A study on Risks of Earthen Architecture due to Climate Change

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ABSTRACT

Climate change (CC) is one of the biggest common problems of humanity. We have only the IPCC reports as main source to understand the issue. In the latest published IPCC report on CC, it is asserted that if necessary measures are not taken, the adverse impacts of CC will emerge sooner than predicted. Despite, the issue affects all over the World in different sizes and forms, the governments still have not taken the necessary and realistic steps to solve the problem. This situation makes heritage more vulnerable to CC.

Some traditional materials such as earthen are more susceptible versus the CC impacts. Therefore, adverse impacts of CC on adobe heritage should be identified and measures should be taken before CC damages the heritage irreversibly. For this reason, in this study, it is aimed to define the general indicators of CC that emerge risks for cultural heritage and, address vulnerability of adobe heritage.

While some of the degradation mechanisms in cultural heritage arising from climate change are fast developing and measurable effects, some are slow and long-term impacts. The most damaging risks of CC to the cultural heritage are related to meteorological events such as extreme rains, flash floods, heat waves and droughts. In addition, unfortunately now the changing climate emerges the risk of occurrence of these weather events successively, especially extreme rain after drought terms. Both drought and, extreme rain are severely hazardous to the adobe heritage because of its material properties. After the drought term, the earthen material becomes more brittle form and, if any flash flood event occurs right after this term, it is devastating for the heritage. In the scope of this study, the CC impacts on cultural heritage and, the emerging risks of the Earthen Architectural Heritage are defined in general.

Keywords: Climate change impacts on cultural heritage, Adobe heritage, Sustainability

1 INTRODUCTION

Scientists have detected an increase of approximately 1°C in the temperature of the earth in the last century compared to the pre-Industrial Period [1]. This 1°C increase, which is certain to be of anthropogenic; has caused the change in the world climate and the increase in atmospheric events.

In the 80s, when climate change was scientifically revealed as a global problem, governments did not yet have the opportunity to predict what they could do about the issue due to lack of data. As a matter of fact, there were great uncertainties about what exactly the problem in front of them was, how it would shape in the future and how it could affect the world. Scientific data and consistent measurements were needed to eliminate uncertainties, and therefore, to prepare scientific reports on climate change the IPCC (Intergovernmental Panel on Climate Change) was established in 1988 under the United Nations in partnership with the WMO (World Meteorological Organization) and UNEP (United Nations Environment Program) [2].

Although climate change is the biggest common problem of the whole world, the fact that the measures to be taken will affect many sectors, especially energy and industry, has caused the problem to be ignored and even denied at the international level for a long time. However, after the 2000s, the remarkable increase in the number of disasters with hydro-meteorological character and it's the concretization of the connection with climate change made the problem more widely accepted in the whole world, first in European countries.

When EM-DAT (Emergency Events Database) comparative natural disaster data is examined, it has been observed that since 1980 there has been a continuous and significant increase in the number of hydro-meteorological disasters in the large-scale natural disasters due to climate change in the world [3]. According to the data obtained, it is stated that 64% of the disasters experienced in Europe since 1980 occur directly due to severe weather and climatic conditions such as floods, storms, droughts and heat waves [4].

In the subtropical Mediterranean climate zone, in which Turkey is located, three major problems such as drought, heavy precipitation and flash flooding, and increase in sea level tend to increase due to climate change [5]. Due to being located in the Mediterranean Basin, Turkey will be more affected by heat waves and droughts, heavy and excessive precipitation events, and weather events such as thunderstorms and tornadoes in the future. However, there is a risk of a decrease and irregularity in precipitation, and excessive precipitation in the western and northern coastal parts of Turkey, especially in summer [6; 7]. In parallel with this, the damage risks due to climate change to the cultural heritage will increase in the future.

2 CLIMATE CHANGE and CULTURAL HERITAGE

Until the year 2000, no national or international study on the effects of climate change on cultural heritage could be found. The first studies on this subject started after 2004 and Europe assumed a leading role in studies. It is thought that the negative effects of the Central European floods that occurred in 2002 on the cultural heritage were effective in raising awareness about the issue in Europe [8]. Noah's Ark, funded under the European Commission 6th Framework Programme, is the first comprehensive project on the subject aimed at identifying all risks posed by climate change on cultural heritage [9]. After the project outputs, the problem started to attract more attention in the field of protection [10].

Reports were prepared after the World Heritage Committee requested observations and determinations from the presidencies of the World Heritage Sites, which are under the threat of losing the heritage criteria due to the negative effects of climate change [11; 12]. Thus, the problem began to be examined more effectively in the field of conservation, and UNESCO, English Heritage, the European Commission and the Council of Europe carried out pioneering studies (Table 1). With the efforts of these organizations with high international effectiveness, the IPCC, in its 5th report published in 2014, included for the first time "the necessity of protecting cultural heritage in climate adaptation policies", unlike its previous reports [13]. After the commitments at the COP 21 Paris Climate Summit in 2015 and the report of the IPCC, the issue of cultural heritage has started to be included more in the climate policies of organizations and countries [14].

Tablo 1. Pioneering initiatives on the effects of climate change on cultural heritage [8] (Gökmen Erdoğan, 2022).

Year	Organization	Action
2004 2007	European Commission 6th Framework Programme	In its 6th Framework programme, the European Commission has agreed to finance the Noah's Ark Project to study the effects of climate change on cultural heritage in Europe.
2005	UNESCO World Heritage Committee	At the 29th meeting of the World Heritage Committee in Durban in 2005, organizations and individuals, including environmentalist groups, drew attention to the problem of the impact of climate change on World Heritage natural and cultural assets.
2005	English Heritage Centre for Sustainable Heritage (University College London)	Commissioned by English Heritage in 2005, the institution published the report "Climate Change and the Historic Environment" prepared by May Cassar.
2009	Council of Europe	The Council of Europe financed the continuation of the activities of the European University Center for Cultural Heritage in Ravello, Italy, in organizing courses on climate change risks for cultural heritage.

According to Rockman, climate change indicators that will cause damage to cultural heritage; sea level rise, storm surges, precipitation, temperature and wind variations, flooding, ocean acidification, increased atmospheric humidity, drought, fire, increase in invasive species [15]. In another similar study conducted by WHC, climate change indicators are given under 7 headings: atmospheric humidity change, temperature change, sea level rise, wind, desertification, combined effects of climate and pollution, climate and biological effects [12]. When climate change indicators are taken into account, it is seen that each of them poses serious risks to existing and emerging degradation mechanisms in cultural heritage.

In this study, it is aimed to determine the risks of adobe heritage due to climate change due to the limited scope. In this direction, in the next section, after the properties of adobe material are mentioned in general, it is tried to be revealed by examining which climate change risks the adobe heritage is more vulnerable to.

3 ADOBE MATERIAL PROPERTIES

When the earliest dates of humanity started to meet the building needs are examined, it is seen that the soil, which can be easily accessed, processed and compatible with the environment, comes to the fore in the context of materials. The combination of soil with other natural materials, especially straw and water, forms adobe. It is seen that adobe was used as a building material when natural materials such as wood and stone could not be acquired since the first periods of the settled civilization [16]. Adobe material, which is a sustainable material due to its low energy requirement and low cost in its production, has been used for thousands of years almost all over the world.

The most common use of adobe material in buildings is construction with adobe blocks or compacted soil [17] (Figure 1). The building will have a long life, if the adobe material is kept for 2 years before being used in the building and the construction is done with appropriate techniques and methods [18]. In addition, the type of soil to be used in adobe material is important because the properties of adobe material vary depending on the type of soil [19]. Although various metal oxides such as iron, magnesium, titanium oxide may be present in the clayey mud-brick soil, whose chemical composition is aluminium silicate, organic substances should not be present [17]. Although the compressive strength of the soil material is high, the tensile strength is low, so straw or similar fibrous materials are added to increase the tensile strength [18].


Figure 1. Adobe material [20]

Adobe material is sensitive to water and if necessary precautions are not taken, water penetrates into the material and starts the dissolution process of the binder clay. For this reason, rainwater washing the surface, water contacts due to insufficient drainage, flooding, rising ground water cause serious damage to the adobe material. However, sensitivity to the increase in humidity in the air and expansion and contraction mechanisms due to temperature changes are the properties that increase the vulnerability of the material to various factors [19].

4 THE RISKS OF ADOBE HERITAGE DUE TO CLIMATE CHANGE

Climate change has many negative effects in almost every field. Studies on their effects on cultural heritage generally examine climate indicators and the risks associated with them. The current threats posed by climate change on cultural World Heritage properties are defined as hurricanes and storms, sea level rise, erosion, floods, changes in precipitation regime, drought, etc. [12] (Figure 2).

Climate change impacts can be subtle and can occur over a long period of time. However, some climate change parameters such as a freezing, temperature and relative humidity shock can change by large amounts over a short period of time and can be measured. As for, slow-developing effects can only be detected by long-term observation and measurements. Therefore, within the scope of this study, while the risks caused by climate change in the adobe heritage were revealed, the slowly developing effects were excluded from the evaluation. To identify the major global climate change risks and impacts on cultural heritage, the climate parameters tabulated in the Table 2 are used by scientists.

Table 2. Principal climate change risks and impacts on cultural heritage [12]

Climate indicator	Climate change risk	Physical, social and cultural impacts on cultural heritage
Atmospheric moisture change	- Flooding (sea, river) - Intense rainfall - Changes in water-table levels - Changes in soil chemistry - Ground water changes - Changes in humidity cycles - Increase in time of wetness - Sea-salt chlorides	- pH changes to buried archaeological evidence - Loss of stratigraphic integrity due to cracking and heaving from changes in sediment moisture - Data loss preserved in waterlogged / anaerobic / anoxic conditions - Eutrophication accelerating microbial decomposition of organics - Physical changes to porous building materials and finishes due to rising damp - Damage due to faulty or inadequate water disposal systems; historic rainwater goods not capable of handling heavy rain and often difficult to access, maintain, and adjust - Crystallisation and dissolution of salts caused by wetting and drying affecting standing structures, archaeology, wall paintings, frescos and other decorated surfaces - Erosion of inorganic and organic materials due to flood waters - Biological attack of organic materials by insects, moulds, fungi, invasive species such as termites - Subsoil instability, ground heave and subsidence - Relative humidity cycles/shock causing splitting, cracking, flaking and dusting of materials and surfaces - Corrosion of metals - Other combined effects eg. increase in moisture combined with fertilisers and pesticides
Temperature change	- Diurnal, seasonal, extreme events (heat waves, snow loading) - Changes in freeze-thaw and ice storms, and increase in wet frost	- Deterioration of facades due to thermal stress - Freeze-thaw/frost damage - Damage inside brick, stone, ceramics that has got wet and frozen within material before drying - Biochemical deterioration - Changes in 'fitness for purpose' of some structures. For example overheating of the interior of buildings can lead to inappropriate alterations to the historic fabric due to the introduction of engineered solutions - Inappropriate adaptation to allow structures to remain in use
Sea-level rises	- Coastal flooding - Sea-water incursion	- Coastal erosion/loss - Intermittent introduction of large masses of 'strange' water to the site, which may disturb the metastable equilibrium between artefacts and soil - Permanent submersion of low lying areas - Population migration - Disruption of communities - Loss of rituals and breakdown of social interactions
Wind	- Wind-driven rain - Wind-transported salt - Wind-driven sand - Winds, gusts and changes in direction	- Penetrative moisture into porous cultural heritage materials - Static and dynamic loading of historic or archaeological structures - Structural damage and collapse - Deterioration of surfaces due to erosion
Desertification	- Drought - Heat waves - Fall in water table	- Erosion - Salt weathering - Impact on health of population - Abandonment and collapse - Loss of cultural memory
Climate and pollution acting together	- pH precipitation - Changes in deposition of pollutants	- Stone recession by dissolution of carbonates - Blackening of materials - Corrosion of metals - Influence of bio-colonialisation
Climate and biological effects	- Proliferation of invasive species - Spread of existing and new species of insects (eg. termites) - Increase in mould growth - Changes to lichen colonies on buildings - Decline of original plant materials	- Collapse of structural timber and timber finishes - Reduction in availability of native species for repair and maintenance of buildings - Changes in the natural heritage values of cultural heritage sites - Changes in appearance of landscapes - Transformation of communities - Changes the livelihood of traditional settlements - Changes in family structures as sources of livelihoods become more dispersed and distant

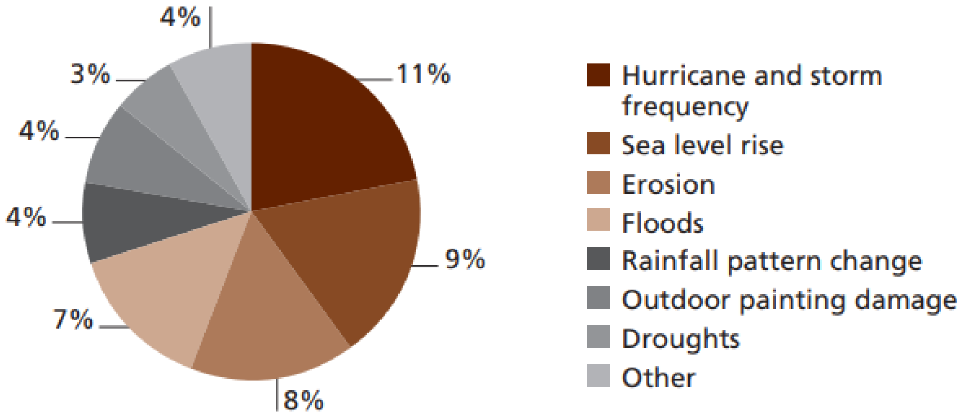

Figure 2. Threats of climate change for World Heritage sites [12]

The World Heritage Earthen Architecture Programme (WHEAP) suggests that 34% of the 150 earthen heritage sites on the UNESCO World Heritage List are currently under threat from climate change [21].

Considering the sensitivity of adobe material to water, air humidity increase, sudden temperature changes and drought, it is thought that all the climate indicators in Table 2 that have adverse impacts on the cultural heritage may pose different damage risks on the adobe heritage. However, when adobe material is evaluated in terms of its properties, it is thought that it is more vulnerable to risks related to atmospheric humidity changes, temperature changes, wind and drought indicators. In this direction, the climate change risks of the adobe heritage are examined below, based on these indicators.

Figure 3 Typical water-ingress problems [22]

- *Risks of Adobe Heritage due to Atmospheric Moisture Change:* The risks posed by this climate indicator are defined below (Table 2) [12]:

~ Sudden intense and heavy rains,
~ Changes in water levels (unlike sea level rise)
~ Floods (coastal / river / urban),

- ~ Changes in soil chemistry,
- ~ Changes in groundwater properties and level,
- ~ Changing humidity cycles,
- ~ Increased wet time

The adobe, earthen, structures are easily damaged by natural erosion as they become exposed to air and rain and require continuous conservation efforts and substantial ancillary measures [23]. Because, the high humidity in the air causes the adobe wall to dissolve, and it's load-bearing to decrease and the tensile and compressive strength of the clay-bound soil walls to decrease [24]. The risk of collapse in the superstructure will increase due to the soil saturation with the rise in the groundwater level. In addition, increases in floods also pose serious threats to the adobe heritage.

Figure 4 The archaeological site of Meroe after flood [28]

- *Risks of Adobe Heritage due to Temperature Change*: The risks posed by this climate indicator are defined below (Tablo 2) [12]:

- ~ Diurnal, seasonal, extreme events such as heat waves and snow looding;
- ~ Changes in freze-thaw cycles and
- ~ Increase in ice storms and wet frost

Although climate projections indicate that freezing temperatures are likely to be less common in the future, increased winter precipitation and periods of seasonal extreme temperatures mean that freeze-thaw cycles will remain a threat to the integrity of adobe structures into the future. Because external surface deterioration is associated with damp frost and subsequent thawing [22].

Extreme temperatures at the surface of material can occur under intense solar radiation. In earthen materials, this can lead to thermoclastic deterioration from repeated expansion and shrinkage. These fluctuations cause internal stresses that can compromise the comprehensive strength of the blocks and reduce overall structural strength [25].

- *Risks of Adobe Heritage due to Wind:* Wind movements have major effects on storm systems and precipitation patterns, and wind and precipitation patterns have changed with climate warming [26]. The risks posed by this climate indicator are defined below:

- ~ Wind-driven rain and sand;
- ~ Wind-transported salt
- ~ Winds, gusts and changes in direction

The moisture susceptibility and friability of earthen building materials makes them highly prone to damage by abrasive processes. Wind-driven rain can impinge directly on the exposed walls, causing considerable damage. Heavy winds cause the rain to come almost horizontally to the building facades, and especially on the facades with porous materials, this wind-blown rainwater reaches the depths of the texture of the buildings. A similar process occurs when wind-driven sand has aggressive effects and causes damage to both soft and hard building materials. Likewise, salts reach the land and structures with the effect of wind in places close to the shore [27]. The wind causes the wall surfaces to dry and cracks to form, sand, salt and dust particles coming with the wind abrade the wall surfaces; porous material penetrates into them and causes contamination [10]. Furthermore, it causes unwelcome accumulations against walls [22]. In storms, loads cause deterioration of building elements; it can cause vertical structures such as adobe minarets to collapse.

- *Risks of Adobe Heritage due to Desertification:* The risks posed by this climate indicator are defined below (Tablo 2) [12]:

~ Drought,
~ Heat waves
~ Fall in water table

Desertification, one of the indicators of climate change, is one of the most serious threats posed by the increase in global temperatures [13; 2]. Desertification consequences include expansion of dunes, further erosion, and sometimes complete loss of vegetation in the area [10]. Drought increases the risk of fire and causes changes in the physical, chemical and biological properties of materials [14]. Heat waves caused by climate change caused the frequency of fires in the Mediterranean, the USA and Australia to increase by 300% and the lakes to dry up [2].

It is known that there is numerous adobe heritage in regions such as Timbuktu in Africa, where desertification due to climate change is experienced. Heritage assets in these areas are exposed to adverse effects of sand and dust due to the expanding desert.

5 CONCLUSIONS

With the Industrial Revolution, the world has begun to experience the first anthropogenic climate change. Initially, the problem was air pollution caused by coal smoke, but it has grown and become more complex. Today, climate change, which has evolved into much bigger problems such as drought, storms, hurricanes, floods and rising sea levels, also poses great risks for cultural heritage. Climate change, which has been accepted as a global problem since the 1980s, poses many different risks of vulnerability for the adobe heritage, including the complete loss of the heritage.

The adobe structures, which are concentrated in Africa, Central Asia, Central and South America, but examples can be found almost everywhere in the world, are quite abundant in our country, especially in the Middle Anatolia, Eastern and South-eastern Anatolia Regions. Apart from these geographical areas, it is known that there are approximately 500,000 adobe structures in England, most of which were built in the twentieth century, and that about 30% of the world's population lives in mud-brick structures [18]. Considering the number of adobe structures in the world, it is understood that many adobe structures are vulnerable to risks arising from the adverse effects of climate change.

Within the scope of this research, the risks posed by climate change on the cultural heritage were examined and, the risks that would affect the adobe heritage in the short term were tried to be determined. In this scope, the climate parameters that are thought to pose serious fragility risks in the adobe heritage are determined as "atmospheric humidity change", "temperature change", "desertification" and "wind", and possible risks are defined due to those. However, due to the limitations of the study, the risks are given in a general framework.

In future studies, the adverse impacts of climate change on the adobe heritage should be examined more comprehensively and how the adobe heritage will be protected from these effects should be discussed. To mitigate the impacts, new conservation methods that are compatible with heritage values should be explored.

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