Climate Risk and Resilience in Angkor

2023 - 2025

Front Cover Image:
View of Angkor Wat
Photograph by LIM BUNHONG, TECHNICAL OFFICIAL, Department of Conservation of Monuments and Archaeology, APSARA National Authority

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Foreword from Dr Victoria Herrmann, Director of Preserving Legacies

You can feel Angkor's wonder before you see it.

As you await sunrise at the temple's base, all is shrouded in the darkness of near dawn. The site looms somewhere beyond our species' scotopic vision – but not beyond our ethereal sense. The feeling is a sensation indescribable, and yet innately known by every human. A gravitational attraction towards something bigger than oneself, something monumental in sacred spirituality and ancient authority.

Angkor Archaeological Park is monumental by every measure. These hallowed grounds of now silent stones and feral forests were once the heart of the mighty Khmer Empire from the 9th to 15th centuries. At its peak, the capital cities located here were home to nearly one million people and boasted the water, transportation, and cultural infrastructure needed to support one of the largest population centres in pre-modern history. To contain such a sprawling epicentre of empire, the footprint of Angkor's remains is impossibly large. It stretches across some 400 square kilometres of diverse topography and rises high into the heavy skies of Siem Reap as tower-like prangs stretch their stone spires above the modern-day smog to the heavens beyond.

Th s – all this – is what tugs your core consciousness towards the temple. It is the anticipation of peering into the ancient world of Khmer engineering and cultural complexity at fi st light. In the darkness, you feel unaccompanied save for the temple stones and whispers of past lives lived here. But of course, you are not alone.

Thousands of other souls hungry for a peek into the past surround you. The crowds of Angkor Wat at sunrise are a swell of humanity in all its beautiful diversity, filled with international tourists, local guides and vendors, and Buddhist devotees visiting in ritual. Together they are a reminder that Angkor is simultaneously a symbol of Cambodian resilience and restoration, and a site claimed as the heritage of all humankind.

Th s local-global crossroad found at Angkor during sunrise is at the heart of Preserving Legacies. Our climate adaptation initiative strives to sustain communities that rely on heritage places and inspire all of humanity to learn from and care for our species' shared legacies for future generations.

In partnership with the International Council for Monuments and Sites, the Climate Heritage Network, and the National Geographic Society, Preserving Legacies is a global initiative with a mission to empower every community to protect their cultural and natural heritage against climate change impacts. We do this by equipping local leaders with climate training based on a plural-knowledge system approach, enabling peer connections with other local leaders around the world, and resourcing climate adaptation actions that protect heritage places. In 2024, Preserving Legacies partnered with 20 remarkable heritage places worldwide, each a testament to resilience, and each year continues to grow a dedicated community of practice committed to securing a sustainable future for heritage in every corner of the world.

The Preserving Legacies risk assessment workshop, held in November 2024 and documented in this report, was the fi st-ever locally led climate convening at Angkor Archaeological Park. The local lead-

ership of this workshop through Chandara Hin, Dara Phoeung, Ly Phally, and Radina Chou, and our partner Ginevra Boatto, truly exemplify the spirit of Preserving Legacies' framework for climate action. Th ough a commitment of becoming local climate experts, through the compassion to bring diverse stakeholders together, and through the courage to try something new, these five custodians led a risk assessment process that was truly of, by, and for the communities it serves.

Preserving Legacies' values-based approach goes beyond assessing risks to the physical attributes of Angkor's temples; it respects the full breadth of heritage values — those that sustain identity, knowledge, and belonging. Th s approach is profoundly community-led, working together with partners like APSARA National Authority and the Siem Reap offic of the World Monuments Fund to identify and respond to the values that matter most to those who use and love Angkor, whether they are rooted in spiritual signifi ance, ecological importance, or cherished memories.

At Angkor Archaeological Park and beyond, our approach is powered by local leadership and sustained by a global community of like-minded leaders — a network of individuals and organizations committed to protecting heritage in a changing climate. Th ough training, knowledge exchange, and the cultivation of inspiring storytelling, we strive to equip local custodians with the skills and resources they need to champion climate resilience in their communities. And in doing so, we aim to inspire more ambitious, collective action on climate adaptation worldwide.

To all those who joined us for the Angkor risk assessment workshop: thank you for your dedication, your insights, and your shared vision of a world where our cultural legacies are not only preserved but celebrated in the face of change. Together, we are weaving a future where Angkor's wonders continue to enrich future generations in Cambodia and inspire all of humanity with its monumentality and ingenuity.

Foreword from Jonathan S. Bell, Vice President of Programs, World Monuments Fund

Climate change is the preservation challenge of our day. Tangible heritage and intangible practices are both under threat from rising seas, unpredictable weather, wildfi es, drought, and other hazards on the rise. Our watchwords, "minimal intervention", and "preservation in situ" mean that by their very nature, traditional preservation practices are often reactive rather than proactive. As the pace and scale of climate change impacts continues to threaten the places we care about, World Monuments Fund is proud to have collaborated with the Preserving Legacies team on a new approach to build local capacity in the development and implementation of climate adaptation strategies.

The Preserving Legacies approach is particularly robust because it integrates scientific, local, and Indigenous knowledge to fi d sustainable solutions to the long-term preservation of cultural heritage sites in the face of the climate crisis. Th s integration of different knowledge systems supports developing lasting, culturally appropriate adaptation strategies. By empowering site managers and local communities with the knowledge and tools to create their own tailored adaptation plans, Preserving Legacies is building a cohort of sites better prepared to face climate uncertainty.

WMF has been working at the Angkor Archaeological Park since 1989, working closely with the APSARA National Authority since its founding to build preservation capacity through multiple large-scale projects throughout the park. We have been working with Preserving Legacies since the beginning of 2023, introducing them to APSARA and helping select key site custodians for their training. The site custodians, selected from three different departments (Water, Forestry and Infrastructure; Conservation, Monuments and Archaeology; Administration), joined the Preserving Legacies' online training for 12 months, supported by our team in Cambodia. The training and close collaboration helped foster understanding of climate change literacy, adaptation and mitigation mechanisms, as well as the concepts of risk and vulnerability, all within the context of values-based cultural heritage preservation. The learning was strengthened by exchanges with site managers and custodians from nine other sites across the globe and fi ld visits to Petra, Jordan and Ifugao Rice Terraces, Philippines. Additionally, Cambodian participants were asked to organize focus group discussions with local community members and management leadership in Angkor to identify key stakeholders and their perspectives.

WMF's role in this partnership has been to ensure success of the training by supporting APSARA staff in their active and thoughtful participation. WMF worked closely with the site custodians to ensure the training was both accessible to them and relevant to the Cambodian context. Their diverse backgrounds contributed to the richness and depth of the conversations, but also required mediation to ensure effective communication and understanding of complex concepts. Ultimately, the collaboration enhanced the learning across the team and facilitated their cooperation and exchange of information between the different departments they represent.

With the completion of the fi st phase of online training, the Cambodian site custodians began developing a workshop to assess climate risk at Angkor. The fi st workshop of its kind in Cambodia, it presented an analysis of the key values associated with Angkor alongside a review of future climatic changes impacting Angkor. The workshop then invited participants, all local community members and high-level site managers, to assess Angkor's capacity to adapt to future climatic threats and pro-

pose relevant strategies. The outcomes from the workshop have been turned into recommendations that will inform a future adaptation plan for Angkor.

Preserving Legacies' leadership in localizing climate action for cultural heritage falls squarely in alignment with WMF's Climate Heritage Initiative. Th ough this effort, we are working with teams on the ground to promote best practice, share climate solutions, and showcase adaptation strategies at heritage sites around the world. By localizing climate action and supporting communities in essential decision-making, World Monuments Fund and Preserving Legacies are helping to ensure that humanity's past has a resilient future.

Foreword by H.E. Mr. Yit Chandaroat, Deputy Director General of APSARA National Authority

The APSARA National Authority is proud to join the Preserving Legacies Project to better understand the impacts of climate change on the World Heritage Site of Angkor, and its communities, and to develop place-specific and people-centred climate change adaptation plans.

Today, we are working against time. The climate emergency is placing stress on places and communities globally, and our response must be ready, rapid and relevant. So far climate action has fallen short, particularly in relation to the interconnections with culture and heritage.

Through the course of the project, the Angkor communities placed specific emphasis on the economic value of heritage, primarily through agriculture and tourism, in addition to the historic, archaeological and natural values.

For the people of Angkor, the integrity of monuments, buildings, landscape, plants and animals of Cambodia are as important as are activities in and around the site that contributed to their wellbeing – and all are experiencing damage as a result of climate change. This damage is pervasive and persistent, requiring a dynamic and continuous response requiring significant investments of time, resources and effort.

As a result, our work through Preserving Legacies focused on finding an innovative and effective approach that emphasised inclusion, valorised local voices and created a space to integrate science, knowledge, learning and community values. By bringing together this diversity of knowledge systems, the project sought to design more nimble, implementable, sustainable and culturally appropriate solutions and adaptation methodologies.

We are pleased to be able to share our findings in this report and to contribute to creating a connected global community of practice, sharing experiences and learning from one another as we address the challenges of climate change impacts on our cultural heritage. Ultimately, we all face a global threat and we share a common goal: to safeguard our heritage for future generations.

We would like to thank our partners, the World Monuments Fund (WMF), the International Council on Monuments and Sites (ICOMOS), the Climate Heritage Network and National Geographic Society for their support and contributions.

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- GIZ, Gesellschaft ür Internationale Zusammenarbeit
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Th s project would not have been possible without the fi ancial support of the National Geographic Society. We would like to thank them for their ongoing trust and commitment to saving the world's cultural and natural heritage. We also wish to thank the World Monuments Fund for the on site coordination and fi ld support over these two years.

Report Outline

Th s report introduces Preserving Legacies as an international training project, describes its philosophy, its methodological approach, and the rich background brought by the people that are part of it.

A description of the Angkor Archaeological Park is offered, the most prominent and representative heritage site in Cambodia, with its historical structures, natural elements and the communities that live in the park, which was listed a World Heritage site in 1992. Angkor Park was among the sites which benefited from the Preserving Legacies' training.

Angkor, like other sites in the world too, is an inspiring example of adaptation and resilience against all events and changes, some more tragic than others, which over a millennium of history have brought forward, the last of which is climate change. A description of the increasingly-more-concerning intersection between cultural heritage and climate change is then provided.

The next section includes a review of the stakeholders and rights holders identifi d through focus group discussions in the fi st year of Preserving Legacies' partnership with the World Monuments Fund and the APSARA National Authority in 2023 and 2024. Th s initial exercise has thus laid the foundation for the future climate change risk assessment workshop, by guaranteeing that everyone would be represented and could participate in the risk assessment event described here.

As previously described, the methodology embraced by Preserving Legacies places a site's values in the very center of the discussion, led by the different communities of the site, and this is described in Chapter 4. Understanding what they are and how these and their attributes, their tangible manifestations, play a role for people (be they villagers, religious people or researchers) is what guides the understanding of climate change risk at the heritage site. Chapter 5 offers the result of the analysis of Angkor's "key" values and attributes, as identifi d throughout the workshop in November 2024.

Chapter 6 is a review of the present and past hazards that climatic changes have caused to the Angkor site, including different precipitation patterns and how these have already had a tangible effect on the historical fabric, the forested areas and the way people live and use them. Building on the learning from the preceding chapter, the next section delves into the future climate hazards at Angkor, based on extensive projections developed in different studies. A key section of this report, in Chapter 8, focuses on the understanding of the different aspects of risk, a concept at the core of the assessment workshop conducted in November 2024.

Chapter 9 raises the critical questions: how vulnerable and at risk is the site and are the communities to forthcoming climatic changes? How is Angkor exposed? And, most importantly, what is the intrinsic capacity of Angkor, its people, its monuments and forested lands to adapt and react to these changes? It is the answers to these questions that led us through the risk statements, the most critical outcome of the workshop, in Chapter 10.

The very last chapter of this report, number 11, importantly sets the stage for the immediate future. How can we most benefit from what we have learned from the workshops How can we identify key

recommendations to guide a possible adaptation plan to adapt to climatic changes at the site of Angkor ? We hope you will enjoy reading this report as much as we have devoted our attention and care in transmitting and sharing as much as possible with all the stakeholders and all the participants, for Angkor and the cultural heritage of Cambodia and the world.

1.Preserving Legacies: Introduction

The fi dings in this report are the outcome of two years of hard work by four professionals from the APSARA National Authority, in consultation with a broad coalition of stakeholders of the Angkor Archaeological Park, to safeguard the site from the future impacts of climate change and under the aegis of World Monuments Fund's team in Cambodia.

The APSARA custodians are supported by Preserving Legacies, a broader global initiative of professionals who work at the Intersection of heritage and climate change. Th s work is wholly funded by the National Geographic Society, and in collaboration with the International Council on Monuments and Sites (ICOMOS) and the Climate Heritage Network.

At its core, Preserving Legacies empowers local leaders with the scientific knowledge and technical training so that they can develop their own climate change adaptation plans. What custodians achieve is a response to key climate change risks that is uniquely tailored to local concerns and cultural contexts. Th s work becomes increasingly necessary for heritage managers, communities and other stakeholders to address climate risk and incorporate climate preparedness in community structures and management policies.

Th s values-based and locally-led approach is essential for communities to develop effective, sustainable responses to climate risk that can be integrated into site management or even broader policy structures. The heart of this work is identifying key risks to what local communities value most about the site, and, when assessed through the lens of local, indigenous, and scientific knowledge systems, enables resilient climate adaptation.

The custodians from the APSARA National Authority are part of a global family of heritage custodians that Preserving Legacies has gathered together. They include custodians from Antigua and Barbuda, Bangladesh, Bhutan, Brazil, Cambodia, Canada, Colombia, France, Ireland, Jordan, Mongolia, the Philippines, Togo and Benin, Taiwan ROC, Tunisia, and the United States of America. Th s global network enables peer-to-peer learning in a supportive environment, each working towards their own adaptation plans in the unique contexts of their heritage sites.

The work represented in the Climate Resilience and Risk Report included community consultations and culminated in a climate change risk assessment workshop, which represents the second year of a three-year program. As a fi al output of their third year in 2025, APSARA custodians will develop climate change adaptation plans.

2. Methodological Background and Overview

Climate change has emerged as a leading threat to cultural heritage around the globe. From rising sea levels and coastal erosion to changes in temperature and precipitation patterns, climate change represents the single greatest challenge to the heritage sector. It has been estimated that one in three natural sites and one in six cultural sites are currently at risk from the impacts of climate change and these figu es are steadily increasing. In their 2023 report, the Intergovernmental for Panel on Climate Change (IPCC) noted the broad geographical scope of these impacts and the complexity of this challenge which extends beyond tangible monuments and structures to the intangible, including the heritage of local and indigenous communities who are often uniquely vulnerable to climate hazards.

The current and future impacts to cultural heritage from climate change extend far beyond World Heritage (WH); however, WH properties have an important role to play in climate action. The 2023 UNESCO Policy Document on Climate Action for World Heritage notes that climate change may impact the Outstanding Universal Value (OUV) of WH properties, including their integrity and authenticity, as well as communities social and economic development. It further notes the important role which iconic WH properties can play in promoting climate action through mitigation and adaptation measures. Heritage is both at risk from climate change but also an asset in realising sustainable change and building the resilience of communities.

The temporal and spatial scale of this challenge cannot be underestimated and, like many other sectors, the heritage community is struggling to respond. ICOMOS has suggested that new open access tools and approaches to vulnerability assessment, mitigation techniques, monitoring and damage assessment, conservation and adaptation efforts are key to heritage management and conservation. There is a need to rethink some existing approaches including how we assess and respond to climate-related risk. Given the broad impact of climate change on both tangible and intangible culture and communities, it is essential that these assessments are listened to and address the concerns of all stakeholders. These new approaches must align with best-practice in both the heritage and climate science sectors, embracing transdisciplinary approaches and encouraging dialogue amongst often separate groups.

Th s important report records the results from a climate risk assessment undertaken at the Angkor World Heritage property in 2024. It was undertaken as part of an ongoing project called Preserving Legacies which is an action oriented ongoing global initiative, currently working with local leaders from over 30 heritage places, equipping them the scientific knowledge and technical training to develop place and people-based climate adaptation actions. The complexity of the climate change impacts and risk requires unique place-based responses which are appropriate to individual sites and communities. Preserving Legacies proposes a framework for assessing risk which is values-based and community-led, ensuring ethical and equitable engagement by promoting local empowerment and engagement at every step of the process. It takes a broad social and spatial approach which looks beyond traditional boundaries and silos to ensure that wider voices are heard. Crucially, it also embraces diverse knowledge systems including local knowledge of current and past weather, responses and up-to-date climate models and scenarios from the IPCC which facilitate future assessments of risk. Th s framework is directly informed by and aligns with the most recent IPCC approaches to risk, assessing and quantifying climate hazards, vulnerabilities, exposures and responses. It aims to inform

sustainable and impactful adaptation at sites which refl ct the reality of future risk.

The values which make heritage places special are unique so the response to protecting and conserving these places must also be specific to these values. Th s report presents a climate risk assessment approach which has been informed by the Preserving Legacies framework and designed specifi ally for the Angkor WH property. While its primary value is to the Angkor site, it also has broader value to Cambodian heritage practice, illustrating the importance of place-based and locally led risk assessments.

3. Site Introduction and History

An Introduction to Angkor

Angkor is one of the most important archaeological sites in Siem Reap province in northern Cambodia and is a major site in Southeast Asia and the world. Th s site was built as the distinct capital from 9th to 15th century A.D and contains numerous temples, hydraulic structures (ponds, dams, vast reservoirs, canals), as well as communication routes, kiln sites and intangible community heritage. The culture of the site also refl cts the gradual change of religion from Brahmanism-Buddhism (Hindu and Mahayana practices) in the Angkor period to Theravada Buddhism began in the mid/late 13th century CE in the post-Angkorian period at this site. (Harris et al 2022).

In addition, Angkor has evidence from the pre-Angkorian period from the 7th to 8th century A.D principally that divided two main spots, namely Banteay Choeu and Roluos region. The western Baray has Ak Yum temple, Phnom Ruong temple, Kuk Khpus temple, Kuk Po, Prei Khmeng temple, Phum Prasat temple, Prasat Rolus temple and Khnat temple. However, the Roluos region site contains the main temples. Furthermore, Angkor fi ds its roots in the prehistoric periods illustrated by some evidence of inhabitation. These prehistoric sites include bronze artefacts and ceramics east of the mouth of the Roluos River, both bronze and iron age cultures were discovered under late structures, namely: Chau Say Tevoda, Ak Yum, Thommanon, Basei Chamkrong and Trapeang Phong (Choulean et al 1998:26,27).

Angkor as a World Heritage site

Angkor was inscribed as a World Heritage site in December 1992 in Santa Fe, New Mexico, USA for OUV to entire humanity.[1] The protected site property, extending on 401 square kilometers, has been inscribed under criteria (i), (ii), (iii), and (iv) (whc.unesco.org) and includes 91 temples. Th s is a unique cultural heritage of the Khmer nation, deeply influencing Cambodian identity. The vast ancient heritage in Siem Reap province connects Cambodians to their past and offers hope for the future. Beyond its physical artefacts, Angkor illustrates a great civilization that has shaped all aspects of Cambodian society, extending its influence beyond the country's borders (Choulean et al 1998: XV) which represents an essential period of people's history. Therefore, temples like Angkor Wat, Bayon, Preah Khan, Ta Prohm and others, all examples of Khmer architecture, are closely linked to their geographical context, as well as being imbued with symbolic signifi ance. The architecture and layout of successive capitals are a testament to the social order and high status of the Khmer Empire. Angkor is thus a huge site of cultural, religious, and symbolic value, as well as having high architectural, archaeological, and artistic essentials.[2]

The values outlined in the inscription express the immense and globally signifi ant importance of Angkor as a heritage site; however, they do not capture the many other values of signifi ance locally and nationally. As a large and complex property, Angkor lies at the heart of a community of residents, heritage professionals and others who live in and around it. Understanding these values is equally important when considering risk and speaking directly with different stakeholders is an essential part of the risk assessment process.

1.www.apsaraauthority.gov.kh
2.www.whc.unesco.org

4. Stakeholders Mapping

During the fi st year of Preserving Legacies, site custodians were asked to test the Focus Group Discussion (FGD) method and the Angkor communities' interest and responsiveness to the topic of climate change and heritage. A fi st FGD was organised to identify the main stakeholders of Angkor. Th s topic was chosen to guarantee that the second year's climate change risk assessment workshop would be as inclusive as possible to all the people who make Angkor and care about it.

To this end, on July 6, 2023, the FGD was organized at the Angkor Training Center within the APSARA National Authority. Participants included members from the Provincial Department of Environment, APSARA's Departments of Conservation, Monuments and Archaeology, Land Management, Tourism, Communication, and also from Pradak Commune (inside the Park), the Heritage Police, GIZ[3] German Development Agency and Waseda University, Japan (the latter two are conducting archaeological and architectural restoration work at Angkor). The group also included an undergraduate student of Indravichea University in Siem Reap City, as well as the four Preserving Legacies custodians and key staff from WMF who were instrumental in facilitating the entire project for a total of 15 people. The group included 3 female participants: most participants were vice Directors and Directors of their respective Department and people in these positions in the cultural fi ld in Cambodia are male. Of the 15 people, 3 were foreigners (of Italian, German and Japanese nationality).

Upon their arrival, the focus group was administered a basic survey in English to assess their general understanding of climate change through a multiple-choice questionnaire. In general, it can be argued that the topic of climate change is not new to the participants from Angkor and most people have a correct understanding of it. It is however recommended that, in the future, a similar survey be administered in Khmer language.

Site Custodian Chou Radina initially gave a presentation about climate change to give participants a general idea of this global threat, with examples from Angkor and Cambodia and also his trip to Petra, Jordan, which proved very useful. It must be noted that this was the fi st event of this kind for APSARA and others. In the next presentation, Phoeung Dara focused on the impact of climate change on cultural heritage with several examples taken from online published studies and collections of images (Figure 4.1). His comments addressed both the tangible and the intangible dimensions of heritage and served as a conduit to introduce the concept of values. The latter was then developed further by Ly Phally, who presented the OUV and a few examples of local values of Angkor. Finally, Hin Chandara introduced the concept of stakeholders and stakeholder engagement. It should be noted that a corresponding word in Khmer does not exist, and the English had to be used and then explained.

3. GIZ : Deutsche Gesellschaft ür Internationale Zusammenarbeit.

Figure 4. 1 - (left) hou Radina (right) Phoeung Dara presenting to the participants. (Photo: By the authors)

Th oughout the conversations that followed, where participants contributed their ideas and the site custodians would write them on the white board, the perception was that they had a somewhat clear understanding of the concept of stakeholders, although some degree of confusion was still present despite the explanations (the discussion was predominantly held in Khmer). It was observed how people implied that a stakeholder had to be an individual or a group of people who care about the site and its preservation, while for some of the stakeholders, although identifi d as such, there was debate whether they eventually care for Angkor: the clearest example is that of the sellers. Another element of the discussion was whether the local administrations in the Park should be consolidated with the villagers or not. In any case, one participant pointed out that APSARA Authority has presented many times about the importance of Angkor in schools, pagodas and villages in the Angkor Heritage Protected zone, recognizing all of them as stakeholders. Another participant also added that Angkor as a World Heritage Site is inseparable from the community.

The identifi d stakeholders include:

1. APSARA National Authority, the Government agency in charge of the management of the Park.
2. International conservation teams, the principal ones are 9, mostly government affiliated (with the exception of the World Monuments Fund), their relationship to the site of Angkor is regulated through an MoU with a Cambodian authority.
3. Local authorities and villagers, 112 villages organized in 21 communes, belonging to 5 districts, with a total of about 200,000 people scattered through an area of 401 Km^2.
4. Scientific c mmunity, it comprises all international researchers focusing on Angkor.
5. Community and environment-focused organizations and agencies operating in Angkor Park. In Angkor, there are multiple international and national bodies that focus on projects such as hygiene, rural development, improvement of hydraulic systems, handicrafts, ecotourism, and others.
6. National tourists, over 1,100,000 in 2022, during weekdays and mostly during Cambodian festivities.
7. International tourists, in 2022 almost 300,000 people visited Angkor Park.
8. Tour guides, this includes qualifi d tour guides who operate individually or through a company.

9. Drivers (tuk tuk, car), some of these operated individually, others through travel agencies.
10. The private sector, especially the hospitality fi ld, includes both the large and small-sized hotels in the immediate outskirts of the Park and in Siem Reap City, as well as the restaurants and the entertainment market that caters to domestic and international tourists.
11. Schools inside and outside of Angkor (future generations), from kindergarten to primary and secondary schools to universities.
12. Monastic communities in Angkor, serving 35 Buddhist temples (pagoda), some centuries old, others built after the end of the Khmer Rouge regime in 1979 (808 monks as of 2022).
13. UNESCO through its ICC Angkor mechanism which is held twice every year and includes the technical review from the ad hoc expert team for conservation and sustainable development.
14. Ministries of Environment, Land Management and Urban Planning, Culture and Fine Arts, Defence, Interior, Economy and Finance, Tourism, Water Resource and Meteorology. They are united as a Steering Committee which reviews projects and takes decisions and is presided over by the Her Excellency Dr. Phoeurng Sackona, the Minister of Culture and Fine Arts and Chairwoman of the APSARA National Authority (the Authority is also a member of this council). The steering committee also includes Angkor Enterprise, responsible for collecting the revenues from the ticket sales, which are then sent to the Ministry of Economy and Finance for redistribution.

The participants were then explained the concept of rights holders, or that narrower group of Stakeholders who have either a moral or legal right to the Park. There was disagreement on awarding this status to the domestic tourists therefore the organizers decided not to flag them as rights holders too, especially surprising given that there's a general agreement that Angkor belongs to Cambodia and Cambodians, therefore to national tourists. The fi al exercise concerned the mapping of the identifi d stakeholders within a diagram showing their Power in the site (y coordinate) and their Interest in it (x coordinate) (Figure 4.2 and 4.3). The results of this exercise Workshop informed the selection of the participants to the 2024 Risk Assessment Workshop on climate change. They also influenced the selection of key values at the site during a subsequent series of value assessment workshops.

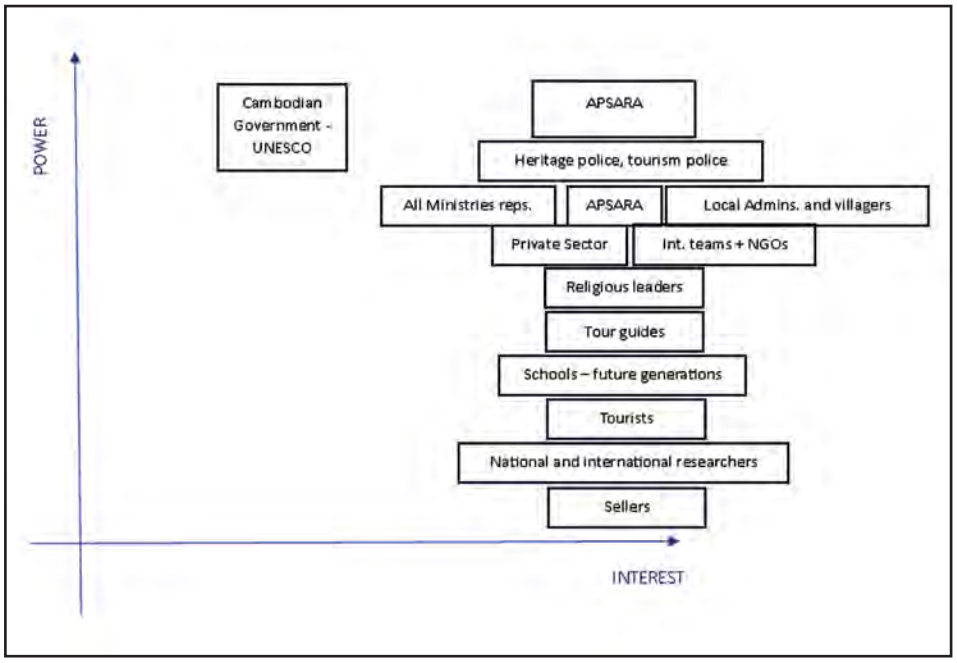

Figure 4.2: Stakeholder power and interest at Angkor. (Image by the authors)

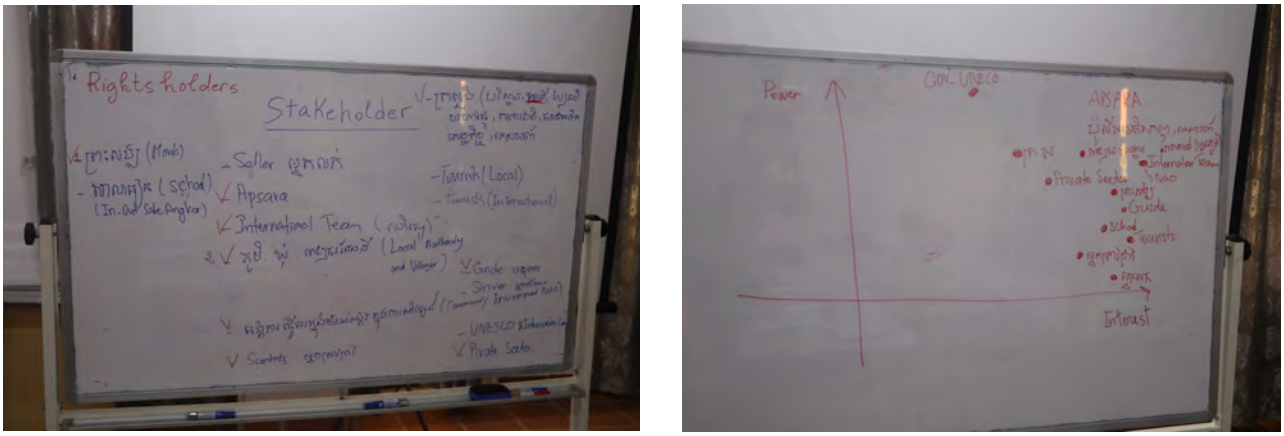

Figure 4.3: Collecting ideas on Stakeholders from the participants (left) nd stakeholders' map according to the workshop attendants (right). (Photos: By the authors)

5. Values and Attributes Mapping

Angkor is an ancient archaeological landscape with extraordinary temples, monuments and layered remains of cities and settlements from the 9th to the 15th centuries. The Angkorian cultural landscape is defi ed by contemporary rice fi lds, ancient thoroughfares, barays, moats, canals and bridges, as well as more recent infrastructure. At Angkor, the environment is inseparable from the monuments including forests, natural features and agricultural lands. The Phnom Kulen, Siem Reap and the Tonle Sap contribute to the dramatic context and setting, as does the ancient hydraulic system, a striking reminder of engineering prowess. Angkor's values are now understood to encompass many more attributes than those acknowledged in the original World Heritage listing statement of Outstanding Universal Value and citation. In particular, there is greater recognition of the importance of intangible values and continuing cultural traditions.[4]

Figure 5.1: The blue landscape of Angkor Wat Temple (Photo: APSARA National Authority)

A key part of the values assessment workshops was identifying these wider values. The workshops, which took place on October 30 and values assessment workshops on November 1st, included stakeholders as identifi d during the focus group discussion outlined in the preceding section. During this workshop and group discussions on the assessment of climate change impacts on the Angkor region, there were two groups of stakeholders in the Angkor region. The fi st group, on October 30, consisted of monks, archaeologists, temple security offic s, forest conservation offic s, tourism agency offic s, teachers, heritage managers, tour guides, temple workers, drivers, vendors, and farmers at the WMF's fi ld classroom location at Phnom Bakheng project site. The second group, on November 1st, consisted of the leadership of the APSARA National Authority, the Director of the Department of Research, Training, and Outreach, the Director of the Department of Temple Conservation and Archaeology, the Director of the Department of Security, the Director of the Department of Water, Forestry, and Infrastructure Management, the Director of the Department of Tourism and Cultural

4.http://apsaraauthority.gov.kh/wp-content/uploads/2024/12/Heritage-Mangement-Framework-October-2013.pd

Development, the Director of the Department of Land, Urban Heritage, and Community Management, a representative of the Bakhong Commune Administration, GIZ Technical Advisor, and a representative of Wat Reach Bo School teachers. These discussions led us to identify key values for the Angkor region.

Table 5.1: Key values identifi d during the workshop

Value	Qualities
Society, history, culture	National symbols, sacred landscapes, places of worship, sacrific al offerings (kochuk), and living historical sites. Kankeung demonstrates a special relationship between the past and the present, refl cting animism, ancestor veneration, and traditional or religious lifestyles. It embodies traditions and customs that testify to the preservation and development of both ancient and modern beliefs, religions, and cultures. Kankeung also serves as a symbol of the nation and identity, the glory of its era, a means of reconciling political confli ts, and a lesson for the development of future generations.
Science Architecture and Urban Planning	Use of space, urban planning, creation of large-scale works (building temples, barays , fi e arts, sculptures, ancient styles, integration between the environment, atmosphere, nature (sunrise at the top of Angkor Wat)/ technology, infrastructure, urbanism, medicine, astronomy, mathematics,
Economy	Small business, industry, agriculture, tourism, transportation, handicrafts, i come, employment
The price of beauty	To raise awareness of history, architecture, literature, culture, traditions, and environmental values
Health value	Grow vegetables naturally, exercise, eat healthy food, reduce the use of plastic bags
Price of the product	To raise awareness of history, architecture, literature, culture, traditions, and environmental values

During the climate risk workshop that followed, on November 20-21, 2024, participants were asked to rank these values in terms of importance to various stakeholders. As a result, three main values emerged, which are explained in further details below:

1. Social, historical, and cultural values;
2. Natural environmental values;
3. Talent, science, architecture, and urban planning.

There three key values are now explored in greater detail including their attributes, which are the physical elements which represent each valuephysical elements which represent each value.

Figures 5.2: Group discussion activities at the Phnom Bakheng fi ld classroom and APSARA Offi (Photo: Ly Phally 2024)

Figure 5.3: Workshop activities at the Public Order Department meeting hall on the 20th and 21st November 2024 (Photo: Elizabeth Carpio 2024)

Key Value 1: Social, historical, and cultural values associated with the Angkor region, a World Heritage Site

Angkor was possibly the world's largest pre-industrial city. Its great architectural remains, featuring complex and massive water management systems, inscriptions, carvings and bas-reliefs, eyewitness accounts, archaeological and documentary evidence are the legacy of a once great civilization. Angkor reflects the development of complex societies in southeast Asia, demonstrating the significant shift in the region from agrarian village life to a centralized, pre-industrial urban society. Its origins may date from as early as the first century BCE. The incipient social complexity of Angkor is demonstrated by later large-scale urban infrastructure and archaeological evidence. The exquisite and detailed carvings and bas-reliefs offer great detail about classical period Angkor, including Angkorian people, their way of life, economy, customs, religious beliefs, warfare and artefacts.

Angkor Wat is the largest religious structure on the planet. Its immense size and artistic qualities reflect the significance of the Angkorian empire in world history. At its height, the empire had a profound and unrivalled impact on the historic development of human settlement and society in southeast Asia. Throughout Southeast Asia, there is evidence of a significant phase of development of and changes to architecture, design, sculpture, engineering and water management. The Angkorian water management systems demonstrate the historical importance of the Khmers as the architects and engineers of the region's most elaborate and geographically extensive hydraulic system.

Angkor illustrates and commemorates the lives and works of great rulers and the people of a great civilization; it also provides an enduring record that links those people to the current Angkorian communities. The architecture at Angkor illustrates the complex religious development of the Khmer civilization and attests to the deep historical influence that animist, Brahmanical and Buddhist religions have had on Southeast Asia, as well as the complex syncretism of these religious beliefs.

Animism underlies the layers of Brahmanical and Buddhist religion and is strongly evident in the villagebased structures, rights and beliefs of villagers in the area today. Contemporary village social structures, village affiliations and hierarchical relationships bear a strong relationship to Angkorian traditions and historical geopolitical structures. The enduring and overwhelming significance and symbolism of Angkor to all generations of Khmer and all the successive regimes which have ruled Cambodia since the Angkorian period (as shown by its continued use as a symbol for the nation, the Khmer people and their aspirations) demonstrate its continuing historic impact on the Khmer identity and nation, and the importance of the Angkorian period to modern Khmer identity and culture.

Angkor is a living historic site where cultural and religious traditions continue and villagers maintain special and enduring connections to the landscape. The site today is an outstanding example of both the continuity of Khmer tradition relating to Angkorian culture, and the continued use of Angkorian and pre-Angkorian landscape and irrigation systems. Angkor contains traditional village landscapes incorporating historically established and ongoing features such as rice fields, ponds and forests, with villages featuring houses of traditional form and materials. Village names often reflect ancient natural and cultural features. Khmer traditions at Angkor are manifest in the naming of places, placement of villages, oral histories, land ownership, respect for temple mounds, festivals, ceremonial and ritual activities, and a range of related cultural practices.

Angkor played a very signifi ant role as a flagship for the French colonial empire, as one of its most publicised and romanticised colonial possessions. Angkor has also been a site of religious veneration in Asia over an extended period of time, beyond the current national boundaries of Cambodia. It remains an important site for Japanese and Indian Buddhist pilgrims. The extraordinary size, grandeur, complexity and conservation challenge of Angkor has attracted outstanding heritage conservation efforts. Th ough the École Française d'Extrême-Orient, the French pioneered a massive program of conservation and research at Angkor. Th s work is signifi ant in the history of conservation and contributed to advances in theory, methodology and practice. UNESCO and the ICC have subsequently nurtured and co-ordinated an international conservation effort that continues to this day.[5]

Attributes: National Symbols, Sacred Landscape, Sacred (for Religion), Sacrifice (Kor Chuk), a lively historical site, has a special connection between the past and present, animism, the traditional way of life religions, traditions, customs, preservation and development of ancient and modern, religious beliefs. Racial evidence, identity, prosperity of the era, reconciliation, political confli t, development lessons for all generations.

Figure 5.4: Wall carvings of Angkor Wat temple (Photo: Will Megarry 2024)

5.https://apsaraauthority.gov.kh/wp-content/uploads/2024/12/Heritage-MangementFramework-October-2013.pdf

Key Value 2: Natural values associated with the Angkor region as a World Heritage Site

Angkor's natural sites include water, forests and mountains, which together enhance the cultural landscape of the Angkor World Heritage Site. The forests, mangroves and wetlands of the Angkor World Heritage Site not only provide the environment for the monuments and religious life of Angkor, but also biodiversity and natural heritage value in their own right. The 2007 tree survey of Forest Zone 1 recorded 168 different tree species in a single layer, indicating a high level of biodiversity. Some tree species are native to the Angkor area and also occur in the important fl oded forest ecosystem of Tonle Sap Lake. Many trees at Angkor have grown to enormous sizes, especially the Dipterocarpus alatus trees that line the Charles de Gaulle Road and the north-south axis through Angkor Wat, through Angkor Thom and through Preah Khan. In many places, these trees also bear the marks of traditional resin tapping. The interaction of mature trees with Angkor monuments and temples provides an aesthetic combination that is prized by international visitors. The species Tetrameles nudifl ra , Lagerstroemia and Ficus at Ta Prohm and along the outer walls of Angkor Thom are clear examples. Four species of birds considered to be of conservation importance for the Indochina bioregion have been recorded in the Angkor World Heritage Site. These are the Siamese Fireback, Bar-bellied Pitta, Orange-breasted Green Pigeon and Black-and-red Broadbill. Important wildlife species at Angkor include monkeys, snakes and squirrels. There are programs to conserve and increase these populations through forest protection activities and the efforts of national institutions such as the Angkor Centre for the Conservation of Biodiversity (ACCB). The sculptures, carvings and bas-reliefs of the Angkor monuments depict a wide range of plants and animals, some of which are still found in the area today. In addition, carvings depict fishing activities and waterfowl associated with the Tonle Sap Lake. Among them are the black and red broadbill, which were historically common in the Siem Reap region but are now rare[6] .

Attributes: Atmosphere, air, water, forests, wildlife, biodiversity of fruit plants and medicinal plants.

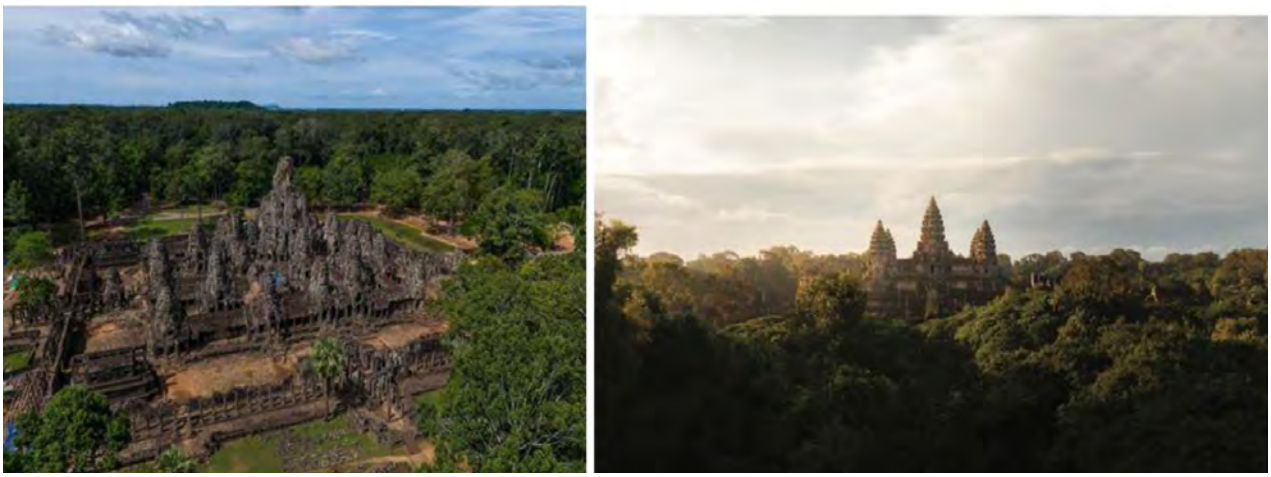

Figure 5.5: Angkor Wat temple (left) nd Bayon Temple (right) and their rich natural settings (Photo: APSARA National Authority)

6. https://apsaraauthority.gov.kh/wp-content/uploads/2024/12/Heritage-MangementFramework-October-2013.pdf

Key Value 3: Knowledge and educational value

The temples, monuments, carvings and water structures of Angkor provide signifi ant evidence of the interaction between people and nature, and the changes in culture and landscape over time. It represents the legacy of one of Southeast Asia's largest pre-modern settlements. Angkor represents an outstanding example of technological innovation in architecture, engineering and hydrology. The Angkor site forms a massive, well preserved and substantially unexplored archaeological resource with demonstrated potential to provide highly signifi ant new information about human society and the environment. As an archaeological site, Angkor has great potential to augment and enrich information about the way of life of ordinary inhabitants during the Angkorian period.

Angkor is crucial in examining the transformation of local settlement patterns of the fourth to the fi st millennium BCE, and the development of organised urban complexes. Unravelling the formation and expansion of the state, as illustrated at Angkor, has universal signifi ance. As the largest known pre-industrial, low-density urban complex, Angkor is of critical scientific signifi ance in understanding the magnitude, form and extent of pre-industrial urbanism, including large scale urban infrastructure and the economics and ecology of land use. Angkor continues to provide unparalleled research information on such issues as the production of staple crops, the operation of the water management system, the domestic economy, external trade, key infrastructure and the effects of climate change. The site is also of practical relevance for comparative analyses on issues faced by modern industrial urbanism, including the effects of environmental impact and climate change, and their relationship to the demise of civilizations. More generally, Angkor is relevant to debates about the formation of complex societies, the archaeology of empires and the patterns of past civilizations.

Overall, the richness of the archaeological resource provides an extraordinary opportunity for testing theoretical models and explanations about the development of human society. As one of the fi st archaeological sites in the world where science and conservation technology were applied, Angkor provides a case study of the development and application of scientific research and conservation methodologies, and represents the fi st major example of anastylosis outside the Mediterranean. Hence, there exists an opportunity for the study of different examples of conservation methodology within the western tradition. Furthermore, Angkor is an outstanding example of the use of extensive multidisciplinary analyses of evidence, and of the development and promotion of new analytical visualisation approaches6.

Attributes: The use of space to organize the city, the creation of large-scale works (making Baray temples, fi e arts, ancient sculptures, integration of the environment, natural environment (sunrise at the top of Angkor) Technology, Infrastructure, Medical, realization, astronomy, mathematics, irrigation design, Urban planning, Arts, Aesthetics.

Figure 5.6: Bayon Temples and Angkor Thom Wall (Photos: APSARA National Authority)

Figure 5.7: Angkor hydraulic network (Source: APSARA National Authority)

6. Assessment of Past and Present Climate Hazards

The “Hydraulic City” of Angkor, the capital of the Khmer Empire in Cambodia, experienced decade-slong drought interspersed with intense monsoons in the 14th and 15th centuries that, in combination with other factors, contributed to its eventual demise. The climatic evidence comes from a seven-and-a half century robust hydro-climate reconstruction from tropical southern Vietnamese tree rings (Im Sokrithy, Archaeologist, Apsara, Personal Correspondence). The Angkor droughts were of a duration and severity that would have impacted the sprawling city’s water supply and agricultural productivity, while high-magnitude monsoon years damaged its water control infrastructure. Hydro-climate variability for this region is strongly and inversely correlated with tropical Pacific sea surface temperature, indicating that a warm Pacific and El Niño events induce drought at inter annual and interdependent time scales, and that low-frequency variations of tropical Pacific climate can exert signifi ant influence over Southeast Asian climate and society.

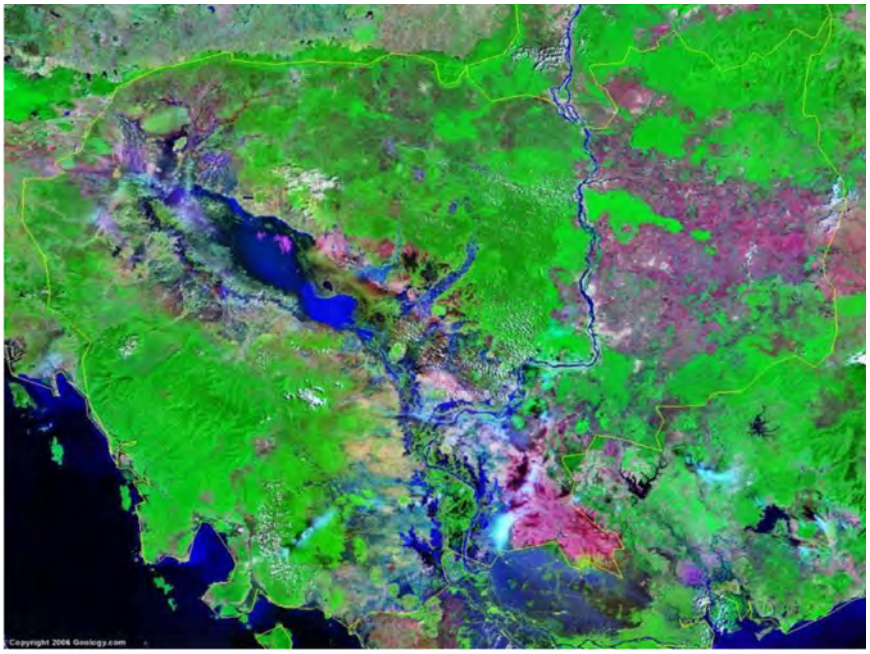

Figure 6.1: Central plain: annual dried and fl oded region (Photo compliments of Im Sokrithy, Archaeologist, Apsara National Authority)

The general altitude of Cambodia is low and the relief makes the central plain a kind of bowl. The plains are dominant throughout the territory. The central plain is fl oded for more than half the year. Th s plain is located on both sides of the Grand Lake and Mekong and extends over a vast alluvial region constituting a cultivable and habitable space. The central plain is watered by a hydro-graphic system composed by the great Mekong River and its tributaries and by several lakes, the largest of which is the Great Lake Tonle Sap. The Mekong has its source in the heights of Tibet. It stretches from north to south of Cambodia for about 500 km, and joins with the Tonle Sap in Phnom Penh, giving birth to the “Four Arms“ rivers.

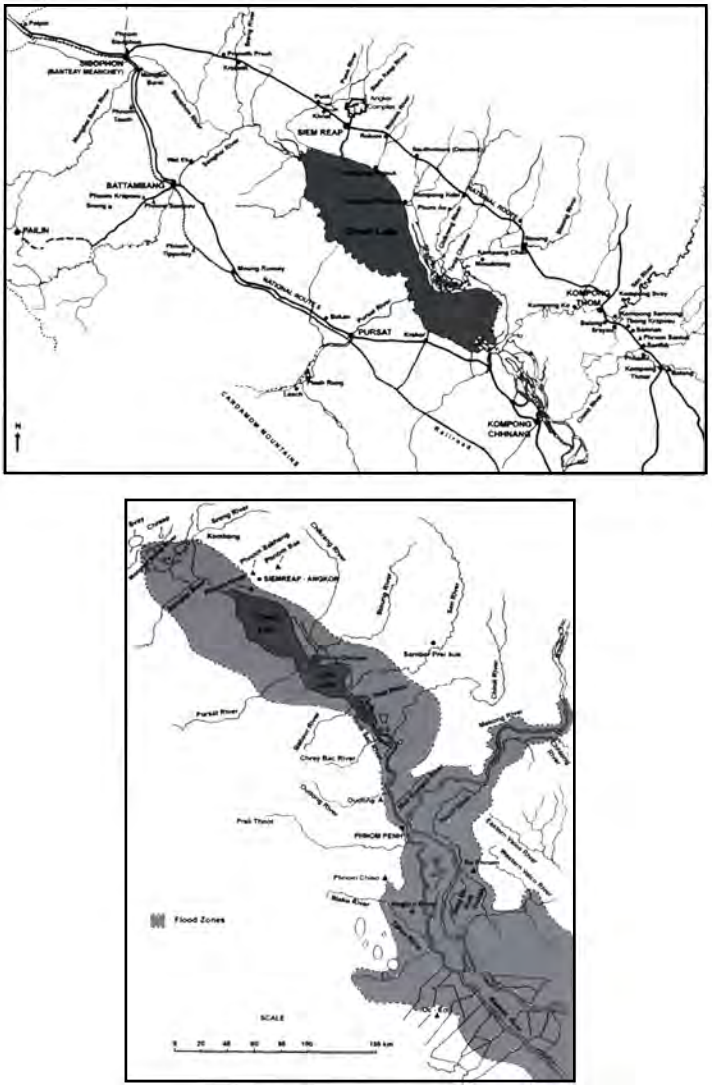

Figure 6.2: Central plain: annual dried and fl oded region (Image after Vann Molyvann 1999)

Historical and Current Climate Overview

Angkor, located in Cambodia, experiences a tropical monsoon climate that signifi antly influences its temperature and rainfall patterns. Th s region is characterised by high temperatures and substantial humidity throughout the year, presenting unique challenges for heritage preservation.

Temperature: Angkor experiences high temperatures year-round, typically ranging from 22°C to 35°C. The hottest months are from March to May, with temperatures often exceeding 35°C. The combination of high temperatures and humidity can make the heat feel even more intense.

Humidity: The region has high humidity levels, averaging around 75-80% annually. The most humid period coincides with the monsoon season, from May to October.

Rainy Season: Angkor's rainy season is marked by heavy monsoon rains, which are most intense from June to September. During this period, the region receives substantial rainfall, often leading to fl oding. The monsoon rains are critical for replenishing water sources but also pose risks to the site's infrastructure.

Dry Season: The dry season spans from November to April, with signifi antly reduced rainfall. However, this period can also bring challenges, such as water scarcity and increased vulnerability to drought.

Climate Challenges and Historical Impact

Historical evidence suggests that climate variability has been a signifi ant factor in the rise and fall of the Khmer Empire, which built Angkor. Research indicates that decades of drought, interspersed with intense monsoon rains, may have contributed to the collapse of Angkor nearly 600 years ago. Analysis of tree rings, archaeological remains, and other evidence reveals that severe droughts, followed by heavy rains, weakened the empire by shrinking water supplies and damaging the extensive irrigation system that was central to Angkor's economy. The droughts led to crop failures and increased the incidence of infectious diseases, exacerbated by the dense population. The intense rainy seasons that followed these droughts likely caused massive siltation and clogging of the hydraulic system, further destabilizing the region's water management infrastructure.

Water Management Challenges

There are many water management challenges in Angkor including:

- The Khmer Empire's sophisticated water management system, including reservoirs (barays), canals, and moats, was designed to harness the seasonal monsoon rains. However, prolonged droughts and intense fl oding likely strained this system, contributing to agricultural failures and urban decline.
- Droughts: Severe droughts in the 14th and 15th centuries may have disrupted rice cultivation, the backbone of the Khmer economy, leading to food shortages and social instability.
- Flooding: Heavy monsoon rains sometimes overwhelmed the hydraulic infrastructure, causing damage to temples and urban areas
- Agricultural Stress: The reliance on monsoon rains for rice farming made the empire vulnerable to climate variability. Droughts reduced crop yields, while excessive rainfall could destroy fi lds and disrupt planting cycles.
- Decline of the Khmer Empire : While climate change was not the sole factor, it likely played a role in the empire's decline. Environmental stress, combined with political and social challenges, contributed to the abandonment of Angkor as the capital in the 15th century.

Climate variables

The climate of Angkor, the historic capital of the Khmer Empire, played a signifi ant role in its development and eventual decline. Angkor's climate variables include:

- **Monsoons:** The region experiences distinct wet and dry seasons due to the monsoon system. Intense monsoons were crucial for agriculture but also posed challenges for water management.
- **Droughts:** Prolonged drought periods, interspersed with heavy monsoons, signifi antly impacted Angkor's water supply and agricultural productivity.
- **Hydroclimate Variability:** The area's climate is influenced by phenomena like El Niño, which can lead to droughts, and La Niña, which brings excessive rainfall. These climate variables, combined with Angkor's reliance on an intricate water management system, highlight the delicate balance between human activity and environmental factors in sustaining such a vast civilization.

Table 6.1: Climate variables summary for Angkor between 1970 and 2000 from the Global Data Hub (Source: Preserving Legacies 2024)

Temperature Variable	**1970 - 2000**
Annual Mean Temperature (°C) BIO1	25.1 to 27.8
Max Temperature of Warmest Month - April (°C) BIO5	32.7 to 35.9
Min Temperature of Coldest Month - December (°C) BIO6	16.4 to 20.1
Mean Temperature of Wettest Quarter (°C) BIO8	25.4 to 28
Mean Temperature of Driest Quarter (°C) BIO9	23 to 26
Mean Temperature of Warmest Quarter (°C) BIO10	27 to 29.8
Mean Temperature of Coldest Quarter (°C) BIO11	22.8 to 25.5
Annual Precipitation (mm) BIO12	1123 to 1442
Precipitation of Wettest Month BIO13	222 to 315
Precipitation of Driest Month (mm) BIO14	0 to 2
Precipitation of Wettest Quarter (mm) BIO16	529 to 757
Precipitation of Driest Quarter (mm) BIO17	13 to 29
Precipitation of Warmest Quarter (mm) BIO18	211 to 369
Precipitation of Coldest Quarter (mm) BIO19	18 to 112

Yearly temperature change in Angkor between 1979 and 2023. Figure 6.4 shows an estimate of the mean annual temperature for the larger Angkor region. The dashed blue line represents the linear climate change trend. If the trend line slopes upward from left to right, the temperature trend is positive, indicating that Angkor is getting warmer due to climate change. If it is horizontal, no clear trend is observed; if it slopes downward, conditions in Angkor are becoming colder over time.

The lower part of the graph presents the so-called "warming stripes." Each coloured stripe represents the average temperature for a given year—blue for colder years and red for warmer years. An interactive version of the graph is available here.

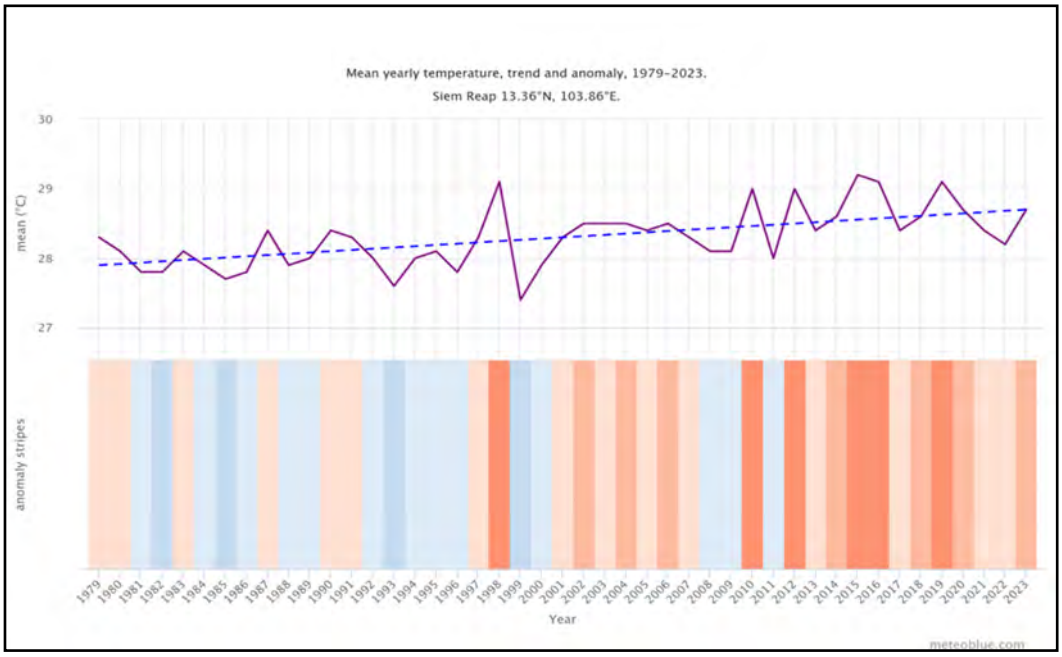

Figure 6.4: Mean temperature, trend and anomaly
(Source: Preserving Legacies Global Data Hub 2024)

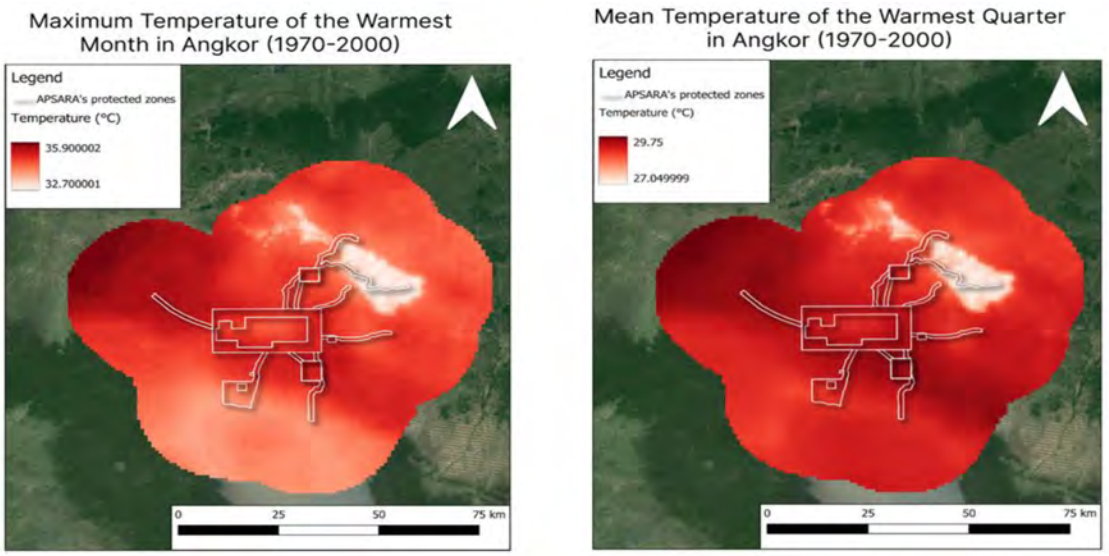

Figure 6.5: Maximum left) nd mean (right) temperature of the warmest month and quarter in Angkor between 1970 and 2000 (Source: Preserving Legacies global data hub 2024)

Present Climate Impacts on Angkor and Communities

The Angkor region of Cambodia, home to the iconic Angkor Wat and other historic temples, is not only a monument of cultural signifi ance but also a vital area for local communities relying on agriculture and tourism. However, the impacts of climate change are increasingly threatening both the

heritage sites and the livelihoods of the people living in and around this UNESCO World Heritage site.

As global temperatures rise and weather patterns become more unpredictable, Angkor faces signifi ant challenges. Increased temperatures, altered rainfall patterns, and extreme weather events contribute to environmental changes that affect agricultural productivity, water availability, and the structural integrity of ancient monuments. Such climate impacts not only jeopardize the preservation of Angkor's archaeological treasures but also threaten the economic stability of surrounding communities that depend on these sites for their livelihoods.

Understanding these climate-related challenges is essential for developing effective strategies to protect both the cultural heritage of Angkor and the well-being of its people. By addressing these issues, stakeholders can work towards creating a resilient future for Angkor and its communities in the face of ongoing climate change.

Erratic Rainfall Patterns

Erratic rainfall patterns, particularly during the monsoon season from May to October, have become increasingly unpredictable, with heavy downpours leading to severe fl oding in many regions. The impact of these fl ods is often catastrophic, as they not only disrupt daily life but also damage critical infrastructure like roads, bridges, and power lines. In rural areas, agricultural fi lds are submerged, leading to crop loss and food insecurity. The fl oding is also known to erode the foundations of historical landmarks, including ancient temples, which are vulnerable to water damage over time. For example, the ancient temples of Angkor Wat in Cambodia have experienced severe erosion due to rising fl odwaters, and similar occurrences have been observed at historical sites in India and Southeast Asia. Additionally, the fl oding can displace thousands of people, pushing them into temporary shelters where health risks, such as waterborne diseases, become more prevalent (Figure 6.6). In some areas, the heavy rainfall and fl odwaters have even led to the collapse of traditional homes made from mud and thatch, leaving communities homeless and further exacerbating the socioeconomic challenges they face.

Prolonged dry seasons and reduced rainfall have signifi antly impacted both agriculture and daily life, leading to severe water shortages in many regions. Additionally, the reduced rainfall has strained household water usage, forcing many communities to implement strict water rationing, which limits daily activities such as cleaning, cooking, and bathing. Th s increasing unpredictability of rainfall and the severity of dry spells underscore the urgent need for sustainable water management strategies to protect both people and the environment.

Rising Temperatures

Rising temperatures have a profound impact on water scarcity, as higher heat levels accelerate evaporation from rivers, lakes, and reservoirs, leading to a reduction in the available water supply for irrigation and domestic use. In addition, the rising temperatures have made it difficult to maintain outdoor attractions, such as historical sites and nature reserves, which further discourages tourists and leads to a loss in revenue. As temperatures continue to rise, it becomes evident that addressing the challenges of water scarcity and heat stress will be critical for sustaining both local communities and the tourism industry.

Higher temperatures exacerbate water scarcity and increase evaporation rates from reservoirs and rivers, reducing the availability of water for irrigation and domestic use. Heat stress affects both the local population and tourists, potentially impacting tourism, a major economic driver for the region. Mr. Sokha, a conservator from APSARA Authority observed that “changes to the working hours may be necessary. Normally we start in afternoon at 1pm but when temperature is high we need to adapt and delay to work at 2pm and fin sh the working day later.

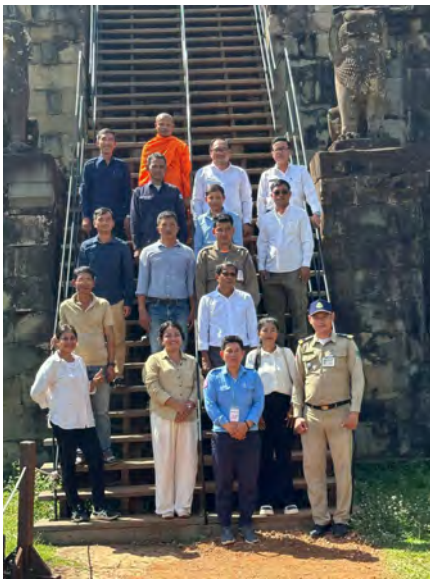

Figure 6.7: Focus Group Discussion WMF's fi ld classroom at Phnom Bakheng temple (31/10/24) (Photo: Hin Chandara 2024)

Impact on Agriculture

Agriculture continues to be a vital source of livelihood for many communities around Angkor, but erratic rainfall and prolonged droughts are severely affecting crop yields, threatening food security and the economic stability of local farmers. In Cambodia, where rice is a staple crop, unpredictable rainfall patterns have led to lower harvests, especially in regions where irrigation systems are either outdated or insuffici t. Similarly, in other Southeast Asian countries like Thailand and Vietnam, the shifting monsoon cycles have resulted in delays in planting and harvesting, reducing the productivity of essential crops like rice, maize, and vegetables. Changes in the timing and intensity of the wet season also force farmers to adopt new agricultural techniques or shift to more drought-resistant crops, which may not always be fi ancially viable in the short term. For example, some farmers in the Angkor region have turned to more resilient crops like cassava and drought-tolerant varieties of rice to cope with the changing climate, but these crops may not provide the same level of income as traditional crops. Additionally, the unpredictable weather patterns have disrupted the cycle of traditional farming practices, which are deeply connected to cultural events and local economies, leaving many farmers uncertain about their future. As these changes continue, the pressure on agricultural

communities to innovate and adapt to the shifting climate will grow, requiring greater investment in sustainable farming practices and water managemen solutions.

Figure 6.8: Rice harvest at Preak Dak Village (Photo: Hin Chandara 2024)

Figure 6.9: while fi e Khna Romvas Village , Banteay Srei District
(Photo: Sovan Narith, Leader of famer association , 2024)

Tourism and Economy

Angkor Wat and other temples in the Angkor Archaeological Park are among the most visited tourist sites in the world, attracting millions of visitors each year and contributing signifi antly to the local economy. However, climate impacts such as fl oding, extreme heat, and prolonged droughts can deter tourists, leading to a decrease in visitation and a subsequent decline in tourism revenue. In 2019, Cambodia experienced intense fl oding that affected major roads and infrastructure around the Angkor temples, leading to accessibility issues and a drop in tourist numbers for that year. Additionally, extreme heat during the summer months has made visiting the temples less comfortable for tourists, causing some to seek alternative destinations. Climate-related hazards such as fl oding and vegetation overgrowth are also causing physical damage to the ancient temples themselves, with roots from aggressive vegetation putting pressure on stone structures, and water damage eroding delicate carvings and foundations. For example, the Temple of Ta Prohm, famous for the massive tree roots growing over its ruins, has been experiencing accelerated deterioration due to increased humidity and rainfalls, further jeopardizing its condition and tourism potential. The resulting damage can make certain parts of the temples unsafe or less appealing, reducing the number of visitors and harming businesses that rely on tourism, such as local guides, hotels, and souvenir shops. Th s growing vulnerability underscores the need for sustainable tourism practices that address climate risks and protect both cultural heritage and the livelihoods of those who depend on tourism.

Figure 6.10: Eastern entrance to Banteay Srei temple
(Photo: Tourism Agency, Apsara National Authority)

Health Risks

Increased fl oding and stagnant water during the wet season can lead to waterborne diseases such as dengue fever and malaria. Higher temperatures and humidity levels can exacerbate health issues, particularly for vulnerable populations. Mr. Seng Sotheara (Director of the Department of Tourism Development and Culture, APSARA National Authority) noted that, 'Regarding the impact of climate change, I have observed that rising temperatures signifi antly affect visitors to Angkor Wat, especially older tourists. The extreme heat poses challenges as the stones absorb and radiate heat, making it uncomfortable for visitors to remain inside the temple during their visit'.

For instance, visitors often experience difficulties even in December, as the high temperatures make

them uneasy. Some visitors have even fainted due to heat waves. Th s creates a health concern for foreign tourists, as the intense heat limits their ability to explore. Many plan to spend the entire day sightseeing but are forced to cut their visits short, only touring in the morning when the temperature is more bearable. Additionally, the widespread use of air conditioners contributes to higher temperatures through their greenhouse gas emissions. On the bright side, this situation may present increased opportunities for air conditioner technicians, as the demand for their services is likely to grow in the future.

Figure 6.11: Visitors are experiencing health problems due to the hot weather at Angkor Wat temple (Photo: Tourism Agency, Apsara National Authority)

Cultural Heritage at Risk

The ancient stone temples of Angkor are vulnerable to climate-related damage. Increased humidity, temperature fluctuations, and extreme weather events can accelerate the weathering and erosion of the structures. Vegetation overgrowth, fueled by heavy rains, can damage temple foundations and carvings. Mr. Im Sokrithy (Director of Department of Research, Training and Communication) further noted that: 'Talking about fl ods, droughts, and the restoration of the irrigation system, could this affect the people living in the Angkor Archaeological Park?' (Figure 6.12).

Figure 6.12: Stone damages Increased humidity, temperature (Photo: HIN Chandara 2024)

Figure 6.13: Mr. Im Sokrithy (left) nd traditional village ceremonies take place in Kompong Phluk (Photos: Elizabeth Carpio and Mr. Im Sokrithy, Director of Department of Research, Training and Communication)

7. Assessment of Future Climate Hazards

Climate Change in Cambodia

Cambodia figu es amongst the most vulnerable countries to climate change according to the "Climate Change Vulnerability Mapping for South East Asia". Disasters related to climate change will have consequences on rural human activities that may affect up to 80% of the Cambodian population. These impacts will be acutely felt by the agricultural sector which employs 57.6 % of the national labour force (National Climate Change Committee 2013). The signifi ant role that agriculture plays in the economy of the country indicates the high importance of having reliable sources of water. However, the complex and cross-sector character of natural disasters can have devastating impacts, notably involving water cycle deregulation. Indeed, water is a crucial natural resource for human development and environmental preservation. However, in the case of climate change hazards it has become a major issue. Sector-wide, climate change poses the most signifi ant challenges to the following national efforts in Cambodia.

Food Security

Seasonal changes under climate change and variability are causing perturbations in the cropping calendars of smallholding farmers. Early commencement of the rainy seasons easily misleads farmers into sowing which eventually result in crop failures. Extreme events such as fl ods and droughts which are projected to increase in frequency and intensity are going to impact food security in Cambodia.

Agriculture Production

The impacts of climate change on agriculture are particularly signifi ant to Cambodia because a large portion of the population is involved in smallholding and subsistence farming livelihoods, and agriculture constitutes the backbone of the economy. Agricultural practices in Cambodia are mostly rainfed systems which increase their vulnerability to a changing climate. We have witnessed severe fl ods and droughts that have caused a signifi ant loss in agricultural productivity.

National Development Target

Agricultural productivity is expected to increase by about 3-5% to meet national GDP growth targets. Climate change poses signifi ant threats in achieving this target following the impacts of droughts, fl ods, pests and disease outbreaks likely to affect agricultural productivity. Increasing rice productivity which is a dominant stable, and required to increase rice export, will be affected by climate change. Fisheries which provide livelihoods and employment opportunities to people will also be affected.

Public Health

The outbreaks of some diseases such as malaria and dengue fever linked to climate change, will pose signifi ant challenges to Cambodia. Similarly, sanitation and pollution of freshwater, e.g. during fl od events are likely to increase incidences of cholera and other water-borne diseases.

Physical Infrastructures

The qualities of current infrastructures are not designed to cope with the intensity of climate change impacts we are experiencing today. We have witnessed damages caused by fl oding to our roads, drainage structures, irrigation systems, and other connecting infrastructures such as bridges and culverts. Under heavy rainfall and fl oding, embankments and slopes have been damaged by water erosion further rendering our road systems impassable for an extended period with a signifi ant economic loss to the country. Th s is only going to get worse under future climate impacts predicted to be of higher intensity and with more frequent extreme events. Road systems that constitute a significant part of our economic development in facilitating people movement and the fl w of goods and services both within the country and in the ASEAN will be affected by climate change.

Climate Change Futures in Cambodia

Cambodia has made substantial efforts to address climate change in the country, and is united with the global community in combating climate change. There are adopted clear objectives for the fi ht against climate change. These efforts are attempting to limit global warming to the 1.5°C threshold above preindustrial levels as outlined in the Paris Agreement (1.5 is already on the way to be exceeded, and even 2° will probably be exceeded before 2100[7]) . The relevance of this temperature threshold was explored even more in the 2018 IPCC Special Report on Global Warming of 1.5°C. In that report, and further supported by subsequent IPCC reports and other scientific literature, they found that limiting global warming to 1.5°C will reduce the impacts on human systems and terrestrial, freshwater and coastal ecosystems. It made clear that every increment of global warming above 1.5°C matters for the scope and magnitude of these impacts. The 1.5°C limit is sort of like a highway speed limit. Backed by plenty of science about the dangers of speeding, we know that every bit of additional speed increases the danger of an accident. There is no single speed below which the risks are zero and above which (within reason) an accident is guaranteed to occur or to be deadly. Still, we pick a limit beyond which the risks become larger than we are willing to tolerate.[8]

Climate Projections and Climate Data

Climate models are one of the key outputs derived from climate reports. They are built using a combination of historical observations and contemporary climate data to simulate and project future climate conditions. These models analyze the behavior of the Earth's climate system by accounting for variables such as greenhouse gas concentrations, land use changes, ocean currents, and atmospheric dynamics.

One critical fi ding from climate models is that human-induced warming had already reached approximately 1°C above pre-industrial levels by 2017. If current emission trends continue, global average temperatures are projected to rise to 1.5°C around the year 2040.

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7. https://www.greenpeace.fr/2024-annee-la-pluschaude/#:~:text=2024%20marque%20un%20tournant%20préoccupant,mettant%20en%20péril%20notre%20ave nir.

8. https://www.climate.gov/news-features/features/whats-number-meaning-15-c-climate-threshold

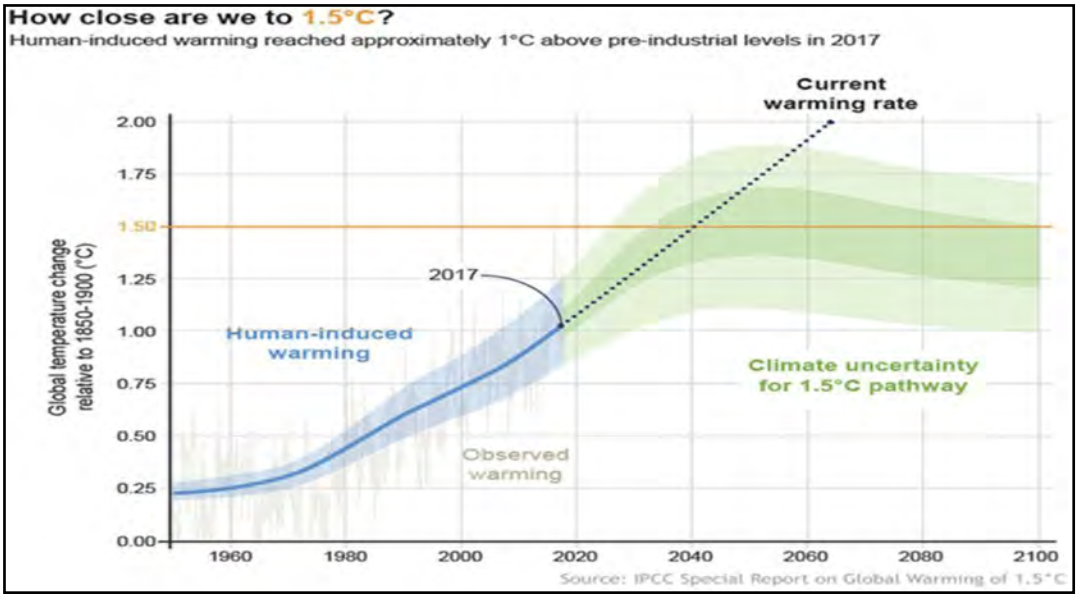

Figure 7.1: How close are we to 1.5 (Source: IPCC Special Report on Global Warming)

To avoid surpassing this threshold, the models suggest a stylized 1.5°C pathway that would require immediate and substantial reductions in greenhouse gas emissions. Specifi ally, CO_2 emissions would need to begin declining sharply and reach net-zero around 2055. Th s trajectory is based on simulations that show how different emission scenarios can influence long-term climate outcomes.

These models are crucial tools for policymakers, scientists, and environmental planners because they forecast future climate risks under various emission scenarios, support evidence-based policy decisions on mitigation and adaptation strategies, help assess the potential impacts of climate change on ecosystems, economies, and human health, and guide international climate agreements by providing measurable targets for emission reductions.

There are different climate models and scenarios. They are:

- SSP1-2.6 is the most **optimistic low emissions** scenario driven by sustainability.
- SSP2-4.5 is a **middle-ground**, continuation of current trends scenario.
- SSP3-7.0 and SSP5-8.5 are both **high emissions, "pessimistic" scenarios** but differ in their underlying socioeconomic narratives - regional rivalry vs fossil-fuelled development respectively.
- SSP5-8.5 is still considered more plausible as a long-term business-as-usual outcome compared to SSP3-7.0

All scenarios predict some changes to climate at Angkor. Th s includes: 1) Annual mean temperature is expected to rise signifi antly from a baseline of 25.1-27.8°C (1970-2000) to 27.4-30°C by 2060 under the highest emission scenario (SSP5-RCP8.5). Th s represents an increase of 2.3-2.2°C; 2) Maximum temperatures are expected to increase. The warmest month's maximum temperature is projected to increase from 32.735.9°C to 34.6-37.8°C by 2060 under the highest emission scenario, an increase of 1.9°C; 3) Minimum temperatures are also expected to increase. The coldest month minimum temperature is also expected to rise, from 16.4-20.1°C to 19.3-22.9°C by 2060 under SSP5-RCP8.5, indicating warmer winters overall; and 4) Seasonality will change. A slight increase in the temperature difference between the warmest and coldest quarters is anticipated, indicating more pronounced sea-

sonal temperature variations: increase of temperatures of the warmest and coldest quarters (Figure 7.2).

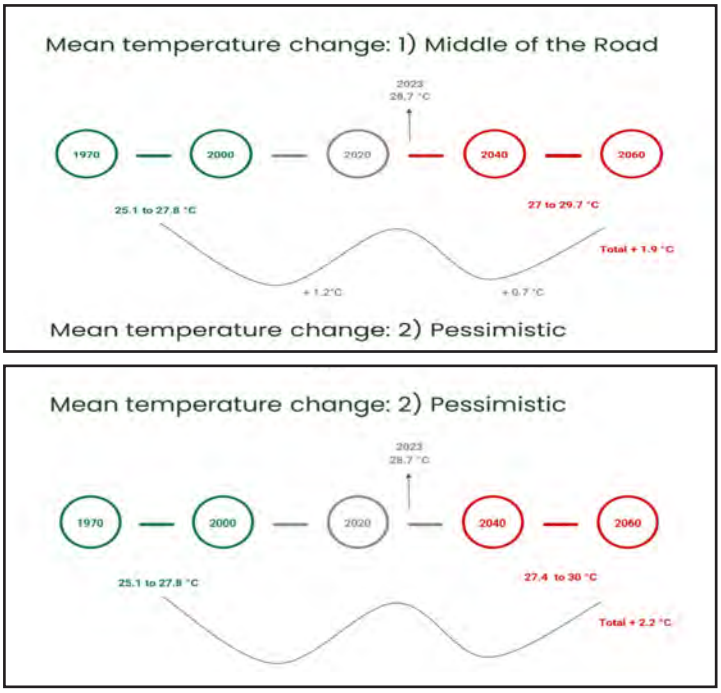

Figure 7.2: Temperature change in SSP 2-4.5 (top) and 3-7.0 (bottom) scenarios (Source: Regional Data Hub, Preserving Legacies, 2024)

Example: Pessimistic projection in Angkor site

Temperature is expected to rise to 27.4-30°C by 2060. Th s represents an increase of 2.3-2.2°C. April's maximum temperature is projected to increase from 32.7-35.9°C to 34.6-37.8°C by 2060, an increase of 1.9°C. The coldest month (December) minimum temperature is also expected to rise, from 16.4-20.1°C to 19.3-22.9°C by 2060, indicating warmer winters, corresponding to about 3 degrees (Figure 7.3).

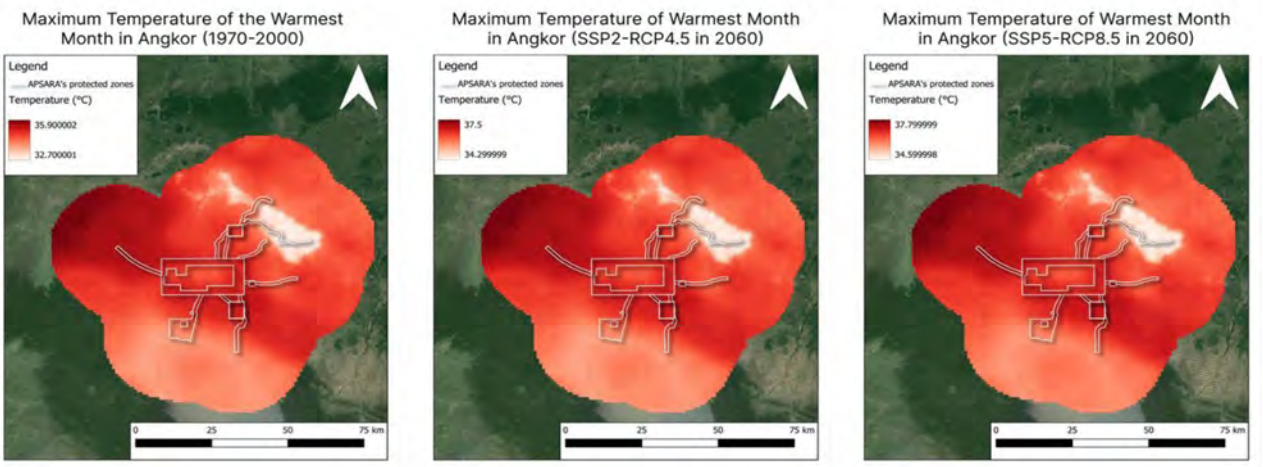

Figure 7.3: Temperature changes in Angkor under different scenarios (Source:Regional Data Hub, Preserving Legacies, 2024)

Annual precipitation is projected to increase slightly from the past of 1123-1442 mm (1970-2000) to 1177-1502 mm by 2060 under the pessimistic scenario, an increase of 54-60 mm. Precipitation during the wettest month is expected to increase from 222-315 mm to 238-333 mm by 2060. Precipitation during the driest month is projected to remain stable, consistently ranging from 0-2 mm across all scenarios and time periods (Figure 7.4).

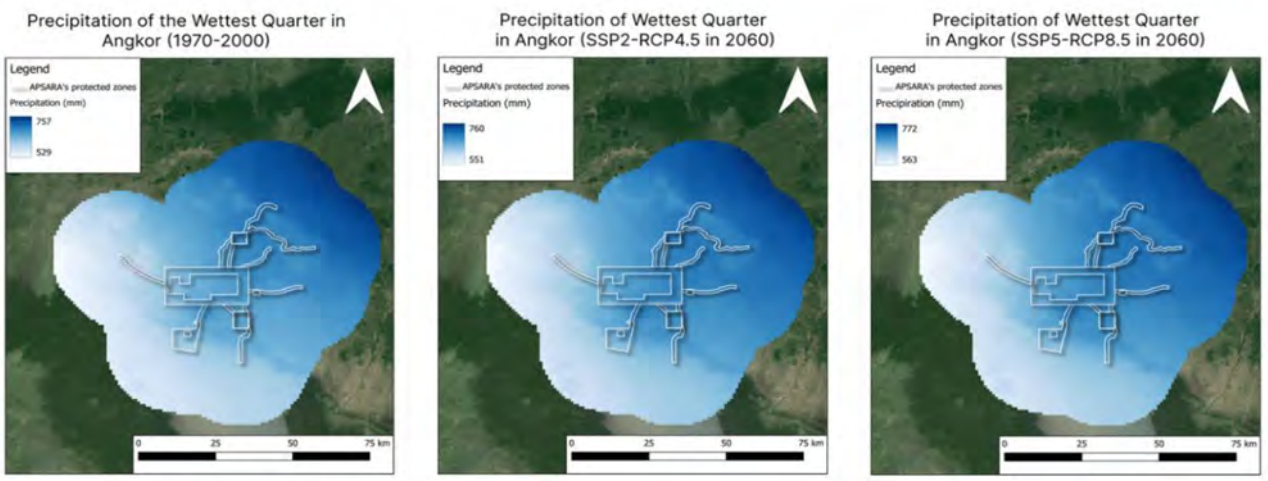

Figure 7.4: Precipitation changes in Angkor under different scenarios (Source: Regional Data Hub, Preserving Legacies, 2024)

Table 7.1: Difference between scenarios by 2060 (Regional Data Hub, Preserving Legacies, 2024)

Hazard	Middle of the Road	Pessimistic
Strong storms	Moderate increase in precipitation (551-760mm for wettest quarter)	Slightly higher increase in precipitation (563-772mm for wettest quarter)
Flooding	Increased risk of fl oding due to higher precipitation (551-760mm for wettest quarter)	Slightly higher risk of fl oding (563-772mm for wettest quarter)
Heatwaves	Increased heatwave risk (max temperature 34.3-37.5°C)	Higher heatwave risk (max temperature 34.6-37.8°C)
Drought	Moderate drought risk (precipitation of warmest quarter 213-371mm)	Similar drought risk (precipitation of warmest quarter 216-375mm)
Growing Seasons	Moderate changes in growing seasons due to temperature increase (max temperature 34.3-37.5°C)	Slightly more pronounced changes in growing seasons due to higher temperatures (max temperature 34.6-37.8°C)

Impact on Heritage

The current and expected impacts on heritage are diverse and complex due to the variety of global climate and environmental changes, compounded with local anthropogenic factors and vulnerabilities (such as pollution and urbanisation), as well as the diversity of heritage, including its characteristics of value. Critical to understand is that hazards are what cause direct or indirect impacts to heritage, as well as many other non-heritage elements that can in turn increase risk and impact to a site. At Angkor, impacts will vary depending on the attributes, but may include:

- **Accelerated stone deterioration:** Higher temperatures combined with increased moisture from precipitation may lead to more rapid dissolution of carbonate materials in the stone, increased salt crystallization cycles, causing more damage to porous stone surfaces and faster biological growth (algae, lichens, etc.) on stone surfaces.
- **Structural instability:** The combination of temperature fluctuations and increased groundwater levels from higher precipitation could result in differential thermal expansion and contraction of building materials, changes in soil moisture content and stability and potential subsidence or heaving of foundations. Th s can be further exacerbated by fl od risk and erosion especially during monsoon seasons, the more erosive power of water runoff, potentially damaging structures and archaeological sites and changes in the ancient hydraulic systems, requiring reassessment and modifi ation.
- **Biological threats:** Warmer temperatures and increased moisture create favorable conditions for accelerated growth of vegetation on and around monuments, proliferation of invasive species and increased risk of pest infestations (e.g., termites) that could damage wooden structures.
- **Microclimate changes:** The combination of higher temperatures and altered precipitation patterns could create more pronounced wet-dry cycles, potentially leading to increased cracking and material fatigue, changes in relative humidity, affecting the preservation of organic materials and painted surfaces and altered evaporation rates, potentially affecting water features and surrounding ecosystems.
- **Water management challenges:** The interplay between increased temperatures and precipitation could result in more pronounced seasonal differences in water availability, potential water scarcity during dry periods due to increased evaporation and challenges in managing excess water during wet seasons.
- **Tourism impacts:** The combined effects of higher temperatures and changing precipitation patterns could alter peak tourist seasons, potentially concentrating visitor pressure in shorter periods and increase the need for climate control measures in buildings, potentially affecting their historical integrity
- **Landscape changes:** Over time, the combined climate changes could lead to shifts in local ecosystems and biodiversity and alterations to the cultural landscape surrounding the monuments.

Figure 7.5: Experts activities of mapping the risks at Phnom Krom Temple (Source : APSARA National Authority)

Compounding Impacts

Finally, impacts are not going to be singular events as caused by climate change. Rather there will be a variety of complex and compounding impacts - hazards, exposures or vulnerabilities that will increase the risk of heritage to climate change, and influence the type and degree of impact. Thi k about it as a web that triggers and is relational amongst the different strands.

8. Sensitivity, Exposure, Vulnerability and Adaptive Capacity

There are four main variables when considering risk from climate change at heritage sites namely vulnerability, sensitivity, exposure, and capacity to adapt. These are key in understanding how societies, ecosystems, and individuals respond to the impacts of climate change. These four variables are crucial in understanding how a site like Angkor, an ancient cultural heritage site, may be affected by climate change. Th s report provides defin tions of these four concepts and also provides examples of each that are applied to this site. However, in order to understand risk, we need to understand each of these variables. In the workshop, each was discussed with stakeholders to get a broad understanding.

Sensitivity

Sensitivity is the degree to which a system or species is affected, either adversely or benefic ally, by climate variability or change. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range, or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal fl oding due to sea level rise) (IPCC, 2021; IPCC, 2022a; IPCC, 2022b). Sensitivity describes how the components of the Angkor site respond to changes in climate conditions.

For example, temperature and rainfall. If there is a rise in temperatures or a shift in seasonal rainfall patterns, the site's structures, particularly those made of porous materials like sandstone, could face accelerated erosion and deterioration. (Sopearin, in person, November 2, 2024) Similarly, for hydrological impacts: Changes in rainfall patterns could affect the water management systems used by the ancient Khmer civilization, such as the famous reservoirs (Barays) and canals. Water quality and availability could also impact the local communities and ecosystems that rely on these systems. Angkor's sensitivity is also linked to its historical signifi ance as a World Heritage site. The affection of cultural heritage, namely sculptures, inscriptions and reliefs, would be irreversible if damaged by changing climatic conditions. We can ask how sensitive are attributes to climate change (now and in the future)?

For example:

1. Is the rock (sandstone) used to build the site vulnerable to erosion from rainfall?
2. Are building interiors sensitive to increasing damp/ humidity (if relevant)?

Adaptive Capacity and Adaptation

Adaptive capacity is 'the ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences' (IPCC, 2021; IPCC, 2022a; IPCC, 2022b). Adaptation, on the other hand, capacity refers to the ability of Angkor and its surrounding systems to adjust to changing climatic conditions. Th s can involve both physical measures (such as strengthening the infrastructure) and social or cultural adaptations (such as altering practices or governance structures).

For example, at Angkor there are physical adaptations including restoration and conservation efforts that can enhance the resilience of the site. including building infrastructure to manage water fl w more effectively or reinforcing vulnerable structures could help minimize damage. Similarly, changes in management and governance including local communities who, along with national and international organizations, could increase their adaptive capacity through improved environmental planning, better early-warning systems, or capacity-building efforts in heritage conservation. Finally, there is cultural and societal adaptability. The people of the region may need to adapt their agricultural and water management practices in response to changing rainfall patterns, while still preserving the cultural signifi ance of the site.

The ability to adapt also depends on fi ancial resources, technical knowledge, and the cooperation of stakeholders such as our government, our local communities, especially UNESCO, and international conservation organizations.

Vulnerabilities

Vulnerabilities are 'The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt. Vulnerability is then a function of sensitivity and adaptive capacity' (IPCC, 2021; IPCC, 2022a; IPCC, 2022b).

Th s word is related to what are the social and economic factors which increase the vulnerability of the attributes to climate change hazards (PL). For example, poor planning decisions or underinvestment in conservation activities. Related to these effects: we can ask the question, are there any economic, social, cultural, etc. factors which make attributes more vulnerable to climate change (now and in the future)? For example: The scale of the site may mean that it is very hard to undertake conservation everywhere.

At Angkor, the vulnerability is heightened due to the combination of many factors including the age and condition of structures: many temples are made from sandstone, bricks and laterites, which can degrade due to rising humidity, increased rainfall, or changing temperature conditions. Ecosystem stress can also play a role. The surrounding ecosystem, including forests and water systems, is sensitive to climate changes that could affect biodiversity, water availability, and soil quality.

However, certain temples possess a natural resilience that can reduce their vulnerability. Forest cover, for instance, can help moderate temperatures and reduce pollution. At the Angkor site, many temples are sheltered by surrounding forests. Annual reforestation programmes have been implemented, resulting in the planting of approximately two million trees to date, alongside the distribution of seedlings to local communities and public institutions to promote continued planting.

Exposure

Exposure is 'The presence of people; livelihoods; species or ecosystems; environmental functions, services, and resources; infrastructure; or economic, social, or cultural assets in places and settings that could be adversely affected' (IPCC, 2021; IPCC, 2022a; IPCC, 2022b).

The presence of people, livelihoods, services, the environment and resources, infrastructure or property, economically, socially or culturally that may be severely exposed to climate change (Ministry of Environment et all 2017:80). Example: the sandstones are very exposed to the impacts of flash fl oding. However, exposure refers to the extent to which the Angkor site is directly affected by climate change. Th s can include factors like fl oding, specifi ally where the site is located in a region with seasonal fl oding, and changes in the timing, frequency, or severity of fl ods that could lead to the submerging or erosion of structures, and extreme weather events including the increased frequency of extreme weather events like storms, droughts, or extreme heat could expose Angkor to direct damage, especially if protective infrastructure is inadequate. The exposure of the site also includes the broader impacts on the population around Angkor, who might face displacement or changes in livelihood due to environmental shifts.

Conclusion

In conclusion, four main points of parameters in climate change risk assessment at heritage sites. These are vulnerability, sensitivity, exposure, and capacity to adapt to climate change. At the Angkor site, vulnerability is high due to its age and the environmental stress it faces. The site's sensitivity is linked to the delicate nature of its structures and ecosystems, while its exposure is primarily to fl oding, extreme weather, and changing hydrological conditions. Finally, the capacity to adapt depends on the concerted efforts of conservationists, local communities, and our government to implement sustainable and effective climate adaptation strategies.

9. Adaptation and Mitigation

Introduction

Preserving Legacies advocates for a values-based and community-led methodology that embraces diverse knowledge systems to understand climate change risk and impacts on heritage places, both present and future. It understands risk as a dynamic intersection of the four determinants of risk: hazards, vulnerabilities, exposures and especially responses that are related to the main points of adaptation and mitigation. According to some scholars, the Angkor site faced signifi ant challenges due to climate change, which ultimately contributed to the collapse of Angkor nearly 600 years ago. Analysis of tree rings, archaeological remains, and other evidence reveals that severe droughts, followed by heavy rains, weakened the empire by shrinking water supplies and damaging the extensive irrigation system that was central to Angkor's economy. However, some scholars argue that the Angkor site changed the royal capital city but local communities continued living on this site. Thus, people had adapted to living here. APSARA National Authority is not just thinking about climate change, for many years and has been paying close attention to a clear measure to combat climate change that could have a positive impact on the Angkor site.

Adaptation

Adaptation is described as 'the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit benefic al opportunities. In natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate and its effects' (IPCC, 2021; IPCC, 2022a; IPCC, 2022b). At Angkor, there are specific adaptation actions which are relevant when considering climate risk.

Water management

Water management including the restoration of ancient water systems, including rebuilding and preserving the intricate network of reservoirs, canals, and moats that once supported the Angkor site, improved irrigation systems including implementing modern irrigation techniques to ensure sustainable agricultural practices in the region, and fl od control measures including constructing fl od barriers and drainage systems to protect the site from rising water levels.

APSARA National Authority made various waterways to prevent fl oding of temples and the restoration of the ancient irrigation system is a major task of the APSARA Authority, with the restoration of ancient canals, ancient ponds, and the replenishment of large reservoirs in the Angkor area. Continuing to repair and replenish water in many other ancient Baray (water reservoirs) around Angkor site and continue to cooperate with international partner to monitor air quality in Angkor. In addition, there were other water management activities undertaken, and namely: establishing surface and groundwater monitoring systems, measuring water fl w along waterways, researching and restoring of the ancient water system, researching on solutions to manage groundwater to reduce groundwater use, establishing an automatic groundwater monitoring system, monitoring groundwater levels and seasonal groundwater map, monitoring groundwater quality and making the maps of water level change, installing a meteorological station system to collect data in the catchment area, installing

portable and permanent air monitoring system, establishing geographic information systems (GIS) and satellite technology to facilitate local situation management, especially in disaster management, informing the local authorities about the risks posed by air pollution, proposing solutions to ensure the support of public health and well-being and safety of the temples[9].

Conservation and Restoration

Conservation and restoration, including the preservation of ancient structures, are essential to ensuring that these monuments remain structurally stable and protected from the risk of collapse. Such works also safeguard the authenticity of the temples by preserving their original materials, including sandstone, brick, laterite, and wood. Recently, modern technical innovation necessitate changes in conservation and restoration techniques. Examples include technical anastylosis (fi st French technical practicing at Banteay Srei temple in 1931 by Henri Marchal), photogrammetry, scanner (GPR), geotechnical study (soil mechanics), analysis materials (old and new materials), epoxy glue, level machine, monitoring tools (studying the risk maps of the temples), construction site equipment (stainless steel, fiberglass, motors and total station) (Sarith, in person, October 19, 2024).

The restoration and conservation of the temples have been carried out with a strong emphasis on authenticity and sustainable tourism development. Restoration work has focused on preserving original materials, traditional construction techniques, architectural designs, and appropriate workforce practices. According to Ms PICH Jira, an engineer from the APSARA Authority during an in-person interview on October 20, 2024, these elements were carefully implemented to maintain the historical integrity of the temples.

For sandstone temples, the architectural behavior of the towers has been respected, and the original bonding patterns have been strictly followed. The physical and chemical characteristics of the sandstone—such as its color, strength, and texture—have been carefully matched with the original material. In an interview on October 18, 2024, Mr. HOUN Socheat, an engineer from the APSARA Authority, emphasized the need for further analysis of both ancient and modern materials to ensure the long-term quality of restoration works.He highlighted that inappropriate substitute, such as brick or wood, must not be used to repair sandstone towers. Restoration work has included stone consolidation and conservation treatments that respect the original conditions of the monuments. Where possible, original sandstone blocks have been returned to their original positions, and architectural elements have been clearly identifi d and restored.

In brick temples, traditional materials like shell lime mortar, palm sugar, cow skin glue, sand, and brick powder have been used in the restoration process. Socheat also stressed the importance of conducting strength tests—both compression and tensile—on new and ancient materials to confi m their suitability for conservation.

In parallel with structural restoration, environmental sustainability efforts have been integrated into the broader conservation strategy. Reforestation activities have been implemented to help combat the effects of climate change, which contributes to soil erosion and biodiversity loss. At the Angkor site, approximately two million trees have been planted as part of annual campaigns. In addition, seedlings

9. https://www.apasaraauthority.gov.kh

have been distributed to local communities and public institutions to encourage continued planting and environmental responsibility.

Community-based conservation initiatives have also played a key role in preservation efforts. These initiatives aim to engage local communities in heritage conservation by promoting awareness, participation, and long-term stewardship of cultural sites.

Furthermore, to support both preservation and community development, tourism has been carefully managed and diversifi d. In an effort to reduce dependency on traditional temple visits and manage the impact of seasonal tourism, a variety of alternative experiences are now offered to visitors. According to Mr. SENG Sotheara, Director of the Department of Tourism Development and Culture at the APSARA Authority, during an interview on October 2, 2024, tourists can now visit destinations such as Tonle Sap Lake, including the fl ating villages of Kampong Khleang and Kampong Phluk, as well as traditional villages renowned for their handicrafts and local culinary products. Other attractions include the Angkor Botanical Garden, the ancient wall of Angkor Thom, and scenic sunset points at Phnom Bakheng, Phnom Krom, and Pre Rup temples. Tourists are also encouraged to visit cultural institutions such as the Angkor National Museum, the Preah Norodom Sihanouk Museum, and the Cambodia Landmine Museum. Additionally, cultural experiences such as ox cart rides in Bakong and Toeuk Vil offer authentic and immersive experiences for visitors.

To accommodate this growing diversity in tourism activities, infrastructure has been upgraded to improve visitor safety and comfort. The APSARA Authority has developed paved walkways, parking areas, and visitor information centers. These improvements not only enhance the overall tourist experience but also help protect the temples from overcrowding and physical damage.

Mitigation

Mitigation of climate change refers to human interventions aimed at reducing greenhouse gas emissions or enhancing the natural sinks that absorb these gases, such as forests, oceans, and soil (IPCC, 2021; IPCC, 2022; IPCC, 2022b). Th s involves cutting emissions from major sources including power plants, factories, vehicles, and farms. Natural systems like forests, oceans, and soils play a crucial role in absorbing and storing these gases, making them a key part of the solution. Much of how we mitigate climate change depends on reducing emissions and changing the way we use and manage land and related resources.

One major approach to mitigation is the adoption of renewable energy, such as solar power, which can provide clean energy for the site and surrounding communities. For example, electric bicycles supported by private sector initiatives could offer sustainable transportation, although their effectiveness in the Cambodian energy context remains uncertain. Building on the experience of multiple conferences held on this topic, particularly in the French West Indies, a similar event could be organized in Cambodia to share best practices and foster stakeholder engagement, if there is suffici t interest.

To implement solar energy, panels can be installed at strategic locations such as visitor centers and key facilities, and partnerships can be established with local organizations for maintenance and community engagement. As the site is inscribed on the UNESCO World Heritage List, any such instal-

lations must fi st undergo a Heritage Impact Assessment (HIA) in accordance with the Operational Guidelines of the World Heritage Convention. The benefits of this approach include reduced reliance on fossil fuels, lower operational costs, and improved sustainability. It also supports tourism services at the temples by ensuring revenue from cultural events, arts, festivals, and ceremonies, and helps balance various impacts in the Siem Reap–Angkor area.

Th s includes retrofitting non-heritage existing buildings, such as visitor facilities and administrative offices with energy-effici t lighting and HVAC systems, and incorporating passive design principles to naturally reduce energy use. If any heritage buildings are considered for retrofitting, such works must fi st undergo a Heritage Impact Assessment (HIA) in accordance with the Operational Guidelines of the World Heritage Convention. These measures help lower overall energy demand and promote a culture of sustainability among staff and visitors. By implementing renewable energy and effici cy strategies, the Angkor site can lead by example in environmental conservation and sustainable tourism.

Sustainable agriculture is another critical component of mitigation, focusing on environmentally friendly practices such as organic farming to reduce carbon emissions and conserve natural resources. For instance, the GIZ project trained local communities to grow organic food without using chemical fertilizers, thereby promoting local production and supporting regional economies.[10] Agroforestry systems, which integrate trees with agriculture, can also be used to enhance soil health, improve biodiversity, and create more resilient farming systems.

Community engagement is equally important in addressing climate change. Education and awareness programs help inform local populations about climate change and its effects, while sustainable livelihood initiatives support environmentally friendly economic activities that reduce pressure on the environment. These efforts empower communities to participate actively in conservation and sustainable development.

In conclusion, both adaptation and mitigation are essential for protecting the cultural and historical integrity of the 91 temples at Angkor, which were inscribed on the World Heritage List in 1992, while also enhancing the site's resilience to the effects of climate change.

10. GIZ Projects Supporting Organic Farming and Agroforestry in Cambodia

10. Risk Statements for Angkor

The assessments of risk undertaken during the risk assessment workshop, alongside research and expediences from the stakeholders and values workshops, allow us to explore the future climate risks to the key values outlined in Section 5. These are explored under two scenarios: middle-of-the-road and pessimistic and presented as risk statements which attempt to bring together the different elements of risk and climate action to identify potential areas which may benefit from adaptation actions.

Angkor Value 1 : Historical/ Cultural Values

Figure 10.1: The Battle of Kurukshetra in Mahabharata (Photo: Will Megarry 2024)

Middle-of-the-road scenario

By 2060 under a middle-of-the-road scenario, historical and socio-cultural values attested to by the grand and iconic historic buildings, living and ongoing traditions in and around these buildings and archaeological deposits at and around the Angkor site face a moderate risk of damage or loss due to unpredictable weather including changing precipitation patterns and extreme heat. Within this timeframe precipitation is due to increase by 4% and temperatures are due to increase by up to 2.2 degrees. These buildings and archaeological deposits are moderately exposed to impacts including overheating and efflorescence, erosion and fl oding. Their vulnerability is increased by issues of water insecurity and the scale and conservation status of the structures. Responses including existing conservation efforts at some structures and projects which manage water fl w at the site contribute to reducing this risk.

Additionally, maladaptive responses, such as using inappropriate materials for repairs or conservation, could accelerate deterioration and reduce authenticity.

Pessimistic scenario

By 2060 under a pessimistic scenario, historical and socio-cultural values attested to by the grand and iconic historic buildings, living and ongoing traditions in and around these buildings and archaeological deposits at and around the Angkor site face a moderate risk of damage or loss due to unpredictable weather including changing precipitation patterns and extreme heat. Within this timeframe precipitation due to increase by 5% and temperatures due to increase by up to 2.4 degrees. These buildings and archaeological deposits are moderately exposed to impacts including overheating and efflorescence, erosion and fl oding. Their vulnerability is increased by issues of water insecurity and the scale and conservation status of the structures. Responses including existing conservation efforts at some structures and projects which manage waterfl w at the site contribute to reducing this risk. Additionally, maladaptive responses, such as using inappropriate materials for repairs or conservation, could accelerate deterioration and reduce authenticity

Angkor Value 2 : Natural Values

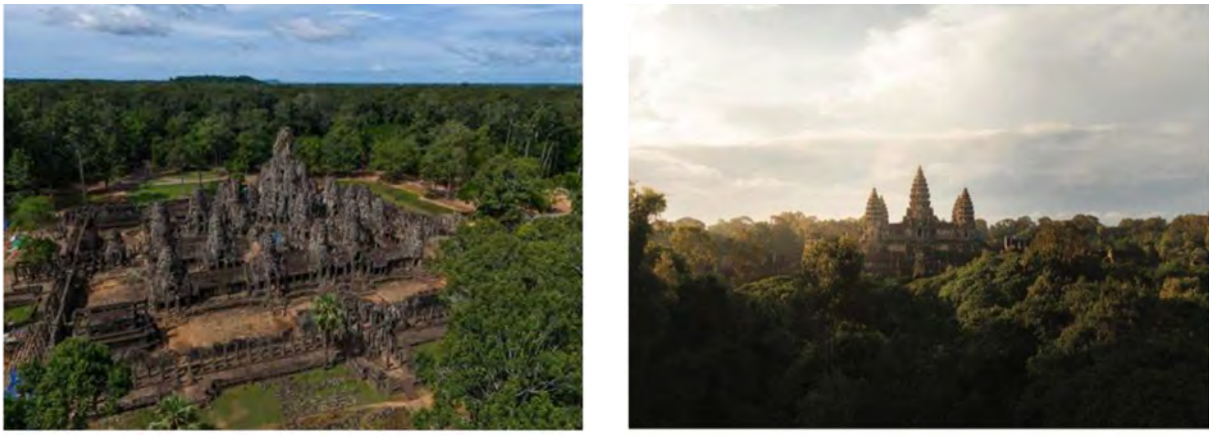

Figure 10.2: View of Bayon and Angkor Wat temples from above
(Figure: APSARA National Authority)

Middle-of-the-road scenario

By 2060 under a middle-of-the-road scenario, natural values illustrated by forests, water systems and biodiversity, face moderate risks due to climate change. Rising temperatures, shifting rainfall patterns, and extreme weather events are expected to impact the delicate balance between the site's natural and cultural heritage. While increased precipitation is due to increase by 4% and due to increase by up to 2.2 degrees could help sustain the region's vegetation and water reservoirs,it may also lead to soil erosion, destabilization of temple foundations, and an overgrowth of vegetation that could threaten ancient structures. Conversely, prolonged dry seasons could stress local fl ra and reduce water availability for both heritage conservation and local communities.

Wildlife populations, including native bird species and forest ecosystems, may experience habitat shifts due to changing climatic conditions. While some species could adapt, others may decline if mitigation measures are not implemented. The increased risk of invasive species and pests could also alter the ecological landscape, potentially affecting biodiversity and the long-term sustainability of An-

gkor's natural environment. Despite these challenges, ongoing conservation and reforestation efforts provide a buffer again some of these risks. The restoration of Angkor's ancient water management systems, combined with community-led conservation initiatives, offers an opportunity to maintain ecological balance. If these efforts continue and are scaled appropriately, Angkor's natural values can be preserved in the face of climate change. However, without consistent monitoring and intervention, climate related disruptions could gradually degrade the site's environmental integrity over time.

Pessimistic scenario

By 2060 under a pessimistic scenario, natural values mentioned forests, water systems, and biodiversity are at signifi ant risk due to intensifying climate change impacts. Rising temperatures, prolonged droughts, and erratic rainfall patterns threaten the delicate ecological balance that has long supported both the cultural heritage and surrounding communities. Within this timeframe precipitation is due to increase by 5 % and to increase by up to 2.4 degrees. Increased heat stress and reduced water availability could lead to forest degradation, biodiversity loss, and a decline in the health of native plant and animal species. The disruption of Angkor's ancient water management systems due to extreme weather events, such as more intense monsoons and extended dry spells, may result in both fl oding and water shortages. Soil erosion and sedimentation could weaken temple foundations, while invasive species and unchecked biological growth might accelerate damage to historic structures. The drying of natural water sources could also impact local agriculture, further straining community livelihoods and increasing pressure on the site's natural resources. Without sustained intervention, the natural environment of Angkor could deteriorate rapidly, leading to irreversible loss of biodiversity and longterm ecological imbalance. Conservation efforts may struggle to keep pace with these accelerating climate threats, particularly if resources and policy support remain insuffici t. If adaptation and mitigation measures are not expanded, Angkor's natural values may be signifi antly compromised, further endangering the site's cultural heritage and the well-being of surrounding communities.

Angkor Value 3: Knowledge and educational value

Middle-of-the-road scenario

Figure 10.3.1: Equinox at Angkor Wat and restoration activities of the temples
(Figure: APSARA National Authority)

By 2060 under a middle-of-the-road scenario, knowledge and educational values, which encompass its archaeological signifi ance, historical insights, and cultural teachings, face moderate risks from climate change and environmental degradation. While the site remains a vital resource for scholars, students, and heritage professionals, the increasing impacts of extreme weather, rising temperatures, and biodiversity loss pose challenges to both the preservation and transmission of its historical and scientific knowledge. Within this timeframe precipitation is due to increase by 4% and temperatures is due to increase by up to 2.2 degrees. Erosion, biological growth, and material degradation of temple inscriptions, carvings, and bas-reliefs may gradually diminish the ability of researchers to study and interpret Angkor's rich history. Unpredictable weather patterns and the increasing frequency of extreme climate events could also disrupt fi ld studies, conservation training programs, and educational tourism, limiting opportunities for knowledge exchange. However, advancements in digital preservation, conservation science, and remote learning offer opportunities to mitigate these risks. Initiatives such as 3D mapping, climate-adaptive site management, and local education programs help sustain Angkor's role as a centre for knowledge. If investment in research and adaptive conservation continues, the site can remain a living educational resource. Yet, without sustained funding and coordinated efforts, climate-related damage could progressively erode the ability to study and learn from Angkor, weakening its role in global heritage education over time.

Pessimistic scenario

By 2060, under a pessimistic scenario, knowledge and educational values face a critical and accelerating decline due to the worsening impacts of climate change. Rising temperatures, increased humidity, and extreme weather events threaten the preservation of vital historical records, inscriptions, and architectural details that serve as primary sources for research and education. Within this timeframe, precipitation is projected to increase by 5%, while temperatures are expected to rise by up to 2.4 degrees Celsius, further exacerbating the vulnerability of cultural heritage sites. The gradual erosion of sandstone carvings, fading bas-reliefs, and the proliferation of biological growth such as moss, lichen, and algae on temple surfaces could lead to an irreversible loss of historical information, signifi antly limiting future scholarship and cultural understanding. Furthermore, the physical deterioration of these cultural assets is likely to be compounded by a decline in institutional capacity and funding for conservation efforts. As global resources are increasingly diverted to address urgent climate-related crises—such as food insecurity, displacement, and public health emergencies—less attention and fewer funds may be allocated to the protection and restoration of cultural heritage. Th s combination of environmental stressors and human neglect threatens to reduce access to tangible links with the past, gradually eroding the educational foundations that support identity, critical thinking, and historical awareness. Without urgent and sustained action, the invaluable knowledge embedded in ancient structures may be lost to future generations, leaving gaps in collective memory and diminishing the richness of human culture.

11. Recommendations and Next Steps

Preserving Legacies is an international project that has raised awareness in Cambodia and trained dozens of people on the effects of climate change in general, and particularly on its impacts on heritage sites. Between 2023 and 2025, project activities brought together professionals, caretakers, and individuals from diverse fi lds, fostering the exchange of ideas and perspectives. Based on these discussions, a set of recommendations was developed as proposed next steps for advancing climate action at Angkor.

Climate change literacy in Cambodia

Climate change does not appear to be included in public school curriculum across the country. The site custodians agree that climate change literacy should be strengthened and for these reasons advocate for more awareness raising initiatives addressed to school kids in Cambodia, possibly starting from the Angkor Archaeological Park, but not only. To this end, a one day or multi-day training on the basics of climate change, adaptation and others could be planned, possibly including a fi ld visit too. Collaborations with Civil Society Organizations such as for example Heritage Watch could be envisioned, which already has experience in educational classes on cultural heritage and preservation in Cambodia, including also the production of comics on this very theme.

Studies on Impacts to Stone

It appears critical at this point to promote a scientific study on the impact of increasing temperatures on the main building materials in Angkor, including in particular sandstone and laterite, but others too. These studies would consider how (whether?) fluctuations, combined with humidity changes, can lead to the weakening of sandstone structures. At the same time, the research would describe the role of water sources (moats, canals, and ponds) around the temples to help regulate temperature and moisture levels, preventing excessive drying and cracking. The research should include a fi st part of analysis of the existing knowledge on the fi ld, followed by tests and simulations conducted on new samples. A scientific aper should then be generated and be made publicly available.

Water Reservoir Monitoring

Site custodians also point at developing or strengthening the existing monitoring plans for water reservoirs in Angkor and forested areas around the temples and in the Park. Th s recommendation would require working closely with APSARA National Authority to get a better understanding of the agency's existing monitoring plans and see how these could be further expanded by, for instance, liaising national and international specialists, conducting additional research also on traditional and new mechanisms to control water level in the different reservoirs across the Archaeological Park.

Carbon Reduction in the Park

In the past, the APSARA National Authority has already conducted studies to reduce vehicle emissions within the Angkor Park, in the awareness that air pollution and greenhouse gases could contribute to weathering processes affecting the temples. It would be important to reassess these plans in

light of the new climatic data generated since their drafting in the past years.

In the third year of Preserving Legacies, the site custodians will discuss these recommendations with the APSARA Authority and other stakeholders and possibly work on their implementation as needed.

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CASE STUDY: Siem Reap Flooding (Trip Report), 2011[11]

As most know by now, there has been fl oding across Cambodia and the region for almost two weeks, including in Siem Reap town. I drove from Phnom Penh to Siem Reap day before yesterday (Sunday) - the usual route up 6A to Skun, then National Route 6 through Kampong Thom and on to Siem Reap. The road was mostly clear of fl oding save a couple of short stretches with a few inches of water across the road that were easily passable. The countryside to either side of the road was fl oded to the horizon in many places, especially along 6A south of Skun and also near Kampong Thom City. The water was right up to the road's edge for much of the trip and just a little bit of rain would likely put it over the top. All of the rivers and streams (that could be distinguished from the fl oded countryside) were full to the brim and moving fast and hard. Animals - cows and water buff loes mostly - lined the sides of the road in several areas, driven out of the fi lds and to the high ground by the fl oding.

Figure: 6.3 Mild fl oding in Siem Reap Town, prior to water infrastructure refurbishment (Photo: by C Jacobson)

11. Source: LTO Cambodia: Siem Reap Flooding - Trip Report

Siem Reap town has experienced varying levels of fl oding for better than a week, the worst of it toward the south end of town. When we arrived on Sunday it hadn't rained in Siem Reap for more than 24 hours and the fl oding had reportedly stabilized and even retreated a bit. I'm staying at the north end of town where the fl oding is minimal at the moment. Tuk-tuks and motodups were reluctant to try to cross from this side of town to the Old Market area, claiming that there was a 50-50 chance of the engine fl oding out in the deeper sections along the way, so I decided to walk over to the Old Market in the early afternoon, about 8 hours ago. The following are some of the photos (Figure 6.3) I took along the way. (Turns out that wading 2-3 kilometers through ankle to knee-deep water is surprisingly good exercise. Suffering some sore leg muscles tonight as a result.)

As mentioned above, the weather has been mostly dry in Siem Reap for at least 48 hours. Yesterday (it is now just after midnight) was sunny and pleasant in the morning with only a brief rain in the afternoon. The waters are receding from town at the moment, quite visibly so in the later evening.

12. References

Ang, C., Prenowitz, E. & Thompson, A., 1998. Angkor. APSARA, Royal Government of Cambodia, Phnom Penh.

Apsaraauthority.gov.kh. Available at: https://apsaraauthority.gov.kh/apsara-authority-main/departments-and-units

Discovermagazine.com. Available at: https://www.discovermagazine.com/environment/how-climatic-changes-toppled

Eea.europa.eu.com. Available at: https://www.eea.europa.eu/en/topics/in-depth/climate-change-mitigationreducing-emissions

Freshnewsasia.com. Available at: https://freshnewsasia.com/index.php/en/local-news/298499-2023-0706-09-04-37.html

Harris, A. et al., 2022. Towards a temporal assessment of Angkor Thom's Theravāda Buddhist terrace archaeology Asian

Ministry of Environment, National Council for Sustainable Development & National Council for Khmer Language, 2017.

National Climate Change Committee, 2013. Cambodia Climate Change Strategic Plan 2014·2023. Royal Government of Cambodia.

Nationalgeographic.com. Available at: https://www.nationalgeographic.com/science/article/angkor-wat-civilization-collapsed

Preserving Legacies. (n.d.). Global Data Hub. Based on:
-Fick, S.E. & Hijmans, R.J., 2017. WorldClim 2: New 1km spatial resolution climate surfaces for global land areas. International
-Vousdoukas, M. et al., 2018. Global extreme sea level projections. European Commission, Joint Research Centre (JRC) Preserving Legacies. (n.d.). Guiding principles and framework for assessing climate risk.

Un.org. Available at: https://www.un.org/en/climatechange/what-is-climate-change [Accessed 14 Oct. 2024].

Whc.unesco.org. Available at: https://whc.unesco.org/en/list/668/ [Accessed 13 Jan. 2024].

Fieldwork Interviews:

Chea Sarith (2024, October 19). Personal Communication [Personal interview].

Doun Jira (2024, October 20). Personal Communication [Personal interview].

Houn Socheat (2024, October 18). Personal Communication [Personal interview].

Seng Sotheara (2024, October 17). Personal Communication [Personal interview].

Say Sopearin (2024, November 2). Personal Communication [Personal interview].

Ou Kongkear (2024, October 17). Personal Communication [Personal interview].

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