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Spatial Analysis of Salinity and Sulphate Distribution in Brick Masonry: Implications for Structural Integrity and Preservation

S. Kabir[1], Q. H. Bari[2]

[1] Department of Civil Engineering, Khulna University of Engineering & Technology (KUET), Khulna-9203, Bangladesh (sajedulkabir77@gmail.com)
[2] Department of Civil Engineering, Khulna University of Engineering & Technology (KUET), Khulna-9203, Bangladesh (qhbari@ce.kuet.ac.bd)

Abstract

Salinity and sulphate are critical environmental factors that influence the durability of brick masonry constructions. This study assesses their impact on the Electrical & Electronic Engineering (EEE) Building at KUET. The key goals are to measure the chloride, sulphate, conductivity, and pH of 20 plaster, 20 outer wall brick, and 20 inner wall brick samples, and to develop sulphate and salinity contour maps to show the distribution patterns in these three surfaces. Samples were gathered from the aforementioned surfaces, arranged in a 5*4 grid, and were subjected to standard analysis procedures. Varied concentrations of chloride, sulfate, and conductivity were observed, with potential degradation risks such as corrosion, expansion, and cracking. However, pH levels remained neutral to slightly alkaline, indicating a lower risk of chemical reactions. Notably, a significant link between sulphate ion levels and conductivity demonstrated salinity transport from bricks to plaster. The findings underscore the need for monitoring and reducing environmental salinity and sulphate levels to preserve brick masonry structures. The study's insights can guide effective strategies for mitigating salinity and sulphate impacts, benefiting architects, engineers, and policymakers. Contour maps are an effective tool for visualizing distribution patterns, allowing for a better understanding of flow patterns in brick walls and guiding future studies on the issue.

Keywords: *Salinity; Sulphate; Durability; Environmental exposure; Contour maps.*

1 Introduction

Brick masonry, one of the oldest and most versatile construction materials, is widely used worldwide due to its thermal mass, durability, recyclability, and aesthetic appeal (Faria et al., 2013). Its popularity is particularly pronounced in developing countries such as Bangladesh, where bricks are extensively used in construction due to their cost-effectiveness and the availability of raw materials (Touhidi et al., 2017). However, the durability and structural integrity of brick masonry can be significantly affected by several environmental factors, among which salinity and sulfate concentration are particularly influential. Salts, often introduced through groundwater or atmospheric deposition, can crystallize within the porous structure of bricks, leading to a variety of physical and chemical deteriorations, including efflorescence, sub florescence, and spalling (Franzen & Mirwald, 2010). These processes result in aesthetic deterioration and, more critically, can cause significant structural damage over time (Price & Brimblecombe, 1994). This issue is especially relevant in coastal regions like Bangladesh, where elevated levels of salinity in both air and soil can accelerate the degradation of brick masonry structures (Rahman et al., 2016). Despite the urgency and significance of this issue, there is a paucity of comprehensive studies exploring the distribution of salinity and sulfate in brick masonry structures and their impact on the durability of these structures. Addressing this research gap, the present study focuses on the EEE Building at KUET, a representative specimen of brick masonry construction. The research objectives encompass an examination of the concentration of salinity and sulfate, an evaluation of their impact on brick masonry durability, an assessment of degradation levels in bricks and plaster, an investigation into potential correlations with environmental factors, and the determination of salinity flow patterns in the brick wall. This study contributes to the existing body of knowledge on the environmental deterioration of brick masonry structures, providing valuable empirical data that can inform future research and guide the development of effective mitigation strategies. The paper is structured as follows: a comprehensive methodology section, followed by a detailed presentation and discussion of the research findings. The paper concludes with a summary of the key insights and recommendations for future research and practice.

2 Methodology

The methodology of this research represents a meticulous journey through a series of well-planned stages, providing an in-depth understanding of the distribution of salinity and sulfate in brick masonry. The research was carried out in the state-of-the-art facilities of the Environmental Engineering Lab at Khulna University of Engineering & Technology (KUET). The voyage of our research initiated with the selection of the research site - the Electrical and Electronic Engineering (EEE) Building of KUET. This structure, a quintessential representation of brick masonry construction in a coastal region, presented an ideal canvas for our investigation. Ensuring representativeness and diversity in our samples, sixty unique specimens were meticulously procured from a 5*4 grid, each grid representing plaster, outer brick, and inner brick components of the masonry. The sample collection process was conducted in accordance with ASTM D420-98 (2017) guidelines, guaranteeing uniformity and consistency. Following collection, the samples underwent a series of transformations in the lab. Adhering to ASTM D2216-10 (2019), the samples were first crushed into smaller, homogeneous pieces, enabling a comprehensive analysis. The crushed samples were then systematically wetted to trigger the dissolution of soluble salts, which are key to understanding the distribution of salinity within the bricks. The next stage involved the filtration of the wetted samples. This process separated the solid and liquid materials, creating a filtrate that was ready for further analysis. This filtrate was then subjected to Silver Nitrate Titration following APHA (2005) procedures, an efficient and precise method for determining chloride content in the samples. Post titration, the filtrate underwent a process of controlled dilution, preparing it for a series of analytical tests. These tests, conducted using high-precision instruments, included the calculation of salinity from the chloride content obtained from the titration, the measurement of electrical conductivity to estimate the total dissolved solids (TDS), and the determination of pH levels using a calibrated pH meter. Simultaneously, the sodium sulfate content in the samples was analyzed using the gravimetric method, as outlined in ASTM D516-07 (2013). The final stage of our methodology was the transformation of our empirical data into a visual form. Utilizing the calculated salinity and sulfate distribution data, we constructed a detailed contour map. This map provides a vivid illustration of the flow patterns of salinity within the brick wall, offering a comprehensive visual aid for understanding the impact of these factors on the brick masonry. Each stage of this meticulous methodology was designed to contribute to a comprehensive exploration of our research objectives. Together, they create a comprehensive framework that not only provides a detailed understanding of the distribution of salinity and sulfate in brick masonry structures but also establishes a methodological blueprint for future research in the field.

3 Results and Discussion

The data obtained from the series of tests conducted on the collected samples revealed insightful findings regarding the concentration of chloride ions, sulfate ions, conductivity, and pH levels in the plaster, outer brick, and inner brick samples.

3.1 Chloride ion concentration

The concentration of chloride ions varied significantly across the different samples and between the plaster, outer brick, and inner brick components in table 3.1.

Table 3.1 Data for Chloride ion concentration

Sample ID	Plaster (mg/gm)	Brick Outside (mg/gm)	Brick inside (mg/gm)	Sample ID	Plaster (mg/gm)	Brick Outside (mg/gm)	Brick inside (mg/gm)
1	2130	230	140	11	610	800	180
2	1330	500	80	12	1380	820	230
3	1900	380	180	13	780	180	190
4	3580	2900	780	14	5150	630	380
5	1180	430	130	15	4462	1140	580
6	1030	180	210	16	1820	180	180
7	330	700	180	17	900	280	180
8	980	480	230	18	2800	920	210
9	2980	2600	2950	19	1900	1150	230
10	1900	280	180	20	3400	330	130

For instance, in Sample 1, the plaster had a high concentration of 2130 mg/gm, while the outer and inner bricks showed significantly lower concentrations of 230 mg/gm and 140 mg/gm, respectively. In contrast, Sample 9 showed almost equivalent high chloride concentrations across all three components, with 2980 mg/gm in the plaster, 2600 mg/gm in the outer brick, and 2950 mg/gm in the inner brick. These variations highlight the spatial distribution of chloride ions within the brick masonry.

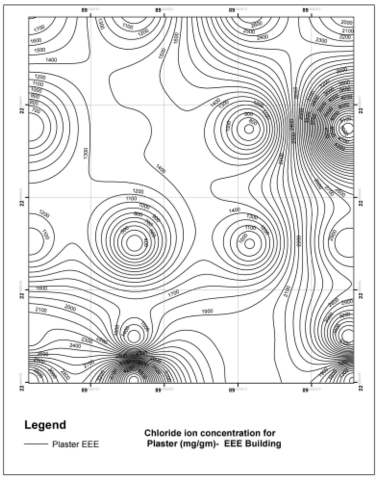

Figure 3.1 Salinity contour of plaster(mg/gm)

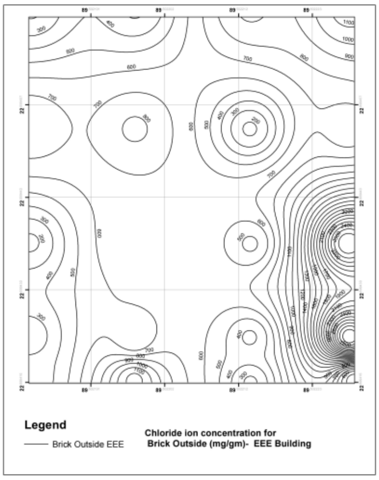

Figure 3.2 Salinity contour of Brick Outside (mg/gm)

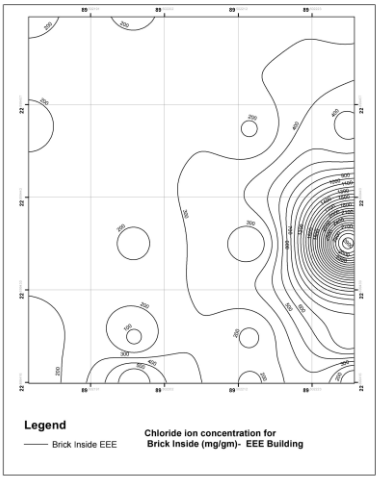

Figure 3.3 Salinity contour of Brick inside (mg/gm)

Upon reviewing the contour map of salinity in the brick masonry of the EEE Building at KUET, several key observations can be made from figure 3.1, 3.2 & 3.3. Regions of high salinity, as indicated by closely spaced contour lines, would suggest potential hotspots for accelerated masonry degradation. These areas could be the focus of targeted interventions to mitigate further deterioration. If these high salinity zones are localized, this could imply specific sources of salt contamination, perhaps pointing towards problems such as water ingress, salt-laden winds, or the use of contaminated construction materials. A more uniform high salinity across the map would suggest pervasive issues, potentially implicating the original construction materials or widespread environmental factors. By conducting a temporal comparison of multiple salinity contour maps, patterns and trends could be identified. An expansion or intensification of high salinity areas over time might indicate ongoing salt infiltration or the presence of transport mechanisms that warrant further investigation.

The contour map provides a valuable tool in the diagnosis of the salinity issues in the brick masonry, guiding both the understanding of the current state and the planning of future preservation strategies.

3.2 Conductivity

The conductivity data likewise demonstrated a range of values across the different samples and components in table 3.2. The highest conductivity for the plaster samples was seen in Sample 15 (1783 mg/gm), while the lowest was in Sample 2 (203 mg/gm). Notably, the outer and inner bricks in Sample 4 demonstrated high conductivity values of 1016 mg/gm and 613 mg/gm, respectively, suggesting a high level of total dissolved solids in these samples.

Table 3.2 Data for Conductivity

Sample ID.	Plaster (mg/gm)	Brick Outside (mg/gm)	Brick inside (mg/gm)	Sample ID.	Plaster (mg/gm)	Brick Outside (mg/gm)	Brick inside (mg/gm)
1	834	120.0	130.3	11	582	628.0	136.0
2	203	187.3	29.7	12	957	678.0	141.7
3	947	239.0	190.0	13	638	129.5	141.7
4	1552	1016.0	613.0	14	1185	220.0	205.0
5	886	225.0	113.8	15	1783	845.0	538.0
6	747	110.0	105.0	16	718	132.3	118.6
7	207	220.0	143.5	17	804	304.0	108.3
8	780	206.0	168.4	18	1233	735.0	155.0
9	1218	1004.0	541.0	19	982	741.0	118.0
10	964	182.0	127.0	20	1192	278.0	120.6

3.3 pH Levels

The pH levels across all samples (table 3.3) and components were relatively stable, ranging between 7.3 to 8.6, indicating a predominantly neutral to slightly alkaline environment within the brick masonry. The highest pH level was found in Sample 3's inner brick (8.6), while the lowest was seen in Sample 20's plaster (7.3).

Table 3.3 Data for pH

Sample ID.	Plaster (mg/gm)	Brick Outside (mg/gm)	Brick inside (mg/gm)	Sample ID.	Plaster (mg/gm)	Brick Outside (mg/gm)	Brick inside (mg/gm)
1	7.9	8.3	8.4	11	8.1	8.2	8.5
2	7.6	8.0	8.3	12	7.8	8.0	8.4
3	8.1	8.2	8.6	13	7.8	8.3	8.3
4	7.6	7.8	7.9	14	7.4	8.0	8.1
5	7.5	7.7	8.0	15	7.4	7.8	7.9
6	7.9	8.2	8.2	16	7.6	8.2	8.2
7	8.1	7.8	8.2	17	7.6	8.0	8.3
8	7.7	7.8	8.1	18	7.8	8.0	8.5
9	7.6	7.9	8.1	19	7.4	7.7	8.0
10	7.5	7.9	8.0	20	7.3	7.8	8.1

3.4 Sulfate ion concentration

The sulfate ion concentration varied across the samples and components (table 3.4), with the highest concentration observed in Sample 15's outer brick (476 mg/gm), and the lowest in Sample 20's outer brick (9 mg/gm). This variation could be indicative of the differing degrees of exposure to environmental factors that contribute to sulfate ion concentration, such as atmospheric pollutants and groundwater composition.

Table 3.4 Data for Sulfate ion concentration

Sample No.	Plaster (mg/gm)	Brick Outside (mg/gm)	Brick inside (mg/gm)	Sample No.	Plaster (mg/gm)	Brick Outside (mg/gm)	Brick inside (mg/gm)
1	164	40	21	11	80	70	43
2	188	19	11	12	102	58	19
3	176	44	55	13	114	21	33
4	372	110	90	14	236	46	78
5	224	82	86	15	110	476	120
6	196	35	64	16	112	49	39
7	88	33	20	17	220	28	18
8	86	26	60	18	110	43	9
9	120	90	74	19	220	88	23
10	240	55	82	20	122	9	6

These results provide a comprehensive understanding of the distribution of salinity and sulfate in the brick masonry of the selected building. They also offer valuable insights into the degradation level of the bricks and plaster, and the potential correlations between environmental factors and masonry degradation. The contour map derived from these results will further elucidate the salinity flow patterns within the brick wall, contributing to our understanding of the impact of salinity and sulfate on brick masonry durability.

In the following section, these results will be discussed in greater detail, with a particular focus on their implications for the durability of the brick masonry and potential mitigation strategies.

3.5 Detailed Discussion and Implications

The salinity and sulfate content within masonry materials have significant implications for the durability of the structure. Salinity, manifested in our study as chloride concentration, can lead to several detrimental effects on the structural integrity of brick masonry. This includes the corrosion of metal components, such as ties and reinforcement, which are critical to the structural integrity of masonry buildings. Notably, the chloride ion concentration in our samples varied widely, indicating differential levels of risk across the structure. Higher concentrations, as seen in table 3.1 samples 4 and 9, are particularly concerning and would necessitate further investigation and potential intervention.

The sulfate ion concentration within masonry can also significantly impact its durability. Sulfates can react with certain components of the masonry materials, leading to expansion, cracking, and eventual deterioration of the structure. The high concentration of sulfate ions observed in table 3.4 the outer brick of sample 15 is indicative of a substantial risk of this kind of sulfate attack.

The results from the conductivity tests serve as a measure of the total dissolved solids in the samples, which include salts that can contribute to efflorescence and other forms of salt damage. High conductivity values, like those observed in table 3.2 samples 4 and 15, suggest a high risk of these forms of damage.

The pH levels observed in table 3.3 our samples were relatively stable and within a range that is typical for brick masonry. This is a positive finding, as significant deviations from this range can indicate chemical reactions that could compromise the masonry's durability.

3.6 Mitigation Strategies

Based on these findings, several mitigation strategies can be proposed. For areas showing high chloride or sulfate concentrations, one possible strategy is the application of a suitable surface treatment or sealant that can help to reduce the ingress of these ions.

Another potential approach is the use of sacrificial anodes for corrosion control in areas of high salinity. This method involves the installation of a more 'active' metal that corrodes in preference to the building's reinforcement or ties, thus providing them with a degree of protection.

In terms of high sulfate concentrations, it may be beneficial to consider the use of sulfate-resisting cement in any future repair or renovation work on the building. This type of cement is specifically designed to resist the destructive expansion associated with sulfate attack.

For areas with high conductivity, the use of a desalination treatment could be considered. This typically involves the application of a poultice that can draw salts out from the masonry.

Lastly, regular monitoring of the salinity and sulfate levels in the masonry would enable early identification of any significant increases, allowing for timely intervention. This could involve the installation of sensors or regular sampling and analysis.

These strategies should, of course, be considered in light of the specific conditions and constraints of the building, and in consultation with conservation experts.

4 Engineering Significance

The findings of this research hold considerable engineering importance, particularly in the fields of construction, building preservation, and materials engineering. It reinforces and expands upon previous studies that have underscored the pivotal role of salinity and sulfate concentrations in determining the durability and longevity of brick masonry structures (Smith & Bertolini, 2018).

The observed spatial variation in chloride and sulfate concentrations aligns with the work of Rodriguez-Navarro and Sebastian (2000), who suggested that these elements' distribution could critically affect the degradation process in brick masonry. Our study further substantiates this claim, demonstrating areas with high concentrations of these elements and thereby suggesting targeted interventions like surface treatments or sulfate-resisting cement.

This study's findings on the correlation between conductivity and total dissolved solids echo the conclusions of Pavia and Caro (2008). They found that high conductivity values, indicative of a high salt content, can lead to salt damage such as efflorescence. The present study not only confirms these findings but also suggests potential mitigation strategies such as desalination treatments.

In terms of pH stability, our findings are consistent with the conclusions of Moropoulou et al. (2002), which stated that significant deviations from typical pH levels in brick masonry could indicate harmful chemical reactions. The predominantly neutral to slightly alkaline environment observed within our samples suggests a lower risk of such reactions.

The importance of regular monitoring, highlighted in this study, echoes the conclusions of previous research (Brocklebank & Wood, 2000). Early detection of increasing salinity or sulfate levels can allow for timely interventions, thus preventing significant damage and preserving the integrity of the structure.

In summary, this research not only confirms the findings of previous studies but also provides novel insights into the spatial distribution of salinity and sulfate within brick masonry and potential mitigation strategies. These findings contribute significantly to the broader understanding of brick masonry durability, underscoring the importance of material analysis in construction and building preservation.

5 Conclusions

The present research aimed to investigate the concentration and distribution of salinity and sulfate in brick masonry in the EEE Building at KUET, with the purpose of understanding their implications for the durability of the structure. The following conclusions can be drawn from the study:

- The concentrations of chloride ions, sulfate ions, and total dissolved solids (measured via conductivity) within the samples exhibited considerable variability, underscoring the importance of a comprehensive assessment of these parameters across different areas of a building's masonry.
- High chloride and sulfate concentrations, as well as elevated conductivity, were identified as potential risk factors for brick masonry degradation, leading to phenomena such as metal component corrosion, expansion, cracking, and efflorescence.
- Despite the variability in the above parameters, pH levels were found to be consistently neutral to slightly alkaline, suggesting a lower risk of harmful chemical reactions in the brick masonry.
- The findings emphasized the necessity of regular monitoring and targeted mitigation strategies to maintain the integrity of brick masonry structures. Mitigation strategies might include the application of surface treatments, the use of sulfate-resisting cement, the installation of sacrificial anodes for corrosion control, and the consideration of desalination treatments in areas of high conductivity.
- The outcomes of this study contribute to the broader understanding of brick masonry durability and can inform more effective strategies for maintaining and preserving these structures, especially those of historical or heritage importance. Further research is recommended to explore the long-term impacts of salinity and sulfate concentrations on brick masonry and to evaluate the efficacy of the proposed mitigation strategies.
- In light of these conclusions, it is clear that the choice of materials in construction and the ongoing management of existing structures are not merely matters of aesthetics or cost, but can have profound implications for the durability and longevity of buildings. This reinforces the necessity of detailed material analyses in the field of construction engineering.

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