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Analyzes of Stone Deterioration on the Facades of the Şehidiye Madrasah in the Central District of Mardin Province

Ayşe BİÇEN ÇELİK [1], Şefika ERGİN [2], Murat DAL [3], İlhami AY [4*]

[1] Dicle University, Institute of Science, Diyarbakır, 21830, Turkey.
[2] Dicle University, Faculty of Architecture, Diyarbakır, 21830, Turkey.
[3] Munzur University, Faculty of Art, Design and Architecture, Tunceli, 62000, Turkey.
[4] Hakkari University, Çölemerik Vacotional School, Hakkari, 30000, Turkey.

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Abstract

Stone material is one of the most preferred construction materials in traditional buildings. The fact that stone has drilling, crushing and shaping properties and does not need any other binding material is an important factor in the frequent preference of stone material. The durability of stone is important for stone structures to survive until today. However, when the stone material is exposed to environmental and climatic factors, deterioration occurs on the surfaces of the stone. It is important to detect and classify these deteriorations on stone surfaces and to take measures against deterioration in order for the structure to survive for a longer period of time. In this study, stone deterioration was identified and classified as physical, chemical, biological and anthropogenic deterioration and the deterioration of the facades of the Şehidiye Madrasah in Mardin is discussed. The deterioration of the building was classified and analyzed. Visual, mapping and X-Ray Fluorescence Spectroscopy (XRF chemical analyzes method) were used as analyzes methods. The aim of the study are to determine the types and causes of deterioration in the building, to offer solutions and to ensure that the building is transferred to future generations without losing its originality for many years. With the data obtained as a result of the study, it is aimed to form the basis for the conservation projects to be realized in the following years.

Anahtar Kelimeler: Şehidiye Madrasah, Stone Deterioration, XRF Chemical Analyzes Method, Mardin.

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Mardin İli Merkez İlçesinde Yer Alan Şehidiye Medresesi'nin Cephelerinde Görülen Taş Bozunmalarının Analizi

Özet

Geleneksel yapılarda taş malzemesi en çok tercih edilen yapı malzemelerinden biridir. Taş malzemesinin sıkça tercih edilmesinde taşın delme, kırma, şekil verme özelliklerine sahip olması ve bağlayıcı başka malzemeye ihtiyaç duymaması önemli bir etkendir. Taş yapıların günümüze kadar ulaşmasında taşın dayanıklılığı önemlidir. Ancak taş malzeme çevresel ve iklimsel etkenlere maruz kaldığında taşın yüzeylerinde bozunmalar meydana gelir. Taş yüzeylerde meydana gelen bu bozunmaların tespiti, sınıflandırılması ve bozunmalara karşı önlemlerin alınması yapının daha uzun süre ayakta kalması açısından önemlidir. Çalışmada taş bozunmaları tespit edilmiş; fiziksel, kimyasal, biyolojik ve antropojenik bozunmalar olarak sınıflandırılmıştır. Bu çalışmada Mardin'de yer alan Şehidiye Medresesi'nin cephelerinde meydana gelen bozunmalar ele alınmıştır. Yapıda oluşan bozunmalar sınıflandırılmış ve analiz edilmiştir. Analiz yöntemi olarak görsel, haritalama ve X-Işınları Floresan Spektroskopisi (XRF kimyasal analiz yöntemi) yöntemi kullanılmıştır. Çalışmanın amacı; yapıda meydana gelen bozunma türlerini ve nedenlerini tespit etmek, çözüm önerileri sunmak ve yapının uzun yıllar boyunca özgünlüğünü kaybetmeden gelecek nesillere aktarılmasını sağlamaktır. Çalışma sonucunda elde edilen verilerle ilerleyen yıllarda gerçekleştirelecek koruma projelerine altlık oluşturması hedeflenmektedir.

Keywords: *Şehidiye Medresesi, Taş Bozunmaları, XRF Kimyasal Analiz Yöntemi, Mardin*.

1. Introduction

Mardin province has served as a significant trade hub because of its location on the Silk Road, a vital trade route, and has witnessed the rule of diverse civilizations and empires throughout history (Çağlayan, 2018). Communities of varying cultural, ethnic, and linguistic backgrounds have coexisted harmoniously in this region (Alioğlu, 1989).

Over time, Mardin has played host to numerous civilizations, each of which has left an indelible mark. While some of the structures erected during these periods remain in use for their original purpose, others have been repurposed. Traditional sites, including mosques, madrasahs, churches, monasteries, and tombs, were constructed during this era (Uyar, 2019). Madrasahs served as important sites for cultural and educational activities throughout the historical process (Yardımlı, 2018). Limestone served as the primary material for constructing traditional stone buildings in Mardin (Semerci, 2017). Limestone's petrographic properties exacerbate surface deterioration when exposed to environmental factors like atmosphere, humidity, and water (Biçen Çelik et al., 2023; Dal & Öcal, 2013a; Dal & Öcal, 2013b), leading to a decrease in the stone's durability over time (Öcal, 2010; Ergin, Gökdemir, Yardımlı & Dal, 2022). It is crucial to take preventative measures against structural deterioration to ensure longevity. The procedures to be implemented in buildings vary depending on the type of deterioration encountered (Dal & Öcal, 2017). Correct analyzes of the deterioration is essential to minimize damage and ensure appropriate action is taken. Regular

inspections and measures to improve durability are crucial for the long-term survival of structures (Doehne & Price, 2010; Karkaş & Acun Özgünler, 2022).

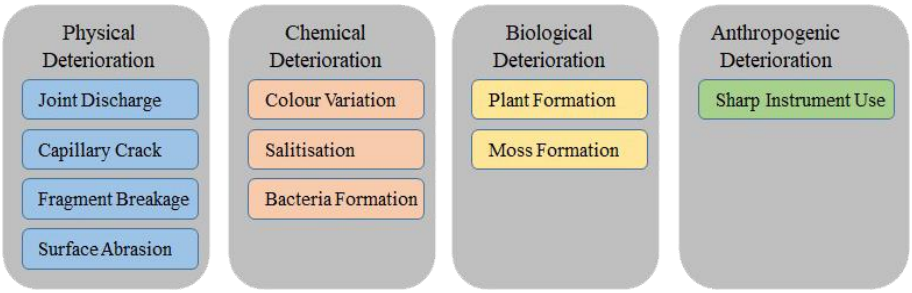
The objective of the research is to investigate and classify the degradation of the stonework on the facades of the Şehidiye Madrasah in Mardin, with the ultimate goal of prolonging the building's lifespan by implementing preventative measures against deterioration. To achieve this, the stone degradation present at the Şehidiye Madrasah was analyzed thoroughly and systematically. Initially, the degradation was assessed visually and then analyzed in three phases, incorporating physical, chemical, biological, and anthropogenic deterioration. In the second stage, the mapping method was employed following the identification of facade deterioration, to determine the types of decay on the facades and their proportional distribution. The mapping method utilised software programs including Autocad 2018 and Adobe Photoshop CS6. In the third stage, X-Ray Fluorescence Spectroscopy (XRF chemical analyze method) was implemented to identify the chemical composition of the stone. The ratios of the CaO, SiO_2, Al_2O_3, SO_3, Fe_2O_3, and P_2O_5 components present in the stone were measured and illustrated with graphs. The obtained data will serve as the foundation for forthcoming conservation projects, as per the results of the research conducted by Biçen Çelik in 2021.

2. Material and Method

Stone has been a popular main construction material from ancient times to the present day. One of its key advantages is that it can be used without the need for binding material. However, exposure to environmental and climatic factors can cause deterioration and changes on its surfaces (Umaroğuları & Kartal, 2021). This study focuses on the Şehidiye Madrasah in Mardin. The study scrutinized the deterioration of the facade surfaces of the madrasah, to identify the types, rates, variations, and causes of the damage.

To determine the underlying causes and processes of deterioration in traditional stone structures, it is crucial to classify and examine the pertinent factors. Table 1 demonstrates the various factors that contribute to the degradation.

Table 1. Classification of the deterioration observed in Şehidiye Madrasah (Öcal & Dal, 2012)



2.1. Study Area Features

2.1.1. History of Mardin Province

Mardin has hosted diverse civilizations across history and has borne multiple names (Alioğlu, 2000; Noyan, 2008; Yousif, 2011). Situated in the rich plain of Mesopotamia, Mardin was founded in the region renowned as the "Fertile Crescent."

Upon studying traditional architectural relics in Mardin, remains dating back to 3000 BC are discerned (Aydın, Emiroğlu, Özel & Ünsal, 2000). Throughout the ages, Mardin has been ruled by various civilizations, resulting in the city boasting works bearing the marks of those times (Yıldız, 2007; Aliveya, 2007; Biçen Çelik, 2021). Nonetheless, the Artuqid State played a crucial role in shaping the identity of Mardin (Dal & Öcal, 2017). Following the Artuqids, the city came under the dominion of Karakoyunlu, Akkoyunlu, Safavid and Ottoman rule, leaving vestiges of those periods still visible in the city (Çağlayan, 2018). The Şehidiye Madrasah, constructed from 1239 to 1260, is one of the enduring structures to have survived until the present day (Demir, 2019). The location of the Şehidiye Madrasah is depicted in Figure 1, generated from Google Earth.

Madrasah buildings have had a significant educational and cultural role in societies throughout history. Library structures were commonly located within the temples of Mesopotamian societies (Yıldız, 2003). In the Ottoman Empire, madrasas were influential as the main educational institutions, and they were situated within complexes that formed universities. As time progressed, these madrasas merged with the mosque courtyard (Karakök, 2013).

During the Ottoman era, the architecture of madrasah buildings followed a specific design - a courtyard at the center, student rooms situated around the courtyard, and a classroom facing the entrance. Typically, these buildings featured two floors (Tayla, 2007; Dobrowolski, 2001).

Currently, 11 madrasah buildings (including Kasımiye, Şehidiye, Zinciriye, Altunboğa, Şah Sultan, Muzafferiye, Savur Kapı, Melik Mansur, Hatuniye, Marufiye, and Hüsamiye) have been

identified in Mardin. The city's location on the Silk Road has contributed significantly to the large number of madrasas. Its position on this trade route, as well as its role as a cultural, commercial, and scientific hub, has led to the proliferation of such institutions.

Figure 1. Şehidiye Madrasah satellite image (processed from Google Map)

2.1.2. Geographical Features of Mardin Province

Mardin, a city in the Southeastern Anatolia Region of Turkey, is situated at latitudes 36^{o} 54' and 37^{o} 47' north and longitudes 39^{o} 55' and 42^{o} 41' east. It covers an area of 8891 km^{2}, standing at an altitude of 1100 meters. The city shares borders with Şanlıurfa, Diyarbakır, Batman, Şırnak, Siirt provinces, and Syria (Figure 2). Due to its elevated position (1083 m above sea level), the settlements were aligned in an east-west direction of the castle. As the northern part of the mountain was unsuitable for settlement, the city was established on the high plateau facing south (Karataş, 2018). The settlements are situated on sloping terrain necessitating access to the buildings by steep ramps and stairs (Bekleyen, Dalkılıç & Özen, 2014).

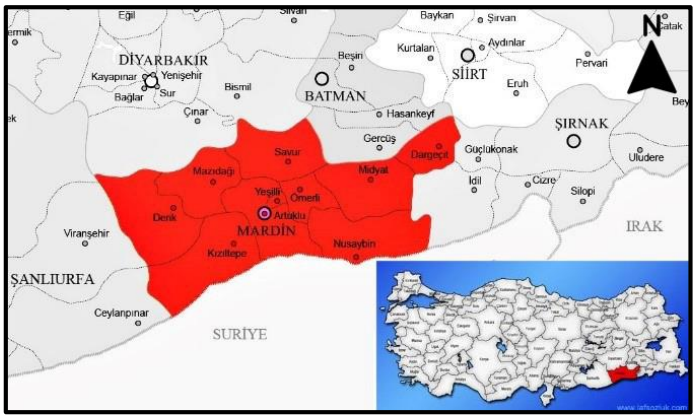
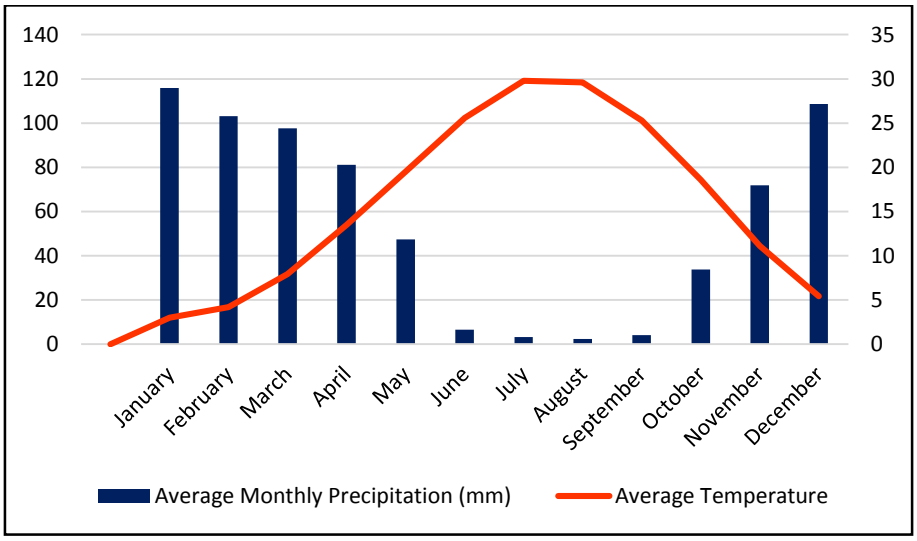


Figure 2. Location of Mardin in Turkey

Mardin Province has a continental climate in its center and a Mediterranean climate in its districts. The winter season is cold, while the summer season is dry and hot owing to the pressure and wind coming from the desert. In the city, the highest temperature value occurs in July, reaching 29.8 ^{o}C, while the lowest temperature value occurs in January, dropping to 3.0 ^{o}C (see Table 2 for annual average temperature values). Deterioration occurs on the stone surfaces of buildings in Mardin due to differences in daily and yearly temperatures (Karataş, 2018).

Table 2. Average temperature and precipitation of Mardin province according to meteorological data (Measurement Period1941-2022) (Processing meteorological data) (General Directorate of Meteorology, 2023)



2.1.3. Architectural Features of Şehidiye Madrasah

Limestone served as the principal construction material for the Şehidiye Madrasah, situated on the street opposite the old Post Office building on 1st Avenue in the Şehidiye Quarter. The site plan and aerial photograph of the Şehidiye Madrasah can be seen in Figure 3, with the building located at street level below. The main portal inscription bears the name of Melik El Sadi, son of Melik Mansur Nasreddin Aslan. The origin of the building's construction, however, remains unknown. The building has undergone several interventions leading up to the present day. Consequently, few remnants of its original state have survived to date. The Şehidiye madrasah is believed to have derived its name from the presence of martyr graves during its construction (Biçen Çelik, 2021).

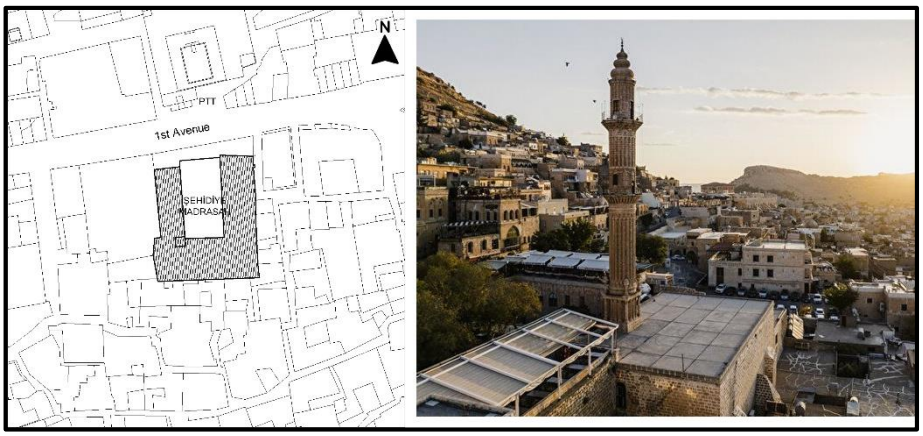


Figure 3. Şehidiye Madrasah Site Plan (İbrahim Duyan Archive)
and Aerial Photograph (URL-1)

Bulduk's work reports that the eastern side of the madrasah structure was demolished and reconstructed suitably, whilst the west side of the building stayed dilapidated for several years. On the east side of the building, both the lower and upper floors had cells where impoverished individuals were housed. The author states that an ablution room was located on the north side of the iwan. However, it was reported that this area was closed during road construction (Bulduk, 1999).

Oktay Aslanapa, who researched the Şehidiye Madrasah in the 1950s, and Aptulah Kuran, who studied the building in the 1960s, mentioned similar findings. Aslanapa mentioned that the building's northern iwan has a selsebil, while the western iwan is located in the middle of the cross-vaulted porticoes (Aslanapa, 2007). Kuran states that the madrasah is not a cohesive unit when seen

from the outside. He observed that the components of the building were scattered unevenly across the courtyard. (Kuran, 1969)

The main entrance to the building is accessed through the portal in the center. The courtyard can be reached by passing through a barrel-vaulted corridor. A perpendicular section intersects the corridor, containing opposing cells that have been used as places of education during the building's time as a madrasah. In the northern part of the courtyard section of the building, an iwan with a selsebil can be found. During the 1967 renovation, the iwan was partitioned into two, with the rear portion repurposed as a water tank. The western section of the courtyard was leased as a carpentry workshop and functioned as such (Altın, 1971). Today, this space serves as an ablution area and women's masjid while the southern side houses a mosque with dual naves. The building's upper level features additional cells (Figure 4).

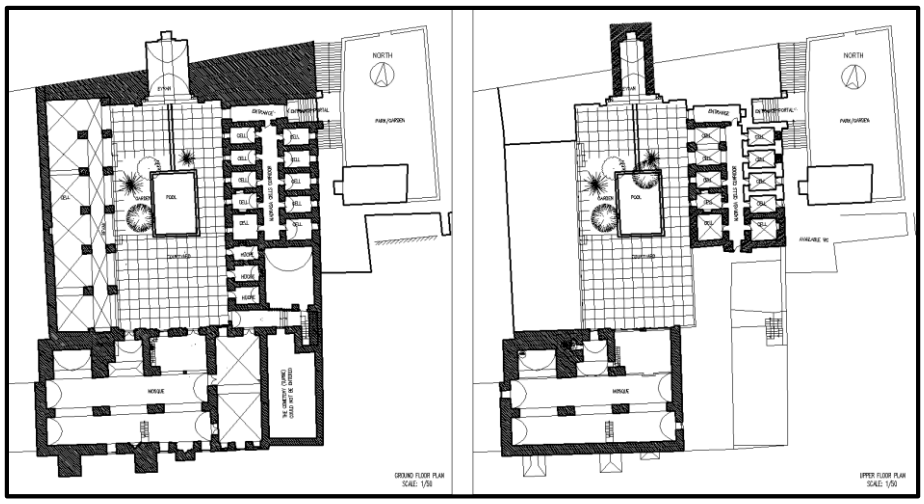


Figure 4. Şehidiye Madrasah Floor Plans (İbrahim Duyan Archive)

The structure comprises five facades, four of which face the courtyard with the remaining facade featuring the main portal. Currently, the madrasah is being used as a mosque (Zeka, 2020). The primary construction material used was regional limestone supplemented with cut stone and, in certain areas, kabayonu stone on the facades (Figure 5). Due to restoration work that occurred at different points in time, the building lacks stylistic coherence. The analyze suggests that the south buttresses of the mosque section, the western area housing the porticoes, and the iwan section were a result of interventions before the 17th century. The student quarter and the northern facade of the mosque received interventions during the 17th and 18th centuries respectively. The mosque's minaret was added and the western area with porticoes were constructed at the onset of the 20th

century. In 2004, during the repair work, the madrasah underwent renovation in which the iwan was refurbished, and a pool was installed (Çağlayan, 2017).

Figure 5. Facade photographs of Şehidiye Madrasah

3. Finding and Discussion

Identifying the factors responsible for the decay of stone materials in preserving historic landmarks is crucial (Karataş & Peyker, 2023). Stone materials deteriorate upon exposure to weather conditions, including pressure, temperature and wind (Dal, 2016). Such deterioration results in reduced durability and strength, making the stone susceptible to further decay or accelerating the process (Ergin, Çelik & Dal, 2020). Failure to implement necessary measures against decay and incorrect interventions lead to consequential harm and destruction in structures (Yardımlı, Hattap, Khooshroo & Javadi, 2017).

The decay of the Şehidiye Madrasah was addressed by categorizing it into physical, chemical, biological and anthropogenic factors (Öcal & Dal, 2012). Physical decay is defined as the loss of the surface of the stone due to mechanical impacts. Instances of damage to stones may take forms such as fractures, cracks, fragment breakage, deformation, abrasion, cuts, honeycombing, and joint discharges (Dal & Yardımlı, 2021).

Degradation of stones due to atmospheric events is referred to as chemical deterioration and is manifested through color change, salting, crystallization (blooming), crusting, blistering, sugaring, and foliation (Öcal & Dal, 2012; Ergin, Karahan & Dal, 2020).

Organic substances in stone cause biological deterioration, characterized by phenomena such as algae and plant formation or biological accumulation (Dal, Zülfikar & Dolar, 2020; Dolar & Yardımlı, 2017).

Anthropogenic deterioration refers to the damage caused to structures by human actions, both conscious and unconscious.

Examples of anthropogenic deterioration include improper application, misuse, and wear over time (Hattap, 2002).

The Şehidiye Madrasah's deterioration was evaluated through three distinct approaches in this study, namely visual examination, mapping-based examination, and XRF chemical analyze.

3.1. Visual Investigation of the Deterioration Occurring in Şehidiye Madrasah

The analyze of the deterioration of Şehidiye Madrasah due to external environmental and climatic factors was carried out in four groups: physical, chemical, biological and anthropogenic.

Based on the visual analyzes, Figure 6 illustrates the physical deterioration of the building. The structure displays several physical deterioration types such as capillary cracks, joint discharges, fragment rupture and surface abrasion.

Cracks in stones can result from weather conditions and petrographic properties. Additionally, vibrations arising from natural catastrophes like earthquakes, fires and frost may also lead to cracks on stone surfaces (ICOMOS, 2008). As a consequence of the weather in Mardin province, the structure experienced thermal shock, resulting in capillary cracks in the limestone which comprises the primary material of the structure (Figure 5a). The façade of the building exhibited joint failure (Figure 5b and Figure 5c) and fragmentation (Figure 5d and Figure 5e), likely due to surface abrasion caused by dust grains carried by the wind (Figure 5f) over an extended period.

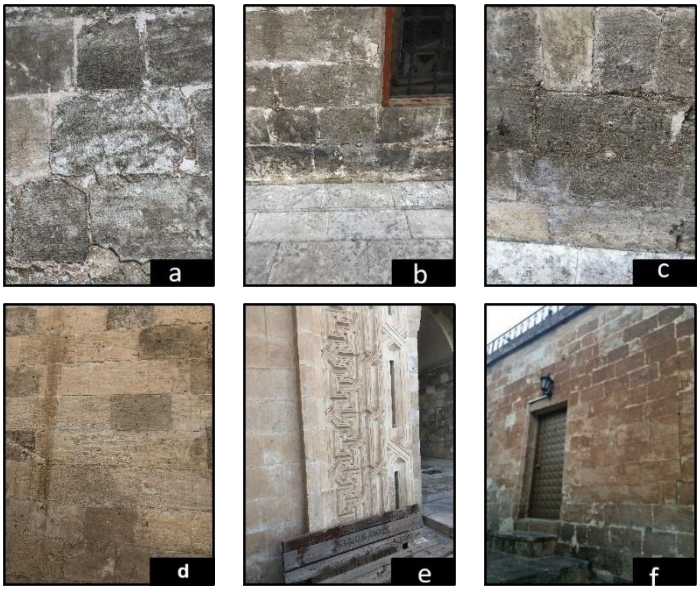


Figure 6. Physical deterioration of Şehidiye Madrasah

The limestone, which forms the primary material of Şehidiye Madrasah, has undergone significant chemical degradation over time due to both internal and external factors. Figure 7 demonstrates these deteriorations. Discoloration is noticeable on the primary access portal of the edifice (Figure 7a).

Changes in the stone surfaces can be attributed to the effects of salt, metal corrosion, microorganisms or fire exposure (ICOMOS, 2008). Discoloration is visible on the facade that faces the inner courtyard of the building which also houses the women's masjid (Figure 7b). The Şehidiye Madrasah reveals that limestone is salted as a result of interaction with air (Figure 7d and Figure 7e). Additionally, bacterial formations are observable on the limestone (Figure 7c and Figure 7f).

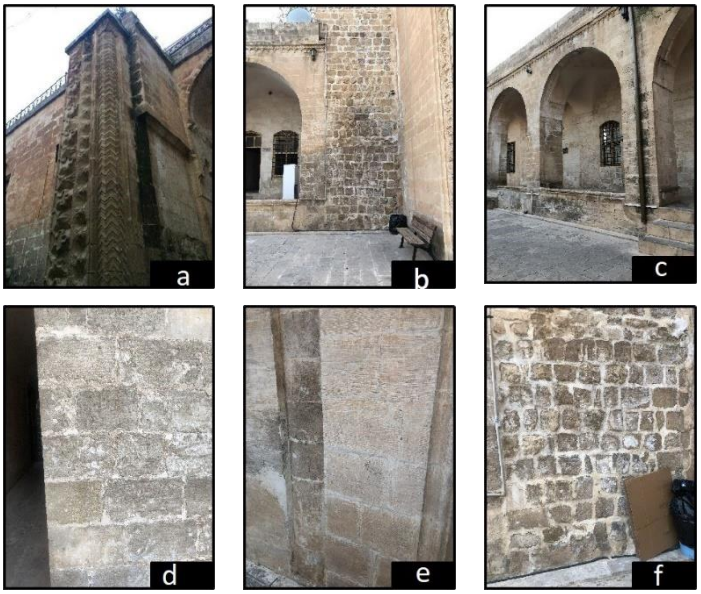


Figure 7. Chemical deterioration in Şehidiye Madrasah

Figure 8 illustrates the biological deterioration in Şehidiye Madrasah. Plant growth has been detected on the façade of the women's masjid (Figure 8a) and the façade of the selsebil (Figure 8b). The root systems of these plants can expand joints and cracks in the stonework, thereby accelerating physical degradation processes.

Furthermore, they may also increase the rate of chemical degradation by promoting salinization due to the persistent moisture in these areas. Moss was observed along the water fountain-facing façade, specifically in areas exposed to water (Figure 8c). Moss generally flourishes in stone crevices or gaps, and moist or wet stone surfaces accelerate its growth (ICOMOS, 2008). Buildings in contact with water often experience biological decay (Dal & Yardımlı, 2019).

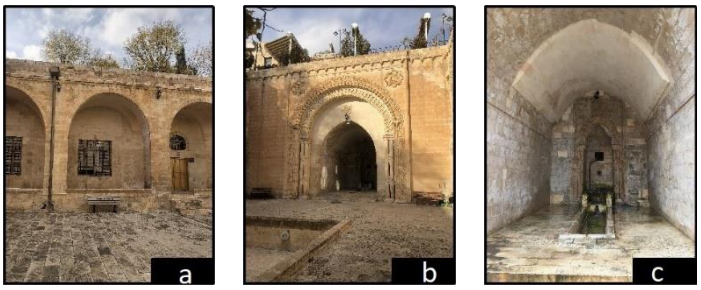


Figure 8. Biological deterioration in Şehidiye Madrasah

Figure 9 illustrates the impact of human activity on the deterioration of Şehidiye Madrasah. The north-facing interior façade of the building shows evidence of deterioration caused by sharp tools, as demonstrated in Figure 9a and Figure 9b.

Figure 9. Anthropogenic deterioration of the Şehidiye Madrasah

3.2. Investigation of the Deterioration of the Şehidiye Madrasah by Using the Mapping Method

The physical condition of the Şehidiye Madrasah is revealed in the mapping charts. The study conducted a detailed analyze of the building's eastern facade, south-facing, north-facing, and east-facing courtyard facades. After the selected facades were observed, they were photographed.

Table 3 demonstrates the physical deterioration that was observed. It was identified that the most prevalent type of physicomechanical decay in the madrasah was surface abrasion whilst fragment rupture was the least common. Joint discharge was found to occur at a greater frequency than capillary cracks.

Table 4 presents a discussion of the building's chemical decay. As depicted in the table, discoloration and salting were the most prevalent forms of chemical decay on the chosen facades of the structure. Bacterial formation was observed to a lesser extent.

Table 3. Physical deterioration of of Şehidiye Madrasah

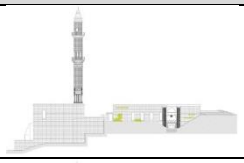
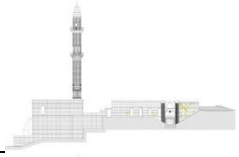
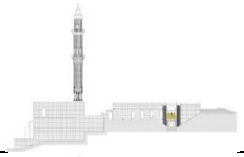
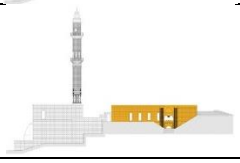
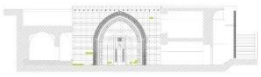
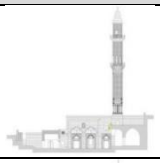
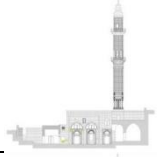
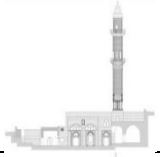
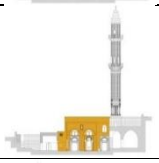
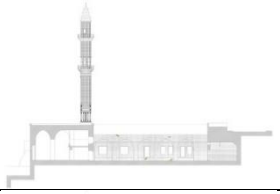
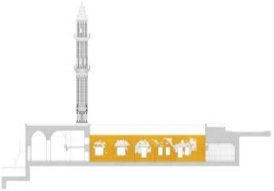
	Physical Deterioration Type	Facade Deterioration Ratio	Rate (%)
EAST FACADE	Joint Discharge		8
	Capillary Crack		6
	Fragment Breakage		5
	Surface Abrasion		93
SOUTH FACING COURTYARD FACADE	Joint Discharge		1.5
	Capillary Crack		2.3
	Fragment Breakage		0.8
	Surface Abrasion		21
NORTH FACING COURTYARD FACADE	Joint Discharge		1.2
	Capillary Crack		1.4
	Fragment Breakage		0.3
	Surface Abrasion		90
EAST FACING COURTYARD FACADE	Joint Discharge		10
	Capillary Crack		12
	Fragment Breakage		1
	Surface Abrasion		87

Table 4. Chemical deterioration of Şehidiye Madrasah

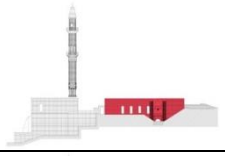
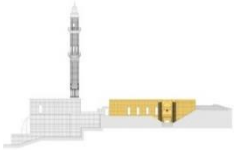
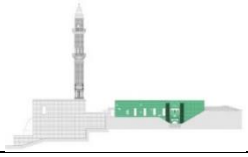
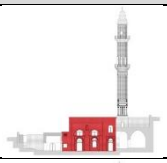
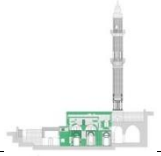
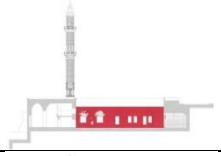
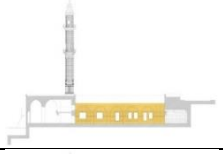
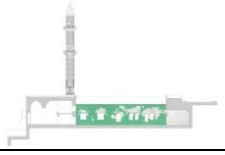
	Chemical Deterioration Type	Facade Deterioration Ratio	Rate (%)
EAST FACADE	Colour Variation		100
	Salitisation		100
	Bacteria Formation		98
SOUTH FACING COURTYARD FACADE	Colour Variation		88
	Salitisation		100
	Bacteria Formation		42
NORTH FACING COURTYARD FACADE	Colour Variation		100
	Salitisation		100
	Bacteria Formation		43
EAST FACING COURTYARD FACADE	Colour Variation		94
	Salitisation		100
	Bacteria Formation		82

Table 5 displays the biological decay that transpired in Şehidiye Madrasah. Upon scrutinizing the biological decomposition within the madrasah, moss and plant growth were visible on the facade by the selsebil. On the facade by the entrance of the madrasah, plant growth was identified in only two places.

Table 6 portrays the degeneration of Şehidiye Madrasah caused by human activity. Sharp instruments were only detected on the interior facade of the building facing north.

Table 5. Biological deterioration of Şehidiye Madrasah

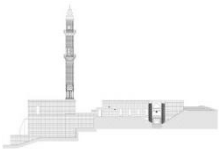
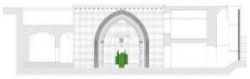
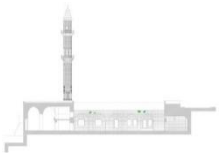
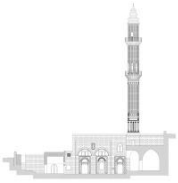
	Biological Deterioration Type	Facade Deterioration Ratio	Rate (%)
EAST FACADE	Plant Formation		0.2
SOUTH FACING COURTYARD FACADE	Plant Formation		0.1
	Moss Formation		1.3
EAST FACING COURTYARD FACADE	Plant Formation		0.4

Table 6. Anthropogenic deterioration of the Şehidiye Madrasah

	Antropogenic Deterioration Type	Facade Deterioration Ratio	Rate (%)
NORTH FACING COURTYARD FACADE	Sharp Instrument Use		0.1

3.2. Investigation of the Deterioration of the Şehidiye Madrasah Using XRF Chemical Analyze Method

All forms of damage that happened in the Şehidiye Madrasa were examined using codes determined by X-Ray Fluorescence Spectroscopy (XRF chemical analyze method). The codes found (Table 7), along with depictions of the chosen stones on the blueprint (Figure 10) and on the front (Figure 11), are provided below. The primary aim of examining the stone structure of historic buildings is to identify the physical and chemical elements present in the stone material and respond accordingly (Karataş, Alptekin & Yakar, 2022).

Table 7. Stones selected for the use of XRF chemical method for the deterioration of the Şehidiye Madrasah

STONE CODE	TYPE OF DETERIORATION	
C0	Clean Stone	
C1a	Abrasion	Physical Deterioration
C1b	Capillary Crack	
C1c	Joint Discharge	
C2a	Colour Variation	Chemical Deterioration
C2b	Salitisation	
C2c	Bacteria Formation	
C3a	Microorganism Formation	Biological Deterioration
C3b	Moss Formation	
C4a	Sharp Instrument Use	Anthropogenic Deterioration

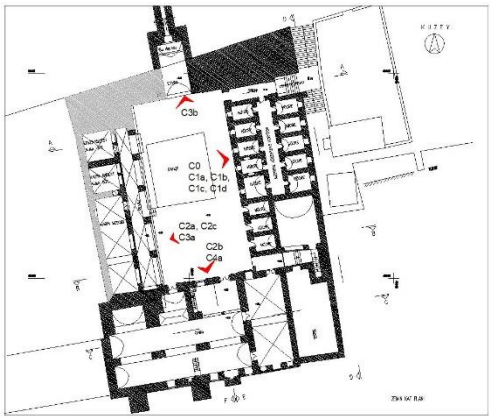


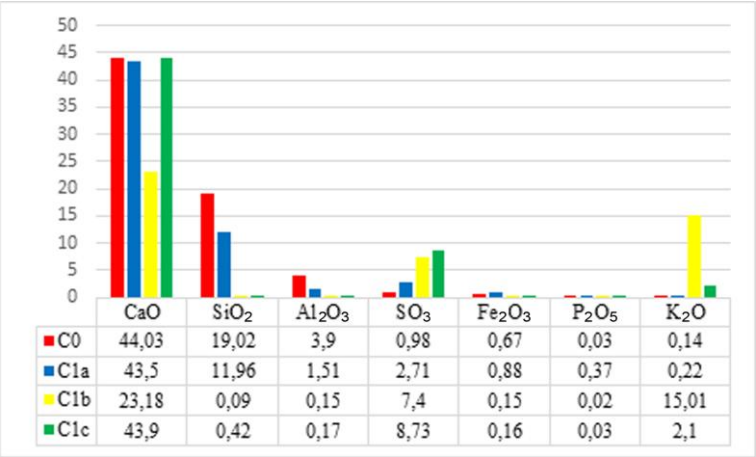
Figure 10. The plan representation of the stones selected for the use of XRF chemical method for the deterioration of Şehidiye Madrasah

Figure 11. Demonstration of the stones selected for the use of XRF chemical method for the deterioration of Şehidiye Madrasah on the façade

Table 8 presents the findings from the XRF analyze on the physical decay detected in Şehidiye Madrasah. Results reveal that the SiO_2 ratio was 19.02% in C0 stone, while C1b stone presents a mere 0.09% of this element. Thus, the C1b stone exhibits lower strength than C0. In addition, while the SO_3 ratio was 0.98 in the C0 stone, it reached 8.73% in the C1c stone, and an increase in SO_3 was also observed in other stones. There were no significant differences in the values of other components. Physical deterioration is evident on the stone surfaces due to variations in the stone material components and temperature differences (Karataş, Alptekin & Yakar, 2023).

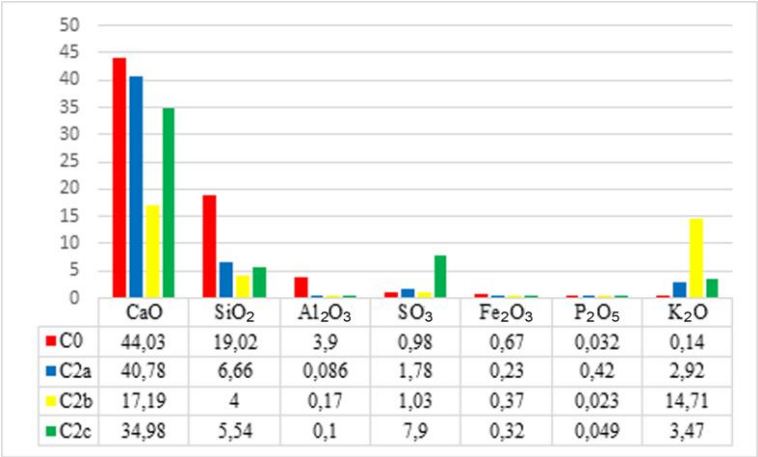
Table 9 presents the results of XRF chemical analyzes of chemical deterioration in Şehidiye Madrasah. The obtained results indicate an increase in SO_3 in all of the stones due to city air pollution. The rise of the SO_3 ratio in C2c stone is noteworthy. In the C0 stone, the SiO_2 ratio was at 19.02%, whereas in other chosen stones, it declined. For instance, the SiO_2 ratio in C2b stone was only 4%.

Table 8. XRF chemical analyze results of physical deterioration observed on the facades of Şehidiye Madrasah



	CaO	SiO_2	Al_2O_3	SO_3	Fe_2O_3	P_2O_5	K_2O
C0	44,03	19,02	3,9	0,98	0,67	0,03	0,14
C1a	43,5	11,96	1,51	2,71	0,88	0,37	0,22
C1b	23,18	0,09	0,15	7,4	0,15	0,02	15,01
C1c	43,9	0,42	0,17	8,73	0,16	0,03	2,1

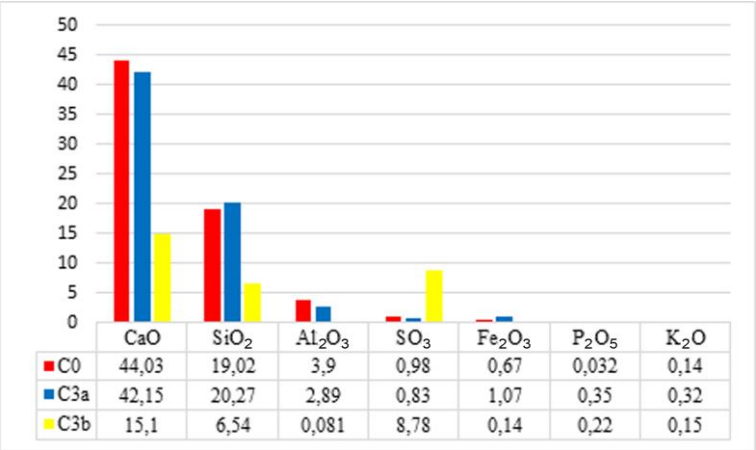
Table 9. XRF chemical analyze results of chemical deterioration observed on the facades of Şehidiye Madrasah



	CaO	SiO_2	Al_2O_3	SO_3	Fe_2O_3	P_2O_5	K_2O
C0	44,03	19,02	3,9	0,98	0,67	0,032	0,14
C2a	40,78	6,66	0,086	1,78	0,23	0,42	2,92
C2b	17,19	4	0,17	1,03	0,37	0,023	14,71
C2c	34,98	5,54	0,1	7,9	0,32	0,049	3,47

Table 10 presents the findings of the analyze concerning the biodeterioration that occurred at Şehidiye Madrasah. The results of the analyze indicate that the value of the SiO_2 component in C0 stone is 19.02%, while it is 20.27% in C3a stone. Clay minerals were hardened and silicified as a result of atmospheric weather conditions' interaction. This process led to the creation of a protective layer on the surface of the stone. Furthermore, C3b stone has the highest SO_3 value attributable to air pollution.

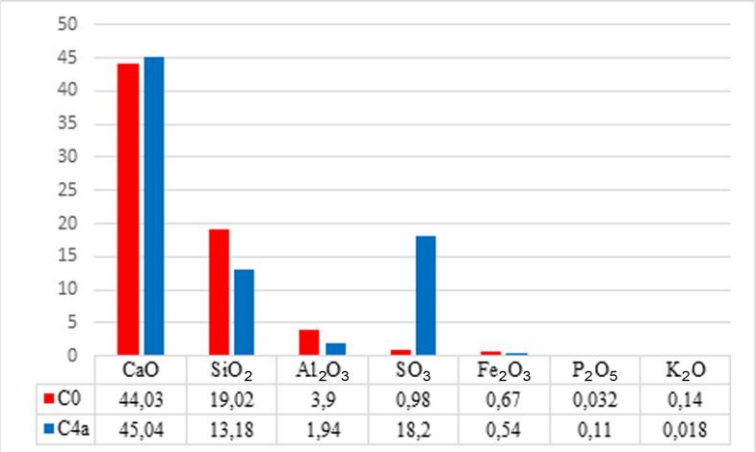
Table 10. XRF chemical analyze results of biological deterioration observed on the facades of Şehidiye Madrasah



	CaO	SiO_2	Al_2O_3	SO_3	Fe_2O_3	P_2O_5	K_2O
C0	44,03	19,02	3,9	0,98	0,67	0,032	0,14
C3a	42,15	20,27	2,89	0,83	1,07	0,35	0,32
C3b	15,1	6,54	0,081	8,78	0,14	0,22	0,15

The findings from the XRF chemical analyze method on the anthropogenic deterioration in Şehidiye Madrasah are presented in Table 11. Upon comparison of the selected stone with the clean stone, a significant increase in SO_3 stone was observed, indicating air pollution as the cause. The SiO_2 ratio in C0 stone was found to be 19.02%, while C4a stone exhibited a rate of 13.18%.

Table 11. XRF chemical analyze results of anthropogenic deterioration observed on the facades of Şehidiye Madrasah



	CaO	SiO_2	Al_2O_3	SO_3	Fe_2O_3	P_2O_5	K_2O
C0	44,03	19,02	3,9	0,98	0,67	0,032	0,14
C4a	45,04	13,18	1,94	18,2	0,54	0,11	0,018

4. Conclusion and Suggestions

Stone, an essential building material, is used for various purposes, functions, and shapes in every aspect of our lives. It serves as the primary construction material for historical structures in Mardin. The petrographic properties of limestone make it prone to deterioration from external

environmental and climatic factors, causing damage to the stone surface. This study analyzes the deterioration of the Şehidiye Madrasah stone. The structure's deterioration was analyzed using visual, mapping and XRF analyze methods.

The results showed that chemical deterioration occurred at a higher rate compared to anthropogenic deterioration. Four types of physical deterioration were identified, namely capillary cracks, abrasion, joint discharge and fragment rupture. Surface abrasion was found to be the most prevalent form of physical deterioration, while fragment rupture was the least. Chemical deterioration was identified by discoloration and salination, while biological deterioration was seen through plant formation and moss growth. Anthropogenic deterioration, which is characterized as intentional or unintentional damage to the structure by humans, was evident due to the use of sharp tools on the structure.

Upon analyzing each facade, it was observed that all facades showed signs of physical deterioration including capillary cracks, abrasions, joint failure and fragment breakage. Moreover, chemical deterioration like discoloration, salinization and bacterial growth were also noted on all facades. Due to the altitude of 1083 meters and the prevailing climatic conditions, the eastern façade of the building and the inner courtyard facades facing north, south and east were subject to surface abrasion, color changes in stones, and salinization deterioration. Regarding biological deterioration, plant growth was observed on the east façade, the south-facing inner courtyard façade, and the east-facing inner courtyard façade, while moss growth was detected on the south-facing inner courtyard façade. Furthermore, Table 12 reveals the identification of the use of cutting tools, one of the types of anthropogenic deterioration, on the façade of the east-facing inner courtyard.

The research named "Investigation into the Decay of Stone on the Facades of Hatuniye Madrasah" by Biçen et al. (2023) explored comparable techniques to inspect stone decay in Hatuniye Madrasah, a different building of the same kind in Mardin. The research employed a visual display, mapping and XRF chemical analyze method. During the research, the Hatuniye Madrasah facades on the east, south, south-facing courtyard and west-facing courtyards showed signs of surface abrasion, discoloration, salinization and bacterial growth. The two madrasahs share the same region, climate and altitude, leading to comparable findings.

In their study titled "Stone material decay patterns of historical buildings in Southeastern Anatolia," Karataş et al. (2023b) have discovered similar results. The Mardin İzzetpaşa Old Prison

has been examined for the decay of its building elements and materials. After classification and analyze of the deterioration, the study focused on the degradation of the facade base.

Table 12. Deterioration on the facades of Şehidiye Madrasah

Şehidiye Madrasah	**Physical Deteriorations**				**Chemical Deteriorations**			**Biological Deteriorations**		**Anthropogenic Deteriorations**	
	Abrasion	Capillary Crack	Joint Emptying	Fragment Breakage	Colour Variation	Salitisation	Bacteria Formation	Plant Formation	Moss Formation	Sharp Instrument Use	Paint Usage
East Facade	+	+	+	+	+	+	+	+	-	-	-
South Facıng Courtyard Facade	+	+	+	+	+	+	+	+	+	-	-
North Facıng Courtyard Facade	+	+	+	+	+	+	+	-	-	-	-
East Facıng Courtyard Facade	+	+	+	+	+	+	+	+	-	+	-

Chemical changes in selected stones were analyzed through X-Ray fluorescence (XRF) analyzes conducted in the Şehidiye Madrasah. The findings reveal substantial variations in the CaO, SiO_2, and SO_3 ratios in the stones, while no significant changes were detected in other components. The CaO ratio in C0 stone is 44.03%, whereas it is 45.04% in C4a stone. Additionally, the SiO_2 ratio in C0 stone is 19.02%; however, it decreased to 0.09% in C1b stone. Moreover, the SO_3 ratio in C0 stone is 0.98%, whereas it increased to 8.78% in C3c stone, as reported in Table 13.

Table 13. XRF chemical analyze results of the deterioration observed on the facades of Şehidiye Madrasah

Component	**C0**	**C1a**	**C1b**	**C1c**	**C2a**	**C2b**	**C2c**	**C3a**	**C3c**	**C4a**
CaO	44.03	43.5	23.18	43.9	40.78	17.19	34.98	42.15	15.1	45.04
SiO_2	19.02	11.96	0.09	0.42	6.66	4	5.54	20.27	6.54	13.18
Al_2O_3	3.9	1.51	0.15	0.17	0.086	0.17	0.1	2.89	0.081	1.94
SO_3	0.98	2.71	7.4	8.73	1.78	1.03	7.9	0.83	8.78	18.2
Fe_2O_3	0.67	0.88	0.15	0.16	0.23	0.37	0.32	1.07	0.14	0.54
P_2O_5	0.03	0.37	0.02	0.03	0.42	0.023	0.049	0.35	0.22	0.11

Based on the analyze results, it was found that physical and chemical deterioration were the most commonly observed types of deterioration in all facades that were examined in Şehidiye Madrasah. Physical deterioration included capillary cracks, abrasion, joint discharge, and fragment

rupture, while chemical deterioration included discoloration, salting, and bacterial formation, and all these were observed in the examined facades. Upon analyzing the XRF results, a correlation was established between clay ratio and deterioration. It was observed that as the clay ratio increased, the deterioration also increased. Additionally, an inverse relationship was found between silica ratio and deterioration.

The longevity of structures can be ensured by detecting physical, chemical, biological, and anthropogenic degradation resulting from climatic conditions and human impact, and taking appropriate precautions. It is crucial to inform individuals about the usage of sharp tools, which are a primary cause of anthropogenic degradation in buildings, and to raise awareness about historic buildings with cultural significance. Efforts ought to be made to reduce the physical and chemical decay instigated by climatic elements on the outer walls and those overlooking the inner courtyard. The episode of plant and moss formation seen in the edifice, specifically in places where water is present, should be supervised, and the interaction of stone surfaces with water ought to be lessened.

The study's data and analyzes should inform plans for upcoming building conservation projects to effectively address structural deterioration. Early intervention is vital for prolonging the building's lifespan. It is crucial to precisely detect and assess the decay and devise enhancement methods to pass on the buildings to future generations.

Contribution of Authors

1st author 40%, 2nd author 20%, 3rd author 20% and 4th author 20% contributed.

Conflict of Interest Statement

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

This article is derived from the Master's thesis titled "Mardin İlindeki Medrese Yapılarının Cephelerinde Oluşan Taş Bozunmalarının İncelenmesi ve XRF Spektrometresi İle Analizi" completed at Dicle University, Institute of Science and Technology, Department of Architecture. The article complies with national and international research and publication ethics. Ethics committee permission was not required for the study.

The study complied with research and publication ethics.

References

Bulduk, A. F. (1999). *Mardin Tarihi* (Burhan Zengin, trans.), Ankara: GAP Publications.

Alioğlu, F. E. (1989). *Mardin Şehir Dokusu ve Evler Üzerine Bir Deneme.* (PhD thesis). Istanbul Technical University Institute of Science and Technology, İstanbul.

Alioğlu, F. E. (2000). *Mardin Şehir Dokusu ve Evler.* İstanbul: Tarih Vakfı Publications.

Aliveya, M.A. (2007). *Makalelerle Mardin I. Tarih-Coğrafya: Mardin ve Çevresini İçine Alan Türk Devletleri Tarihi.* İstanbul: Mardin Governorship.

Altun, A. (1971). *Mardin'de Türk Devri Mimarisi*. İstanbul: Gün Press.

Aslanapa, O. (2007). *Anadolu'da İlk Türk Mimarisi Başlangıç ve Gelişmesi.* Ankara: Atatürk Culture Center.

Aydın, S., Emiroğlu, K., Özel, O. & Ünsal, S. (2000). *Mardin Aşiret-Cemaat-Devlet.* İstanbul: Tarih Vakfı Publications.

Bekleyen, A., Dalkılıç, N. & Özen, N. (2014). Geleneksel Mardin Evi'nin Mekânsal ve Isısal Konfor Özellikleri. *Türk Bilim ve Araştırma Vakfı*, 7(4): 28-44.

Biçen Çelik, A. (2021). *Mardin İlindeki Medrese Yapılarının Cephelerinde Oluşan Taş Bozunmalarının İncelenmesi ve XRF Spektrometresi İle Analizi* (Master's thesis), Dicle University Institute of Science and Technology, Diyarbakır.

Biçen Çelik, A., Ergin, Ş. , Dal, M. & Ay, İ. (2023). Analysis of Stone Deterioration on the Facades of Hatuniye Madrasah. *Journal of Architectural Sciences and Applications*, 8 (1), 355-369.

Çağlayan, M. (2017). *Mardin Anıtsal Yapılarında Değişmişlik ve Özgünlük Sorunları.* (PhD thesis). Istanbul Technical University Institute of Science and Technology, İstanbul.

Çağlayan, M. (2018). Bir Mimari Karşılaştırma: Mardin Zinciriye ve Kasımiye Medreseleri. Karacoşkun, M. D. & Köse, O. (Ed.). *İlk Çağlardan Modern Döneme Tarihten İzler II.* (s.147-165).. Ankara: Berikan Publications.

Dal, M. & Öcal, A. D. (2013a). Limestone Used in Islamic Religious Architecture From Istanbul and Turkish-Thrace. *METU Journal of the Faculty of Architecture.* 30 (1): 29-44.

Dal, M. & Öcal, A. D. (2013b). Investigations on Stone Weathering of Ottoman Architecture: A Kirklareli Hizirbey Kulliye Case Study, *PARIPEX – Indian Journal of Research*, 2 (11): 1-7.

Dal, M. (2016, December). Decays Occurring in The Structure of Adobe Materials. *Proceedings for the 5. International Conference Kerpiç'16* (p. 71-80). İstanbul: Istanbul Aydın Universty.

Dal, M. & Öcal, A. D. (2017). Mardin Şehrindeki Taştan Yapılmış Eserlerde Görülen Bozunmalar, *Balıkesir Üniversitesi Fen Bilimleri Enstitüsü Dergisi,* 19(1): 60-74.

Dal, M. & Yardımlı, S. (2019, 23-25.08). Karadeniz Bölgesindeki Yağışların Yapılara Etkisi, *UBAK Uluslararası Bilimler Akademisi Karadeniz 2. Uluslararası Uygulamalı Bilimler Kongresi* (s. 347-352). Rize: UBAK Publications.

Dal, M. & Yardımlı, S. (2021). Taş Duvarlarda Yüzey Bozunmaları. *Kent Akademisi*, *14*(2), 428-451.

Dal, M., Zülfikar, H. C. & Dolar A. (2020). *Mimari Taş Yapılarda Görülen Biyolojik Bozunmalar.* Geleneksel ve Çağdaş Mimari Yapılar Üzerine Akademik Çalışmalar. Chapter 2 (s.29-62). Ankara: İksad Publishing House.

Demir, H. (2019). Anadolu Selçuklu Dönemi Külliye Düzenlemesinde Cami ve Medrese'de Ortak Avlu Kullanımı. *Hacettepe Üniversitesi Türkiyat Araştırmaları (HÜTAD)*, (30), 143-166.

Dowrolowski, J. (2001). *The Living Stones of Cairo.* Cairo: American University in Cairo Press.

Doehne, E. & Price, C. A. (2010). *Stone Conservation an Overview of Current Research.* Los Angeles: Getty Conservation Institute, Getty Publications.

Dolar A. & Yardımlı S. (2017). *Tarihi Yapı Taşlarındaki Alg ve Bakteri Alterasyonları*. TMMOB İnşaat Mühendisleri Odası Uluslararası Katılımlı 6. Tarihi Yapıların Korunması ve Güçlendirilmesi Sempozyumu (s. 143-152), Trabzon: TMMOB Chamber of Civil Engineers.

Ergin, Ş., Çelik, A.B. & Dal, M., (2020, January). *Şeyh Çabuk Camiisinde Meydana Gelen Taş Bozunma Sorunlarının İrdelenmesi.* 3. Uluslararası Mardin Artuklu Bilimsel Araştırmalar Kongresi (s. 113-114). Türkiye: Farabi Publications.

Ergin, Ş., Gökdemir, B., Yardımlı, S. & Dal, M. (2022). Deterioration on the Stone Surfaces of the Diyarbakır Nebi Mosque. *Uluslararası Hakemli Tasarım Ve Mimarlık Dergisi*, 27(Autumn Term), 1-32.

Ergin, Ş., Karahan, B. & Dal, M. (2020). Sultan Hamza-i Kebir Camii'nde Görülen Taş Bozunmaları. *Kent Akademisi*, 14(2), 414-427.

General Directorate of Meteorology. (2023). Mardin Province Meteorological Statistics and Analyzes. Access Address (01.06.2023): https://mgm.gov.tr/veridegerlendirme/il-ve-ilceler-istatistik.aspx?k=A&m=MARDIN.

Hattap, S. E. (2002). *Doğal Taş Malzeme Koruyucuların Performans Ölçümünde Deneysel Metot Araştırması* (PhD thesis). Mimar Sinan Fine Arts University Department of Building Physics and Materials, İstanbul.

ICOMOS (2008). Illustrateed Glossary on Stone Deterioration Patterns. Page:86. ISBN: 978-2-918086-00-0. France.

Karakök, T. (2013). Yükseköğretim Kurumu Olarak Osmanlı'da Medreseler: Bir Değerlendirme. *Bartın University Journal of Faculty of Education* 2(2), 208-234.

Karkaş, Z. S. & Acun Özgünler, S. (2022). Koruma Kararlarını Etkileyen Parametrelerin Belirlenmesine Yönelik Bir Anket Çalışması. *Journal of Architectural Sciences and Applications*, 7 (1) , 364-382.

Karataş, L. (2018). *Mardin Kenti İbadet Yapılarında Malzeme Kullanımı ve Sorunları Üzerine Bir Araştırma.* (Master's Thesis). Uludağ University Institute of Science and Technology, Bursa.

Karataş, L., Alptekin, A. & Yakar, M. (2022). Detection of Materials and Material Deterioration in Historical Buildings by Spectroscopic And Petrographic Methods: The Example Of Mardin Tamir Evi. *Engineering Applications*, 1(2), 170-187.

Karataş, L., Alptekin, A., & Yakar, M. (2023). Material Analysis for Restoration Application: A Case Study of the World's First University Mor Yakup Church İn Nusaybin, Mardin. *Heritage Science, 11*(1), 1-17.

Karataş, L., Ateş, T., Alptekin, A. & Yakar, M. (2023b). Stone Materials Decay Patterns of Historical Buildings in The Southeastern Anatolia Climate: A Case Study of Mardin History İzzetpaşa Old Prison. *Advanced Engineering Science*, 3: 37-45.

Karataş, L. & Perker, Z.S. (2023*). An Observational Research for the Determination of Stone Material Problems in Mardin Kasımiye Madrasa.* Architectural Sciences and Theory, Practice and New Approaches-I. *2023*, Chapter:8, 199-228. Iksad Publications.

Kuran, A. (1969). *Anadolu Medreseleri.* Ankara: METU Publications.

Noyan, S. (2008). *Bir Şehir Bir Malikâne Sıra Dışı Evler Mardin.* Ankara: Bizim Büro Publications.

Semerci, F. (2017). Mardin Kireçtaşının Yapı Malzemesi Olarak Kullanımına Yönelik Analizlerinin Yapılması: Şehidiye Medresesi Örneği. *Journal Architectural Sciences and Applications*, (2)2, 60-79.

Öcal, A.D. (2010). *Kayaçtan Yapılmış Eski Eser Koruma Çalışmalarına Arkeometrik Bir Yaklaşım: Ayrışma Durumu Haritası. Türkiye Ve Kolombiya'daki Anıt Eserlerin Bozunma Analizi.* (Master's thesis), Çukurova University, Institute of Science and Technology, Department of Archaeometry, Adana.

Öcal, A. D. & Dal, M. (2012). *Doğal Taşlardaki Bozunmalar.* Istanbul: Architecture Foundation Economic Enterprise.

Tayla, H. (2007). *Geleneksel Türk Mimarisinde Yapı Sistem ve Elemanları*. İstanbul: Taç Vakfı Publications.

Umaroğulları, G. & Kartal, S. (2021). A Model Proposal on Results of Physical And Mechanical Properties of Trakia Region Küfeki Stone Used at Early Period Ottoman Buildings. *Journal of Architectural Sciences and Applications*, 6 (2), 384-395

Uyar, S. (2019). *Mardin'in Kutsal Mekân ve Ritüelleri* (Undergraduate Graduation Thesis). Artuklu University Faculty of Literature, Mardin.

Yardımlı, S. (2018). *Madrasas As Educational Buildings in Van.* Cultural Landscape of Van-Turkey. Chapter 6. (76-92). Istanbul: Aydın University Publications.

Yardımlı S., Hattap S. O., Khooshroo S. & Javadi N. (2017, December). İstanbul Süleymaniye Camii Taş Yüzeylerinde Tespit Edilen Bozunmalar. *Türkiye 9. Uluslararası Mermer ve Doğaltaş Kongresi.* Antalya: Önka Publications.

Yıldız, S. (2007). *Makalelerle Mardin II Ekonomi-Nüfus-Kentsel Yapı: Mardin Şehir Dokusu ve Mimari Yapı.* İstanbul: Mardin Goverment.

Yousif, E. İ. (2011). *Mezopotamya'nın Yıldız Şehirleri Mezopotamya'nın Yıldız Şehirleri Urfa, Nusaybin, Diyarbekir, Mardin, Erbil, Kerkük, Süleymaniye, Duhok.* İstanbul: Avesta Publications.

Zeka, S. (2020). Mardin'i Romandan Tanımak: Abbara/Bir Umudun Masalı. *Karamanoğlu Mehmetbey Üniversitesi Edebiyat Fakültesi Dergisi*, 3(1), 11-24.

URL-1: https://www.aydinlik.com.tr/fotogaleri/mardin-birbirinden-guzel-goruntulere-sahne-oldu-mardin-drone-goruntusu-guneydogu-anadolu-bolgesi-olmeden-once-gorulecek-10-sehir-351091 (Date of access: 05-10-2023).