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Original Research Article

Climate change and cultural heritage: Challenges for historical monuments and traditional communities

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ABSTRACT

Climate change has emerged as one of the most significant global challenges of the twenty-first century, influencing natural ecosystems, human societies, and cultural heritage alike. While the impacts of climate change on biodiversity and infrastructure have received extensive scientific attention, the vulnerability of cultural heritage—including historical monuments, archaeological sites, sacred landscapes, traditional settlements, and indigenous knowledge systems—has only recently gained recognition as a major concern for sustainable development. Rising temperatures, sea-level rise, changing precipitation patterns, floods, droughts, storms, desertification, and wildfires are accelerating the deterioration of built heritage and threatening the survival of communities whose cultural identities are closely linked to their surrounding environments. Climate-induced migration, loss of traditional livelihoods, and changing ecological conditions further weaken intangible cultural heritage by disrupting customary practices, languages, rituals, craftsmanship, and local knowledge.

This paper examines the multidimensional relationship between climate change and cultural heritage, emphasizing both tangible and intangible dimensions. It reviews the mechanisms through which climate-related hazards damage historical monuments and examines their socio-cultural consequences for traditional communities. The study further discusses conservation challenges arising from limited funding, inadequate climate adaptation policies, insufficient documentation, and weak community participation. Various adaptation and mitigation strategies—including digital documentation, climate-resilient conservation techniques, ecosystem-based approaches, traditional ecological knowledge, community participation, and international cooperation—are evaluated as practical pathways for protecting cultural heritage under changing climatic conditions. Selected global case studies demonstrate that successful heritage conservation increasingly depends upon integrating scientific knowledge with local cultural practices. The paper concludes that safeguarding cultural heritage should become an essential component of climate adaptation planning and sustainable development policies. Strengthening interdisciplinary collaboration among governments, heritage professionals, scientists, and local communities will be essential for ensuring the resilience of cultural heritage for future generations.

1. Introduction

Climate change has become one of the defining challenges facing humanity during the twenty-first century. Increasing atmospheric greenhouse gas concentrations have resulted in global warming, altered precipitation patterns, rising sea levels, and an increase in the frequency and intensity of extreme weather events [1]. While these environmental transformations directly affect ecosystems and economic activities, they also pose substantial risks to cultural heritage, which represents the collective memory, identity, and historical continuity of societies [2].

Cultural heritage encompasses both tangible and intangible elements. Tangible heritage includes monuments, archaeological sites, historic cities, museums, temples, churches, forts, palaces, traditional buildings, and cultural landscapes. Intangible heritage comprises languages, folklore, music, dance, rituals, festivals, traditional craftsmanship, oral

traditions, indigenous knowledge, and customary practices transmitted across generations [3]. Together, these forms of heritage contribute to social cohesion, education, tourism, and cultural diversity.

Historically, cultural heritage has survived wars, political transitions, earthquakes, and natural disasters. However, climate change introduces new challenges because its impacts are gradual, cumulative, and often irreversible. Unlike isolated disasters, climate change continuously modifies environmental conditions, accelerating physical deterioration while simultaneously disrupting the social systems responsible for preserving cultural traditions [4].

Many historical monuments were constructed centuries ago using locally available materials and traditional architectural techniques that were adapted to historical climatic conditions. Changes in temperature, humidity, rainfall, groundwater levels, and atmospheric chemistry alter the



physical and chemical properties of stone, brick, timber, metal, and mortar. Consequently, monuments experience accelerated weathering, biological colonization, salt crystallization, structural instability, corrosion, and material degradation [5].

Traditional communities are equally vulnerable because their livelihoods often depend upon agriculture, forests, fisheries, pastoralism, and natural ecosystems. Climate variability reduces agricultural productivity, alters seasonal cycles, threatens water security, and increases the frequency of displacement. These environmental stresses affect traditional occupations, religious practices, community festivals, indigenous knowledge systems, and cultural continuity [6].

International organizations increasingly recognize the relationship between climate change and heritage conservation. The integration of cultural heritage within climate adaptation strategies contributes not only to preservation but also to sustainable development by strengthening community resilience, promoting cultural tourism, and protecting traditional knowledge that supports environmental sustainability [7].

This paper investigates the challenges climate change poses to historical monuments and traditional communities while identifying practical strategies for enhancing cultural resilience through integrated conservation approaches.

2. Climate change and cultural heritage

Climate change influences cultural heritage through a complex interaction of physical, environmental, economic, and social processes. Unlike sudden disasters that produce immediate destruction, climate-related impacts accumulate gradually, reducing the long-term integrity and authenticity of heritage assets.

Tangible Cultural Heritage: Tangible heritage consists of physical structures and cultural landscapes possessing historical, artistic, archaeological, architectural, or religious significance. These include: Archaeological sites, Historic buildings, Religious monuments, Museums, Cultural landscapes, Historic urban centres, Forts and palaces, and Traditional settlements. These heritage assets were generally constructed under climatic conditions considerably different from those experienced today. Consequently, many structures are increasingly vulnerable to changing environmental conditions [8].

Intangible Cultural Heritage: Intangible heritage encompasses living traditions maintained through continuous social interaction. These include: Oral traditions, Folk music, Indigenous languages, Traditional medicine, Agricultural knowledge, Craftsmanship, Rituals and ceremonies, Festivals, and Culinary traditions. Climate-induced environmental changes often interrupt the transmission of these traditions by forcing migration, altering resource availability, and transforming cultural landscapes [9].

Table 1: Major components of cultural heritage and climate-related threats.

Heritage component	Examples	Major climate threats
Historical monuments	Temples, forts, churches	Weathering, erosion, flooding
Archaeological sites	Excavated ruins	Sea-level rise, soil erosion
Cultural landscapes	Sacred forests, terraces	Drought, vegetation change
Historic cities	Old urban centres	Heat stress, flooding
Traditional settlements	Indigenous villages	Storms, coastal erosion
Museums	Collections	Humidity, temperature fluctuations
Intangible heritage	Rituals, festivals	Migration, livelihood loss
Traditional knowledge	Agriculture, medicine	Ecological disruption

Mechanisms of Climate-Induced Heritage Degradation: Climate change affects heritage through several interconnected mechanisms:

Rising Temperature: Increasing temperatures accelerate thermal expansion and contraction in construction materials. Repeated thermal cycling produces micro-cracks in stone, brick, marble, and concrete. Organic materials such as wood deteriorate more rapidly under prolonged heat exposure.

Changing Rainfall Patterns: Irregular precipitation increases moisture infiltration into masonry. Wetting and drying cycles promote salt crystallization, biological growth, and chemical weathering.

Flooding: River flooding and flash floods weaken building foundations, transport sediments, and increase moisture content within heritage structures.

Sea-Level Rise: Coastal archaeological sites experience inundation, shoreline erosion, and saltwater intrusion, accelerating structural deterioration.

Extreme Weather Events: Cyclones, hurricanes, storms, and high winds cause immediate structural damage while increasing maintenance requirements.

Wildfires: Increasing wildfire frequency threatens wooden heritage structures, historic landscapes, and cultural ecosystems.

Climate Change and Sustainable Development: The protection of cultural heritage directly supports sustainable development through: Tourism, Local employment, Cultural identity, Education, Traditional knowledge, Social resilience, and Environmental stewardship. Integrating heritage conservation into climate adaptation policies therefore contributes simultaneously to cultural sustainability and environmental resilience [10].

3. Impacts of climate change on historical monuments

Historical monuments represent irreplaceable records of human civilization. Climate change accelerates both physical and chemical deterioration processes, reducing their structural stability, aesthetic value, and historical authenticity.

Stone Weathering: Stone monuments are especially vulnerable to changing climatic conditions. Increased rainfall and atmospheric pollutants accelerate chemical reactions that dissolve carbonate minerals in limestone and marble. Freeze-thaw cycles in colder regions widen existing fractures, while higher temperatures promote granular disintegration.

Granite, sandstone, marble, and limestone all exhibit different responses depending upon mineral composition, porosity, and environmental exposure.

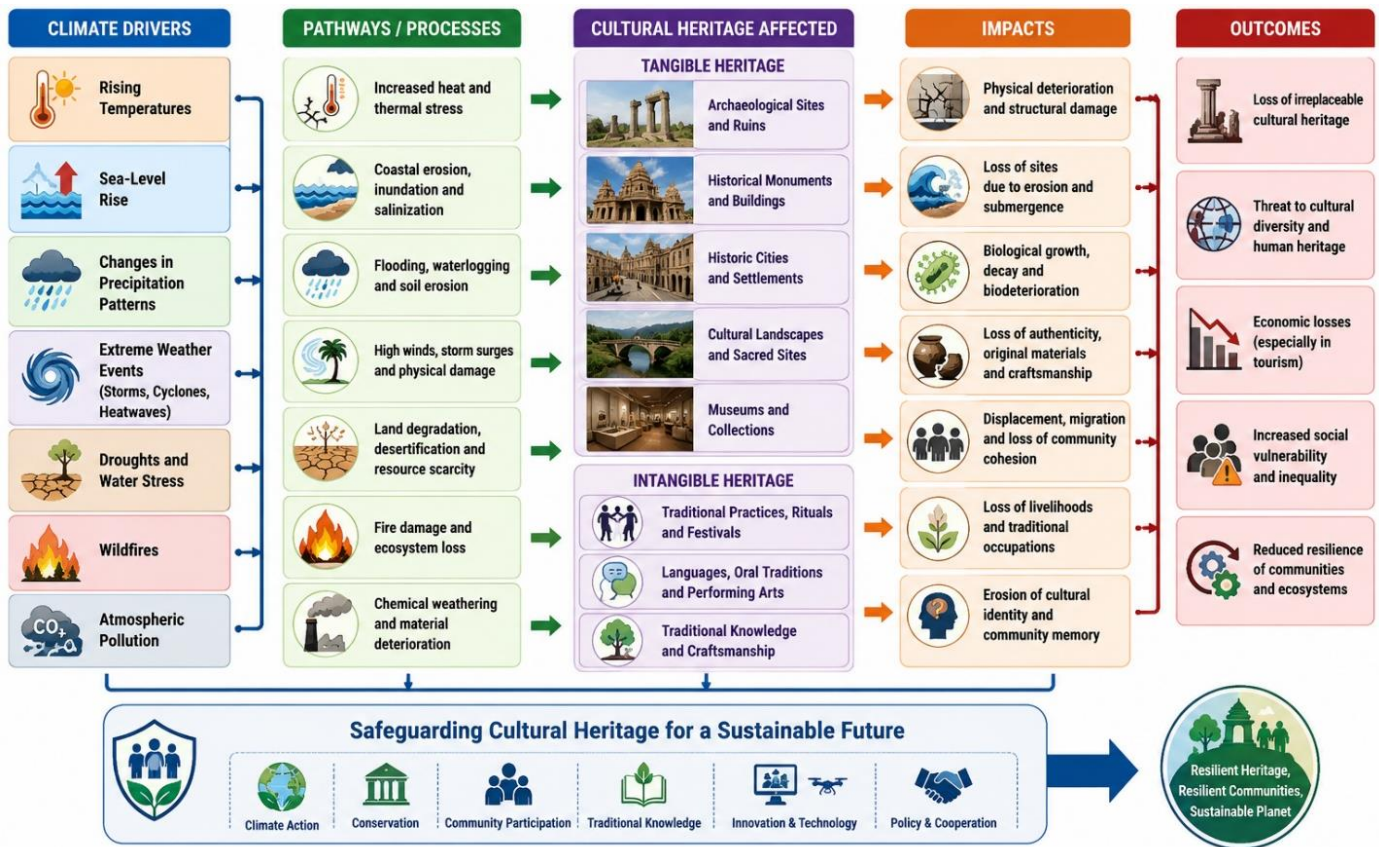


Figure 1: Climate change pathways affecting cultural heritage.

Moisture Damage: Moisture infiltration remains one of the most destructive processes affecting heritage structures. Climate change increases: Capillary rise, Groundwater fluctuations, Wall dampness, Salt crystallization, Biological colonization, and Fungal growth. Repeated wet-dry cycles significantly reduce the durability of masonry materials.

Biological Colonization: Warmer temperatures combined with increased humidity encourage: Moss, Lichens, Algae, Fungi, and Higher vegetation. Plant roots penetrate masonry joints, accelerating structural deterioration while microbial activity contributes to biochemical weathering.

Coastal Heritage: Many historically significant monuments are located near coastlines because ancient

civilizations developed around maritime trade routes. Climate-related coastal threats include: Shoreline retreat, Salt crystallization, Marine erosion, Storm surges, and Coastal flooding. Ancient ports, temples, forts, and archaeological settlements face increasing risk from sea-level rise.

Urban Heat Islands: Historic cities increasingly experience urban heat island effects resulting from: (i) Dense construction; (ii) Asphalt surfaces; (iii) Reduced vegetation; and (iv) Air pollution. Higher urban temperatures accelerate deterioration of building materials while increasing maintenance costs.

Table 2: Climate hazards affecting historical monuments.

Climate hazard	Physical impact	Conservation challenge
Rising temperature	Thermal cracking	Structural instability
Heavy rainfall	Moisture penetration	Masonry deterioration
Flooding	Foundation damage	Restoration complexity
Sea-level rise	Coastal erosion	Site relocation impossible
Storms	Roof damage	Emergency conservation
Wildfires	Fire destruction	Loss of wooden heritage
Humidity	Biological growth	Continuous maintenance

4. Climate change and traditional communities

Climate change affects not only monuments and archaeological remains but also the communities that create, preserve, and transmit cultural heritage. Traditional communities—including indigenous peoples, pastoralists, fishing communities, mountain populations, forest dwellers, and rural societies—possess distinctive cultural identities that are closely connected with their local environments. Changes

in climate alter ecological systems, livelihoods, and social structures, thereby threatening both tangible and intangible cultural heritage [11].

Traditional communities have historically adapted to environmental variability through locally developed knowledge systems, sustainable resource management practices, and social institutions. However, the unprecedented pace of contemporary climate change often exceeds the

adaptive capacity of these communities. Economic pressures, globalization, urbanization, and environmental degradation further compound their vulnerability.

Loss of Traditional Livelihoods: Many traditional occupations depend directly upon climatic conditions. Agriculture, pastoralism, fisheries, handicrafts, forestry, and medicinal plant collection are all influenced by temperature, rainfall, and ecosystem health.

Climate change affects these livelihoods by: (i) Declining agricultural productivity; (ii) Increased drought frequency; (iii) Water scarcity; (iv) Changing fish migration patterns; (v) Forest degradation; (vi) Pest outbreaks; and (vii) Reduced biodiversity

Loss of livelihoods often forces migration to urban areas, weakening community cohesion and reducing opportunities for intergenerational transmission of cultural practices.

Displacement and Climate Migration: Extreme weather events increasingly displace populations from their ancestral lands. Floods, cyclones, sea-level rise, desertification, and prolonged droughts have contributed to climate-induced migration across many regions.

Migration has several cultural consequences: (i) Abandonment of sacred places; (ii) Loss of indigenous languages; (iii) Decline of oral traditions; (iv) Reduced participation in festivals; (v) Breakdown of community institutions; and (vi) Weakening of customary governance systems. When communities relocate permanently, their cultural landscapes often disappear together with their traditional ecological knowledge.

Threats to Indigenous Knowledge Systems: Indigenous and traditional knowledge has evolved through centuries of interaction with local ecosystems. Such knowledge includes: Rainfall prediction, Water harvesting, Crop diversity, Forest conservation, Herbal medicine, Sustainable grazing, Soil management, and Disaster preparedness. Climate change alters ecological indicators upon which traditional forecasting depends. Species migration, altered flowering seasons, unpredictable rainfall, and changing river flows reduce the reliability of inherited environmental knowledge.

Cultural Festivals and Rituals: Many traditional festivals are synchronized with seasonal cycles. Agricultural ceremonies, harvest festivals, fishing rituals, and religious observances depend upon predictable environmental conditions. Climate variability has resulted in: Crop failures,

Delayed flowering, Reduced harvests, Altered river flows, and Water shortages. Consequently, many communities are forced to modify or abandon long-established cultural practices.

5. Major climate threats to historical monuments

Historical monuments experience multiple forms of deterioration resulting from interactions among physical, chemical, and biological processes. Climate change intensifies these mechanisms through increasingly unstable environmental conditions.

Temperature Fluctuations: Daily and seasonal temperature variations produce repeated cycles of expansion and contraction within construction materials. Stone, brick, wood, and metals respond differently to thermal stress, leading to cracking, deformation, and gradual structural weakening. Repeated thermal cycles contribute to: Surface scaling, Joint failure, Material fatigue, Detachment of decorative elements, and Loss of structural cohesion.

Moisture and Humidity: Moisture remains one of the most destructive agents affecting heritage conservation. Increased rainfall and humidity accelerate: Salt crystallization, Chemical weathering, Biological growth, Timber decay, Corrosion of metals, and Paint deterioration. Moisture-related deterioration often continues long after flooding events have ended.

Flooding: Floodwaters threaten monuments by: (i) Undermining foundations; (ii) Depositing sediments; (iii) Transporting pollutants; (iv) Increasing hydrostatic pressure; (v) Damaging interior decorations; and (vi) Weakening structural stability. Historic riverfront settlements are particularly vulnerable.

Coastal Erosion: Many ancient civilizations flourished along coastlines. Rising sea levels now threaten numerous archaeological sites through: Shoreline retreat, Wave erosion, Saltwater intrusion, Permanent inundation, and Increased storm surges. Unlike movable museum collections, coastal monuments generally cannot be relocated without losing their historical context.

Biological Deterioration: Warmer temperatures encourage biological colonization by: Algae, Moss, Lichens, Higher plants, Insects, and Fungi. Biological activity accelerates physical deterioration by retaining moisture and producing organic acids.

Table 3: Climate change impacts on traditional communities.

Climate driver	Community impact	Cultural consequence
Drought	Crop failure	Decline of agricultural rituals
Floods	Displacement	Loss of sacred landscapes
Sea-level rise	Coastal migration	Abandonment of heritage settlements
Heat waves	Health stress	Reduced participation in cultural events
Forest degradation	Loss of medicinal plants	Decline in traditional healing knowledge
Biodiversity loss	Reduced ecosystem services	Loss of cultural practices linked to species

6. Challenges in cultural heritage conservation

Protecting cultural heritage under changing climatic conditions presents complex scientific, technical, institutional, and financial challenges.

Limited Financial Resources: Conservation projects require substantial investments for: Structural stabilization, Scientific monitoring, Digital documentation, Skilled restoration, Climate adaptation, and Disaster preparedness.

Many developing countries possess rich cultural heritage but lack adequate conservation funding.

Inadequate Climate Integration: Conventional heritage management plans often focus on restoration after deterioration rather than proactive climate adaptation. Many conservation policies still overlook: Climate risk assessment, Hazard mapping, Long-term environmental monitoring, and Adaptive maintenance planning. Integrating climate science into heritage management remains an emerging field.

Insufficient Documentation: Thousands of archaeological sites remain undocumented or poorly recorded. Without comprehensive inventories: (i) Damage cannot be accurately assessed; (ii) Restoration becomes difficult; (iii) Digital reconstruction is limited; and (iv) Cultural losses remain unquantified. Modern technologies such as Geographic Information Systems (GIS), drones, LiDAR, Building Information Modelling (BIM), and three-dimensional laser scanning significantly improve documentation quality.

Shortage of Skilled Professionals: Climate-resilient conservation requires interdisciplinary expertise involving: Archaeologists, Architects, Climate scientists, Conservation engineers, Geologists, Material scientists, Ecologists, and Anthropologists. Many regions lack sufficient trained personnel to address increasingly complex conservation needs.

Community Participation: Successful conservation depends upon active involvement of local communities. Challenges include: Limited awareness, Economic pressures, Youth migration, Declining traditional skills, and Weak institutional coordination. Community-based conservation often produces more sustainable outcomes than externally imposed management systems.

7. Adaptation and mitigation strategies

Addressing climate-related threats requires integrated strategies combining scientific innovation with traditional knowledge.

Climate Risk Assessment: Risk assessments identify vulnerable heritage sites based on: Elevation, Flood

susceptibility, Coastal erosion, Material vulnerability, Visitor pressure, and Environmental exposure. Prioritization enables efficient allocation of conservation resources.

Preventive Conservation: Preventive conservation aims to reduce deterioration before significant damage occurs. Key measures include: Drainage improvement, Moisture control, Vegetation management, Protective shelters, Regular maintenance, and Structural monitoring. Preventive approaches are generally more economical than extensive restoration.

Digital Documentation: Advanced digital technologies greatly strengthen heritage conservation. These include: 3D laser scanning, Photogrammetry, Drone surveys, Virtual reality, Digital archives, Artificial intelligence-assisted monitoring, and Digital twins. Digital records preserve detailed information even if physical structures suffer damage.

Nature-Based Solutions: Natural ecosystems often provide effective protection for heritage sites. Examples include: Mangrove restoration, Wetland conservation, Riverbank stabilization, Urban green infrastructure, and Forest conservation. These approaches simultaneously support biodiversity conservation and climate adaptation.

Traditional Ecological Knowledge: Traditional ecological knowledge complements scientific conservation through: (i) Sustainable water harvesting; (ii) Indigenous architecture; (iii) Climate-responsive building design; (iv) Local construction materials; (v) Community disaster preparedness; and (vi) Biodiversity conservation. Combining indigenous knowledge with modern engineering often improves resilience.

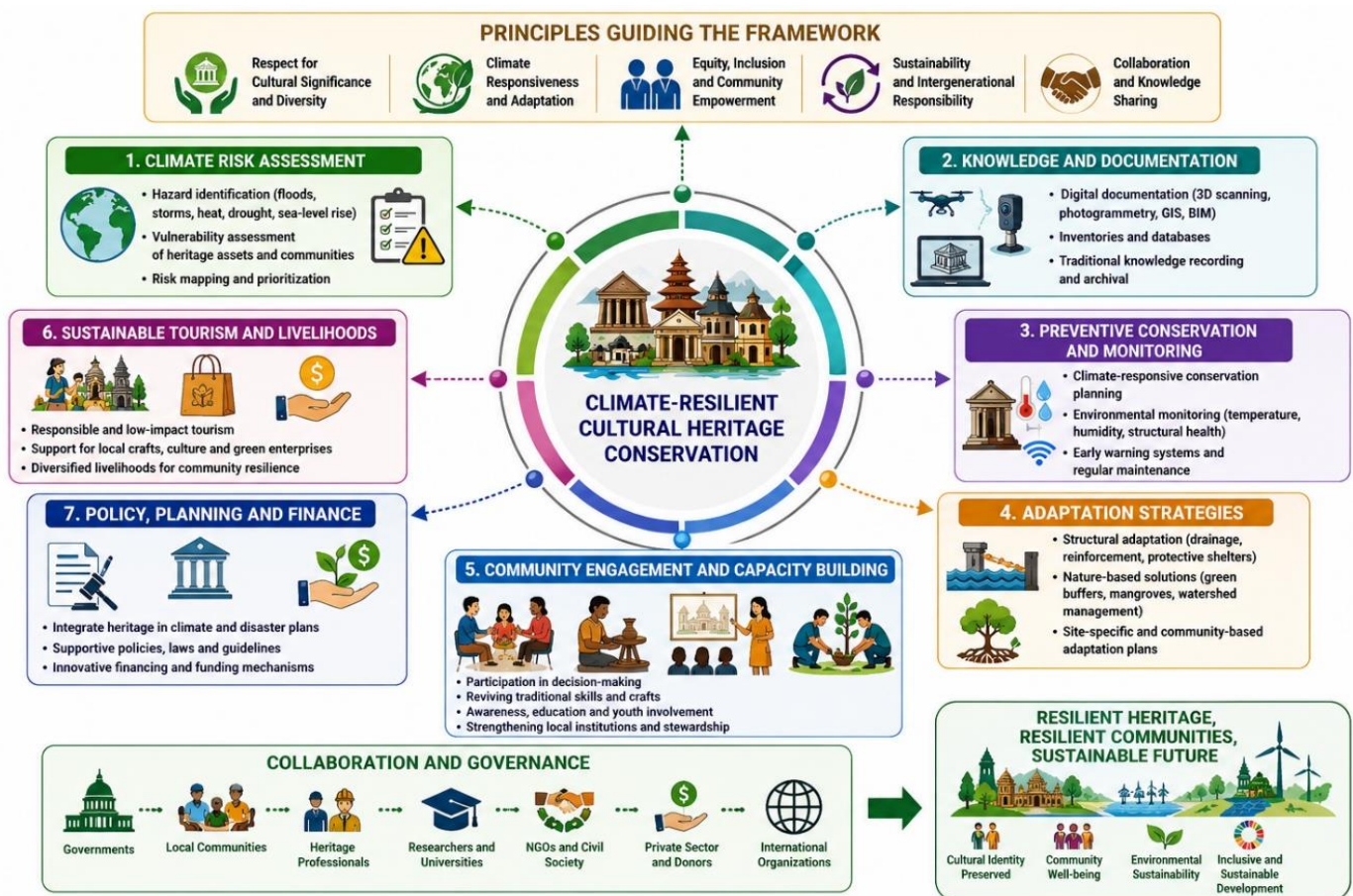


Figure 2: Integrated framework for climate-resilient cultural heritage conservation.

8. International case studies

The impacts of climate change on cultural heritage are evident across diverse geographical regions. Historical monuments and traditional communities face varying climate-related threats depending on their environmental settings, construction materials, socio-economic conditions, and governance systems. The following case studies illustrate the global nature of these challenges and highlight effective adaptation measures.

Venice, Italy: One of the world's most celebrated historic cities, Venice has experienced increasing episodes of flooding due to sea-level rise, land subsidence, and more frequent storm surges. Saltwater intrusion damages stone masonry, bricks, frescoes, and wooden foundations, while prolonged moisture accelerates biological growth and structural deterioration [12].

The Italian government has implemented the MOSE flood barrier system, improved drainage infrastructure, and strengthened monitoring of historic buildings. Nevertheless, long-term preservation requires continuous adaptation because projected sea-level rise may exceed current engineering capacities.

Archaeological Sites in Egypt: Ancient monuments along the Nile Valley are increasingly exposed to extreme temperatures, desertification, groundwater fluctuations, and flash floods. Increased thermal stress accelerates cracking in limestone monuments, while changing groundwater levels contribute to salt crystallization within archaeological structures [13].

Conservation authorities have expanded environmental monitoring, improved visitor management, and introduced scientific restoration techniques to minimize deterioration.

Coastal Heritage in Bangladesh: Bangladesh possesses numerous archaeological remains, historic mosques, temples, and traditional settlements located in coastal regions. Cyclones, tidal flooding, saline intrusion, and shoreline erosion threaten both physical heritage and the livelihoods of surrounding communities.

Community-based adaptation programmes integrating mangrove restoration, disaster preparedness, and traditional ecological knowledge have demonstrated promising outcomes in enhancing resilience [14].

Himalayan Cultural Landscapes: Mountain communities throughout the Himalayas maintain rich traditions linked to forests, glaciers, rivers, and alpine ecosystems. Accelerated glacier retreat, changing snowfall patterns, landslides, and water scarcity increasingly affect pilgrimage routes, monasteries, sacred forests, and traditional agriculture.

Local communities have responded by reviving traditional water harvesting systems, strengthening community forestry institutions, and documenting indigenous knowledge for future generations [15].

Indigenous Communities in the Arctic: Rapid warming in Arctic regions has transformed sea ice conditions, wildlife migration patterns, and permafrost stability. Indigenous communities dependent upon hunting, fishing, and seasonal mobility face unprecedented environmental changes that threaten traditional knowledge and cultural continuity.

Collaborative research involving indigenous knowledge holders and climate scientists has improved understanding of environmental change while strengthening community resilience.

Table 4: Selected global case studies of climate change and cultural heritage.

Region	Heritage type	Major climate threat	Adaptation strategy
Venice, Italy	Historic city	Sea-level rise, flooding	Flood barriers, monitoring
Egypt	Archaeological monuments	Heat, groundwater changes	Scientific restoration
Bangladesh	Coastal heritage	Cyclones, salinity	Community-based adaptation
Himalayas	Cultural landscapes	Glacier retreat, landslides	Traditional water management
Arctic	Indigenous heritage	Permafrost thaw	Indigenous knowledge integration

9. Future research directions

The conservation of cultural heritage under changing climatic conditions remains an evolving interdisciplinary field. Future research should prioritize the following areas:

Advanced Climate Risk Modelling: High-resolution climate models can improve predictions regarding the vulnerability of heritage sites to flooding, erosion, storms, droughts, and temperature fluctuations.

Artificial Intelligence: Artificial intelligence offers significant opportunities for: Automated damage detection, Predictive maintenance, Crack monitoring, Image-based deterioration assessment, Digital reconstruction, and Heritage documentation.

Machine learning algorithms can process large datasets to identify deterioration trends before visible damage occurs.

Digital Twins: Digital twins are virtual replicas of monuments that continuously integrate monitoring data, enabling conservation professionals to simulate environmental impacts and evaluate restoration strategies.

Community-Based Heritage Conservation: Future conservation initiatives should strengthen partnerships with local communities by encouraging participatory planning,

traditional craftsmanship, indigenous knowledge documentation, and youth engagement.

Sustainable Tourism: Tourism provides financial support for conservation but also increases environmental pressure. Sustainable tourism strategies should balance visitor access with heritage protection through carrying-capacity assessments, eco-friendly infrastructure, and responsible visitor management.

International Collaboration: Climate change is a global phenomenon requiring coordinated international action. Strengthening collaboration among governments, universities, heritage organizations, museums, and international agencies will facilitate knowledge exchange, funding, and technological innovation.

10. Conclusion

Climate change has emerged as one of the greatest long-term threats to both tangible and intangible cultural heritage. Rising temperatures, changing precipitation patterns, sea-level rise, floods, storms, droughts, wildfires, and biological deterioration increasingly endanger historical monuments, archaeological sites, museums, cultural landscapes, and

traditional settlements. Simultaneously, traditional communities experience declining livelihoods, displacement, disruption of cultural practices, and erosion of indigenous knowledge systems.

The conservation of cultural heritage can no longer rely solely on conventional restoration methods. Instead, climate resilience must become an integral component of heritage management through preventive conservation, scientific monitoring, digital documentation, climate risk assessment, ecosystem-based adaptation, and community participation. Emerging technologies—including Geographic Information Systems, remote sensing, laser scanning, artificial intelligence, digital twins, and Building Information Modelling—provide valuable tools for documenting and protecting heritage resources under changing environmental conditions.

Traditional ecological knowledge also represents an important resource for climate adaptation. Indigenous communities possess centuries of experience in sustainable resource management, climate-responsive architecture, water conservation, and biodiversity protection. Integrating scientific knowledge with local cultural practices offers a comprehensive approach to safeguarding heritage while strengthening community resilience.

Policy makers should mainstream cultural heritage into national climate adaptation plans, disaster risk reduction strategies, environmental policies, and sustainable development programmes. Greater financial investment, interdisciplinary collaboration, public awareness, and international cooperation are essential for ensuring that cultural heritage continues to inspire future generations despite accelerating climatic change.

Ultimately, preserving cultural heritage is not merely about protecting monuments or traditions; it is about safeguarding humanity's shared history, cultural identity, and collective memory. Climate-resilient heritage conservation therefore represents both a scientific responsibility and a moral commitment toward present and future generations.

Author contributions

The author solely conceived the study, reviewed the literature, analyzed the available evidence, interpreted the findings, and prepared the manuscript.

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