

VULNERABILITY OF HERITAGE SITES TO CLIMATIC EXTREME EVENTS: KHALIFATABAAD ANCIENT MOSQUE

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Abstract

Built heritage is the pride of human civilisation and the built environment. But nowadays, they are gradually threatened by various natural decay, deterioration, and effects of extreme climate events. Khalifatabaad (present Bagerhat) in the southwestern part of Bangladesh has a rich heritage value and was also enlisted as one of the world heritage sites by UNESCO in 1985. The Department of Archaeology Bangladesh and UNESCO are working together to conserve Khalifatabaad's heritage sites. But due to climate change and the increased number of tropical climate extreme events like sea-level rise, tropical cyclones, super cyclones, storms, tidal surges, waterlogging, salinity, dampness, etc., significant problems are arising to preserve and conserve the heritage structures of tropical regions. This paper aims to investigate and analyse the vulnerabilities of these heritage structures due to extreme climate events by following building pathology principles. The DPSIR (Driver-Pressure-State-Impact-Response) method is used as the research framework. The research data are collected and documented through a literature review, site survey, detailed observation, documentation, oral statement records, and qualitative analysis. The research outcome is focused on investigating the most responsible climate extreme events, their short-term and long-term impacts on heritage buildings, and presenting conservation strategies for the historical sites in Khalifatabaad.

Keywords: *Vulnerable heritage buildings; Investigation; Climate extreme events; Conservation*

Introduction

Background

Heritage buildings are successively becoming more vulnerable due to environmental decay and deterioration, the effects of climate change, and human-persuaded impacts [1]. An increasing number of extreme weather events associated with climate change are causing significant problems in managing and conserving cultural heritage around the globe [2]. Scientific analysis, studies, and research are ongoing under the observation of various international organisations to protect these vulnerable archaeological sites for future generations' sake [3, 4]. Bangladesh, the 136th member of the UN [5], is one of the world's most densely populated countries. It is located in the south-west region of Asia, with its people in a delta of rivers that empties into the Bay of Bengal [6]. This deltaic country has a rich historical background with many remarkable cultural and natural heritage sites [7]. But according to "BBC country profile (Bangladesh)-2018, "as a low-lying country, Bangladesh is very vulnerable to random flooding, unpredictable cyclones, and extreme salinity and stands to be seriously struck by sea level rise [8]. These extreme climatic conditions also threaten the existence of this deltaic basin's natural and cultural heritage [9]. As a country with a large coastline, one of the adverse impacts of climate change is increased surface water, underwater,

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soil salinity, and dampness [10]. Salinity mainly affects land use, landscape, and freshwater sources in coastal areas, as well as the structural durability of heritage buildings [11, 12]. Also, many projected climate extreme events, including sea-level rise, temperature increases of 1.4°C and 2.4°C, are projected by 2050 and 2100, respectively; evapotranspiration losses, irregular monsoon precipitation, rainwater run-off, reduction of dry season precipitation, and uncertain and random cyclones, would increase many of these baseline's vulnerabilities that already pose a serious effect on the coastal archaeological sites of Bangladesh [13].

But despite the threat of vulnerability due to climate change, specialised research to preserve and conserve the historic sites of Bangladesh is still insufficient. Though UNESCO has declared “the historic mosque city of Khalilabad” near Sunderban as a world heritage site [14], which is the only existing evidence of Khan-e-Jahan style and is one of the most vulnerable archaeological sites to climate change and various climate extreme events, it is still missing the research limelight from the point of view of conservation and climatic vulnerability. This paper aims to focus on the vulnerability issues, responses, and conservation strategies directly or indirectly related to the changing patterns of climate extreme events in Khalifatabaad.

Khalifatabaad and existing heritage sites

“Khalifatabaad”- now known as Bagerhaat, located in the southeast part of coastal Khulna and about 50km north of UNESCO's world heritage site Sundarban Mangrove Forest (Fig. 1), was one of the oldest cities of Muslim rule in Bengal (1204–1757 A.D.) [15]. Numerous mosques, bridges, roads, palaces, mausoleums, and other public buildings were built in a very short span of time under the great aegis of Khan-Jahan Ali [16]. The magnificent city extends 50km² and is the only evidence of the Khan-E-Jahan style of Muslim architecture in Bengal. In its golden age, this city contained about 360 mosques, public buildings, mausoleums, bridges, roads, water tanks, and other public buildings [17].

From these conditions and constraints of setting the style, we came up with a solution that produced the remarkable phase of Bengali architecture, which is called the Khan-E-Jahan style. The contextual and utilitarian character was the key concept of the Khan-e-Jahan style [18]. Buildings here were perceived not as an art form but as pieces of architecture, where forms are generated by contextual needs and organisational simplicity [19]. In their introductory note in 1985 about Khalifatabaad, UNESCO said that “*The city's infrastructure reveals considerable technical skill, and an exceptional number of mosques and early Islamic monuments, many built of brick, can be seen there*”.

Extreme climate events in Bangladesh

Climate extremes encompass both extreme weathers, with durations of minutes to days (the synoptic timescale), and extreme climate events, with durations of months in the case of periods of wet or stormy weather or years in the case of drought. In all cases, the frequency and outbreak of extreme events may be affected by seasonal to inter-annual fluctuations of large-scale climate variations [20]. Bangladesh, a South Asian disaster-prone country, experiences a range of extreme tropical climate events almost every year. Global warming, climate change, sea-level rise, etc. are adding fuel to the fire [21]. According to the United Nations' Intergovernmental Panel on Climate Change, global sea levels could rise by 0.28 to 0.98m (1–3 feet) by 2100, which will have serious impacts on coastal cities, deltas, and low-lying countries [22]. Various extreme climate events affect every socio-economic sector in Bangladesh [23]. Bangladesh ranked 7th in the Global Long-term Climate Risk Index, 2021, a ranking of 185 countries that are most vulnerable to climate change [24]. According to the 4th assessment of the IPCC, the frequency and outbreak of tropical cyclones will increase remarkably in the next few decades (Table 1), making Bangladesh the most vulnerable country because of sea surface temperature and global warming [25]. So, this region, which is already in threat of various climate extreme events, is going to face more challenges of climate change through not only its direct and fast impact of tropical cyclones (Table 2), floods, tidal surges, extreme precipitation, etc., but also indirect and slow long-term impacts of extremes like sea level rise, extreme

salinity, dampness, biological and chemical weathering, etc. Due to the argo-based economy and lower per capita income, the impacts of climate extremes make the situation more vulnerable in Bangladesh [26].

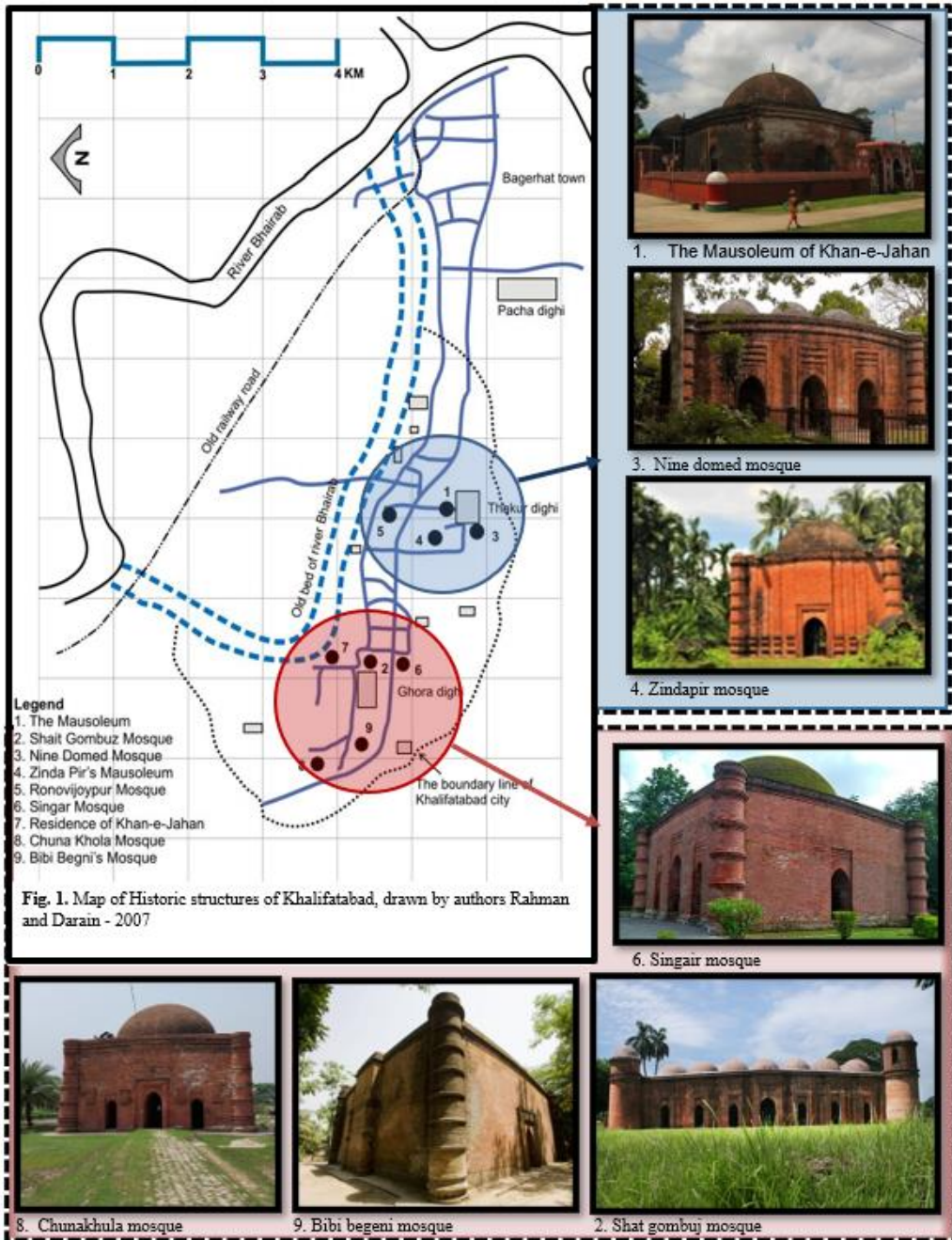


Fig. 1. The Historic City Map and Structures of Khalifatabad

Table 1. Description of few well-known heritage structures of Khalifatabaad

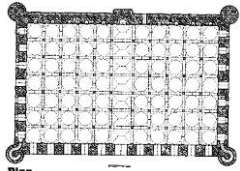
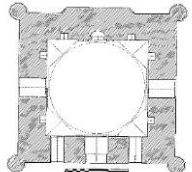
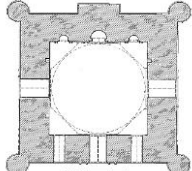
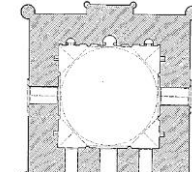
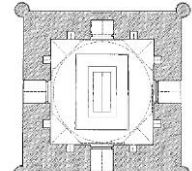
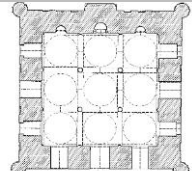
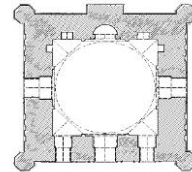
Group	Heritage structure	Description	Plan
<p>01 (During the rulership of Khan - E- Jahan)</p>	<p>2. Sixty Domed Mosque</p>	<p>Earliest and most renowned heritage structure of Khalifatabaad. Built in around 1300-1400 AD. Roof with 81 domes with average height 28'. Wall thickness 8'-0", handmade terracotta clay bricks 60 octagonal stone columns. 11 entry-exit doors with pointed arches. 4 circular planned corner turrets.</p>	 <p>Plan</p>
	<p>6. Singair Mosque</p>	<p>At the south-east of Sixty domed mosque complex. Just beside the Heritage highway and enclosed by boundary wall. 30'-6" Square plan, single domed and exposed brick structures with 4 corner turrets. Wall thickness 7'- 0" and height is 33'- 0".</p>	 <p>Plan</p>
	<p>8. Chunakhola Mosque</p>	<p>At the far west of sixty domed mosque complex, on an isolated low and vast flat land surrounded by paddy field and fish hatchery with poor connectivity. 40'- 0". Square plan, single domed and exposed brick structures with 4 corner turrets with terracotta details 7'- 6" thick wall with 3 entrance doors in the east. The height is 32'- 9".</p>	 <p>Plan</p>
	<p>9. Bibi-begini Mosque</p>	<p>At the west of sixty domed mosque complex surrounded by unplanned vegetation and residential settings 51'- 0". Square plan, single domed and exposed brick structures with 4 corner turrets. Wall thickness 9'- 6" and 3 main entrance doorways in the east. The height is 40'- 6".</p>	 <p>Plan</p>
<p>02 (After the rulership of Khan - E- Jahan)</p>	<p>1. Musoleum of Khan-E- Jahan</p>	<p>On the northern corner of the then 'Thakur dighi' presently known as 'Dargah dighi' Single domed, square plan (46'-0") Exposed brick expression, 8'-0" wall thickness with multi-coloured tiled floor decoration The total height is 37'-8"</p>	 <p>Plan</p>
	<p>3. Nine domed Mosque</p>	<p>On the western bank of the then 'Thakur dighi' presently known as 'Dargah dighi' Nine domes, square plan (54'-8") 7'-7" exposed brick wall with four slender octagonal columns The height is 31'-0" The roof cornices are decorated with terracotta ornamentation</p>	 <p>Plan</p>
	<p>4. Zingapir Mosque</p>	<p>On the southern side of Khan-e-Jahan Road Just beside the Mausoleum complex of Zindapir Single domed square plan structure (24'-6") Wall thickness is 4'-6" with exposed brick expression Octagonal corner turrets.</p>	 <p>Plan</p>

Table 2. Timeline of Super cyclone after 2005 in Bangladesh.
Source: Bangladesh Meteorological Department

SL	Super cyclone	Year
1	Akash, Sidar	2007
2	Rashmi	2008
3	Bijli, Aila	2009
4	Roanu	2016
5	Mora	2017
6	Fani, Bulbul	2019
7	Amphan	2020
8	Yaas	2021

Heritage conservation in Bangladesh

Like the other sectors, the built environment and building durability are also in vulnerable condition in this deltaic region due to various extreme climate events. New structures will have to be designed to cope with these extreme climate conditions to avoid unwanted vulnerabilities [27]. But the heritage sites of the southwest coastal region are facing extreme vulnerability because of their super-vulnerable traditional building materials like clay brick, mud mortar, terracotta, wood etc. [28]. The Department of Archaeology (DOA) is responsible for all planned conservation, preservation, and promotion of the cultural heritage of Bangladesh. The main conservation legislation is the Antiquity and Monuments Act 1968 (amended in 1976) and the Heritage Act 2009. But the heritage experts feel that the existing rules, regulations, research, and conservation are not sufficient to conserve the heritage sites from the upcoming challenges [29].

Therefore, it is imperative that we approach the conservation of our heritage structures with greater intelligence. This research focused on identifying the most responsible climate extreme events that make the heritage sites of the southwest coastal region of Bangladesh, especially the structures of the historic mosque city of Khalifatabaad, more vulnerable. We anticipate that this research will contribute to the creation of more efficient and intelligent conservation policies and strategies for the preservation of heritage in Bangladesh.

Materials and Method

Data collection

Primary Data collection

For a detailed survey and data collection here, seven historical structures were chosen. Among them, a few are in very stable and perfect condition. For example, Shat Gambuj mosque and Khan-e-Jahan mausoleum are visibly in better condition. Few are in an averagely stable condition from the point of view of usability. People still use them for their daily prayers. These mosques are treated as their daily neighbourhood mosques. For example, the Nine Dome Mosque, the Bibi Begeni Mosque, and the Chunakhola Mosque. On the other hand, a few historical structures are almost abandoned and close to destruction. These structures are mostly victimised by various climatic and non-climatic extreme events. For example, the Rezakhuda Mosque and Jindapir Mausoleum. According to the survey, we mapped the site and structure.

Repeated site surveying and evidence collection

Repeated site surveying was carried out for detailed information about the present scenarios of Khalifatabaad's historic spots. Three main surveys can be noted:

- Primary Survey: Map development, exact historic spot selection, historic evidence collection, background, and timeline analysis.
- Secondary Survey: Targeted focus group selection, detailed site investigation, historic building layout, and investigation of the visible impacts of climate extreme events on them.
- Final Survey: FGD with a semi-structured questionnaire, detailed material collection for the lab test, local KII for the conservation proposal.

During the field survey, according to building pathological principles, three major steps were followed for data collection: (i) Survey observations (ii) Data documentation and (iii) Evidence investigation.

The visible impacts of extreme climate events on the vulnerability of historical sites were observed carefully. Photographs were taken of the area, and connectivity maps were generated to illustrate later. Important observed information was noted, and noticeable changes in heritage sites had also been marked. Authorised information about the historical sites of Khalifatabaad was collected from the concerned museum and the Khulna divisional branch of the Department of Archaeology. The collected data and evidence of heritage sites, like- maps, pictures, material samples, FDG Summery etc., was documented by maintaining the interlinkage for better investigation.

Focus Group discussion. Oral history collection and field observation

Collecting historical details and past climatic scenarios of Khalifatabaad FGD was one of the keyways.

The focus group selection criteria was shown in figure 2.

- Local residence.
- Age-wise grouping (more than 65 years old).
- Involvement in historical site maintenance and conservation.
- Socially and politically active people for authentic information.

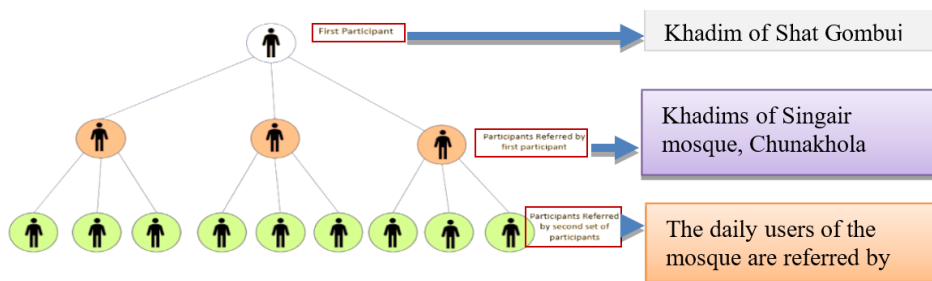


Fig. 2. The applied snowball data sampling structure of this research. Source: Field survey

Decision about the impacts of climatic and non-climatic factors on heritage sites from their point of view as users.

As we know, Khalifatabaad is one of the oldest and largest settlements of the sultanate period in Bangladesh.

It contains many historical treasures, and the stories are still alive among the local people.

Our focus groups are the main resource for narrating the history of the heritage buildings. In the historical discussion, we have focused on a few particular points. They are:

- The very fast construction process and techniques to face the contextual issues (historical fiction and evidence)
 - How did the local people use these historical buildings, and what are the present situations?
 - After Khan-E-Jahan what was the social condition of Khalifatabaad and its historical structures?
 - Discussion about the conservation history of the historical mosques of Khalifatabaad?
- Also, try to collect the related evidence to justify the information.
- History of climate extreme events and their current impacts on Khalifatabaad.
 - What were the impacts of becoming a UNESCO World Heritage Site?

- About the major conservations, the concerned authority, local techniques, and durability.

Key Informants interview

Informal interviews with key informants were carried out about the visible and nonvisible impacts and vulnerability of historical sites, responsible climatic indicators, extreme climatic events, etc. Discussion about existing conservation techniques, material durability, future conservation plans, and policies of authorities was on the checklist while having a discussion with the Khulna Regional Director of the Department of Archaeology Bangladesh.

On the other hand, the oral history-based narrations, and the social, religious, and cultural impacts of the heritage structures of Khalifatabaad were the focal points of our discussion with the Khadim of Sixty domed mosque who has been serving this heritage site for 64 years. He is also a direct source who has seen many climates extreme events, their changing patterns, and their impacts on the heritage sites of Khalifatabaad.

Public awareness and involvement in heritage site preservation are also important issues here. So, while discussing with the Chairman of the 7th Union Parish of Shat Gombuz Union, public and political involvement, awareness, and collaboration with the department of archaeology were the focal points.

Secondary data collection

Literature review and Conservation document collection

This research heavily draws on a literature review and an archival study. A few records of various structural damages due to climate extreme events on historical buildings were also collected from the official records of the Department of Archaeology Khulna divisional office. The present conservation strategic plan (technical and policy) has also been collected from the Department of Archaeology as well as from the UNESCO-world heritage site conservation policies.

Analytical tools

DPSIR Model for Data Analysis. The generic DPSIR framework is adapted to be used for the vulnerability assessment of historical sites in Khalifatabaad to climate extreme events, which is shown in figure 3.

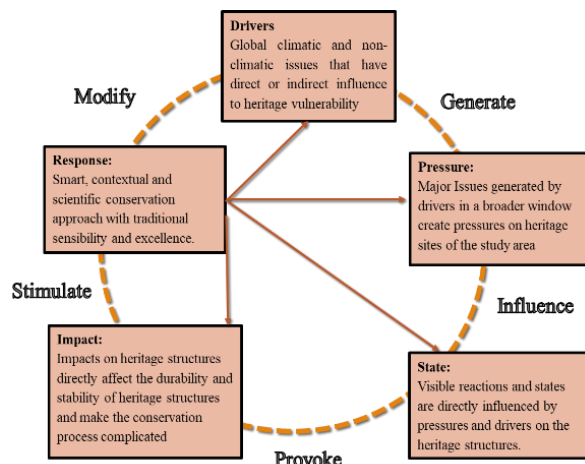


Fig. 3. The applied DPSIR structure of this research

Graphical and Architectural details for Microanalysis

Relevant graphical details like plans, sections, elevations, etc. are included accordingly for micro-analysis. Conceptual cross-sections and indoor spot sections are also applied where necessary for impact assessment and analysis.

Survey Findings and Results

Vulnerability assessment for extreme climate events

The local material-based heritage sites are now facing the most vulnerable condition due to changing climatic behaviour and being affected by random climate extreme events in Bangladesh. Heritage conservation is also becoming more challenging for experts and concerned authorities. During the vulnerability analysis of the heritage sites of Khalifatabad, it has been clear that the vulnerabilities due to climate extreme events can be divided into two parts.

Short-term vulnerabilities due to extreme climate events

The seasonal climate and extreme events like severe cyclones with tidal surges, sudden and seasonal floods, uneven heavy precipitations, etc. are the reasons for the short-term vulnerabilities of the structures. Waterlogging and increasing dampness are so harmful to brick-made structures like Khalifatabad. Just a few years ago, in 2007 and 2009, the tidal surge and floods directly affected the structures.

From FDG, it has been heard that people witnessed a heavy tidal surge that reached the plinth of Shat Gombuj in the 1961s, 1966s, and 1970s. and caused serious damage to these historic structures. At that time, waterlogging caused extreme dampness, material erosion, and extreme salinity in this area. The local people, family, and followers repaired a few damaged structures, such as the mosque and mausoleum of Jindapir (Fig. 4B), after the extreme climate events of that time. Few structures in remote places become abundant during the rainy season. Waterlogging due to heavy rainfall, low land, and a lack of proper drainage systems makes the heritage structures more vulnerable from the point of view of material durability and structural stability as well. Even in present times, few structures like Chunakhola mosque (Fig. 5) have regular waterlogging in the monsoon.



Fig. 4. The condition of the Rezakhuda (six domed) mosque (A) and Mausoleum of Jindapir in present days (B)



Fig. 5. Chunakhola mosque during monsoon

Long-term vulnerabilities due to extreme climate events

The long-term impacts of climate extreme events are making the heritage sites in this region more vulnerable. The long-term effects are more threatening for the historical materials, their expressions, durability, and stability. Though their impact and visibility are slower than short-term effects, the damages are permanent and more complex to solve for conserving the heritage structures (Fig. 6).

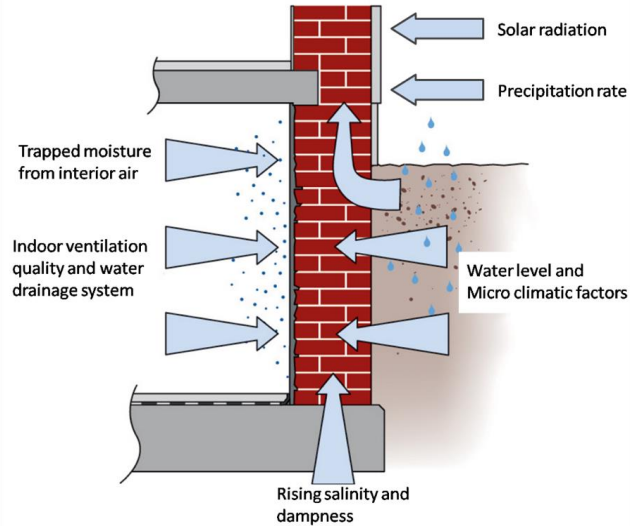


Fig. 6. Climate extreme events responsible for long term impacts on the stability of Heritage Structure in Khalifatabaad

Sea Level Rise and Extreme salinity

In current times, due to sea level rise, various climate extreme events like rapid surges, seasonal and flash floods, extreme salinity, biological and ecological imbalances, etc. are becoming more alarming for the structures of Khalifatabad, where dampness and salinity were always major issues for structural sustainability. Even Khan-e-Jahan took various precautions at that time to protect the structures from dampness and salinity. Columns of Shat Gombuj Mosque were built on stone bases to protect the columns from soil salinity and dampness, which was a wise solution for that time. Still, they are 4 inches projected from the plinth level (Fig. 7).



Fig. 7. 4” pillar-base to protect them from dampness

But clay-made bricks are always highly affected by soil salinity, water salinity, high humidity, and other extreme conditions. The brick-made walls are already the most repair-demanded portions here. In dry times, because of the hydration and hydrolysis processes, the salinity level increases both in the water and soil layers. The local clay-made brick patronises salt crystallisation most (Fig. 8A). From the field survey and FGD, it is confirmed that the rate of crystal formation of the salt in local materials is very high. Which causes extreme erosion of materials (Fig. 8B).

Wall-section of Khalifatabad

Due to extreme humid weather, uneven monsoons, building materials (like clay brick, lime mortar, etc.), and high salinity, dampness affects the structures and makes them more vulnerable. Moss, fungi, and various types of parasite flora and fauna caused extreme erosion of the historic structures of this area (Fig. 9). This biological weathering is almost unavoidable due to our weather pattern.

Extreme Dampness and Biological Weathering

Traditional ornamentations with important cultural details are also in great threat for biological extreme conditions. In fact, indoor dampness becomes a great threat to the indoor environment. Structures with huge volumes, thick exterior walls, and fewer ventilators are also a reason for indoor dampness. In the phase of site observation, it has been found that indoor walls are also highly affected by flora and fauna (Figure 10). Detail dusting and regular maintenance are a must to control these kinds of vulnerable conditions.

Extreme Temperature and Radiation Effect

Bangladesh faced its highest temperature, 41.2°C (106.2°F), last April. And lowest 7.1°C in December. The variation of temperature change is uneven and shows a significant fluctuation and alternative increase-decrease pattern in recent times [30]. This temperature fluctuation could be a reason for uneven material expansion and shrinkage, which can develop cracks in the structures. In Khalifatabad, it has been heard that after the last repair in the domes of Shat Gombuz mosque in 2016, during the shortest period, a few cracks had already developed (Fig. 11). Which could be a reason for uneven temperature fluctuations and solar radiation.

Extreme Chemical weathering effect

The water solution is the primary phase of chemical weathering. The structural pattern and material used in the structures of Khalifatabad are easily solved in water. A few chemical elements used in these structures can be a big threat in that case. For example, the mud materials that were used as the brick binding materials in Khaligfatabad are highly soluble in water. Limestone, thin bricks, and lime-mud mortar are also solved at the medium level by water impact and gradually eroded.



Fig. 8. Crystal formation of salt and erosion of the building materials in Khalifatabad

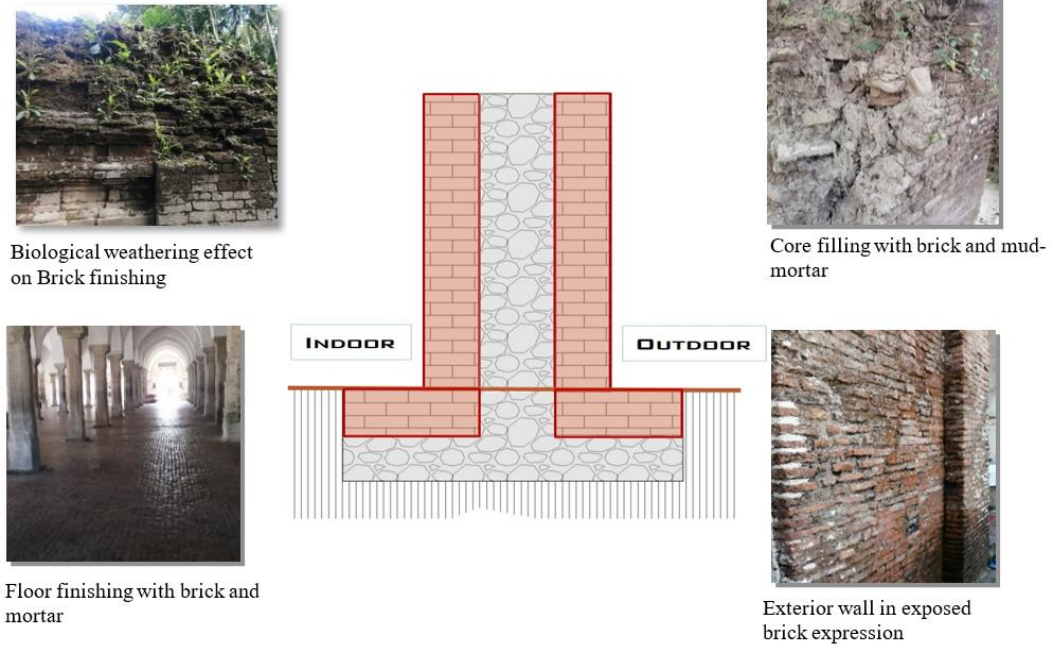


Fig. 9. impacts of dampness and biological weathering on the historical structures of Khalifatabad



Fig. 10. Crystal formation of salt and erosion of the building materials in Khalifatabad



Fig. 11. Visible joint cracks of Shat Gombuj Mosque

According to the above analysis and discussions, the degree of vulnerability of heritage structures due to various extreme climate events can be categorised into three major groups (Table 3).

Table 3. The degree of vulnerability of heritage structures due to various climate extreme events in Khalifatabaad

Groups	Description	Visible impacts of climate extremes
01 - Well Conserved 1. Sixty Domed Mosque 2. MMAusoleum of Khan-e-Jahan	<ul style="list-style-type: none"> Well-known and most visited heritage structures of Khlifatabaad The most frequently conserved heritage structures of Khalifatabaad The heritage buffering and boundary, property line, and land use are carefully maintained. Tourist facilities and guidelines are properly managed Entry restrictions, museum, and other supporting facilities are also available in the heritage complex. 	<ul style="list-style-type: none"> Impacts of salinity as crystallisation of salt on building materials are visible in a few facades, like the North Façade of Sixty Domed Mosque Impacts of dampness and biological weathering are clearly visible in the indoor portion. Few ceiling and roof cracks can be evidence of temperature fluctuations. Impacts of dust blows and other non-climatic extremes are very low because of rapid maintenance.
02 - In threat but still usable 1. Singair Mosque 2. Bibi Begini Mosque 3. Chunakhola mosque 4. Nine domed mosque 5. Zindapir mosque	<ul style="list-style-type: none"> These mosques are being used as local mosques. Not well conserved and have no further conservation planning by the authorities in recent times The buffering, heritage property law, land use, and tourist law are not maintained in these heritage sites yet. Lack of regular monitoring by the authorities and public awareness 	<ul style="list-style-type: none"> Impacts of salinity as crystallisation of salt on building materials are highly visible and make the sites highly vulnerable Dampness and biological weathering effects like the attack of moss and fungi are creating extreme conditions. Material erosion is clearly visible in every heritage structure in this category. Due to a lack of proper conservation planning, many have already lost their material expression and fabrications
03 - Collapsed 1. Rezakhuda Mosque 2. Mausoleum of Zindapir	<ul style="list-style-type: none"> These heritage structures are already collapsed and not in use Authorities have a big lack of information about how and why these structures were being collapsed. From FDG, it has been heard that a lack of maintainace and supercyclone are responsible for these destructions Few remnants are still there as their memorabilia. 	<ul style="list-style-type: none"> As these heritage structures are already collapsed, the impact summery is very limited here People said these structures were in vulnerable condition due to salinity, dampness, and material erosion. Drought and supper cyclones became the straight blow on the die.

The DPSIR analysis (Drivers-Pressure-State-Impact-Response)

Drivers - Unpredictable tropical climate extreme events are directly or indirectly linked to climate change and the changing weather patterns around the globe. The sea level is rising, and the temperature of the seawater is also increasing, which causes various deltaic tropical climate extreme events like tropical cyclones, storms, tidal surges, etc. These extreme events cause rapid short-term impacts on historical sites, as discussed in above. A highly populated developing country like Bangladesh always faces various vulnerabilities for its huge population, especially when the land area is only 147,570 km² (or 56,977 square miles). Population growth is working as one of the important drivers of many climatic and non-climatic pressures. Unplanned development strategies and urbanisation generate pressures for conservation strategies. Lack of heritage site conservation master plan strategies: many historical sites already face various pressures. Conservation and maintenance have become more complicated.

Pressure - In Khalifatabad, salinity is the most serious long-term climate extreme pressure on structural durability. Sea level rise is one of the main reasons for extreme surface and soil salinity. Climate change also has impacts on regular weathering, like irregular

precipitation and uneven solar radiation. Due to nearby highways, the rate of dust blowing is high in this area, which creates pressure for regular maintenance of the historical sites of Khalifatabad. Local land-use policy and land law are not very historical site-friendly.

State - Due to water and soil salinity, the material erosion rate is extremely high in this region. The Department of Archaeology also addresses salinity as the most dangerous issue for historical conservation in this region. Material erosion and structural collusion are the most common phenomena. In some cases, the crystal formation of salt on building materials is visible. The material erosion due to salinity and structural distractions was visible during the field survey. Irregular precipitation influences structural dampness and biological weathering, like the rapid attack of mass and fungi.

Impact - The main impacts of driver pressure on the historical site are mainly its material durability and structural stability. Short-term impacts are sudden structural collapses or damage from sudden climate extreme events like cyclones, storms, tidal surges, etc. These impacts are sudden and easily solvable. These impacts are clearly visible and can be solved with a regular conservation process.

Response - Conservation with expected technological maintenance is the most effective response for the conservation of the heritage structures of Khalifatabad. As the concerned authority, the Department of Archaeology, Bangladesh, is working on advanced conservation technology to conserve the historic structures with their limited resources. Though the policy level and budget allowance are not completely under their control, they try to minimise the vulnerable conditions of the historical sites with prompt local solutions. For example, they are now bringing the brick for the exposed walls of Khalifatabad from the upper regions of Bangladesh, which have a moderate salinity effect. As a result, the conservation and maintenance timeline took approximately a long time. Though mud mortar and lime mortar are now replaced by concrete mortar, they still need more analysis on their accuracy. In conservation policy, the whole mosque city of Khalifatabad should be declared and properly considered as a historical site to preserve all its heritage essences. The land-use policy and land law of the proposed heritage city can be enhanced by following international heritage law. National tourism law can be more specific and specialised for these kinds of religious historical sites, which will also ensure the adaptive reuse of the historical places.

In figure 12 is presented the summary of findings using DPSIR framework

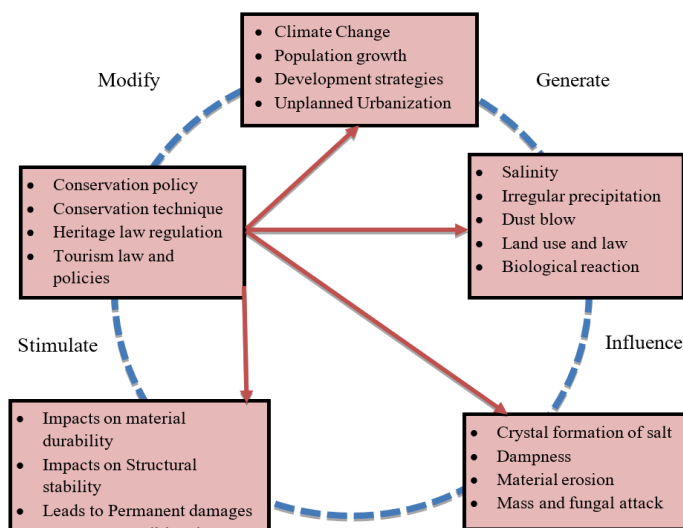


Fig. 12. The applied DPSIR structure of this research

Discussions and Recommendations

From the above data and literature, one thing is almost certain: the heritage sites of Khalifatabaad are more vulnerable due to long-term climate extreme events like salinity, dampness, biological weathering, etc. Traditional building materials are already showing the impacts of these extreme conditions. Clay brick, mud mortar, lime mortar, and terracotta are all in danger. An impact assessment table has been created from the survey data analysis and evidence observation (Table 4).

Table 4. The vulnerability level of the traditional materials of Khalifatabaad to long term climate extreme events

Climate Extremes	Traditional Building Materials of Khalifatabaad				
	Clay Brick	Stone	Mud-mortar	Lime-mortar	Terracotta ornamentation
1. Salinity	Very high	Moderate	High	High	Very high
2. Dampness	High	Moderate	Very high	High	High
3. Temperature	Moderate	Moderate	Moderate	Moderate	High
4. Precipitation	High	Moderate	High	High	High
5. Biological extremes	Very high	Moderate	Very high	Moderate	High

According to this analysis, salinity is the most serious threat to material durability in this region. Almost every local, traditional, and contextual material, like brick, mud mortar, lime mortar, wood, and clay terracotta, has become vulnerable due to the extreme water and soil salinity. Which is clearly visible now, is increasing day by day, and is going to be the biggest challenge for heritage conservation (Figure 8). The concerned authority is already in an alert condition regarding the salinity issue. Chemical solutions are trying to apply in recent times on a small scale, which is effective but very costly. Large-scale use of chemical solutions is still not possible on a moderate budget like ours. That's why passive solutions are mostly used here, like bringing brick from low-salinity areas, continuous dusting, and maintenance, using filtered water for construction, etc., to decrease the salinity impact on traditional materials.

The second extreme condition is dampness and the biological weathering effect on building materials. These two extreme climate conditions are interlinked. They are also associated with irregular precipitation and an uneven monsoon condition, which is a serious and frightening outcome of global warming in this region. Indoor and outdoor dampness promotes the development of moss and fungi (Figure 9, 10). Moss and fungi release a few chemical partials during their evaluation period, which is mostly responsible for material erosion. Due to dampness, the biological weathering effect is getting faster, like the rapid growth of various flora and fauna, which can collapse the heritage structures so badly. Jindapir mausoleum and Reza Khuda Mosque present evidence of this (Figure 9). Regular, systematic maintenance is the only way to decrease the biological weathering effect. Few well-known heritage structures like Sixty domed and the Singair Mosque, which are regularly maintained by authorities, show approximately less salinity, dampness, and biological weathering than other heritage sites like Chunakhola Mosque, Bibi Begi Mosque, etc.

Extreme temperature or solar radiation effects are also important for heritage structures. A few cracks are observed in various heritage sites in Khalifatabaad (Figure 11), which can be a reason for extreme temperature and heat fluctuation. Though this is an observation-based assumption, the FGD outcome has also supported this probability.

The present condition of the heritage sites of Khalifatabaad is very vulnerable; a few are already collapsed. Zindapie Mausoleum and Rezakhuda Mosque are examples of them. Other structures like the Chunakhola mosque, the Bibi Begaini Mosque, the Zindapir mosque, etc. are

in vulnerable condition. Only a few heritage sites, like the Sixty Dome Mosque, Singair Moque, and Khan-e-Jahan Mausoleum, are still in stable condition. The main reason for these variations between these heritage sites in the same historic mosque city of Khalifatabaad is the frequency of conservation and maintenance of these sites. The sixty-domed Khan-e-Jahan mausoleum is the main tourist attraction in Bagerhat, and the Department of Archaeology has also planned most of the conservation strategies for it. According to their reference, regular maintenance has been done on a few historic structures, and the rest are not regularly maintained. Even they cannot provide proper documentation about a few structures. During KII, they cannot answer the question, why was the Rezakhuda mosque collapsed? And still, the authority doesn't take any action to revive this historic structure. So, one discrimination line is clear in Khalifatabaad from the point of view of conservation and maintenance.

Through this research, a few things are highly recommended to protect the Historic Mosque City Khalifatabad from tropical climate extreme events.

- A structured conservation policy with compatible law and order can protect this historical city from various climatic and non-climatic extreme events.

- For the short-term vulnerabilities of climate extreme events prompt conservation action is a must. The concerned authorized body of the Department of Archelogy Khulna divisional branch. It is highly recommended that the conservation and maintenance centre should be established in Bagerhat for quick response while needed. The local branch should be well equipped for prompt response to minimize the sudden effects of super cyclones, surges, and so on.

- Specialized local craftsmen should be trained up for rapid response and continuous maintenance.

- Stick maintenance of historical properties and land-use law is a must. Social awareness and conservation education are also important.

- Active conservation techniques like chemical solutions for long-term conservation are very effective but very much costly and required perfect workmanship. Which is not possible all the time. So passive conservation techniques like- special material production, continuous maintenance, structural solutions like the stone bases in Shat Gombuj mosques can be applied.

- The historical site surrounding the water bodies of Khalifatabad- Ghora dighi & Khan Jahan Ali dighi are very helpful for flood and excessive rainwater drainage. They can be treated as a natural solution of seasonal waterlogging and maintained accordingly.

- The whole Khalifatabad is great evidence of the glorious history and heritage of Bengal. The Shat Gombuj Mosque, Mausoleum of Khan-e-Jahan have got most of the light in terms of conservation and tourist facilities. but the whole city should be treated as a single historical site with many magnificent historic structures. The tourist facilities and laws should be applied thereby.

- International collaboration for smart conservation techniques and technologies should be practiced preserving this historical city-Khalifatabad from the impacts of climate extreme events because due to climate change the possibilities of more extreme conditions are increasing day by day. So, we should be well prepared.

Conclusion

Heritage conservation and protection from extreme events are continuous processes. With the advancement of science and technology, this process is becoming smarter and more effective day by day. But the number of extreme climate events is also increasing due to global climate change. So, the challenges of identifying the most effective extreme events and their impacts on historical sites are always evolving.

- More specific studies about the main extreme events in Khalifatabad, like salinity, dampness, biological weathering, tidal surges, waterlogging, super cyclones, etc., and their

impacts on historical structures according to the seasonal timeline should be the most important research.

- The extreme event salinity should be specially addressed in research because it makes not only the historical sites but also the overall living environment very vulnerable.
- How biological weathering can be controlled at historical sites without damaging the overall ecosystem of the area is also a great topic that should be addressed soon.
- Research for more durable, cost-effective, and available materials suitable for historical site conservation, which can also maintain the historic fabrication and texture.
- Research for policymaking and implementation is also very urgent now.
- Non-climatic factors are also responsible for the vulnerability of historical sites. They also should be addressed properly in research.
- Educating the local residents about the importance and sensitive use of historical sites is also a great scope of research. Adaptive reuse of historic property is almost impossible without social awareness and local participation.

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