A multi-temporal satellite-based risk analysis of archaeological sites in Qazvin plain (Iran)

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Abstract
In recent decades, we have witnessed a dramatic increase in the risks and damages to archaeological sites and heritage places across the globe. By analysing a case study (the Qazvin plain) in northern Iran, we propose a classification of the types of risks and damages to archaeological sites and we assess the impact of each type over the last 40 years (1980s–2020s). Our research methodology consists of the cross-correlated multi-temporal analysis of different sets of satellite imagery with 167 archaeological sites in the Qazvin plain to determine the types, extension and evolution of the damages over the time. This methodology allowed to develop a three-tier hierarchical framework based on the drivers, threats, and actions jeopardizing the cultural heritage of the region. The result of this study permits to overturn current narratives inferring that the most impacting risks to archaeological sites and heritage places are caused by natural hazards, looting and violent destruction rather than agricultural activity or construction. Consequently, based on this evidence, we draw a distinction between ‘silent’ but constant and pervasive and ‘loud’ but short-living and circumscribed risks.

KEYWORDS
archaeological risk analysis, cultural heritage, GIS, Iran, landscape archaeology, remote sensing

1 INTRODUCTION

In recent decades, archaeological sites and heritage places around the world have experienced a sharp increase in risks and damages, caused by multiple factors including urban sprawl, construction of dams, agricultural activities and the spread of conflicts.

This trend has been already noticed in several Middle East and Northern Africa (MENA) countries which are long plagued by conflicts, unregulated building constructions, increase of farmland and construction of large infrastructures (Agapiou et al., 2020; Bewley et al., 2016; Cunliffe, 2014; Marchetti et al., 2019; Marchetti, Bitelli, et al., 2020; Zaina, 2019).

Among others, Iran has witnessed a remarkable increase in risks and damages to its cultural heritage during recent decades. This trend has become apparent after 1979 Islamic revolution and during the subsequent 8-year war with Iraq in the 1980s (Rouhani, 2011). Factors including the unregulated industrialization of the region (Fazeli, 2006), the spread of farmlands, the economic fluctuations (Hojjat, 1995) and the numerous environmental effects such as flooding, erosion and rain have played a significant role in this phenomenon. The extent and impact of these types of risks and damages have only been partially understood and in-depth analyses and comprehensive reports are yet to be produced. Moreover, the recent political events and the ever-growing issue of climate change, spread
the idea that violent conflicts and human-induced environmental processes represent the most pervasive types of risks and damages to archaeological sites, monuments and cultural landscape in the MENA region, giving less prominence to other equally destructive threats (ICOMOS, 2000; Lopez, 2016; Zaina, 2019). In this regard, documenting and assessing the risks and damages to the cultural heritage in Iran would be the steppingstone for safeguarding and improving the management of the endangered archaeological sites.

In this paper, we aim to understand the risks and damages affecting archaeological sites in Qazvin Plain (Northwestern Iran) during the last 40 years from the 1980s until 2020s, by applying a multi-temporal approach and using a three-tier hierarchical framework defining the damaging process. To do so, we considered 167 archaeological sites located in the Qazvin plain (approximately 140 km west of the city of Tehran) as a case study. By using multi-temporal satellite imagery, we cross-correlated the archaeological areas with the extensions of the damages through time. After the discussion of the results, in the conclusive section we propose to distinguish between ‘silent’ but constant and pervasive and ‘loud’ but short-living and circumscribed threats.

2 | THEORETICAL BACKGROUND

Despite the growing interest towards the endangered cultural heritage around the world, few studies and reports have challenged the systematic documentation of the risks and damages to archaeological sites and identified the reasons behind them (Broschê et al., 2017; Curtis et al., 2008; Stovel, 1998; UNESCO, 2010; Zaina, 2019; Zerbini, 2018). Recent studies have particularly argued that preservation of cultural heritage should not be limited to the assessment of risks and damages to the archaeological sites; rather, it should address the reasons triggering such risks and damages (Lopez, 2016; Zaina, 2019).

By using the Qazvin plain as a case study, the present paper provides a theoretical and empirical contribution to fill this gap also considering the temporal evolution of the risks and damages.

2.1 | Defining the theoretical framework of risks and damages to heritage

Earliest attempts to systematically frame risks and damages to cultural heritage must be searched within the grey literature reports, generally issued by international organizations such as UNESCO, ICOMOS and ICCROM. Among others, blueprints for heritage experts to design their own risk preparedness strategies were published between the late 1990s and the early 2000s by ICCROM (2016; Stovel, 1998), ICOMOS (2000; Palumbo, 2000), then followed by UNESCO (2010) and Global Heritage Fund (2010). However, while representing a step forward in the field, these studies were mostly limited to environmental and armed conflict-related risks.

Moreover, few studies have attempted to frame both the physical destructive actions and the related drivers using a systematic approach. In this regard, earliest attempts have been conducted in the frame of UNESCO’s definition of specific threats to world heritage (2008) followed by the development of the Disaster Risk Management (DRM) cycle concept (UNESCO, 2010). The former stressed the importance of identifying threats at an early stage of management planning so that monitoring programmes can be developed with appropriate indicators and managers can be guided towards priority management activities. By dividing the threats to current and potentials, the UNESCO framework tries to identify what causes the threats. The status of the threat is then reviewed along with any actions that can be undertaken to reduce the impact of the threat. The DRM provided a step forward by defining a specific terminology and a detailed risk analysis process including, as a first step, a list of natural and human-induced hazards. Also, a two-tier hierarchical framework was developed consisting of a list of primary hazards from which other types of hazards (secondary) may derive (UNESCO, 2010). The DRM has been further developed by recent studies focusing on Europe (Lopez, 2016) and the Near East (Zaina, 2019). The theoretical advance of the frameworks proposed by these new studies relies on the equal importance given to the types of risks and damages and their related drivers (Table 1).

Based on these approaches, we applied a three-tier hierarchical framework (Zaina, 2019), with the first tier represented by the drivers that is a condition, a necessity or a decision causing one or more subsequent processes. The second hierarchical level is characterized by the threats triggered by the drivers. Threats can be defined as one or more types of risks and damages related to one specific driver, even though often possibly connected to more than one, and generating a specific set of physical dangerous actions. The third tier of the framework consists of the physical actions deriving from threats, meaning the tangible activities jeopardizing the cultural heritage preservation.

| Description | UNESCO, 2010 | Lopez, 2016 | Zaina, 2019 |
|-------------|--------------|-------------|-------------|
| A necessity or a decision causing one or more subsequent processes. | – | Risk factors | Drivers |
| One or more types of risks and damages related to one specific driver, even though often possibly connected to more than one, and generating a specific set of physical dangerous actions. | Primary hazards | Threats | Threats |
| The tangible activities jeopardizing the cultural heritage preservation. | Secondary hazards | Physical actions | |
2.2 | Main types of damaging processes to cultural heritage in the MENA region

In this section, we illustrated the main types of drivers, threats, and physical damages to archaeological sites and heritage places in the MENA region. For each of them, we provide a definition, the methodology/ies applied to identify them, and the main literature concerning these types of damages in the MENA region.

2.2.1 | Illicit trade of antiquities—Looting—Holes and trenches

Looting refers to an illegal activity of digging trenches and pits on a site, to eventually recover antiquities for sale on the international market (Brodie & Renfrew, 2005; Proulx, 2013). Looting is a threat that can be expedited and even fuelled by another major driver which is conflict (Zaina, 2019). There is the worldwide growing request for antiquities that primarily leads to looting (Brodie, 2006, 2008a, 2008b, 2011a) which sometimes is fed with the indirect contribution of academic studies and publications of looted objects providing information on the location of important sites and ancient artefacts (Brodie, 2011b). Looting is physically identifiable through remote sensing thanks to the generally circular-shaped holes visible in the satellite imagery. These holes may be isolated or clustered in different parts of the archaeological sites. This type of damages is among the most extensively documented across the MENA, especially in Iraq (Stone, 2008, 2015; Marchetti et al., 2018; Marchetti & Zaina, 2020), Cyprus (Agapiou et al., 2017), Syria (Casana, 2015; Casana & Panahipour, 2014), Egypt (Parcak, 2015; Parcak et al., 2016) and Afghanistan (Hammer et al., 2018; Lauricella et al., 2017).

2.2.2 | Conflict 1—Military activities—Bombing

Attacks to cultural heritage sites are frequent during armed conflicts and have caused international objections over time. In this regard, the 1954 Protocol to the Convention for the Protection of Cultural Property in the Event of Armed Conflict (UNESCO, 1954, 1999) has been developed to ensure the protection and respect of cultural property during an armed conflict. The guiding principles of the Convention not only oblige states not to attack cultural property (art. 4), moreover enforce them to respect the cultural property of the occupied territory (art. 5). According to international agreements, targeting cultural sites is a war crime; however, this does not stop military groups or other terrorist organizations from doing it.

Bombing and missiles can create craters; the bowl-shaped hollowed-out area on the ground. The exact localization of bombing craters by field surveying is the most precise identification method yet time-consuming (Dolejš et al., 2020). Therefore, methods for distant identification using remote sense can be useful. Bomb craters that are smaller in size, that do not have a perfectly circular shape, that blend into the surrounding terrain (Lin et al., 2020).

The cultural heritage of many MENA countries (Hammer et al., 2018) was utterly devastated during armed conflict or civil war. Among others, prominent examples include the bombarding campaign of Iraq in the Gulf war (Forsyth, 2004), the destruction of the temple of Bel in Palmyra (Cunliffe & Curini, 2018) and serious damages to some of the archaeological sites such as Ivan Karkheh in Khuzestan Province (Karimian & Baghban Koochak, 2012) or UNESCO listed heritage, Jame Mosque of Isfahan (Qale Noei & Kalantari, 2012).

2.2.3 | Conflict 2—Military activities—Berms

Military berms are the physical remains of the fighting positions during the wars. In the MENA region, these were mostly used since the 1980s in the flat regions of Iraq and Iran to house soldiers as well as armoured vehicles, including tanks. In order to build berms, large portions of archaeological deposits were removed. In addition to this, the erection of these large barriers covered portions of the archaeological sites that now cannot be explored without removing those barriers. Thanks to their peculiar horseshoe shape, berms can be easily identified through remote sensing.

Berms have been extensively documented using satellite imagery in Iraq (Zaina, 2019) and Syria (Cunliffe, 2014).

2.2.4 | Conflict 3—Non-military activities—Vandalism

When archaeological sites, historical monuments, or other forms of public cultural property are deemed reprehensible or intolerable, they may become targets of vandalism. Williams (1978) provided a list of vandalism practices which impact cultural sites, stating it can have different forms and types. While he categorized ‘demolishing a part or an entire building’ as one of the forms of vandalism, he also emphasized on other forms of vandalism such as ‘carving or scratching’, ‘climbing or walking’, ‘arson’ or even ‘grazing livestock’.

Vandalism practices cannot be easily detectable through satellite imagery. Actions such as ‘soil stealing’ or ‘arson’ are visible in aerial images, but others such as ‘grazing livestock’ or ‘carving’ needs to be confirmed by ground photos. Vandalism is a physical action that can be triggered by conflict.

2.2.5 | Economic development 1—Construction—Buildings

Construction of buildings, including houses, commercial properties or industrial complexes, has a significant impact on cultural heritage. A considerable amount, or even the entire stratification of an archaeological site, may be removed, as a result of cuts made to allocate the foundations. Buildings can be easily identified through remote sensing thanks to their regular shape, proximity to roads and the specific 3D
layers or tags provided by the online platforms such as Google Earth or Bing Maps.

Urban sprawl effect on archaeological sites over the years affected most of the MENA region. However, detailed assessments of this damaging process are available only small areas of Egypt (Global Heritage Fund, 2010), Iraq (Zaina, 2019), Afghanistan (Hammer et al., 2018) or Syria (Cunliffe, 2014).

2.2.6 Economic development 2—Construction—Roads

Construction of roads does not have the same impact on the archaeological sites as construction of buildings does. Building roads over sites means to remove at least the topsoil deposit and the uppermost archaeological layers and to generally replace it with tarmac. As a result, the underlying archaeological levels are sealed, compressed and potentially crushed by the asphalting machines, and subsequently by the means of transport. As for the buildings, roads can be detected through remote sensing thanks to their shape, and colour, the proximity to building and the specific 3D layers or tags provided by the online platforms Google Earth or Bing Maps.

The substantial impact of road construction on archaeological sites in the MENA region as has been highlighted in Iraq (Marchetti et al., 2018) and Syria (Cunliffe, 2014).

2.2.7 Economic development 3—Construction—Earth movement

Earth movement or levelling are among the physical results of the construction activities and consist in the movement of earth, by using bulldozers or other machinery, to create features (like ditches, embankments or walls) or to level ground for allocating structures. Earth movement may significantly modify the archaeological deposits.

Evidence of soil levelling can be gleaned on satellite imagery from different elements, including the presence of flat, single-colour, often regular shaped areas showing traces Earth movement has been recently documented through remote sensing in Iraq (Marchetti et al., 2018; Zaina, 2019).

2.2.8 Economic development 4—Construction/agriculture—Canalization

The use of modern canal systems for irrigation or navigation represented a common practice in the ancient Near East for millennia (Wilkinson, 2003). Depending on the function and, in the case of agricultural interventions, on the area to be cultivated, the depth and width of the canals vary from a few centimetres to several metres. Excavating canals causes not only the removal of archaeological deposits, but also their dumping following the removal, with the consequent sealing of other layers. Dumps located outside of the archaeological site may cause wrong or misleading archaeological interpretations. Very often, the materials emerged from the excavation, can be transported by the water canal even for several kilometres.

Canalization, have been identified through remote sensing thanks to the characteristic bluish regular or irregular lines of the water canals cutting through the sites.

It is generally associated with the identification and study of the impact of ploughing. Examples in the MENA region include, among others southern Iraq (Marchetti et al., 2018; Zaina, 2019) or Syria (Cunliffe, 2014).

2.2.9 Economic development 5—Agriculture—Salinization

Soil salinity is becoming a major issue for crop production and food security in the Near East. This is particularly apparent in large floodplains such as southern Iraq (Wu et al., 2014). The high salt content of river waters, high levels of evaporation, low soil permeability, raised water tables, low gradients, and application of too much irrigation water result in poor drainage and a progressive buildup of salts which reduces crop yields (Wilkinson, 2012).

This phenomenon can be observed through satellite imagery thanks to the characteristic brilliant whitish colour of the saline crust, but it also necessitate confirmation through ground truthing as demonstrated by recent researches in southern Iraq (Zaina, 2019).

2.2.10 Economic development 6—Agriculture—Ploughing

Construction of water infrastructures and the consequent increase of farmlands have heavily damaged the archaeological heritage of the MENA region for decades (Cunliffe, 2014; Zaina, 2019). Besides affecting numerous sites previously identified, the extensive cultivations reveal new ones that had disappeared during the millennia beneath the alluvial deposits. Furthermore, the new modern ploughing systems employ methods (i.e., deeper tilling) and equipment that exploit even the high and steep mounds where the majority of the archaeological deposits are concentrated and as a result, the new agricultural technologies are more disruptive to the historical heritage. Agricultural fields can be easily detected through satellite imagery thanks to their regular shape, the distinguishable number of parallel lines of the ploughing activities and the fact that they are often surrounded by irrigation channels.

Despite its massive and pervasive impact, this type of damage has been poorly documented and understood. Few case studies have been tackled using remote sensing methodologies in Iraq (Marchetti et al., 2018; Zaina, 2019), Afghanistan (Hammer et al., 2018), Egypt (Chyla, 2017) or Syria (Cunliffe, 2014).
2.2.11 | Economic development 4: Construction/agriculture—Dams and water reservoirs

Dams and other large-scale hydraulic infrastructures have a major impact on the cultural heritage, with thousands of archaeological sites and monuments flooded in the MENA region (Cunliffe et al., 2012; Marchetti et al., 2019; Marchetti, Bitelli, et al., 2020) and beyond (Banks et al., 2011; Shen, 2000). The development of these massive infrastructures represents another type of action resulting from construction, as well as from agricultural activities.

Dams create massive water reservoirs that can be easily detected through satellite imagery. Recently, a specific methodology to document the multi-temporal damage caused by slow process of impounding has been proposed by Marchetti, Bitelli, et al. (2020).

In general the study of the impact of dams on archaeological sites in the MENA focuses on the largest ones, where international rescue archaeological projects have been conducted. This is the case of the Aswan dams in Egypt (Marchetti et al., 2019), the Merowe dam in Sudan (Kleinitz & Näser, 2011) the Euphrates dams in Turkey and Syria (Cunliffe et al., 2012; Marchetti et al., 2019; Marchetti, Bitelli, et al., 2020; Shoup, 2006) and the Tigris dams in Turkey and Iraq (GAP, 2000; Lawler, 2002).

2.2.12 | Research and management—Abandonment—Decay

Decay is the physical result of the abandonment of an archaeological site or monument due to the lack of management by the archaeological team or by the local authorities.

Decay is detectable through satellite imagery in those excavated archaeological sites which have been excavated by the shadows made by fallen horizontal structures.

2.2.13 | Environmental process 1: Erosion—Rain and wind

Erosion is the result of the wind or rain activities damaging the surface of the sites. This process leads to gradual wearing away of an archaeological site, revealing previously buried parts of that site. Alternatively, a site can be buried, due to the action of eroded soil earth from elsewhere.

The remote sensing analysis does not help to gather precise data about erosion. As a result, erosion has not been considered in this article.

2.2.14 | Environmental process 2: Geological—Shifting dunes

Over the past 60 years, the massive investments for the development of new irrigation channels in the region have strongly changed the previously desert or semi-desert territory, creating large areas of farmland. However, there are still mainly desert areas characterized by sand dunes of variable size. Dunes cover the surface of the sites and then slowly move forward, due to the wind blowing. In this way, they do not damage the sites, but make them inaccessible for an undetermined period. Thanks to their distinctive curvilinear shape and colour, dunes can be identified through remote sensing.

The effects of dunes have been recently documented in central Iraq (Zaina, 2019).

2.2.15 | Environmental process 3: Geological—Earthquakes

Cultural heritage sites are particularly vulnerable to extreme natural events such as earthquakes and their associated secondary effects such as landslides, ground failures, tsunamis (Pecchioli et al., 2020). The Middle East has one of the best records of historical seismicity in the world, with records extending back more than 2000 years for some areas (Degg & Homan, 2005).

Earthquakes can be hardly identified through remote sensing. Indeed, the most widespread methodologies to document their effect rely on ground truthing. In this regards both academic studies and grey literature extensively addressed this type of environmental-induced damage. Among others, a Global Heritage Fund report (2010). In Iran the effects of earthquake on the UNESCO WHS ancient citadel of Bam, Kerman were investigated by several studies (Ibrion et al., 2015; Nadim et al., 2004). In 2003, it took 10 s to turn this ancient walled city into ruin.

3 | DOCUMENTING THREATS TO CULTURAL HERITAGE IN QAZVIN PLAIN: AIMS AND METHODS

3.1 | Aims

The present study regarding the risks and damages to the cultural heritage in the Qazvin plain is underpinned by two groups of research questions:

1. What types of risks and damages threaten archaeological sites in Qazvin plain?
2. How did these risks and damages developed from 1980s to 2020s? Which ones have had the strongest impact on the archaeological sites?

3.2 | The case study: Introducing the Qazvin plain

Qazvin plain, which meets the city of Tehran 140 km to the east, is a flatland situated at the western end of the central Iranian
plateau (Figure 1). This horseshoe shape area is limited by Alborz mountain ranges to the north and Ramond mountain ranges to the south. The fine-textured alluvial soil here is fertile and when irrigated, extensive agriculture can be sustained, as confirmed by the rich history dating back to as early as the 7000 BC (Fazeli, 2006).

While sporadic explorations of archaeological sites are documented during the 19th and the early 20th centuries CE, the first systematic and extended investigations were conducted from the 1970s onwards (Fazeli, 2006). Particular attention has been paid to the prehistoric period demonstrated by the excavation of a group of sites also known as ‘Sagzabad Cluster’. This consists of three prehistoric and protohistoric mounds known as Zagheh, Qabristan and Sagzabad, located within 2 km far from each other, forming a settlements sequence ranging from the seventh to the first millennium BCE (Majidzadeh, 1977; Neghaban, 1977a, 1979; Schmidt & Fezeli, 2007). Archaeological research in the plain was halted during 1979 political unrest in Iran which was followed by the eight-year war with Iraq in the 1980s. The new wave of excavations and surveys resumed since 1990s has enriched our knowledge of the entire history of the area, chiefly the pre-Islamic periods (Fazeli, 2006; Fazeli et al., 2005). As a result, 167 archaeological sites have been officially documented in the Qazvin plain and the foothills nearby.

### 3.3 Research methodology

The geographic area and the time span considered in this study have been selected for three reasons:

1. Qazvin plain is characterized by a rich and widespread cultural heritage, with a settlement history stretching over millennia from eighth millennium BCE incipient pre-historical villages to Medieval towns (Azarnoush & Helwing, 2005).
2. From 1980 onwards, Iran has experienced a long period of major political instabilities, economic fluctuations and cultural changes (Hojjat, 1995), which have deeply changed the landscape of the Qazvin plain itself (Fazeli, 2006), possibly affecting the local archaeological sites and heritage places.
3. High-quality satellite imagery of the region has become available from 1980s onwards, thus allowing in-depth remote sensing analysis of the risks and damages to archaeological sites and heritage places.²

To answer the aforementioned research questions, we used manual remote sensing technique on multi-temporal satellite imagery (from the 1980s to 2020s) of the selected area. Thanks to its synoptic view and its repeatability, satellite remote sensing provides an effective and powerful tool for monitoring and interpreting changes at
global, regional and local scales (Banks et al., 2017; Elsadaly et al., 2020; Kuenzer et al., 2015; Lasaponara & Masini, 2012; Tapete & Cigna, 2019a). Together with the growth of the open-access data sharing through the web and the increase in using of software for the management and analysis of geographic data (GIS), the online open-access availability of satellite and aerial imagery through platforms such as Google Earth, Bing Maps, the European Space Agency (ESA) and the USGS Earth Explorer represented a game-changer in the way archaeologists and cultural heritage experts documented and monitored the endangered archaeological sites worldwide (Agapiou & Lysandrou, 2015; Bevan, 2015; Davis, 2020; McCoy, 2017).

In the MENA region, this approach has already been applied in numerous countries such as Afghanistan (Hammer et al., 2018; Lauricella et al., 2017), Cyprus (Agapiou et al., 2017, 2020), Egypt (Fradley & Sheldrick, 2017; Parcak, 2015; Parcak et al., 2016), Iraq (Fisk, 2008; Richardson, 2011; Stone, 2008, 2015; Zaina, 2019), Yemen (Banks et al., 2017), Turkey (Marchetti et al., 2019; Marchetti, Bitelli, et al., 2020) and Syria (Casana, 2015; Casana & Panahipour, 2014; Cunliffe, 2014, 2016; Danti, 2015; DGAM, 2013).

The workflow of our study is based on the methodology proposed by Marchetti, Bitelli, et al. (2020), and it is characterized by three steps (Figure 2):

1. **Data Collection**: This step consisted of collecting archaeological and geographical data from hard copy publications and online platforms and their integration into a GIS environment (see Data S1 supporting information). Specifically, the complete list of archaeological sites was retrieved through scientific companions (Fazeli, 2006; Fazeli et al., 2005), while for more detailed information on each site, we used several preliminary reports (Biglari, 2004; Mafi & Akhoundi, 2009; Majidzadeh, 1977; Mashkour et al., 1999; Mollasalehi et al., 2006; Neghaban, 1977a, 1977b, 1979; Rezaei, 2010; Schmidt & Fazeli, 2007; Tahan & Naghshineh, 2016). These publications allowed us to determine the position and dimensions of the archaeological sites. Moreover, we linked each site to an attribute table including several non-spatial information such as site dimensions, type of damage and areal extension of the damages. Geographical data included different types of open access satellite imagery of the five different decades (i.e., 1980s, 1990s, 2000s, 2010s and 2020s) obtained through Google Earth Pro, the ESA and the USGS platforms (Table 2). For each archaeological site, we compared all the images available through the abovementioned platforms in each decade (1980s to 2020s) attempting to keep a consistent temporal distance as shown in Table 2. The highest quality images (in terms of resolution and visibility) were used (one to two images on average per site and decade) to identify the types of damages considering also the seasonal changes which can greatly influence their identification. For example, we have excluded images that presented visibility problems caused by atmospheric agents (i.e., clouds). Each image was left in the original format to test its visibility potential without any enhanced visualization. This is particularly useful for those who are not fully expert in the use of satellite imagery.

It must be pointed out that the resolution of the satellite imagery slightly affected the interpretation and identification of the damages.
Indeed, while the open-access satellite imagery from the 2000s, 2010s and 2020s generally provided a high-quality level of information (ranging between 90% and 100% of our samples), earlier imagery were less reliable in some parts of the Qazvin plain and therefore must be considered as preliminary and subjected to ground-truthing confirmation.

For the 1980s, we used declassified KH-9 Hexagon imagery obtained from the USGS official website, a series of photographic reconnaissance satellites launched by the United States between 1971 and 1986 (Yenne, 1985). Thanks to its average camera resolution of 9–6 m (in some cases up to 0.6 m), the Hexagon mission provided high quality to perform the risk assessment of the archaeological sites of the region. High variability of the data quality was obtained with 1990s SPOT 2 (downloaded from the ESA official website) and Landsat 5 satellite imagery (obtained from the USGS official website) acquired between 02-07-1989 to 27-09-1991.

For the 2000s, 2010s and 2020s, we used the different types of open access high-resolution satellite imagery which are provided by Google Earth Pro®. For both 2000s and 2010s, we used Maxar® satellite imagery acquired respectively between 10 and 09-2002 and 06-02-2004 and between 06 and 02-2011 and 23-09-2011. For the 2020s we used Maxar® or CNES/Airbus® satellite imagery acquired between 22 and 05-2018 and 17-05-2020. Generally, the 2000s to 2020s satellite imagery coverage of Qazvin plain provides high-quality photos reaching up to 0.3 m.

2. Data Processing: In the second step, we correlated archaeological and geographical data in QGIS environment to classify the different types of damages and then to understand their trend over the last 40 years.

In order to identify and quantify the damages, we correlated multi-temporal satellite imagery and the shapefile of the archaeological sites and then manually detected risks and damages. The damaged areas vectorized using QGIS and the extension (calculated in ha) was included in the attribute table. The statistical quantification of damages, based on the decade or the type of risk/damage, was calculated automatically by the QGIS software.

This analysis first allowed us to define the framework for the risks (see below) threatening or damaging archaeological sites in the selected area along with their evolution from 1980s until 2020s.

3. Results: The last step consisted of the analysis of the results both at a single site and the regional level. Figure 3 shows an example of the results provided by the multi-temporal analysis of satellite imagery in terms of identified damages to the archaeological sites.

### TABLE 2 Detailed description of the multi-temporal satellite imagery

| Date(s)                  | Satellite                      | Spatial resolution | Source                                      |
|--------------------------|-------------------------------|--------------------|---------------------------------------------|
| 17-07-1980 to 02-09-1980 | KH9-hexagon                   | 6–9 m              | https://earthexplorer.usgs.gov/            |
| 02-07-1989 to 27-09-1991 | Landsat 5 and SPOT 2          | 10–30 m            | https://earthexplorer.usgs.gov/           https://tpm-ds.eo.esa.int/collections/ |
| 10-09-2002 to 06-02-2004 | Maxar® satellites             | 0.3–15 m           | Google earth pro®                          |
| 06-02-2011 to 23-09-2011 | Maxar® satellites             | 0.3–15 m           | Google earth pro®                          |
| 17-02-2018 to 17-05-2020 | Maxar® or CNES/Airbus® satellites | 0.3–15 m       | Google earth pro®                          |

FIGURE 3 Cross-correlated multi-temporal analysis and assessment of the damages in the site of Erik Tepe from 1980s until 2020s [Colour figure can be viewed at wileyonlinelibrary.com]
The study of the Qazvin plain has revealed a great variety of physical actions connected to both construction and agriculture, while the actions related to other threats are less variable (Figure 4). Detailed explanations for each physical action are provided in the paragraphs below.

It must be pointed out that this framework is specifically designed for the Qazvin plain. Other regions may be affected by different types and number of drivers, threats and actions (UNESCO, 2010; Zaina, 2019). For example, threats and damages to archaeological sites which are not documented in the Qazvin plain include military activities or geological processes that may lead to physical actions such as earthquakes or bombing.

### Quantitative multi-temporal assessment of the risks and damages

In the following paragraphs, risks and damages specifically targeting the tangible cultural heritage in the Qazvin plain (Figure 5) are illustrated according to the three-tier framework (Figure 6). Human-induced risks are described first, followed by environmental risks. While the definitions and the descriptions of their tangible effects have been illustrated in 2.2, here we provide a detailed assessment of the damages through time in our specific case study.

#### Illicit trade of antiquities - looting - holes and trenches

During the last 40 years, the archaeological sites of Qazvin plain damaged by looting holes and trenches have doubled (Figures 5a and 6d), passing from 32 sites (19% of the total) in the 1980s to 75 sites (44% of the total) in 2020s. In terms of archaeological areas, while in 1980 20.01 ha were damaged, 40 years later the archaeological area looted reached 45.74 ha.

#### Economic development 1—Construction—Buildings

Despite the widespread urban development, buildings construction does not represent a major physical action in Qazvin plain (Figures 5b and 6f). In terms of absolute numbers, we passed from 16 archaeological sites damaged in 1980 (9.5% of the total) to 45 in 2020 (26.9% of the total). Although this datum has tripled in 40 years, the overall area affected does not exceed 34 ha.

#### Economic development 2—Construction—Roads

In Qazvin plain, construction of roads increased during the last 40 year causing substantial damages to many archaeological sites (Figure 6a). After an initial impact on 36 sites in the 1980s (20% of the total), the overall trend had two major boosts, one between 1990s and 2000s with 76 sites (45.5% of the total) damaged by new roads, while the other between 2010s and 2020s, when 95 (56.8% of the total) site were partially damaged. However, in terms of archaeological area affected by this physical action, a low impact (comparable to that of buildings) is observable, gradually increasing from 10 ha in the 1980s to 33.38 ha in 2020s.

#### Economic development 3—Construction—Earth movement

Earth movement had a massive impact on the archaeological sites in Qazvin plain over the last 40 years (Figures 5c and 6e). Interestingly, the trend observed is the opposite of roads and buildings. Indeed, if on one hand the number of sites partially or entirely levelled did not exceed the 35% of the total sample (from 33 sites in the 1980s to 59 in 2020s), on the other hand, the area levelled passed from 10% (107.03 ha) of the entire sample in 1980s to 27.4% (282.71 ha) in 2020s.
4.1.5 | Economic development 4—Construction/agriculture—Canalization

In 1980, 35 sites (20.9% of the total) were partially damaged by modern canals in Qazvin plain. In total, this corresponded to 8.23 ha of the archaeological area affected (Figures 5d and 6c). The absolute number reached 86 in the 2020s (51.4%) corresponding to 27.23 ha following a trend already observed for both roads and buildings.

4.1.6 | Economic development 5—Agriculture—Salinization

Despite the low number of archaeological sites affected, this physical action is quite pervasive covering more than 59 ha (5.7% of the total archaeological area of Qazvin plain) in the 2020s.

4.1.7 | Economic development 6 - agriculture - ploughing

As in many other regions around the world, in Qazvin plain, ploughing represents the most dangerous physical action threatening archaeological sites. Already in the 1980s almost 1/3 (28.7%) of the 167 sites and the 15.3% of the archaeological area in the region were damaged by cultivations (Figures 5e and 6b). Over the decades, the number has sharply increased, especially between the 2010s and 2020s when cultivations affected 93 archaeological sites corresponding to 411.75 ha (39.8% of the total archaeological area).

4.1.8 | Research and management—Abandonment—Decay

In Qazvin plain, decay has had a minor impact on cultural heritage. Most of the documented archaeological sites experienced a good level of management in recent years, however, an example of abandoned site has been observed in the Sagzabad cluster (Figure 5f). Here, most of the excavation areas have been left uncovered, with no safeguarding after the end of the archaeological campaign by the in-charge authorities. This was a contributing factor in a slow but continuous decay of the ancient structures due to weathering. We detected these elements at the site of Zagheh. This evidence is also confirmed by the excavation reports (Fazeli, 2006; Mollasalehi et al., 2006; Neghaban, 1979) and other recent photographs of the sites.

4.2 | General trends through time

In this section, we discuss the general trends emerged from the present study and we provide answers to the research questions listed in the beginning of the paper.

The development of the three-tier framework of threats has helped to answer the first research question regarding the definition of the types of risks and damages affecting archaeological sites in Qazvin plain. The framework identifies the drivers that trigger the threats and the associated physical actions, emphasizing the equal importance of the entire process. Moreover, the framework suggests to shift the attention towards drivers in order to mitigate more threats and physical action at the same time.
The second research question regarding the development of different types of drivers, threats and actions has been answered by using the multi-temporal analysis of the open-access satellite imagery and the archaeological sites. From a geographical perspective, the multi-temporal analysis suggested an even distribution of risks and damages in the region, with no relevant spatial patterns.

The second research question regarding the development of different types of drivers, threats and actions has been answered by using the multi-temporal analysis of the open-access satellite imagery and the archaeological sites. From a geographical perspective, the multi-temporal analysis suggested an even distribution of risks and damages in the region, with no relevant spatial patterns.

Figure 7a shows a remarkable boost in the damages to archaeological sites by the entire set of physical actions between the 1980s and 2020s. The majority of them occurred between the 1980s and 2000s when the percentage of archaeological sites affected rose from 53.5% to 92.9%. On the contrary, during the last two decades, we noticed a significant change in the general trend with an overall increase of about 2%.
The analysis of the drivers (Figure 7b), confirmed that economic development had the greatest negative effect on the cultural heritage. Between the 1980s and 2020s, the number of archaeological sites impacted by physical actions resulting from economic development (such as road and building constructions and ploughing) has fluctuated between 80.5% and 84.2% of the total damaged for each decade. Even more dramatic is the percentage of the archaeological areas affected which varied between 93% and 94.5% during the each decade. The only other relevant driver is the illicit trade of antiquities reaching up to 19.5% of archaeological sites corresponding to 7% of the entire archaeological area of the region.

The long-term trend of threats resembles that of the drivers. Nevertheless, thanks to this second tier of the framework, it is possible to better isolate the groups of threats that have the greatest impact as well as any temporal patterns that were recognized throughout decades under analysis. In the first case, it is possible to notice how the two types of threats generated by economic development have impacted in a similar number of archaeological sites. As for the time frame, however, we note that the looting has doubled between the 1980s and 2000s, while the number of sites affected by construction increased to almost 50% between the 2000s and 2010s.

Further trends on a regional-scale can be proposed. Several physical actions mostly occurred between 1980s and 2000s. For example, the digging of holes and trenches rose from 18.75 to 37.5 ha within the first two decades and then remained steady during the following 20 years. The same situation applies to the damages caused by earth movement which increased during the 1980s and 1990s by destroying 175 ha of the archaeological area. Nevertheless, the majority of physical actions increased between the 2000s and 2020s. For example, road constructions have caused substantial damages to the cultural heritage of the Qazvin plain reaching 31.5 ha in the 2020s, which is three times more than the 1990s (with 10.5 ha). Another major growth has been observed for the archaeological area damages by ploughing which increased from 270 to 410 ha between the 2010s and 2020s. This analysis confirms two broad temporal trends, the former between the 1980s and 2000s, while the second between 2000s and 2020s, with different types of physical actions affecting archaeological sites.3

The most significant trend is the lack of correlation between the numbers of archaeological sites (which partially damages by several physical actions) and the corresponding extension of the damaged area. This is particularly apparent in the case of roads, canalization, looting holes and trenches and building (Figure 8).
5 | DISCUSSION

The implications of these results along with the current narratives described in the introduction on the most impacting type of threats illustrated in the introduction, could lead to the identification of a specific pattern. Indeed, the present research confirmed that the most impacting risks and damages to the archaeological sites in the Qazvin plain during the last 40 years include ploughing, earth movement, road construction and canalization, despite the current academic and popular narratives mainly focused on natural hazards, looting and violent destruction (in our case vandalism). The first group (meaning ploughing, earth movement, road construction and canalization) can be distinguished from the latter based on four factors (Table 3):

1. Awareness: How much the issue is known at any level?
2. Time span: How long does each risk and damage may last?
3. Frequency: How often does each risk and damage happen?
4. Extension: How much of the archaeological area is destroyed by each risk and damage?

The calculation of the first factor is mostly based on the literature review provided by Agapiou et al. (2020) and Tapete and Cigna (2019b). For the second factor ‘Time span’, we considered the period during which each physical action was more impacting based on our data. The third factor corresponded to the frequency with which each damage occurs and it can be divided into four groups (rarely, sometimes, often, and very often). The extension (Factor 4) is calculated based on the data collected for each physical action and prolonged to 2020 (see also Figure 8).

Based on this, we suggest distinguishing between ‘silent risks’ (SR) and ‘loud risks’ (LR). SR include those types of damages matching at least three out of four factors in the following way: despite being poorly considered by both grey literature and academic studies and with little impact at a popular level (low knowledge), they occur for long periods (Between 20 and 40 years), with a high frequency (often or very often) and in a pervasive way (at least some hectares). On the contrary, LR should respond at least three out of four factors in the following way: they should be well known and studied (high knowledge), they should be limited in time (less than 20 years) and frequency (rarely or sometimes) and they should impact over the relatively modest area. In our case study, for example, holes and trenches represented an LR since they are well-known, limited to the 1980s–2000s decades, with a moderate frequency and affecting a low percentage of the total archaeological area of the Qazvin plain. On the contrary, ploughing is a perfect example of SR, since it is poorly known and perceived as a risk, although it has been perpetrated for the entire period under analysis (1980s–2020s) and it occurs almost every day on almost half of the archaeological sites of the Qazvin plain (45.6%).

6 | CONCLUSION

In this paper, we provided a detailed assessment of the risks and damages to 167 archaeological sites in Qazvin plain, by applying a multi-temporal approach using 1980s to 2020s satellite imagery and a three-tier framework.

This analysis was performed by overlaying open access satellite imagery in four-time frames of 1980, 1990, 2010 and 2020. In general, the results showed an overall increase in damages between 1980 and 2020.

In particular, economic development represents the major driver, triggering threats like construction and agriculture, from which derive different physical actions including buildings and roads construction, ploughing and earth movement. While the frequency and extension of the damages caused by these physical actions cover the entire time span considered, a substantial increase has been observed for the last two decades.

Less impacting drivers encompass illicit trade of antiquities triggering looting by means of holes and trenches, conflict which in the case of Qazvin plain resulted in non-military activities such as
vandalism, as well as different physical actions triggered by environmental processes or heritage mismanagement.

This result was then compared with current literature and narratives to understand if they also reflect the trend highlighted. The result showed that the situation is the opposite, with most of the studies carried out in recent years focusing on damages caused by drivers such as conflict, illicit trade in antiquities and natural hazards having a lesser impact than economic development both in the Qazvin region and in most of the MENA countries. Based on this evidence we proposed to distinguish physical actions between (1) loud risks, such as looting, which are well known and studied, although generally limited in time and frequency and impacting over a relatively modest area, and (2) silent risks, poorly considered by both grey literature and academic studies and with little impact at a popular level, although occurring for long periods, with a high frequency and in a pervasive way.

This distinction aims to raise awareness among stakeholders at local, national and international level towards the different types of damages to archaeological sites that have so far been partially or largely neglected. Moreover, in line with previous researches (Lopez, 2016; Zaina, 2019), we call the attention towards the entire damaging process including drivers, threats and physical actions, rather than focusing only on the latter. This suggestion should be taken into consideration for the improvement of existing national and international legislation and guidelines for the documentation, monitoring and protection of endangered heritage. In particular we recommend to include tailor made protocols for the mitigation of all the drivers, threats and actions illustrated in this paper.

Overall, damages to the archaeological sites in Qazvin plain are increasing. In this regard, we must notice that the number of archaeological sites in the region might be higher as not all the sites are visible from the satellite imagery and many of them are not accessible for researchers to conduct fieldwork. Yet satellite imagery represent an efficient tool to analyse the damages already occurred, plan any necessary mitigation for the potential risks, thus allowing authorities to efficiently conduct safeguarding actions. On the other hand, as stated by Cunliffe (2014), the damage has a horizontal aspect (how far across the site it goes), and a vertical aspect (the depth of the site affected). Our approach covers the former aspect but it cannot efficiently cover the latter one due to the limitations of satellite imagery in providing height information. That is, most of our discussions about sites damages are limited to a two dimensional area as if the sites are flat entities with no height or depth. To address the limitations of remote sensing studies, it is advisable to be associated with ground-truthing activities. It is, therefore, expectable that the results of this research could be used by researchers and local authorities to validate and enrich the data including the vertical damage extent.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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ENDNOTES

1 The definition of ‘risk’ used in this paper follows the one proposed by the Emergency Management Australia (2000) and re-used by UNESCO (2010).

2 Moreover, despite the availability of open-access late 1960s to early 1970s CORONA satellite imagery through the USGS Earth Explorer platform, the low quality of the frames covering the Qazvin plain prevented a secure identification of the damages to archaeological sites.

3 It is important to note that at the moment it is not possible to provide a multi-temporal quantitative evaluation of the effects of erosion. For the sake of completeness, future studies will have to take this into consideration.

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