INTERNATIONAL JOURNAL OF SOCIAL SCIENCES BULLETIN
ISSN: (E) 3007-1917 (P) 3007-1909
Volume 4, Issue 1, 2026

ANALYSIS OF ENVIRONMENTAL DEGRADATION PATTERNS IN SELECTED MUGHAL ERA MONUMENTS FROM PUNJAB, PAKISTAN

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DOI: https://doi.org/10.5281/zenodo.18454639

Received	Revised	Accepted	Published
27 Dec 2025	10 Jan 2025	29 Jan 2026	31 Jan 2026

ABSTRACT

Buildings constructed out of bricks and other porous materials are subject to both physical and chemical damage over the course of their lifetimes as a result of exposure to the weather. After that, deterioration takes place as a result of a variety of intrinsic and extrinsic factors, and the damage to the urban environment is extremely extensive, which causes the material's form to change. As a result of the Mughal monuments in the Punjab Province of Pakistan being subjected to comparable environmental dangers and serving as an experimental ground for inadequate conservation, these historic structures are deteriorating at an alarming rate and cannot be reversed. The study and analysis of a variety of brick samples taken from a selection of monuments served as the base for this work. As time passes, many of its elements and features diminishing as can be seen in a number of different locations. In order to ensure the preservation of this irreplaceable heritage asset, it is necessary to develop a conservation strategy for these monuments. This strategy should involve the characterization of the materials, the identification of the environmental impacts, and the evaluation and development of conservation scenarios.

Keywords: *Heritage, Historical buildings, Bricks, Punjab Pakistan, Mughal Monuments*

1. Introduction

The historic Mughal buildings in Punjab and Pakistan are a major step in the architectonic history of South Asia, though which the brick masonry was widely used with the lime-based mortars and plasters. These buildings represent the ancient knowledge of constructions, the choice of material, and the craft methods which kept changing throughout centuries. Most of the Mughal-period buildings in Punjab are, however, undergoing gradual material deterioration, especially in the brick bits, and this is a critical threat to their structural viability and historical fidelity.

Deterioration of bricks in historic buildings is a complex process that is control by inherent properties of materials and external environmental factors. The Composition of the raw clay in the bricks, the firing temperature, porosity, the soluble salt in the bricks and compatibility of the mortar would be determining factors as far as it comes to establishment of durability of historic bricks (Moropoulou et al., 1993; Pauri et al., 1994; Cultrone et al., 2004). In Punjab, moisture penetration, temperature variation, air pollution, and salt crystallization are some of the environmental stresses which enhance deterioration mechanisms and result into cracking, surface scaling, loss of cohesion and decreased mechanical strength (Fielden, 1982; Charola, 2000; Viles et al., 1997).

Although the Mughal monuments in Punjab are of architectural significance, the conservation has mostly been based on physical observation and traditional repair techniques and mostly replaced the damaged bricks with new manufactured ones. These types of interventions are often undertaken, whose scientific knowledge of the original properties of the bricks, which led to their material incompatibility and subsequent faster degradation (Ashurst, 1988; ICOMOS, 1964). Lack of planned experimental investigations aiming the physicochemical and degradation behaviour of historic Mughal bricks has reduced performance of conservation measures within the region.

Experimental study of historic bricks by using scientific methods is required in the determination of the mechanisms of deterioration and the formulation of compatible conservation means. Physical, mechanical, chemical and microstructural analysis allow evaluation of original production technology, level of firing and heterogeneity of materials as well as changes which occur because of weathering (Brocken and Nijland, 2004; Elert et al., 2003; Cardiano et al., 2004). These data can form a confident basis of a design of restoration material that does not interfere with the authenticity and functionality of historic masonry.

This paper outlines an experimental research on the degradation of historic bricks retrieved to be part of the Mughal monuments in Punjab in Pakistan. The study is supposed to determine important physical and chemical characteristics of bricks, their microstructure, and prevalent agents of deterioration, which impacts their performance over an extended period. Creating scientific evidence regarding the history of Punjab Mughal bricks, this piece of work is aimed at providing evidence-based conservation in terms of preserving historic masonry buildings.

2. Literature Review

Architectural conservation is a process that is multidisciplinary, dealing with research and diagnosis, design, implementation and long-term maintenance (Weaver and Matero, 1997). At masonry conservation, the compatibility of repair materials, and the quality of workmanship are given a special focus because inappropriate interventions usually increase the rate at which it deteriorates instead of acting as a moderator. Ethics are the perfect principles of conservation philosophy that have guaranteed the preservation of historic authenticity and material integrity.

According to Forster (2010), these ethics are so called guiding lights in conservation practice and values that include authenticity, integrity, no conjecture, appreciating historic patina, valuing any contributions made by all historical periods, contextual integrity, respect of the right of indigenous communities is the core values. Such principles are supplemented with such operational principles as minimum intervention, reversibility, repair legibility, and material compatibility, documentation, and sustainability.

Fielden (1982) also adds that conservation interventions must conserve as much original material as can be done, be reversible or repeatable when it is possible, should not limit future treatments, and be in visual harmony but not confusable with natural fabric. Notably, the interventions to be implemented should be those carried out by professional conservationists to ensure that permanent destruction is not caused.

The compatibility of the original materials and repair mortars becomes of a great importance in determining the durability of historic masonry. Van Balen et al. (2007) have described the essential parameters used to determine the compatibility of mortar, which comprise the surface conditions, composition, mechanical properties, elasticity, porosity, temperatures, and environmental stress resistance. Mortars that are not compatible with each other may result in salt build up, storage of moisture and concentration of stress, contributing to increased break down of bricks.

Substantial measures of diagnosis, including microscopy, spectroscopy, and electron microscopy, have also been much utilized to detect the mechanisms of deterioration by means of sulphate attack, leaching by binder, crystallization of salts, and frost breakage (Larbi, 2004; Van Hees et al., 2004). These researches prove that one of the most destructive factors on historic masonry is the moisture movement and salt transportation inside the porous brick matrices.

The conservation system in Pakistan traces its origins back to the British colonial rule namely the formation of the Archaeological Survey of India under Sir Alexander Cunningham (Mughal, 2011).

Establishment of legislative milestones of safeguarding monuments in Pakistan traditionally started with the Ancient Monuments Preservation Act (1904) and subsequently with the Antiquities Act (1968).

Nevertheless, the conservation practice in Pakistan continues to encounter numerous problems, such as lack of research before the interventions, poor craftsmanship, and inadequate documentation guidelines (Rahman, 2016). The research on the Mughal monuments, including Shish Mahal, Tomb of Jahangir, and Nawankot Monument, brings up support of moisture ingress, salt crystallization, temperature strains, bio-growth, and using unsuitable restoration materials (Kamran, 2015, 2016; Malik et al., 2020; Awan et al., 2016).

High management of sites in Punjab in recent years has been enhanced because of administrative devolution of provincial governments, especially at the World Heritage Sites such as the Lahore Fort and Shalimar Gardens. Nevertheless, systematic scientific research on historic construction materials, in particular, bricks, is still constrained.

The identification of the nature of deterioration in historic masonry is based on the characterization of materials. Testing of porosity, water absorption, capillarity, mechanical strength and salt resistance is usually an addition to traditional petrographic and mineralogical analyses (Doehne, 2005). Such analyses as SEM-EDS, XRD, FTIR, and thermal analysis allow us to see the difference in the microstructural and chemical composition of historic bricks (Van Hees et al., 2009; Riccardi et al., 1999).

It has been shown that the firing temperature, proper raw clay composition, and pore structure play a great role in the durability of bricks (Lopez et al., 2003; Brozovsky et al., 2008). Calcareous and non-calcareous bricks respond differently to the moisture and salt crystallization process, and the distribution of porosity is such an influential factor in the long-term working results (Stryszewska and Kanka, 2017).

Physical, chemical and biological processes which hasten degradation are also caused by environmental exposure. The processes of freeze-thaw, thermal expansion, acid rain, air pollution and microbial contribute to the breaking down of brick matrices that results into cracking and spalling as well as surface powdering of the brick (Camuffo, 2022; Viles, 2013; ICOMOS, 2008).

The Mughal bricks are especially prone to salt crystallization, capillary moisture level, thermal stress and improper choice of the repair material. South Asian and European research also attests to the truth that stresses caused by salt usually surpass the tensile strength of historic bricks, leading to progressive loss of material (Manohar et al., 2022). Poor drainage, urban pollution, improper maintenance, and unscientific conservation practices among other human induced factors also worsen the process of decay.

3. Methodology

The methodology employed was to conduct systematic archival research followed by surveying the fieldwork sites and to pinpoint key types of deterioration present in these Mughal monuments. To gather information about the factors causing and contributing to the deterioration, a plan of chemical and physical characterization and non-destructive testing of the building materials, particularly historic bricks, and monitoring and visual inspections at the site was implemented. The findings enabled guidelines to be made about the handling of these monuments and the individual monuments treatment, and they are applicable to other historic buildings made of bricks that are likely to deteriorate in a similar manner.

3.1 Site selections

3.1.1 Old Fort

The Old Fort in Lahore is a medieval fortification that has long served as the center of the city's history. Since the country's historic preservation industry is underdeveloped, with a lack of appropriate training and education and insufficient documentation skills, the slowly deteriorating monuments have long gone uncared for. The Picture Wall, the biggest mural wall in the world, is one of the main reasons why the Fort was named a UNESCO World Heritage Site in 1981. It was originally constructed as an old mud 25 fortification, and many consecutive dynasties have since demolished and rebuilt it. The Mughal ruler Akbar re-fortified the previous foundation construction to become the brick fort that we see today. In the 20 hectares of a fortified area, the bulk of the 21 monuments that are still standing today were also constructed during the Mughal Empire. Unfortunately, hardly many

conservation efforts have been performed in this world heritage site up until this point. Numerous monuments are still unrecorded, have no prior drawings or documents, are at risk of being lost forever, and need immediate conservation.

3.1.2 Sheikhupura Fort

The dwellings of the town have completely amalgamated with Sheikhupura Fort. 3.5 meters above the marshy depressions that encircle the site on its western, southern, and eastern sides, it is perched on the level but artificially created terrain. Most of the information we have regarding Sheikhupura Fort comes from Tuzuk-e-Jehangiri, which mentions that building a "strong fortress" was a crucial component of the strategy for creating a royal hunting retreat in the area. During his visit to the Hiran Minar in 1607, the second year of his reign, Jahangir gave Sikander Moeen this assignment. It is now abandoned and in disrepair in the center of the busy city; it is closed to visitors and is in danger of collapsing completely. Rich and intricate fresco artwork from the Sikh era still exists in fragments, hidden from view even for those who dwell in the shadow of the Fort itself. While most of the fresco artwork is now beyond repair due to destruction, there are still enough pieces left to provide a look into the lifestyle and culture that existed in Sheikhupura during the Sikh era.

3.1.3 Shalimar Gardens

Ali Mardan Khan produced the idea for the Shalimar Gardens Lahore project in 1641 AD, and Shahjahan and the Persian ruler of Punjab gave their approval for its 26 construction. Unquestionably a turning point in the evolution of Mughal Garden architecture, Shalimar Garden is recognized as one of Shahjahan's finest achievements after the Taj Mahal. There are five waterfalls in the garden, including Sawan Bhadoon and a sizable marble cascade. To make use of the cooling winds from the nearby fountains, the main structure on the site also contains Sawan Bhadoon pavilions, a Naqar Khana (chamber of colored artwork), Khawab Gah of Begum Sahib, and Baradaries. The Diwan-e-Khas-o-Aam garden features two enormous gates and minarets in its corners (Kausar et al., 1990).

3.1.4 Wah Gardens

The Mughal rulers enjoyed visiting and camping at Wah Gardens. Raja Maan Singh constructed the garden's initial structure between 1581 and 1586. (Alexander, 1909). When they were first constructed, Wah Gardens were a part of the Hasan Abdal grounds. However, owing to administrative changes, these gardens are now the pinnacle of Wah Cantt.

3.1.5 Jehangir's Tomb

The Jahangir tomb was constructed in the 17th century in accordance with Persian customs, and it is in the middle of a walled garden called Chahar-Bagh. The garden is 27 divided into sixteen sections by being separated into four gardens, each of which is further subdivided into four. The walkways and water channels that divide these sections are ornately ornamented with geometric designs, fountains, and waterfalls. Due to the continual and quickening decay, it is losing its historic structure.

3.1.6 Wazir Khan Mosque

The Wazir Khan Mosque complex is the focal point of a picturesque urban setting. The Chowk Wazir Khan and the stores on the northern side of the mosque complex are included in this assemblage. Wazir Khan's Mosque functioned as the imperial Jamia Masjid throughout Shah Jehan's rule, and the emperor and his grandees often offered Friday prayers there with a sizable entourage. Three horizontal planes may be seen in the mosque's construction. The stores on the eastern and northern sides make up Level 0. All the mosque's primary areas are on Level I, which takes up the largest portion of the building. The areas that are accessible from level I through the stairs are designated as level II. The mosque has a rectangular floor plan. The Wazir Khan Mosque's formal "bazaar," a significant part of the entry system to the mosque's courtyard, stands out amid its architectural details and ornaments, which represent pre-Mughal influences as well as those from adjacent Persia and Central Asia. This is the first instance of a specifically constructed market in a Central Asian church adaptation on the subcontinent (and hasn't been widely duplicated elsewhere). The magnificent mosque is constructed of brickwork and covered with mosaic tiles with bright glazes. The mosque is 279.5' x 159' in total, whereas the hall measures 131.3' x 42'.

4. RESULTS & DISCUSSION

4.1 Bricks morphological and chemical composition

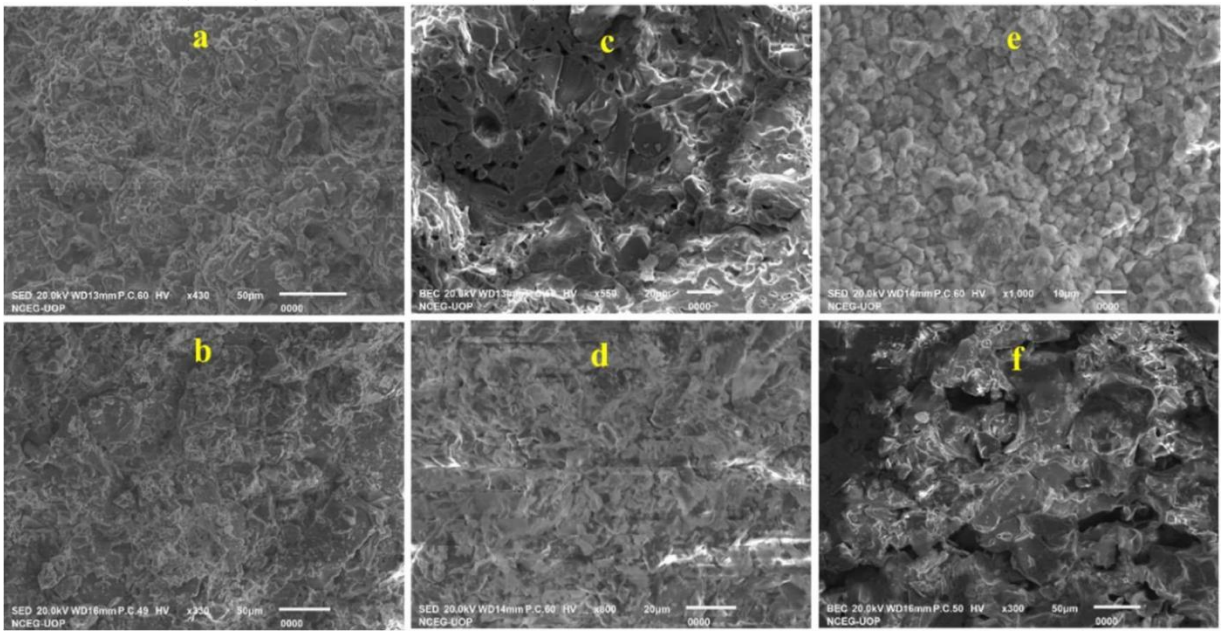
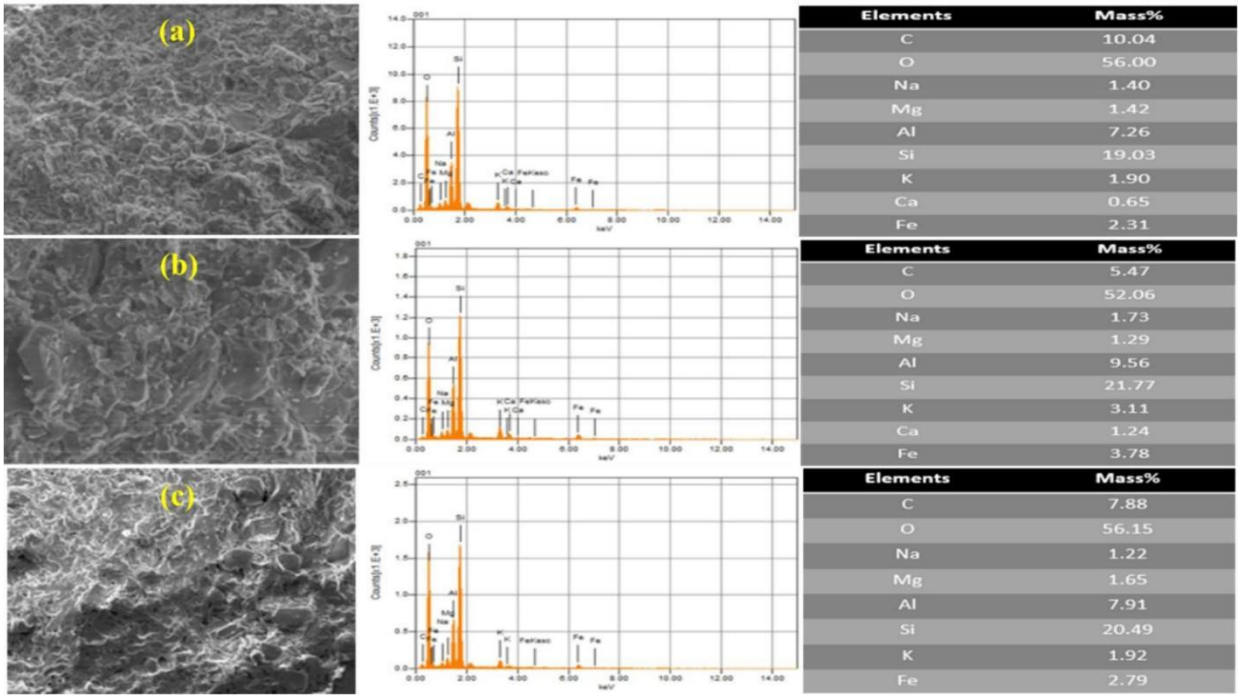


Figure 1: displays the images of bricks samples collected site from Punjab province of Pakistan. (a) SEM micrograph of Jahangir Tomb North courtyard named JT-01. (b) SEM micrograph of Lahore Fort (Sheesh Mehal) named LF-03. (c) SEM micrograph of Sheikhupura Fort (Eastern gate) named SF-01. (d) SEM micrograph of Shalimar Garden (Lower Terrace) named SG-01. (e) SEM micrograph of Wah Garden (Hammam) named WG-02. (f) SEM micrograph of Wazir Khan Mosque (Courtyard) named WKM-01

Morphological analysis of bricks samples collected from Punjab province was performed by scanning electron microscope (SEM). Figure 1 shows the analysis of these samples. (a) displays the SEM micrograph of Jahangir Tomb North courtyard named JT-01. These bricks are deteriorated due to some environmental constraints. Mineral salts are also present in larger quantities than other samples taken from Khyber Pakhtunkhwa province which is also verified by EDS analysis. While (b, c, d, and f) displays incrustation in bricks samples. Scales presence is also shown on the surface of the brick's samples. On the other side (d) shows the impact of deterioration on the surface of bricks.

EDS analysis to determine the chemical composition of bricks samples taken from Punjab site. Figure 5 (a), (b) and (c) showing the chemical composition of bricks samples taken from Punjab sites. All the samples contain almost similar salts like Si, Mg, Al, Ca, Fe, C and O with promising amount which reveals that clay containing these salts in higher ratios. SEM micrographs also wetted the presence of salts on the surface of the bricks which deteriorate the bricks. In all samples from Punjab province there is more silica present than that of samples taken from Khyber Pakhtunkhwa. The sintered matrix, which is made up of silicates rich in Mg (diopside), also contained prismatic secondary minerals. By the higher atomic density (chemical analysis was performed by EDS) formed, Mg, Ca, Al, Fe- rich pyroxenes (augite) were observed.

4.2 EDX Analysis and Elemental Composition



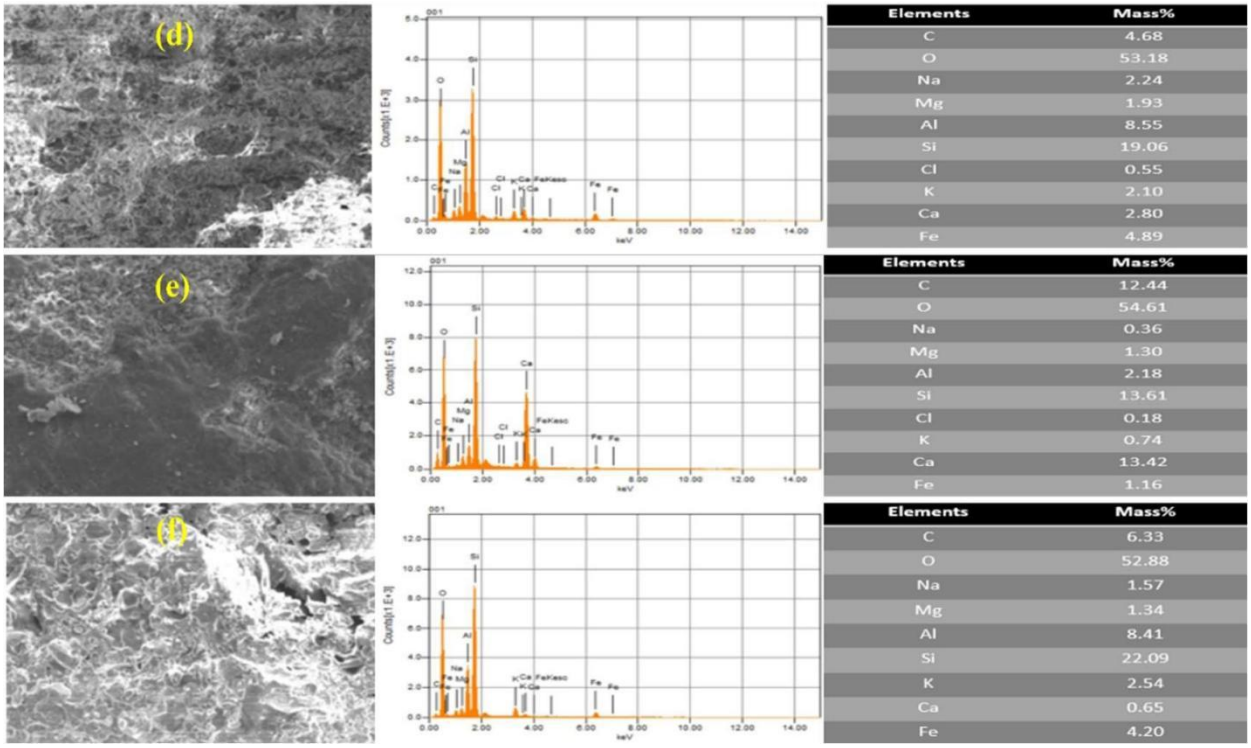
Elements	Mass%
C	10.04
O	56.00
Na	1.40
Mg	1.42
Al	7.26
Si	19.03
K	1.90
Ca	0.65
Fe	2.31

Elements	Mass%
C	5.47
O	52.06
Na	1.73
Mg	1.29
Al	9.56
Si	21.77
K	3.11
Ca	1.24
Fe	3.78

Elements	Mass%
C	7.88
O	56.15
Na	1.22
Mg	1.65
Al	7.91
Si	20.49
K	1.92
Fe	2.79

Figure 2: shows the EDX analysis of the brick's samples taken from Punjab province of Pakistan. (a) EDX analysis of sample taken from Jahangir Tomb (North courtyard) named JT-01. (b) EDX analysis of sample taken from Lahore Fort (Sheesh Mehal) named LF-03 (c) EDX analysis of sample taken from Sheikhupura Fort (Eastern gate) named SF-01.

Figure 2 EDX analysis to determine the chemical composition of bricks samples taken from Punjab site. (d), (e) and (f) showing the chemical composition of bricks samples taken from Punjab sites. All the samples contain almost similar salts like Si, Mg, Al, Ca, Fe, C and O with promising amount which reveals that clay containing these salts in higher ratios. SEM micrographs also wetted the presence of salts on the surface of the bricks which deteriorate the bricks. In all samples from Punjab province, there is more silica present than that of samples taken from Khyber Pakhtunkhwa. Remaining illite also contained iron-bearing phases, where the grains partially melted and displayed the typical "bubble-like" porosity (Freestone & Middeltone, 1987).



Elements	Mass%
C	4.68
O	53.18
Na	2.24
Mg	1.93
Al	8.55
Si	19.06
Cl	0.55
K	2.10
Ca	2.80
Fe	4.89

Elements	Mass%
C	12.44
O	54.61
Na	0.36
Mg	1.30
Al	2.18
Si	13.61
Cl	0.18
K	0.74
Ca	13.42
Fe	1.16

Elements	Mass%
C	6.33
O	52.88
Na	1.57
Mg	1.34
Al	8.41
Si	22.09
K	2.54
Ca	0.65
Fe	4.20

Figure 3: (d) EDX analysis of sample taken from Shalimar Garden (Lower Terrace) named SG-01. (e) EDX analysis of sample taken from Wah Garden (Hammam) named WG-02 (f) EDX analysis of sample taken from Wazir Khan Mosque (Courtyard) named WKM-01.

To understand the textural and mineralogical changes in relation to differential heating/temperature, the microstructure of the bricks was studied by SEM images with EDS spot analysis at various locations (Freestone & Middeltone, 1987). The SEM showed how the texture of bricks changed significantly because of the temperature gradient. The traditional kiln firing technology used in the sub-continent prevented the studied samples from being fired at controlled incremental temperatures. Microscopic studies also revealed multiple regions of firing temperatures in a brick with various colorations (Schwertmann, 1993; Chandra, 2003). According to Elert et al. (2003), the brick texture in Figs. 5 and b clearly illustrates the uneven/differential heating of the bricks during the firing process. The phyllosilicates' sheet-like fabric is maintained on the surface after firing at 700 and 800 degrees Celsius (Figs. 2 and 3). Only sintering caused by solid state reactions between adjacent crystals was seen at 700–800°C, which results in a slight reduction in porosity (Segnit & Anderson, 1972; Yates, et al., 1994; McConville and Lee, 2005).

EDX Analysis Results of Selected Sites from Punjab, Pakistan

Jehangir Tomb (North Courtyard) Sample No: JT-01		Lahore Fort (Sheesh Mehal) Sample No: LF-03		Sheikhupura Fort (Eastern Gate) Sample No: SF-01		Shalimar Gardens (Lower Terrace) Sample No: SG-01		Wah Gardens (Hammam) Sample No: WG-02		Wazir Khan Mosque (Courtyard) Sample No: WKM-01	
Elements	**Mass%**	**Elements**	**Mass%**	**Elements**	**Mass%**	**Elements**	**Mass%**	**Elements**	**Mass%**	**Elements**	**Mass%**
C	10.04	C	5.47	C	7.88	C	4.68	C	12.44	C	6.33
O	56.00	O	52.06	O	56.15	O	53.18	O	54.61	O	52.88
Na	1.40	Na	1.73	Na	1.22	Na	2.24	Na	0.36	Na	1.57
Mg	1.42	Mg	1.29	Mg	1.65	Mg	1.93	Mg	1.30	Mg	1.34
Al	7.26	Al	9.56	Al	7.91	Al	8.55	Al	2.18	Al	8.41
Si	19.03	Si	21.77	Si	20.49	Si	19.06	Si	13.61	Si	22.09
K	1.90	K	3.11	K	1.92	Cl	0.55	Cl	0.18	K	2.54
Ca	0.65	Ca	1.24	Fe	2.79	K	2.10	K	0.74	Ca	0.65
Fe	2.31	Fe	3.78			Ca	2.80	Ca	13.42	Fe	4.20
						Fe	4.89	Fe	1.16		

4.3 Strength Testing

Compressive strength tests were carried out in order to determine the mechanical behavior of historic bricks. The findings indicate that there are major inconsistencies, as raw materials, firing technology, and levels of deterioration vary. The compressive strengths were moderate to relatively high and incomparable to reported values historic bricks used in Mughals.

The compressive strength tended to be lower in bricks with higher porosity, easy cracking, and salt contamination. Conversely, samples that had more compact microstructures with fewer defects had higher load bearing capacity. Mean compressive strength indicates that a significant portion of Mughal bricks in Punjab will be structurally intact even after several centuries of exposure to the environment. Load-displacement curves showed that the character of the failure was mainly brittle with a linear elasticity of response and abrupt failure. Failure in some of the samples was by gradual cracking, which implies that internal flaws were formed in the process of long weathering. These findings emphasize the sensitivity of the mechanical compatibility in the choice of materials used to do the replacement during the process of conservation.

Compression Test Report of brick samples from various Mughal Monument in Punjab Province

To:	**Tehmash Khan**	**Testing Date:**	**November 26, 2022**
Our Ref No	**NICE/STR/**		
Your Ref No	Nil	Receiving Date:	November 24, 2022
Testing Standard:	ASTM C67-16		

Compression Test Report

Historic Bricks from various Archaeological Monuments
Specimen Received on: November 24, 2022 Tested on: November 26, 2022

Sr.No	Mark	Sampling Date DD/MM/YYYY	Length (mm)	Width (mm)	Height (mm)	Weight (kg)	Area of xsection (mm^2)	Ultimate Load (KN)	Ultimate Stress (Mpa)	Ultimate Stress (Psi)
1	SG-05	15/11/2022	230	110	45	1.898	25300	223.4	8.8	1276
2	WKM-02	15/11/2022	220	120	30	1.41	26400	238.6	9	1305
3	SF-02	16/11/2022	220	120	30	1.418	26400	245.9	9.3	1349
4	JT-04	15/11/2022	220	120	30	1.418	26400	255.3	9.7	1407
5	LF-04	15/11/2022	220	120	30	1.418	26400	258.3	9.8	1421
6	WG-04	18/11/2022	220	120	30	1.418	26400	219.5	8.3	1204

4.4 Water Absorption Characteristics

The test of water absorption showed a range of values inclined more towards the levels of 12%-13% which means that there was high porosity and a high connection of capillaries. These findings agree with other samples gathered at geographically separated Mughal monuments of Punjab which implies that the Mughals were engaged in homogeneous brick production methods.

When the water absorption is higher it is associated with greater vulnerability to moisture-influenced corrosion procedures as salt crystallization, freeze-thaw effect, or biological growth. The findings show that Mughal bricks have reasonably good compressive properties but are highly susceptible to certain unfavorable environmental circumstances due to the huge moisture absorption capacity.

The fact that the values of absorption are relatively consistent appears to point to homogeneity in manufacturing methods and in the choice of raw materials as well, bringing back to the idea that durability problems are more to do with environmental exposure and post-construction modifications instead of the inherent weakness of the material.

Water Absorption Test Report of brick samples from various Mughal Monument

To:	Tehmash Khan
Our Ref. No:	NICE/STR/
Your Ref. No:	Nil
Testing Standard:	BS 3921 : 1985
Testing Date:	November 25, 2022
Receiving Date:	November 24, 2022

Water Absorption Test

Historic Bricks from various Archaeological Monuments Punjab, Pakistan

S. No	Sample	24 Hour % Absorption
1	JT-02	12.13

2	SG-03	12.76
3	LF03	12.45
4	SF01	12.69
5	WG02	12.84
6	WKM01	12.36

4.5 Discussion on Deterioration Mechanisms

According to the experimental findings, the processes that control Deterioration of the Mughal monuments in Punjab includes a combination of flaws in manufacturing, exposure to climatic conditions, and the practice of inappropriate conservation. Different firing temperatures had a heterogeneous effect on the microstructures making them porous and less resistant to the passage of moisture.

The most harmful deterioration process appeared salt crystallization since it was supported by the utilization of water and capillary action. Soluble salts are in place, humidity and rainfall changes are increasing; the rate at which granular is disintegrating and scaling the surface. Laboratory experiments indicate that the strength will decline under long-term loading to such processes, resilience to the load being diminished in the long run.

These observations indicate that the feelings of substituting the historic bricks with new high strength and low porosity brick can create incompatibility. There and conservation strategies should thus pay priority to material compatibility in regard to porosity, strength and behavior of moisture.

5. Conclusion

This paper deals with an elaborate experimental evaluation of the decay attributes of the historic bricks taken off chosen monuments of Mughals in Punjab, Pakistan. The study offers useful information about how the material acts, degrades, and its conservation issues using integrated microstructural, chemical, and physical investigations, of Mughal brick masonry in the area. SEM studies found the microstructures were heterogeneous with irregular pore structures, micro-cracking and partial vitrification, demonstrating nonhomogeneous firing temperatures (as of the initial processing) of the product. The microstructural features play an important role in transporting moisture and make the deterioration processes easier. The EDX analysis revealed that the presence of the bricks is mostly a mixture of siliceous and alumino-silicate phases containing different levels of calcium, iron, sodium, and potassium. Soluble salts in the brick matrices underline salt crystallization as one of the major causes of surface scaling, powdering, and granular disintegration. Testing on compressive strength revealed that numerous historic bricks in Punjab have moderately good structural capacity even after many years of experience in an environment of stress factors. The variability of strength of the samples however relates to a variance in the choice of raw materials, firing methods as well as the level of weathering. The values of water absorption ranging between 12-13 percent signify high levels of porosity and capillary connectedness, which is extremely susceptible to moisture induced looseness in the bricks considering the climatic conditions of Punjab. The results highlight the fatalities behind the masonry of Mughal building in Punjab as not only the fragility of material used but also the summation of conventional production methods, exposure to weather, salt action, and improper decisions taken in the past. The findings demonstrate the need to institute scientifically informed conservation policies, which include material compatibility, humidity, and as little treatment as possible. The study expands the small pool of experimental researches on historic brick degradation in Pakistan, and would serve as a useful critical source in conservation planning in Punjab. The created dataset could be useful in building congruent replacement materials and inform sustainable restoration methods used to retain the original Mughal architectural care and quality.

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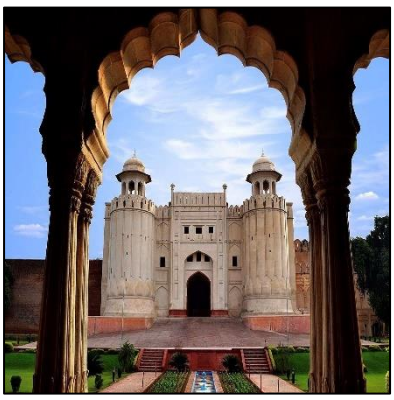
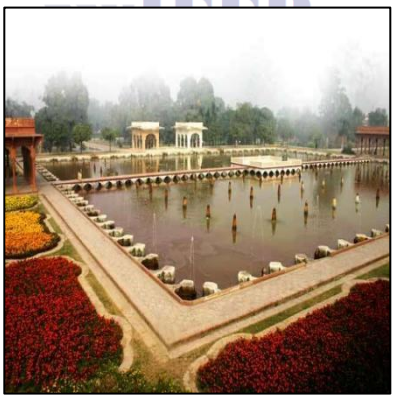
PLATES

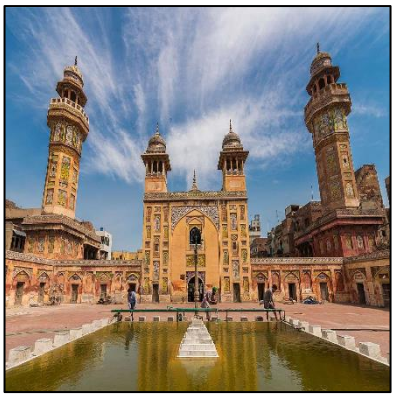


Pl-I: Lahore (Punjab): A view of Alamgiri Gate at Old Fort



Pl-II: Lahore (Punjab): A view of Middle Terrace of Shalimar Gardens.

Pl-III: Lahore (Punjab): A view of main tomb complex at Jehangir's Tomb.



Pl-IV: Lahore (Punjab): Façade view of Wazir Khan Mosque.

Pl-V: Sheikhupura (Punjab): Facade view of Fort gate showing architectural details.

Pl-VI: Hasanabdal (Punjab): A view of Middle Terrace of Shalimar Gardens.

Figures

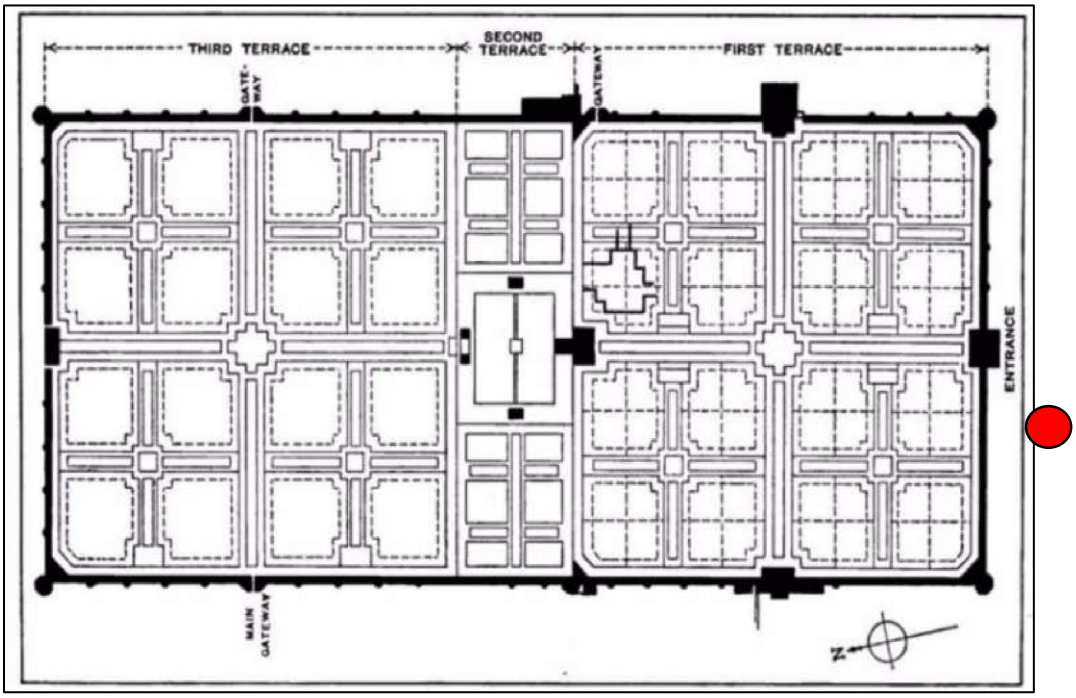


Figure.1: Shalimar Gardens, Lahore: Layout Plan and sampling area (encircled) (After KKM)

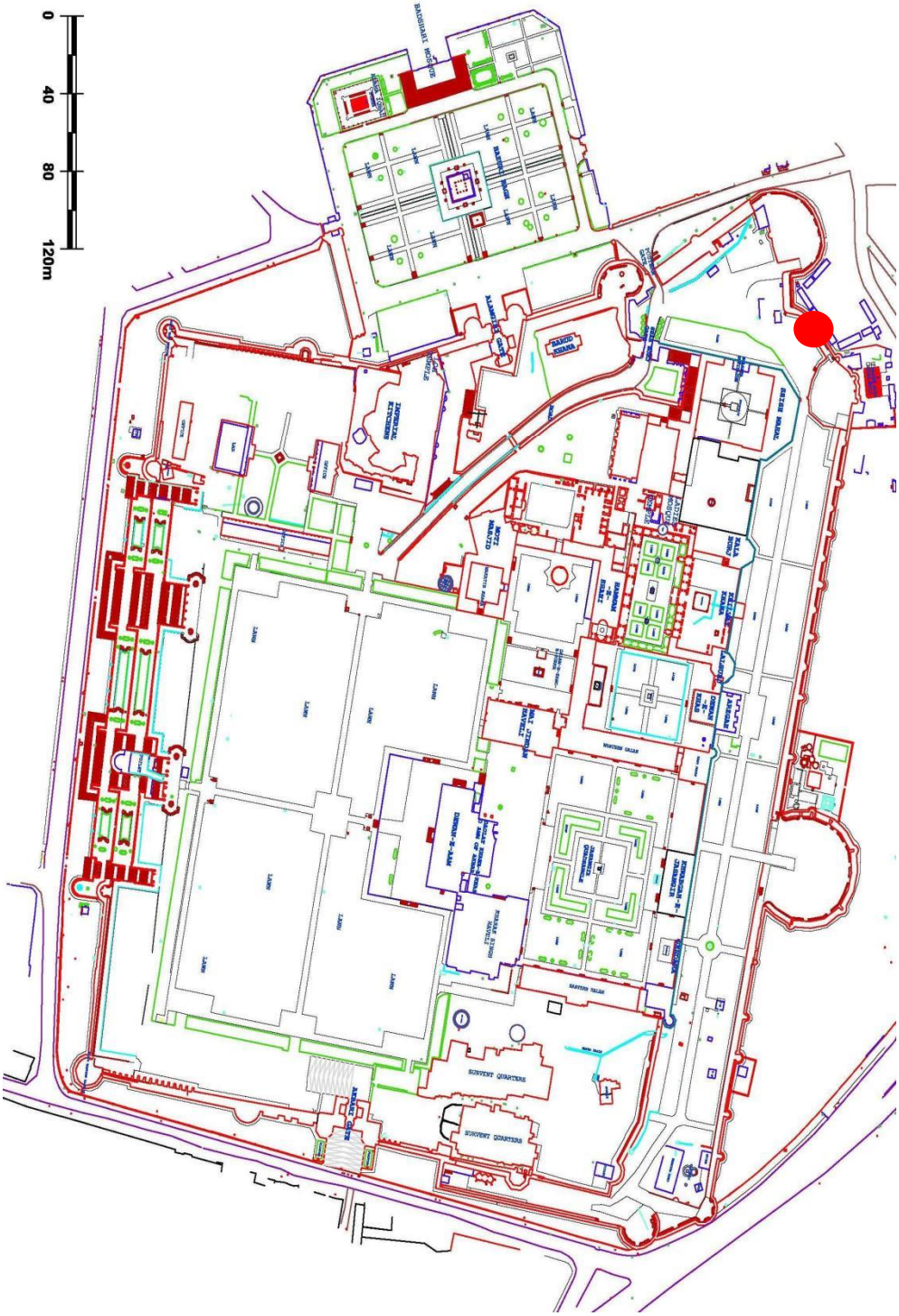


Figure.2: Old Fort, Lahore: Layout Plan and sampling area (encircled)

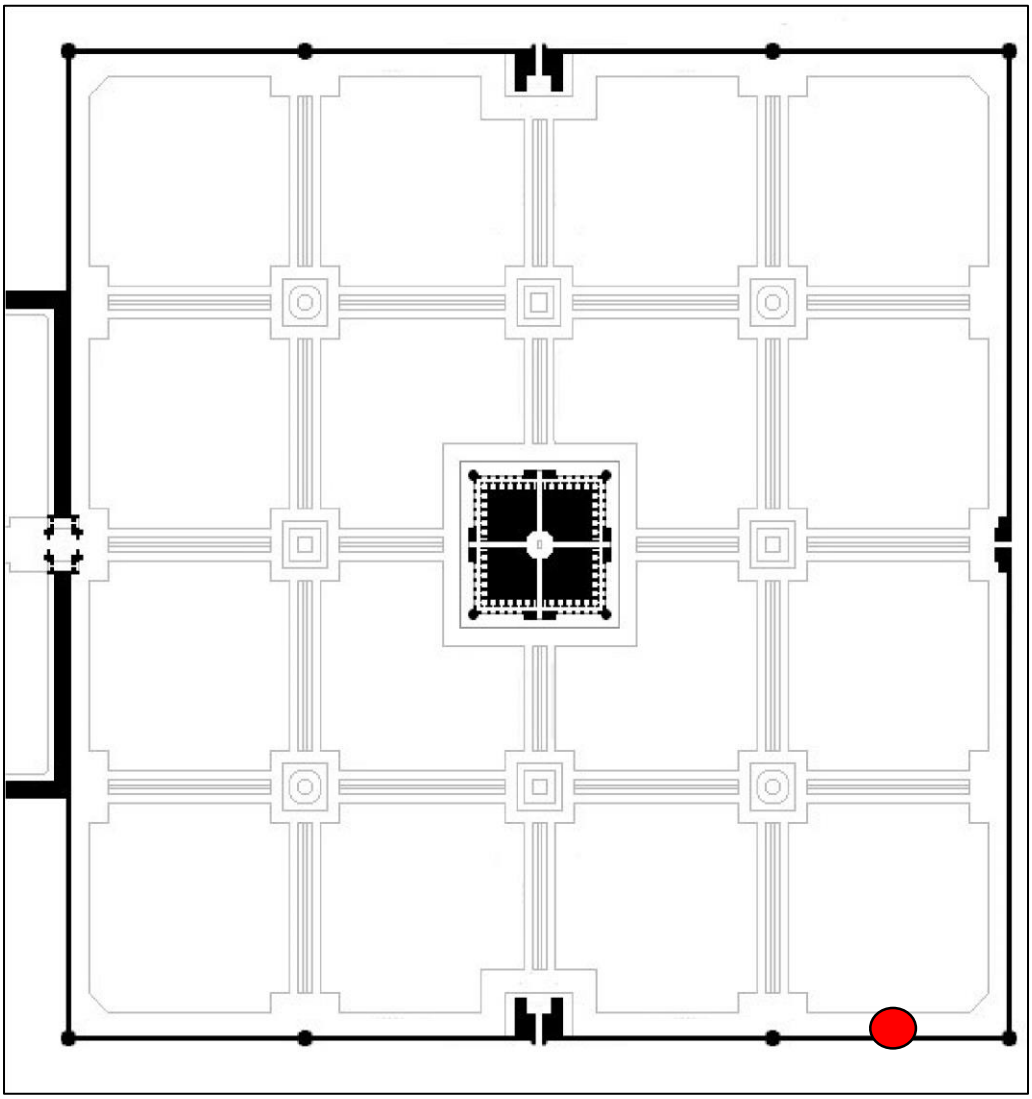


Figure.3: Jehangir Tomb, Lahore: Layout Plan and sampling area (encircled) (After KKM)

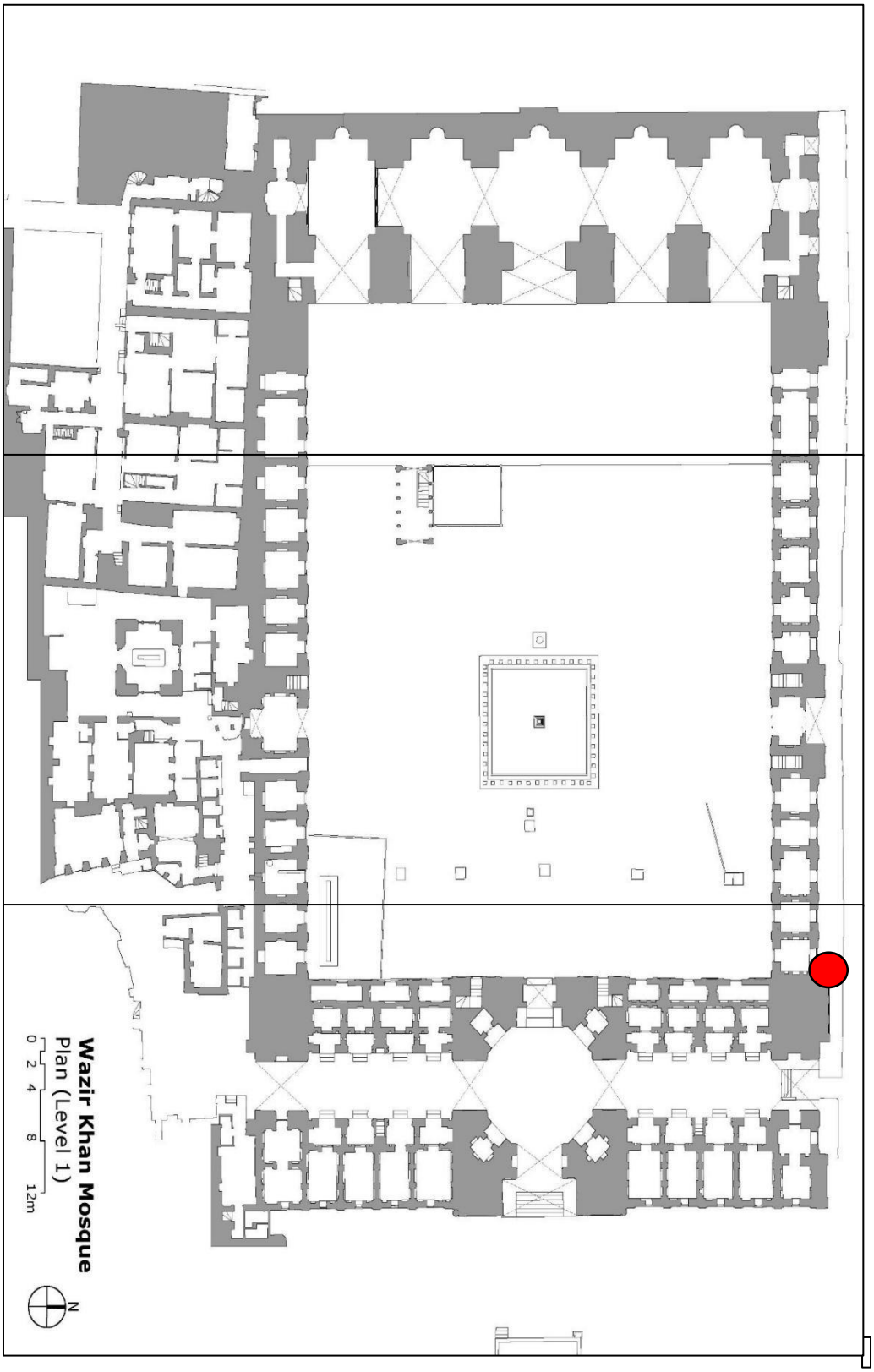


Figure.4: Wazir Khan Mosque, Lahore: Layout Plan and sampling area (encircled) (After AKCSP)

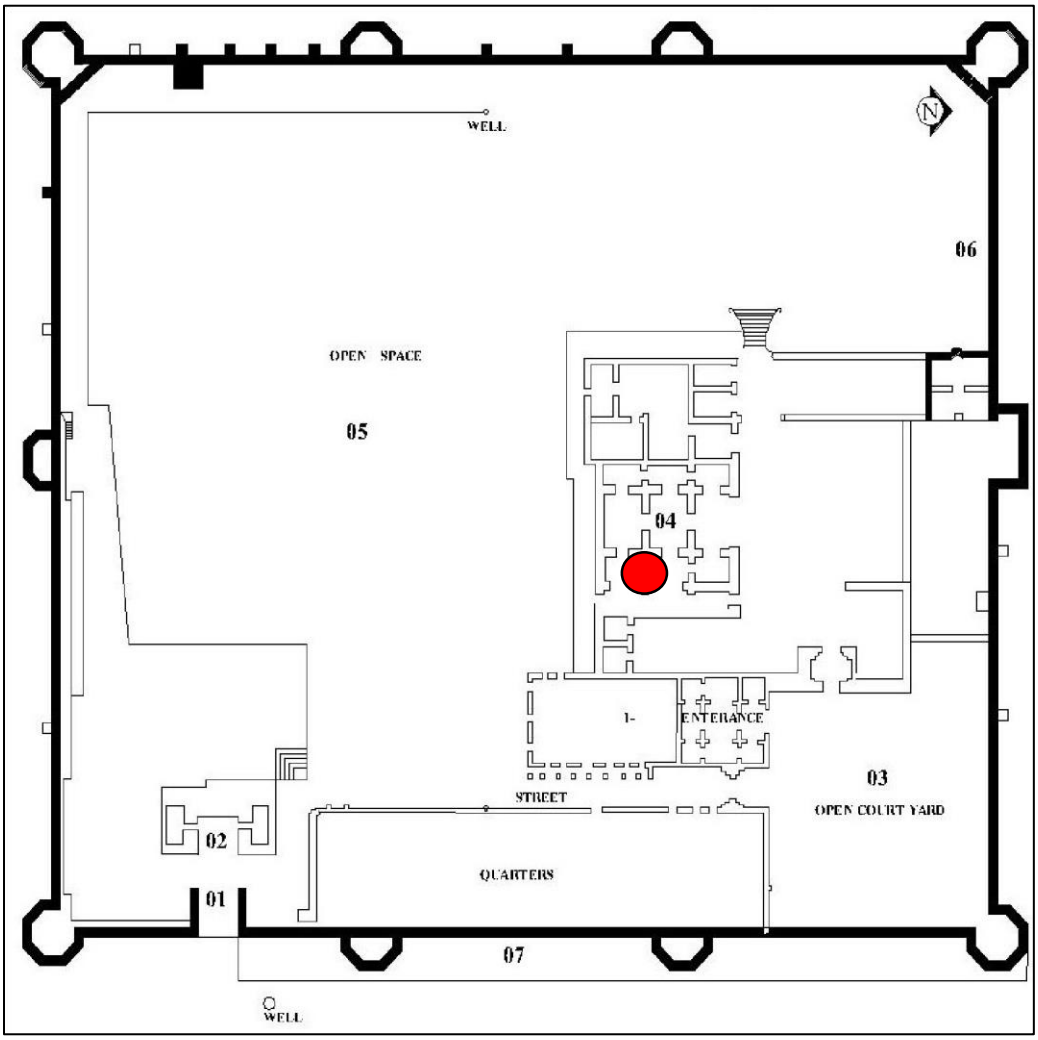


Figure. 5: Sheikhupura Fort, Sheikhupura: Layout Plan and sampling area (encircled) (After DOAM Punjab)

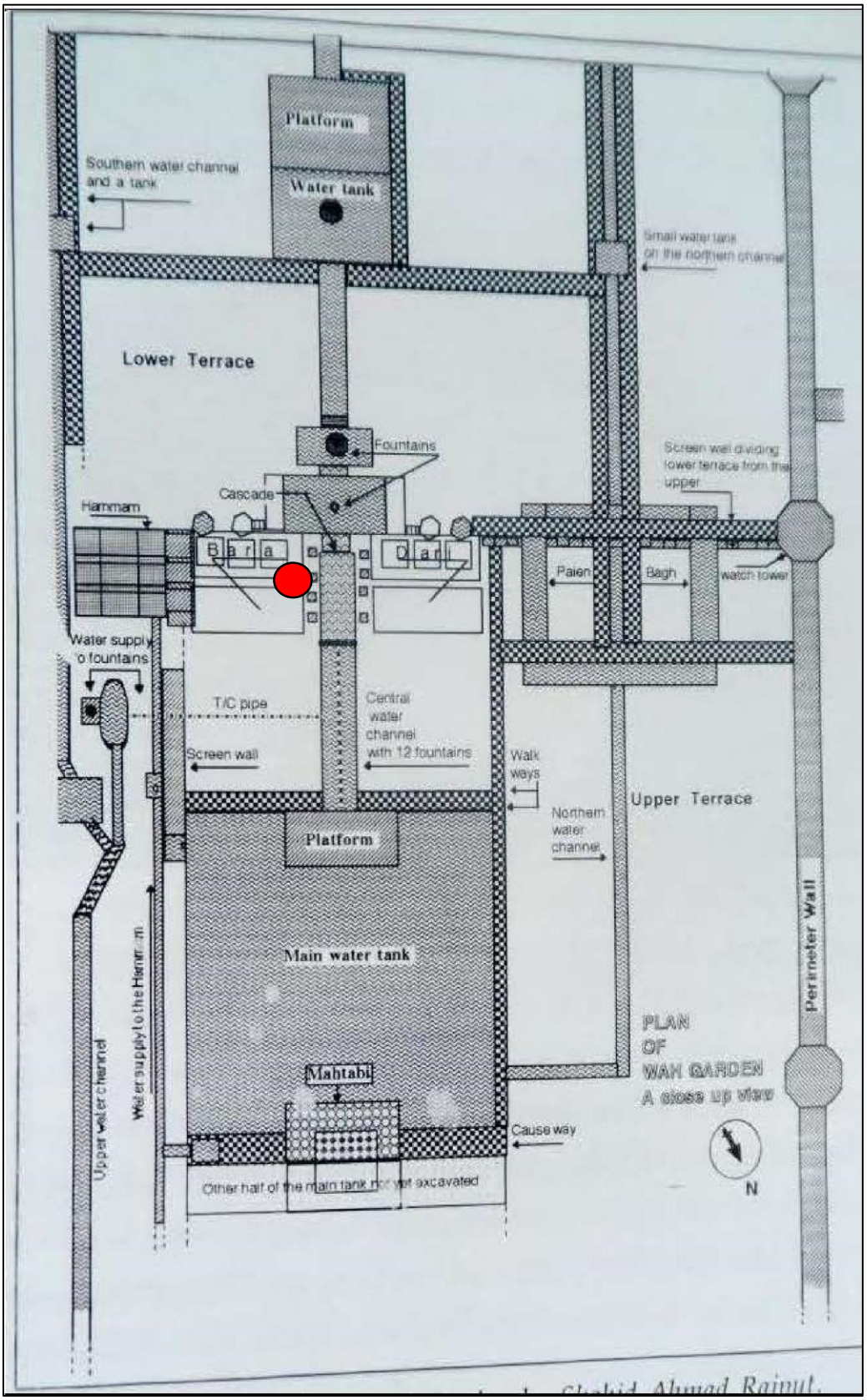


Figure.6: Wah Gardens, Hasanabdal: Layout Plan and sampling area (encircled) *(After Rajput, 1996)*

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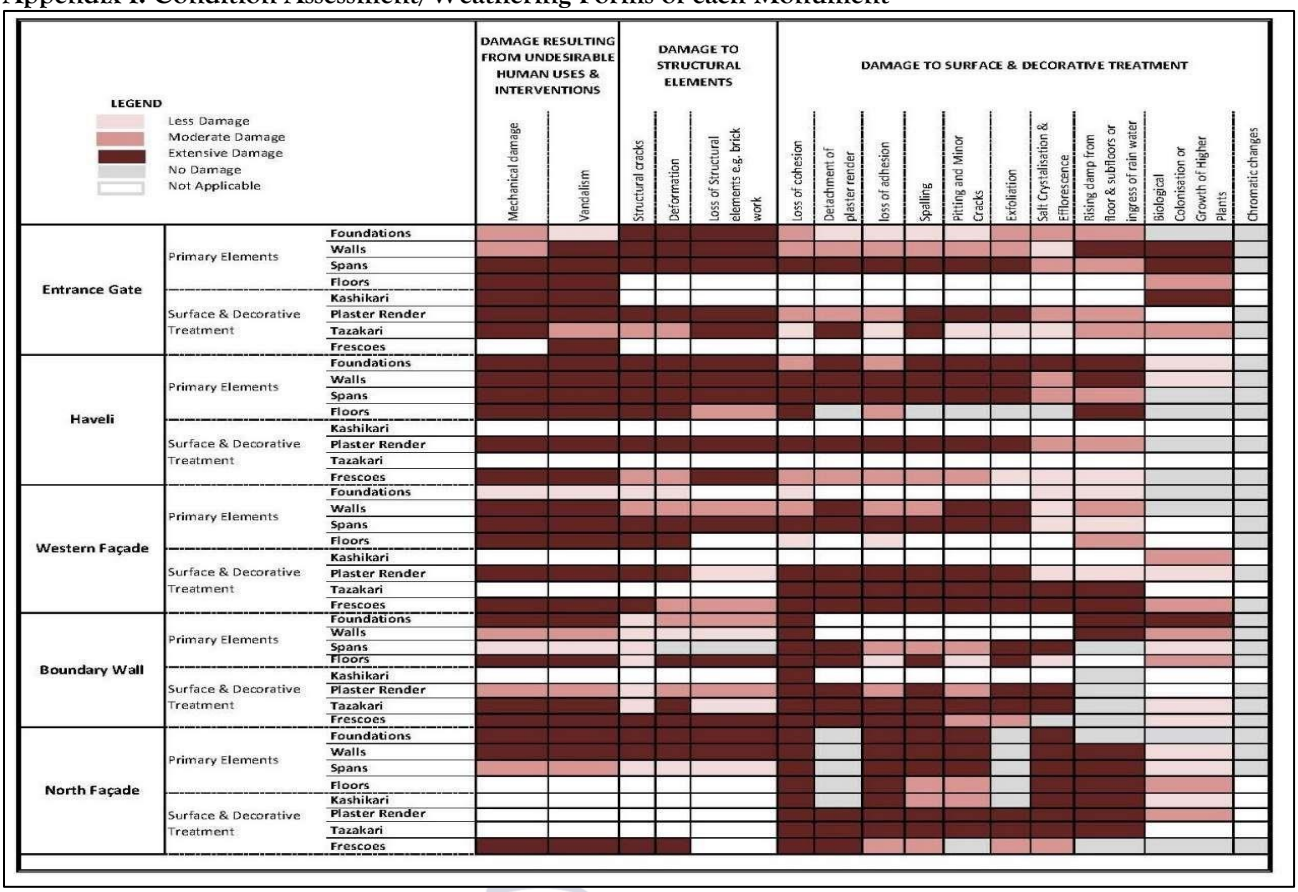
Appendix I: Condition Assessment/Weathering Forms of each Monument



Documentation of Instances of damage, weathering, and deterioration. (Sheikhupura Fort)

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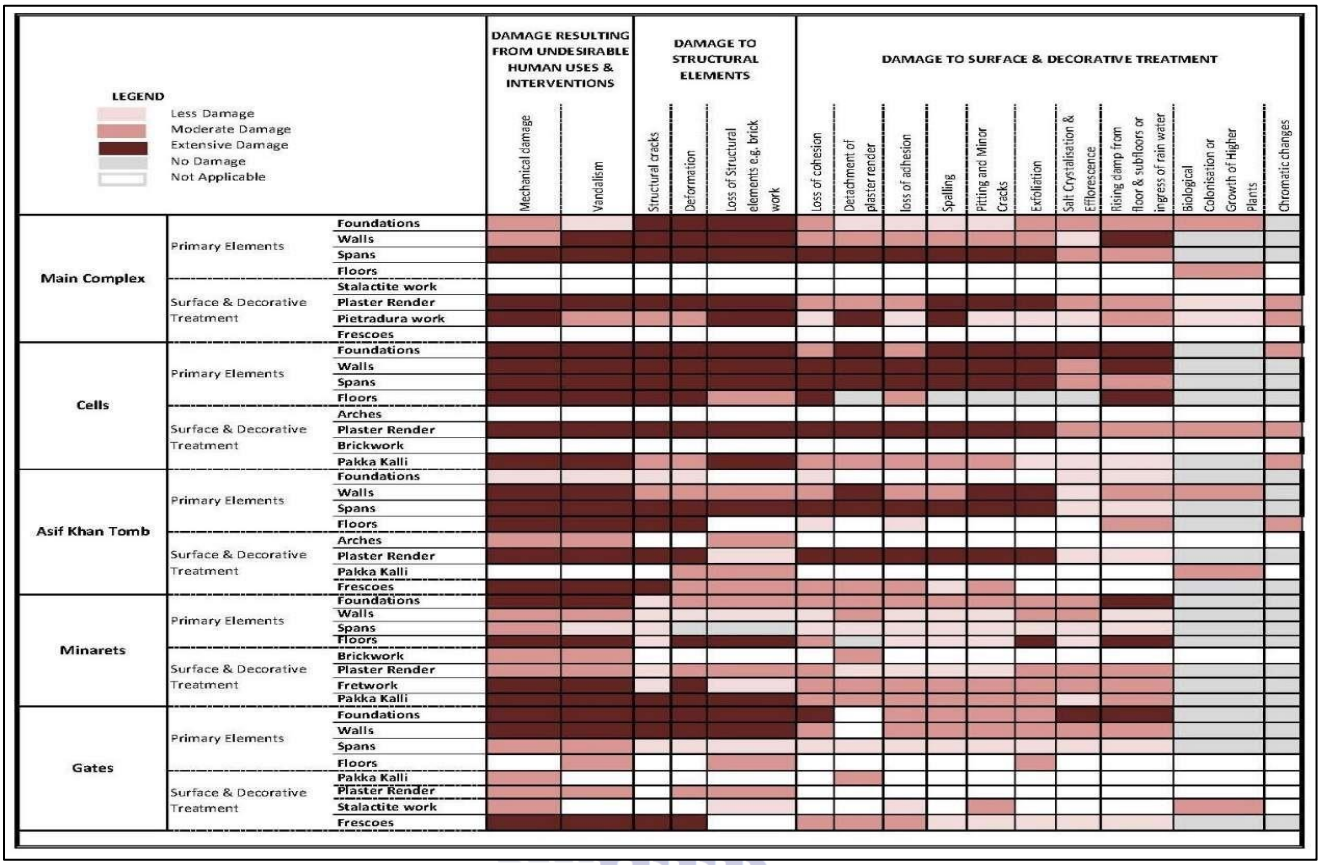

Documentation of Instances of damage, weathering, and deterioration. (Jehangir Tomb, Lahore)

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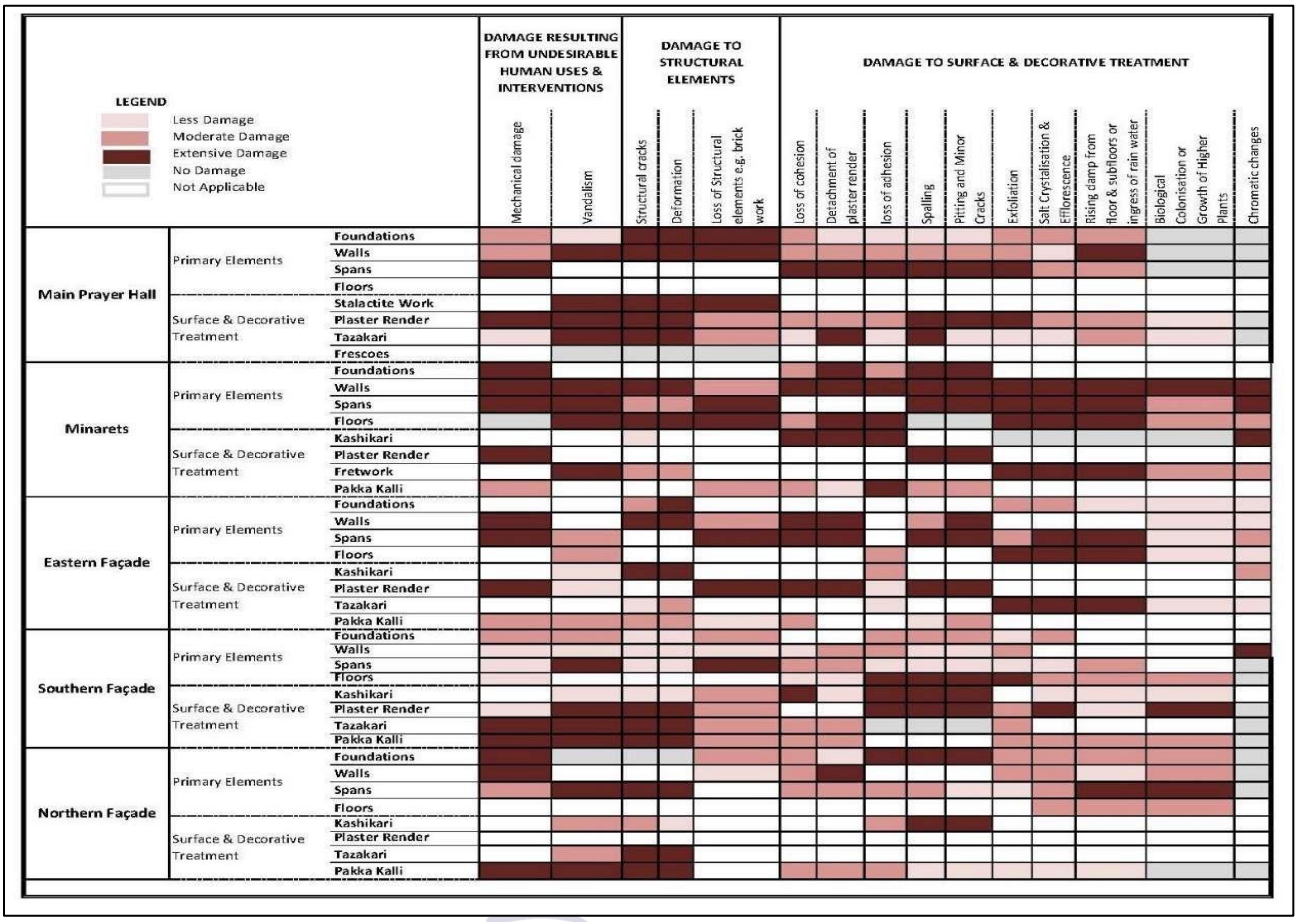

Documentation of Instances of damage, weathering, and deterioration. (Wazir Khan Mosque, Lahore)

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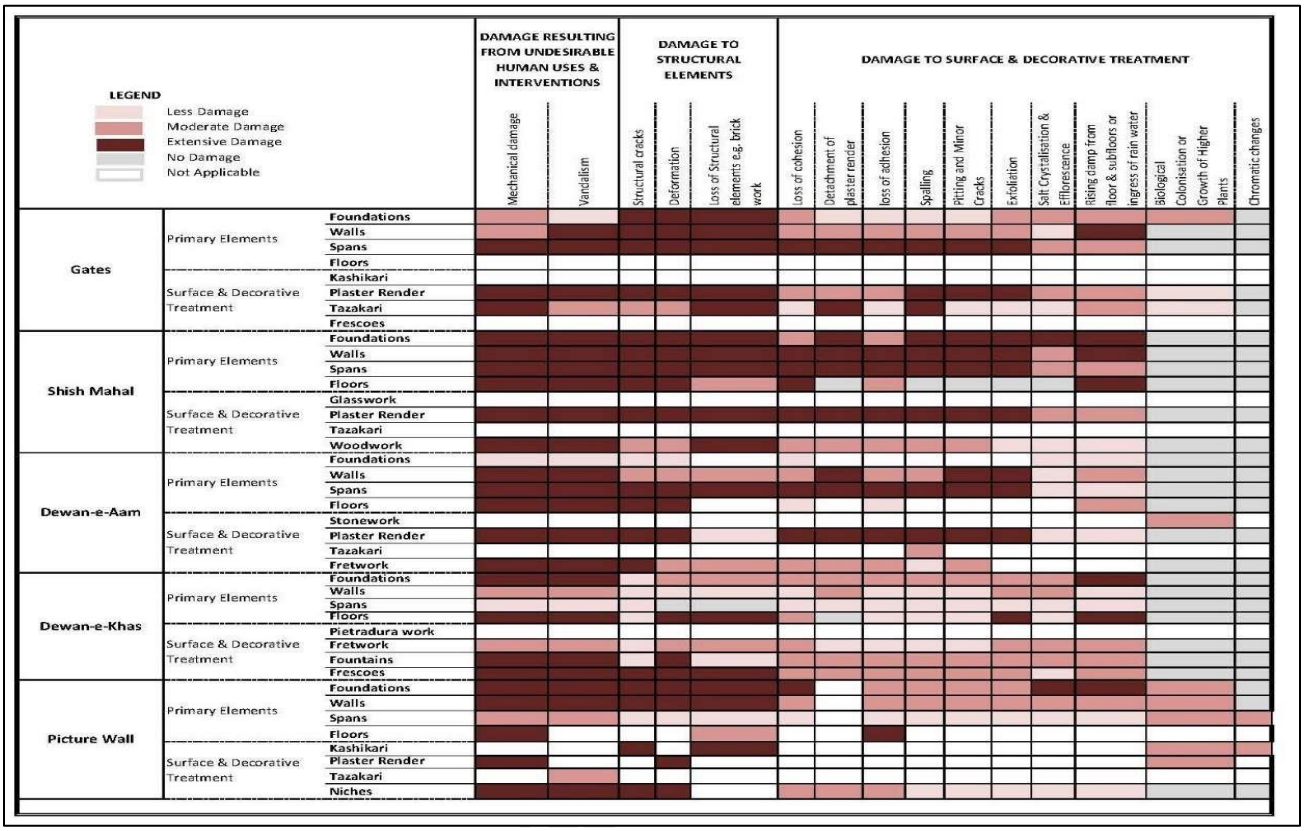
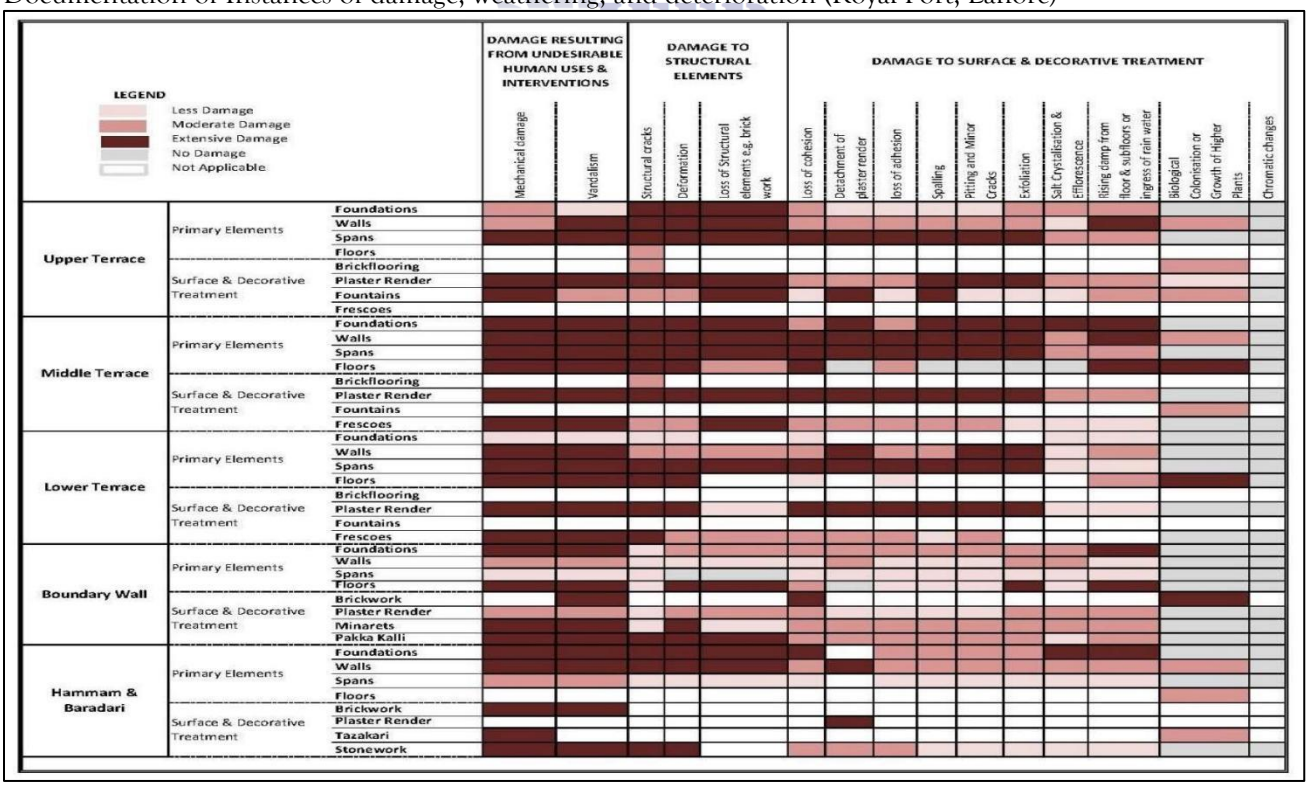


Documentation of Instances of damage, weathering, and deterioration (Royal Fort, Lahore)



Documentation of Instances of damage, weathering, and deterioration (Shalimar Gardens, Lahore)

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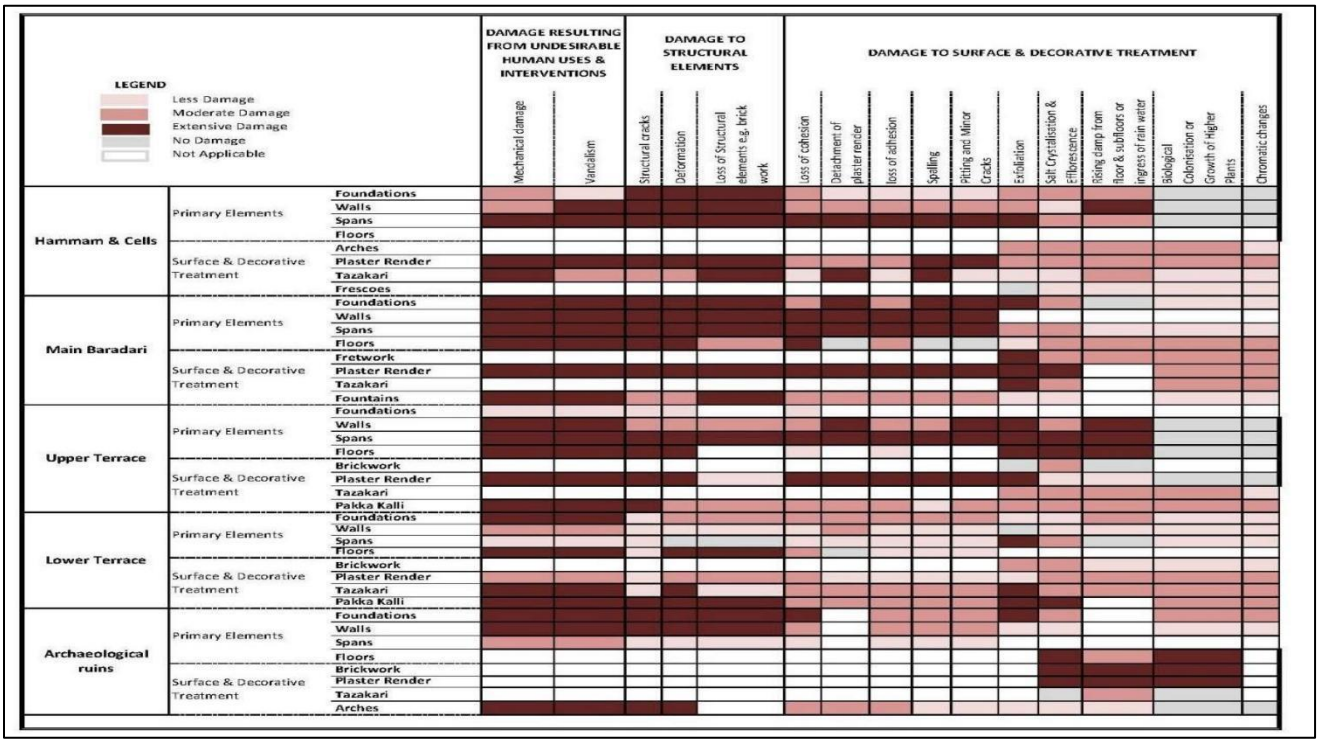

Documentation of Instances of damage, weathering, and deterioration. (Wah Gardens, Hasanabdal)