 when the Mosque of Prophet Jonas was blown up, and continued during 2015 and 2016.

Between 2016 and 2017, the inversion of the fundamentalist damage category trend, and the corresponding increase of the military one, reflects the evolution of the conflict in Iraq, which saw the advance of government forces and the consequent retreat of ISIL militias. This trend can be also found considering the distribution of type of damage, as shown below.



**Figure 13.** Percentage of damage by type observed respect to the total (100%) over the entire period (November 2013–March 2018).

The peak of this destructive escalation is represented by the most dramatic damage that occurred in the area, between May and June 2016, i.e., the destruction of Sennacherib's Palace and the three ancient gates by ISIL. In late 2016 and during 2017, during heavy clashes between Iraqi and ISIL forces, more military-related damages were observed within the site and its direct vicinity. Damage depicted in 2013 most likely corresponds to acts of looting done before ISIL's presence in Mosul.

Analyzing the yearly distribution of damage by type, Figure 13 highlights that the predominant component of the damage in 2013, i.e., partial destruction with 93% of the total damage observed, has been completely replaced by the construction type just one year after (2014). The component of construction type damage between 2014 and 2017 reduce its percentage up to reach 47%. In that year, as identified in Figure 13, the starting of armed clashes in the city produced evident components of weapon impact damage type (44%).

#### 5.1. Detailed Analysis—Damage Evolution 2013–2018

The following paragraphs show a detailed analysis of the evolution of the damage over time within five different areas in the Nineveh Archaeological Site perimeter. The detailed analysis covers the damage assessment observed during the monitoring period over the following sites:

- Nebi Yunus Mosque
- Senacherib's Palace
- Nergal Gate
- Adad Gate
- Mashki Gate

#### 5.1.1. Nebi Yunus Mosque

The hill of Nebi Yunus lies within Nineveh in the Mosul city (Figure 14). The mosque of Prophet Yunes a Sunni mosque and previously an Assyrian Church was located on top of the mound. The Mosque of Prophet Jonah was believed to be the burial place of the Prophet Jonah. This place was a key figure in Christianity, Judaism, and Islam.

This site was severely damaged between July 2014 and April 2016. The first satellite image considered, a Quickbird image of 19 July 2014, shows the status of the Mosque before the attack (Figure 15a). A ground picture dated 2013 shows a ground view of the Mosque before the presence of ISIL within Mosul city (Figure 15b). The main parts of the mosque (such as the main prayer hall, minaret, and dome) were recognizable.

Late July 2014, ISIL released a video showing the destruction of Jonah's tomb (Figure 16). In the Quickbird satellite imagery of 30 July 2014, after the explosion, the main parts of the mosque (main prayer hall, minaret, and domes) and some of the secondary parts (ablution and part of the courtyard) have been observed destroyed (Figure 17a). After this destruction, construction equipment, and several earthworks have been observed at the site of the former mosque's prayer hall and its eastside in the GeoEye-1 satellite imagery of 21 August 2014 (Figure 17b).



Figure 14. Nebi Yunus location—WorldView-2, 18 March 2018 ©DigitalGlobe.



**Figure 15.** Overview of the Nebi Yunus Mosque before the destruction: (**a**) QuickBird, 19 July 2014 ©DigitalGlobe; and (**b**) ground picture in 2013 [74].



(a) pre-demolition

(**b**) moment of the demolition

**Figure 16.** Destruction of Nebi Yunus Mosque—two frames of the video released by ISIL in late July 2014 [27].



Figure 17. Cont.



Figure 17. Satellite imagery of the Nebi Yunus Mosque (2014–2017).

Besides, in the Pléiades-1 satellite imagery of 19 December 2015, a new secondary entrance has been detected at one side of the access road. The excavations could have been due to gain access to the palace of King Esarhaddon, located under the former mosque, and discovered by ISIL (Figure 17c). In the WorldView-1 satellite imagery of 14 November 2017, a high volume of light utility vehicles starts to be observed at the parking area to the west of the former mosque. In the same image, the secondary entrance appeared to be closed at that time (Figure 17d). Nebi Yunus suffered heavy damage, and possible plundering during the monitoring period. It has not been possible to understand if some cultural artifacts were removed from the mosque before the explosion.

#### 5.1.2. Sennacherib's Palace

On the Kouyunjik hill, about 20 m above the surrounding plain of the ancient site, the remains of the ancient Sennacherib's Palace were located (Figure 18). The palace was destroyed between April and May 2016. Figure 19a shows the Palace before the attacks in a GeoEye-1 image of 1 April 2016, while Figure 19b shows the corresponding ground view before the presence of ISIL within city of Mosul (2011). In the WorldView-2 image of 2 May 2016, the roof that is protecting the site has been removed, but no signs of the explosion have been observed, with largely intact reliefs being left in the open/exposed to the meteorological elements (Figure 20a). Later in the month, as reported in the WorldView-3 image of 21 May 2016, the Palace has been destroyed, probably with explosives. Possible raw materials (former structure frames) have been observed amongst the remaining debris within the site perimeter (Figure 20b). On 11 August 2016, the previously observed raw materials were no longer present (Figure 20c).

These tragic acts have been condemned by UNESCO's Director-General in a note issued 18 April 2018 (https://whc.unesco.org/en/news/1483), which stated that: "[...] These deliberate destructions are a war crime against the people of Iraq, whose heritage is a symbol and medium of identity, history, and memory. These destructions are linked to the suffering and violence on human lives, and weaken the society over the long term. They are also attacks against the humanity we all share, against the values of openness and diversity of this region, as the cradle of civilizations" [sic].

The Sennacherib's Palace suffered almost total destruction; large parts of the ruins and artifacts have probably been removed from the site and transported to unknown locations.



Figure 18. Sennacherib's Palace location—WorldView-2, 18 March 2018 ©DigitalGlobe.



**Figure 19.** Overview of the Sennacherib Palace before the destruction: (**a**) GeoEye-1, 1 April 2016 ©DigitalGlobe; and (**b**) ground picture of Sennacherib's Palace 2011 [75].



(a) WorldView-2, 2 May 2016 ©DigitalGlobe.

(b) WorldView-3, 21 May 2016©DigitalGlobe.



Figure 20. Satellite imagery of Sennacherib Palace (2016).

# 5.1.3. Nergal Gate

Nergal Gate was one of the former gates of Nineveh, located within the northern site perimeter (Figure 21), where ancient ruins have been severely damaged or destroyed during the monitoring period.

In Figure 22a, a GeoEye-1 image acquired on 21 August 2014 confirms the integrity of the Nergal Gate, as reported in a ground view picture of 2006 (Figure 22b). The access ramp, the ancient rock wall on both sides of the gate, and some pre-existing excavations are visible.



Figure 21. Nergal Gate location—WorldView-2, 18 March 2018 ©DigitalGlobe.



**Figure 22.** Overview of the Nergal Gate before the destruction: (**a**) GeoEye-1, 21 August 2014 ©DigitalGlobe; and (**b**) ground view as seen in 2006 [76].

In May 2016, ISIL released pictures showing a bulldozer close to Nergal Gate's ramp, apparently disgorging a possible section of sculpture into a waiting dump truck (Figure 23).



Figure 23. Image released by ISIL of heavy equipment vehicles at Nergal Gate in May 2016 [76].

The analysis of the satellite image acquired on 21 May 2016 (Figure 24a) confirmed the presence of heavy equipment vehicles in the area at that time. The ruins of the gate and the pre-existing excavations have been demolished.



(b) WorldView-3, 16 June 2016©DigitalGlobe.

Figure 24. Satellite imagery of Nergal Gate (2016).

In June 2016, the site perimeter appeared leveled and covered with earth, as documented by the WorldView-3 satellite image acquired on 16 June 2016. Only the remains of the former access ramp were visible. No vehicle or human activity has been observed around at that time (Figure 24b).

Nergal Gate suffered near-total destruction during the reporting period; large parts of the ruins and artifacts have been probably removed from the site and transported to unknown locations.

# 5.1.4. Adad Gate

Adad Gate was one of the former gates of Nineveh, located within the northern site perimeter (Figure 25), where ancient ruins have been severely damaged or destroyed during the monitoring period. The Adad Gate ruins and the ancient rock wall were visible on both sides of the gate in the GeoEye-1 satellite imagery dated 1 April 2016 (Figure 26a) and in the ground picture (Figure 26b) acquired before the ISIL presence in the area (before 2013).



Figure 25. Adad Gate location—WorldView-2, 18 March 2018 ©DigitalGlobe.



**Figure 26.** Overview of Adad Gate before the destruction: (**a**) GeoEye-1, 1 April 2016 ©DigitalGlobe; and (**b**) ground view (before 2013) [77].

In the WorldView-3 image on 2 May 2016, the ruins of the gate have been partially demolished and an entire section of the ancient rocky wall has been destroyed, leveled, and probably covered with earth (Figure 27a).



(a) WorldView-3, 2 May 2016 ©DigitalGlobe.

(b) Pléiades, 9 October 2016 © Airbus.

Figure 27. Satellite imagery of Adad Gate (2016).

Before that date, ISIL released a video where it is observed how a bulldozer demolished both the gate and the adjacent wall by flattening them (Figure 28).



Figure 28. Heavy vehicle during the destruction of Adad Gate—April 2016 [77].

In the Pléiades-1 satellite imagery of 9 October 2016, some of the rocky wall debris previously observed have been removed from the area and new revetments have been raised (Figure 27b). Figure 29 reports a comparison of two WorldView-2 satellite images dated November 2013 and May 2018 of the northern limit of Nineveh Site, where Adad and Nergal Gates were located. It is evident that the area suffered near total destruction during the ISIL presence; large parts of the ruins and artifacts have been probably removed from the site and transported to unknown locations during the destruction process.



**Figure 29.** Visual comparison of the damages produced on Nergal and Adad Gates sites between 15 November 2013 (WorldView-2) and 1 May 2018 (WorldView-2), ©DigitalGlobe.

# 5.1.5. Mashki Gate

Mashki Gate was one of the former gates of Nineveh, located within the western site perimeter (Figure 30), where ancient ruins have been severely damaged or destroyed during the monitoring period. In the GeoEye-1 imagery dated 1 April 2014 and in the ground picture dated before the presence of ISIL in Mosul (Figure 31a,b, respectively), Mashki Gate ruins and the ancient rock wall were visible and in good status, at both sides of the gate.

The destruction of the Mashki Gate started between the midfle of April and the beginning of May 2016. In the WorldView-3 satellite imagery of 2 May 2016, the ruins of the gate proved to be demolished, leveled, and probably covered with earth. Part of the ancient rocky wall have been also destroyed (Figure 32a).

In mid-April 2016, ISIL released a video showing the destruction of Mashki Gate (Figure 33).

However, in Aug 2016, two sections of the destroyed walls have been recovered by removing the nearby earth (Figure 32b).



Figure 30. Mashki Gate location—WorldView-2, 18 March 2018 ©DigitalGlobe.



**Figure 31.** Overview of Mashki Gate before the destruction: (**a**) GeoEye-1, 1 April 2016 ©DigitalGlobe; and (**b**) ground view (April 1990) [77].







Figure 33. Frame of a video reporting Mashki Gate destruction (April 2016) [77].

#### 6. Discussion

The protection and monitoring of cultural heritage present a number of unique difficulties in the case of conflict situations. The results presented in this paper demonstrate how observations made via EO-based analyses can reveal patterns in the type of damage, its severity, geographic distribution, and timing for archaeological sites in conflict zones. The analysis shows that looting activity already was present before the conflict, however, it was replaced by military and fundamentalist activity during the presence of ISIL. A detailed study of the damage suffered by the Nineveh and Nebi Yunus ancient sites was performed. The analysis was conducted in relation with the main events that occurred in the city of Mosul between November 2013 and March 2018. The archaeological sites of Nineveh and Nebi Yunus suffered irreversible damage during this period. The most dramatic and widely known examples are the destruction of the ancient city gates and Sennacherib's Palace (Section 5.1.2). In addition to the tragic destruction inflicted by ISIL and their believers, the entire sites have also been subject to war-related activities and consequent damage during the monitored period. Furthermore, the lack of adequate protection of the archaeological remains, combined with agricultural and residential expansion (new farms and roads constructed), has also damaged the areas.

The present study is related to an activity that SatCen conducted in cooperation with the EU Counter-Terrorism Office and PRISM Office. The result of this activity was provided to archaeologists in the field that were supporting the work of local authorities in trying to understand the situation

at these ancient sites, some of which are still inaccessible. The reported analysis is based on 27 VHR satellite optical images and collateral information. It tries to summarize all the observed damages suffered by the sites, via a classification based on three categories and five types of damage.

A description of the methodology and the classification in category and type of damage is presented. The combination of satellite and collateral data allowed the characterization of the damage over time. The use of such a large number of images allowed tracking the damage suffered by each site, narrowing the time-frame in which the destruction occurred. However, it needs to be underlined that, due to inherent limitations of satellite images (e.g., spatial resolution), the identification of damage typology can sometimes be ambiguous. As a result of this analysis, the evolution of the damage and its typology was identified and classified. Moreover, this paper highlights the fundamental role that satellite remote sensing can play in monitoring the looting of archaeological sites as well as other forms of damage, particularly in zones where conflict is ongoing and access to sites by heritage officials or archaeologists is limited. While satellite imagery may not be able to reveal the destruction of an individual statue or damage on the inside of a museum, it offers an extremely powerful mean for assessing patterns of looting and damage at a regional scale. Detailed and careful analyses presented here reveal insights about the frequency, scope, and severity of damage that would be impossible to obtain by any other mean.

Future activities aim at extending this analysis to other sites and countries (e.g., Syria and surrounding regions) that are being affected by the ongoing war. New methods will be explored to better identify the types of site that are most commonly being targeted by looters, the chronology of damage throughout the war's history, and the correlation between damage and the shift of the factional control. Moreover, different sensors and data processing will be considered to improve detection capabilities.

Ultimately, it is expected that the information produced will be of value to heritage officials and archaeologists after the war in Iraq has subsided, while also providing a model for remote sensing-based monitoring of archaeological sites in conflict situations more broadly.

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