

Postgraduate Dissertation

«Comparative approach of environmental and structural impacts of climate change on selected monuments of archaeological park of Dion (sanctuary of Isis, roman baths, and villa of Dionysos)»



School of Applied Arts and Sustainable Design
MSc Protection of Cultural Heritage and Monuments of
Nature from the Effects of Climate Change (CCC)

Postgraduate Dissertation
«Comparative approach of environmental and structural impacts of
climate change on selected monuments of archaeological park of
Dion (sanctuary of Isis, roman baths, and villa of Dionysos)»

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Supervisor: Dr. Zoi Sakki

Athens, June 2026

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«Comparative approach of environmental and structural impacts of climate change on selected monuments of archaeological park of Dion (sanctuary of Isis, roman baths, and villa of Dionysos)»

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“Acknowledgments and / or Dedication”

I would like to express my deepest and most sincere gratitude to my family, my friends, as well as my professors who have each been supportive in their own way on this beautiful scientific journey.

Abstract

Epicenter of the present thesis is the thorough, as much as possible, study of the environmental and structural impacts on selected monuments (Isis Sanctuary, roman baths, and villa of Dionysus) under the prism of climate change. The aim of the research is to assess the vulnerability of these monuments to climate-related hazards and environmental stressors, while also examining their structural behavior, material deterioration, and the challenges of their long-term preservation. With the objective to develop a comparative comprehending of the monuments' exposure to hydrological processes, seismic activity, temperature fluctuations, biological colonization, and material degradation mechanisms, this investigation integrates architectural documentation, historical analysis, environmental assessment, and structural evaluation.

Particular emphasis is placed on the geomorphological and hydrological conditions of Dion, where the presence of groundwater, alluvial deposits, and intense environmental humidity significantly influence monument stability and conservation conditions. The research further examines how climate change acts as a catalyst for deterioration processes through the intensification of precipitation patterns, flooding phenomena, thermal stress, and environmental fluctuations. Structural vulnerability is additionally assessed through the examination of masonry behaviour, material displacement, cracking phenomena, and the seismic sensitivity of archaeological remains.

The analysis further examines previous restoration operations and assess their impact on the monuments' current conservation status. Based on the identified risks and deterioration mechanisms, several types of conservation, monitoring, and structural strengthening strategies are proposed, such as geotechnical investigations, environmental and seismic monitoring systems, preventive conservation approaches, and interdisciplinary management frameworks. Furthermore, stakeholder collaboration and integrated heritage management are emphasized as key factors in ensuring long-term monument preservation. Overall, the study demonstrates that the preservation of the monuments of Dion requires a multidisciplinary and preventive conservation approach capable of addressing both environmental and structural threats intensified by climate change.

Keywords: Dion archaeological park, climate change, environmental deterioration, structural vulnerability, risk analysis, management plan

«Συγκριτική προσέγγιση των περιβαλλοντικών και δομικών επιπτώσεων της κλιματικής αλλαγής σε επιλεγμένα μνημεία του αρχαιολογικού πάρκου στο Δίον (ιερό της Ίσιδας, ρωμαϊκά λουτρά και έπαυλη του Διονύσου)»
Σίδερης Παναγιώτης

Περίληψη

Το επίκεντρο της παρούσας διπλωματικής εργασίας είναι η διεξοδική, όσο το δυνατόν, μελέτη των περιβαλλοντικών και δομικών επιπτώσεων σε επιλεγμένα μνημεία (Ιερό της Ίσιδος, ρωμαϊκά λουτρά και βίλα του Διονύσου) υπό το πρίσμα της κλιματικής αλλαγής. Σκοπός της έρευνας είναι η εκτίμηση της ευαλωτότητας αυτών των μνημείων σε κινδύνους σχετιζόμενους με το κλίμα και περιβαλλοντικούς παράγοντες πίεσης, ενώ εξετάζεται επίσης η δομική τους συμπεριφορά, η φθορά των υλικών και οι προκλήσεις της μακροπρόθεσμης διατήρησής τους. Με στόχο την ανάπτυξη μιας συγκριτικής κατανόησης της έκθεσης των μνημείων σε υδρολογικές διαδικασίες, σεισμική δραστηριότητα, διακυμάνσεις της θερμοκρασίας, βιολογική αποίκιση και μηχανισμούς διάβρωσης των υλικών, αυτή η έρευνα ενσωματώνει αρχιτεκτονική τεκμηρίωση, ιστορική ανάλυση, περιβαλλοντική αξιολόγηση και δομική εκτίμηση.

Ιδιαίτερη έμφαση δίνεται στις γεωμορφολογικές και υδρολογικές συνθήκες του Δίου, όπου η παρουσία υπόγειων υδάτων, αλλουβιακών αποθέσεων και έντονης περιβαλλοντικής υγρασίας επηρεάζει σημαντικά τη σταθερότητα των μνημείων και τις συνθήκες συντήρησής τους. Η έρευνα εξετάζει περαιτέρω πώς η κλιματική αλλαγή λειτουργεί ως καταλύτης για τις διαδικασίες φθοράς μέσω της ενίσχυσης των προτύπων βροχόπτωσης, των φαινομένων πλημμύρας, της θερμικής καταπόνησης και των περιβαλλοντικών μεταβολών. Η ευπάθεια των κατασκευών αξιολογείται επίσης μέσω της εξέτασης της συμπεριφοράς της λιθοδομής, της μετατόπισης των υλικών, των φαινομένων ρηγματώσεων και της σεισμικής ευαισθησίας των αρχαιολογικών λειψάνων.

Η ανάλυση εξετάζει περαιτέρω προηγούμενες αναστηλωτικές εργασίες και αξιολογεί τον αντίκτυπό τους στην τρέχουσα κατάσταση διατήρησης των μνημείων. Βάσει των εντοπισμένων κινδύνων και των μηχανισμών φθοράς, προτείνονται διάφοροι τύποι στρατηγικών διατήρησης, παρακολούθησης και δομικής ενίσχυσης, όπως γεωτεχνικές έρευνες, συστήματα περιβαλλοντικής και σεισμολογικής παρακολούθησης, προληπτικές προσεγγίσεις διατήρησης και διεπιστημονικά πλαίσια διαχείρισης. Επιπλέον, υπογραμμίζεται η συνεργασία των ενδιαφερομένων και η ολοκληρωμένη διαχείριση της κληρονομιάς ως βασικοί παράγοντες για την εξασφάλιση της μακροπρόθεσμης διατήρησης των μνημείων. Συνολικά, η μελέτη δείχνει ότι η διατήρηση των μνημείων του Δίου απαιτεί μια διεπιστημονική και προληπτική προσέγγιση διατήρησης ικανή να αντιμετωπίσει τόσο τις περιβαλλοντικές όσο και τις δομικές απειλές που εντείνονται από την κλιματική αλλαγή.

Λέξεις – Κλειδιά: Αρχαιολογικό πάρκο Δίου, κλιματική αλλαγή, περιβαλλοντική υποβάθμιση, δομική ευπάθεια, ανάλυση κινδύνου, σχέδιο διαχείρισης

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List of Addreviations

AD–Anno Domini
BC–Before Christ
CCC - Climate Change and Cultural Heritage
GIS - Geographic Information Systems
GPS - Global Positioning System
IPCC - Intergovernmental Panel on Climate Change
UNESCO - United Nations Educational, Scientific and Cultural Organization
ICOMOS - International Council on Monuments and Sites
UNFCCC - United Nations Framework Convention on Climate Change
UNDRR -United Nations Office for Disaster Risk Reduction
EO - Earth observation
RS - Remote Sensing
DEM -Digital Elevation Model
RH - Relative Humidity
PM -Particulate Matter
CO - Carbon Monoxide
SO₂ -Sulfur Dioxide
NO₂ - Nitrogen Dioxide
O₃ – Ozone
NaCl - Sodium Chloride
EEA -European Environment Agency
ESA - European Space Agency
Copernicus EMS -Copernicus Emergency Management Service
HOU - Hellenic Open University

Title:

«Comparative approach of environmental and structural impacts of climate change on selected monuments of archaeological park of Dion (sanctuary of Isis, roman baths, and villa of Dionysos)»

1.Introduction

Dion is a settlement in the Pieria region, located 15 kilometers south of the city of Katerini. The ancient city of Dion is built on the eastern foothills of the mythical and highest mountain in Greece, mount Olympus. (Zarz, 2024). It is a huge area covering 1,500 acres, while the ancient city occupies a total area of 360 acres (Hellenic Ministry of Culture and Sports, n.d.). The first excavations at the site began in 1928 on the initiative of the first rector of the University of Thessaloniki, Georgios Sotiriadis. Systematic exploration of the site began in the 1970s under the supervision of Dimitrios Pandermalis (Παπαγιάννη, 2023). Traditionally recognized as Macedonia's sacred city, Dion served as a cultic hub, municipal settlement, and strategic urban center from the Classical to the Roman periods (Παντερμαλής, 1997).

The wider archaeological site consists of various types of ancient monuments such as public buildings, workshops, private residences, as well as sanctuaries. It is worth noting that the various sanctuaries are located outside the city walls and therefore stand apart from the various buildings of the ancient city. For the most part, the current appearance of the archaeological site corresponds mainly to the Roman period of the city (Hellenic Ministry of Culture and Sports, n.d.). Ancient Dion was the religious center of the Macedonians and, as such, a landmark for extremely important events, as evidenced by both written sources and archaeological evidence. However, more details on the issue of identity from various perspectives will be discussed in the next chapter. Finally, archaeological research continues unabated to this day, revealing more and more findings about this important archaeological park, which is significant not only for the Macedonian kingdom but also for the ancient Greek world in its entirety.

Since climate change is a growing hazard to cultural assets, especially exposed and vulnerable archaeological sites, it has become beneficial to conduct a dissertation on the risks posed to the archaeological park in Dion. According to the IPCC assessment, there is a high possibility that human induced global warming is happening rapidly than previously assumed. In reality, cultural heritage sites are already being impacted by climate change, as evidenced by slow variations in temperature, precipitation, atmospheric moisture, wind speed as well as the frequency of extreme events (Elena Sesana, 2020). Arguably, one of the most vulnerable is the Mediterranean region which is considered to be one of the cradles of the global civilisation areas to climate change in the upcoming decades (Kapsomenakis et al., 2022). In addition, the impending global warming will in turn affect other climatic parameters, such as sea level rise (Masson - Delmotte et al., 2019: IPCC, 2021).

Although the archaeological park of Dion is not located directly to the coastline but kilometres of distance, sea level rise poses a considerable indirect threat, primarily through the elevation of the groundwater table and the amplification of flood episodes induced by adjacent rivers and torrents (Τσιάρας, 2021). Nevertheless, due to the complete exposure of the park's monuments to climatic conditions, it is certain that all climatic parameters will determine the effects that will gradually lead to the deterioration of the condition of the materials.

Objective

The epicentre of this scientific research will involve both past and current environmental conditions and the role they have performed in the current state of the materials of the selected monuments, as well as the prediction of further deterioration that will occur with the future effects of climate change, which appears to be particularly acute at the present time. To elaborate more, the primarily goal would be accomplished through the use of archaeological, environmental as well as architectural criteria of the selected monuments. In fact, with the aid of these types of evidence it is more reliable to extract conclusions about natural variables like earthquakes activity as well as climate circumstances have affected the monuments preservation over time. Besides that, other elements that could affect the integrity of the monument materials will also be examined, such as human impact through tourist activity, fluctuations in humidity and temperature, and the hydrological changes currently taking place in the archaeological park at Dion. In conclusion, both the collection and recording of past events and contemporary ones in the context of global climate change, which have contributed to the change in the state of the monuments, will form the basis for an approach aimed at proposing beneficial and targeted preservation and conservation strategies (IPCC, 2021; Kapsomenakis et al., 2022).

To be more specific, this thesis comprises the following research objectives:

- The determination and evaluation of the principal anthropogenic as well as environmental which might involve salinity, atmospheric pollution, climate fluctuation, seismic activity, pressures from tourists, as well as their combined effects on material deterioration and structural vulnerability.
- The evaluation of the cultural, architectural, and historical significance of the Sanctuary of Isis, the Roman Baths, and the Villa of Dionysos within the archaeological site of Ancient Dion, situating these monuments within the broader framework of religious, public, and domestic architecture of Roman Macedonia, and examining their roles in the urban organization, social life, and religious landscape of the city.
- The examination of the long-term impacts of climate change on the materials and structural integrity of the Sanctuary of Isis, the Roman Baths, and the Villa of Dionysos, employing hazard and risk assessment approaches and a comparative analysis of monuments exposed to hydrological stress, high groundwater levels, and increasing climatic variability within low-lying archaeological environments.

- An assessment which is related with the current state of preservation that the three aforementioned monuments exhibit fulfilling particular attention to the status of the building materials, the stability of the structure, and the quantity, integrity as well as the importance of the remaining architectural and decorative elements.
- Finally, the creation of an integrated conservation and risk mitigation approach for Ancient Dion's selected monuments, with a focus on preventive conservation, systematic monitoring, and climate-related hazard preparedness, all within the larger context of sustainable heritage management and long-term climate adaptation would be the last main objective.

Methodology

Since it is necessary to evaluate the vulnerability of particular monuments within the ancient Dion archaeological site, the data collection and methodological approaches in this thesis are based on a multidisciplinary framework that integrates field-based investigation, remote sensing techniques, and archival research. In order to record structural states, material deterioration, and environmental context for each monument, primary data are gathered through systematic on-site macroscopic inspections as well as photographic documentation. These techniques make it possible to recognize and record apparent deterioration occurrences as well as their geographical spread.

Meteorological and hydrological data obtained from national climate databases and Copernicus Earth Observation Services, such as long-term temperature trends, precipitation patterns, groundwater changes, and flood frequency, are examples of secondary data. These datasets offer the environmental context required to assess the site's exposure to climate-related stresses. The identified deterioration mechanisms at the Sanctuary of Isis, the Roman Baths, and the Villa of Dionysos are then correlated with environmental characteristics using a comparative analytical approach. In order to identify vulnerabilities and prioritize threats, a qualitative and semi-quantitative risk analysis is finally carried out for each climate-related parameter. This will ultimately aid in the development of well-informed conservation, maintenance, and adaptive protection plans. The study has been organised adjacent to the following research challenges beneath this methodological framework:

- Which environmental and climatic parameters currently exert the greatest influence on the deterioration of the selected monuments in Ancient Dion?
- How do differences in location, function, and environmental setting among the Sanctuary of Isis, the Roman Baths, and the Villa of Dionysos affect their vulnerability to climate-related degradation mechanisms?
- What correlations can be identified between observed material decay patterns and climatic or hydrological data derived from Earth observation and national databases?
- Which monuments exhibit the highest level of risk under present environmental conditions, and which climate-related hazards pose the most immediate threats to their preservation?

- How can risk analysis support the development of targeted conservation, maintenance, and adaptive management strategies for monuments exposed to climate change impacts?

2. The archaeological park of Dion

2.1 Historical overview

The wider area of Dion is occupied by a narrow plain located between the Thermaic Gulf and the foothills of Mount Olympus. In its immediate vicinity are a series of mountains, the closest being Dion, Mount Titaros, and the Pierian Mountains. The coordinates of the site are 40.1736825 north latitude and 22.4915970 east longitude. Administratively, it belongs to the prefecture of Pieria and the regional unit of Pieria in the region of central Macedonia with its turn (fig.1). The current setting differs significantly from the period referred to, yet certain elements that likely influenced the choice of settlement remain present (Γεροφωκά, 2015). More specifically, a key criterion for selecting the location was the fact that there are four different passes which have historically emphasized its strategic importance (fig.2).

In addition, its proximity to the sea, just 1.5 kilometers away in ancient times, played a crucial role in allowing trade to flourish. The ancient city was also accessible by sea via a navigable river, the Vafra, which still flows in our days to the east of the park. This feature is mentioned by Strabo in his book Geography, stating that the distance is 7 stadia (1.5 kilometers). Currently, this distance has expanded significantly due to the accumulation of sediment carried down from Mount Olympus, which has essentially extended the coastline. The outcome of these geological processes has resulted in the distance now being 5 kilometers, which is 3.5 kilometers more than it was 2,000 years ago (Στεφανίδου, 1998).

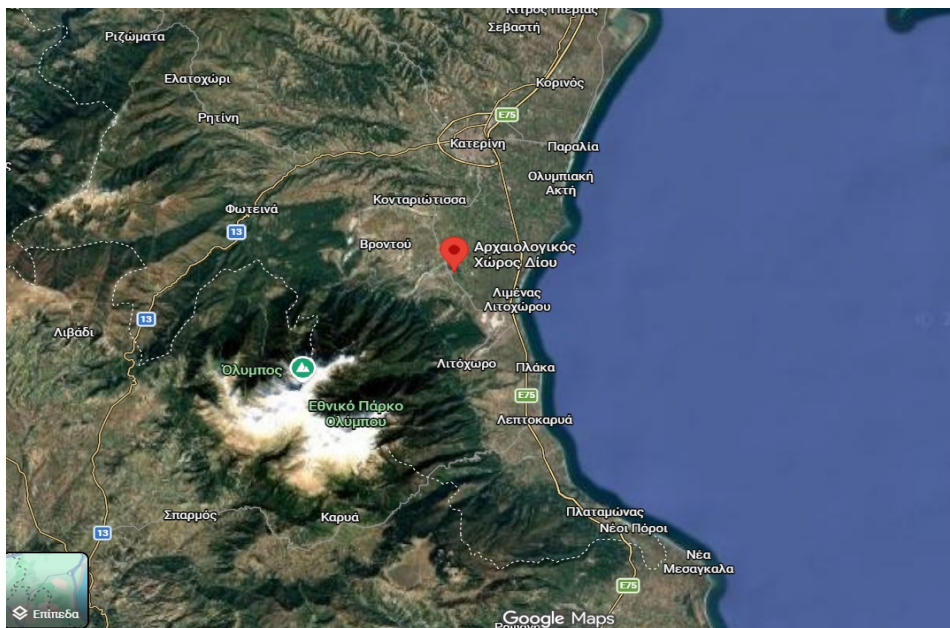


Figure 2.1: The topographical location of the archaeological park in Dion (google maps).



Figure 2.2: Aerial photograph showing the strategic passes in the area, indicated by yellow arrows (google maps).

Initially, settlement in the wider area began quite early in the Iron Age, i.e. 1600-600 BC, as evidenced by the findings. It was a geographically advantageous location, combining a large mountainous area with all that this entails, as well as a plain adjacent to the sea (Σχοινά, 2020). The first time Dion is mentioned in antiquated sources is by Thucydides (IV 78.6), who indicates that in the summer of 424 BC, the Spartan commander Brasidas, on his route from Thessaly to Chalkidiki stopped at Dion thanks to

the assistance of Perrhaebians. As Thucydides mentions «οἱ δὲ Περραιβοὶ αὐτόν, ὑπήκοοι ὄντες Θεσσαλῶν, κατέστησαν ἐς Δῖον τῆς Περδίκκου ἀρχῆς, ὃ ὑπὸ τῷ Ὀλύμπῳ Μακεδονίας πρὸς Θεσσαλοὺς πόλισμα κεῖται»(Θουκυδίδης IV 78,6).

Another very important written testimony that has been preserved, this time by Diodorus Siculus, mentions that the king of Macedonia, Archelaus during whose years the city flourished, established nine days of athletic and theatrical competitions in honor of Olympian Zeus and the Muses. As he states «πρὸς τοὺς ἀγῶνας θυσίας μεγαλοπρεπεῖς τοῖς θεοῖς συνετέλεσεν ἐν Δίῳ τῆς Μακεδονίας καὶ σκηνικοὺς ἀγῶνας Δίῃ καὶ Μούσαις, οὓς Ἀρχέλαος ὁ προβασιλεύσας πρῶτος κατέδειξε. τὴν δὲ πανήγυριν ἐφ' ἡμέρας ἑννέα συνετέλεσεν, ἐκάστη τῶν Μουσῶν ἐπώνυμον ἡμέραν ἀναδείξας» (Διόδωρος Σικελιώτης XVII, 16). This event further highlights Dion's prominent position as the religious center of the Macedonians as it made Dion a pan-Hellenic sanctuary, resulting in the arrival of large numbers of pilgrims. Perhaps this fact contributed to the boom of construction activity, due to efforts to meet the needs of visitors (Παντερμαλής, 1997). Both King Philip II and his son Alexander the Great showed their respect for the sacred site of Olympus. More specifically, Philip held the victory celebrations for the conquest of Olynthus at the Olympus Games in 348 BC. For his behalf, Alexander the Great conducted the grand ceremonial preparation of his campaign to Asia Minor, at the sanctuary of Zeus at Dion. Furthermore, after his significant victory in the battle of the Granicus River (334 BC), he made sure to honor the sacred religious center once again by erecting the Lysippean bronze regiment with 25 equestrian statues (Παντερμαλής 1999).

The first destruction of this sacred city occurred during the reign of the Macedonian king Philip V. At that time, around 219 BC, the king was absent from the region due to military operations he was conducting in Aetolia. The Aetolians seized the opportunity to attack the defenseless city, destroying not only its walls and various public and private buildings, but even its sanctuaries (Πολύβιος, IV). However, as can be seen from later testimony by Titus Livius (169 BC.), the city must have been radically rebuilt after the destruction (Παντερμαλής, 1997). The year 148 BC. was decisive, as it marked the definitive end of the Macedonian kingdom and the beginning of a new era of Roman rule. Dion is now considered part of the so-called province of Macedonia ((Provincia Macedoniae) and specifically one of four self-governing regions (regiones).

Later on, in 27 BC. it completely lost its sovereignty, as it became a roman colony under the then emperor Octavian Augustus. As evidenced by inscriptions and the coins minted by the city, it was named Colonia Iulia Augusta Diensis and was subject to the political organization and administrative institutions modeled on those of the capital of the Roman Empire. Although the city was under foreign rule, the economy flourished during this period owing to the Roman Empire's policy of improving the standard of living of its inhabitants. More specifically, aqueducts and luxurious baths were rebuilt, as well as fora, temples, and theaters (2nd century AD).

In fact, at the beginning of the 3rd century AD, the city experienced its greatest prosperity after that which it had enjoyed during the reign of Archelaus. Then magnificent public and private buildings were constructed the remains of which are still visible today. During the early Christian years, Dion maintained its prestige as the seat of the bishopric of the wider region and took part in the religious decisions of the time. From the 6th century AD, when the barbarian invasions began, the city was gradually abandoned. The

latest surviving written testimony comes from the work of Constantine Porphyrogenitus, entitled "On Matters," in the 10th century AD. (Παντερμαλής, 1993).

Moving on to more recent times, it was in 1806 when an English traveler and officer visited the area and reported that Dion was a very famous city with luxurious buildings, its only drawback being the unhealthy marshes (Σχοινιά, 2020). Furthermore, he was the first to identify the ruins as ancient Dion. Several years later, in 1955, French archaeologist Léon Heuzey recorded some tombstones and identified the route of the ancient city through the walls that surrounded it (Ymca_User, 2021). The first scientific research was conducted by Georgios Sotiriadis in 1929. Although he did not manage to locate the sanctuary of Zeus that he was looking for, he achieved something remarkable for the time. On his own initiative, the first building to shelter the movable finds was constructed. Sotiriadis' excavations ended in 1932, and it was not until almost 30 years later, in 1960, that they were resumed, this time by Georgios Bakalakis, who continued them until 1970. The results of this long-term research showed us something very important in terms of location, where it became clear that there are two distinct parts, the ancient city within the walls, while the other concerns the sanctuaries outside the walls (fig3).



Figure 2.3: Aerial photograph depicting the two distinct parts of the park, the city within the walls and the sanctuaries outside (Παπαγιάννη, 2023).

In 1970, systematic research began under Dimitrios Pandermalis. Initially, the sanctuary of Dion was located, thus confirming the importance of Dion as a religious center of Macedonia (fig.4). In general, during that period, there were numerous findings that highlighted the identity of the archaeological park (fig.5). More specifically, the offerings and various inscriptions that were found fully confirmed the importance of Dion, as it was known from the writings of ancient authors. In addition, the results of systematic research brought to light new shrines such as those of Demeter, Isis, and Zeus, thus demonstrating the existence of many cults and, more importantly, cults that were not historically recorded as existing in Dion. Finally, the most numerous type of finds in terms of quantity are those of pottery, many of which are preserved intact and kept in the archaeological museum in Dion (Παπαγιάννη, 2023).



Figure 2.4: Epistle from King Philip V found in the sanctuary of Olympian Zeus (Παπαγιάννη, 2023).



Figure 2.5: Funerary relief from Dion (Πινγκιάτογλου, 2022).

As already mentioned, the archaeological park at Dion spans a huge area. It is therefore necessary to map out the monuments that have been found in the area as a result of the systematic research carried out to date. Initially, the wall of the ancient city, which has been uncovered across its entire length (2,500 meters), is the dividing line between the city inside and the sacred sites outside. It is characterized by two different construction phases, one during the Hellenistic period and the other during the late Roman period. The materials used in the first phase include limestone, while the later phase features rubble masonry (fig.6), (Αριστοτέλειο Πανεπιστήμιο Θεσσαλονίκης, n.d.) The city, which evolved in the 4th century BC, with the remains of the Roman era being particularly prominent, includes the following types of monuments (fig.7).

- The main road axis of the city, as well as its aqueduct, water supply and drainage system. Since Hellenistic times, the road has crossed the city from north to south. In Roman times, it was named *cardo maximus*. Based on the total area of the ancient city, as determined by the perimeter of the wall, the excavated and currently accessible section corresponds to approximately one quarter of the total, while the rest of the city of Dion is unexplored and unknown to archaeological research (Παπαγιάννη, 2025).

- Large public buildings such as baths, luxurious residences, and villas. Baths have been found in many parts of the city, but the largest is located on the main road in the southern part of the city which are named as "the great baths", next to which there is also a roman odeion. More specifically, odeion is a small indoor theater and is an integral part of the same building block with the great baths. There are also the thermal baths on the main street and other bathing facilities. On the eastern side is the vespasian, essentially public latrines that took their name from Vespasian. Also, north of the great baths is the central market, the forum which was the multifunctional center of public life for the citizens of Dion.
- On the eastern side of the main road lies the praetorium. This building served as accommodation for high-ranking officials of the Roman Empire. Apart from the five rooms that were found, dining areas were also discovered, providing a more comprehensive insight into this type of building. Another luxurious building that adorned the city and was excavated is the macellum. It is located in a prominent position, specifically at the point where the main road (cardo maximus) meets the road (decumanus) that leads to the western gate of the wall. It is a luxurious polygonal building which was essentially a covered market intended for the sale of food, mainly meat and fish, but also fine foods.
- In the ancient city, additional luxurious Roman residences with four-columned atriums and peristyle courtyards have been identified, which are splendid examples of private buildings of the period. The most splendid surviving example is undoubtedly the mansion of Dionysus, which captivates the eye both for its beauty and for the size and variety of its rooms. The most important discovery is the mosaic floor that has been found, which depicts scenes from the Dionysian cycle. What's more, this building complex served various purposes, such as workshops, bathing facilities, and a library.
- Finally, the latest discoveries regarding their chronology within the ancient walled city are the early Christian churches that have been found. The most important are the episcopal church and the cemetery basilica. The former is a three-aisled basilica that had a baptistery and a built baptismal font in the shape of a Maltese cross. The cemetery basilica was built in the 5th century AD, like the first one. It was identified outside the southern wall of the city and is also a three-aisled church (Βαστελή, 2016).



Figure 2.6: Section of the ancient city wall (Αριστοτέλειο Πανεπιστήμιο Θεσσαλονίκης, n.d.).



Figure 2.7: Aerial photograph of the ancient city of Dion, with the central street cardo maximus in the center and various public and private buildings on either side (Αριστοτέλειο Πανεπιστήμιο Θεσσαλονίκης, n.d.).



Figure 2.8: Viewpoint of the ancient city of Dion (Παντεμαλής, 1995).

The next distinctive feature of the archaeological park is the area where the various sanctuaries are located. The city essentially serves the functional purposes of the sanctuaries, as it attracts numerous visitors being the religious center of the Macedonians. The area where they develop is located south of the city in an area covered with lush vegetation, natural beauty, and gushing waters. The most ancient sanctuaries in the area are those of Olympian Zeus, whose worship is predominant in Dion, Asclepius, and the goddess Demeter. The southernmost is that of Olympian Zeus, which is enclosed by a rectangular perimeter and includes a monumental built altar 22 m long, a large stoic building with a propylon in the middle, and the remains of stone bases that were used for animal sacrifices in honor of Zeus. The multitude of inscriptions that have been found confirms the prominent importance of the sanctuary where the "ἐν Δίῳ Ὀλυμπίων" were performed (fig.9), (Βαστελή, 2016). Finally, the image of the architectural configuration of the sanctuary is extremely disturbed, with building remains located almost at foundation level and in a particularly fragmented state.

The sanctuary of Asclepius is located 300 meters north of that of Zeus. It has been preserved at foundation level, while its worship dates back to Hellenistic times. As a deity with healing properties, its location is not accidental, as the element of water, associated with healing and well-being, plays a dominant role. The most remote sanctuary, approximately 3.5 kilometers south of the ancient city, is that of Demeter. It is a rectangular temple, distyle in antis or tetrastyle prostyle with external dimensions of 17m × 10m. A sanctuary with very early worship dating back to the Archaic period (700-480 BC) is dedicated to the goddess Demeter (fig.10). It is a unique structure, consisting of six different temples arranged side by side in the western part of the sanctuary and on the same axis (north-south). To the east of this sanctuary, 50 meters away, the sanctuary of Zeus the Supreme has been identified. It is the one with the most distinct architectural layout in relation to the aforementioned. The temple has a square floor plan, measuring 10.30 m × 10.70 m, with auxiliary rooms arranged around its perimeter. Finally, east of

the sanctuary of Zeus the Supreme is that of Isis, which dates back to the 2nd century AD. (Κασσερόπουλος, 2024).



Figure 2.9: Offering by Cassander, king of Macedonia, in honor of the supreme god Zeus (Πινγιάτογλου, 2022).



Figure 2.10: On the left, an aerial photograph of the sanctuary of the goddess Demeter, and on the right, the head of the cult statue of the deity (Πινγιάτογλου, 2022).

In addition, the city's theaters, one Hellenistic and one Roman, as well as the stadium, have been found in the wider area where the sanctuaries are located. The Hellenistic theater was built on artificial fill and replaced the existing one from the Classical period. It was erected in the second half of the 3rd century BC. (Fig.11). On the other hand, the Roman stadium was probably built when the Hellenistic one ceased to function in order to host the theatrical competitions of the "ἐν Δίῳ Ὀλυμπίων." Finally, the city's stadium was also associated with the worship of Zeus and the games held in his honor, while its construction is dated to the 5th century BC. (Βαστελή, 2016).



Figure 2.11: The Hellenistic theater in the archaeological park at Dion (personal archive).

2.3 Historical and archaeological context

2.3.1 Sanctuary of Isis

The first landmark that will form the basis for the comparative approach is the sanctuary of Isis. Isis is an Egyptian goddess whose worship was introduced to ancient Greece during the Hellenistic period (323-30 BC). The gradual shift in belief from the gods of Olympus, which was largely influenced by the collapse of the city-state system, led to the introduction of foreign deities. This was also the case with Isis, who was primarily a goddess of vegetation and the underworld, identified with Demeter and Persephone, promising redemption, rebirth, and support in the hardships of everyday life. During her cult in ancient Greece, she was enriched with new attributes (Ντόντου, 2016). The goddess was Hellenized in Greek ancient art, particularly in plastic, as early as the third century BC. The Ptolemies introduced depictions of Isis in Egypt, which later spread to Greece (Chrimatopoulos, 2020).

In the specific area under study, before Isis appeared in the 2nd century BC. Artemis was worshipped as the goddess of nature, and childbirth and Aphrodite as the goddess of the foothills of Olympus, named Hypolybia (fig.12) (Ντόντου, 2016). In the places of worship of the goddess, there was often joint worship with other Egyptian deities such as Anubis, Harpocrates, as well as her husband Sarapis (Hell. Osiris). Finally, the cult of Isis gained more accolades and privileges in Greece than in Egypt.

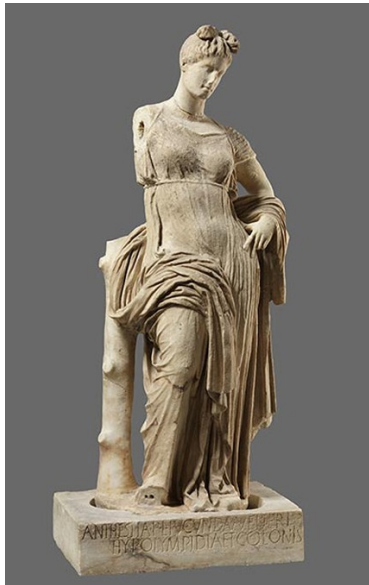


Figure 2.12: Statue of Aphrodite Hypolympidia, Dion. 2nd cent. BC. (Chrimatopoulos V, 2020).

The monument is located 20 m east of the sanctuary of Zeus and 50 m south of the southern section of the fortification wall, covering a total area of 50 m × 42m. Excavations began in 1978, and by 1982 most of the sanctuary had been excavated, revealing the facades of the four temples, the north and south wings, the central open space, and the enclosure of the temple, under the supervision of archaeologists M. Nikolaidou and D. Ignatiadou (Κασσερόπουλος, 2024). The majority of the buildings date back to the Severian period. Excavations also uncovered previous Hellenistic construction phases beneath the sanctuary's primary temple. During excavations, the sanctuary discovered a vast number of artworks, including statues and reliefs. The 19 sculptures, including seven engraved reliefs span the Hellenistic period to the third century CE. The sculptures include portrayals of greek goddesses like Aphrodite, Artemis and Poseidon. The sanctuary's inscriptions are divided into two categories: votive reliefs for the Isiac gods and statue bases, with the names of Aphrodite, Artemis and Poseidon (fig.13) (Maikidou, 2021).



Figure 2.13: Relief of Isis, Dion. (Παντερμαλής, 1999).

2.3.2 Roman baths

The Roman baths in the archaeological park are the second monument to be included in the analysis of this thesis. Firstly, it is necessary to clarify that the baths in question are those known as the Great Baths. Thus far, ten other public and private baths have been discovered, ranking Dion as the second Macedonian city in terms of the number of such baths, behind only Thessaloniki. Some of these bath complexes are the baths on the main street, the baths next to Dionysus' mansion, the so-called market baths, etc. (Σχοινά, 2020) (fig.14). During the period when Dion was under Roman rule as a colony (27 BC – 2nd century AD.), in accordance with the Roman custom of building Roman complexes for the needs of both the city's inhabitants and the army, the great baths were also constructed.

Roman baths were either public or private, and served a variety of social groups, including affluent individuals and their families, clients and others. Other than being a spot of hygiene as well as cleanliness, it functioned also as an important centre of recreation and social contact where inhabitants spent a substantial amount of their time. Baths in terms of the amusement manufacturing of that time are classified as hot springs (spa) and regural baths. The difference between them is that, while the latter may not have as vast pools as the former, they nevertheless waste a lot of water because they are continually operating (Hodge, 1992). It is the first complex to be excavated within the ancient city in the 1970s (Παπαγιάννη, 2025). The great baths were built in the 2nd century as part of a wider construction program resulting from the economic prosperity of the Severan dynasty in the 2nd century AD. They were built on top of the ruins of the Hellenistic wall. (Σχοινά, 2020). Nevertheless, a recent preliminary study of pottery from sections beneath the floors showed that the initial construction of the complex cannot be dated earlier than the beginning of the 4th century AD. (Παπαγιάννη, 2025). The area cover a region of 2000 m², making them the largest bath complex in Dion which had a public character (fig.15). They are located next to the main road of the city, at the point where it leads to its southern limits (Σχοινά, 2020).

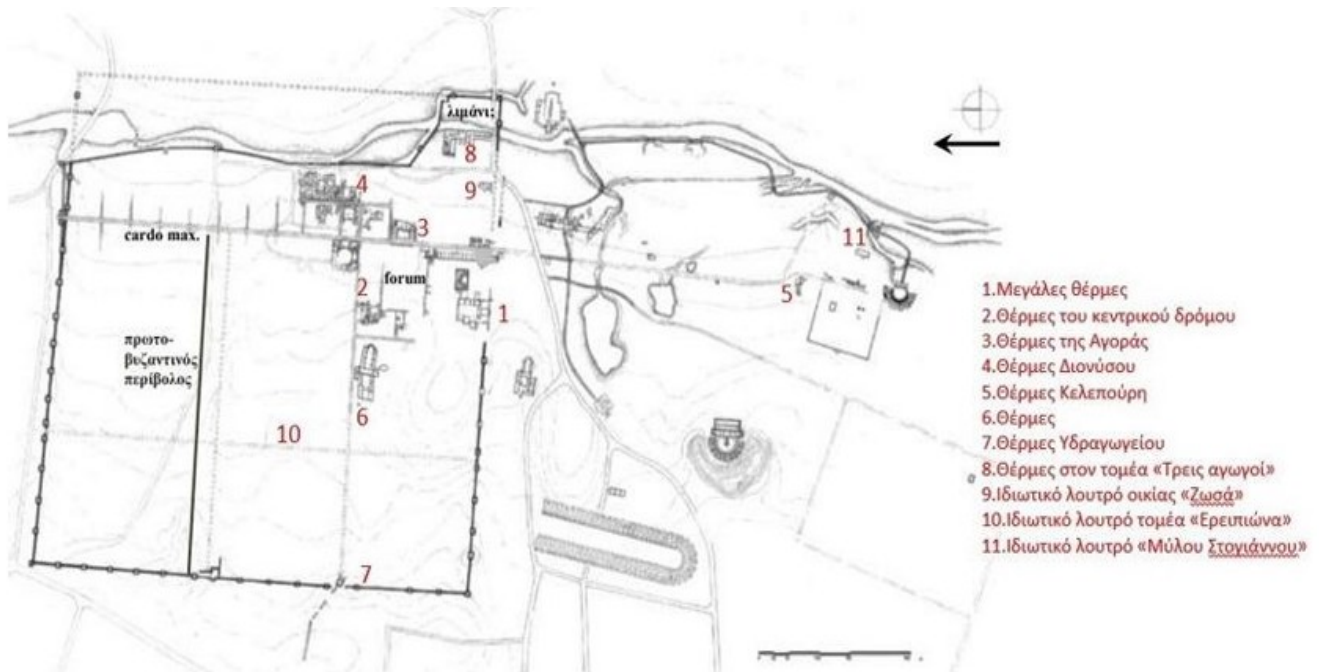


Figure 2.14: Topographical sketch with numbering of the baths, (Καραδέδος, 2000).



Figure 2.15: Aerial photograph of Great baths (Παντερμαλής, 1999).

2.3.3 Villa of Dionysos

The archaeological monument that will complete the scientific analysis of environmental and structural impacts is the so-called Villa of Dionysus (Hellenic Ministry of Culture and Sports, n.d.). The eastern road of the city passes west of the mansion, while the eastern wall is located a short distance to the east. In addition, it is generally located in the eastern wing of the city of Dion (Κοτσάκη, 2016). Excavations at the site began in 1982, when the facade of a large building was initially discovered along a road. A series of workshops and shops were initially identified, followed by a medium-sized bathhouse.

A little further north, a small four-columned courtyard was discovered, which once connected to the bathhouse (Παντερμαλής, 1987). It is essentially a luxurious private residence consisting of a complex of different buildings (fig.16). More specifically, this building block is divided into two main sections. The northern area includes open facilities surrounded by worship and banquet rooms as well as ancillary ones. As for the southernmost part, it is developed by a complex of baths. In addition, the facilities had their own water supply and sewage network. Some of the most important archaeological finds consist of sculptures (Κοτσάκη, 2016).

Given the typology of the buildings, the villa dates back to the second half of the 2nd century AD, which was also constructed on top of a building from the 4th century BC. (Γεωργίου, 2021). Finally, the most important space in this architectural complex is the banquet hall, in which a mosaic of the god Dionysus was found, measuring (100 sq. m.), which essentially confirmed beyond any doubt the identification of this god with the mansion (fig.17). This mosaic is preserved in the archaeological museum, a special indoor exhibition space designed to protect this rare example of art of such dimensions (Hellenic Ministry of Culture and Sports, n.d.)



Figure 2.16: Aerial photograph of Dionysos's villa with a view from the northwest (Κοτσάκη Μαγδαληνή, 2016).



Figure 2.17:The mosaic found in the banquet hall depicting a Dionysian scene (Κοτσάκη Μαγδαληνή, 2016).

2.4 Architectural description and construction materials

2.4.1 Sanctuary of Isis

First and foremost, the sanctuary of Isis consists of four temples on the west side and a central court with an altar. In addition, the sacred area has two porticos on the north and south sides, each with ancillary areas and rooms for visitors and priests, while the main entrance of the whole buildings entity is on the eastern side (fig.18) (Maikidou, 2021). The first of the four main structures of the sanctuary is a temple with a podium, which also has an access staircase on the eastern side measuring 6.95×2.15 m. Podium in the Roman

architecture is essentially a tall, solid base (platform) on which the temple was built, raising it significantly above the surrounding ground. The staircase comprises six stairs with marble veneer and is also surrounded by low brick walls with orthostats (fig.19). The podium measures 1,47 metres in height and was most likely simply plastered with a lime plaster and given a red external coating. As for the structure of the temple, it has a pronaos and a sekos and has total preserved dimensions of 8.53×10.95 m. The interesting architectural fact involves the side walls which bend at a right angle to the front, generating elongated brick pillars that are each 0,45m long. In addition, in front of the temple there is an altar consisting of a built core of bricks and mortar, while on the outside it is covered with vertical limestone slabs. Finally, between the staircase of temple A and the altar, there is a four-columned pillar, which had previously been attributed to the temple and was considered to be its facade.

The second main building is also a temple structure with a pronaos and cella parallel to the aforementioned temple, measuring 5.26×7.03 m. The main difference is that it does not have a pediment like the first one. Even the thickness of the walls and the ratio of the dimensions are similar to that of the previous one. In terms of building materials, both temples were constructed using the opus mixtum technique, with alternating bands of four rows of bricks and stone masonry, while in some places they feature pure brickwork.

The next structure, conventionally named building C, is located approximately 1.70 m east and in front of the previous temple. It is a rectangular, single-room building with a protruding arch on the rear wall, measuring 5.90-6.06 m wide and 3.60-3.94 m long. Furthermore, it has rectangular niches, which would have ended in brick arches, helping to support the vaulted ceiling of the building. The walls were covered with white and red mortar, while the floor was paved with hydraulic mortar and small, irregularly shaped marble fragment. In addition, in the centre of the floor there is an elliptical tank with marble cladding, in front of which a statue of Isis was found on a reused pedestal.

Finally, the architectural design of the fourth main building in the sanctuary of Isis would be discussed. This building is located 1.30-1.60 m north of the first temple and is a rectangular, single-room building measuring 4.19-4.42×4.73-4.78 m, with rectangular niches with arched ends formed on the inside of its side walls. It bears similarities to the previous building, specifically in that the niches begin a few centimeters above the floor of the space. The niches are 1.5 m high and 0.5 m wide, with a width of 0.5 m. Finally, as regards the construction materials, both this building and the previous one are made of pure bricks, while in some lower construction points of the third building, limestone is used. Marble was also used for decorative use, and also mortar served as the binding material for the masonry (Κασσερόπουλος, 2024).

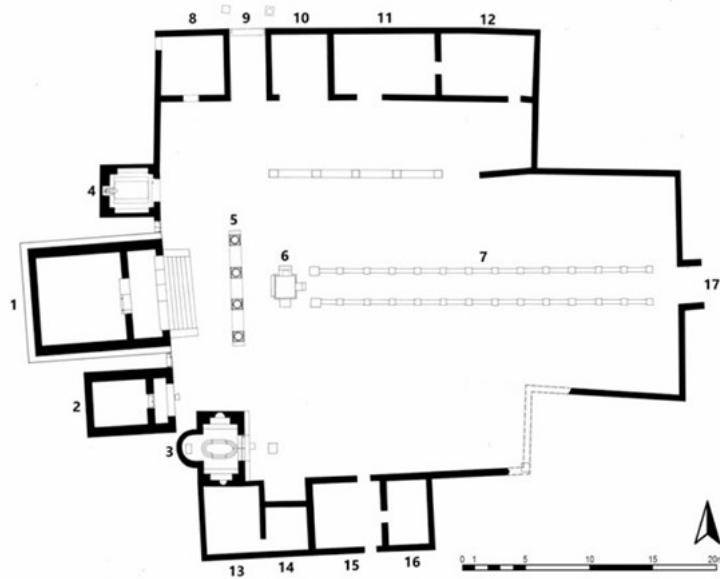


Figure 2.18: Plan of the various buildings of the sanctuary of Isis at Dion. Numbers 1-4 are the four main buildings, while the rest are auxiliary spaces and 17 is the eastern entrance (Παπαγιάννη, 2025)



Figure 2.19: Aerial photograph of the sanctuary of Isis at Dion (Σχοινά, 2020).

2.4.2 Roman baths

The Great Roman baths of Dion, which occupy an area of about 2,100 m² with overall dimensions of about 50×41m, are one of the largest and most architecturally sophisticated public buildings of the ancient city. The complex is situated next to a *cardo*, one of the main urban streets of the city, indicating its integration within the organised urban grid of Dion. Architecturally, the building follows the typical layout of Roman bathing complexes, organized around a large central hall (fig.20). This hall measured about 18.80×13.40 m and connected the surrounding rooms through triboled openings that allowed for controlled movement between the various bathing and recreational areas.

Roman bathing customs were characterised by a functional sequence, which is reflected in the internal spatial organisation. The main entrance (room 1) on the complex's eastern side led guests into the central hall and then to the ancillary rooms. While rooms on the northern wing (rooms 5,6 and 7) seem to have served as areas for socialising and relaxation before and after bathing, adjacent spaces like rooms 8 and 9 probably acted as *apodyteria*. (changing rooms). A notable architectural feature was the *frigidarium* (room 3) which included two more rectangular bathtubs, ornate niches for sculptures and a sizable cold water *piscina* that measured around 8 meters.

The heated bathing facilities, such as the *tepidarium* (room 14) and the *caldaria* (rooms 13 and 15) were located in the southern wing and had hypocaust heating systems powered by furnaces (*praeurnia*). Among the bathtubs, a magnificent mosaic depicts Tritons, Nereids, and a bull with a whale's tail (fig.20). In fact, they've also uncovered other mosaics at the site. The technological intricacy of Roman bath architecture as well as the meticulous control of the heat circulation throughout the facility are demonstrated by this exquisite thermal infrastructure. Supplementary, efficient water supply and drainage were guaranteed by additional hydraulic structures, such as the *castellum* (water reservoir) west of the complex and an underground sewer system linked to the *cardo maximus*. The monument's monumental grandeur was further accentuated by architectural embellishment. Marble revetments and sculptures enhanced the interior areas, while polychrome mosaics with geometric and marine designs covered the floors. The baths, which were constructed during the Severan dynasty at the close of the second century AD, continued to be actively used throughout the third and fourth centuries, demonstrating its crucial significance in Roman Dion's urban and social life. Finally, a macroscopic examination of the site revealed that the building materials consisted of bricks, limestone, and mortar as a binding agent.



Figure 2.20:A mosaic in the Great baths depicting a bull's head with a whale's tail (personal archive).

2.4.3 Villa of Dionysos

One of the most remarkable residential complexes of the Roman city is the villa of Dionysos, which is situated in the eastern part of the archaeological part of Dion. The structure is part of a large architectural that exemplifies the functional complexity and spatial arrangement of Roman Macedonian elite household architecture. The building's architectural layout which is organised around a series of atria (plural of atrium which means central open space) and courtyards integrates residential quarters, service areas, bathing facilities as well as a cultic sector (Παντερμαλής, 1997; 2002).

To elaborate more, the four atria and a tetrastyle courtyard serve as the main points of circulation and spatial articulation in the villa's architectural layout. In addition to offering natural light and ventilation, these open areas organized the complex's internal flow. The residence's main entrance is located in the western side and emerges into an open courtyard with a vestibule. A colonnaded stoa held up by ionic columns encircled this courtyard, creating a transitional area between the surrounding chambers and the open

area. These architectural configurations are typical of Roman home design, in which courtyards, in which courtyards had both utilitarian as well as symbolic purposes.

The structure's numerous functional parts are connected by corridors and entrances from this entrance. The existence of amenities often seen in high status Roman residences is highlighted by one tunnel that leads to a private bath complex. The central atrium, which has a water basin in the center of the room, is accessible by another aperture. The incorporation of hydraulic facilities, wells, and basins highlights the significance of water management in the villa's architectural design (Γεωργίου, 2021).

The cultic area attributed to Dionysos, situated on the eastern side of the central atrium is a distinctive architectural feature of the complex. This area is formed up of a number of smaller spaces, one of which is an extended hall that ends in an apse that probably hosted a cult statue of the god. An intricate mosaic of Dionysos was placed in front of this, underlying the area's symbolic and ceremonial nature. This existence demonstrates how domestic and religious purposes are integrated into the residence's architectural design. Overall, the villa of Dionysos design captures the blend of social representation, ritualistic activity as well as the domestic luxury of a typical aristocratic residence in ancient Dion's urban setting (Παντερμαλής, 2002). A macroscopic examination of the site revealed that the building materials consist of bricks, marble, and limestone, with mortar used as a binding agent.

2.5 Geomorphological and environmental setting

First and foremost, Greece features the most seismically active land in Europe due to its location at both the western end of the North Anatolian Fault zone and the meeting point of the Eurasian and African plates. Furthermore, Greece's active stress field is complicated since it typically alternates between compression and extension from east to west, with its main axis exhibiting many directions. Dion's archaeological park is located in the tectonically active region on the Eurasian plate. Although, it is not positioned immediately on a major plate boundary, the African plate's northward convergence beneath the Aegean area causes significant regional seismicity. As a result, northern Greece receives considerable seismic activity, which poses a risk to the preservation of historic sites (Pavlides, 2008). Due to the fact that it has steep slopes mainly in its northeastern part, it is easy to transport rocks from the mountain to the foothills where the area of interest is located. This fact, combined with the hydrology of the area, which is dominant, contributes to the formation of alluvial deposits.

Initially, the climate and wider environment of the region work in synergy with the region's hydrological systems. To elaborate more, climate is one of the elements that determines a region's hydrology and is measured in terms of precipitation, temperature, wind intensity as well as wind direction. Besides that, the fact that the area is characterised as one of the richest in flora in Greece, with abundant vegetation, is a decisive criterion. (Σχοινιά, 2020). However, the greatest impact is exerted by the intense hydrological presence of the area, which, in combination with the above, poses an extremely dangerous risk to the integrity of the monuments. More precisely, the presence of the Vafira river, a

navigable river that offered access to the sea throughout antiquity, flows through the eastern part of the archaeological park. This fact, in conjunction with the presence of tributaries and streams, further maximises the presence of water and, therefore, a series of immediate threats to the monuments (Xenios Project 2021).

The geomorphological evolution of the wider Dion plain has decisively contributed to the environmental conditions under which the archaeological remains have been preserved. Wide alluvial deposits dominate the region. Constant transport from Mount Olympus by fluvial and torrential processes results in these deposits. These deposits have led to the formation of a relatively low and humid environment, characterized by a particularly active groundwater circulation. These conditions have been favourable to the long-term preservation of archaeological deposits, but also pose a number of problems in terms of soil instability, waterlogging and moisture damage. The interaction of the geological formations, sedimentary processes and hydrological conditions, therefore, is a critical factor influencing both the conservation state and structural behaviour of the Dion monuments (Pavlidis, 2008; Xenios Project, 2021).

Furthermore, Dion's particular environmental setting has a direct bearing on the three monuments studied. The maximum interaction with groundwater is at the Sanctuary of Isis, as it is positioned in a persistent water presence and saturated soils environment. Similar to that, the Great Roman Baths are situated in an environment where high moisture levels may facilitate the decay of masonry materials and mortar joints by prolonged wetting and drying cycles. Finally, even though the Villa of Dionysos itself seems to be less directly impacted by standing water, the general hydrological conditions of the archaeological park persist in influencing its conservation via increased environmental humidity and seasonal changes in groundwater levels (Sesana et al., 2018; Colette, 2007).

3. Climate change as a regulator of cultural influence

To begin with, the phenomenon that is in a direct position to inflict unprecedented and potentially irreversible harm on tangible cultural heritage is climate change. Primarily, climate change is defined as a variation which is caused directly or indirectly by human activity and exhibits a role of modification in the composition of the global atmosphere and which also goes beyond natural fluctuations through time. There is therefore a clear distinction between human and natural causes. This definition involves the official scientific, which has been determined by the United Nations Framework Convention on Climate Change (UNFCCC). It constitutes a distinct category of prime concern, the subject of study and research by many international scientific bodies, one of which is the IPCC. As this scientific organisation states in its third assessment report it is since the pre-industrial era that the Earth's climate system has undergone significant modifications on both a global as well as a regional scale, concerning several of these alterations correlated to human activity. Other organisations that deal with such issues are UNESCO, ICOMOS, and many others (Colette, 2007).

Climate change entails a severe threat to World heritage sites, that encompass both cultural and natural heritage with outstanding universal value. These monuments

comprising monuments, buildings, archaeological sites as well as landscapes (UNESCO, 2007). A factor which reinforces the assertion concerning threats is related with the fact that according to a 2005 World heritage centre assessment, 72 % of natural and cultural heritage sites have been affected by climate change (Antoniou, 2024). Unquestionably, extreme events and gradually changing weather patterns constitute an imminent threat to tangible cultural heritage. For example, an increase in temperature combined with variations in wind, precipitation and relative humidity can pose a detrimental effect on the materials that make up cultural heritage objects. This is due the fact that variations in the normal climate as well as fluctuations in the frequency and severity of extreme weather events can have an impact on the biological, chemical and physical processes that cause the assets of deterioration (Fig.20) (Sesana, 2018).

Threats of climate change reported for cultural World Heritage properties

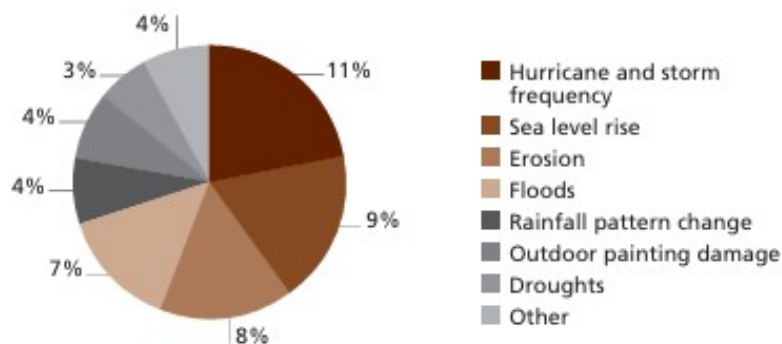


Figure 3.21: Chart showing the relative risk of climatic and non-climatic factors (Colette, 2007).

3.1 Precipitations and hydrological impacts

Key climatic factors that are currently undergoing change and directly affect cultural assets include hydrological cycle and, by extension, precipitation. Primarily, precipitation is inextricably linked to temperature, which, by general agreement, has been on the rise over the past century. What is actually occurring in essence lies within the context of the general circulation of the atmosphere. More specifically, as temperatures rise, more water evaporates from the oceans into the atmosphere. As a result, clouds become saturated with more water vapor, leading to more intense storms (Letcher, 2021). With other words, global warming is anticipated to aggravate the hydrological cycle, leading to more intense precipitation and flooding. Even if warmer circumstances should enhance the atmosphere's water holding capacity, this is not always the case, particularly when water availability is restricted.

It is certain that the impact of global warming is anticipated to trigger more extreme precipitation as atmospheric water vapour concentrations rise proportionally to saturation levels at a rate of 6-7% per degree increment in temperature according to the thermodynamic Clausius – Clapeyron equations. Furthermore, it is a proven fact that global land precipitation has grown by 2% since the beginning of 20th century (Dore, 2005). As the regions located in the Mediterranean have a distinct hydrological character, they are directly exposed to such phenomena (Tabari, 2020). These effects of precipitation in the Mediterranean context include heavy rainfalls, flooding in low-lying areas as well as mass movement phenomena as a matter of heavy precipitation events. These type of phenomena are undoubtedly imperilling Greece's archaeological monuments which is encircled by the Mediterranean sea (Antoniou, 2024).

This claim becomes even more irrefutable when one considers the increasingly frequent occurrence of extreme weather events of this kind, such as the recent storm Daniel which took place in the region of Thessaly, located south of and a short distance from Dion. (fig21). These extreme storms occurred in September 2023, causing extensive damage across a total area of 98,584 acres (ΙΑΑΔΕΤ, 2023). With regard to tangible heritage, increased precipitation existence could deteriorate monumental materials through soil saturation, metal corrosion as well as surface recession of carbonate stones like marble and limestone (Tringa, 2025).

It is worth noting that the hydrological cycle includes various "bodies", whether on the surface as well as subsurface that are directly affected by precipitation. These may include streams, lakes, groundwater and rivers also. Since the frequency and intensity of precipitation events have a decisive influence on these phenomena, which are intrinsically linked to precipitation regimes, it is valuable to further elucidate the variations among them. In this regard, the IPCC states that the phenomena of both more frequent flooding in areas with a pronounced hydrological character (rivers, nearby lakes, etc.) as well as the increase in river flow will be the result of climate change affecting the hydrological system (IPCC, 2021).

It seems highly likely that river systems and landscapes near them, particularly in environments such as those of the Mediterranean where short but intense rainfall events have been occurring recently, can swiftly translate into torrential flooding. More specifically, such situations will be caused by the rise in the water levels of water sources such as lakes and rivers, which in turn can trigger the movement of sediments as well as further erosion of the monument materials, especially when combined with the low infiltration capacity which is essentially the water that does not seep from the soil surface into the soil. Such hydrological changes may lead to additional hazards for archaeological sites, especially those located in lowland or riparian areas, where prolonged waterlogging and flooding can undermine structural integrity and accelerate material deterioration (fig.22) (Tabari, 2020). As for the area of the archaeological park in Dion, given that water is a dominant feature, with the Vafyra River as the central feature but also other hydrological elements, it is at immediate risk from such processes that compromise its integrity.

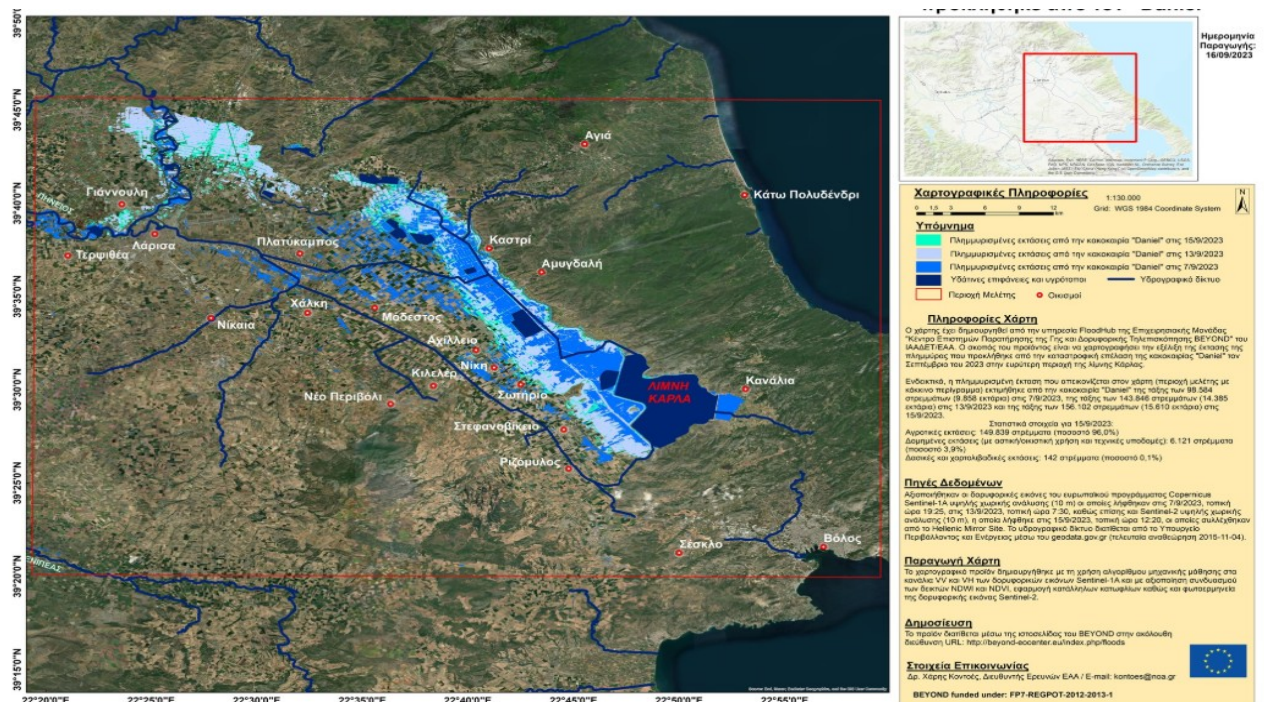


Figure 3.22: A map showing the areas affected by storm Daniel in September 2023 (IAAΔET, 2023).

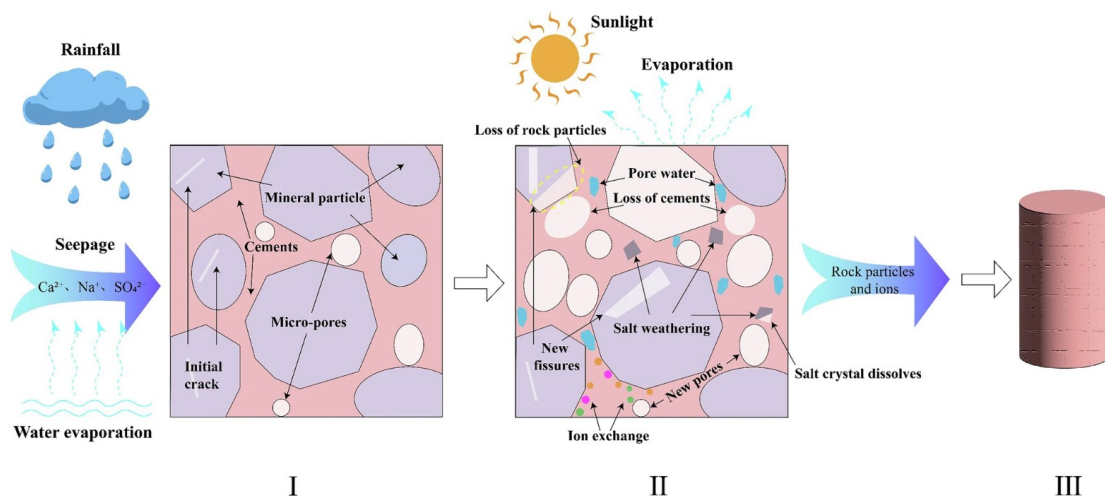


Figure 3.23: Processes that lead to the erosion of the stone in the presence of water (Heritage Science, 2026).

3.2 Temperature and humidity fluctuations

Another highly critical factor that has undergone a transformation relates to temperature, affecting both extreme hot days as well as frost ones. The earlier ones apply to days with temperatures of higher than 37 degrees, while the latter cover days with temperatures of lower than 0 degrees of Celsius (Kapsomenakis et al., 2022). It is a consensus among the scientific community that, the Earth's surface temperature has risen by 0.6°C since direct temperature measurements (1860 – 2000) which is unprecedented (fig.23). More precisely, throughout the last 1.000 years, this rise is probably the most dramatic of any century. This scientific evidence is based on proxy data such as corals, ice cores, tree rings as well as historical records calibrated with the use of thermometer assessments (Colette, 2007).

The rising temperature trend could be detrimental to the integrity of the monuments at Dion. To elaborate more, the materials that comprise the historical complexes which had been selected for analysis could feature cracks as a result of thermal stress caused by the monuments materials interacting with the high ambient temperatures. Furthermore, the long term consequences of this threat considerably weaken materials, thereby rendering them susceptible to deterioration of any kind (Fatorić & Seekamp, 2017).

On the other hand, temperatures as low as 0 °C directly jeopardise the selected monuments. In particular, water enters fractures and pores in stone through capillary action. When temperature drop, trapped water freezes and expands, creating internal pressure that gradually degrades the material. Continuous freeze – thaw cycles can widen fissures and create spalling. This damage occurs when exterior stone layers break off, causing surface erosion and substance degradation (Kapsomenakis et al., 2022). Besides, temperature fluctuations play a decisive role in matters related to the deterioration of exposed materials. In particular, the degradation processes is based on materials expanding as their rises and shrinking as it declines. There are two scenarios that can result in damage. In the first case when the components of an assembly feature various coefficients of expansion while in the second when a material is subjected to a fluctuation faster than its ability to respond uniformly. (Canadian Conservation Institute, 2018). Each material has different strengths and behaves differently under such conditions. In the case of the monuments under consideration, such a risk is evident. This is particularly true at the Sanctuary of Isis and the Villa of Dionysus, where groundwater makes its presence felt. In both monuments, though to a much greater extent in the former, water levels fluctuate throughout the year, leading to changes in the environment of the materials and, consequently, to their deterioration.

Since atmospheric moisture is closely related to temperature, changes in air temperature under global warming conditions are expected to affect water vapor levels. In many cases, increases in temperature lead to enhanced evaporation and a corresponding rise in atmospheric moisture, a relationship commonly described by thermodynamic principles linking temperature and saturated vapor pressure. However, the response of atmospheric moisture to temperature changes also depends on variations in relative humidity, which may vary significantly depending on regional climatic conditions. Relative humidity thus plays an important role in influencing atmospheric moisture variability. When relative humidity is relatively steady, fluctuations in atmospheric water

vapor tend to correlate with temperature variations closely. Noteworthy oscillations in relative humidity, on the reverse hand, may disrupt this relationship and result in more complex moisture dynamics in the atmosphere. In many mid-latitude and low-latitude continental locations, relative humidity variability can play a vital part in regulating atmospheric moisture conditions, particularly where precipitation patterns and moisture transport influence the atmospheric system.

Variations in atmospheric humidity are especially relevant in cultural asset conservation because they have a direct impact on the deterioration of archaeological material. More specifically, variations in relative humidity can affect moisture absorption in porous materials like stone, brick and mortar, potentially accelerating physical and chemical weathering processes. As a result, climate changed induced changes in temperature and atmospheric moisture regimes may exacerbate environmental stress on the exposed archaeological sites of the selected monuments in Dion (Hao & Lu, 2022).

Changes in global surface temperature relative to 1850–1900

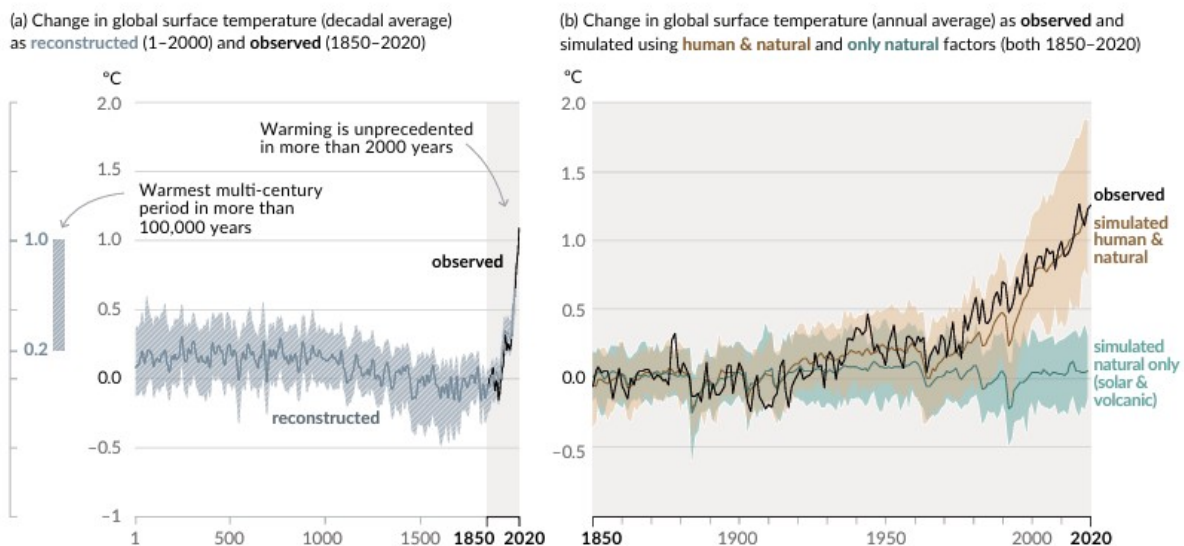


Figure 3.24: Development of global temperature changes over time and the factors contributing to recent warming trends development of global temperature changes over time and the factors contributing to recent warming trends (IPCC, 2021).

3.3 Seismic phenomena and combined hazards

A decisive factor, though not an environmental one, is undoubtedly seismic activity. Earthquakes have always been responsible for the destruction of hundreds of monuments, let alone under the current changed climatic conditions (Despotaki V., 2018). More specifically, the intensity of seismic activity is directly linked to both temperature and hydrological changes. This is because soil composition is directly affected by the presence of water through a process known as liquefaction. Such a process has been shown to be

capable of altering the cryosphere of the Earth's mantle. In other words, soil composition plays a decisive role in the vulnerability of a site, especially when that site consists of an archaeological structure threatened by collapse under such conditions (Simon V., 2025). The degree of risk associated with a location in conjunction, of course, with the level of risk it faces during a prolonged period of high temperatures and a prolonged hydrological threat depends on the maximum ground acceleration (Kapsomenakis, 2022). As for Dion, such a threat to the archaeological structures is a real possibility, as environmental parameters point to such a combined risk. In particular according to archaeological evidence, both the Great Baths and, likely, the Temple of Isis were destroyed by an earthquake, a fact that underscores the importance that must be attached to such a risk (ΕΦΑ Περίας).

3.4 Atmospheric contamination and pollutant deposition

Wrapping up with the effects that climate change causes to heritage sites through its environmental factors, air pollution and the impending presence of pollutants will be discussed. Initially, air pollution is defined as a complicated mixture of gaseous and particle contaminants that harms environmental quality, material integrity as well as the most significant human health (fig.24). The context we will be discussing concerns the environmental science frameworks which identify the top air pollutants the following ones. These include particulate matter (PM), ozone (O₃), carbon monoxide (CO), sulfur dioxide (SO₂), nitrogen dioxide (NO₂), and lead (Pb). These are also often known as "criteria pollutants". Moreover, hazardous air pollutants (air toxics) such as volatile organic compounds and heavy metals are becoming increasingly problematic due to their long-term toxicity and persistence in the environment. These pollutants occur in various physical forms, including gases, vapors, and aerosols, and their behavior in the atmosphere is determined by physicochemical transformations, transport mechanisms, and deposition processes.

Climate change has significantly exacerbated air pollution and modified its spatial distribution. The increase in global temperatures accelerates photochemical reactions within the atmosphere, thereby intensifying the production of secondary pollutants, including ground-level ozone and fine particulate matter. Moreover, climate-related events, such as wildfires, desertification, and increased dust transport, contribute to elevated concentrations of airborne particles. Human activities, particularly the combustion of fossil fuels, release not only greenhouse gases but also other pollutants, such as NO₂ and SO₂, which can subsequently react to form acidic compounds. Such processes are those which highlight the close relationship between climate change and air pollution, with each exacerbating the other through feedback mechanisms. Besides that, the various changes which occur in air circulation and precipitation patterns also influence pollution dispersion and deposition, typically leading in greater pollutant accumulation in urban and industrial areas.

Regarding the impacts of air pollution on archaeological materials is of utmost importance since these materials constitute valuable cultural patrimony. Supplementary, pollutants which are particularly sulfur dioxide as well as nitrogen oxides could undergo atmospheric changes and produce acidic species such as sulfuric and nitric acids. These type of acids are deposited on surfaces though wet and also dry deposition, a fact which leads in chemical weathering of stone, metals, and other materials. As an instance limestone and marble, which are often employed in ancient monuments, react with sulfuric acid to produce gypsum, a more soluble substance that promotes surface deterioration and structural weakness. To elaborate more, this process is accelerated by wetness and drying cycles, which encourage crystallisation within the material pores, resulting in mechanical stress and fragmentation. Although the archaeological park in Dion is not located in an industrial area or a city, such a risk does exist, as it is situated in a rural area where tractors and possibly pesticide sprayers are present, which could threaten the integrity of the monuments.

Additionally, a monument's proximity to the sea can play a decisive role in accelerating the deposition of chloride ions on its materials as well as salt corrosion. The transport of gas masses from the sea into porous building materials can damage them through various mechanisms. Primarily, a type of deterioration caused by salts within the pore network involves the crystallization of soluble salts, such as sodium chloride (NaCl). Furthermore, as the saline solutions penetrate and then evaporate, salt crystals form under supersaturated conditions, exerting crystallization pressure on the pore walls. This pressure causes internal strains, resulting in microcracking, granular disintegration, and final material loss. Another type of mechanism that exacerbates the stress involves crystal growth, which initially occurs in larger pores and progressively expands into smaller ones, intensifying stress concentrations. Other than that, repeated cycles of dissolution and recrystallization accelerate the degradation processes over time (Theoulakis P., 1998). As noted by Feliu, these effects, which are mainly accelerated by the wind, are decreased exponentially within the first 400 to 600 meters. Therefore, since the archaeological park is located approximately 5km from the coastline, such a risk is limited (Feliu et al., 1999).

Equally, metallic archaeological artifacts are susceptible to corrosion. In particular, pollutants such as SO₂, ozone, and particulate matter have been shown to cause accelerated oxidation and material loss by provoking electrochemical reactions on metal surfaces, especially in combination with moisture. Additionally, acidic conditions can destabilise the protective oxide layers that naturally form on metals, accelerating the corrosion process. Furthermore, particle deposition can trap moisture and contaminants on surfaces, accelerating localized corrosion.

In conclusion, atmospheric pollutants whose negative impacts are exacerbated by climate change pose a significant threat not only to ecosystems and human health, but also to archaeological remains. The synergistic effects of increased pollutant concentrations, changes in atmospheric chemistry, and shifting environmental conditions accelerate the deterioration of cultural heritage. Last but not least, gaining an insight into these interactions is essential for developing effective conservation strategies and mitigating the long-term impacts of climate change on archaeological resources (Vallero, 2014).

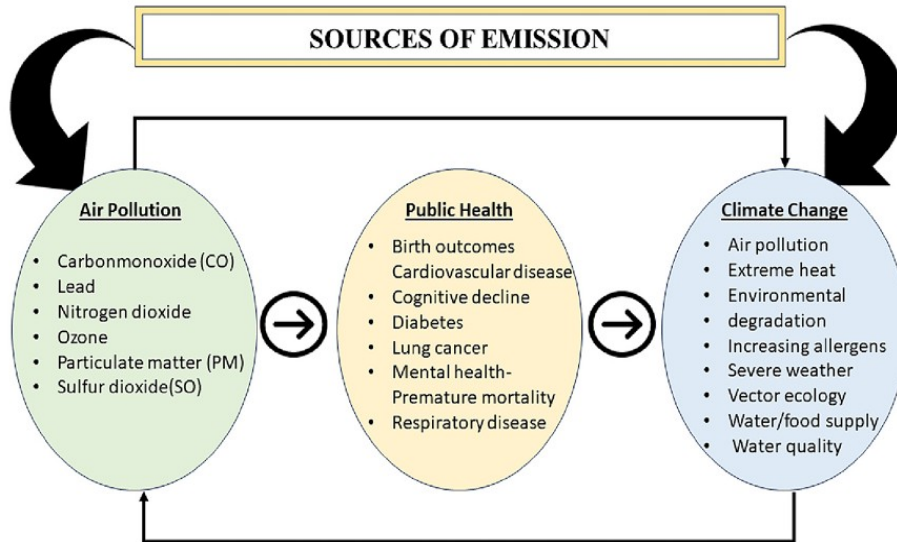


Figure 3.25: The interconnection between air pollution, human health and climate change (Afifa, 2024).

4. Deterioration patterns and previous restoration interventions

This chapter deals with a very valuable scientific approach that is essential for the holistic management of an archaeological site. This involves diagnosis, which is essentially a qualitative process during which information is gathered regarding the monument's various damages, such as cracks, seismic effects, or various structural changes that have occurred in the past. Furthermore, it is a highly reliable method that links causes and effects (Penelis, 2020). The following three monuments will be examined: The sanctuary of Isis, the roman baths as well as the villa of Dionysus.

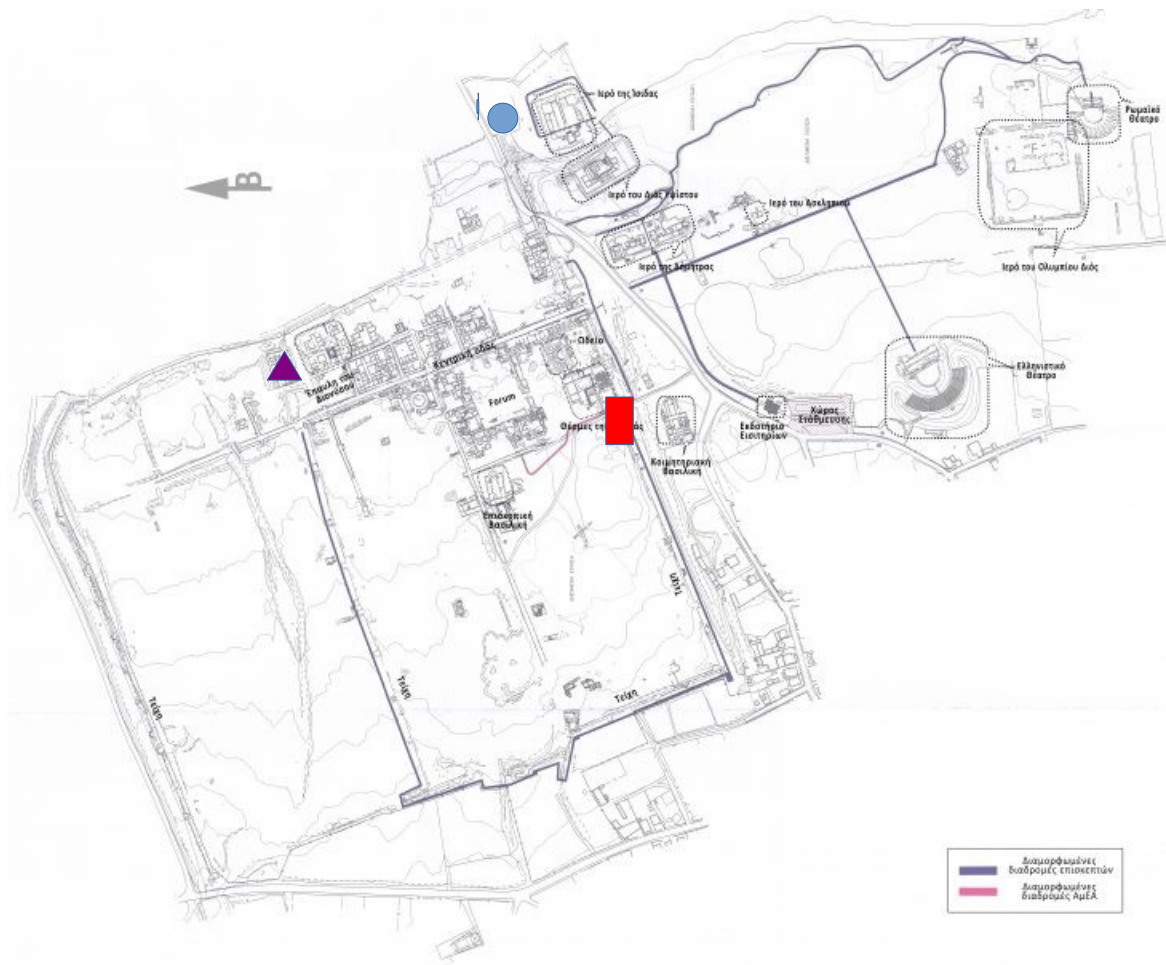


Figure 4.26: The diagram above shows the layout of the monuments in the archaeological park: the temple of Isis is shown in blue, the Roman baths in red, and the Villa of Dionysus in purple.

4.1 Sancturary of Isis: Current condition and material deterioration

In the first site of investigation, there are two different types of Roman masonry. More specifically, the opus mixtum technique was used, combining stones and bricks in alternating courses, along with mortar while the second technique opus latericium (testaceum) technique, featuring bricks (fired clay bricks) combined with mortar (Quelhas B., 2014).

Following an on-site investigation, it was determined that there is a significant amount of water coming into contact with the masonry, and that its level fluctuates throughout the year (fig 4.27). The water issue, and specifically the issue of flooding, is the most critical one in the area historically, as evidenced by past flooding events that the region has faced (fig.4.28). These fluctuations in water level have caused a layer of salt deposits to form at the points where this change occurs. During the floods that occur periodically (e.g., in 2002 and 2017), the monument also fills with mud. This is a situation the site has faced

from the very moment it was excavated (the heavy presence of mud), a fact that has actually been beneficial for the preservation of its materials (ΕΦΑ Περίας). It is worth noting that the large accumulation of water in the monument is probably due to the phenomenon of artesianism (ΕΦΑ Περίας), Artesianism occurs when groundwater confined within permeable geological layers is subjected to hydrostatic pressure, resulting in the natural upward movement or emergence of water through fractures, permeable sediments, or openings in the ground surface (Freeze & Cherry, 1979).

In addition, vegetation was observed both around the perimeter and inside, as shown in the image below (fig 4.29). This vegetation changes depending on the period of the season. In addition, vegetation is also growing within the joints. Furthermore, there is deformation in the walls, which is most likely due to structural instability. Another sign of deterioration caused by rising damp is the presence of salt efflorescence. In addition, biological colonization, evidenced by the growth of moss and lichen, is visible. Besides that, cracks are visible in various parts of the walls as well as material loss in some parts (Fig. 4.30).



Figure 4.27: A wide view of the Temple of Isis, showing the predominance of water in the site mainly during winter period (personal archive).



Figure 4.28: The Sanctuary of Isis inundated with water and after the flood on November 25, 2019 (Xenios Project, 2021).



Figure 4.29: The Sanctuary of Isis buried in mud after the flood on November 17, 2017 (Xenios Project, 2021).



Figure 4.30: Dense vegetation at the sanctuary of Isis during the summer months.



Figure 4.31: Photographic record of the Temple of Isis showing a number of visible signs of pathology: displacement of structural elements, loss of material, biological colonization, cracks, and the presence of vegetation in joints (personal archive).

Another part of the monument that has suffered damage is the floor. It is almost entirely covered by water, except during the summer months, as shown in the photo. There is mud present, and consequently plants growing on it, which, combined with the moisture, makes it vulnerable (fig. 4.31). Furthermore, an integral part of the monument is the marble columns, some of which have fallen into the water (fig 4.32). The type of deterioration they have encountered is the presence of moss and lichen, which has caused a yellowish discoloration on their surface, as shown in the image (fig. 4.33). Besides that, the surface of the columns displays salt deposits, mainly at the bottom where they come into contact with water, as well as some areas of material loss (ICOMOS-ISCS, 2008).



Figure 4.32: Ritual water basin and headless statue of Isis of fortune, illustrating the floor's strong association with water and its deterioration due to hydrological features.



Figure 4.33: Fallen column at the sanctuary of Isis in Dion (personal archive).



Figure 4.34: Column with visible presence of moss and lichen growth, as well as salt crusts (personal archive).

An integral part of the monument are the cult statues that have been found, as well as others that once adorned the site, such as the statue of the god of love. The statues on the site are replicas of the originals, which are kept safe in the Dion Archaeological Museum so that they are not exposed to the effects of the weather (ΕΦΑ Περίας). Nevertheless, it is advisable to document the damage they exhibit in order to understand the impact that external conditions pose on them. More specifically, they have a yellowish tint on their surface due to the presence of algae and lichen, as well as salt crusts (fig. 4.34).



Figure 4.35: Statue of Isis Lochia showing clear signs of moss and lichen growth, salt crusts, cracks and material loss (personal archive).

4.1.1 Structural response and mechanical behaviour

This chapter presents an interpretation of how the monument is expected to respond structurally, given the forces exerted upon it by both environmental and seismic factors. Above all, it is beneficial to clarify some specific engineering terms that will be discussed below. These are tensile strength, compressive strength, and shear strength. To start with, tensile strength concerns the highest amount of stress that a material can withstand before it breaks. With other words, it measures a material's resistance to stretching. On the contrary, compressive strength is related to the highest amount of squeezing force that a material has the capability of withstanding before it fails. In particular, it determines the maximum stress that a material can endure when forced together from opposite sites, expressed as force divided by the area it acts upon. Finally, shear strength applies to a material's resistance to distortion under shear loading circumstances. That is to say it can be described as the highest stress that a material is capable of sustaining without failing or deforming excessively when subjected to shearing force (William D. Callister Jr, 2013)

With regard to the sanctuary of Isis, it is characterized of a structural system that is composed mainly of fragmented masonry remains. The dominant materials are bricks, limestone and lime based mortar while marble architectural elements present a minor presence. As is the case with most ancient masonry structures, the monument relies primarily on the compressive strength of its materials, while exhibiting limited resistance to tensile and shear stresses (table 1). Masonry monuments generally withstand gravitational loads satisfactorily; however, their structural behavior becomes significantly more vulnerable under seismic action and long-term environmental deterioration.

Rock type	Aggregation properties			Thermal properties			Mechanical properties			
	ρ (g/cm ³)	φ (%)	μ^a (-log d)	α (1/10 ⁶)	$\frac{K}{[mcal]}$ cm/s °C	k (10 ⁻² cm ² /s)	H	E (Mb)	S (kb)	R (kb)
Granite	2.5-2.7	0.1-4	9-6	5-11	3-10	0.5-3	5-7	0.3-0.6	0.8-3.3	0.1-0.7
Gabbro	2.8-3.1	0.3-3	7-5	4-7	4-6	1-2	5-6.5	0.5-1.1	1.1-3.0	0.1-0.7
Rhyolite- andesite	2.2-2.5	4-15	8-2	5-9	2-9	0.4-3	5-6.5	0.6-0.7	0.6-2.2	0.01-0.7
Basalt	2.7-3.1	0.1-5	5-1	4-6	2-5	0.4-1.5	4-6.5	0.5-1.0	0.5-2.9	0.1-0.9
Quartzite	2.5-2.7	0.3-3	7-4	10-12	8-16	2-8	4-7	0.6-1.0	1.1-3.6	0.1-1.0
Marble	2.4-2.8	0.4-5	6-3	5-9	3-7	0.5-1.5	2-4	0.2-0.7	0.4-1.9	0.04-0.3
Slate	2.6-2.9	0.1-5	11-8	8-10	3-9	0.5-3	3-5	0.3-0.9	0.5-3.1	0.05-1.0
Sandstone	2.0-2.6	1-30	3-0	8-12	2-12	0.4-5	2-7	0.03-0.8	0.2-2.5	0.01-0.4
Limestone	1.8-2.7	0.3-30	9-2	4-12	2-6	0.4-1.5	2-3	0.1-0.7	0.2-2.4	0.1-0.5
Shale	2.0-2.5	2-30	9-5	9-15	1-8	0.3-2	2-3	0.1-0.4	0.3-1.3	0.02-0.5
Soapstone	2.5-2.8	0.5-5	6-4	8-12	2-7	0.4-1.5	1	0.01-0.1	0.1-0.4	0.01-0.1
Travertine	2.0-2.7	0.5-5	5-2	6-10	2-5	0.4-1	2-3	0.1-0.6	0.1-1.5	0.02-0.1
Serpentine ^b	2.2-2.7	1-15	7-3	5-12	3-9	0.5-3	2-5	0.1-0.5	0.7-1.9	0.05-0.1

Table 1: Mechanical properties of stones (Penelis, G.G., 2020).

First and foremost, the existing structural state of the Sanctuary is greatly influenced by the interaction between the monument and its humid environment. In addition, the fact of utmost importance involves that the study area is situated in a zone characterized by high groundwater levels, saturated soils, and constant exposure to hydrological processes linked to the Dion hydrological network. These circumstances undermine the mechanical stability of the subsoil, which can lead in turn to differential settlement, loss of bearing capacity, and localized displacement of the masonry walls. Unstable and wet soil conditions also heighten the monument's vulnerability to seismic activity, as soft and saturated sediments tend to amplify ground motion during earthquakes (Penelis, G.G., 2020). At this point, it is worth noting that the sanctuary was destroyed by an earthquake and, after being flooded, was permanently abandoned (Κουλίδου, Σ.- Σπανοδήμος, Χ. 2022).

From a structural standpoint, the Sanctuary functions largely as a system of partially decoupled stone walls and architectural elements as opposed to a fully integrated structural entity. Besides that, the absence of continuous shear action and the fragmented state of preservation limit the monument's ability to effectively redistribute horizontal forces. In accordance with masonry theory, structures lacking rigid connections between walls are particularly vulnerable to out-of-plane forces, overturning, and local collapses under seismic loads. This is particularly serious at the Sanctuary of Isis, where many of the remaining sections of the masonry are weak and disconnected. The likelihood of a collapse is further heightened when we take into account the environmental conditions to which it is exposed.

More precisely, the monument's long-term exposure to environmental degradation has likely altered its original structural balance. Material loss from joints and surfaces, biological colonization, and corrosion processes reduce the cohesion of the masonry and contribute to the emergence of instability phenomena. Existing cracks and weakened joints may act as critical points during future seismic events, increasing the likelihood of partial collapses or the detachment of architectural elements. It is worth mentioning that the presence of water and subsequent moisture in the lower parts of masonry plays a significant role in weakening the cohesion of masonry materials as a homogeneous material, as it can cause internal microcracks and gradually reduce the overall mechanical strength of the structure.

Regarding the freestanding statues and columns in the sanctuary of Isis the following can be declared. They behave as isolated vertical elements with limited lateral resistance, making them particularly vulnerable to instability, tilting, and displacement during seismic events. The weakening of their foundations due to soil saturation and erosion further increases the risk of local failure or overturning. The Sanctuary of Isis at Dion's statues and columnar elements show increased structural vulnerability due to their slender geometry, exposure conditions, and prolonged interaction with moisture-related deterioration processes (Penelis, G.G., 2020).

On the whole, the structural behavior of the Sanctuary of Isis is determined by a complex interplay between material deterioration, moisture-induced weakening, cracked masonry, and unstable ground conditions. These characteristics significantly enhance the

monument's vulnerability to both environmental stresses and seismic activity, making the Sanctuary one of the most vulnerable monuments in the Archaeological Park of Dion.

4.2 Roman baths: Current condition and material deterioration

The complex of the Great baths mainly consists of roman masonry. The visual inspection showed that the types of roman masonry construction used to build the baths area are, opus mixtum as well as opus incertum. The first technique involves alternating stones and bricks using mortar, while the second uses individual elements of more uniform stone masonry (Quelhas B., 2014). The remaining parts of the thermal baths consist of the surviving hypocausts on which the floor rested, which supplied the hot water to the baths, as well as the mosaics. The hypocausts are composed of fired clay bricks which were bonded with lime-based mortar while the mosaics stone tesserae, probably made of limestone. Moreover, with regard to the mosaics, the visual inspection showed that they have been recently restored and, as a result, exhibit only biological colonization due to the environmental conditions prevailing in the archaeological site (fig.4.36). Apart from that, there is a sculpture which has biological deposits (lichens) and loss of parts (e.g., head, limbs) (figure 4.38).

According to the field survey, pathological phenomena have been observed at Great baths, primarily attributed to deterioration caused by moisture and biological colonization. Furthermore, vegetation growth, including mosses, lichens, grasses, and climbing plants, is observed on the surfaces and joints of the masonry, contributing to moisture retention and the mechanical degradation of the masonry structure. Furthermore, mortar loss, surface erosion of the limestone blocks, and visible structural fragmentation indicate a progressive weakening of material cohesion and structural integrity (fig.4.37). Finally, moisture and possible capillary rise further intensify the deterioration processes, promoting chemical corrosion and biological activity within the monument (ICOMOS-ISCS, 2008).



Figure 4.36: Mosaic section in the great baths (personal archive).



Figure 4.37: A section of the hypocausts of Great baths where traces of biological activity and material displacement are evident (personal archive).

4.2.1 Structural response and mechanical behaviour

The Great baths were constructed to endure substantial vertical and thermal loads caused by the baths complex's functioning and the underfloor heating system. However, like other ancient masonry constructions, its structural performance is mostly determined by compressive strength, with low resistance to tensile and shear stresses (Penelis, G.G., 2020). The monument's current fragmented condition suggests a severe loss of structural continuity, limiting its ability to properly transfer loads and resist horizontal stresses. Archaeological evidence indicates that the baths were severely damaged by a massive seismic event, resulting in collapse, displacement of masonry elements, and increasing structural destabilization. (ΕΦΑ Περίοδος).

In particular, the monument's current condition shows numerous signs of structural deterioration caused by both seismic activity and long-term environmental degradation. Cracks, displacement of masonry elements, partial collapses, loss of mortar, and deformation of sections of the walls are examples of visible issues. The photograph below illustrates indicative signs of the monument's structural instability, such as material displacement and cracks in the masonry. Ultimately, the interaction of seismic susceptibility, unstable soil conditions, and environmental degradation processes significantly enhances the structural sensitivity of the Great roman baths as well as heightening the likelihood of future localized failures or material deterioration.



Figure 4.38: Section of masonry in great baths with visible signs of structural vulnerability.

4.3 Villa of Dionysos: Current condition and material deterioration

Initially, the masonry system of the Villa of Dionysos is primarily characterized by a mixed Roman construction technique combining elements of opus incertum and opus mixtum, consisting of irregular limestone masonry reinforced with horizontal brick courses bonded by lime mortar (Quelhas B., 2014). Furthermore, the remaining structural elements consist of marble columns. In addition, the covered symposium hall features statues of philosophers, which are likely replicas made of plaster. Following an on-site inspection of the area, it was found that the ground in most parts of the site is waterlogged due to the standing water, resulting in mud in most cases (fig.4.39).



Figure 4.39: Intensive presence of groundwater and mud at the Dionysos villa (personal archive).

A visual inspection conducted at the Villa of Dionysus revealed various types of deterioration that the archaeological materials have undergone due to their exposure to weather conditions, as well as the high humidity and moisture levels in the environment that they are surrounded by. More specifically, biological colonization was observed at several points, as evidenced by the presence of vegetation, moss, and lichen, as well as localized displacement of material. In fact, vegetation is also found within the structure of the materials. In addition, signs of cracks as well as disintegration of bricks were observed (ICOMOS-ISCS, 2008). The types of material deterioration described will be illustrated in the following images, which were recorded during the on-site survey (fig.4.40, fig.4.41, fig.4.42). It is noteworthy that as it appears in some of the columns have been repaired using mortar. Finally, the main causes of this deterioration are prolonged exposure to humidity, groundwater action, and wet–dry cycles.



Figure 4.40: Columns from the Dionysus Villa displaying evidence of biological colonization (personal archive).



Figure 4.41: Penetration of vegetation into masonry (personal archive).



Figure 4.42: A column at the Villa of Dionysus featuring clear signs of cracks and biological colonization (personal archive).

4.3.1 Structural response and mechanical behaviour

Observing the structure of the monument, which consists primarily of masonry combining limestone, fired bricks, and lime mortar, while studying the function of such structures, the following can be noted. More specifically, the structural principles as articulated by Penelis, state that masonry walls of this type tend to perform effectively under compressive loads. However, they are particularly vulnerable to tensile and shear stresses due to the absence of reinforcement and their limited ductility. From one side, construction using horizontal rows of bricks and stones contributes to the partial absorption of deformation forces and also to the improved redistribution of stresses in cases of risk from settlement and seismic loads. On the other hand, however, the heterogeneous composition of the structure can create areas of varied mechanical behavior, especially where moisture-related deterioration has weakened the mortar's cohesion and reduced the integrity of the masonry joints (Penelis, G.G., 2020).

The prevailing geotechnical and environmental conditions undoubtedly influence structural behavior. Thus, alluvial deposits, high groundwater levels, and persistent soil moisture may reduce the bearing capacity of the subsoil and contribute to differential settlement, local displacement of masonry, and gradual destabilization of structural elements. Furthermore, the fact that these are porous materials and the area has high humidity can lead to moisture penetration and, consequently, accelerate the deterioration of the mortar and internal weakening due to salt crystallization. Such a situation leads to a progressive reduction in structural integrity. Additionally, the visible signs of deformation, localized cracks, and displacement of architectural elements observed in the mansion indicate a long-term interaction between environmental deterioration and mechanical stresses (Doehne, 2010).

An integral part of the Villa of Dionysus are the surviving columns, which are structurally vulnerable because of their function as isolated vertical structural elements with limited lateral support. In particular, their geometry and fragmented state make them even more vulnerable to instability phenomena such as rotational displacement, tilting, cracking, and potential overturning during seismic excitation (Penelis, G. G. 2007). In addition, their structural behavior becomes further affected by the weakening of foundation conditions produced by moisture-rich soils and potential subsidence events. Subsequently, the interplay between seismic activity, environmental degradation, and unstable ground conditions significantly amplifies the mechanical vulnerability of the Villa of Dionysus and its surviving architectural elements.

4.4 Overview of previous restoration measures

Initially, a number of conservation and restoration interventions have been carried out throughout the archaeological park of Dion over the last few decades in order to reduce material deterioration, increase structural stability, and promote the long-term preservation of the monuments. As for the sanctuary of Isis, from the instant it was uncovered during the excavation, there have been flooding problems within the site, as can be seen in the photo (figure 4.43). The first recorded intervention affecting even the sanctuary of Isis occurred in 1951 with the construction of a trench in order to drain the marshes and irrigate the area, incorporating part of the Vafyra River within the archaeological site. In addition, in order to address the hydrological issues, flood protection projects were carried out in the area between 1994 and 1995. These projects included the excavation of a trench in the northern section of the city wall to manage the waters of the Urlia stream.

In the years that followed, specifically between 1994 and 2000, funding from the Second Community Support Framework for the region of Central Macedonia was used to carry out maintenance and restoration work on various monuments within the archaeological park. Among the works carried out, the ancient Vafyras River was regulated through riverbed dredging, backfilling, the construction of protective retaining walls, and slope stabilization. This river runs adjacent to the sanctuary of Isis, so these works were of the utmost importance. Furthermore, on-site observation revealed that maintenance work had been carried out within the sanctuary grounds, and it is likely that this took place during that period. In addition, the sanctuary's bridge was constructed during that project, making it possible to visit the site by floating (Καπλύρη Γεωργία, 2025). Finally, within the framework of 'Anti-flood projects in Dion,' with a budget of €2,250,000.00 and implemented by the Ministry of Culture through the Directorate of Restoration of Ancient Monuments and the Ephorate of Antiquities of Pieria, a metal bridge was created that connects the sanctuary of Isis with the sanctuary of Zeus (Hellenic Parliament).



Figure 4.43: Flood in the sanctuary of Isis during the excavation phase in 1982 (Σχοινά Ε., 2020).

Regarding the monument of the Great Baths, within the framework of the program 'Restoration and Promotion of the Baths of Dion Market,' with a budget of €1,500,000.00 (ΕΣΠΑ 2021-2027), and with the Ephorate of Antiquities of Pieria as the implementing authority, maintenance works are being carried out (Hellenic Parliament). Finally, with regard to the interventions in the Villa of Dionysus, as observed during the on-site investigation, conservation work has been carried out on the monument in the past.

5. Risk assessment analysis

5.1 Risk assessment theory

First and foremost, yet another component that would serve as a cornerstone for the successful cultural management of the archaeological park at Dion is undoubtedly risk assessment theory. More specifically, both an understanding of the risks involved and the immediate consequences they entail are vital elements of a modern, comprehensive approach to safeguarding a site of cultural significance. Therefore, for the purposes of this study, it is deemed necessary to first present a theoretical overview of this recent scientific approach to issues of cultural heritage management and promotion. The primary objective of risk analysis is to support decisions that impact future well-being, particularly regarding human life and cultural heritage sites, which are closely linked to threats and harmful events (Rausand, 2013).

Prior to implementing risk management, it is essential to develop a thorough comprehension of the concept to gain a deeper familiarity with the area of study. To be more specific, risk assessment is defined as the quantification of risk that is calculated as the product of the probability of failure and the impact of failure for systems exposed to different hazards or a combination of hazards, according to one of the numerous definitions surrounding this topic (Michel Ghosn, 2020). A probabilistic methodology is used to assess risk, considering the interaction of hazard, exposure, vulnerability, and capacity. In addition, the three previously mentioned elements are the fundamental elements of disaster risk (UNDRR, 2023). The possible risks must also be recognized and afterwards divided into three categories: environmental hazards like biological deterioration and erosion, human-caused hazards like vandalism and looting, and natural hazards like floods and landslides.

Essential parameters that should be considered as part of a risk assessment include the probability as well as the extent to which an event may occur. Quantitative and qualitative analyses are conducted to verify this hypothesis, with the aim of drawing beneficial insights. Regarding qualitative analysis, observational studies are primarily used to determine whether the risk is high, low, or moderate. In contrast, quantitative analysis is performed using probabilistic calculations and statistical models. By combining these two

different processes, the most probabilistic scenario is derived, which predicts the future impacts the monument will encounter.

The key area of research that can't be overlooked to advance the process of assessing the cultural site's risk is the identification of the vulnerabilities it runs into. To elaborate more, among the factors that contribute to this are structural integrity, as well as environmental exposure, which refers to the degree of resistance to weather conditions and environmental pollution. In addition to these factors, the state of preservation of the monument in question, as well as the sensitivity of its materials, contribute to its overall vulnerability. It is noteworthy that quantification is a critical step in a comprehensive risk management plan. Through utilizing current approaches such as remote sensing, GIS as well as computational modelling, the probability of a potential risk tends to be measured in a more scientific and accurate way. The equation applicable to this quantification process involves **Risk=Probability of Failure×Consequence of Failure.**

Once the measurements and future scenarios have been recorded, the next step involves implementing adaptation measures as well as managing the risks and their scope. These plans of action may include disaster preparedness strategies, adaptive measures and preventive conservation. Once all these steps have been successfully completed, the only remaining task is that of hazard communication. This approach includes both stakeholder participation and decision- making. Stakeholders could consist of local communities, researchers/experts as well as government entities which are responsible for cultural heritage protection.

Finally, risk analysis could be considered as maybe the most rational method for evaluating the performance of structures and infrastructure systems. The above should serve as the basis for creating structural codes and standards. Such a management process can also be applied in other contexts, such as decision-making regarding maintenance, strengthening the resilience of infrastructure systems and communities, as well as other types of upgrades.



Figure 5.44: Risk assessment analysis for cultural heritage (Hadjimitsis D. et al., 2011).

5.2 Risk analysis approach and data processing

It has been decided that the assessment of the vulnerabilities caused by climate change through future environmental conditions in the archaeological park of Dion will be evaluated using a comprehensive risk analysis framework. To elaborate more, the methodological approach is based on the framework proposed by Kapsomenakis et al. (2022) and is implemented using the “DEAR-Clima” tool, a specialized computational platform designed for assessing climate-related risks. Essentially, this software allows for the processing of climatic and geophysical data in the aim of generating quantitative assessments of the risks facing selected monuments.

Supplementary, the geographical coordinates of the archaeological site of Dion at Pieria (approximately 40.17° N, 22.48° E) serve as input parameters for the analysis. The assessment focuses on three representative monuments: the Sanctuary of Isis, the Roman Baths, and the Villa of Dionysos. It is noteworthy that the methodology adopted involves a structured sequence of steps, which includes risk identification, assessing vulnerability and exposure, quantifying the severity of risks, and integrating these elements into an overall risk assessment. This approach provides a systematic examination of both climatic and seismic factors that are relevant to the preservation of monuments.

Future climate conditions are simulated using two representative concentration pathways (RCP4.5 and RCP8.5), which correspond to the more moderately optimistic and less optimistic future scenarios, respectively. The scenarios predict key climate variables, such as temperature, precipitation, and drought, for various future periods. For the purposes of this research, comparisons will be made between a reference period (1971–2000) and future time horizons (2021–2030, 2041–2050, and 2091–2100), allowing for the identification of temporal trends in risk evolution.

First and foremost, the severity of the risk is assessed based on a series of widely recognized indicators. These indicators include environmental parameters as well as the seismic factor. To be more specific, **TX37** corresponds to annual number of days exceeding 37°C as a representator of extreme heat conditions while **TN0** means the number of frost days which are associated with freeze–thaw processes. Beside them, **PR99** relates to the frequency of extreme precipitation events and as a matter of fact related to flooding potential whereas the Aridity Index **AI**, acts as a balancing factor between the expected total precipitation and the corresponding evapotranspiration. In addition, **FWI** - Wildfire hazard subindex which refers to the days of the year when there is a high risk of fire It will be part of the investigation. It was deemed unnecessary to study the factor of **SLR** – sea level rise, as the park is located a considerable distance from the sea (5 km) and is therefore not at risk. The final factor which would be part of this research and is also linked to all the above, concerns Peak Ground Acceleration (**PGA**) which essentially refers to the maximum ground acceleration and determines the seismic intensity and impact that a seismic event will exert. All these parameters are particularly beneficial for examining deterioration mechanisms in stone

built and other type of archaeological materials or structures while also offer a semi-quantitative framework for evaluating environmental stresses.

A more comprehensive approach to risk will be taken by utilizing more complex indicators. This is the so-called **CCTHaz** index (Combined Climate Threat Hazard index), which is used to assess climate-related risks, as well as the **HHI** (Heritage Hazard Index), which incorporates both climatic and seismic parameters into a unified risk assessment. There is no doubt that these indices render it simpler to integrate distinct hazard variables and predict the risk conditions determining monuments in both current and future scenarios. Risk levels are classified into five categories (No risk, Low, Moderate, High, Extreme), as proposed by Kapsomenakis et al. (2022), enabling consistent comparison across different time periods and emission scenarios. The only risk that will not be included in the study is sea-level rise. The combination of risk indicators with an assessment of material vulnerability and environmental exposure enables an assessment of the overall risk levels for each monument (Kapsomenakis, 2022). (see **Appendix A**).

5.3 Analysis of hazards

First and foremost, the severity of the risk is assessed based on a series of selected indicators that reflect the main climatic and geophysical factors affecting the monuments of the Dion Archaeological Park. These stressors include extreme days (TX37) frost (TN0), extreme rainfall (PR99), drought (AI), and seismic activity (PGA). Undoubtedly, these hazards may have an impact on monuments both directly, through material deterioration and structural stress, and indirectly, by exacerbating long-term vulnerability mechanisms.

Elevated temperatures can cause thermal stress in the materials of the monuments and lead to microcracks due to repeated cycles of expansion and contraction. In particular, the mosaics found in the Great baths are especially sensitive to temperature fluctuations (Sesana et al., 2021; IPCC, 2021). Regarding frost days, freeze-thaw processes occur when moisture penetrates porous materials and then freezes. The expansion of water during freezing creates internal stresses that lead to cracking, spalling, and progressive material loss. At the case of Dion selected monuments, high groundwater levels and persistent moisture tends to increase the vulnerability of porous stones and mortars, particularly at the Sanctuary of Isis, where water-related features dominate the site.

In the context of the archaeological park of Dion environment, extreme precipitation events (PR99) can be especially notable considering the fact of the presence of Vaphyras River-related flooding disasters. To elaborate more, intense rainfall speeds up material deterioration by encouraging water infiltration, salt transport, chemical weathering, and biological growth (Sesana et al., 2021). The villa of Dionysos and the Great baths are similarly impacted by soil saturation and increased moisture retention, but the sanctuary of Isis is particularly vulnerable because of its low elevation and proximity to water. Since the archaeological park coexists with both low vegetation and trees across most of its area, wildfires pose a potential threat to the integrity of the

monuments. Such circumstances can potentially cause thermal shock, cracks, as well as corrosion (Sesana et al., 2021).

Extended droughts may expedite salt crystallization processes, increase thermal stress, and contribute to soil shrinkage, thereby compromising foundation stability (Kapsomenakis et al., 2022). Alternating wet and dry conditions in Dion can accelerate degradation cycles, particularly in materials exposed to fluctuating moisture levels. In addition, seismic activity may further exacerbate existing structural weaknesses, particularly in monuments affected by material degradation and unstable foundation conditions. Ground shaking can induce cracking, displacement of masonry elements, and partial structural failure. The impact is significantly intensified in areas with saturated soils, such as the Sanctuary of Isis, where reduced soil cohesion may increase the likelihood of differential settlement and structural instability. It can cause displacement of structural elements as well as cracking of stone and mortar. In particular, the Sanctuary of Isis is highly vulnerable due to its environmental setting (high water table). Besides that, high groundwater table of the area plays a critical role in amplifying the effects of precipitation, leading to prolonged moisture exposure, reduced soil bearing capacity, and increased vulnerability of structural foundations.

Finally, another important factor is undoubtedly air pollution. However, this factor is not included among the parameters examined by the preferred method of analysis. Nevertheless, it was decided to include a reference to it. More specifically, measurement data for key air components such as organic matter, sulfur dioxide, etc., were collected and are presented in the tables below. The measurements were taken at the nearest monitoring station, located in the city of Katerini and were sourced from Copernicus. In conclusion, the measurements are within permissible limits, and given that Katerini is 14 kilometers from Dion, this is not considered a high-priority risk. However, The Katerini air-quality station should be treated as a regional background proxy rather than as a measurement of atmospheric exposure at the archaeological site.

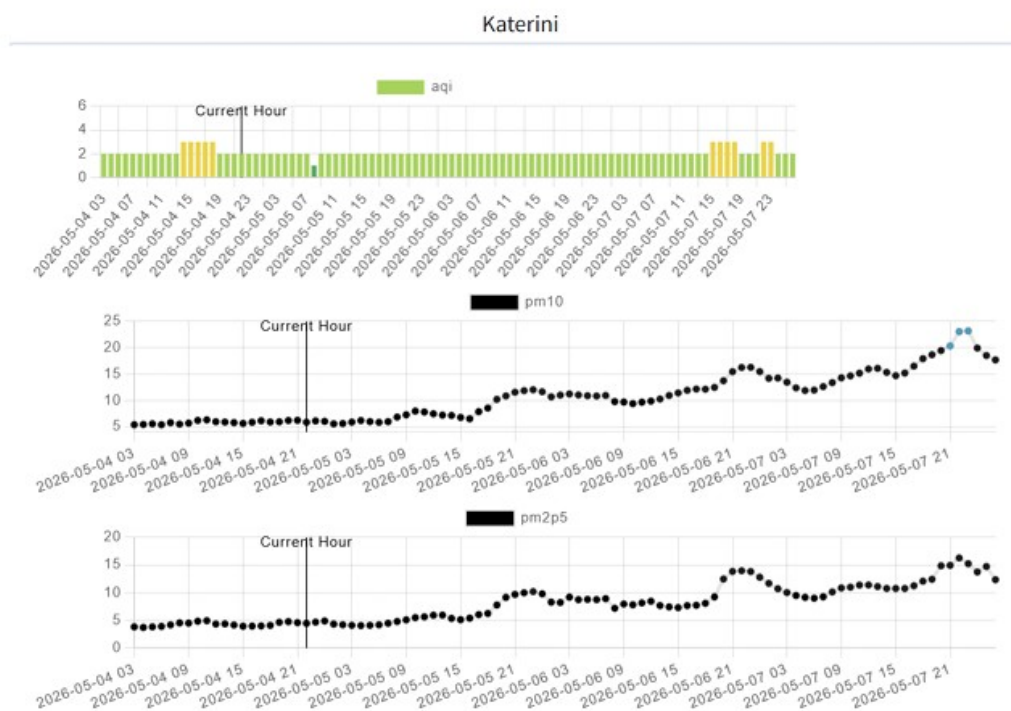


Table 2: Air quality measurements, organic matter 10 and 2 2.5 millimeters from the station in Katerini.

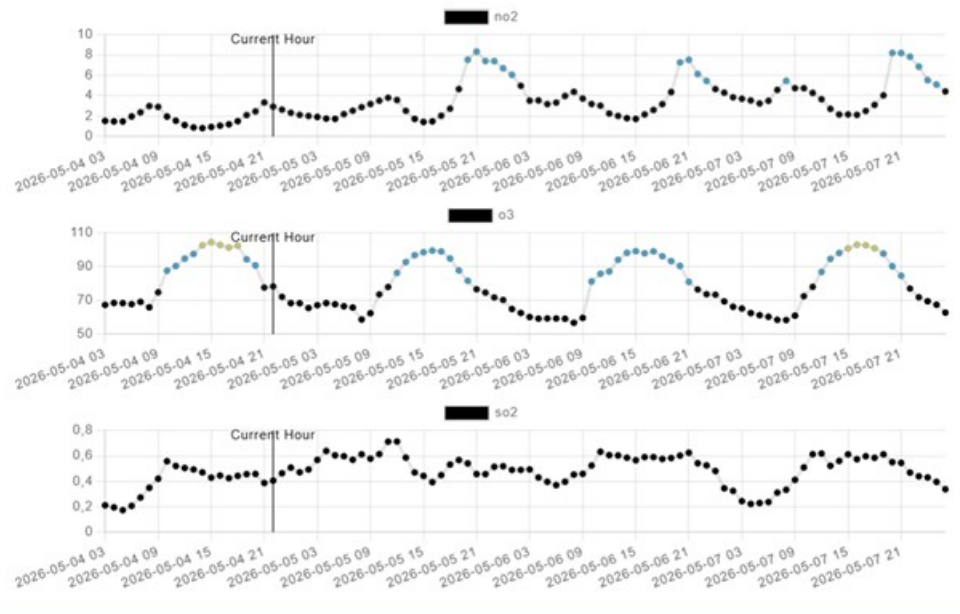


Table 3: Measurements from station of Katerini regarding gases of no2, o3 and so2.

5.4 Research results and evaluation

The following tables present the results of the computational study that was conducted:

Time Period	R.Change TX37 (%)	Days per year	Value	Qualitative assessment
2021-2030				
RCP 4,5	116,09	1,8	4	Extreme
RCP 8,5	54,02	1,34	3	High
2041- 2050				
RCP 4,5	159,77	2,26	4	Extreme
RCP 8,5	278,16	3,29	4	Extreme
2091-2100				
RCP 4,5	233,33	2,9	4	Extreme
RCP 8,5	660,92	6,62	4	Extreme

Table 4: Future trends of extreme heat hazard (TX37) in Dion.

Time Period	R.Change TN0 (%)	Days per year	Value	Qualitative assessment
2021-2030				
RCP 4,5	-51,25	1,3	-3	High
RCP 8,5	80	4,8	0	No Hazard
2041- 2050				
RCP 4,5	-32,5	1,8	-2	Moderate
RCP 8,5	20	3,2	0	No Hazard
2091-2100				
RCP 4,5	-100	0	-4	Extreme
RCP 8,5	-85	0,4	-4	Extreme

Table 5: Future trends of frost days (TN0) for Dion.

Time Period	R.Change PR99 (%)	Value	Qualitative assessment
2021-2030			
RCP 4,5	-6,25	0	No Hazard
RCP 8,5	3,125	1	Low
2041- 2050			
RCP 4,5	3,125	1	Low
RCP 8,5	-15,625	0	No Hazard
2091-2100			
RCP 4,5	-6,25	0	No Hazard
RCP 8,5	-15,625	0	No Hazard

Table 6: Future trends for extreme precipitation days (PR99) for Dion.

Time Period	Aridity Index (AI)	Value	Qualitative assessment
2021-2030			
RCP 4,5	0,352	2	Moderate
RCP 8,5	0,451	2	Moderate
2041- 2050			
RCP 4,5	0,437	2	Moderate
RCP 8,5	0,371	2	Moderate
2091-2100			
RCP 4,5	0,379	2	Moderate
RCP 8,5	0,331	3	High

Table 7: Future trends for aridity index (AI) for Dion.

PGA	Value	Qualitative characterization
0,216	3	High

Table 8: Value of seismic factor (SHaz) for Dion.

Time Period	R.Change FWI (%)	Value	Qualitative assessment
2021-2030			
RCP 4,5	17,52	1	Low
RCP 8,5	18,38	1	Low
2041- 2050			
RCP 4,5	39,74	2	Moderate
RCP 8,5	70,94	3	High
2071-2080			
RCP 4,5	54,06	3	High
RCP 8,5	125	4	Extreme

Table 9: Future trends for wildfire risk (FWI) for Dion.

Time Period	2021-2030	2021-2030	2041-2050	2041-2050	2090-2100	2090-2100
Scenario	RCP 4,5	RCP 8,5	RCP 4,5	RCP 8,5	RCP 4,5	RCP 8,5
Extreme heat	4	3	4	4	4	4
Frost days	-3	0	-2	0	-4	-4
PR99	0	1	1	0	0	0
Aridity	2	2	2	2	2	3
FWI	1	1	2	3	3	4
$\Sigma(\text{CCTHaz})$	4	7	7	9	5	7
Seismic activity (SHaz)	3	3	3	3	3	3
HHI	7,46	11,58	11,58	14,20	8,87	11,58

Table 10: Calculation of the complex risk indicators (CCTHaz, HHI).

The findings of the above tables regarding the degree of intensification of critical parameters display a degree of heterogeneity. Firstly, days with extreme temperatures show the greatest increase, as they exhibit very high trends in all decades under consideration and in both scenarios. For all three monuments, this implies that the

materials will be subjected to high stress, thereby accelerating their deterioration, primarily through material fatigue and micro-cracking. In contrast, frost days demonstrate a decreasing tendency in the first two decades (2021–2030, 2031–2040), except for RCP 4.5 for the decade 2021–2030, which is high. Furthermore, it shows a particularly strong upward trend in the last decade for both scenarios. It should be noted that the values for days with freezing temperatures behave in the opposite way to the other climatic parameters. In other words, for example, a ‘high’ risk rating implies that days with low temperatures are low-risk. In general, while these trends may overall reduce freeze–thaw related damage, it is outweighed by the intensification of other degradation mechanisms, especially those associated with heat and moisture.

Furthermore, the impacts of extreme rainfall have not increased significantly over time; however, they remain a critical risk due to the region’s inherent environmental characteristics. The low elevation, high water table, and proximity to the Vafyra River and the other nearby streams ensure that even consistent rainfall patterns can maintain conditions of soil saturation and prolonged exposure to moisture, particularly affecting the sanctuary of Isis but not exclusively. Based on the projections regarding aridity index, a stable trend is evident in this area across all decades and scenarios, with the sole exception of RCP8.5 for the decade 2091–2100, which shows a sharply increasing trend. This stability is likely influenced primarily by the fact that the site is characterized by a distinctly humid microenvironment, influenced by the presence of multiple water bodies, including the Vaphyras River, seasonal streams, and a consistently high-water table.

As far as seismic risk is concerned, it constitutes critical hazard for the monuments of the Archaeological Park of Dion. To be more specific, local soil composition and stratigraphy play an important role in determining seismic risk in Dion. The site is located on a low-lying alluvial plain produced by river deposits from the Vaphyras River and the adjacent hydrological network. These deposits are primarily made up of unconsolidated sediments such as silts, sands, and clayey materials, which are frequently associated with a high groundwater table. Such soil conditions are known to have a substantial effect on seismic wave propagation, resulting in amplification of ground motion when compared to more capable, rocky substrates (Καβαλιεράτου, 2007). Furthermore, water-saturated soils enhance the risk of soil instability events such as differential settlement and, in certain situations, localized liquefaction.

Finally, the following table shows the change in fire risk compared, once again, to the reference period (1971–2000). The trend is clearly one of increasing severity as the decades progress. Thus, while the first decade begins with low risk, all subsequent decades see an increase, eventually reaching the highest risk level. This upward trend makes perfect sense, as temperatures are also forecast to be high, thereby making the risk of a fire much more plausible.

5.5 Comparative assessment of the selected monuments and hazards prioritisation

Despite being located on the same region, the selected monuments susceptibility to environmental and geophysical risks varies greatly due to variances in

microenvironmental circumstances, structural configuration, and level of exposure. This emphasizes the need of conducting site-specific assessments, since localized factors can enhance or decrease the influence of larger climatic and environmental processes. Regarding exposure to temperature, all three monuments have similar exposure and, consequently, similar levels of vulnerability. However, the great baths are more vulnerable due to their construction configuration. As this monument is comprised of mosaics made of stone pebbles, there is a higher level of vulnerability under such conditions because of their sensitivity.

The next factor regarding rainfall features greater variations. The sanctuary of Isis, due to its proximity to the Vafyra river and the presence of permanent groundwater there, is at greater risk than the others. Dionysus's villa is next in terms of vulnerability to such a phenomenon, as it is not on a slope and water can flow in more easily. Finally, the great baths are situated on a slope and at a higher elevation, from which water drains away and does not remain within the monument's grounds. The aridity index does not seem to be a decisive factor for any of the monuments. The abundance of water and vegetation in the area serves as a deterrent against the occurrence of such situations.

A potential seismic event would likely not have the same effects on all three monuments. The sanctuary of Isis would be at greater risk due to the greater instability of the soil caused by the presence of water in it. This phenomenon is called soil liquefaction and leads to greater seismic vulnerability. Furthermore, the sanctuary's construction method featuring columns and small, separate temples without structural continuity makes it more vulnerable, as it is not a cohesive structure. In addition, the foundation conditions are not stable and as a matter of fact the vulnerability tends to be higher.

The next monument in terms of risk level is Dionysus's villa, since the presence of water there for most of the year causes the soil to become liquefied. Finally, the large thermal baths pose the least risk, as they are also structurally more compact. In contrast, the risk of fire poses a different priority. The greatest risk comes from the great baths, as they are in very close proximity to trees. On the other hand, the immediate surroundings of the temple of Isis are also surrounded by high vegetation, but at a slightly greater distance. Furthermore, the abundant water acts as a deterrent in the event of a fire. Finally, the Villa of Dionysus faces the lowest risk, as it is quite a distance from dense vegetation; nevertheless, such a risk does exist. The following tables present the risk prioritization for each monument individually:

Risk factor	Type	Severity	Likelihood	Priority level
Seismic Activity	Natural	High	Medium	Medium
Extreme days	Climate change	Very high	High	Medium
Frost days	Climate change	Very high	High	Critical
Extreme precipitation	Climate change	Very high	Medium	High
Aridity	Climate change	Medium	Low	Low
Wildfire	Climate change	Medium	Low	Low

Table 11: Prioritization of risks in Sanctuary of Isis.

Risk factor	Type	Severity	Likelihood	Priority level
Seismic Activity	Natural	High	Medium	Medium
Extreme days	Climate change	Very high	High	Critical
Frost days	Climate change	Very high	High	Critical
Extreme precipitation	Climate change	Medium	Low	Low
Aridity	Climate change	Medium	Low	Low
Wildfire	Climate change	High	High	High

Table 12: Prioritization of risks in Great baths.

Risk factor	Type	Severity	Likelihood	Priority level
Seismic Activity	Natural	Very high	Medium	Medium
Extreme days	Climate change	Very high	High	Critical
Frost days	Climate change	Very high	High	Critical
Extreme precipitation	Climate change	High	Medium	Medium
Aridity	Climate change	Medium	Low	Low
Wildfire	Climate change	Medium	Medium	Medium

Table 13: Prioritization of risks in Villa of Dionysos.

The terms listed in the tables above are defined as follows:

- **Severity:** Impact in case of the event occurrence (Low – Moderate – High – Very high).
- **Likelihood:** Probability of occurrence (Very low – Low – Medium – High).
- **Priority level:** Based on combination of severity and likelihood.

- **Critical:** Requires immediate attention.
- **High:** Requires immediate or short-term intervention.
- **Medium:** Should be monitored and incorporated into planning strategies.
- **Low:** Should be acknowledged and periodically reassessed.

Furthermore, it was deemed necessary to present a comparative table in order to explain more clearly and make it easier to comprehend the varying extent to which these risks affect the monument (Table 14).

Parameter	Sanctuary of Isis	Great Baths	Villa of Dionysos	Main reason
Groundwater/flooding	Very High	Low/Moderate	High	elevation/hydrology
Seismic vulnerability	High/Very High	Moderate	High	structural form + subsoil
Biological colonization	High	Moderate	High	moisture
Thermal stress	Moderate	Moderate	Moderate	materials/exposure
Fire	Moderate	High	Moderate	vegetation

Table 14: Comparative assessment of the degree of influence of key parameters of the three monuments

6. Strategies for conservation and climate adaptation

6.1. Conservation framework

In the previous analyses, both data from past climatic events that highlight the main issues of the selected archaeological monuments and on-site research through which the damages they have suffered during their exposure and were identified, were also presented. Subsequently, a practical application of data for risk magnitude assessment was carried out through risk analysis. Next, the risk prioritization was carried out based on specific criteria concerning their sustainability dimensions. At this point, the conservation proposals that are suggested in order to achieve a stable condition regarding the integrity of the materials will follow.

The principle of conservation constitutes a cornerstone for the protection and promotion of cultural heritage. As it is also stated in the Venice Charter, it is our duty to safeguard cultural heritage while always respecting the authenticity of the monuments. In other words, 'by adhering to the principles of conservation,' the sustainability would be accomplished. From the first charter of Athens of 1931 to the most recent ones, basic principles of interventions have emerged which must be adhered to if it is deemed necessary to apply to the monuments under consideration. and perpetual resilience of cultural heritage will be achieved (Venice Charter, 1964).

Initially, once the deterioration type of the materials and the masonry as a whole has been recorded, a thorough assessment must be made regarding the type and degree of intervention that can be applied to them. It is of utmost importance to uphold the fundamental principle of preservation, according to which the original material must be safeguarded and further deterioration prevented. Therefore, interventions must be limited and in no case should they threaten the historical character of the monument as a whole. Furthermore, interventions are permissible after thorough scientific documentation, having as a primary goal the revelation of the aesthetic and historical value of the monument.

Another fundamental element that must always be taken into account is the fact that replacement and supplementation of elements is allowed only when absolutely necessary. More specifically, the new elements must be integrated harmoniously, but distinguished from the original ones, in order to avoid falsifying history. Furthermore, emphasis must be placed on the fact that maintenance and prevention constitute continuous care, which is of greater and more essential importance than that of major interventions (Petzet M., 2004). Thus, in order to prevent irreversible loss, continuous monitoring of the vulnerable parts of the monument is necessary.

In this particular case, the following practices can be applied. Initially, regarding biological colonization, a gentle mechanical cleaning of the surfaces where microorganisms are observed is suggested (Liu, Y. et al. (2020). Supplementary, the deterioration and loss of mortar can be addressed by removing the damaged parts and re-pointing with compatible mortars that ensure mechanical and hydrological balance (Caroselli, 2021). Regarding the presence of vegetation both on the materials and within the structures of the masonry, it can be dealt with through regular cleaning (Silva, R. A. et al. 2022). Finally, another basic element of pathology mainly found in the sanctuary of Isis is the appearance of salt crusts. Proposed solutions to this involve desalination techniques such as cellulose patches (Pel Leo, 2009).

However, it is important to clarify that the conservation proposals presented are not intended to be implemented arbitrarily. More specifically, a preliminary diagnosis of all vulnerable elements should first be carried out by specialist staff in order to ensure the best possible scientific documentation. Thus, for example, the sequence of procedures involves, first, biological growth; then, identification/assessment; and finally, cleaning tests. Similarly, with regard to salts, soluble salt identification/quantification takes place before desalination. Finally, with regard to mortars, characterisation of historic mortar comes first, followed by compatibility tests.

6.2 Structural strengthening interventions

In this subchapter, there will be discussion about the steps proposed to be implemented in order to provide for the structural issues of the selected monuments. Initially, as was evident both from the historical data (the 2 monuments were destroyed by an earthquake) and from the calculation of the seismic coefficient risk as high, it becomes clear that there must be a provision for such an event.

To begin with, particular emphasis should be placed on the geo-environmental conditions of the site, which include geological, hydrological, hydrogeological, and environmental parameters affecting the stability and preservation of the archaeological remains. Geotechnical investigations are therefore strongly recommended in order to determine the soil composition, stratigraphy, groundwater conditions, and mechanical behaviour of the subsoil, factors which are directly related to the seismic vulnerability of the monuments. The investigation of soil conditions constitutes a critical component in the assessment of monument vulnerability, as it directly influences a series of interconnected environmental and structural processes. Furthermore, the presence of groundwater significantly affects the geotechnical stability of the subsoil and may consequently influence the structural integrity of archaeological remains, especially those located in low-lying areas or in close proximity to water-related features. In particular, the humid environment of Dion and the elevated groundwater table may contribute to differential settlement phenomena, reduction of soil bearing capacity, and gradual destabilization of masonry remains (Penelis, G.G., 2020).

In addition to geotechnical investigations, detailed structural engineering assessments should also be implemented in order to evaluate the current mechanical condition of the monuments and identify zones of structural weakness. Such investigations may include assessment of displaced architectural members, and non-destructive testing methods for evaluating the internal condition of masonry structures. These procedures would contribute significantly to the early detection of structural instability and facilitate preventive intervention before severe damage occurs. Last but not least, these specific actions must be carried out by specialized scientific staff for these purposes, such as engineers and also specialists specialized in hydraulic engineering.

6.3 Environmental and seismic monitoring strategies

An extremely critical parameter regarding the future condition and integrity of monuments is undoubtedly the environmental parameters with the synergy of seismic action as well. As presented through the current research, both in the context in which the alternating environmental conditions strengthen the mechanisms of material stress and through the expected environmental scenarios, their monitoring is of utmost importance. Perhaps the most reliable way to monitor the environmental conditions most critical for monuments can be achieved through the use of new technologies, specifically sensors. To be more specific, sensors are instruments capable of monitoring system states and provide health assessment information, such as structural reactions and environmental amounts.

Initially, for the proper monitoring of the seismic factor, the following practice is suggested. Structural monitoring systems could be installed in vulnerable areas in order to record possible movements, crack propagation, or dynamic response during seismic activity. To elaborate more, accelerometers, that are sensors suitable for detecting in situ applications for seismic phenomena constitute a wide choice of placement at critical points of the monuments. Besides that, the application of crack gauges is also detrimental for this purpose as it measures the cracks growth. Other types of sensors that are indirectly related to an upcoming seismic activity and the potential impact are inclinometer, level sensor as well as displacement sensor. In particular, the first has the ability to detect any soil movements, the middle one with sudden ground shifts, while the latter with possible displacements of structures. Their placement is considered beneficial to be done in points that will be indicated by the structural engineer after a corresponding study is conducted.

For the proper monitoring of sensitive environmental data, the following placement methodology is proposed. Initially, since humidity is a critical component in the deterioration of materials, it is necessary to install humidity sensors. Since some potential gas emission is possible due to the fuels emitted by agricultural machinery, the choice of placing electrochemical gas detectors must be included in the monitoring plans. In addition, the selection for their exact position will be made by the competent scientific personnel. Finally, it is scientifically necessary to note that the thresholds specified for the sensors in the tables below are indicative. The exact thresholds will be determined by the relevant specialist following systematic monitoring of the monuments.

In conclusion, the installation of environmental and seismic monitoring systems is critical for the long-term preservation and risk management of the selected monuments throughout the Archaeological Park of Dion. Structural Health Monitoring (SHM) systems enable continuous assessment of monument structural condition through recording and interpreting structural response data, allowing for early damage detection and the implementation of preventive maintenance measures before deterioration reaches critical levels. In archaeological environments like Dion, where monuments are subjected to seismic activity, groundwater fluctuations, moisture-related deterioration, and long-term environmental stressors, monitoring systems can help identify progressive structural instability and environmental impacts on the monuments over time (Vistasp M Karbhari, 2009). Finally, in the table below, the plan regarding the sensors will be presented in

detail, such as the quantity that will be needed, the monitoring frequency, as well as the limits set for each one.

Sensor Type	Quantity per monument	Monitoring frequency	Alarm limit
Accelerometer	3	Continuously/ real time	Seismic acceleration > 0.1 g
Inclinometer	3	Weekly or after significant events like earthquake	Soil movement > 5 mm
Level sensor	3	Weekly or after significant events like earthquake	Abrupt settlement >10 mm over a single day.
Displacement sensor	2	Continuously	>1 mm widening in a single day or sudden significant displacement.
Humidity sensor	4	Hourly/daily	Exceeding material tolerance limits for prolonged periods
Electrochemical gas detector	1	Hourly/daily	Percentages with a significant increase in relation to the normal levels of gases like CO ₂ , NO _x , SO ₂ .

Table 15: Sensors plan for monitoring.

6.4 Stakeholders and management policies

First and foremost, in order to achieve the protection and long-term preservation of the cultural heritage monuments in Dion, beyond the technical issues that were presented, it requires the cooperation between various involved parties that will be presented next. Indeed, the contemporary approaches to heritage management emphasize that effective conservation strategies must be based on interdisciplinary cooperation, integrated planning, and coordinated decision-making processes involving a series of different stakeholders. Finally, In complex archaeological environments like the Archaeological Park of Dion, where monuments are subject to environmental degradation, groundwater-related deterioration, and seismic hazards, the establishment of collaborative management frameworks becomes essential for ensuring sustainable preservation and long-term resilience (UNESCO, 2013).

The role of governmental as well as archaeological authorities is of utmost importance. These bodies consist mainly of the Ministry of Culture, the Ephorate of Antiquities of

Pieria, Municipality of Pieria, the Directorate for the Restoration of Ancient Monuments, Ministry of Tourism as well as Ministry of Civil Protection and Climate Change. The collaboration between these organizations is of primary importance as it is capable of leading to integrated management strategies depending on the prioritization of needs, climate adaptation planning, funding coordination as well as sustainable heritage management.

In addition, the maintenance and long-term protection of the selected sites inside Dion's Archaeological Park necessitates an interdisciplinary scientific approach that draws on knowledge from a variety of sectors, including cultural heritage preservation and environmental risk assessment. These sectors involve archaeologists, conservators, civil engineers, geologists, hydrologists, climate scientists, environmental engineers and others. The promotion of interdisciplinarity enhances faster and at the same time scientifically correct decision-making. At this point, it is worth noting that the presence of universities as scientific institutions promoting cultural heritage is decisive. In this particular case, Aristotle University of Thessaloniki has had the exclusive role of the excavations from the very beginning. Beyond this, the university has created two online websites within the framework of highlighting the findings. More specifically, one concerns the archaeological work that has been carried out with the research and publication of the findings (<https://dion-excavation.web.auth.gr/-/index.php/el/>) while the second focuses on the numerous inscriptions that have been found, including an online book for this purpose (<https://decaindion.gr/en/educational-material/>). Finally, the collaboration of the university with other institutions is also suggested in order to achieve a more holistic approach.

The implementation of a modern conservation approach that incorporates protection against climate change highlights the necessity for the active involvement of Environmental and Climate Monitoring Institutions. More specifically, climate resilience and digital heritage monitoring could be achieved through the synergy of meteorological agencies, Copernicus services, remote sensing technologies, climate databases, and environmental monitoring networks. These systems may provide valuable data regarding temperature fluctuations, precipitation patterns, humidity levels, groundwater behaviour, and the occurrence of extreme climatic events that directly affect the preservation conditions of the monuments within the Archaeological Park of Dion. Finally, the integration of satellite observations and Geographic Information Systems (GIS) could significantly enhance the monitoring of environmental changes and landscape dynamics surrounding the archaeological site.

Local community and public interaction are critical to the long-term preservation of archeological heritage since they serve to safeguard, raise awareness of, and acknowledge cultural sites. In the Archaeological Park of Dion, the involvement of local stakeholders and visitors strengthens conservation strategies by encouraging responsible site utilize, raising public awareness of environmental and structural vulnerabilities, and promoting heritage-oriented education and tourism practices. Public engagement activities such as educational programs, guided tours, and interpretative materials strengthen the community's relationship to the archeological environment, supporting the concept of heritage as a shared cultural resource.

All interactions between the many different bodies involved are considered of equal importance in order for there to be an internationalization of the broad audience of the

cultural value of the monuments in Dion. Such a perception will bring about International Cooperation with strong funding, which will prove to be of enormous value for solving the issues raised by the competent scientific staff. Such stakeholders include EU funding programs, UNESCO, ICOMOS and other.

6.5 Implementation of proposed measures

Applying preservation measures within the Archaeological Park of Dion demands a holistic and monument-specific approach that takes into account each monument's inherent environmental, structural, and material deficiencies. Based on the previous chapters' comparative risk assessment and degradation analysis, the implementation framework below suggests targeted preservation and adaptation actions for Dion's Sanctuary of Isis, Great Roman Baths, and Villa of Dionysos. Preventive conservation, environmental monitoring, hydrological management, structural assessment, and long-term climate adaption measures are prioritized in order to improve the resilience and sustainable preservation of the selected monuments in the face of changing climatic circumstances. In the following tables, the proposals for each monument will be presented separately according to their particularities and the most significant risks they present. It is worth mentioning that the large baths constitute the most recently conserved monument compared to the others and, therefore, the measures mainly concern continuous monitoring in order to maintain the current condition and, to a lesser extent, immediate interventions.

Identified Threat	Proposed Preservation Measure	Implementation Objective	Monitoring Method	Priority Level
Groundwater rise and flooding episodes	Improvement of drainage systems and hydrological management	Reduction of water accumulation around the monument	Moisture and groundwater monitoring	Very High
Biological colonization due to excessive humidity	Periodic removal of vegetation and biological deposits	Limitation of biodeterioration processes	Visual inspections and photographic documentation	High
Material deterioration caused by prolonged moisture exposure	Preventive conservation interventions on stone surfaces	Stabilization of deteriorated materials	Surface condition assessment	High
Structural instability related to hydrological stress	Structural monitoring and crack assessment	Early identification of structural weaknesses	Crack monitoring surveys	High
Climate variability and extreme weather conditions	Continuous environmental monitoring	Long-term assessment of environmental impacts	Temperature and humidity sensors	Medium

Table 16: Implementation Framework for Preservation Measures – Sanctuary of Isis

Identified Threat	Proposed Preservation Measure	Implementation Objective	Monitoring Method	Priority Level
Seismic vulnerability and structural instability	Installation of seismic monitoring systems and structural stabilization measures	Improvement of structural resilience	Accelerometers and crack monitoring systems	High
Cracking and displacement of masonry elements	Structural assessment and localized consolidation interventions	Prevention of further structural deterioration	Displacement sensors and visual surveys	High
Biological growth and vegetation presence	Vegetation removal and maintenance program	Limitation of biodeterioration mechanisms	Visual inspections	Medium

Table 17: Implementation Framework for Preservation Measures – Great Roman Baths

Identified Threat	Proposed Preservation Measure	Implementation Objective	Monitoring Method	Priority Level
Environmental exposure affecting architectural remains	Environmental monitoring and preventive conservation measures	Reduction of climate-related deterioration	Temperature and humidity sensors	High
Groundwater fluctuations and soil moisture accumulation	Improvement of drainage systems and groundwater monitoring	Reduction of moisture-related deterioration and soil instability	Groundwater level sensors and humidity monitoring	High
Surface erosion and material degradation	Preventive conservation of architectural elements	Preservation of structural and material integrity	Surface condition mapping	High
Climate-related deterioration processes	Long-term monitoring and adaptive conservation planning	Enhancement of monument resilience	Periodic reassessment of deterioration patterns	Medium

Table 18: Implementation Framework for Preservation Measures – Villa of Dionysos

7. Conclusion

The current research analyzed the environmental and structural effects of climate change on three representative sites of the Dion archaeological park: the Sanctuary of Isis, the Great Roman Baths, and the Villa of Dionysos. The comparative examination of their architectural features, geomorphological setting, material composition, and deterioration patterns revealed that climate change poses a serious and multifaceted threat to the preservation of archaeological heritage. The research determined that Dion's conditions, particularly the intensive hydrological presence, groundwater activity, humidity changes, and alluvial geomorphology, exhibit a substantial role in the deteriorating processes affecting the antiquities. Simultaneously, the seismicity of the adjacent area affects the structural instability of archaeological remains, particularly in terms of masonry unsteadiness, cracking, displacement events, and foundation sensitivity. The combination of environmental stresses and structural flaws emphasizes the importance of coordinated conservation planning and long-term risk management strategies.

Additionally, research pointed out the requirement of preventive conservation, continuous surveillance, and interdisciplinary collaboration in the long-term maintenance of monuments. The suggested interventions, consisting of structural strengthening measures, environmental monitoring systems, drainage management, and stakeholder collaboration frameworks, seek to strengthen the monuments' resilience to future environmental and seismic threats. The preservation of Dion's archaeological heritage focuses not only on technical restoration interventions, but also on the development of adaptive conservation techniques capable of adjusting to changing climatic and environmental conditions.

The following conclusions are considered to be the main key findings of the research. To be more specific, through the research, the evaluation of climatic parameters as well as the seismic assessment for each monument individually was understood, and subsequently the measures that need to be implemented aimed at their preservation. Finally, the cognitive barriers that arose for a more interdisciplinary approach open the field for future research from branches more specialized in structural impacts as well as hydrological, geological research and material analysis.

7.1 *Limitations and challenges*

Notwithstanding the thorough methodology used in this dissertation, certain limitations and obstacles must be mentioned. In particular, the fact that the research focused on macroscopic research, visual observation, bibliographic research as well as the practical part of creating a risk analysis leads to the following thought. Certain insights concerning structural behaviour, material condition, and geotechnical vulnerability are preliminary and would require additional quantitative analysis for thorough verification, such as substantial in-situ laboratory testing or structural simulations. Moreover, the fact that three monuments were analyzed led to a more limited examination of various parameters, but a more concise presentation of the main ones was maintained for the needs of the comparative approach.

Apart from that, the lack of detailed geotechnical data, structural monitoring records, and long-term environmental observations, as well as the author's archaeological scientific background, limited the ability to conduct a comprehensive engineering study of the monuments. Moreover, the archaeological park's hydrological circumstances tend to be complex, particularly in terms of groundwater variations and artesian phenomena, making it difficult to adequately assess the long-term impacts of moisture on structural stability and material deterioration.

Another technical difficulty was the fact that the monuments cover a very large area. In addition, the methodology of Kapsomenakis that was followed did not make it possible to analyze the air pollutants. Moreover, the results should be interpreted as relative/semi-quantitative risk estimates rather than absolute risk values. . Finally, due to the lack of an electronic platform, and specifically Diavgeia, it was not easy to gather material concerning previous maintenance interventions on the monuments before the year 2010, when they started being published on the website.

7.2 Recommendations and prospects for future research

Regarding the recommendations for future research, it would be scientifically beneficial for a structural engineer specialized in monument restoration to be involved in the present research in order to conduct a deeper analysis of the structural behaviour, material condition, and geotechnical vulnerability of the selected monuments. Of particular importance for the development of the research regarding the hydrological issues of the sanctuary of Isis regarding the hydrological aspects, the following is proposed.

In particular, further research focusing on the hydrological conditions of the Sanctuary of Isis at Dion is strongly recommended. More specifically, specialized investigation is required in order to examine the possible occurrence of artesian groundwater phenomena within the sanctuary area, as well as to evaluate potential strategies for managing and reducing the persistent accumulation of water observed at the site. For this reason, the involvement of a hydraulic engineer or hydrogeology specialist is considered essential for the proper assessment of groundwater behaviour, water circulation mechanisms, and the development of appropriate water management solutions aimed at improving both the environmental conditions and the long-term preservation of the monument. This will result in identifying issues with scientific accuracy as well as providing targeted measures for their resolution.

References

- Antoniou A., 2024, Assessment of the impacts of climate change on a world heritage site in Greece.

- Admin. (2021c, March 11). *The problem of flooding at the archaeological site of Dion*. Xenios Project. <https://xenios-project.eu/en/news-en/the-problem-of-flooding-at-the-archaeological-site-of-dion/>
- Afifa, 2024, Air pollution and climate change as grand challenges to sustainability.
- Caroselli M, 2021, Mortars and plasters—how to manage mortars and plasters conservation.
- Chrimatopoulos, V., 2020, Title: THE SANCTUARIES OF DION. Ihu-gr. https://www.academia.edu/44696102/Title_THE_SANCTUARIES_OF_DION
- Canadian Conservation Institute. (n.d.). Temperature. Government of Canada. <https://www.canada.ca/en/conservation-institute/services/agents-deterioration/temperature.html>
- Colette, A. 2007, Climate Change and World Heritage: Report on Predicting and Managing the Impacts of Climate Change on World Heritage and Strategy to Assist States Parties to Implement Appropriate Management Responses. UNESCO World Heritage Centre.
- Danciu, L., Nandan, S., Reyes, C., Basili, R., Weatherill, G., Beauval, C., Rovida, A., Vilanova, S., Sese tyan, K., Bard, P-Y., Cotton, F., Wiemer, S., Giardini, D. (2021). The 2020 update of the European Seismic Hazard Model: Model Overview. EFEHR Technical Report 001, v1.0.0, <https://doi.org/10.12686/a15>.
- Despotaki V., 2018, Evaluation of Seismic Risk on UNESCO Cultural Heritage sites in Europe.
- Dore H.I., 2005, Climate change and changes in global precipitation patterns: What do we know?
- Doehne, E. & Price, 2010, Stone Conservation: An Overview of Current Research
- Fatorić S., Seekamp E., 2017, Assessing Historical Significance and Use Potential of Buildings within Historic Districts: An Overview of a Measurement Framework Developed for Climate Adaptation Planning.
- Feliu et al., 1999, Effect of distance from sea on atmospheric corrosion rate.

- Freeze, R. A., & Cherry, J. A. 1979, Groundwater,
- Ghosn M., Graziano Fiorillo, Ming Liu, Bruce R. Ellingwood, (Eds.), 2020, Risk Based Structural Evaluation Methods: Best Practices and Development of Standards, American Society of Civil Engineers.
- Hao, J., & Lu, E. (2022). Variation of relative humidity as seen through linking water vapor to air temperature: An assessment of interannual variations in the near-surface atmosphere.
- Hadjimitsis D. et al., 2011, Exploring natural and anthropogenic risk for cultural heritage in Cyprus using remote sensing and GIS.
- Heritage Science, 2026, January 6, Deterioration mechanism of LGB sandstone in a water seepage environment, Nature. <https://www.nature.com/articles/s40494-025-02180-1/figures/16>
- Hodge T., 1992, Roman Aqueducts and Water Supply.
- ICOMOS-ISCS, 2008, Illustrated glossary on stone deterioration patterns.
- IPCC. 2021, Sixth Assessment Report: The physical science basis. Intergovernmental Panel on Climate Change.
- IPCC, 2022: Climate Change 2022: Impacts, Adaptation, and Vulnerability.
- Kapsomenakis, J., Douvi, C., Poupkou, A., Zerefos, S., Solomos, S., Stavraka, T., Melis, N. S., Kyriakidis, E., Kremlis, G., & Zerefos, C. (2022). Climate change threats to cultural and natural heritage UNESCO sites in the Mediterranean.
- Letcher M. Trevor, 2021, Observed Impacts on Planet Earth.
- Liu, Y. et al. (2020) “Microbial deterioration and sustainable conservation of stone monuments”.
- MaikidouPoutrino D., 2021, The Sanctuary of the Egyptian Gods in Dion.
- Masson-Delmotte, V., et al. (2019). IPCC special report on the ocean and cryosphere in a changing climate. Intergovernmental Panel on Climate Change.
- Ministry of Culture and Sports | Dion. (n.d.). http://odysseus.culture.gr/h/3/eh352.jsp?obj_id=2508

- Oulkeroglou A., 2017, Public baths in Roman Dion.
- Pavlides S., 2008 Active faults of Greece and surroundings. [33rd International Geological Congress Oslo, Norway].
- Petzet M., 2004, PRINCIPLES OF PRESERVATION: An Introduction to the International Charters for Conservation and Restoration 40 Years after the Venice Charter.
- Pel Leo, 2009, Physical principles and efficiency of salt extraction by poulticing.
- Penelis, G. G. (2007). Earthquake Resistant Design of Ancient Greek Monuments.
- Penelis, G.G., 2020, Structural Restoration of Masonry Monuments: Arches, Domes and Walls, 1st edition
- Pingiatoglou, S., 2022. Dion: The inscriptions unfold human stories.
- Quelhas B., 2014, Characterization and reinforcement of stone masonry walls.
- Rausand, M. (2013). Risk assessment: theory, methods, and applications (Vol. 115). John Wiley & Sons.
- Sesana E., 2018, Adapting cultural heritage to climate change risks: Perspectives of cultural heritage experts in Europe.
- Sesana E., 2021. Climate change impacts on cultural heritage: A literature review.
- Silva, R. A. et al. (2022) “Plant-induced biodeterioration of cultural heritage stones”.
- Simon V., 2025, Climate-change-induced seismicity: The recent onset of seasonal microseismicity at the Grandes Jorasses, Mont Blanc Massif, France/Italy .
- Tabari H., 2020, Climate change impact on flood and extreme precipitation increases with water availability.
- Theoulakis P., 1998, Salt crystal growth as weathering mechanism of porous stone on historic masonry.
- Tringa E., 2025, Assessing the future risk of damage to european cultural heritage due to climate change.

- United Nations Office for Disaster Risk Reduction (UNDRR). (2015). Sendai Framework for Disaster Risk Reduction 2015–2030.
- UNESCO World Heritage Centre. 2007. Case Studies on Climate Change and World Heritage. Paris: UNESCO.
- Vallero D., 2014, Fundamentals of Air Pollution.
- Vistasp M. Karbhari, 2009, Structural Health Monitoring of Civil Infrastructure Systems.
- William D. Callister Jr, 2013, Introduction to materials science and engineering.
- Xenios Project 2021. The problem of flooding at the archaeological site of Dion.
- Ymca_User. (2021, May 23). Ψηφιακοί περίπατοι στην πόλη – Αρχαιολογικός χώρος Δίου – Χ.Α.Ν.Θ. <https://ymca.gr/psifiaki-peripati-stin-poli-archeologikos-choros-diou/>
- Zarz, G. (2024, February 25). Αρχαιολογικό πάρκο Δίου. The Mount Olympus | Greece. <https://themountolympus.com/el/%CE%B1%CF%81%CF%87%CE%B1%CE%B9%CE%BF%CE%BB%CE%BF%CE%B3%CE%B9%CE%BA%CF%8C-%CF%80%CE%AC%CF%81%CE%BA%CE%BF-%CE%B4%CE%AF%CE%BF%CF%85>
- Αριστοτέλειο Πανεπιστήμιο Θεσσαλονίκης. (n.d.-b). Αρχική. <https://dion-excavation.web.auth.gr/-/index.php/el>
- Βαστελή Κ., 2016, Το υδραγωγείο και η κεντρική δεξαμενή του Δίου πρόταση ανάδειξης και επισκεψιμότητας [Μεταπτυχιακή διπλωματική εργασία, Αριστοτέλειο Πανεπιστήμιο Θεσσαλονίκης].
- Γεροφωκά, Ε., 2015. Η αγροικία στη θέση Τρία Πλατάνια του Νομού Πιερίας: Συμβολή στη μελέτη της αρχαίας αγροικίας. [Διδακτορική διατριβή, Πανεπιστήμιο Ιωαννίνων].
- Γεωργίου Ε., 2021, ΑΝΑΤΟΛΙΚΟΣ ΤΟΜΕΑΣ: ΑΙΘΟΥΣΑ ΣΥΜΠΟΣΙΩΝ - «ΕΠΑΥΛΗ ΤΟΥ ΔΙΟΝΥΣΟΥ», [Εν Αθήναις αρχαιολογική εταιρεία].

- Θουκυδίδης. (n.d.). Ιστορίαι (Βιβλ. IV, 78.6).
- ΙΑΑΔΕΤ. (2023, September 18). Χαρτογράφηση της εξέλιξης της έκτασης της πλημμύρας που προκλήθηκε από την κακοκαιρία “Daniel”.
<https://www.astro.noa.gr/news/nea/chartografisi-tis-exelixis-tis-ektasis-tis-plimmyras-poy-proklithike-apo-tin-kakokairia-daniel/>
- Καβαλιεράτου Σοφία, 2007 Ανάλυση και διερεύνηση της βιώσιμης διαχείρισης των υπόγειων νερών με μαθηματικά μοντέλα σε περιβάλλον GIS [Διδακτορική εργασία, Αριστοτέλειο Πανεπιστήμιο Θεσσαλονίκης].
- Καλπύρη Γεωργία, 2025, Ο αρχαιολογικός χώρος στο ΔΙΟΝ. Προσεγγίσεις ενός πολιτιστικού τοπίου στον χώρο και στον χρόνο [Διπλωματική Εργασία, Ελληνικό Ανοικτό Πανεπιστήμιο].
- Καραδέδος Γ., 2000, Υδραυλικές γνώσεις και τεχνολογία - Η περίπτωση του Δίου, Υδάτινες σχέσεις - Το νερό ως πηγή ζωής κατά την αρχαιότητα.
- Κασσερόπουλος Γ., 2024, Ιερά και ναοί του Δίου: χωροθέτηση και αρχιτεκτονική μορφή [Μεταπτυχιακή διπλωματική εργασία, Αριστοτέλειο Πανεπιστήμιο Θεσσαλονίκης].
- Κοτσάκη Μ., 2016, Δίον ο ιδιωτικός χώρος, [Μεταπτυχιακή διπλωματική εργασία, Αριστοτέλειο Πανεπιστήμιο Θεσσαλονίκης].
- Κουλίδου, Σ.- Σπανοδήμος, Χ. (2022). Περιήγηση στα σημαντικά μνημεία του Δίου. Ανακτήθηκε 5 Μαΐου, 2026, από <https://digitalculture.gov.gr/2022/10/periigisi-sta-simantika-mnimia-tou-dion/>
- Ντόντου Α., 2016, Γλυπτά της Ίσιδας στον ελλαδικό χώρο [Μεταπτυχιακή διπλωματική εργασία, Εθνικό και Καποδιστριακό Πανεπιστήμιο Αθηνών].
- Παντερμαλής, Δ. 1993 Δίον: Από την αρχαιότητα στο Βυζάντιο.
- Παντερμαλής, Δ. 1995 Η ανασκαφή του Δίου.
- Παντερμαλής, Δ. 1997, Αρχαιολογικός χώρος και μουσείο.
- Παντερμαλής, Δ., 1997, Η ανασκαφή μιας αίθουσας συμποσίων στο Δίον.
- Παντερμαλής, Δ. 1999. Δίον: Η ανακάλυψη.

- Παπαγιάννη Ε., 2023. Ερευνώντας το αρχαίο Δίον.
- Παπαγιάννη Ε., 2025, Ερευνώντας το αρχαίο Δίον II.
- Σικελιώτης Δ., (n.d.). Ιστορική βιβλιοθήκη (Βιβλ. XVII, 16).
- Στεφανίδου-Τιβερίου, Θ. 1998. Ανασκαφή Δίου 1: Η οχύρωση.
- Σχοινά Ε., 2020. Διερεύνηση λειτουργίας υδροσυστήματος αρχαίου Δίου [Μεταπτυχιακή διπλωματική εργασία, Εθνικό Μετσόβειο Πολυτεχνείο].
- Τσιάρας, Σ. 2021, Πρακτικά 20ού Πανελληνίου Δασολογικού Συνεδρίου.

Appendix A: “Methodology for Data Acquisition ”

The environmental data on the climate parameters selected for analysis in the risk assessment were generated through the dear clima program except for that of wildfire **FWI**. Dear clima is a computational model for predicting future scenarios for various environmental aspects such as precipitation, wind, temperature, etc., as well as a repository for historical data. Thus, for all the parameters to be discussed, data were initially collected for the period 1971–2000, which serves as the reference period and was used as a basis for comparison with future scenarios. With regard to the reference period, a common methodology was followed for all parameters except drought. More specifically, after the data were imported into Excel, the cells pertaining to the specific period were selected, and using the appropriate calculation formula, the results were obtained for the days of this 30-year period with temperatures either above 37 degrees or below zero, and similarly for the rest, as mentioned.

With regard to days with extreme temperatures, after the data for the future decades under consideration were downloaded, the cells corresponding to both the dates of interest and the specific scenario (RCP 4.5 and RCP 8.5) were selected. Each of the two scenarios was in a different column. Using the appropriate mathematical formulas, the results were obtained for the number of days per decade when the temperature was above 37 degrees Celsius (**TX37**). The exact same methodology was applied for days with temperatures below zero (**TN0**).

A distinct methodology was employed to calculate the number of days with extreme precipitation (**PR99**). More precisely, the days with 1 millimeter of rainfall or more were initially selected using the appropriate commands in excel. They were then sorted in ascending order, and the PR99 for these days was calculated using the appropriate command. This means that the result was expressed in millimeters and refers to the amount of rainfall that exceeds 99 percent of the days in terms of millimeters. The program was then instructed to calculate the number of days on which daily precipitation exceeded, in millimeters, the precipitation value derived from previous data, thereby determining the number of days with extreme precipitation.

For the calculation of aridity data on both precipitation and average daily temperature were combined. More specifically, using the appropriate commands, the monthly averages for all years were calculated for both climate parameters. The formulas were then applied in order to calculate the variables $I (\Sigma * T_m / 5)$ and $a (0,000000675 * I^3 - 0,000077 * I^2 + 0,01792 * I + 0,49239)$. Once these values were determined, the PET (monthly evapotranspiration) and the Pm (average monthly precipitation exceeding 1 millimeter) were calculated. Finally, by applying the equation $AI = \Sigma (P_m) / \Sigma (PET_m)$, the final value was calculated, and then the value was correlated based on the Kapsomenakis table.

All the final values for the rest the aforementioned parameters were calculated using a standard method. The formula proposed by Kapsomenakis was used, where the value is calculated as the final value (for each comparison period) minus the initial value (for the reference period), divided by the initial value, and then multiplied by 100. As shown here:

$$RC(\%) = \frac{Value_final - Value_initial}{Value_initial} \times 100$$

With regard to fire risk, no data is provided by Dear Clima; therefore, a different methodology was followed. More specifically, Copernicus was used, which is a European Earth observation program that, among other features, collects and provides data on the environment, climate, and Earth through satellites and models. After the appropriate data collection for days with fire risk was completed for the historical period, it was subsequently carried out for the coming decades and for the two different climate scenarios. The only difference, due to the fact that the data extended only to 2080, was that the final future decade was calculated as 2071–2080 rather than 2091–2100, as was the case with the other parameters. Subsequently, for the purpose of calculating the values, the same equation was used as for the rest, while the table mapping the value to the risk level (low-high) was derived from a relevant table provided by Copernicus.

The final parameter calculated—which operates independently of the others and maximizes them in combination—is the seismic hazard (Shaz). To evaluate it, the Peak Ground Acceleration (PGA) was calculated, applying the relevant provisions of EAK2000 as well as Eurocode 8. To determine the agR parameter, data were obtained from the seismic zone coefficients for Greece; for the prefecture of Pieria, this coefficient is 0.16. Next, regarding the selection of the S parameter, which pertains to the soil class, after researching the area's composition (Καβαλιεράτου, 2007), it was assigned to category D, which has a value of 1.35. Regarding the ST coefficient, since the area of interest has a slope of less than 15 degrees, it was assigned a value of 1. Thus, using the equation $PGA = \gamma_I \cdot agR \cdot S \cdot ST$, the PGA is equal to 0.216, indicating a high risk. Initially, γ_I , which corresponds to the importance factor, was set to 1, since the average return period of a seismic event is associated with a γ_I value of 475 years, i.e., $\gamma_I = 1$.

Once the values of all climatic parameters and seismic data had been calculated, the composite factors that would determine the final outcome of the process were applied. These are the **CCTHaz** (Combined Climate Threat Hazard Index) and the **HHI** (Heritage Hazard Index). The first index in the series was derived by summing the values of all climate parameters for a specific period and scenario, while the second was derived using a different method. More specifically, for the **HHI** index, the formula proposed by Kapsomenakis was applied, and this yielded the final result. The equation is:

$$HHI = CCTHaz + \sqrt{(CCTHaz) \times (SHaz)}$$

Appendix B: “Appendix of selected monuments photographic documentation”

During the writing of this thesis, two visits were made to the archaeological park of Dion. The first during the winter period, specifically in the month of January, and the second during the spring, in the month of May. As will be seen in some of the photographs, the first visit is accompanied by a much more intense presence of water and vegetation, mainly in the Sanctuary of Isis and secondarily in the Villa of Dionysus. In the following photographs, signs of pathology that were observed will be presented, as well as the differences in water levels and vegetation growth between the two periods.



Figure 1: Wide view from sanctuary of Isis (January 2026, personal archive).



Figure 2: Wide view from sanctuary of Isis (May 2026, personal archive).



Figure 3: Statue of Eros in sanctuary of Isis (January 2026, personal archive).



Figure 4: Statue of Eros in sanctuary of Isis (May 2026, personal archive).



Figure 4: Deterioration of the surface of inscribed columns (May 2026, personal archive).



Figure 5: Signs of pathology in Sanctuary of Isis (January 2026, personal archive).



Figure 6: Groundwater presence in villa of Dionysos (January 2026, personal archive).



Figure 7: Decreased groundwater presence in villa of Dionysos (May 2026, personal archive).



Figure 8: Signs of pathology in villa of Dionysos (May 2026, personal archive).



Figure 9: Wide view of Great baths (personal archive).



Figure 10: Photographic illustration from Great baths (personal archive).



Figure 11: Masonry in Great baths (personal archive).

Author's Statement:

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