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Weathering and Degradation Risk Assessment of Nubian Sandstone Roofs of Buildings in Medinat Habu

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Abstract

The Temple of Medinat Habu, a vivid record of Pharaonic military life, stands as a crucial heritage site that urgently requires protection from environmental factors and climate changes. This study meticulously focuses on assessing the deterioration of the Nubian sandstone that forms the roofs of Medinat Habu's buildings. By identifying and discussing the contributing factors, the study aims to develop sustainable preservation strategies. Utilizing an analytical approach, the study examines the physical erosion and environmental changes through advanced techniques such as fluorescence and X-ray diffraction. The comprehensive analysis reveals critical deterioration mechanisms, notably rain-induced erosion and the infiltration of clay minerals during rainfall, which significantly compromise the structural integrity of the temple roofs. The findings underscore the pressing need to create innovative environmental materials endowed with self-cleaning and water-repellent properties to effectively protect these heritage structures. Such materials are deemed essential to mitigate further damage and ensure the longevity of these invaluable monuments. Ultimately, preserving the Temple of Medinat Habu necessitates a profound understanding of the intricate details of its construction materials and their interactions with environmental factors. By implementing advanced protective measures, we can safeguard this historically significant site, maintaining its legacy and ensuring that future generations can appreciate a tangible connection to our Pharaonic past. This research not only highlights the importance of heritage preservation but also paves the way for developing cutting-edge conservation techniques tailored to the unique challenges posed by historical structures.

Keywords

Medinat Habu; Weathering; degradation; risk assessment; Nubian sandstone.

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تقييم مخاطر التجوية والتدهور للحجر الرملي النوبي بأسطح مباني مدينة هابو

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الملخص

يعد معبد مدينة هابو، الذي يمثل سجلاً حياً للحياة العسكرية الفرعونية، موقعاً تراثياً بالغ الأهمية ويتطلب حمايته بشكل عاجل من العوامل البيئية وتغيرات المناخ. وتركز هذه الدراسة بدقة على تقييم تدهور الحجر الرملي النوبي الذي يشكل أسطح مباني مدينة هابو. ومن خلال تحديد العوامل المساهمة ومناقشتها، تهدف الدراسة إلى تطوير استراتيجيات الحفاظ المستدامة. وباستخدام نهج تحليلي، تدرس الدراسة التآكل المادي والتغيرات البيئية من خلال تقنيات متقدمة مثل الفلورسنت والحيود بالأشعة السينية. ويكشف التحليل الشامل عن آليات التدهور الحرجة، ولا سيما التآكل الناجم عن الأمطار وتسلل المعادن الطينية أثناء هطول الأمطار، مما يعرض سلامة أسطح المعبد للخطر بشكل كبير. وتؤكد النتائج على الحاجة الملحة إلى إنشاء مواد بيئية مبتكرة تتمتع بخصائص التنظيف الذاتي ومقاومة الماء لحماية هذه الهياكل التراثية بشكل فعال. وتعتبر مثل هذه المواد ضرورية للتخفيف من المزيد من الضرر وضمان طول عمر هذه الآثار الثمينة. في نهاية المطاف، يتطلب الحفاظ على معبد مدينة هابو فهمًا عميقًا للتفاصيل المعقدة لمواد البناء وتفاعلاتها مع العوامل البيئية. ومن خلال تنفيذ تدابير حماية متقدمة، يمكننا حماية هذا الموقع المهم تاريخيًا، والحفاظ على إرثه وضمان قدرة الأجيال القادمة على تقدير الارتباط الملموس بماضينا الفرعوني. لا يسلط هذا البحث الضوء على أهمية الحفاظ على التراث فحسب، بل يمهد الطريق أيضًا لتطوير تقنيات الحفظ المتطورة المصممة خصيصًا للتحديات الفريدة التي تفرضها الهياكل التاريخية.

الكلمات الدالة

مدينة هابو؛ تجوية؛ تحلل؛ تقييم المخاطر؛ الحجر الرملي النوبي.

Introduction

Medinat Habu is one of the most fortunate monuments in preserving its prevailing features. Known for its detailed inscriptions that commemorate the protection of Egypt's northern borders, Medinat Habu holds immense historical significance. The city, constructed by Ramses III, spans approximately 2,000 square feet, and remains a testament to ancient Egyptian architecture and artistry. As one of the key archaeological sites on the West Bank of Luxor, it falls under the protective recommendations of UNESCO. UNESCO emphasizes the importance of preserving cultural heritage and landscapes, particularly in light of various environmental threats. According to UNESCO, sudden environmental or geological events, extreme weather phenomena, climate change, and pollution pose significant risks to cultural heritage sites like Medinat Habu. The temple's survival amidst these challenges underscores the necessity for ongoing monitoring and preservation efforts. Protecting such a vital piece of history involves not only maintaining its physical structure but also ensuring that its cultural and historical narratives continue to be understood and valued by future generations. The dedication to safeguarding Medinat Habu reflects a broader commitment to preserving the world’s cultural treasures, recognizing their importance in connecting us to our past and enriching our shared human experience. By addressing the environmental challenges that threaten these sites, we can better protect and celebrate the legacies of ancient civilizations (1), (2).

Environmental risks resulting from the expansion of urban and agricultural areas around Medinat Habu have been extensively studied, revealing significant degradation processes linked to groundwater activity. The rapid urban sprawl and agricultural development in the region have led to increased groundwater levels, which in turn have caused substantial damage to the ancient structures. The rising groundwater, often exacerbated by seepage from drainage and sewage systems, has introduced harmful salts such as sodium chloride and sodium sulfate into the foundations of the temples. These salts contribute to the deterioration of the building materials, accelerating the weathering and erosion processes. Moreover, the lack of adequate wastewater management systems has allowed pollutants to infiltrate the groundwater, further compromising the structural integrity of the monuments. The study highlights the urgent need for comprehensive environmental monitoring and the implementation of effective mitigation strategies to preserve these invaluable heritage sites. By addressing the challenges posed by urban and agricultural expansion, we can better protect Medinat Habu and other cultural heritage sites from ongoing environmental threats. (3) The analysis or assessment of environmental risks in historical cities represents a crucial technical development for conservation and preventive maintenance strategies. This approach is particularly relevant for the Luxor archaeological area on the West Bank, where the environmental impact and the behavior of rock masses due to long-term geostatic pressures pose significant threats. Over time, these pressures can lead to the displacement and deformation of rock structures, compromising the stability and integrity of ancient monuments. In-depth environmental risk assessments involve monitoring geological conditions, groundwater levels, and the effects of urban expansion. These studies provide valuable data that inform the development of effective conservation strategies. For example, understanding how fluctuations in groundwater levels affect the foundations of historical structures can guide the implementation of drainage systems that mitigate water-related damage. Additionally, assessing the impact of urban and agricultural activities on the Luxor site helps in developing zoning regulations that limit harmful development near vulnerable areas. By integrating advanced technologies such as remote sensing, geophysical surveys, and digital modeling, conservationists can predict potential risks and implement preventative measures before significant damage occurs (4), (5).

A study on heritage buildings found that the analysis of the combined transport of moisture and heat has greatly expanded our understanding of the complex interaction between the environment and forms of deterioration. (6) According to the deterioration map, the main factors of stone surface deterioration arise from the interaction of geological, environmental, chemical, physical and biological factors. (7) One of the serious threats to the world's cultural heritage is the variability in the chemical and physical environment, so the importance of climate risk assessment strategy as a preventive measure has become clear, including the assessment of long-term climate risks associated with rainfall at the regional level. (8)

Changes in rainfall rates, driven by climate change, present significant threats to cultural heritage sites. Increased rainfall can have catastrophic impacts, leading to accelerated erosion, water infiltration, and structural damage. Indicators such as maximum annual rainfall and cumulative heavy rainfall are critical in assessing these risks. Rise in these rainfall metrics poses a severe threat, particularly to ancient structures that lack modern waterproofing technologies. This persistent water exposure can lead to the deterioration of construction materials, undermining their historical and architectural integrity. For instance, in stone buildings, rainwater can seep into the porous material, freeze, and expand, causing cracks and weakening the structure over time. Moreover, heavy and prolonged rainfall can exacerbate the growth of moss, algae, and fungi, which can further damage surfaces and compromise the aesthetic and structural integrity of cultural heritage sites. These biological factors can also lead to chemical reactions with the building materials, accelerating their decay. To tackle these challenges, many physicists and mathematicians have developed sophisticated methods to measure and predict these rainfall indicators. These methods include statistical modeling, remote sensing technologies, and climate simulations, which help in forecasting future changes and assessing potential impacts. By accurately measuring these indicators, conservationists can better plan and implement strategies to protect vulnerable sites. This could involve the development of advanced waterproofing materials, improving site drainage systems, and creating buffer zones to mitigate the effects of heavy rainfall. Overall, understanding and addressing the impact of changing rainfall patterns is essential for the preservation of our cultural heritage. It ensures that these invaluable sites can withstand the tests of time and climate, continuing to educate and inspire future generations. (9), (10).

Most climate studies have concentrated on extreme events, such as storms and floods, due to climate change. In Egypt, rainfall characteristics have shown significant variability. This variability was investigated through a detailed statistical analysis of historical rainfall records. Researchers applied both parametric (Pearson) and non-parametric (Mann-Kendall and Spearman) tests to annual and seasonal rainfall indices to examine temporal trends. These statistical methods helped identify patterns and changes in rainfall over time, providing valuable insights into how climate change is affecting precipitation in Egypt. The findings from these analyses are crucial for developing strategies to mitigate the impacts of extreme weather events on the region's infrastructure and agriculture. (11), (12), (13), (14), (15), (16)

The study aims to evaluate the deterioration of the surfaces of Medinat Habu Temple and study the factors causing it in order to plan sustainable environmental protection. To achieve the aim of the study, the following elements are evaluated (1) evaluation of the physical properties, (2) evaluation using modern techniques such as X-ray fluorescence and, X-ray diffraction.

Evaluation of physical and mechanical properties:

Figures 1 and 2 illustrate that the areas experiencing the most significant damage in the building stones are primarily the outer surfaces and the edges. These regions are directly impacted by various damaging factors, making them particularly vulnerable. The outer surfaces and edges of the stones have become weak, crumbled, and brittle to the extent that samples can be easily detached using just fingernails. The complexity of the damage is attributed to a multitude of environmental factors. The primary contributors include the intensity of sunlight, which causes thermal expansion and contraction, leading to cracks and surface degradation. Additionally, wind erosion continuously wears away the stone surfaces, exacerbating the crumbling effect. The erosion and subsequent accumulation of rainwater on the stone surfaces further accelerate the deterioration process. Rainwater, often slightly acidic, can dissolve certain minerals within the stone, leading to further weakening and breakdown. Moreover, the interaction between these environmental factors can create a synergistic effect, amplifying the rate of damage. For example, wind can carry abrasive particles that continuously scour the stone surface, removing material and exposing fresh surfaces to further erosion and chemical reactions. In summary, the damaged areas of the building stones are primarily the outer surfaces and edges, with the damage being driven by a complex interplay of environmental factors such as sunlight, wind, and rainwater erosion. These factors collectively contribute to the weakening, crumbling, and brittleness observed in the stones. (17), (18), (19).

Figure 1. shows deterioration of the edges of the building stones on the roofs of Madinat Habu

Figure 2a, b shows deterioration of Surface layer of stones on the roofs of Madinat Habu

Deterioration Forms:

A thorough assessment of the various forms of damage observed on the roofs of Habu Temple reveals a range of structural and aesthetic issues. These damages highlight the complex and multifaceted nature of the deterioration affecting the temple, which is attributed to rains and other environmental factors.

Types of Damage:

1. Erosion of Roof Surfaces:

- **Description**: The roof surfaces of Habu Temple show significant signs of erosion, primarily due to prolonged exposure to rainfall. The water flow over time has worn away the surface layers of the stone, leading to a loss of material and a rough, uneven texture.
- **Impact**: This erosion not only affects the aesthetic appearance but also compromises the integrity of the roof, making it more susceptible to further damage and leaks.

2. Water Infiltration and Staining:

- **Description**: Water infiltration has led to staining on the roof surfaces, with visible discoloration in various areas. The stains result from the absorption of rainwater, which carries minerals and other contaminants.
- **Impact**: These stains can weaken the stone over time and contribute to the growth of moss and algae, which further deteriorates the roof material.

3. Cracks and Fissures:

- **Description**: The temple roofs exhibit a series of cracks and fissures, some of which have developed due to thermal expansion and contraction caused by temperature fluctuations. Rainwater seeping into these cracks can cause them to expand, especially during freeze-thaw cycles.
- **Impact**: Cracks and fissures undermine the structural stability of the roof, allowing more water to penetrate and exacerbate the existing damage.

4. Algal and Moss Growth:

- **Description**: The damp environment created by frequent rains has led to the growth of algae and moss on the temple roofs. These biological organisms thrive in moist conditions and can spread rapidly across the surface.

- **Impact**: Algae and moss not only mar the visual appeal of the temple but also hold moisture against the stone, accelerating decay and promoting further biological growth.

5. Corrosion of Metal Fixtures:

- **Description**: Any metal fixtures or elements present on the temple roof, such as drainage systems or ornamental details, have experienced corrosion due to prolonged exposure to moisture.
- **Impact**: Corroded metal can lead to rust stains on the stone surfaces and may weaken the structural components, necessitating repair or replacement.

Underlying Environmental Factors:

1. Rainfall and Humidity:

- **Description**: The primary environmental factor contributing to the deterioration is the high level of rainfall and humidity. The constant wetting and drying cycles take a toll on the stone surfaces, causing them to expand and contract, which leads to cracking and erosion.
- **Impact**: Persistent humidity exacerbates the deterioration by fostering conditions conducive to biological growth and facilitating the absorption of water into the stone.

2. Temperature Fluctuations:

- **Description**: Temperature changes between day and night, and across seasons, cause thermal stress on the stone material. This cyclical expansion and contraction create microfractures that can expand over time, especially when filled with water that freezes and thaws.
- **Impact**: Temperature fluctuations contribute significantly to the development of cracks and the overall weakening of the roof structure.

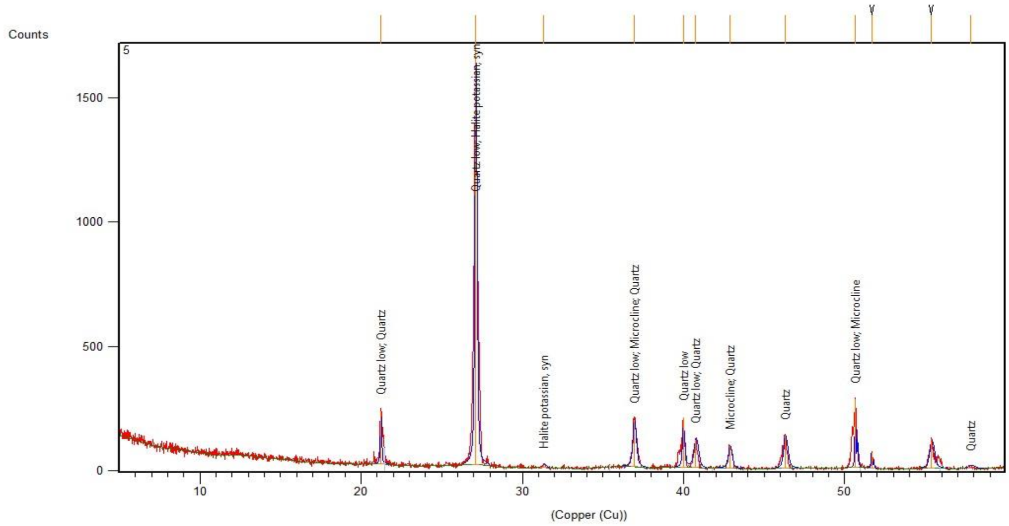
3. Wind Erosion:

- **Description**: Wind erosion plays a role in the wear and tear of the roof surfaces. Fine particles carried by the wind abrade the stone, gradually eroding the surface layers and contributing to material loss.
- **Impact**: Wind erosion, combined with rainwater, accelerates the degradation process and can lead to the exposure of more vulnerable inner layers of the stone.

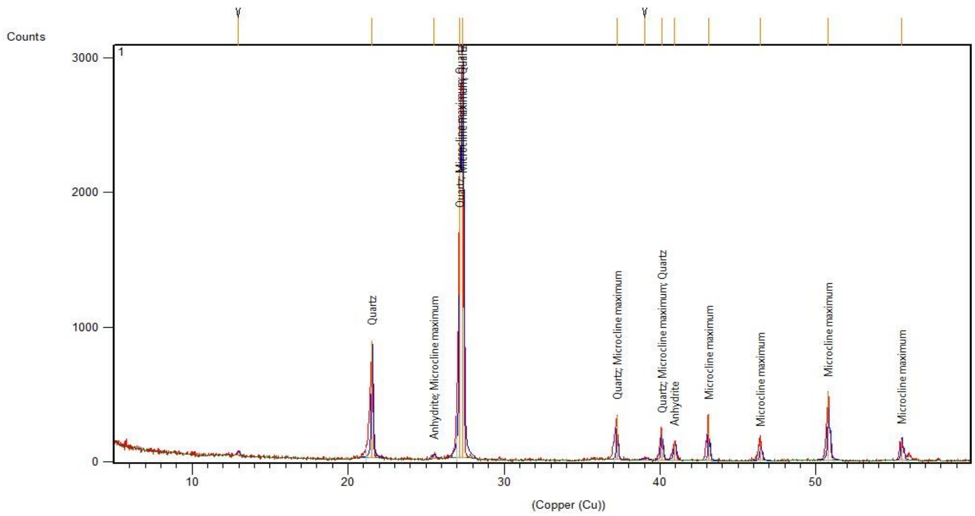
The damage observed on the roofs of Habu Temple is a result of a complex interplay of environmental factors, including rainfall, humidity, temperature fluctuations, and wind erosion. Addressing these issues requires a multifaceted approach that involves both immediate repairs and long-term preservation strategies. Effective moisture management, regular maintenance, and the use of protective coatings or treatments may help mitigate further deterioration and preserve the integrity of this historical structure for future generations (8), (9), (10), (11).

Evaluation by X-ray diffraction spectroscopy:

The X-ray diffraction spectroscopy of two samples, one from the fresh sample and the other from the stone veneer of the temple surface, was compared. The X-ray diffraction analysis of samples from the surfaces of Habu Temple reveals significant insights into the mineralogical changes due to environmental factors. The fresh samples primarily contain microcline and quartz, while the deteriorated samples exhibit the presence of halite salts, indicating chemical processes influenced by air pollution and rainwater. This deposition of salts suggests the penetration of water, leading to crystallization within the stone pores and causing expansion and cracking. Additionally, the X-ray fluorescence analysis highlighted a deficiency in silicon oxide, the main component of sandstone, indicating disintegration. The samples also showed a decrease in calcium, chlorine, and sulfur oxides due to rainwater reactions, and an increase in aluminum, iron, magnesium, sodium, potassium, phosphorus, titanium, and manganese oxides, suggesting the deposition of clay minerals. These findings underscore the multifaceted nature of the deterioration, driven by rainfall, humidity, temperature fluctuations, and wind erosion, all of which contribute to the ongoing degradation of the temple's sandstone surfaces. Addressing these issues will require comprehensive preservation strategies, including moisture management, structural reinforcement, and regular maintenance (20), (21), (22).



(a)



(b)

Figure 3. illustrates XRD of deteriorated sample (a) and fresh sample of Nubian Sandstone (b).

Evaluation using X-ray fluorescence spectroscopy:

When a fresh sample of Nubian sandstone was analyzed using X-ray fluorescence, and compared with the results of a damaged sample of the deteriorated surface crust of the stone, the following was found:

1- A deficiency in silicon oxide, the main component of the stone, which means that the surface stones are disintegrating.

2- A quantitative deficiency in some oxides such as calcium, chlorine and sulfur, which is due to chemical reactions of rainwater with the components of the disintegrated surface stone.

3- An increase in the oxides of aluminum, iron, magnesium, sodium, potassium, phosphorus, titanium and manganese, which means the deposition of clay minerals that may cause further damage to the stone surfaces. (23), (24), (25).

Table to compare XRF between Fresh and deteriorated sample comparison

Oxides (%)	Fresh Sample	Deteriorated Sample	Index
Na2O	0.025	0.08	↑
MgO	0.27	0.7	↑
Al2O3	8.40	9.93	↑
SiO2	81.13	79.57	↓
P2O5	0.86	1.27	↑
SO3	3.091	1.14	↓
Cl	0.35	0.17	↓
K2O	0.82	1.22	↑
CaO	1.65	1.16	↓
TiO2	1.32	1.59	↑
MnO2	0.012	0.05	↑
Fe2O3	0.79	1.54	↑
L.O.I	1.2	1.4	↑

Conclusion:

Medinat Habu stands as one of the most well-preserved monuments, retaining much of its historical and architectural features. Known for its inscriptions that historically safeguarded Egypt's northern borders, Medinat Habu encompasses an area of approximately 2,000 square feet, constructed by Ramses III. This archaeological treasure located in the West Bank of Luxor, however, faces significant damage, particularly on the outer surfaces and edges of the building stones. A comparative analysis using X-ray diffraction spectroscopy on two samples, one fresh and one from the deteriorated stone veneer of the temple surface, revealed key insights. The fresh sample predominantly contains microcline and quartz minerals, while the deteriorated sample shows the presence of halite salts alongside quartz and a minor amount of microcline. This indicates that chemical processes driven by air pollution and rainwater are contributing to the stone's deterioration. Further analysis using X-ray fluorescence on a fresh sample of Nubian sandstone, compared to a damaged sample from the deteriorated surface crust, uncovered a deficiency in silicon oxide, the primary component of the stone, indicating disintegration of the surface stones. Additionally, there is a quantitative deficiency in oxides such as calcium, chlorine, and sulfur due to chemical reactions with rainwater, and an increase in oxides of aluminum, iron, magnesium, sodium, potassium, phosphorus, titanium, and manganese, suggesting the deposition of clay minerals that may cause further damage to the stone surfaces. These findings underscore the complex interplay of environmental factors contributing to the ongoing deterioration of Medinat Habu, necessitating focused preservation efforts to safeguard this invaluable piece of heritage.

Recommendation:

To effectively address the weathering and degradation risks associated with the Nubian sandstone roofs of buildings in Medinat Habu, it is recommended to implement innovative preservation strategies that take into account the impacts of climate change, particularly increased rainfall. These strategies could include installing advanced drainage systems to redirect rainwater away from the stone surfaces and the application of nanotechnology-based sealants that provide a breathable yet water-resistant barrier. Additionally, creating green roofs with vegetation that can absorb excess rainwater and provide natural insulation can be beneficial. Regular structural assessments and maintenance schedules are essential to monitor the stone's condition and promptly address any emerging issues. Collaboration with conservation experts and the integration of traditional knowledge with modern technology will ensure the long-term preservation and resilience of these historic structures.

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