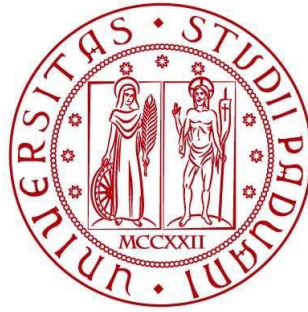


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Department Of Civil, Environmental and Architectural Engineering

**Master's degree in Environmental Engineering (Land planning and
Management track)**



**Assessing factors that influence the resilience of cultural heritage in the face of
climatic change: Bamiyan, Afghanistan case study**

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Abstract

The research aims to demonstrate the significant effects of climate change on cultural heritage sites and important resilience factors. Cultural heritage sites are unique and irreplaceable. It is evident that these sites are confronted with a multitude of challenges, which include, but are not limited to, elevated temperatures, drought, rising sea levels, and an increase in the frequency of extreme weather events. It is imperative that indicators are identified and that plans are devised to mitigate the impact of climate change. Such plans must be meticulously customised to suit each site's distinct circumstances to prevent any inadvertent harm.

The thesis employs qualitative descriptive analysis, a methodological approach that involves the collection and examination of data from a range of literature sources. A compendium of potential ramifications of climate change on cultural heritage has been furnished.

The research study places particular emphasis on the Bamiyan site in Afghanistan. A comprehensive review of pertinent literature was conducted, resulting in the formulation of a synthesised and generalised catalogue of prospective repercussions of climate change on cultural heritage. The objective of this catalogue is to furnish a lucid and accessible framework for the comprehension of these impacts. The subsequent focus is on the development of resilience strategies. The Bamiyan site is utilised as a case study to examine the pivotal factors influencing the site's capacity to adapt to climate change. The analysis of these indicators is based on four main aspects of resilience: structural, social, technological and institutional. The primary objective is to enhance the resilience of cultural heritage by identifying climate change challenges that are unique to the context and proposing feasible alternatives that are tailored to the specific vulnerabilities of the Bamiyan site.

Keywords: cultural heritage, climate change impacts, resilience, preservation

Chapter 1: Introduction

The preservation and transmission of cultural heritage are essential components of the United Nations' Agenda 2030 and the international policy for Disaster Risk Reduction 2015-2030. However, the role of culture in addressing these crucial challenges has not been adequately explored in current scientific literature. Climate change is causing damage to infrastructure and social systems including cultural heritage sites. According to a statistical study over the past 50 years, surface air temperature has increased at an unprecedented rate.

Different sites have different features and situations for instance facing salt weathering at cultural heritage sites in northern Europe, primarily due to changes in air temperature and water in the atmosphere, which are the main parameters responsible for the distribution of stone and brick structure. Given the observed and predicted trends in the main meteorological parameters, the detrimental destructive impact of climate change on cultural heritage sites will only increase.

Assessing the impact of climate change on the world's cultural heritage must consider the complex interactions between natural, cultural and social systems.

The research aims to identify the impacts of climate change on cultural heritage and enhance the resilience in cultural heritage site. The loss of historical and archaeological sites due to climate change is often overlooked. According to IPCC experts, climate change increases the frequency and intensity of hazardous events like droughts, floods, and landslides, leading to significant consequences for cultural heritage. [J. Yang, 2023].

1.2. Problem Statement

While global frameworks for heritage conservation and climate adaptation exist, there is a critical lack of localized, data driven assessments addressing the specific vulnerabilities of heritage sites in fragile states such as Afghanistan. In Bamiyan, the intersection of environmental hazards and institutional fragility poses significant risks to cultural heritage. The area is increasingly vulnerable to climate induced threats. Local conservation initiatives are obstructed by insufficient governance frameworks, a lack of technical resources, and poor execution of policies.

Moreover, the persistence of political instability, limitations on international cooperation, and the aftermath of armed conflict add to the complexity of managing heritage effectively. These challenges hinder comprehensive monitoring, restrict expert access, and limit investment in

conservation infrastructure. The Buddha statues were destroyed in 2001, and this serves as a glaring reminder of how cultural assets can be easily harmed in areas of conflict. As a result, it is imperative to devise resilience based strategies that consider environmental pressures and socio political constraints.

1.3. Research question

This research is directed by the principal inquiry rooted in the literature review findings of which elements play a decisive role in determining cultural heritage sites' climate change resilience in the Bamiyan Valley, and how can conservation measures be designed to bolster these sites' sustainability in the long term? This question emerges from recognized deficiencies in resilience centered research pertaining to conflict affected, environmentally fragile areas like Bamiyan. Global frameworks offer guidance for vulnerability and risk assessments, but localized strategies are needed to account for specific climatic, geological, and socio-political conditions.

There is a main research question: **How can enhance the resilience of cultural heritage against climate change?**

1.4. Research objective

"Assessing factors that influence the resilience of cultural heritage in the face of climatic change " addresses a critical and timely issue, as cultural heritage sites worldwide are increasingly threatened by the impacts of climate change Resilience, in this context, refers to the ability of cultural heritage to withstand, adapt to, and recover from the adverse effects of climate change while maintaining its historical, cultural, and social significance. This study likely focuses on several key aspects of resilience, including the environmental, physical, technological, social, and institutional dimensions, as well as the interplay between these factors in safeguarding cultural heritage.

Researchers and urban planners have started to increase their interest in the analysis of climate change and its impact on cultural heritage sites. In particular, the fight against climate change has been tackled (M. Tremiterra, 2018) by two strategies:

1. Mitigation, which is focused on the climate change drivers
2. Adaptation, which concerns the impacts of climate change. (M. Tremiterra, 2018)

Research objective include:

- To assess the current state of cultural heritage in different site for response to climate change
- To identify the primary factors influencing the resilience of cultural heritage to climate change hazards.
- To evaluate existing strategies and interventions aimed at enhancing the resilience of cultural heritage plan.
- To propose recommendations for improving the adaptive capacity of cultural heritage sites.

1.5. Significance of study

Cultural heritage sites around the world are increasingly threatened by the effects of climate change, including rising temperatures, intensified precipitation patterns, and extreme weather events (UNESCO, 2021; IPCC, 2023). These environmental changes not only damage the physical structures of heritage monuments but also erode the cultural narratives, practices, and identities they represent. While the global conservation community has begun recognizing the urgency of this issue, many heritage sites particularly in developing or conflict affected regions remain critically under researched and under protected (ICOMOS, 2019).

Afghanistan, with its rich yet vulnerable cultural landscape, is one such example. The country's heritage sites face compounding risks from both natural hazards and human induced pressures, exacerbated by limited institutional capacity and political instability (UNEP, 2022). The Bamiyan Valley, a UNESCO World Heritage Site, holds exceptional historical, artistic, and spiritual value. However, it is increasingly exposed to climate related hazards such as freeze thaw cycles, soil degradation, flash floods, and erosion (Meteoblue, 2025; UNESCO, 2021). Despite its importance, there is a lack of integrated studies that assess the combined effects of climate hazards, site vulnerability, and resilience planning in this context.

This study addresses that gap by applying a structured risk and resilience assessment framework tailored to the Bamiyan Valley. It contributes to the growing body of literature on heritage conservation in climate stressed regions and provides actionable insights for local authorities, heritage managers, and international stakeholders. The findings are intended to support both the safeguarding of Bamiyan's cultural assets and the broader advancement of climate adaptive heritage management practices.

1.6. Methodology

This research adapts a mixed methods and approach, combining qualitative analysis of literature and case studies with a framework based assessment of indicators which is identify after investigation of impacts and ongoing actions and prevision.

These study being with review of existing literature to stablish a strong theoretical foundation. There is key concepts for instance RESILIENCE, CULTURAL HERITAGE and CLIMATE CHANGE are critically examined through academic sources, international reports and institutional guidelines. Then study focuses on the identification and categorization of climate change impacts on cultural heritage through using the scientific publications and case study. Attention to monitoring is next step and then indicators identify.

The goal is to create a tool that not only measures the resilience capacity of cultural heritage sites but also helps to increase strengthening of cultural heritage sites.

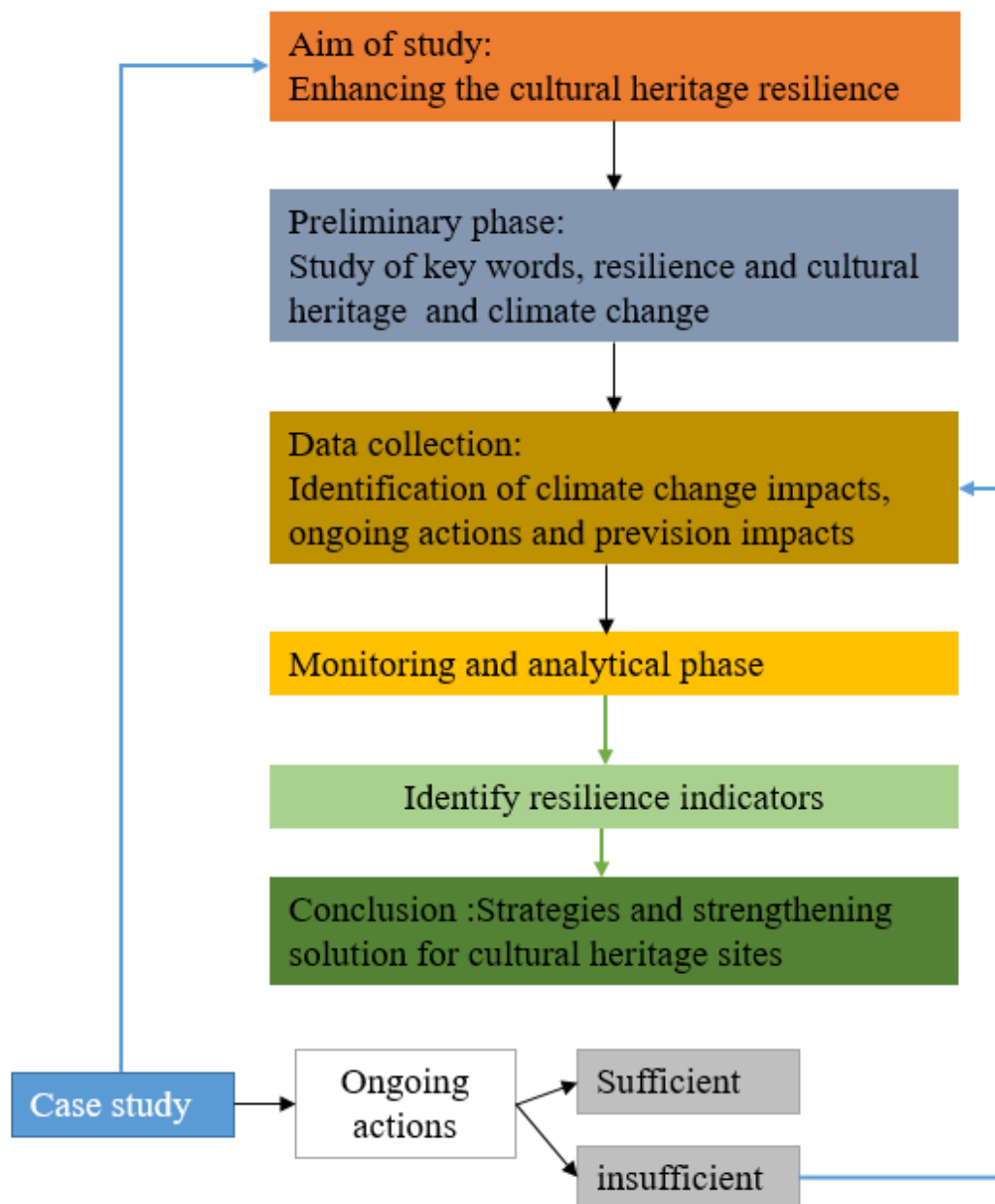


Figure1 methodology followed to reach study aim

Chapter 2: Literature Review

2.1. Introduction

This chapter reviews the existing body of literature related to climate change, cultural heritage, and concept of resilience. It provides a conceptual foundation for understanding how environmental changes impact heritage sites. The chapter outlines key terms, international frameworks, and relevant studies that guide the methodology and analysis of this thesis.

2.2. Cultural Heritage and Climate Change: Global Perspectives

The term “heritage” is an umbrella concept in spatial planning studies: it can refer not only to cultural and natural heritage but, in a broader sense, also to landscape (Amato et al., 2017). Furthermore, it can have various components: tangible or intangible, ancient or new, common or private (S. Dastgerdi et al., 2022).

Different type of cultural heritage in UNESCO legal framework:

Cultural heritage: Tangible, Intangible, Digital

Tangible heritage is probably the main category. It is divided into three sub categories: Cultural, Natural and Mixed.

Digital heritage is yet to be regulated in a convention of its own, but it does not mean that it is unregulated documentary heritage including in digital form: as well as in the 2003 UNESCO charter mentioned about preservation of digital heritage. (L. Lixinski, 2024)

Overall cultural heritage include: archaeological site, art, crafts literature and music, dark heritage, gastronomy, geological heritage, historic city center, industrial heritage, living cultures, living heritage or biodiversity, monuments, movable cultural heritage, museum, natural heritage, underwater heritage.

The values of cultural heritage are various: symbolic, historic, informational, aesthetic and economic, this study more focus on archeological sites. (Table 1)

No.	Values	Details
1	Symbolic	Cultural property provides awareness of and pride in cultural identity. In the postcolonial world, the idea of a national cultural heritage is of particular importance to emerging nations, and the protection of cultural property is a highly political issue
2	Historic	The cultural heritage represents eras and sometimes civilizations that have passed. Much of this heritage symbolizes a florescence of a region's traditions and cultures. Heritage is often of particular importance to non-literate societies and to segments of literate societies often ignored in conventional "historical" documents. In countries such as Australia, we see the implications of cultural heritage in connecting Aboriginal communities with their past and with the continuation of traditional lifestyle
3	Informational	The cultural heritage is essential to both public education and scholarly research. Archaeologists, historians, and ethnographers use material culture to study ancient and traditional cultures. Information about how other cultures met challenges to their existence can help us as we meet the demands of our own world. The study of other cultures can also lead to new intellectual achievements. For scholars, the greatest informational value comes in studying cultural property within its original context.
4	Aesthetic	The cultural heritage can provide an aesthetic, emotional experience for the viewer, leading to personal growth and development. Moreover, these buildings, artworks, and artifacts can serve as a creative inspiration for contemporary artists, both those working within traditional forms and those working in a modern style.
5	Economic	Cultural property – comprising archaeological sites, monuments, historic buildings and quarters, and archaeological and ethnographic materials in museums-is an important focus of tourism in many nations. As such, this tourism, which can be local, national, or international, generates employment and revenue.

Table1: Cultural heritage value (source: I, Norhashemi, 2014)

Climate change poses increasing threats to cultural heritage worldwide. Studies by UNESCO (2021) and the IPCC (2023) indicate that rising temperatures, shifts in precipitation patterns, and extreme weather events are accelerating the degradation of historical sites. Rock weathering, freeze thaw cycles, soil erosion, and biological growth are among the processes intensified by climate variables, leading to both physical and aesthetic deterioration.

The three continents with the greatest number of world heritage sites impacted by climate change since 1985 are listed in Table 2. Europe ranks second in terms of the number of sites impacted, despite having the most UNESCO historic sites by far. This may indicate that the cultural protection efforts already in place are effective.

Regions	World heritage impacted by climate change (CC)	Percentage (%)	State parties CC	Natura ICC	Cultural CC	Mixed CC	List in Danger (LD)	State parties LD	Natural LD	Cultural LD	Mixed LD	List in Danger climate change (LD CC)	State parties LD CC	Natural LD CC	Cultural LD CC
Africa	24	27%	19	6	17	1	35	18	17	17	1	4	4	1	3
Europe	21	24%	11	3	17	0	14	11	2	12	0	0	0	0	0
Asia	15	17%	12	7	8	0	10	8	2	8	0	1	1	0	1
South America	8	9%	5	0	7	1	9	8	5	4	0	2	2	0	2
Central America	7	8%	4	1	5	1	2	2	1	1	0	1	1	1	0
Middle East	6	7%	4	1	5	0	14	5	0	14	0	4	2	0	4
North America	4	4%	4	3	0	0	2	1	2	0	0	1	1	1	0
Australasia	2	2%	1	2	0	0	0	0	0	0	0	0	0	0	0
SIDS	2	2%	2	1	3	0	3	3	2	1	0	1	1	1	0
Global	89	100%	62	24	62	3	89	56	31	57	1	14	12	4	10

Table2: Number of world Heritage sites for which the outstanding Universal value (OUV) was impacted by climate change from 1985 and number of sites listed in the List in Danger with a focus on sites endangered by climate change.

(created using UNESCO World Heritage Centre State of Conservation Information System (SOC) – <https://whc.unesco.org/en/soc/>). The number of sites (total and in the List in Danger) affected by climate change are highlighted in yellow (CC = number affected by climate change; LD = number in the List in Danger; LD CC = number in the List in Danger and affected by Climate Change). Note: This table does not reflect the full range of heritage at risk from climate change, but those recognized WHSs that can be measured. There is likely a vast number of unrecognized sites that are more vulnerable due to climate and non-climatic factors which also require urgent assessment.

2.2.1. Forecasting global climate change

Copernicus Climate change Service (C3S) climate data store (CDS) has been able to project climate next generation for coming decades. Using models that depict physical processes in the atmosphere, ocean, cryosphere, biosphere, and land, as well as their interactions, climate projections are simulations of the future climate. The best instruments for describing the future development of the planet's climate system at both the global and regional levels are these models and the climate projections they produce (Climate Copernicus, 2021)

- Global Temperature Increases

Climate models predict that global temperatures will continue to rise if greenhouse gas emissions are not significantly reduced. The extent of warming depends on the emission scenario.

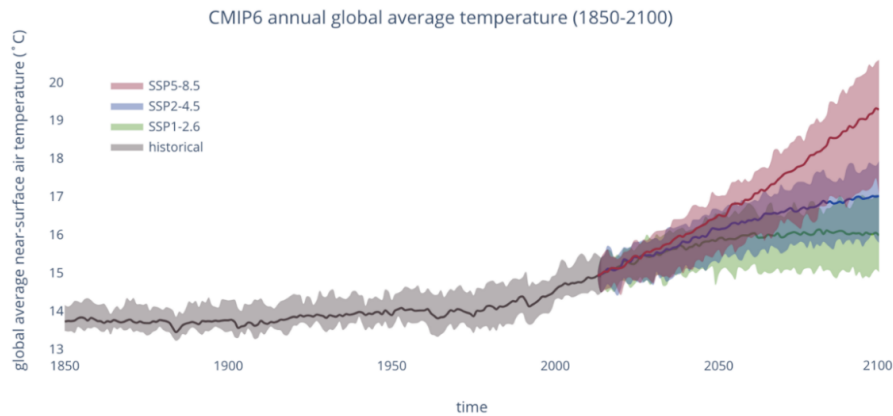


Figure 2 : An illustration based on CMIP6 data available in the CDS showing global mean temperature between 1850 and 2100 for selected CMIP6 models.

The grey shaded area shows the range of historical simulations and the colored areas show potential future temperature change based on different greenhouse gas emission scenarios (red is pessimistic, blue is realistic and green is optimistic). (source: copernicus climate change service, ECMWF)

- Change precipitation

The water cycle will "speed up" as a result of increased evaporation brought on by a warmer average world temperature. Precipitation will increase as atmospheric water vapor levels rise. We are looking at a future with significantly more rain and snow, as well as a heightened risk of flooding in some areas, as global average precipitation can rise by 7% for every degree of warming. It is predicted that heavy rain events will become 14% more intense and 1.7 times more frequent with a 2°C temperature increase. Changes in precipitation, however, won't be dispersed equally. There will be more in some places and less in others.

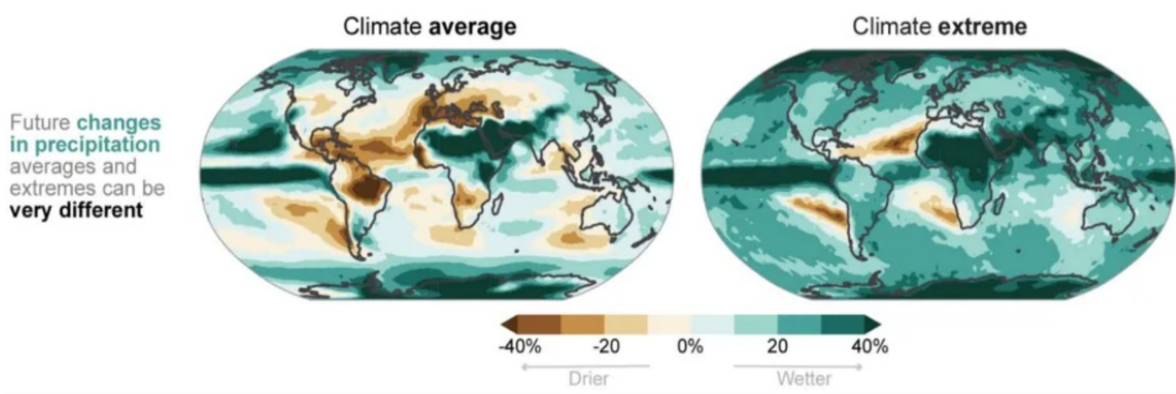


Figure 3: future change in precipitation will vary regionally, with some parts of the globe likely to become wetter and areas projected to become drier. (Source: UCAR (2))

- Melting snow and ice

Both snow and ice evaporate when the environment warms. A reduction in the overall amount of snow and ice on Earth is anticipated as a result of the summertime melting of glaciers, ice sheets, and other snow and ice on land continuing to exceed the winter precipitation. Both the amount of permafrost in the Arctic and the size of mountain glaciers worldwide have shrunk over the last century. The ice sheet in Greenland is also melting more quickly. It is anticipated that there would be less sea ice (frozen seawater) floating in the Arctic Ocean and surrounding Antarctica.

- Sea level rise

Warmer climate caused sea level rise as two way:

- 1- Melting glaciers and ice sheets (ice and land) add water to the oceans, rising the sea level.
- 2- As ocean water heats, it expands, increasing its volume and, consequently, the sea level.

Since 1880, sea levels have risen about 0.10 to 0.20 meters depending on region and location.

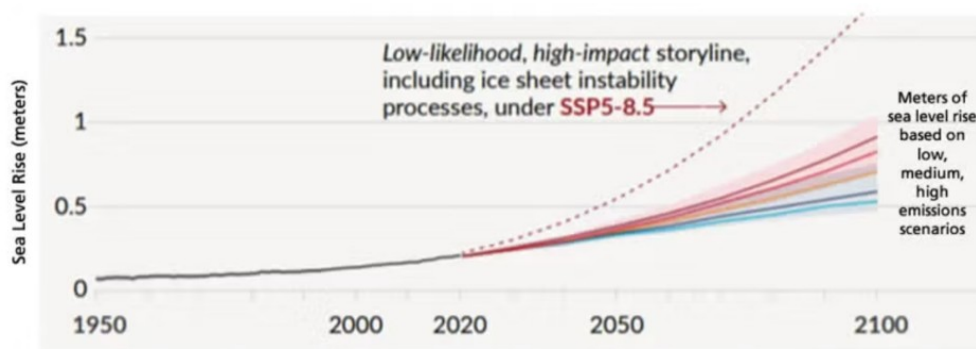


Figure 4: Observed and predicted sea level rise. (Source: Copernicus climate change service, ECMWF)

Anticipated sea level increase and observed sea level rise (black line), with the various colored curves representing various emission scenarios. By 2100, sea levels might rise by around half a meter, even with the lowest emissions scenarios. By the end of the century, a worldwide sea level increase of roughly one meter is anticipated under the scenarios with higher greenhouse gas emissions (IPPC Sixth Assessment Report, 2023).

In addition has been predicted some factors for instance acidic ocean water ,changes to ocean currents, changing sever weather, changing clouds that caused cooling the climate.

2.3. Concept of Resilience

Resilience can be defined as “the capacity of social, economic, and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity, and structure, while also maintaining the capacity for adaptation, learning and transformation” (IPCC, climate change 2014).

International institutions have argued on the relationship between cultural heritage and resilience, setting out some valuable concepts to integrate two such broad subjects (UNESCO, 2013; UNISDR, 2015), also in connection to climate change.

2.3.1. Types to Resilience

These three concepts engineering resilience, evolutionary resilience, and socio-ecological resilience are frameworks used to understand how systems respond to disturbances, adapt to change, and maintain functionality. Each concept originates from different disciplines and applies to different contexts.

Engineering resilience

The first kind of resilience, is quantified in terms of recovery; the more quickly a system's functionality is restored after being threatened by disruptions, the more resilient that system is. According to this understanding, a system has only one stable state or equilibrium that it must return to. For this reason, the engineering resilience approach emphasizes how quickly and easily a system may return to its initial state following a disruption. (UN Habitat, 2017) It emphasizes speed of recovery and stability.

Socio-ecological resilience

Socio ecological resilience (or social-ecological resilience) focuses on the interconnectedness of social and ecological systems. It examines how these systems co-evolve, adapt, and sustain themselves in the face of change. This Resilience is about maintaining functionality, identity, and structure despite disturbances.

Evolutionary resilience

Evolutionary resilience emphasizes the ability of a system to adapt, transform, and evolve in response to change. It recognizes that systems are dynamic and chaotic and fundamentally unpredictable, and it questions the concept of equilibrium altogether may not return to their

original state but can still thrive in new forms (Folke, C, 2010). Then this resilience focus on about adaptability and transformation rather than just recovery.

Therefore engineering resilience useful for designing systems that need to recover quickly from disruptions, such as infrastructure or supply chains. And socio ecological resilience for managing system like ecosystem and cities or communities where social and ecological factors are deeply intertwined and evolutionary resilience Helps in understanding how systems can adapt to long-term changes, such as climate change or technological shifts.

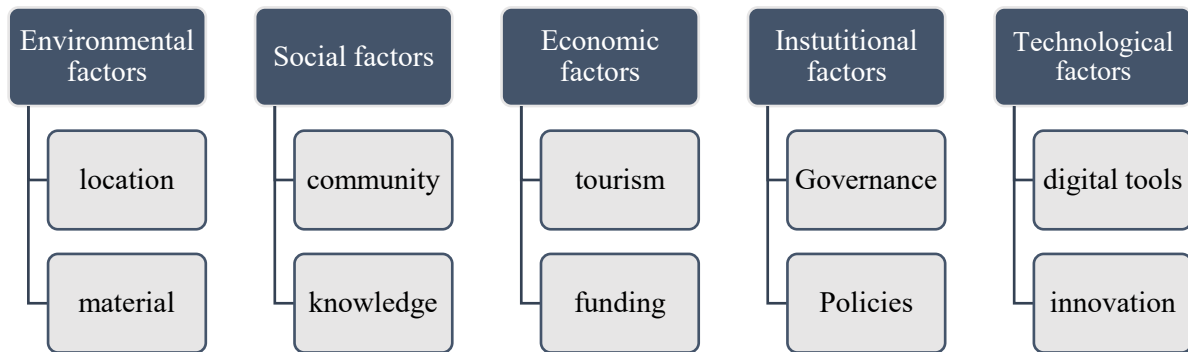
To implement this type of resilience for cultural heritage against climate change impacts there are some strategies:

- Identification of all impacts climate change on cultural heritage
- Risk assessment
- Action plan and monitoring
- Community engagement
- Adaptive reuse and innovation

2.4. Resilience of cultural heritage to climate change

The concept of revolution resilience in cultural heritage focuses on the capacity of heritage sites and practices to adapt, transform, and thrive amidst the challenges posed by climate change. In order to create effective adaptation plans, recent research highlights the significance of combining climate science with heritage management. Technological developments, socio economic circumstances, and environmental stressors are important determinants of resilience. In order to address the various effects of climate change on both tangible and intangible heritage, researchers emphasize the necessity of interdisciplinary approaches and worldwide collaboration. in this study more focus is on how can protect tangible cultural heritage The resilience of cultural heritage against climate change is divided into five important factors that need to be considered in an action plan for achieving the preservation of cultural heritage in the world.

Resilience of cultural heritage against climate change



- Environmental Factors

Environmental factors play a central role in determining the resilience of cultural heritage. The vulnerability of heritage sites to climate change is influenced by their geographic location, material composition, and exposure to environmental stressors (Fatorić & Seekamp, 2017). For example, coastal heritage sites are particularly susceptible to sea level rise and storm surges, while sites in arid regions face risks from desertification and temperature extremes. Adaptive strategies, such as the use of climate resilient materials and ecosystem based approaches, have been proposed to mitigate these risks (Phillips, 2015).

- Social and Cultural Factors

The resilience of cultural heritage is deeply intertwined with social and cultural factors. Community engagement and local knowledge are critical for developing effective adaptation strategies (Harvey & Perry, 2015). Indigenous communities, for instance, have demonstrated resilience by integrating traditional ecological knowledge with modern practices to protect heritage sites (Whyte, 2018). However, social inequalities and marginalized voices can hinder equitable resilience building efforts, highlighting the need for inclusive approaches.

- Economic Factors

Economic resources and funding mechanisms significantly influence the resilience of cultural heritage. Limited financial resources often constrain the implementation of conservation and adaptation measures (Fatorić & Biesbroek, 2020). Conversely, investments in heritage tourism and sustainable development can provide economic incentives for resilience building. Public

private partnerships and international funding initiatives, such as those led by UNESCO and the World Bank, have been instrumental in supporting heritage conservation projects (Labadi & Logan, 2015).

- Institutional and Governance Factors

Effective governance and institutional frameworks are essential for enhancing the resilience of cultural heritage. National and international policies, such as the Paris Agreement and the Sendai Framework for Disaster Risk Reduction, provide a foundation for integrating heritage conservation into climate adaptation strategies (Rockman et al., 2016). However, fragmented governance structures and lack of coordination among stakeholders often impede implementation. Strengthening institutional capacity and fostering multi stakeholder collaboration are key to addressing these challenges (Fatorić & Seekamp, 2017).

- Technological and Innovative Factors

Advancements in technology offer promising opportunities for enhancing the resilience of cultural heritage. Digital documentation, remote sensing, and predictive modeling enable the monitoring and assessment of climate risks to heritage sites (Reimann et al., 2018). Additionally, innovative conservation techniques, such as 3D printing and nanotechnology, are being explored to protect and restore heritage materials (Liritzis et al., 2019). However, the adoption of these technologies requires capacity building and financial investment.

A comprehensive, multidisciplinary strategy that involves a range of stakeholders and makes use of local expertise is needed to address these problems. Future studies should concentrate on creating integrated evaluation instruments and flexible approaches that support sustainable development and strengthen cultural heritage's resilience. In addition to preserving our common past, protecting cultural assets helps communities' social and cultural cohesion in the face of climate change.

2.5. Key concepts: Vulnerability, hazard, exposure and resilience

Understanding the relationship between vulnerability, hazard, and exposure is fundamental to assessing the risks posed by climate change to cultural heritage. These three interconnected concepts form the core of most climate risk assessment frameworks, including those used by UNESCO and the IPCC.

Adaptation, vulnerability, resilience, and risk are concepts that offer overlapping and alternative perspectives on the challenge of climate change (high confidence). Vulnerability is a risk factor, yet also a crucial focus on its own: enhancing comprehension of how climate change affects people differently based on attributes such as gender, race, wealth, social status, and others. Vulnerability is a crucial connecting factor between climate adaptation and disaster risk reduction. Resilience, applicable to both a process and an outcome, includes the idea of sustaining essential functions, identity, and structure, as well as preserving the ability to transform. (IPCC,2022).

Hazard: A situation or factor that has the potential to harm individuals, lead to health issues, or result in fatalities, as well as cause harm to resources. Climate change often exacerbates natural hazards and the level of susceptibility to the hazard (Climate Resilience Resources for Cultural Heritage. 2024.)

Vulnerability: The vulnerability to dangers that includes exposure, sensitivity, possible effects, and adaptive capacity.

- **Risk Exposure:** The existence of individuals, resources, and ecosystems in locations where they might suffer negative impacts from hazards, along with the effects of how often and how severe a particular hazard or set of hazards is.
- **Sensitivity:** The degree to which hazards may impact a system, population, or resource.
- **Adaptive capacity:** The capacity of an individual, resource, or mechanism to adapt to a threat, advantage on emerging prospects, or manage transformation.

Risk: Risk is a measure of the possibility or probability of adverse effects upon a cultural resource (Climate Resilience Resources for Cultural Heritage. 2024).



Figure 5: IPCC risk framework: Risk results from interactions among the determinations of risk, hazard, vulnerability and exposure, shaped by responses which can interact in complex ways.

Hazard, exposure, and vulnerability are terms that can be applied to understand how heritage values may be impacted by climate change and how heritage differs in relation to likely impact and options for management and adaptation (ICOMOS, 2022).

2.6. Vulnerability of cultural heritage in climate change impact

Understanding the current challenges facing cultural heritage is important if it is to be conserved and passed onto future generations. At the 2005 UN World Conference on Disaster Reduction, cultural heritage was emphasized, and the Hyogo Framework for Action (HFA) 2005–2015 was introduced. The Sendai Framework for Disaster Risk Reduction 2015–2030 was adopted as a follow up to the HFA (Hyogo Framework for Action) in 2015, which expanded the scope of disaster risk: "focus on both natural and manmade hazards and related environmental, technological, and biological hazards and risks" (UNISDR, 2015-2030). It also incorporated the concept of "cultural heritage" into disaster resistance and emphasized the significance of disaster risk management. The Strategy for Reducing Risks from Disasters at World Heritage Properties was adopted by the UNESCO World Heritage Center (UNESCO World Heritage Center, 2007), strengthening the protection of world heritages and emphasizing that "Global actors for disaster reduction should give more consideration to cultural heritage".

"Identifying, assessing, and monitoring disaster risks in world heritage areas" was one of the primary goals of the UN World Conference on catastrophe and Natural Heritage, which focused on cultural heritage.

Cultural heritage can be seen in many forms including buildings, areas, dance, food, dress, events, values, lifestyles and handicrafts. Given the values of cultural property, many problems created when such materials was damaged, destroyed, or removed from its context. These

losses include the damage or loss of buildings of historical importance, archaeological sites, monuments, and objects; the loss of traditional knowledge and "scientific" information; the loss of access to objects of cultural or national importance; and the alienation of people from their culture or the loss of national pride.

When vulnerability concept it comes to heritage sites, exposure denotes the positioning of these sites or cultural assets in regions that safeguard potential dangers and impacts that could negatively affect their value. Prior research into cultural heritage has centered on the exposure to dangers like natural disasters, climate change, and mass tourism. UNESCO has compiled a detailed list of elements that could impact World Heritage Sites as part of its routine threat monitoring. This encompasses threats arising from both natural phenomena and human activities.

Natural threats that can cause these sites to deteriorate gradually or suddenly include disasters like earthquakes and floods, as well as the impacts of climate change, including rising temperatures, alterations in sea levels, and extreme weather phenomena; as well as local circumstances of environmental degradation and pollution. Human induced threats include development pressures like rapid urbanization near heritage sites, resource scarcity and exclusion, mass tourism, and inadequate governance and management. Further risks resulting from human actions encompass acts of vandalism, theft, and intentional damage to cultural assets. Risk mapping, vulnerability indices, remote sensing, and geospatial technologies can be valuable in assessing the level of exposure to these threats. (M. Bajracharya, 2025)

The degree to which a cultural heritage site is affected or modified by the hazards and stresses it faces is referred to as sensitivity. It is a characteristic that is intrinsic to a system. The material and structural characteristics of a site, such as the kind of building materials or construction technique employed, ascertain its susceptibility to the pertinent hazards. Surrounding natural and socio economic environments may also affect sensitivity levels. As an illustration, urban development, encroachment, and large-scale tourism are resulting in harmful effects at multiple locations. More intensive heritage protection measures may be required at higher sensitivity levels.

2.7. Overview of Cultural Heritage Conservation and Resilience Actions

According to the United Nations Educational, Scientific and Cultural Organization (UNESCO), one third of natural sites and one sixth of Cultural Heritage Sites (CHSs) are currently threatened by climate change hazards and risks. (A. valagussa et al, 2020)

Numerous discussions and publications about climate change, its effects, and the difficulties it presents for the preservation of cultural heritage have been started by the Council of Europe. The organization has considered the detrimental economic and social effects it has on nearby populations, including the loss of cultural variety, identity, and values brought on by the deterioration and increasing vulnerability of cultural heritage sites. Additionally, it has acknowledged traditional cultural heritage knowledge as a source of information for addressing climate change.

A policy document on the effects of climate change on world heritage properties was accepted by the General Assembly of States Parties to the World Heritage Convention in 2007. A policy advice document on incorporating the 17 Sustainable Development Goals (SDGs) into the World Heritage Convention's implementation was released in 2015 by UNESCO's World Heritage Committee. As a "universal call to action to end poverty, protect the planet, and ensure that by 2030 all people enjoy peace and prosperity," the United Nations (UN) approved the 17 Sustainable Development Goals (SDGs) earlier in 2015. All of the SDGs have connections to both cultural heritage and climate change, even though the eleventh target specifically mentions the need to "strengthen efforts to protect and safeguard the world's cultural and natural heritage." (Climate change report 2023).

These goals are based on derived from respective policies and include improved and enhanced collaboration as well as the effective and synergistic implementation of local, national, and agreed upon climate related policy instruments.

- Goal 1: climate risk assessment

by 2030, In order to assess climate risks and identify potential irreversible or reversible damage to attributes carrying the Outstanding Universal Value associated with current and projected impacts of climate hazards, States Parties should develop and share the necessary tools and build capacity. They should also report the results of these assessments through World Heritage processes, such as Periodic Reporting and state of conservation reports.

- Goal 2: climate adaptation

By 2030 States Parties should In order for their cultural, natural, and mixed heritage to be included in their national adaptation plans, create and develop strong frameworks for climate adaptation at the international, national, and local levels and, if necessary, implement them at the site level.

Achievement: These frameworks should be able to show quantifiable progress in monitoring climate hazards, evaluating and reducing climate risks and vulnerabilities, and, in doing so, improving adaptive capacity and constructing climate resilience for all World Heritage properties.

- Goal 3: Climate mitigation

By 2030, State Parties should, in accordance with their commitments under the UNFCCC's Paris Agreement, develop at the international, national, and local levels and implement at the site level appropriate measures that strengthen the capacity for mitigation action at their cultural, natural, and mixed properties and encourage the reduction of net greenhouse gas emissions associated with World Heritage properties. These measures should, where appropriate, include actions to protect carbon sink natural ecosystems.

- Goal 4: knowledge sharing, capacity building and awareness

By 2030, States Parties should have created and executed initiatives to enhance education, awareness raising, and institutional and human capacity concerning the threats and solutions associated with climate change impacts on World Heritage properties. These initiatives should include knowledge sharing programs and those intended to position these properties as models of climate action. (Policy document on climate action for world heritage, 2023)

Response to implementation of world heritage climate action goals there are applications in context of the convention in different level at universal, national and local. Fig6: shows some of the key sectors that have actions to progress.

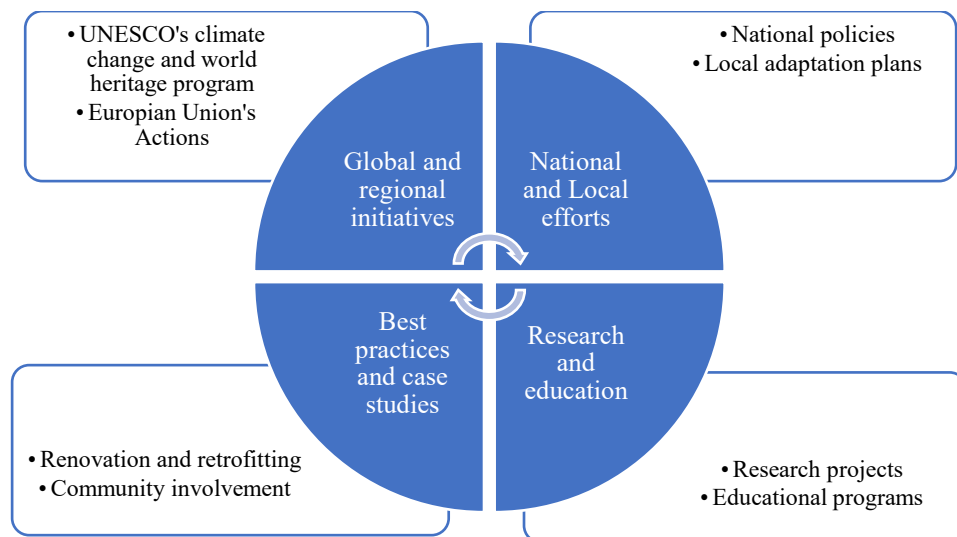


Figure 6: effective actions against the impacts of climate change

Several institutions and conventions are actively working to address the impacts of climate change on cultural heritage. In order to mitigate and adapt to climate change, culture and legacy are essential. To lessen the effects of climate change on people and heritage, the International Centre for the Study of the Preservation and Restoration of Cultural Property (ICCROM) has started a new multi-partner capacity development project to put heritage based mitigation and adaptation techniques into practice (ICCROM net zero, 2022). Table 3 shows key sectors activities against climate change impact in cultural heritage site.

Key sector	Organization	Activity	Achievement
Global and regional activities	UNESCO united nation education ,scientific and cultural organization	International Co-sponsored Meetings: Organizing meetings with partners like the Intergovernmental Panel on Climate Change (IPCC) and the International Council on Monuments and Sites (ICOMOS) to further integrate culture into the international climate agenda.	Improve resilience: Implementation of adaptation measures such as improving drainage systems, reinforcing structures, and using climate-resilient materials in restoration projects at many World Heritage sites.
		Blue Carbon Projects: Promoting projects that focus on the carbon sequestration potential of coastal and marine ecosystems, which are part of UNESCO's World Heritage sites	Increase awareness
		Vulnerability assessments	Strengthening policies: Integration of cultural heritage considerations into national and international climate policies, enhancing the protection of heritage sites from climate-related risks.
		Climate change observatory: Establishing observatories to monitor the effects of climate change on	Educational program and collaborative research to understanding and measure the

Key sector	Organization	Activity	Achievement
		UNESCO-designated sites and world heritage sites. Strengthening the capacities of site managers and local communities through training programs and educational field, engaging local communities in preservation efforts and rising awareness about important of protecting heritage sites, Policy development that integrate cultural heritage considerations into climate action plans.	impacts and development of effective mitigation strategies
	UNFCCC united nation framework convention on climate change	Developing thematic targets focused on protecting cultural heritage from climate-related risks. Conducting capacity-building activities to strengthen the abilities of site managers and local communities to address climate change challenges. Promoting research and share knowledge to protect the CH. Develop Policies and integrate cultural heritage consideration into climate action plans.	Adaptation strategies and designing climate resilient infrastructure. Identifying indicators to measure progress toward protecting CH. Increase awareness, conducting research projects to explore the impacts of climate change on CH. Implementation educational program to inspire future generations to take action in preserving heritage sites and promoting sustainable practices.
	ICOMOS international council on monument and sites	Climate action working group CAWG: Formed in 2017 and renamed in 2021, the CAWG focuses on implementing the ICOMOS Triennial Scientific Plan, education, resource creation, and managing key climate-related projects. Preserving Legacies Project: This project, funded by National Geographic Society and the Andrew W. Mellon Foundation, aims to protect heritage sites from climate change impacts. Heritage Adapts to Climate Alliance (HACA): Launched in collaboration with the Climate	Explore impacts of CC. increase awareness and develop innovations for mitigation and adaptation.

Key sector	Organization	Activity	Achievement
		Heritage Network, this initiative aims to develop model indicators for measuring progress in adapting heritage sites and cultural practices to climate change.	
		Climate Action Toolkit for World Heritage: Developing a toolkit to help World Heritage managers and local communities assess climate vulnerability and implement adaptation measures.	
	European Union, EU	Networking and best practices best practices among member states. Funding and grant through programs like creative Europe to support projects that enhance the resilience of cultural heritage sites.	Adaptation Strategies: Implementing adaptation measures such as improving drainage systems, reinforcing structures, and using climate-resilient materials in restoration projects. Collaborative research and educational impact that is implementing educational programs and public outreach initiatives to inspire future generations to take action in preserving heritage sites.
National and local policy	National policies: European union, united kingdom, national policy of France.	Horizon 2020 program Framework for action on cultural heritage and council work plan for culture 2019-2020.	focused on increasing resilience and sustainable reconstruction of historical area
		Historic England's climate change strategy	focuses on managing risk and adapting historic building to climate change including energy efficiency and resilience to flooding
	Local policies: Venice, Italy-	Has implemented measures to protect its historic city from rising sea level and flooding.	The MOSE project (Modulo Sperimentale Elettromeccanico), which involves the construction of mobile barriers to protect the lagoon.

Key sector	Organization	Activity	Achievement
	New York city local adaptation plan	Resiliency and adaptation measures, using last technology to inform decision making and adaptation strategies, identifying the greatest climate change hazards.	These achievements demonstrate New York City's commitment to becoming more sustainable, resilient, and equitable in the face of climate change.
	Quebec implemented policies to engage local communities in preservation efforts.		
Research and education	European Commission Projects	The European Commission has funded numerous projects under the Horizon 2020 Program to explore the intersection of climate change and cultural heritage. These projects focus on increasing resilience and sustainable reconstruction of historic areas.	Public awareness campaigns, mitigate impacts.
	Environmental law and adaptation		
Practice and case study	Venice, Italy	MoSE project Green and blue infrastructure Early warning systems Restoration projects Public awareness campaigns	Increase resilience of historical area with enhancing natural and artificial water system to manage flooding and improve water quality and knowing about time of high tides and storm.
	New York city , USA	Lower East Side Resiliency Project	Protect the Lower East Side from flooding and storm surges.
	National park Portsmouth village, USA	Tree Canopy Expansion Local Law 97	Planting trees to improve air quality, reduce heat, and manage storm water and reduce building emission to make the city's building stock more energy efficient and climate resilient.

Table3: key sectors activities against climate change impact in cultural heritage site

2.8. Conclusion

This chapter has explored the expanding literature at the intersection of climate change and cultural heritage, providing a conceptual and empirical groundwork for the thesis. Key themes encompass vulnerability, exposure, and hazard identification, as well as the necessity to bolster

resilience against environmental and human-induced threats. Global frameworks created by organizations like UNESCO, ICOMOS, and the Sendai Framework have highlighted the urgent need for proactive heritage management that takes climate considerations into account. Also it emphasizes the significance of localized studies that integrate hazard mapping, institutional analysis, and stakeholder engagement. The insights gained justify the creation of methodology, which is detailed in the next chapter.

Chapter 3: Risk and climate change indicators in cultural heritage sites

3.1. Introduction

This chapter investigates the intersection of climate change and cultural heritage by identifying and analyzing key risk indicators that threaten the integrity of heritage sites. It provides a comprehensive diagnosis of climate change impacts both general and site specific on cultural heritage assets, focusing on how these effects manifest across physical, social, and cultural dimensions. The chapter explores the processes through which climate induced hazards such as temperature variability, precipitation changes, and human induced stressors contribute to the deterioration of heritage materials and values.

In addition to outlining these threats, the chapter emphasizes the importance of monitoring and risk assessment tools in building resilience. By identifying relevant indicators, this section lays the groundwork for implementing effective risk management strategies.

3.2. Identification of climate change impacts

according to scientific literature and the main reports of recent years climate change impact on weather parents and has many risk for human and all other life on earth are defined as "effect" of CC. and IPCC defined the "impact" of CC as : "The effects of CC and extreme weather and climate events on natural and human systems, divided into:

- Effects on natural system
 - Ecosystems and Biodiversity: Climate change leads to shifts in species distributions, loss of habitats, and increased risk of extinction. For example, coral reefs are bleaching due to rising sea temperatures, and polar bears are losing their ice habitats.
 - Water Resources: Changes in precipitation patterns and melting glaciers affect water availability, leading to droughts in some regions and floods in others.
 - Forests: Increased temperatures and changing precipitation patterns can lead to more frequent and intense wildfires, deforestation, and pest outbreaks.
 - Agriculture: Changes in temperature and precipitation affect crop yields, leading to food insecurity in some regions.

- Effects on human system
- Health: Extremes heatwaves can cause heat related illnesses and deaths, while changes in weather patterns can increase the spread of vector borne diseases like malaria and dengue fever.
- Infrastructure: Rising sea levels and increased frequency of extreme weather events like hurricanes and floods can damage infrastructure, leading to economic losses and displacement of communities.
- Economy: The costs of adapting to climate change and recovering from extreme weather events can strain economies, particularly in vulnerable regions.
- Social and Cultural Impacts: Climate change can lead to displacement of communities, loss of cultural heritage, and increased social tensions.

Observed widespread and substantial impact and related losses and damages attributed to climate change Figure 7.

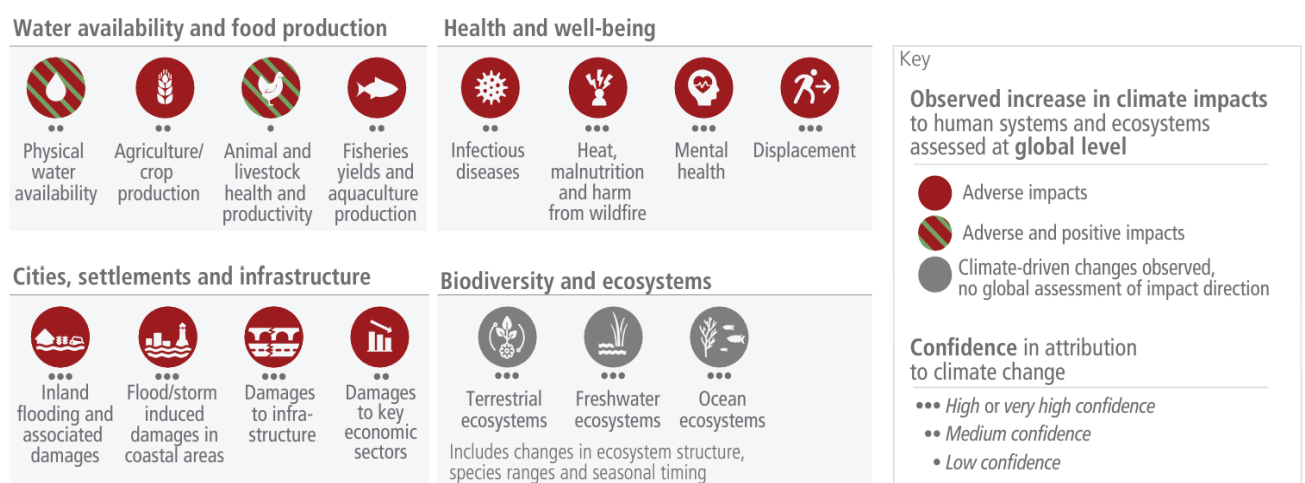


Figure 7: Identification of impacts in four essential sectors, (source: IPCC, 2021)

sector	Impacts	Description of impact
Water availability and food production	Physical water availability	Altered precipitation patterns: climate change leads to more intense and unpredictable precipitation patterns
		Melting glaciers and snowpack
		Increased evaporation
		Sea level rise
		Extreme weather events
		Changes in river flows
	Agriculture and product	Shifts in Growing Seasons: altered temperatures and precipitation patterns can shift growing seasons, affecting when and where crops can be planted and harvested.
		Crop yields: extreme weather events, such as droughts, floods, and heatwaves, can reduce crop yields.
		Soil health: Increased temperatures and changing rainfall patterns can degrade soil quality, reducing its fertility and capacity to support healthy crops.
		Pests and diseases: warmer temperatures can expand the range and increase the activity of pests and diseases, posing additional challenges to crop production.
		Water availability: affecting on irrigation and water resources essential for farming
		Livestock: effect on feed availability and quality
		Food security: reduced agricultural productivity can lead to higher prices and increased risk of insecurity
	Livestock health	Water availability
		Nutrient quality of feed: higher CO2 levels can decrease the nutrition quality
		Spread of diseases

sector	Impacts	Description of impact
		Reproductive health: Extreme temperatures and stress can affect the reproductive health and efficiency of livestock, leading to lower birth rates and higher mortality rates in young animals.
	fisheries	Ocean warming
		Ocean acidification: due to increased CO2
		Changes in fish migration
		Habitat loss
		Reduced Freshwater Inflows: Changes in precipitation and increased evaporation can reduce freshwater inflows to coastal areas, affecting estuarine and coastal ecosystems where many fish species breed and feed.
Health and well-being	Infectious diseases	Warmer temperatures and changing precipitation patterns can expand the habitats of disease-carrying vectors like mosquitoes and ticks. This can lead to the spread of diseases such as malaria, dengue fever, and Lyme disease to new regions.
	Heat malnutrition and harm from wildfire	Higher temperatures can lead to heat stress, which affects the body's ability to absorb nutrients, leading to malnutrition. Also Climate change leads to drier conditions and longer fire seasons, resulting in more frequent and severe wildfires.
		The destruction caused by wildfires can lead to significant economic losses, affecting livelihoods and increasing poverty, which in turn can contribute to malnutrition.
	Mental health	Stress and anxiety: The uncertainty and potential threats posed by climate change can lead to increased stress and anxiety. Concerns about extreme weather events, rising sea levels, and the future of the planet contribute to a pervasive sense of worry.
		Trauma and health related mental issues
	displacement	Economic stress: Climate change can lead to economic instability, affecting jobs, income, and access to resources.
		Floods, and wildfires destroy homes and infrastructure, forcing people to leave their communities. This often leads to temporary or permanent displacement. Resource scarcity and environmental stress can exacerbate existing social tensions and conflicts, leading to displacement as people flee violence and instability.

sector	Impacts	Description of impact
Cities, settlements and infrastructure	Inland flooding and associated damage	Significant impact on inland flooding and damage like increasing the volume of runoff and the likelihood of urban flooding and loose of infrastructure.
	Flood/storm induced damages in coastal areas	Increased storm intensity and costal erosion, salt water intrusion, loss of coastal habitats.
	Damages to infrastructure	Increased frequency and severity of flooding due to intense rainfall and rising sea levels can damage roads, bridges, buildings, and drainage systems. This leads to higher maintenance and repair costs and disruption of services. Higher temperatures can cause roads and railways to buckle.
	Damages to key economic sectors	It can effect on all of sectors for instance economic agriculture, economic transportation, energy sector, tourism and...
Biodiversity and ecosystem	Terrestrial ecosystem	Increased frequency of extreme weather events, disrupt nutrient cycles, habitat loss species distribution and wildfires.
	Freshwater ecosystem	Water temperature change, flow patterns: increased evaporation alter the flow patterns of rivers and streams, impacting aquatic habitats and the organisms that depend on them and about water quality there is some impact for instance nutrient runoff and pollution.
	Ocean ecosystem	Effect on coral bleaching and can lead to their death and species migration, This shift disrupts existing ecosystems and affects the species that depend on these migratory organisms for food. Ocean acidification and impact on marine life. Changes in ocean currents and increased storm intensity.

Table 4: General impact of climate change

Changes in multiple physical climate conditions drive impacts shows in figure 8 which are increasing attributed to human influence.

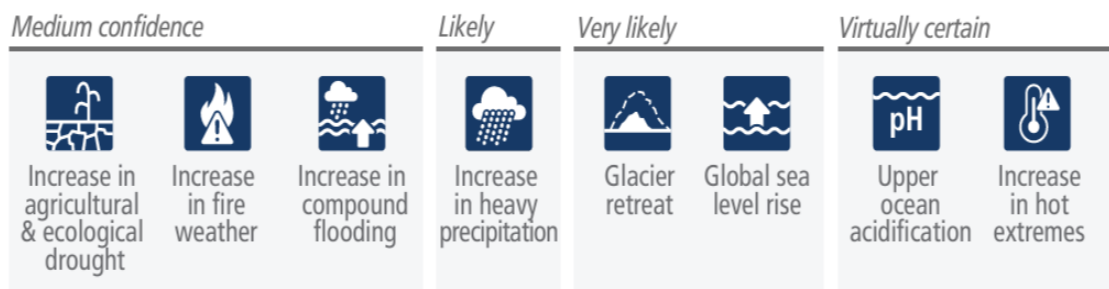


Figure 8: Attribution of observed physical climate change to human influence, (source: IPCC, 2021)

Attribution of observed climate change to human influence directly related to the emission of greenhouse gases like carbon dioxide CO₂ methane CH₄ and nitrous oxide N₂O, according to IPCC reports include human influence is extremely likely (95 -100 probability) that more than half of the observed increase in global mean surface temperature was caused by human activities (IPCC, 2023).

3.3. Climate change impacts on cultural heritage

Tangible and intangible kinds of cultural heritage are seriously threatened by extreme weather. In order to safeguard important sites and keep them intact for future generations, these risks must be addressed.

1. Physical impacts of climate change on cultural world heritage

Impacts cultural heritage is becoming increasingly prone to the impacts as two way:

- Natural hazards: earthquakes, floods, drought
- Anthropogenic impact: vandalism, theft, rapid urbanization.

2. Social impact of climate change on cultural world heritage

It is impossible to consider climate change related changes to cultural heritage in isolation from socioeconomic, demographic, and behavioral shifts, the influence of opposing societal ideals, and land use planning, all of which must adapt to the changing climate.

- Loss of cultural identity: displacement and loss of traditions
- Social cohesion: weaken social bonds and economic impact
- Community resilience: adaptation challenges and engagement and education
- Psychological impact: loss of heritage and cultural memory

Through analysis and output data, it is possible to identify how climate change has affected the cultural heritage sector. In general and according to the latest IPCC reports main type of CC impact that will affect CH, shows in Figure 9.

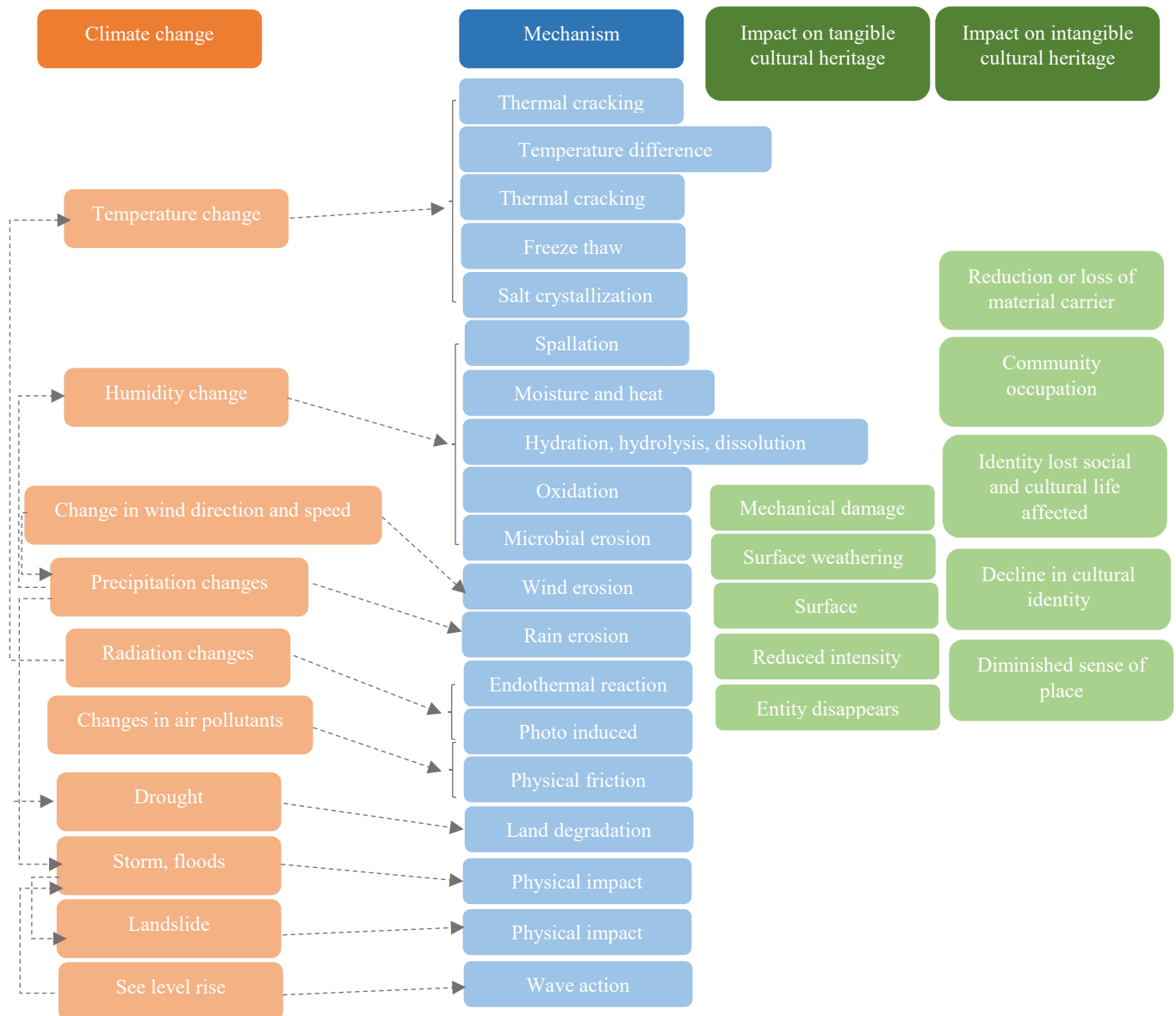


Figure 9: The mechanism and process of how climate and environmental change affect cultural heritage

According to scale of site, impacts can be observed as follows:

- At the site level, physical damage to the site concerned (erosion, soil displacement Land deposition, and damage to forest, park, or individual trees)
- At the building level, through physical damage related to the architectural object that indicates material degradation processes (damage to roofs, facades, and structures)
- At the object level, regarding movable heritage.(F. Giglio et all, 2024)

Scale level	Area	Climate change risk
the level	Coastal heritage sites	Threated by See level rise and coastal erosion: damage to structures located near the shore.
	Historical buildings	Temperature fluctuations: cause material to expand and contract also leading to cracks and structural damage. humidity changes: affect the integrity of building materials causing decay and deterioration
	Archeological sites	Flooding: can wash away or damage artifacts and structures, loos of historical information. Soil erosion: buried artifacts and structure.
	Cultural landscapes	Desertification: lead to the degradation of cultural landscapes. Changing vegetation: Shifts in vegetation due to climate change can alter the appearance and ecological balance of cultural landscapes.
	world heritage sites	Extreme Weather Events: Hurricanes, storms, and wildfires can cause significant damage to heritage sites, leading to structural instability and loss of historical integrity. Permafrost Thaw: In regions with permafrost, thawing can lead to ground instability, causing damage to archaeological sites and historic structures.
the building level	Physical damage	Temperature fluctuations cause materials like wood stone and metal to expand and contract that is problematic for historic buildings made from traditional materials. Increased moisture ,flooding and wind damage has numbers effect on material and elements building
	Material degradation	Salt efflorescence: increase salinity can cause salt to crystallize on building surfaces

Scale level	Area	Climate change risk
		Biological growth: warmer and wetter conditions can promote the growth of algae lichen and moss on building surfaces.
		Corrosion: effect on iron and steel beam and structure.
	Aesthetic and historical value	Discoloration and loss of unique features: both affecting the aesthetic and historical value of buildings.
	Economic and social impacts	Increase maintenance costs and damage to heritage building can affect tourism.
the object level	Material degradation	Chemical reactions like oxidation and corrosion, increased humidity and change temperature cause damage objects heritage.
	Biological damage	Pest infestations and fungal growth: cause weaken material and stain.
	Physical damage	Crystallization and erosion

Table 5: significant impact on cultural heritage in different scale

3.4. Identifying Climate change Indicator

According to previous section that determined climate change impacts on cultural heritage and proses of risk assessment, this part has specified indicators.

Climate indicator	Climate change risk	Physical, social and cultural impacts on cultural heritage
Atmospheric moisture change	– Flooding (sea, river)	– PH changes to buried archaeological evidence
	– Intense rainfall	– Loss of stratigraphic integrity due to cracking and heaving from changes in sediment moisture
	– Changes in water table levels	– Data loss preserved in waterlogged / anaerobic / anoxic conditions
	– Changes in soil chemistry	– Eutrophication accelerating microbial decomposition of organics
	– Ground water changes	– Physical changes to porous building materials and finishes due to rising damp
	– Changes in humidity cycles	– Damage due to faulty or inadequate water disposal systems; historic rainwater goods not capable of handling heavy rain and often difficult to access, maintain, and adjust

Climate indicator	Climate change risk	Physical, social and cultural impacts on cultural heritage
	– Increase in time of wetness – Sea salt chlorides	– Crystallisation and dissolution of salts caused by wetting and drying affecting standing structures, archaeology, wall paintings, frescos and other decorated surfaces – Erosion of inorganic and organic materials due to flood waters – Biological attack of organic materials by insects, moulds, fungi, invasive species such as termites – Subsoil instability, ground heave and subsidence – Relative humidity cycles/shock causing splitting, cracking, flaking and dusting of materials and surfaces – Corrosion of metals – Other combined effects e.g. Increase in moisture combined with fertilisers and pesticides
Temperature change	– Diurnal, seasonal, extreme events (heat waves, snow loading) – Changes in freeze-thaw and ice storms, and increase in wet frost	– Deterioration of facades due to thermal stress – Freeze-thaw/frost damage – Damage inside brick, stone, ceramics that has got wet and frozen within material before drying – Biochemical deterioration – Changes in ‘fitness for purpose’ of some structures. For example overheating of the interior of buildings can lead to inappropriate alterations to the historic fabric due to the introduction of engineered solutions – Inappropriate adaptation to allow structures to remain in use
Sea level rises	– Coastal flooding – Sea water incursion	– Coastal erosion/loss – Intermittent introduction of large masses of ‘strange’ water to the site, which may disturb the metastable equilibrium between artefacts and soil – Permanent submersion of low lying areas – Population migration – Disruption of communities – Loss of rituals and breakdown of social interactions
Wind	– Wind-driven rain	– Penetrative moisture into porous cultural heritage materials

Climate indicator	Climate change risk	Physical, social and cultural impacts on cultural heritage
	– Wind-transported salt – Wind-driven sand – Winds, gusts and changes in direction	– Static and dynamic loading of historic or archaeological structures – Structural damage and collapse – Deterioration of surfaces due to erosion
Desertification	– Drought – Heat waves – Fall in water table	– Erosion – Salt weathering – Impact on health of population – Abandonment and collapse – Loss of cultural memory
Climate and pollution acting together	– pH precipitation – Changes in deposition of pollutants	– Stone recession by dissolution of carbonates – Blackening of materials – Corrosion of metals – Influence of bio-colonialization
Climate and biological effects	– Proliferation of invasive species – Spread of existing and new species of insects (eg. Termites) – Increase in mould growth – Changes to lichen colonies on buildings – Decline of original plant materials	– Collapse of structural timber and timber finishes – Reduction in availability of native species for repair and maintenance of buildings – Changes in the natural heritage values of cultural heritage sites – Changes in appearance of landscapes – Transformation of communities – Changes the livelihood of traditional settlements – Changes in family structures as sources of livelihoods become more dispersed.

Table 6: identification indicators

3.5. Risk Management and Monitoring

Climate risk management incorporates all actions necessary to assess and manage the risks of a changing climate, considering:

- The multiplicity of climate related hazards, including both rapid and slow onset events:
 1. Events with a rapid onset are brief, severe, intense, frequent, extremely harmful, and uncontrollable. Storm surge, intense precipitation, hailstorms, flash floods, landslides, heat waves, wildfires, hurricanes, typhoons, and severe winds are a few examples. In many parts of the world, climate change is predicted to increase the frequency and severity of many of these kinds of disasters.
 2. Long lasting, gradual, and possibly permanent shifts that are less harmful in the short term but may have significant long term effects are known as "slow onset" events. These include changes in seasonality and species distribution, acidification, desertification, sea level rise, and glacier melt.
- Variations in how vulnerable heritage sites are to certain climate related risks.
- How risks associated with climate change intensify other risks and stressors, frequently having detrimental effects on cultural sites.(policy document on climate action for world heritage,2023)

Risk management

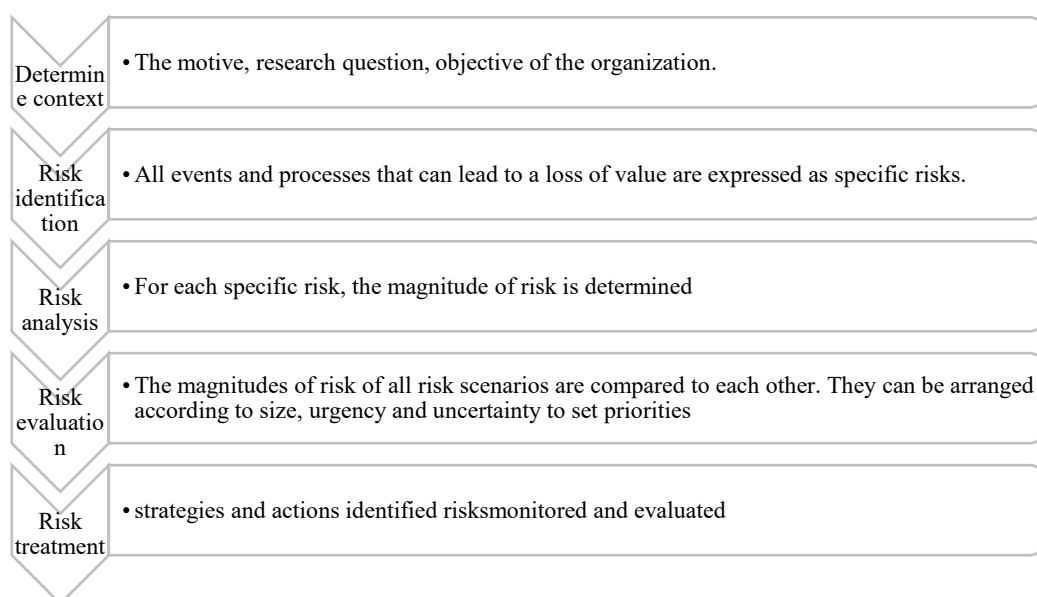


Figure 10: The risk management process according to studies

After investigate about risk identification includes hazard identification and vulnerability assessment, have to implement risk analysis or risk assessment for that there are operational steps:

- **Likelihood Analysis:** Evaluate the likelihood of each identified hazard occurring. This can be based on historical data, climate models, and expert judgment.
- **Impact Analysis:** Assess the potential impact of each hazard on the cultural heritage site. This involves considering the severity of damage and the significance of the heritage at risk.
- **Risk Evaluation:** Combine the likelihood and impact analyses to prioritize risks. High-likelihood, high impact risks are usually prioritized for immediate action.

Data analysis and creation using advanced technologies (ATs) are considered as climate mitigation techniques for cultural protection. These technologies enhance documentation, conservation, monitoring and accessibility by ensuring the preservation, transmission and interaction of cultural heritage with a wider audience (E. Asprogerakas, 2021).

1. **Remote Sensing and GIS:** Remote Sensing: LiDAR (Light Detection and Ranging), satellite photography, and aerial drones all offer useful information for tracking and evaluating the state of ecosystems, landscapes, and CH sites. This makes it easier to recognize possible hazards, such man-made or natural disasters, and to put preventative measures in place.
2. **Environmental Sensors:** Installing sensors to keep an eye on the temperature, humidity, light levels, and air quality in areas designated for cultural heritage will assist preserve the best possible conditions and stop environmental elements from causing harm.
3. **Three-dimensional (3D) modeling and scanning:** 3D scanning methods, such photogrammetry and laser scanning, produce incredibly precise digital copies of historical places, monuments, and relics. Virtual restoration, analysis, and documentation can all be done with these 3D models.
4. **Digital Documentation and Archiving:** By producing thorough records, digital documentation techniques (DDMs), such as high resolution photography and multispectral imaging, allow the preservation of delicate artifacts. Planning for conservation, additional research, and remote access are made easier by digital archives.

Also Augmented reality (AR) and virtual reality (VR) technology provide immersive experiences that let people virtually explore and engage with artwork, antiques, and cultural heritage places. They have been utilized to improve tourist interaction, provide educational opportunities.

To preserve and safeguard our priceless cultural treasures from the year round effects of climate change, monitoring cultural heritage is an essential practice. In order to detect possible hazards and put appropriate preservation measures in place, effective seasonal monitoring entails methodically observing and documenting these changes.

Establishing a thorough monitoring program will help us better understand how various weather patterns and seasons impact cultural resources. This proactive approach contributes in the development of long term policies to ensure the sustainability and resilience of heritage sites in addition to minimizing current threats. monitoring offers a comprehensive picture of the environmental issues facing cultural assets by combining cutting edge technologies like remote sensing, Geographic Information Systems (GIS), and climate modeling with local expertise and community interaction. Monitoring empowers heritage managers, policymakers, and communities to make informed decisions that safeguard cultural legacy for future generations.

Monitoring by communities and the general public is one of the most basic types. A campaign of awareness raising on the value of the legacy and the necessity of observing and reporting changes is necessary for this monitoring to be successful.

- Mitigation strategy

Implementing proactive measures to lower greenhouse gas emissions and improve the resilience of heritage sites is necessary to mitigate the effects of climate change on cultural heritage (CH). Using energy efficient technologies in historic structures, encouraging the use of climate resilient materials in restoration projects, and implementing sustainable tourist practices to reduce environmental footprints are important mitigation initiatives. Fostering a sense of ownership and accountability also requires increasing public awareness and involving local communities in preservation initiatives. We can protect cultural heritage from the negative effects of climate change and guarantee its preservation for future generations by combining these strategies.

- Adaptation strategy

In order to reduce the adverse effects and increase resilience, cultural heritage sites and activities must be modified as part of climate change adaptation. Important tactics include employing climate resilient materials in restoration projects, putting preventive measures like flood barriers and reinforced structures into place, and carrying out thorough risk assessments to detect weaknesses. Incorporating climate considerations into heritage management plans, training employees and communities, and developing and revising emergency response plans are also crucial. We can make sure that cultural heritage sites are better prepared to face the difficulties presented by climate change and survive for future generations by implementing these adaptation strategies.

Climate change adaptation strategies vary greatly depending on region and threat, and often several must be combined to address specific concerns. Adaptation interventions should be chosen properly considering the buildings' capacity to change due to its protection status under the law, the principle of preservation, and the need to apply effective mitigation actions.

The International Council on Monuments and Sites (ICOMOS) principles of preservation.

- Understand and respect CH and its significance;
- be cautious in designing interventions;
- respect authenticity and integrity;
- Propose reversible interventions to as much as possible keep intact existing original materials;
- prioritize preventive and effective care;
- prioritize minimum intervention: "do as much as necessary and as little as possible";
- propose compatible design solutions, i.e., use adequate materials, techniques, and detailing with regard to material and physical, chemical and mechanical interactions between the new and the existing;
- enhance the use of cultural assets and regularly programmed maintenance necessary to extend the service life of the CH;
- enhance multi-disciplinary action i.e., call upon skill and experience from a range of relevant disciplines (ICOMOS, 2004)

In addition there is another concept that is related to safeguarding of cultural heritage, antifragility, a concept that goes beyond resilience. 'antifragile territory' as a spatial context that does not merely withstand a shock, but improves because of it. In this perspective, the concept of antifragility goes beyond robustness. It refers to systems that not only withstand shocks but actually improve and become stronger as a result of them. The focus is on thriving and growing from stress and uncertainty. An antifragility cultural heritage site is one that not only recovers from a climate related event but also integrates new, stronger materials and techniques during restoration, thus becoming more resilient to future events. If fragility is the effect of a set of political, social and natural causes, then antifragility is also necessarily a political and social construct.

By integrating both resilience and antifragility into strategies for cultural heritage preservation, we can ensure that heritage sites not only survive but also evolve to become more robust in the face of climate change. This dual approach enhances their ability to withstand future challenges and continue to thrive for generations to come. Caring for fragile heritage involves several approaches to ensure its preservation and protection. Here are some key strategies:



Figure 11: key strategy to preservation of fragile cultural heritage

By implementing these approaches, we can make cultural heritage sites more antifragile, enabling them to not only withstand climate change impacts but also to grow stronger and more resilient in the process.

3.6. Conclusion

This chapter has explored the key risks and climate change indicators that affect cultural heritage, emphasizing both environmental hazards and human induced pressures. It identified critical physical threats flood, drought, water infiltration, erosion, and extreme weather as well as socio cultural vulnerabilities linked to governance, land use, and tourism pressures. These

interconnected risks reveal that cultural heritage is not only exposed to external environmental factors but is also shaped by internal resilience capacities.

The chapter concluded by emphasizing the necessity of ongoing risk monitoring and localized indicator based assessments as essential tools for managing and mitigating and adapting impacts. These insights establish the analytical foundation for the following chapter, which presents the case studies of heritage conservation in various international contexts and examines how resilience strategies can be adapted for the Bamiyan Valley.

Chapter 4: Case Study – Bamiyan Valley

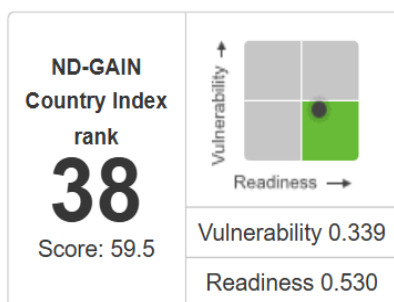
4.1. Introduction

This chapter draws insights from globally recognized heritage sites such as Olympia in Greece, Longmen in China, Petra in Jordan, Venice in Italy, and Vardzia in Georgia. This research identifies a range of successful conservation actions that respond to diverse environmental challenges. These international examples serve as reference points for evaluating the vulnerabilities and adaptive potential of Bamiyan. As a UNESCO World Heritage Site situated in a region with limited institutional support and a history of conflict, Bamiyan faces complex threats including rock weathering, drought, flash flood, water seepage, erosion, and human induced pressures. This chapter applies a structured approach, what the risk is and what actions are taken to enhance resilience in these sites, also recommending resilience based conservation strategies tailored to Bamiyan's unique context.

4.2. Archaeological site of Olympia

Location and climate: Western Peloponnese, Greece .Mediterranean Climate, Hot, dry summer and wet winter.

Heritage status: UNESCO World Heritage Site (since 1989)



The low vulnerability score and high readiness score of Greece places it in the lower right quadrant of the ND-Gain Matrix. Adaptation challenges still exist, but Greece is well positioned to adapt. Greece is the 19th most vulnerable country and the 48th most ready country.

The sanctuary of Olympia, in the North West of the Peloponnese, in the Regional Unit of Elis (Elis), has been established in the valley created by the confluence of the Alpheios and Kladeos rivers in a natural setting of beauty and serenity.(UNESCO, world heritage site)

The archaeological site of Olympia is characterized not only by its structures and monuments but also by a unique landscape that complements the main archaeological area and draws many visitors. The overall system can be affected by climatic drivers like heatwaves, droughts, fire weather, and changes in precipitation, as well as non-climatic factors such as population dynamics, land cover, geophysical characteristics, and fuels.



Figure12: Archaeological site of Olympia, Greece



Figure 13: Cultural heritage site of Olympia

The archaeological site of Olympia receives significantly more annual rainfall than the Greek average, nearly 40% more (906 mm vs. 649 mm). However, under the RCP 8.5 scenario, rainfall in the archaeological site decreases slightly but remains higher than the national average. Furthermore, the archaeological site has a higher drought indicator than the national average, indicating more severe drought conditions. In the future, the drought index is expected to decrease slightly, but it will remain higher than the national average. Historically lower

summer humidity is observed than the national average, while the trend continues in the future, with humidity slightly decreasing. Higher soil moisture levels than the national average is observed. However, in the future, both the archaeological site Olympia and Greece are expected to experience reduced soil moisture, with Olympia dropping to 708 kg/m²/s. Despite a slight future decrease in the drought index, the archaeological site of Olympia will continue to face significant drought risks, with reduced soil moisture, lower summer humidity and increased air temperature intensifying the region's vulnerability to drought, leading to vegetation withering and landscape degradation, and the risk of wildfires. (Mavrakou. T, 2024).Emerging risks driven by rising temperatures, shifting precipitation patterns and changes in land use.

	Climatic driver	Emergent risks	Action
Hazard	Heatwaves.....wildfire	Moderate to High	1. Afforestation of mountain area and Technological Innovations for Fire Prevention
	Fire weather	High, Increasing temperatures, drier conditions, and reduced soil moisture create a high risk of fires.	
	Drought.....erosion	Moderate, Although the drought index is slightly decreasing, Olympia archaeological site will continue to face drought risks due to declining soil moisture and reduced relative humidity in the summer.	2. Slop stabilization and erosion control: construction of retaining walls, vegetation management
	Increased precipitation,...flash flood	High	3. Enhance drainage and flood management: Enhancement of existing drainage infrastructure to cope with intense rainfall events.

Table 7: Action and Emerging climate change related risks for Olympia archaeological site

1. Afforestation of mountain area and Technological Innovations for Fire Prevention

Wildfires are a significant component of the environmental characteristics of the Mediterranean, as well as other ecosystems impacting and molding vegetation and landscapes over time. Presently, forest fires are occurring more frequently than before, particularly in the

Mediterranean region, leading to adverse effects on the environment and the destruction of properties, crops, infrastructure, and economic endeavors, often resulting in human casualties.

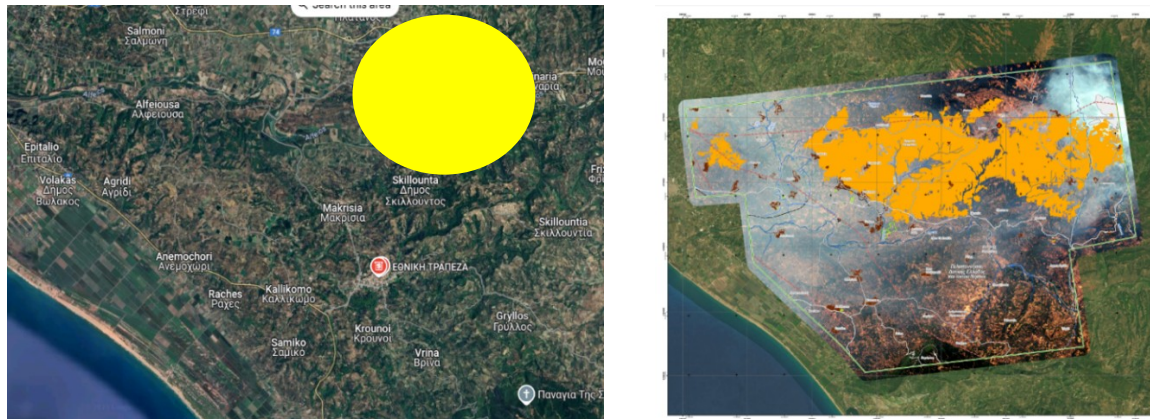


Figure14: Ancient Olympia - GREECE Wildfire - Situation as of 08/08/2021

The most significant wildfire affecting Ancient Olympia occurred in August 2021, burning approximately 130,000 acres and destroying around 450,000 olive trees, there have been ongoing concerns about wildfire risks in the region. As of April 21, 2025, no major wildfires have been reported near Ancient Olympia. However, the area remains vigilant due to the increasing frequency and intensity of wildfires across Greece, attributed to climate change.

- ✓ Olive Tree Restoration: The Arete Fund launched a crowdfunding campaign to purchase approximately 80,000–100,000 olive trees to replace those lost in the fires. The project includes uprooting burned trees, treating and fertilizing the soil, and planting new root stock, with an estimated cost of €750,000 to €900,000.
- ✓ Community Engagement: that 135000 olive trees plant by local farmers.it is important because the olive tree is such a symbol from ancient Greece. Symbol of peace and friendship throughout the millennia.

2. Slope stabilization and erosion control

Management of water retention in the wider region of Ancient Olympia, Elia, Peloponnese, specifically, the afforestation of mountainous regions. The measures encompass the temporary setup of structures made from locally sourced timber to enhance water retention, as well as strategic afforestation in mountainous regions to stabilize hill slopes, thereby reducing erosion and potentially improving water retention in these areas. The primary targets of the measures. Include controlling floods and reducing flood risk, while the secondary target is to conserve have been designed to reduce the hill slopes thus attenuate the surface runoff as well as the

sentiment volume. This measure enables the increase of soil moisture, water absorption, and infiltration. Additionally, it create suitable sites for natural regeneration or technical afforestation of the burned area.

The morphology, vegetation, climate and geology of the area are important to design like this project. Due to the morphology of the area (large slopes), surface runoff is increased, resulting in soil erosion and a heightened risk of landslides and flooding. In order to deal with this issue, geotextile had to be applied in most of the sloping and vulnerable areas. As a consequence of the fires, the vegetation has been removed and a hydrophobic layer has formed in the soil due to the combustion of organic matter. This layer heightens surface runoff and the risk of flooding. Flood events are often exacerbated by the local climate, which features annual precipitation exceeding 1,000 mm and frequent intense occurrences. It is a medium scale project as it involves the 4 hills around the Ancient Olympia. (NWRM project, 2014)



Figure 15: Kronios hill after the implementation of the measure, continuous Lines, Bourletslikas Athanasios, 2014

3. Enhance drainage and flood management

The Kladeos River flows through the city of Ancient Olympia (with a population of 835 inhabitants) and near the archaeological site of Ancient Olympia, which attracts over 500,000 visitors each year. The Kladeos River is a contributor of the Alpheios River. Both rivers are known for “providing” floods since ancient times (fourth century AD) and modern times. The archaeological site is located less than 50 m away, and almost 1.5 m higher than the Kladeos channel in its lower reaches.

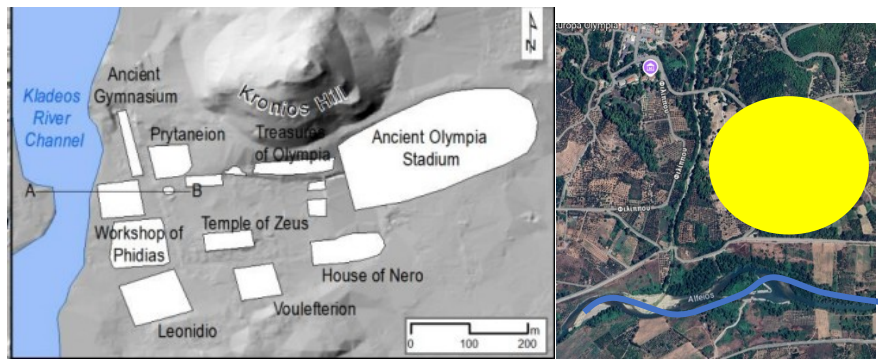


Figure 16: Left: Location of Kladeos river drainage basin I NW peloponnes, Right: Location of Alpheios river near the Olympia cultural heritage

- ✓ As report of UNESCO for protection of Olympia cultural heritage the dikes that have been constructed along the banks of Alpheios River, south of the sanctuary, protect the archaeological site effectively from the river's flooding phenomena.

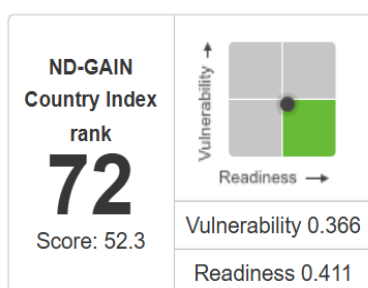


Figure 17: Alphiose Dam, Greece, source: Axis of katakolo, ancient Olympia R.W.G.

4.3. The ancient city of Petra

Location and climate: southern Jordan, Arid and semi-arid desert climate

Heritage status: UNESCO world heritage site (since 1985)



The low vulnerability score and high readiness score of Jordan places it in the lower right quadrant of the ND-Gain Matrix. Adaptation challenges still exist, but Jordan is well positioned to adapt. Jordan is the 132nd most vulnerable country and the 19th most ready country.

The ancient city of Petra situated between the Red Sea and the Dead Sea and among mountains filled with passages and gorges, and it is half constructed and half carved into the rock. During the Nabataean, Roman, and Byzantine periods, a clever water management system facilitated the extensive settlement of an area that was fundamentally arid. This archaeological site, located in a striking red sandstone landscape, is among the largest and wealthiest in the world. The sandstone carved historic buildings and the cultural landscape and the built structures (temples, roads, bathhouses, etc.). This includes the different historic layers including Nabatean, Roman, etc. (Abdalhaleem. H, 2024)



Figure 18: Archeological site of Petra, Jordan

Jordan is part of the Mediterranean Region, located approximately 80 km east of the Mediterranean Sea. The country's unique topographic nature is shaped by its position between 29°10'–33°45'N and 34°55'–39°20'E, resulting in a predominantly Mediterranean climate characterized by hot and dry summers and wet and cool winters.

Jordan is confronted with multiple climate hazards, including extreme temperatures, droughts, flash floods, storms, and landslides. Climate change will probably lead to an increase in the frequency and severity of these risks. Jordan has experienced three major flood events since the 1980s: in 1987, 1991, and most recently in 2018 (The World Bank Group, 2021). Flash floods are a significant danger to urban areas with high population density, such as Amman,

the historic site of Petra, and Aqaba. They threaten lives and lead to severe harm to infrastructure, farmland, and real estate. Landslides and erosion have especially focused on steep mountain slopes and wadis. The looming effects of climate change require extensive adaptation planning in various sectors, including agriculture, coastal regions, biodiversity, urban settings, society, water resources, and health.

	Climatic driver	Emergent risks	Action
Hazard	Flash Flood	Moderate to High Increased precipitation (rainfall) leading to flash flooding in and around the Petra Archaeological Park. These are exacerbated by drier weather making the soils less absorbent and more resistant to water.	1. Restoration of Nabataean water channels, cisterns, aqueducts, and dams. These systems collect, store, and direct rainfall, helping reduce flood damage and improve. Modern drainage systems and retention basins have been added along vulnerable paths like the Siq.
	Drought and water scarcity	moderate, Warmer weather leading to drought events, especially during the summer period. These events are exacerbated by less regular rainfall and the inability of drier soils to absorb moisture.	2. Stabilization of cliffs, particularly in high-risk zones; limited vegetation planting to reduce surface erosion.
	Winds/ storm....erosion	moderate, Wind and increased storminess including erratic weather conditions can cause sandstorms. These events are exacerbated by drier weather and drought events.	3. Application of consolidate and water repellent treatments on exposed sandstone surfaces. Limiting tourist access in fragile zones prone to wind erosion. Regular inspections and laser scanning or 3D documentation to track surface loss due to erosion.

Table 8: Action and emerging climate change related risks for Ancient City of Petra, Jordan

1. Flash flood action in Petra: Petra is situated at an average elevation of approximately 820-850 meters above sea level, while the eastern slopes of Jabal As Sharah rise to about 1400 meters. Consequently, the location is rather susceptible to seasonal flash floods. Another aspect that requires consideration is goat herding, which may be causing a loss of

the vegetation cover if not properly managed. The result is that the soil becomes loosened, desertification begins, and the occurrence of flash floods becomes more probable. Flash floods can have severe consequences. Besides the risk to life and property, they contribute to soil loss that worsens desertification, transport sediments down slopes leading to pollution, may trigger landslides, and pose significant dangers regarding erosion and weathering of the monuments (Talal S. Akasheh, 2018).

The Nabataeans were experts at surviving in the desert because they knew how to collect and distribute water. An impressive system of rock cut channels and underground water pipes carried water from permanent springs and seasonal streams. The Nabataeans also developed a way to collect and store water in watertight holes or cisterns. Hidden underground, these cisterns kept water safe from both evaporation and enemies.

A team of specialists in water harvesting and geology chose to apply the ancient flood control techniques of the Nabataeans in Wadi Madras, Petra. They hope to mitigate the severe flash floods that erode sandstone monuments and threaten the lives of residents and tourists by reconstructing the old system. The first aim of revival of ancient terrace project is to collect hydrological data by using rainfall simulation experiments, stream gauges, weather stations and infiltrometers.



Figure 19: *Photos showing traditional Nabatean water management strategies.*

Clockwise from top right: Renovated terrace above the WH site, water cistern at Little Petra, water channel and renovated dam in the Siq, Petra (Photos: Taher Falahat 2023 and Will Megarry 2023).



Figure 20: Reconstruction of dam (left : before)(right :after)

2. Drought and water scarcity:

Jordan is the second most water scarce country in the world, with an annual per capita water availability below 100m^3 (and countries are placed in the category of ‘absolute water scarcity’ when the annual per capita water availability drops below 500m^3) (the water diplomat,2024) In the limit of its desert ecosystem, the wheat and fruit orchards that remain will be further stressed by drought as temperatures steadily rise and heatwaves get more frequent. Sandstorms, too, are expected to increase in size, frequency, and severity, potentially eating away at the sandstone facades of Petra’s tombs and temples.

For stabilization of petra to prevent erosion there is ongoing project like the UNESCO Siq stability project The laser scanning survey of Petra is part of the Siq Stability project, which is a "Funds In Trust" project of the Italian Ministry of Foreign Affairs for UNESCO. It is managed by the UNESCO Amman Office and has as main partners Italian geological experts from ISPRA.

3. Wind, storm caused erosion,

In Petra, Jordan, the safeguarding of sandstone monuments is crucial because the material is susceptible to environmental influences like wind, water erosion, and salt crystallization. In order to tackle these challenges, conservation initiatives have included the use of consolidates and water repellent treatments designed to improve the longevity of exposed sandstone surface.

In support of the Government of Jordan’s Response Plan for the Syria Crisis, the UNESCO Amman office, with generous funding from the Government of Italy, is implementing the project.



Figure 21: Stabilization of rock in Petra site by UNESCO

The project will work to mitigate landslide risks in the 'Siq', ensuring the improved management and conservation of cultural heritage. Training will be delivered in the areas of safety and security; geology; engineering geology as it applies to cultural heritage; and site conservation and maintenance activities in select areas of the site.(Unesco.2023)

Many rupestrian sites have been carved into soft rock, generally with $UCS < MPa2$, in vertical cliffs and show major conservation issues in the domain of rock slope stability and rock weathering. The low strength range of rock might be influenced by physical characteristics, such as size, saturation degree, weathering and mineral content. Finally, the investigations generally show that the strength reduces significantly with saturation. The subsequent serves as a confirmation, illustrating the link between UCS and porosity at several rupestrian sites mentioned in this article. The association between a low UCS value and high porosity is particularly clear in volcanic materials (Lalibela and Vardzia).

In contrast, the continental/sedimentary geological the formations of Bamiyan and Petra display significant vertical heterogeneity, thus the values reported here are merely rough estimates. (Margottini.C,Spezzichino.d,2016)

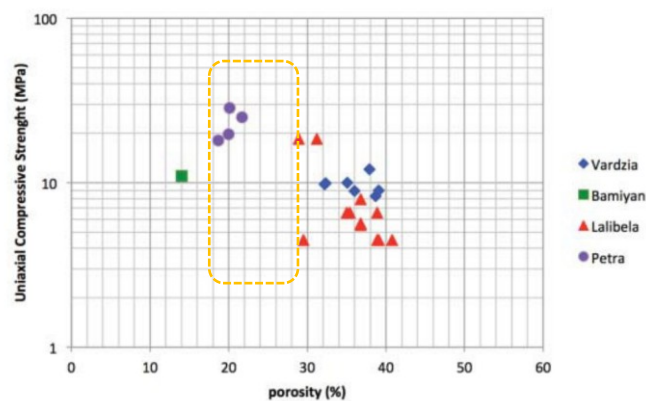


Figure 22: The relationship between Uniaxial Compressive Strength and porosity

Visitor management

PDTRA has completed the Tourism Development Master Plan for 2023–2033, which is in line with its long term vision and establishes a strategic framework to reconcile visitor growth with the preservation of Petra's cultural and natural heritage. In the plan, sustainable practices in visitor management are emphasized, improvement of infrastructure and integration of the community, guaranteeing that tourism bolsters the region's socio economic resilience while maintaining the site's integrity.

Crucial measures have been implemented to enhance the visitor experience and mitigate the effects of mass tourism. To broaden the range of tourist activities, PDTRA has implemented various initiatives, such as pinpointing and designating secondary paths for future use. These paths will be opened step by step over the next two years, along with the creation of new attractions like the Nabatean Cultural Village. The goal of these endeavors is to spread out visitor traffic to lesser known areas, reducing congestion on the main trail and limiting damage to Petra's famous landmarks.

PDTRA's strategy has also concentrated on improved mobility solutions. Shuttle services have been introduced to link visitors with major attractions, and there are plans to implement a fleet of electric buses to enhance on site transportation and minimize environmental impact. The combination of these initiatives with a proposed e-ticketing system and crowd management strategies guarantees a high quality sustainable tourism model that maintains Petra's legacy and meets the needs of contemporary travelers (Kingdom.H, 2023).

Social and Economic vulnerabilities

Climate impacts do not occur in isolation. They can be exacerbated by social and economic vulnerabilities, which can include past maladaptation. While considerable efforts have been made to boost the adaptive capacity of the site and community, some factors continue to exacerbate climate risk.

- Over tourism raises the amount of people present at the world heritage site. This affects the monuments and raises the danger to life from flash floods triggered by heightened rainfall.
- Camping and picnicking also heighten the risk to the archaeological site and the surrounding landscape.
- The growing number of tourists in Wadi Rum puts additional strain on water resources that are already stretched thin, heightening the potential effects of drought.

- The effects of inadequate planning and infrastructure on draining and traditional irrigation systems have been significant, with insufficient maintenance resulting in reduced water levels in conventional wells. This worsened the effect of drought on farming.
- Overgrazing of limited foliage has increased the risk from sandblasting and erosion caused by increased storminess.

Contemporary Adaptations

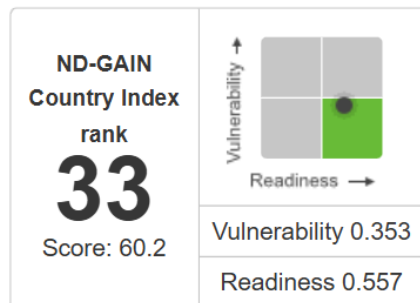
- The integration of traditional knowledge and technologies. Also collaborative efforts with state agencies such as the Civil Defense Directorate and the Crisis and Risk Management Center have facilitated comprehensive training programs.
- The construction of a wadi mousa reuse treatment water plant was a major undertaking to address water pressures due to tourism, easing water pressure on the community and reducing the impact on agriculture. There have been substantial hard adaptation projects to help channel water through the archaeological site and away from congestion points.
- Barriers have been placed in strategic locations to prevent water inundation.
- Cleaning and maintenance activities for water cisterns, dams, and water canals distributed throughout the archaeological site.

The planting of native vegetation not only aids in soil conservation but also helps mitigate the impacts of climate change, such as soil erosion and water runoff. By retaining more water, instances of flash flooding are greatly reduced. These efforts are an effective adaptation measure to reduce impacts from all three key hazards increased precipitation, drought, and increased storminess and wind erosion.

4.4. Longmen Grottoes

Location and climate: south of Luoyang City, china. Temperate continental climate

Heritage status: UNESCO world heritage



The low vulnerability score and high readiness score of china places it in the lower right quadrant of the ND-Gain Matrix. Adaptation challenges still exist, but china is well positioned to adapt. China is the 14th most vulnerable country and 38th most ready country.

The grottoes and niches of Longmen contain the largest and most impressive collection of Chinese art of the late Northern Wei and Tang Dynasties. The Longmen Grottoes, situated on either side of the Yi River south of Luoyang's ancient capital in Henan province, consist of over 2,300 caves and niches that have been carved into steep limestone cliffs along a distance of 1km. They house nearly 110,000 stone statues of Buddha, over 60 stupas, and 2,800 inscriptions on steles.

In Chongqing, humidity poses the greatest threat to the grottoes. As extreme weather becomes more frequent, the incidence of floods and increased rainfall will raise the humidity levels in the vicinity of the grottoes. This humid air interacts with the dense sandstone of the grottoes, resulting in acid formation on the statues, which corrodes them and leads to irreversible damage.

Currently, specialists informed the Global Times that they have suggested several technology based solutions: a real time monitoring system, 3D laser scanning, and a developing air curtain.



Figure 23: Longmen Grottoes cultural heritage site, china

Hazard	Climatic driver	Emergent risks	Action
	Water Seepage and Erosion	High The grottoes are susceptible to water infiltration, leading to erosion of the limestone structures. This issue has been exacerbated by increased rainfall and extreme weather events, which accelerate the deterioration of the carvings.	1. Restoration of Temple using waterproof materials and sealing techniques Drainage system upgrades to divert rainwater away from caves. Use of ground penetrating radar to detect water paths and internal weaknesses. Installation of stone consolidation materials to strengthen weakened limestone.
	Humidity-Induced Degradation	Moderate Elevated humidity promotes biological colonization, which can lead to surface degradation.	2. Environmental monitoring systems to track humidity. Cleaning and removal of moss, algae, and lichen using safe, non-invasive methods Creation of microclimate control zones using barriers and shading. Research into biological growth control treatments.
	Extreme Weather Events	High Sudden heavy rain events cause flash flooding and structural instability.	3. Temporary site closure during extreme weather events. Installation of early warning systems for flooding. Rerouting tourist access paths away from water-sensitive areas.
	Acid rain and air pollution	Moderate Acidic pollutants chemically degrade limestone over time.	4. Development of “air curtains” to block and filter pollutants (in collaboration with Tsinghua University). Government led pollution control in nearby industrial zones. Monitoring of pH levels and surface corrosion on statues. Periodic washing of carvings to remove pollutants.

Table 9: Action and emerging climate change related risks for Longmen Grottoes

1. Action against water seepage and erosion

Of all environmental geological factors, water permeability has the greatest effect on grottoes. The primary cause of cave destruction is the ongoing and repeated occurrence of water seepage. In the initial efforts to prevent seepage at the Longmen Grottoes, epoxy resin and superfine cement were primarily used as grouting materials. Superfine cement is prone to efflorescence. The epoxy resin material is characterized by significant shrinkage and inadequate durability.

- ✓ The non-permeable materials were transported. The results indicated that the modified epoxy resin exhibited greater strength, reduced shrinkage, and lower volatility compared to the waterborne epoxy resin.

There are special protection objects, cultural relics are protected by the following principles:

- (1) Protective treatment of cultural relics can only be carried out when necessary.
- (2) Do not change the original appearance of cultural relics to maintain the beauty of the stone surface.
- (3) In terms of protection, it also gives consideration to validity and durability.
- (4) The protective material is reversible for future reprocessing.
- (5) In accordance with the ecological requirements, the construction conditions and the influence on the surrounding environment must be taken into consideration while selecting the protective materials. (Sun. B, Fang, U.2018)

- ✓ In December 2021, a significant restoration project commenced at Fengxian Temple, the largest cave within the Longmen Grottoes complex. This initiative aimed to address issues of water seepage and reinforce unstable rock formations. Advanced technologies, including ground penetrating radar detection and the installation of protective nets, were employed to ensure the structural integrity of the site. By April 2022, approximately 70% of the restoration work had been completed, with the project expected to conclude by June of that year (Beijing review, 2025).

✓ GPR for Void Detection

When detecting underground voids, such as storm water tanks or septic tanks, GPR is particularly effective at identifying empty spaces beneath the surface. These voids are typically identified by the distinct radar reflections they produce, allowing the survey team to pinpoint their location and size. This data is crucial for planning excavation and

construction activities, ensuring that no unexpected voids compromise the stability of the site.

✓ CFRP in Longmen for Beam reinforcement project

In the reinforcement project of the cantilever beam of the plank way, numerous factors should be taken into account. In light of the qualities of the tourist area, numerous reinforcement schemes are proposed. Finally, the approach utilizing CFRP sheets is chosen in order to strengthen the cantilever beam of the plank way. The reinforcement effect demonstrates that the approach using CFRP material results in only a slight increase in the weight of structural members. The reinforced member looks harmonious with its surroundings. (Gao. X, Lio. X, 2011)



Figure 24: CFRP strips wrapped on the beam, Longmen site

✓ Biomimetic Technology

The Longmen Grottoes have suffered considerable damage due to natural weathering processes. The stone materials are corroding, which puts Longmen's continued preservation in jeopardy. In particular, the process of their aging has been hastened by air pollution and acid rain over the last several decades, leading to an increased focus on their conservation.

Researchers have explored the application of biomimetic calcium oxalate films as a protective measure for the limestone surfaces of the Longmen Grottoes. These films are synthesized through chemical reactions that mimic natural processes, resulting in a protective layer that can enhance the stone's resistance to environmental degradation. (Q. Liu, B. Zhang, G. Yang, 2010)



Figure 25: Sculptures damaged by natural weathering processes, Longmen Grottoes



Figure 26: Field test site. Longmen Grottoes

3. Extreme weather, flash flood

The Longmen Grottoes, located along the Yi River near Luoyang in Henan Province, China, specific details about dike construction directly adjacent to the Longmen Grottoes are limited, broader regional flood control measures have been implemented to protect cultural heritage sites like the Longmen Grottoes. In the broader context of the Yellow River basin, which includes the Yi River, various flood control strategies have been employed. Levee Protection Works is Structures such as spur dikes have been constructed in regions like Henan Province to reinforce riverbanks and prevent erosion. These structures help in directing the flow of water and reducing the risk of flooding in adjacent areas.

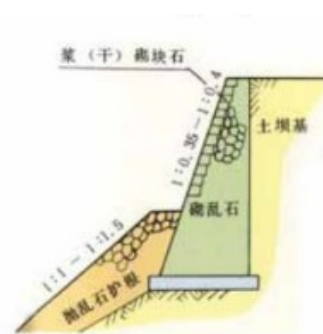


Figure 27: Levee protection works, stone masonry spur dike

4. Acid rain and air pollution

Humidity is big threat for Longmen Grottoes. When humid air meets the dense sandstone material of the Grottoes, acid form on the statues, corroding the statues and causing irreversible damage. Experts have proposed some solutions based on technology: a real time monitoring system, 3D laser scanning and an air curtain that is being developed. This system create a

controlled stream of air, forming an invisible barrier to separate and protect sensitive environments from external contaminants. In the context of cultural heritage conservation, these systems aim to:

- Block airborne pollutants such as dust, acidic particles, and industrial emissions that can erode stone surfaces.
- Regulate humidity and temperature, mitigating the effects of moisture and thermal fluctuations that contribute to stone decay.
- Prevent the ingress of insects and microorganisms that may cause biological degradation.

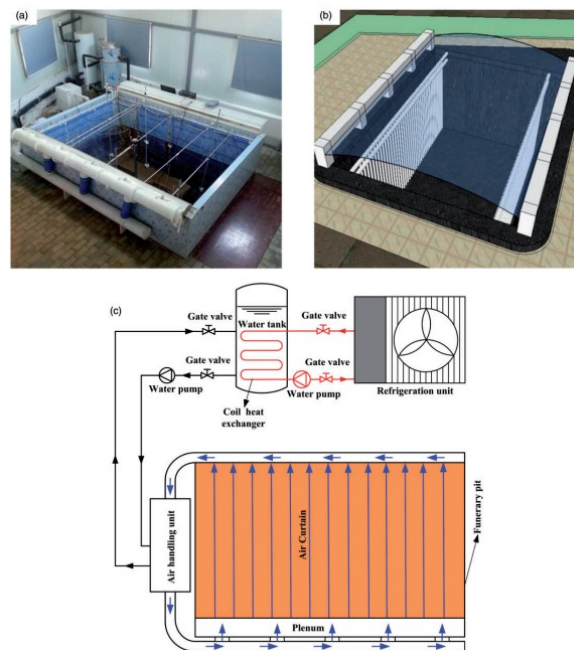


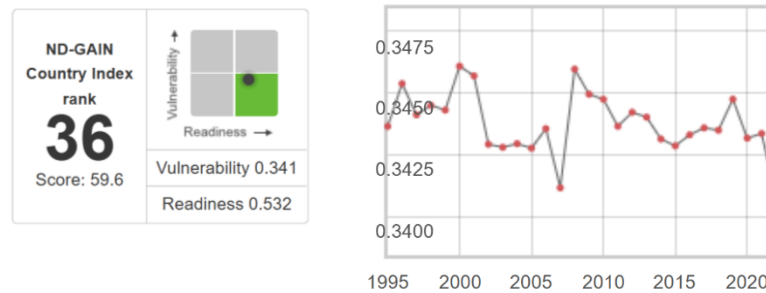
Figure 28: The diagram of the experimental pit with the air curtain system

4.5.Venice cultural heritage site

Location and climate: Italy, Humid Subtropical

Heritage status: UNESCO world heritage since 1981.

Venice is an iconic cultural heritage site that embodies both the challenges and opportunities associated with protecting heritage in the face of climate change. Its unique geographical, historical, and cultural characteristics make it an exemplary case for studying resilience, and its struggles with climate related threats, such as sea level rise and flooding, provide valuable insights into the broader issues facing cultural heritage worldwide. According to main aim of studies investigation of Venice from different aspects is relevant.



The low vulnerability score and high readiness score of Italy places it in the lower right quadrant of the ND-GAIN Matrix. Adaptation challenges still exist, but Italy is well positioned to adapt. Italy is the 157th most vulnerable country and the 46th most ready country.

The UNESCO world heritage site of the Venice lagoon is located in the north Adriatic Sea (Italy), covering an area of approximately 550 km². About 255,000 people live in the city boundary lagoon and 50,000 in the historical city of Venice (data from the City of Venice 2021). Around 30 million tourists visit Venice every year putting intense pressure on infrastructures and services (City of Venice 2021).

Venice is the perfect outdoor testing ground and laboratory to expand our understanding of rising damp in structures with shifting climates and tidal flooding circumstances. This information serves as the foundation for a conversation about the impact of interventions and the future management of coastal cities that are at risk from sea level rise (Falchi.L, 2024)

The second worst flood in the city's history occurred in November 2019, and four more extraordinary tides occurred in six weeks. Concerns over the increasing effects of climate change on this vulnerable metropolis have been raised by these regular and severe flooding disasters.

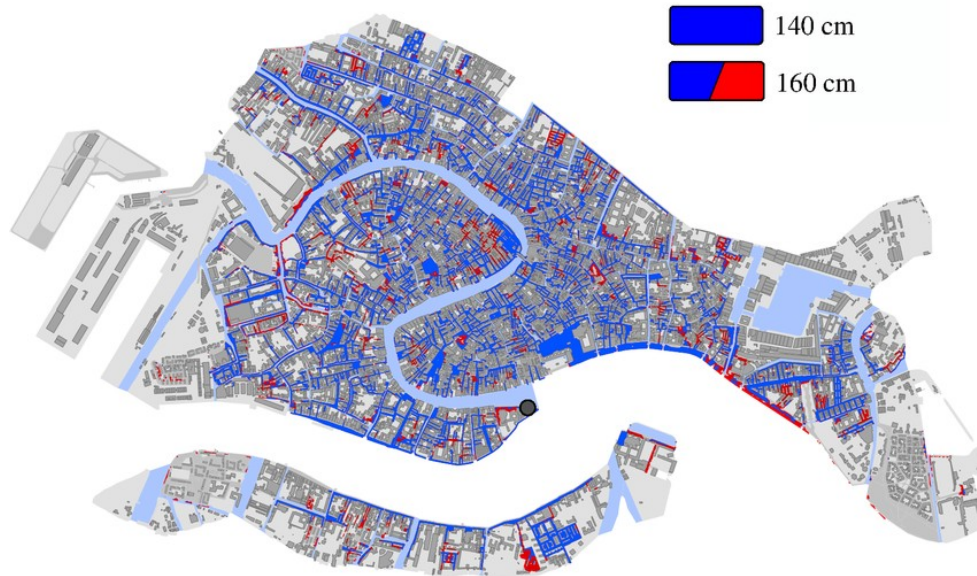


figure29: Flooding map of the city of Venice according to the predicted sea level height at Punta della Salute (black dot).

The colors represent the flooded pedestrian area for sea levels of 140 cm (blue; MEAN scenario) and 160 cm (blue and red; MAX scenarios). Light blue indicates the canals. (Source: F. Christian et al, 2019)

Due to the low land level, caused by high tides has been part of the city's daily life centuries. The analysis of the altimetry level and high tides show that: at the tide of +110 cm about 12 %of the historic city of Venice is flooded, while tides above +140 cm cause flooding of about 59%of the city. (G. Umgiesser, 2020)

Records show that the frequency of high tide events is increasing (60 occasions above 110 cm were recorded between 1960 and 1980, 70 between 1980 and 2000, and 163 between 2000 and 2020). Various attempts have been undertaken to project future scenarios of average sea level rises in the Venice Lagoon (D. Zanchettin, et al, 2021).

In the lowest areas of Venice, small barriers are placed at the door entrance, and pumps are turned on to remove the water from the ground floors Buildings, electricity, and subsurface supplies may sustain direct damage as a result of salty and unclean water coming into contact with them. Also MOSE is made up of 78 floodgates that are hinged and moored at the bottom of the three inlets that divide the Adriatic Sea from the Venetian Lagoon. Without the addition of incoming water from the sea caused by winds and tides, the lagoon turns into a closed system similar to a lake whenever the gates of MOSE at the three lagoon inlets are closed. Depending on the corresponding weather forecast, the ZMPS predicts a tide height of 110–130 cm that triggers the closing of MOSE. Since most of the pavements in the historic city have been lifted

to this topographic level, this threshold was selected. As a result, a sizable section of the city is not inundated, and direct water damage and the resulting economic losses are decreased.

Impact	Description	Consequence
Sea Level Rise	Rising global sea levels due to melting ice caps and thermal expansion of seawater.	Increased frequency and severity of flooding (acqua alta).
High Water	Seasonal high tides exacerbated by sea level rise and subsidence.	Damage to historic buildings, infrastructure, and cultural heritage sites.
Subsidence	Natural sinking of Venice combined with human activities like groundwater extraction.	Amplifies the effects of sea level rise, making the city more prone to flooding.
Erosion	Increased wave action and storm surges due to rising sea levels.	Loss of coastal land, damage to the lagoon ecosystem, and weakening of foundations.
Saltwater Intrusion	Infiltration of saltwater into freshwater aquifers and soil.	Contamination of drinking water, damage to agriculture, and degradation of ecosystems.
Extreme Weather Events	More frequent and intense storms, heavy rainfall, and heatwaves.	Increased flooding, infrastructure damage, and health risks to residents.
Biodiversity Loss	Changes in temperature and salinity affecting the lagoon ecosystem.	Decline in native species, disruption of food chains, and loss of biodiversity.
Tourism Impact	Damage to historic sites and infrastructure due to flooding and erosion.	Economic losses, reduced tourist numbers, and increased maintenance costs.

Table 10: Significant climate change impacts on Venice

Resilience factors in Venice

An interdisciplinary approach is necessary in the case of Venice, integrating knowledge from the social sciences, urban planning, climate research, and historical conservation. As of 2024, a mix of natural, infrastructural, socio-economic, and governmental factors influence Venice's ability to withstand the effects of climate change. These elements are essential for assisting the

city in adjusting to flooding, sea level rise, and other climate related issues. Based on data and advancements through 2024, the following are Venice's primary resilience factors:

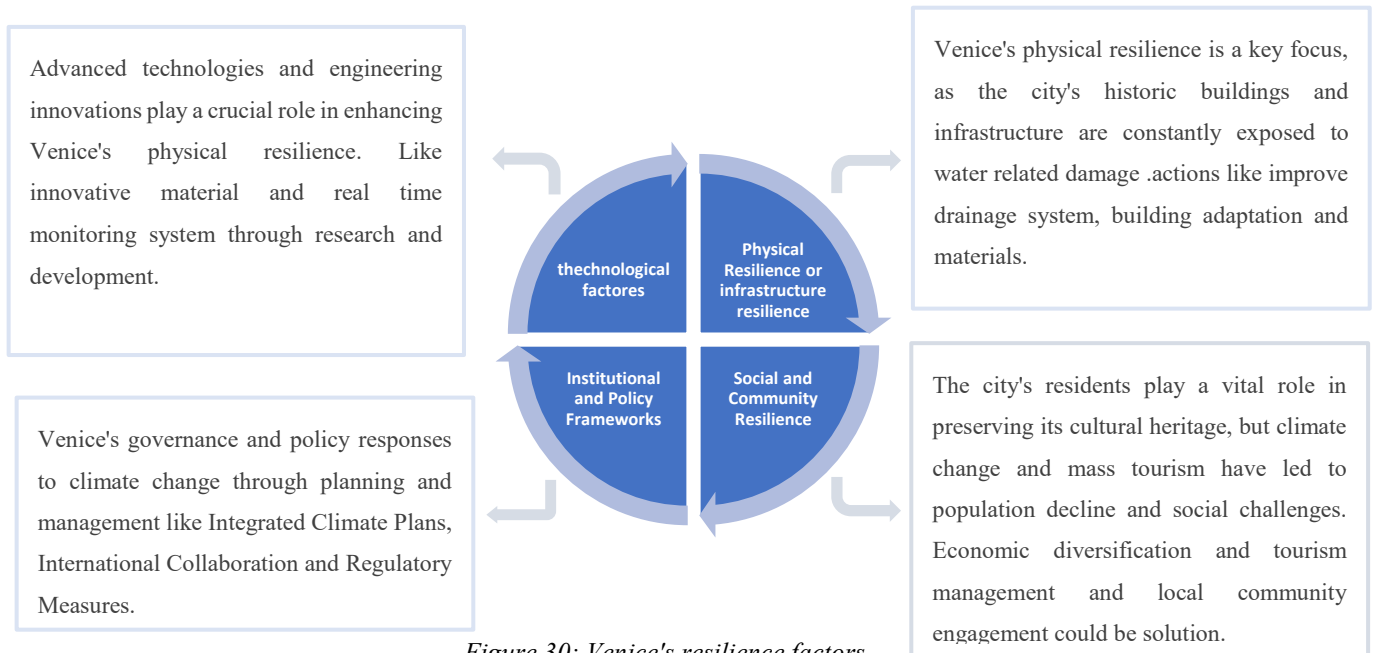


Figure 30: Venice's resilience factors

Adaptation strategies in Venice

Venice's vulnerability to flooding and high tides requires quick response and cooperation from all stakeholders. To secure this famous city's long-term survival, climate resilience and sustainable development strategies must be given top priority.

Venice can reduce the risks of floods, adapt to the challenges presented by climate change, and preserve its cultural legacy by taking proactive steps. Given the gravity of the issue, everyone is obligated to protect Venice's natural beauty and historical value for future generations (A. Bakker et al. 2017).

In addition the stockholders determined the action plan for addressing SLR in Venice in 3 levels, short-term (within 1 year), medium-term (within 1 to 3 years) and long term (within 3 to 5 years).

More coordinated emergency response procedures		
Training of residents on emergency procedures	Actions that need to be taken both while the flood alarms sound and after the flooding incident has ended should be included in the training. During the workshop, this latter was found to be a gap.	Short-term
Targeted emergency awareness-raising for tourists	Actions that need to be taken both while the flood alarms sound and after the flooding incident has ended should be included in the training.	Short-term
Strategy for the management of alarm systems	There are various alarms that sound in the City of Venice depending on the intensity of the predicted flooding event.	Medium-term
Greater awareness-raising		
Provision of educational and awareness-raising activities at Schools and public.	School children are a key target audience for the awareness raising activities. Awareness should be raised on the issue of climate change (its causes, impacts and how to mitigate it) as well as specifically on the topic of SLR.	Short-term
Improve scientific communication to all stakeholders.	This involves the communication of scientific data and information in a way that is comprehensible by the various target audiences, including the public, media, and decision-makers.	Short-term
Protection of vulnerable areas and infrastructure		
Mapping of vulnerable areas	Mapping of areas that are currently vulnerable to erosion, storm surges, SLR and those that will likely become vulnerable in the future, to design a prioritized plan of action for the protection of these areas.	Short-term

Maintenance and reinforcement of natural protection systems	Natural systems, including sand dunes, salt marshes, and littorals, protect coastal areas from flooding and erosion. These natural systems should be maintained, and where necessary, reinforced to ensure they remain functional.	Short-term
Identification and implementation of new nature-based solutions	Additional nature-based solutions should be implemented on vulnerable coastal areas to enhance the protection offered to them.	Medium-term
Protection of vulnerable areas and infrastructure		
Ensure that urban buildings are resilient and protected	This relates to ensuring that buildings, including schools and businesses, remain safe and functional. This could be done through a series of measures that are implemented in Venice, including flood protection measures, water pumping, sacrificing the ground floor, etc.	medium-term
Maintain city infrastructure	This includes the proper maintenance of the canals through dredging and the continued raising of pedestrian areas to make the city more resilient to high tide events.	medium-term
Identification and implementation of best practices to address the issue of water shortages	One significant issue that Venice must confront is the scarcity of water. This action focuses on identifying and implementing best practices to deal with this problem. These initiatives could include everything from technical research on water recirculation to educating people about water conservation.	
Quicker and more flexible management of MoSE (Experimental electromechanical module)		
Better definition of the governance of the MoSE through improvement in the communication between interested parties.	It should be made clear what each body responsible for managing and implementing the MoSE is expected to do. Better communication amongst the interested parties should accomplish this.	Short-term

Improvement of the deployment procedures and Continuous monitoring and reporting.	The MoSE and its operation (together with all relevant aspects of it, including cost) should be closely monitored and this information should be shared with interested parties.	long term
Build climate change resilience		
Define a clear strategic direction with regard to climate change	This should be a direct result of Venice's Climate Adaptation Strategy and should stem from multi-sectoral collaboration.	Short-term
Increase resources and capacities in relevant research and data centers	Data and research facilities are giving Venice useful information. It's critical to make sure these centers have the tools and capabilities necessary to efficiently communicate accurate and pertinent data to decision makers, the general public, the media, and other pertinent stakeholders.	Medium term
Greater international networking and transfer of best practices	This entails keeping an eye on global developments, particularly those pertaining to creative adaptation and mitigation strategies, and modifying and bringing them to Venice.	Medium term

Table 11: Action plan for addressing SLR in Venice, as developed by the engaged stakeholders

In addition Stakeholders in Venice also recognized the necessity of protecting the lagoon's weak be very successful, these include improving the native sand dune vegetation and restoring salt marshes. Stakeholders thought that the application of nature based solutions, which can lessen the effects of storm surges and SLR along the coastal zone, could help with this. In order to make the city more resilient to high tide events, stakeholders also pushed for the preservation of canals and pedestrian zones, as well as the protection of civic infrastructure that is susceptible to damage. (M.Anzidei et al, 2023)

In order to preserve Venice's uniqueness and livability, community driven projects like regional conservation initiatives and cultural preservation are essential. Restoring salt marshes and wetlands are examples of natural solutions that reduce floods by stabilizing the lagoon ecology and absorbing surplus water. Modern technology, such as the MOSE flood barrier system, demonstrates human ingenuity in defending the city against harsh weather events and increasing floods.

The MOSE system (Modulo Sperimentale Elettromeccanico), which the city has been operating since October 2020, serves as an exemplary model of how the city supports urban resilience against frequent natural hazards such as floods, using innovative technology to integrate early warning systems. With their extensive experience in protecting cultural heritage and adapting to climate change.



Figure 31: Mose flood barrier/ <https://www.dutchwatersector.com/news/strukton-awarded-contract-to-immersed-caissons-for-venice-storm-surge-barrier>

The storm surge barrier system is made up of movable barriers being constructed at the three entrances to the lagoon, near Lido, Malamocco and Chioggia. The barriers will only be closed in the case of extremely high water.

In addition, Venice and surrounding lagoons have explored and implemented projects involving salt marshes and other nature-based solutions (NBS). These initiatives aim to restore the lagoon's natural ecosystems to mitigate flooding, reduce erosion and enhance long-term resilience.

One of the projects that restore salt marshes and mudflats using low-impact techniques. The Project of Life VIMINE aims to showcase the efficacy of a unified strategy for safeguarding the lagoon of Venice's most inland salt marshes from erosion specifically, those marshes that lie away from the main waterways and regions affected by powerful waves and currents.



Figure 32: Soil-bioengineering techniques against erosion, (source: brief of LIFE VIMINE , Venice integrated management of intertidal environments)

But these efforts are insufficient on their own. Addressing the persistent dangers posed by climate change requires consistent investment in adaptation strategies, such as modernizing infrastructure and creating creative solutions. International efforts to curb global warming and cut greenhouse gas emissions are equally crucial because Venice's future is closely tied to the state of the ecosystem on Earth. Venice is a potent representation of human ingenuity and weakness as of 2024. It emphasizes the resilience needed to adjust to an unpredictable future while serving as a reminder of the pressing need for coordinated action to prevent climate change.

A broad strategy is necessary for the next steps. The first step is to put into effect sustainable tourism principles, which include restricting the number of visitors, promoting travel during off-seasons, and urging tourists to behave responsibly. Second, it is crucial to continue investing in adaptive infrastructure, such as strengthening the MOSE system and investigating natural alternatives like reclaiming salt marshes to absorb floodwaters. Third, as Venice's destiny is linked to the planet's overall health, international actions to address climate change must be given top priority. Lastly, it's critical to empower the local people; in order to guarantee that the city stays a lively, livable place rather than a museum, Venetians must be at the center of decision-making. Venice can remain a resilient and culturally significant city by integrating innovation, sustainability, and community involvement.

4.6. Vardzia- Khertvisi

Location and climate: Georgia, continental climate

Heritage status: Vardzia- Khertvisi remains on the Tentative List and has not yet been inscribed as a UNESCO World Heritage Site.

Vardzia, a rock-cut city, is a cave monastery located in the southwestern part of Georgia. It was carved out from the Erusheti mountain slopes on the Mtkvari River's left bank. The primary construction phase occurred in the latter half of the 12th century. The caves extend along the cliff for around eight hundred meters and as much as fifty meters within the rocky wall with 130 m high. The monastery comprises over six hundred concealed rooms across thirteen floors, enabling the protection of the monastery from Mongol domination.

This site represents one of the most remarkable and important touristic CH sites in Georgia, strongly connecting its peculiar architectural features with an outstanding landscape and geological environment.

Due to its complex geo-lithological, geo-structural, morphological setting and the active tectonics of the area, the site has been historically affected by several types of slope instability phenomena, as well as processes of deterioration of the tuff rocks.

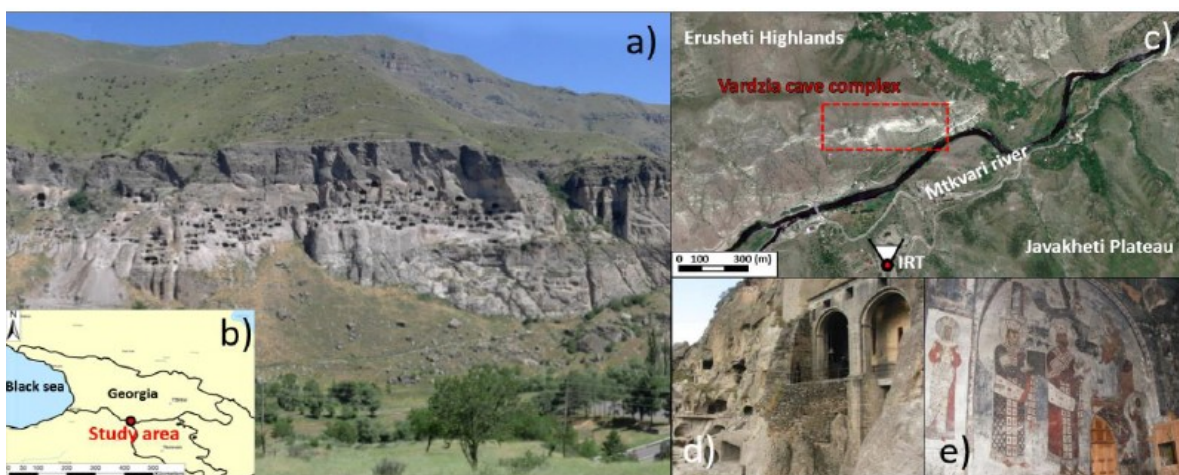


Figure33: the rock –cut city of vardzia, (a)geographic location of the study area. (b)the Mtkvari river vally and the Vardzia complex location, including InfraRed thermography camera installation point (c),the monastery complex: arched structures (d)frescoed chapels (e)

Water runoff at the upper and lower sections of the slope, along with continuous weathering and degradation, affects the rock cliff.

In figure 34 In central section it is possible to observe the effect of the water diverting structures, constituted by a runnel retaining wall system (red line).

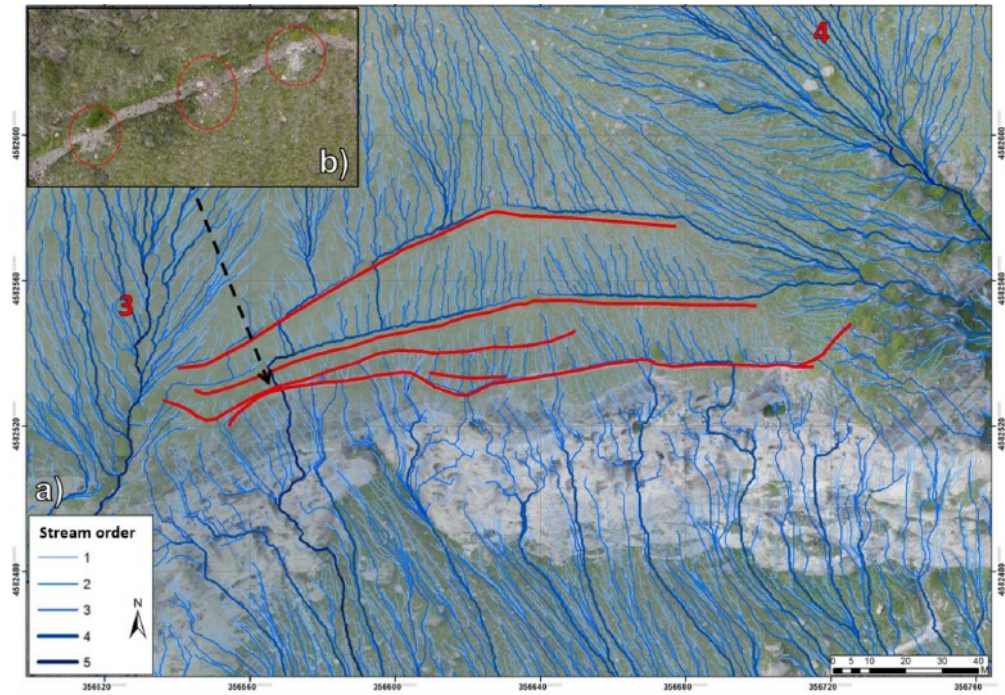


Figure 34: UAV-DP products: a) 2D orthoprojection of Vardzia's hydrographic network on the Upper slope sector and cliff face, b) detail of runnel- retaining wall sector impacted by boulders.

Hazard	Climatic driver	Emergent risks	Action
	Freeze-thaw damage	High Water enters cracks in the rock during warmer seasons, freezes during cold winters, and expands, causing the rock to crack and spall over time.	Installation of environmental monitoring systems (temperature, humidity sensors). Micro drainage systems around key structures to reduce water infiltration. Use of compatible repair mortars and rock reinforcements.
	Intense Rainfall & Flooding	High Increased water runoff causes erosion of pathways, instability of slopes, and interior water damage in cave churches and tunnels.	Construction of rainwater diversion channels and retaining walls. Reinforcement of eroded slopes and foundations. Improved site drainage planning to avoid water accumulation inside caves.
	Landslides & Rock falls	High Steep terrain and weakening rock faces make the site prone to landslides, which can destroy or block access to key heritage areas.	Rock bolting and netting systems installed in unstable cliff sections. Topographical and LiDAR scanning to detect movement or new fractures. Restricted access to at-risk areas for visitor safety and site protection.
	High Temperature & Drought	Moderate, high Accelerates dry cracking and salt crystallization in rock pores, especially on frescoed surfaces; contributes to vegetation loss, which increases erosion.	Regular cleaning and salt removal using dry conservation techniques. Monitoring of microclimates in sensitive interior areas (e.g., churches). Use of non-invasive shade or climate buffering systems at vulnerable entrances.

Table 12: Significant climate change impacts on Vardzia

4.7. Afghanistan, Bamiyan Case study

Afghanistan is the landlocked nation at the juncture of the central, west, and south Asian regions with a diversified population of over 41 million, has seen significant political unrest recently. Sanctions and other restrictions have also been implemented, endangering years of progress. Mountains constitute about 63% of the country, featuring the Hindu Kush glacier in the north and deserts in the southwest.

Precipitation varies throughout the country, typically being minimal and highly variable, and in some areas, it is confined to just a few days during the rainy season. Rainstorms can generate all the rain a month usually holds within just a few hours, often causing flash floods, erosion, and landslides. The IPCC's 2022 report indicates that increasing temperatures raise the likelihood of heatwaves throughout Asia, droughts in the arid and semi-arid areas of West, Central, and South Asia, floods in monsoon regions, and accelerated glacial melting in the Hindu Kush Himalayan (HKH) region.(Shaw,R;Leo,Y.2022)

Afghanistan already challenged by environmental pressure. The high vulnerability score and low readiness score of Afghanistan places it in the upper left quadrant of the ND-GAIN Matrix. It has both a great need for investment and innovations to improve readiness and a great urgency for action. Afghanistan is the 14th most vulnerable country and the 181st most ready country. Figure35.

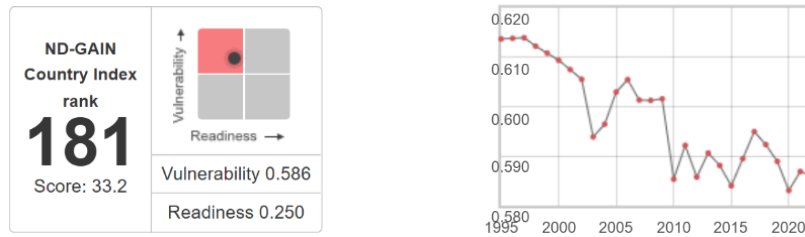


Figure 35: Vulnerability score over time, <https://gain.nd.edu/our-work/country-index/rankings/>

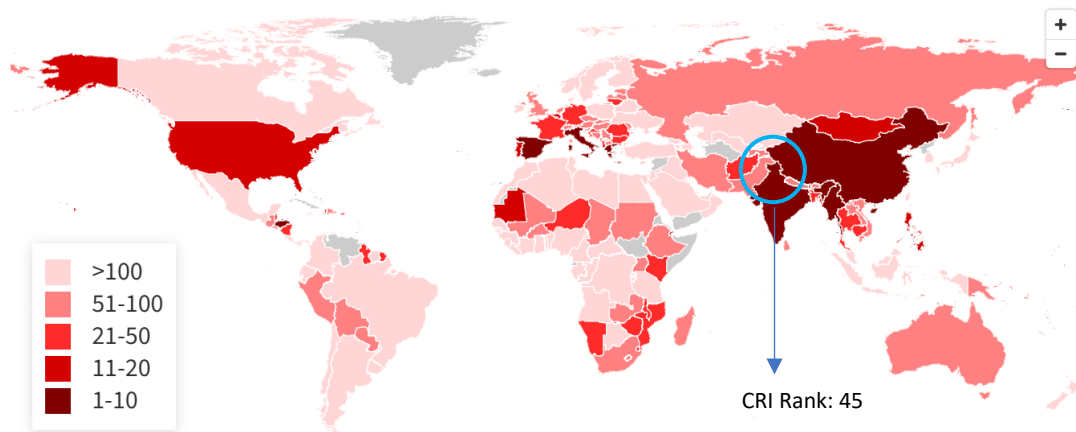


Figure 36: Climate risk index (CRI): Most affected countries in 1993-2022. this map shows the countries extreme weather events most affected from 1993 to 2022, based on the impacts on people and on economic loss, source: Germanwatch 2025

The latest analysis of Afghanistan's progress towards the Sustainable Development Goals (SDGs) highlights both achievements and ongoing challenges. That is shown in figure 37:

- **Economic Instability:** The economic situation remains fragile, with high poverty rates and food insecurity.
- **Conflict and Security:** Ongoing conflict and security issues continue to hinder progress and pose risks to achieving the SDGs.
- **Health and Education:** Access to quality healthcare and education remains limited, especially in rural areas.
- **Gender Inequality:** Despite efforts, gender inequality persists, with women and girls facing significant barriers to education and employment (United Nations Afghanistan, 2021).



Figure 37: Status of SDGs targets for Afghanistan, (source: <https://dashboards.sdindex.org/profiles/afghanistan>)

Between 1991 and 2020, Afghanistan experienced significant seasonal variations in temperature and precipitation, largely influenced by its diverse topography. Mountainous regions consistently recorded annual temperatures below freezing, while southern arid areas frequently saw temperatures exceeding 35°C. Precipitation patterns also varied, with the southwestern arid zones receiving less than 150 mm annually, contrasted by over 1,000 mm in the northeastern mountain ranges. Additionally, Afghanistan's climate is affected by large scale phenomena like the El Niño Southern Oscillation (ENSO) and the Indian Ocean Dipole, with the latter often linked to drought conditions in the region. (climateknowledgeportal.worldbank.org)

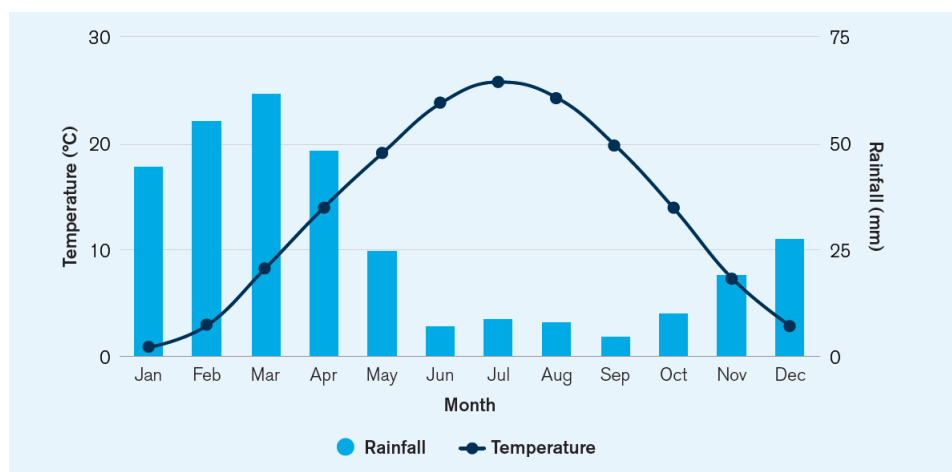


Figure38: average monthly temperature and rainfall in Afghanistan, 1991-2020

WBG Climate Change Knowledge Portal (CCKP, 2021). Climate Data: Historical. URL: <https://climateknowledgeportal.worldbank.org/country/afghanistan/climate-data-historical>

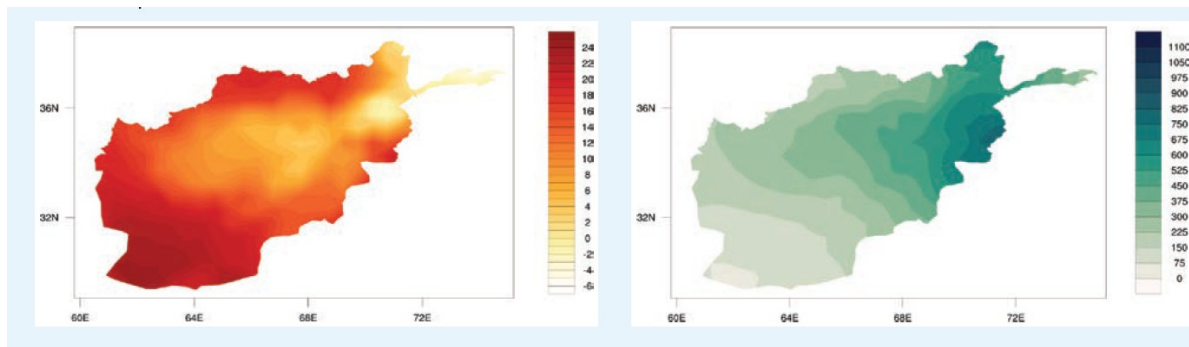


Figure 39: annual mean temperature (°C) (left), and annual mean precipitation (mm)(right) in Afghanistan over the period 1991-2020

Climate future in Afghanistan

There is good agreement among climate models that Afghanistan can expect levels of warming above the global average. The ensemble projects an average rise of 5.5°C by the 2080s and the 2090s, under the highest emission pathway (RCP8.5). This is significantly higher than the projected global average rise of 3.7°C, over the 1986–2005 baseline. And Projections in rainfall have greater uncertainty. Projected precipitation trends indicate a minimal reduction in average daily rainfall, but an increase in intensity for extreme rainfall events.

In summary, the key messages from climate change in Afghanistan are as follows:

- Afghanistan faces rates of warming higher than the global average with a potential rise of 1.4°C–5.4°C by the 2080s and the 2090s, compared with the baseline of 1986–2005. The range in possible temperature rise highlights the significant differences between 21st century emissions pathways.
- Rises in the annual maximum and minimum temperature are projected to be greater than the rise in average temperature, likely amplifying the pressure on human health, livelihoods, and ecosystems.
- Changes to Afghanistan’s rainfall regime, and hence water resources, are highly uncertain, but an increase in the incidence of drought conditions is very likely, and the shifts in the runoff regime have already been documented. Over the long-term, loss of glaciers could fundamentally disrupt regional water and hydropower supplies.
- Arid land cover is likely to expand either side of the Hindu Kush, leading to shifts in ecosystems and potentially loss of biodiversity.

- Events over the early 21st century show the extreme vulnerability of Afghanistan's communities to hazards Such as drought and flash flooding. This vulnerability is amplified by poverty, undernourishment, food insecurity, and inequality.
- Temperature increases are likely to place strain on urban dwellers, outdoor laborers, and the country's energy network, with increased risk of heat related sickness and fatalities under all emissions pathways.
- Comprehensive understanding of current and future climate risks across multiple sectors is severely constrained by a lack of data and research. This is an obstacle to adaptation and disaster risk reduction for Afghanistan.(World Bank Group,2020)

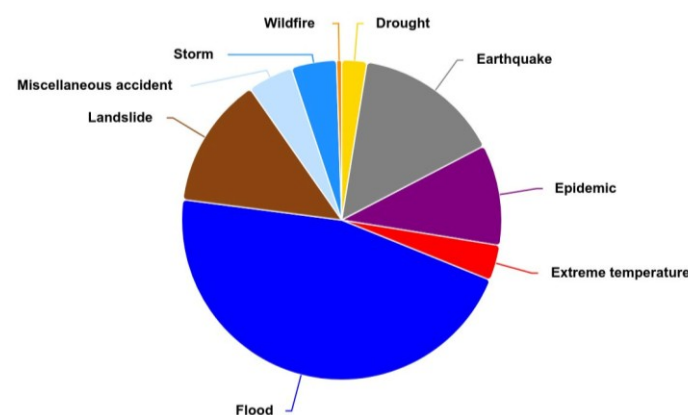


Figure 40: average annual natural hazard occurrence for 1980-2020 in Afghanistan, (source: <https://ecocrm.ir/natural-disasters-2/>)

Bamiyan case study

Location and climate: Afghanistan, cold semi-arid according to the Köppen climate classification system.

Heritage status: UNESCO world heritage since: 2003, category tangible, cultural landscape, circa 1500 years old.

The region of Bamiyan, 200 km North-West of Kabul, Afghanistan was one of the major Buddhist canters from the second century AD up to the time when Islam entered the area in the ninth century. The Bamiyan Valley is a remarkable fusion of artistic and religious developments that shaped the Central Asian region from the 1st to the 13th century CE (common era). Bamiyan is considered a crossroads between the civilizations of the East and the West and was a historical center of early cross cultural exchange between China and India.

The valley served as a prominent center of Buddhist art along the Silk Road. The cave complexes and their iconic Buddha figures were symbols of cultural exchange and religious tolerance. (UNEP, 2015)

There are locations in this cultural landscape and archeological remains of Bamiyan valley as define by UNESCO.

Heritage Site	Description
Buddhas of Bamiyan	Two monumental standing Buddha statues (38m and 55m tall), carved into a cliff in the 6th century; destroyed by the Taliban in 2001. Their niches and remains are UNESCO-protected and central to Bamiyan's cultural identity.
Shahre Gholghola (City of Screams)	Ruins of a fortified city destroyed by Genghis Khan in the 13th century. Offers panoramic views of Bamiyan Valley; contains remains of walls, towers, and Buddhist and Islamic layers.
Bamiyan Cliff Caves	Over 750 caves carved into the Bamiyan cliffs surrounding the Buddha niches. Used by Buddhist monks for meditation, worship, and murals, some dating back to the 5th century.
Foladi Valley (Qoul-i Akram and Qoul-i Pasha Caves)	A series of Buddhist cave complexes located in the Foladi Valley, to the south of Bamiyan town. Important for their preserved frescoes and architectural features.
Kakrak Valley Caves	A smaller but significant Buddhist monastic site east of Bamiyan with 6th–8th century murals and sculptures, including a depiction of a smaller standing Buddha.

Table 13: Bamiyan cultural heritage sites

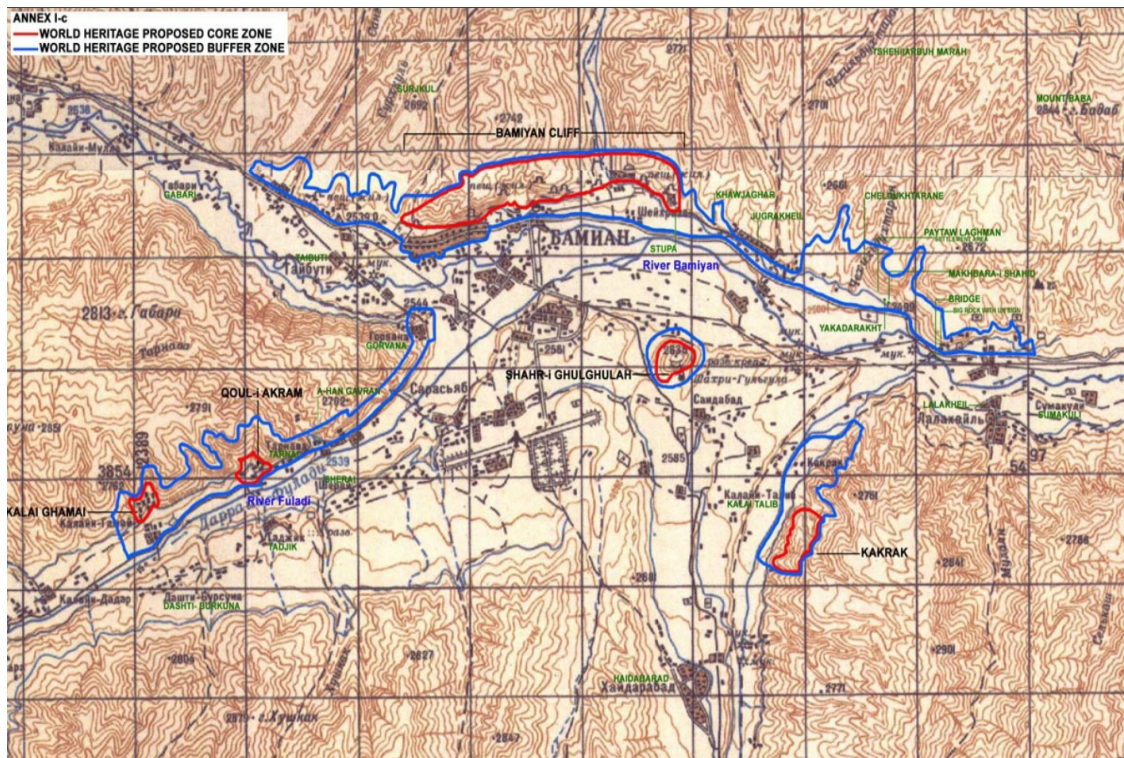


Figure 41: location of cultural heritage sites in Bamiyan valley

Climate change trends in Bamiyan

Under the Köppen–Geiger climate classification Bamiyan features a subarctic climate (Dsc). Temperatures typically range between -13°C (8°F) and 14°C (57°F) through the year, but rarely can drop to -31°C (-24°F) or can rise to as high as 24°C (75°F). The average annual precipitation amounts to about 374 mm (14.7 inches) and receives 74 rainy days on the 1 mm (0.04 inches) threshold annually. Bamiyan enjoys an average of 4073 hours of sunshine throughout the year, and daylight varies from 9 hours 50 minutes to 14 hours 26 minutes per day. (Nomadseason, 2024)

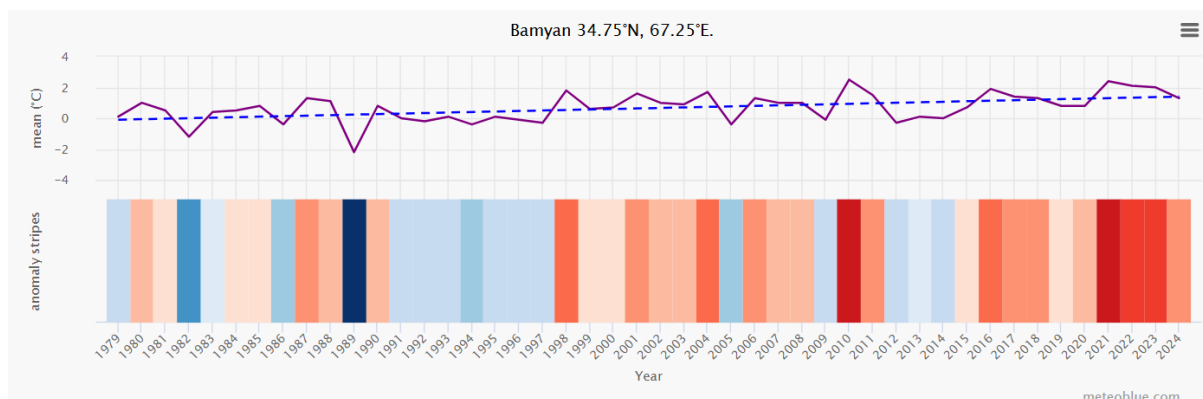


Figure 42: Mean yearly temperature change Bamiyan, 1979-2024

The top graph shows an estimate of the mean annual temperature for larger region of Bamiyan. The dashed blue line is the linear climate change trend. If the trend line is going up from left to right line, the temperature trend is positive and it is getting warmer in Bamiyan due to climate change. If it is horizontal, no clear trend is seen, and if it is going down, conditions in Bamiyan are becoming colder over time. (Meteoblue, 2025)

Based on the observed data, Bamiyan exhibits a noticeable positive temperature trend, aligning with global climate change patterns. The warming accelerates over time, reinforcing concerns about its environmental and socioeconomic consequences. Notable climate developments during 2013-2019 include:

- Minimal temperature variability, with persistent warming trends.
- Absence of blue stripes, demonstrating a complete loss of colder-than-average years.
- ✓ Warming became fully established, significantly altering environmental conditions.

Recent trends highlight severe climate changes, including:

- Total disappearance of cooling years, reinforcing irreversible warming trends.
 - The most intense red warming stripes, suggesting Bamiyan's temperature has reached historically high levels.
 - Climate change is now permanently impacting the region, affecting natural resources, agriculture, and local ecosystems.
- ✓ There is significant high temperature and increase drought in Bamiyan.

Risks:

- ✓ Long-term heating trends accelerate soil degradation, weakening foundations of historically significant sites in Bamiyan.
- ✓ The surrounding landscape becomes arid and unstable, increasing risks of landslides and erosion that could damage or bury fragile relics.

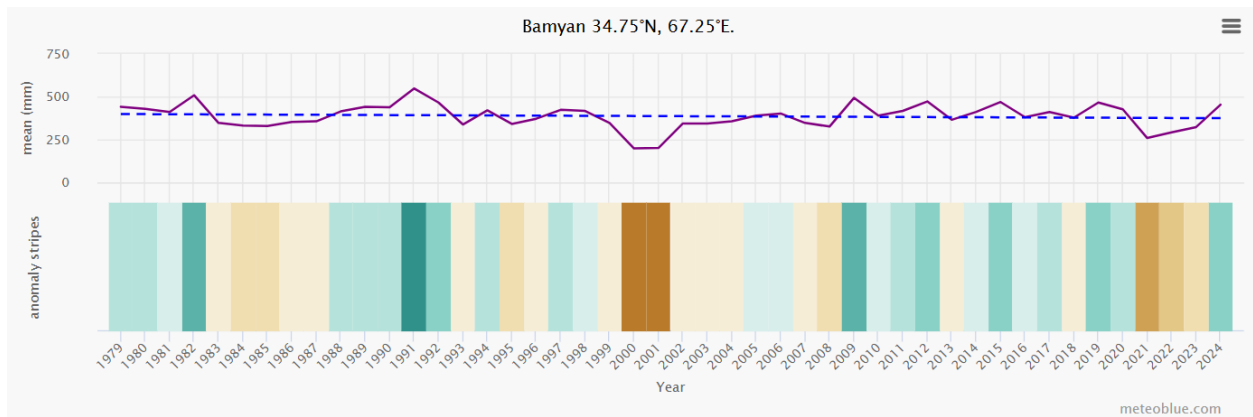


Figure 43: Mean yearly precipitation change- Bamiyan, 1979-2024

The top graph shows an estimate of mean total precipitation for the larger region of Bamiyan. The dashed blue line is the linear climate change trend. If the trend line is going up from left to right the precipitation trend is positive and it is getting wetter in Bamiyan due to climate change. If it is horizontal, no clear trend is seen and if it is going down conditions are becoming drier in Bamiyan over time. (Meteoblue, 2025)

From phase 1979-1999

- Nearly all years in this period were approximately blue, showing a consistent positive trend in annual precipitation.
- ✓ There is positive trend during this years.

From 2000-2024

- Precipitation reached critically low levels, there is low wet years recorded.
- ✓ Bamiyan is now facing an alarming water crisis and drought.

Risks:

- ✓ The trend of decreasing precipitation enhances soil degradation around heritage sites, leading to desertification and unstable landscapes.
- ✓ Increase in drought, important features of the landscape will be taken from historical buildings and will reduce the targeted use of ecotourism capacities.
- ✓ Desertification increases sand accumulation, which can bury historical ruins and cause irreversible damage to preserved archaeological sites.
- ✓ Bamiyan's province experienced the flash flood In 2024.(Ariana neaws, 2024)

Humidity

The perceived humidity level in Bamiyan, as measured by the percentage of time in which the humidity comfort level is muggy, oppressive, or miserable, does not vary significantly over the course of the year, remaining a virtually constant 0% throughout.



Figure 44: Humidity comfort levels in Bamiyan

Risks:

- ✓ Low humidity can cause historical structures made of clay, mud-brick, or stone to dry out excessively, leading to cracking and weakening.
- ✓ Arid conditions contribute to airborne dust, which can settle on delicate carvings and ancient surfaces, accelerating abrasion and erosion.
- ✓ Dust particles obscure engravings and historical details, requiring frequent cleaning, which may damage fragile artifacts.
- ✓ Sudden temperature changes, combined with low humidity, may cause thermal expansion and contraction, resulting in cracks in ancient structures.

Wind

The average hourly wind speed in Bamiyan experiences mild seasonal variation over the course of the year. The windier part of the year lasts for 3.6 months, from January 10 to April 30, with average wind speeds of more than 6.5 miles per hour. The windiest month of the year in Bamiyan is March, with an average hourly wind speed of 7.7 miles per hour.

The calmer time of year lasts for 8.4 months, from April 30 to January 10. The calmest month of the year in Bamiyan is October, with an average hourly wind speed of 5.2 miles per hour. (Meteoblue, 2025)

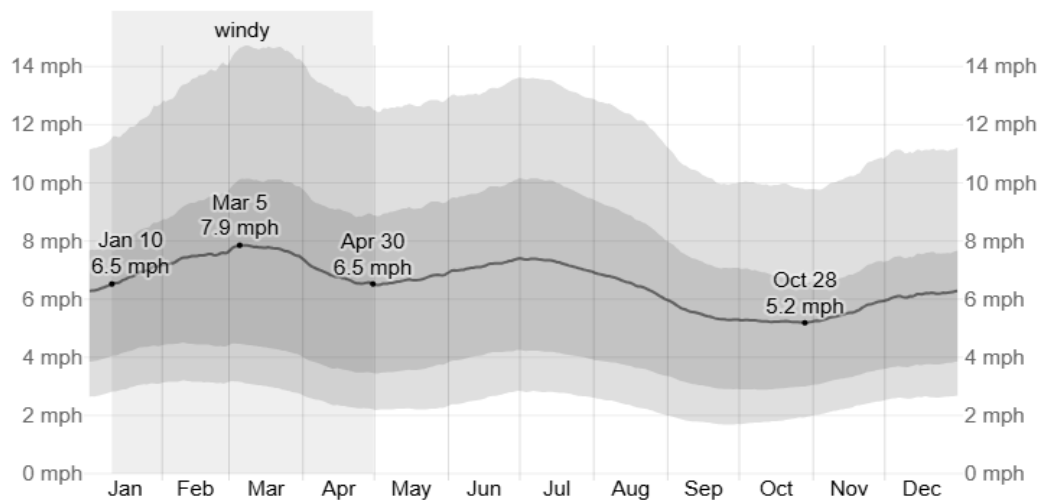


Figure 45: Average wind speed in Bamiyan

Risks:

- ✓ High winds (January–April) can accelerate erosion, wearing down rock carved monuments, mud-brick structures in Gholghola city, and exposed surfaces.
- ✓ Fine dust particles carried by strong winds gradually degrade carvings on ancient walls and statues.
- ✓ Intense seasonal gusts may weaken fragile ruins, increasing the likelihood of cracks and surface degradation over time.
- ✓ Unprotected heritage sites with open exposure are more vulnerable to long-term weathering effects

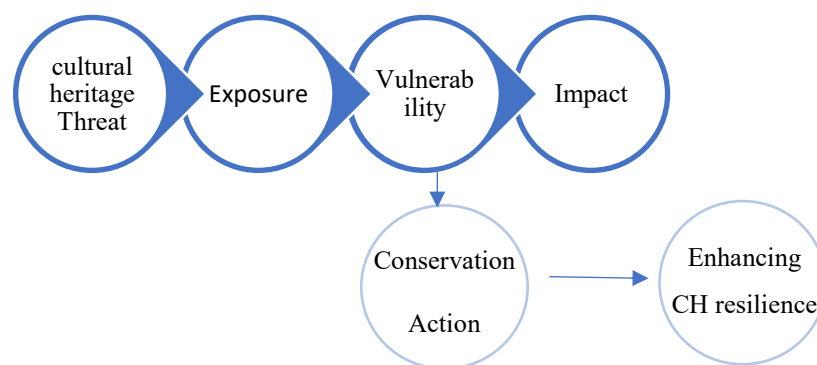
Human induced risk

In addition from environmental dangers, the cultural heritage of the Bamiyan Valley faces growing vulnerability to various human induced risks that greatly undermine its integrity and resilience. Among the most urgent concerns are the lack of regulation for development and urban sprawl into buffer zones that encircle heritage sites. Construction activities in the near of the Buddha niches and throughout the archaeological landscape have escalated, frequently lacking environmental or heritage impact assessments. This has resulted in soil destabilization and a heightened risk of erosion (UNESCO/ICOMOS, 2017). Additionally, uncontrolled tourism while limited in comparison to global sites has brought foot traffic and vibrations to delicate cave complexes that lack adequate visitor facilities and conservation management

(Nazari, 2022). Looting and illicit excavation have also emerged as serious concerns, particularly during periods of political instability, where lack of oversight has allowed unauthorized digging and the removal of valuable artifacts (The Art Newspaper, 2022).

Climate change impact on Bamiyan's cultural heritage

Bamiyan as a UNESCO World Heritage Site, it is confronted with a complicated set of dangers that jeopardize its cultural heritage. Due to the geological and climatic conditions of the valley, natural hazards like rock weathering, flash floods, water seepage, and wind erosion are common. The site's vulnerability is compounded by human induced threats such as unsupervised tourism, infrastructural encroachments, and looting. These hazards increase the exposure of important heritage elements like the Buddha niches, caves adorned with murals, and delicate earthen architecture. The site's vulnerability is exacerbated by limited maintenance capacity, a lack of local conservation training, and institutional challenges. The cumulative effects comprise structural degradation, loss of material integrity, and irreversible cultural erosion.



The data on hazard prevalence in Bamiyan over the last 12 months underscores the significant environmental challenges facing communities in the region. With drought affecting 84% of communities and floods impacting 76%, water related hazards appear to be the most pressing concerns. Other environmental risks, such as agricultural pests (47%), extreme cold (19%), and avalanches (19%), have also posed threats, though at lower prevalence levels. (Afghanistan Climate Vulnerability Assessment, 2025)

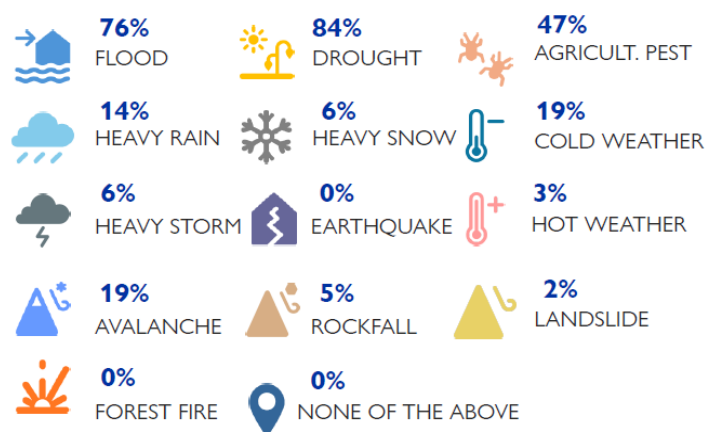


Figure 49: Hazard prevalence in last 12 months in Bamiyan (% of communities)

Hazard	Climatic driver	Emergent risks	Suggestion mitigation plan
	Temperature hike.....drought	High Very dry lands have less water absorption capacity during heavy rains, leading to increased risk of soil erosion, desertification, and floods.	Preservation and maintenance, revival, and improvement of canals Management of catchments, including grasslands, forests, and reforestation
	Fluctuation in Atmospheric precipitation....Landslides	High The landslide is causing more and more destruction of worn-out texture and physical damage to Buddha statues and areas around Bamiyan historical monuments.	Strengthening slopes and controlling erosion and soil drainage by methods like nailing system of stabilization or resistant synthetic carpets Planning improvement to prevent and limit the construction of houses in danger zones.
	Flash flood	Moderate Flash flood events due to shifts in precipitation intensity and land use patterns. These floods damage infrastructure, m , and wash away protective barriers around heritage sites, increasing the risk of sudden collapse or erosion.	Systems for monitoring, forecasting and warning of heavy rains and floods. To divert the flood route from historical monuments, in suitable places, obstacles such as stone fences, tunnels, and diversion dams are some of the measures that can be considered.
	Wind and sand erosion	High-altitude valleys such as Bamiyan are prone to wind abrasion,	

		particularly in dry seasons. Fine sand carried by wind scours exposed rock surfaces, gradually eroding carved features, decorative details, and historic inscriptions. Although the slopes of the mountains around the studied historical monuments are not so high for occurring an avalanche, if it happens, the Zohhak city and Kakrak valley are more at risk due to their proximity to the hillsides.	Create vegetative windbreaks using native species to reduce sand drift near heritage zones. Apply sacrificial protective coatings (reversible) on vulnerable carvings. Limit vehicular movement in nearby open fields to avoid dust generation. Rehabilitation of grasslands, forests and tree fields Warning systems for risky areas Structures to divert and prevent the entry of avalanche, snow walls, or snow barriers
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Table 14: Significant climate change impacts on Bamiyan Valley

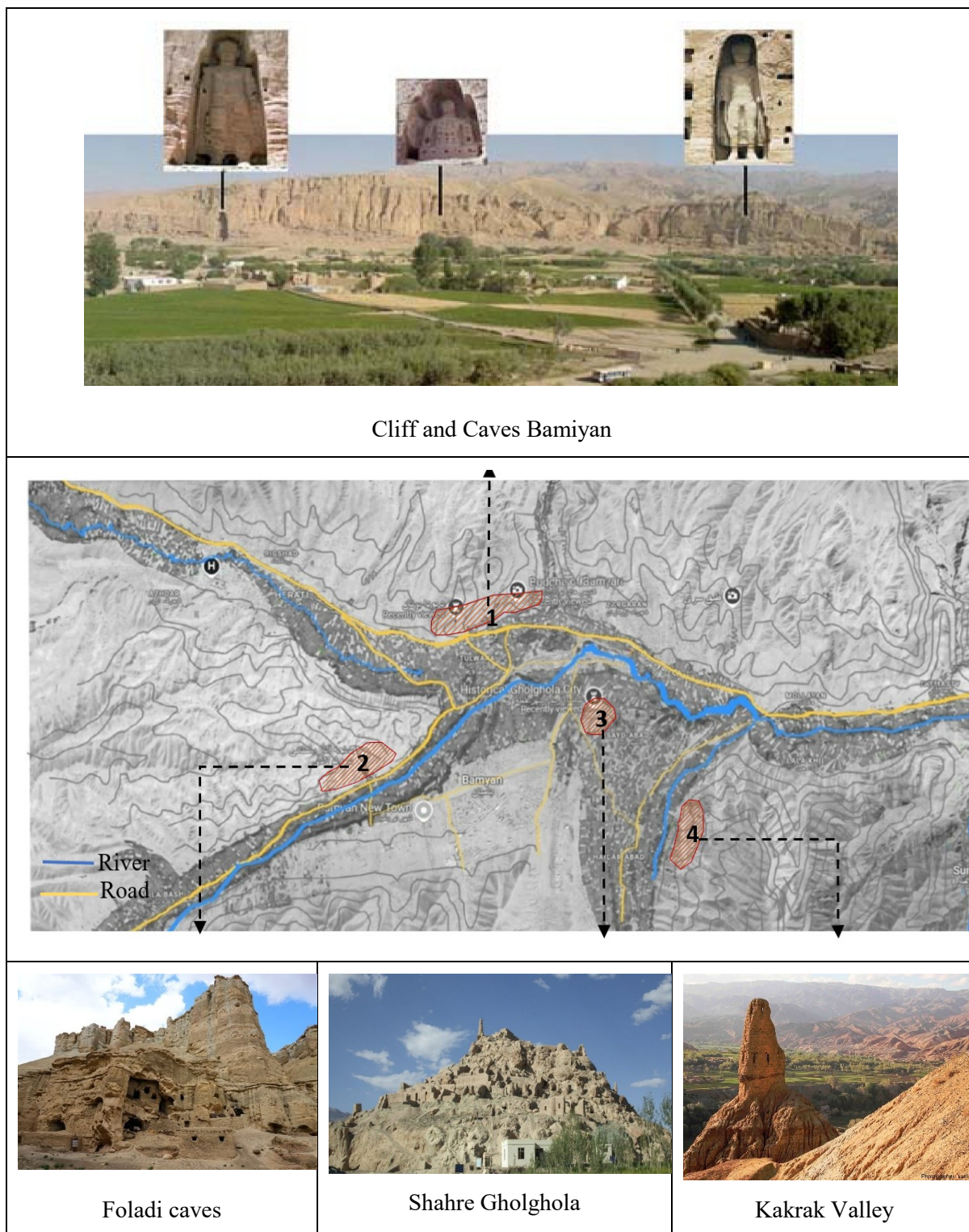


Figure 46: Risk exposure of Bamiyan's Cultural Heritage Sites to Climate Change

Risk map

1, 2: Map of Budah, Kakrak and Fuladi cliff and caves disease and threats

3, 4: Map of Mud- brick structure, Shahre Gholghola and Kakrak valley

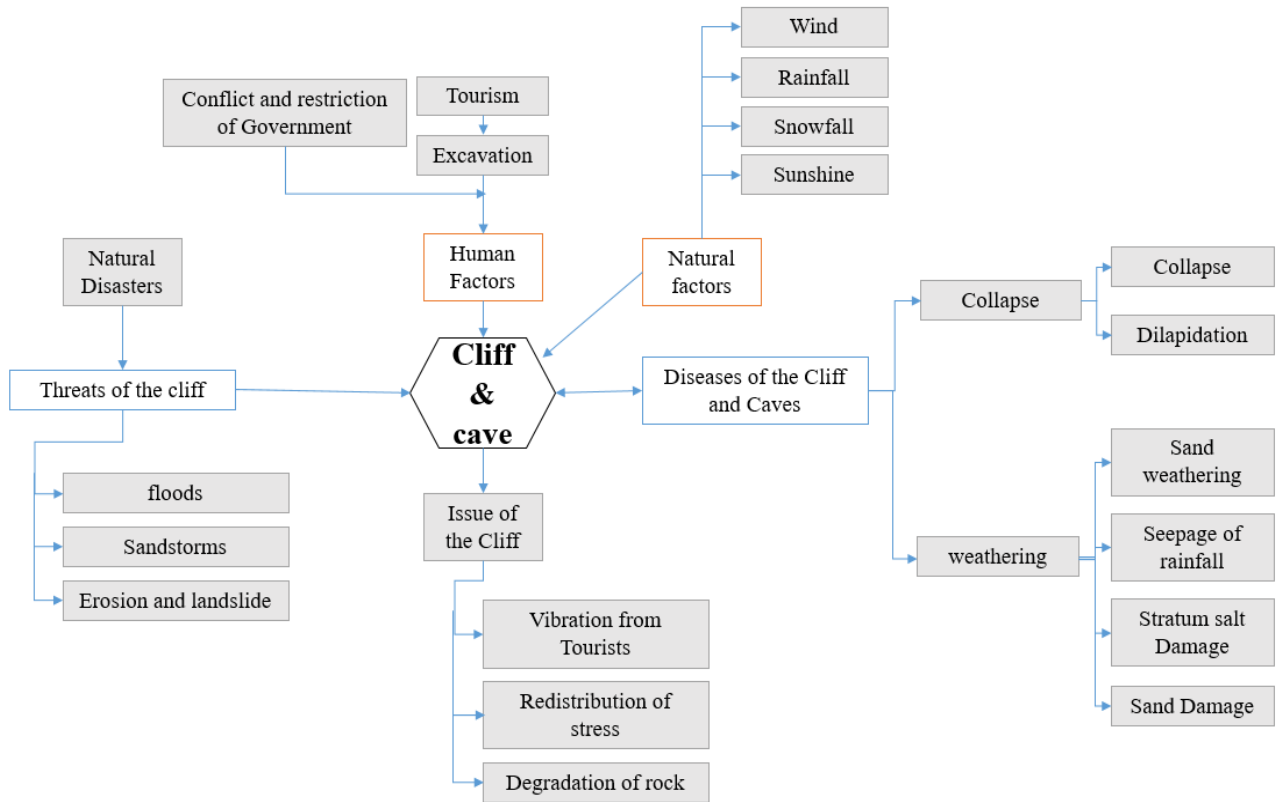


Figure 47: Map of Budah and Fuladi cliff and caves disease and threats

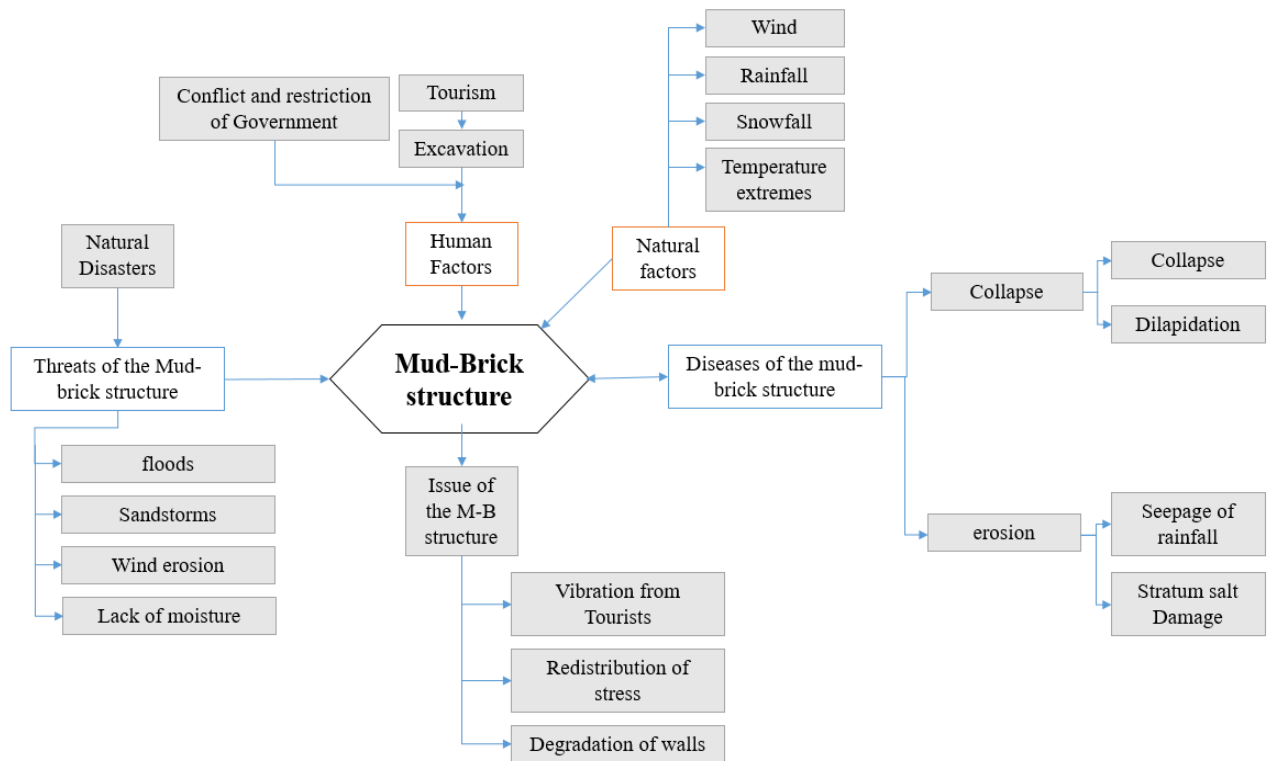


Figure 48: Map of Mud- brick structure, Shahre Gholghola and Kakrak valley

Conservation History in Bamiyan

In 2002, UNESCO and the Afghan Ministry of Information and Culture conducted the first international symposium on the protection and restoration of Afghanistan's cultural heritage. The initial on-site evaluations made it abundantly evident that the niches and the surviving pieces of the Buddha sculptures needed to be preserved immediately (M.Petzet 2009). Since its inaugural conference in Munich in November 2002, the worldwide "Expert Working Group on the Preservation of the Bamiyan Site" has released an annual catalog of recommendations. In July 2003, the Bamiyan Valley's Cultural Landscape and Archaeological Remains were added to the World Heritage List and placed on the List of World Heritage in Danger.

In August 2021, significant political changes took place, which resulted in a shift in the administrative and technical regulations in the sphere of cultural heritage in Afghanistan, even though 2021 commemorated the 20th anniversary of the destruction of the two Buddhas in March 2001. Donors consequently discontinued UNESCO operations and conservation work being carried out on the land. As of February 2023, these Italian and Japanese funded initiatives have gradually resumed. The Republic of Korea government provided funding for the development of the Bamiyan Cultural Center, which was finished in the fall of 2022.

The following information about the execution of the activities supporting the corrective measures is provided by UNESCO through its Office in Kabul and within the framework of the Japan Funds-in-Trust (JFIT) project:

- The Management Plan for the property is under finalization;
- A contract is under establishment for the protection, conservation, monitoring and management of mural paintings and capacity building initiatives to preserve the artistic legacy of the property;
- Artefacts under threat in four separate storages have been housed safely within the Bamiyan Cultural Centre;
- A rapid assessment of the state of conservation of the property has been carried out in February 2023 by UNESCO Office in Kabul.

In addition The Government of Italy, through the Italian Agency for Development Cooperation, supports a 4.1 million Euros initiative for the Preservation and Promotion of the Bamiyan Valley through Culture-Oriented Sustainable Development.

- The elaboration of a management plan;
- The creation of an Archaeological Park that will contribute to protect and enhance the unique heritage, promote local employment and encourage economic growth;
- A detailed analysis of the Buddha Cliff in order to mitigate the hydro-geological risks.

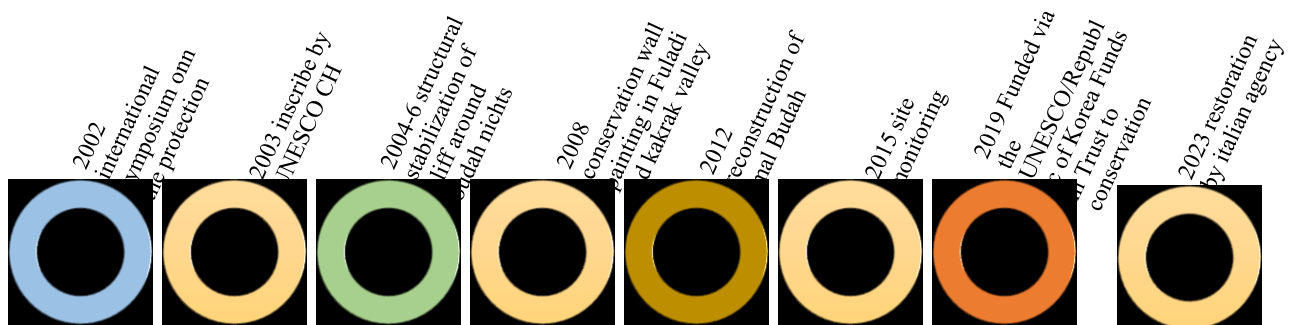


Figure 49: conservation history in Bamiyan

According to UNESCO report in 2024 there are several Threats for which the property was inscribed on the List of World Heritage in Danger.

- Site security not ensured
- Long-term stability of the Giant Buddha niches not ensured
- State of conservation of archaeological remains and mural paintings not adequate
- Management Plan and Cultural Master Plan (the protective zoning plan) not implemented

4.8. Enhancing Resilience- Based Conservation Action

According to study about impacts of climate change in Bamiyan valley, due to its distinctive geology, which includes sedimentary formations and fragile sandstone cliffs. Increased rainfall and freeze thaw cycles, for instance, worsen erosion and cause the caves delicate murals and Buddha statue niches to become unstable. The sociopolitical unrest in Afghanistan also makes conservation more difficult since long-term planning is hampered by a lack of money, poor infrastructure, and erratic government. The concept of resilience in cultural heritage. Clarify that resilience is not only about resisting damage but also about adapting to change and

recovering from disruption (climate or human) and Enhance the resilience as an aim of this study could be solution to safeguarding the Cultural heritage in Bamiyan.

Resilience factors divided to 5 pillar:

- A. Physical Resilience
- B. Environmental Resilience
- C. Technological Resilience
- D. Community and Social Resilience
- E. Institutional Resilience

A. Structural or physical resilience

The ability of constructed heritage, such as Buddha niches, cliff walls, and archeological artifacts, to withstand physical deterioration brought on by climate change is known as structural resilience. Because of its high porosity, the sandstone in the valley is prone to weathering, especially from water seeping in during periods of intense precipitation and temperature fluctuations that cause expansion and contraction. These processes eventually cause cracking, flaking, and collapse. Conservation initiatives must address material vulnerabilities in order to improve structural resilience. Erosion could be reduced, for example, by building drainage systems to redirect rainfall or erecting protective shelters over exposed nooks. Predicting deterioration trends and prioritizing remedies can also be aided by sophisticated monitoring equipment like moisture sensors and 3D laser scanning. To prevent interfering with the site's historic charm, these solutions must strike a balance between contemporary technology and conventional preservation methods.

B. Environmental Resilience

Environmental resilience in Bamiyan refers to the ability of the region's natural and cultural landscapes to cope with climate-related challenges like freeze-thaw cycles, floods, and erosion. Key strategies include sustainable land use, reforestation, traditional building practices, and improved environmental monitoring to protect both ecosystems and heritage sites.

C. Technological resilience

Innovation is used to anticipate and alleviate climate risks in the context of technological resilience. Vulnerable areas can be identified, erosion rates tracked, and future scenarios

simulated using remote sensing, drone surveys, and AI-driven climate modeling. As an example, thermal imaging can identify moisture buildup in cave walls prior to any visible damage. Nonetheless, technology needs to be both accessible and adaptable given Bamiyan's limited resources. It is possible to promote community ownership while democratizing resilience efforts through inexpensive solutions, such as teaching local teams how to use smartphone apps for monitoring.

D. Socio-cultural resilience

The focus of socio-cultural resilience is on how local communities can protect cultural assets. The Hazara people, who live in Bamiyan, have centuries-old knowledge of how to manage water, use land, and build structures. Their involvement is essential to long-term conservation. For instance, the restoration of historic mud-brick building methods or community-led reforestation initiatives could improve structural and environmental resilience. However, tackling systemic issues like poverty and political marginalization that restrict communities' ability to practice legacy stewardship is also essential to achieving socio-cultural resilience. Conservation activities are guaranteed to be in line with cultural values and needs when local stakeholders are empowered through funding, education, and inclusive decision-making.

F. Institutional Resilience

The conservation of Bamiyan has been hindered by Afghanistan's instability, insufficient funding, and disjointed coordination among international organizations, national authorities, and local stakeholders. To enhance institutional resilience, it is essential to implement strong policies like the incorporation of climate adaptation in heritage management plans and to establish sustainable funding mechanisms. While international collaborations such as UNESCO's Climate Change Policy for Heritage offer technical know-how, it is essential that they focus on building local capacity in order to guarantee sustainability.

Strategy		
Resilience	A. Physical Resilience	A1. Rock stabilization in Budah and Foladi cliff and caves, Strengthening slopes and controlling erosion and soil drainage by methods like nailing system of stabilization or resistant synthetic carpets. A2. seepage control, A3. drainage improvement A4. Apply lime-based or reversible fillers to stabilize large cracks while maintaining historical authenticity A5. Maintain controlled humidity in caves to prevent excessive drying or expansion of pigments and mud-brick
	B. Environmental Resilience	B1. Planting native vegetation to reduce wind and sand erosion B2. Flood control —► diversion channels B3. Apply microfiber brushes and non-chemical solutions to remove dust accumulation without damaging pigments. B4. Sustainable Building Materials —► use climate-resistant mud mixtures for restoration, ensuring compatibility with traditional structures. B5. Introduction buffer zones and strict land use regulation B6. Construction of access to different parts of the caves and Shahre Gholghola and Paths designed to prevent direct physical contact with vulnerable monuments
	C. Technological Resilience	C1. Digital documentation (3d scanning and modeling) C2. 3D scanning of caves and statues for future restoration C3. GIS-based mapping of risk zones
	D. Community and Social Resilience	D1. training locals in preventive conservation techniques D2. Supporting local knowledge in sustainable site use
	E1. Institutional Resilience	E1. Integrate climate risk and heritage protection into local and national disaster risk management (DRM) policies E2. Multi-level Coordination, local authorities, national government, international institution E4. Risk mapping and climate adaptation training

E3. Emergency planning develop a heritage risk management office within Bamiyan

E4. Planning improvement to prevent and limit the construction of houses in danger zones



B7. Buffer Zone

B2. Diversion channel

B6. Construction path

B1. Planting vegetation

**1. Shamamah
Budah and Caves**



**1. Salsal Budah
and caves**

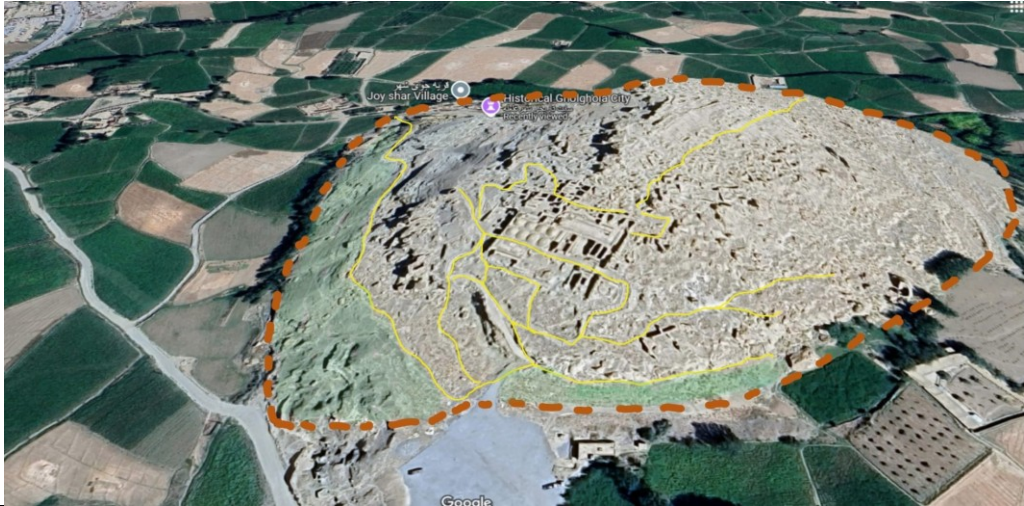
		3. Shahre Gholghola
		4. Kakraak Valley
		5. Fuladi Valley

Table 15: risk and resilience strategy for Bamiyan cultural heritage

4.9. Conclusion

Building upon the lessons learned from global case studies, the Bamiyan Valley presents a unique context where climate related and human induced threats intersect in a fragile and under resourced environment. Unlike sites in countries with robust heritage institutions, Bamiyan faces limitations in infrastructure, governance, and funding, which hinder large scale intervention. Nevertheless, targeted actions such as improved drainage to reduce water seepage, 3D scanning of caves and statues for future restoration and the use of remote sensing for early warning systems offer practical solutions. Community involvement and international collaboration are also essential to strengthen institutional capacity and ensure sustainable conservation. By applying a hazard, exposure, vulnerability, impact and action framework, this study recommends adaptive, low cost strategies that are both climate sensitive and socially inclusive, aiming to enhance the long term resilience of Bamiyan's cultural heritage.

5.Integrated Conclusion and Recommendations

This study investigated the climate related risks and resilience strategies for cultural heritage in the Bamiyan Valley by drawing on comparative lessons from successful case studies such as Olympia (Greece), Longmen (China), Petra (Jordan), Venice (Italy), and Vardzia (Georgia). These sites demonstrated various conservation actions ranging from structural reinforcement and erosion control to institutional coordination and community engagement that offer valuable insights for Bamiyan's preservation.

The findings indicate that Bamiyan's cultural heritage is exposed to multiple natural and human induced hazards, including weathering, flash floods, water seepage, wind erosion, tourism pressure, and institutional instability. These risks are compounded by the region's limited technical capacity, political fragility, and insufficient integration of climate data into heritage planning.

In response, several resilience building actions are recommended:

- ✓ Adaptive Site Management: Implement regular climate risk monitoring and early-warning systems using GIS, remote sensing, and meteorological data.
- ✓ Physical Conservation Interventions: Prioritize stabilization of fragile cliff faces, improve drainage infrastructure, and use weather resistant materials informed by traditional techniques.
- ✓ Community Involvement: Strengthen local participation through capacity-building, education, and co-management frameworks, following the example of community-driven tourism in Petra.
- ✓ Institutional Strengthening: Develop clear governance frameworks and collaboration between national authorities, UNESCO, and local stakeholders to ensure long-term conservation planning.
- ✓ Knowledge Transfer: Adopt successful models of documentation, digital reconstruction, and maintenance from Longmen and Venice, tailored to Bamiyan's unique needs.

This comparative approach not only enhances Bamiyan's site specific resilience but also contributes to a broader understanding of how fragile cultural heritage in conflict prone regions

can adapt to climate change. Future research should focus on long term monitoring, material science in extreme climates, and conflict-sensitive heritage governance models.

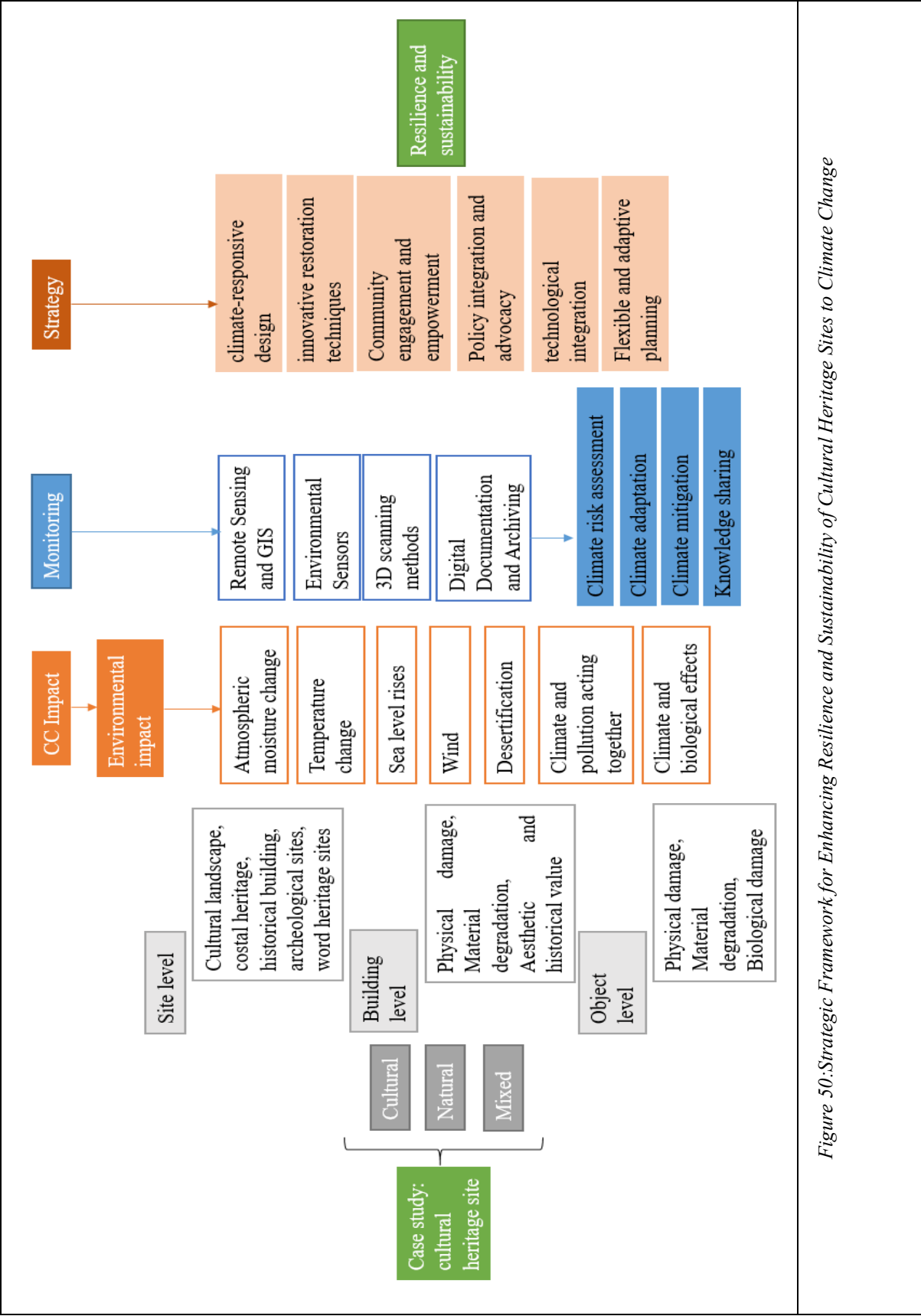


Figure 50: Strategic Framework for Enhancing Resilience and Sustainability of Cultural Heritage Sites to Climate Change

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