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Research Paper

Relative Rate of Durability towards Influence of Water in Stone Degradation: Case Study of Lead Mosque in Shkodra (northwest Albania)

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Abstract: The Lead Mosque is located in the northwest of Albania into a humid Mediterranean environment. It was built in 1773 by the Albanianpasha Mehmed Bushati who was vizier of Shkodra at the time. Through this act, he intended to give his city of birth, the feeling of the capital. The mosque has numerous cultural importances and represents a building built with calcareous stone based materials which have suffered degradation process due to long exposure periods to the existing environmental conditions. The main purpose of this paper is to present the influence of water and relative humidity on stone degradation. Water circulation in stones and water flow between stones and atmosphere or ground are one of the main driving factors in the building degradation processes in other historical monuments of Albania including other religious. It is well known that porous building materials absorb and desorbs water as a function of the weather conditions (temperature, relative humidity, and rainwater), that is why water plays a fundamental role in the phenomena of stone deterioration. The construction of hydropower plants in Drini River (Vaui Dejes) accelerated the water presence through flooding along with diverse water bodies proximity of the mosque location (Adriatic coast, Shkodra Lake and Drini/Buna system). The experimental tests through temperature and humidity were determined using data loggers from selected walls of Lead Mosque. Air temperature and relative humidity were measured every 30 min and processed to obtain average, maximum, and minimum monthly data. The flood history was also considered following archival data of Institute of Geo-science in Tirana.

Keywords*: Limestone, degradation, Mediterranean climate, water, humidity*

Introduction

In all type of construction including those of religion character, since old time ancient times, stone is known as the most durable building material, while it remains as a common base construction material today in Albania. Meanwhile in the current circumstances and apparently serious climate changes accompanied with different types of air pollution, they all may cause a substantial increase in stone degradation.

Limestone materials consist almost entirely of calcite, the most stable polymorph of calcium carbonate ($CaCO_3$). Also, a small content of aragonite is usually found in limestone (Corvo *et al*., 2010; Graedel 2000). Following Corvo*et al*., (2010), carbonate stone tends to be highly porous, usually about 15–20% (or even as much as 45%) for most limestone. Water and chemical components dissolved in water have straightforward access to the porous system of the limestone affecting their durability. It is very probable that stone structures undergo degradation due to the accompanied action of physical, chemical, and biological agents. Three well-defined physical chemical degradation mechanisms have been established (Corvo *et al*., 2010; Cardell-Fernandez *et al.* 2002): (i) attack by air pollutants; (ii) dissolution in clean rain (karst effect) and (iii) dissolution caused by neutralization of rain acidity.

The role of water in contact with carbonate stone is to provide a medium into which the calcium carbonate can get dissolved. During this dissolution, the CO_2 from the air also dissolves in the water establishing the equilibrium of the dissolution reaction as follows:

$$CaCO_3\,(s) + H_2CO_3 \leftrightarrow Ca^{2+} + 2HCO_3^- \quad [1]$$

In the absence of other dissolved species, the equilibrium strongly tends to the left. In tropical climate, water availability is guaranteed by high levels of relative humidity and long rain periods along the year. The presence of high levels of SO_2 in the air promotes the formation of calcium sulphate as

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reported by Gobbi*et al*. (1998). Dry deposition of air pollutants (especially SO_2) is the principal process involved in the formation of $CaSO_4$ along with acid rain, which is also an important factor.

The lead Mosque of Shkodra is located in the Lake Shkodra watershed (Figure 1) and is inspired by the great Sultanic mosques of Istanbul (Kiel, 1983). It represents a perfectly executed building of great dimensions and extremely lively composition. One first enters a relatively spacious cloistered courtyard (12.5 m by 13.8 m, inside the walls), the only one in Albania. This mosque is one of the very few which broke the imperial prerogative of having such an element. The court transversally placed in front of the prayer hall. It has three units on each of the short side and four on the long side. The units are covered by domes except those at the four corners, which have rib less cross vaults. A similar vault is placed over entrance of the court and the entrance of the prayer room, in order to emphasize the axis of the building. Every domed or vaulted unit of the courtyard has one large window with iron grating framed in stone and crowned by a sharply pointed Ottoman arch.

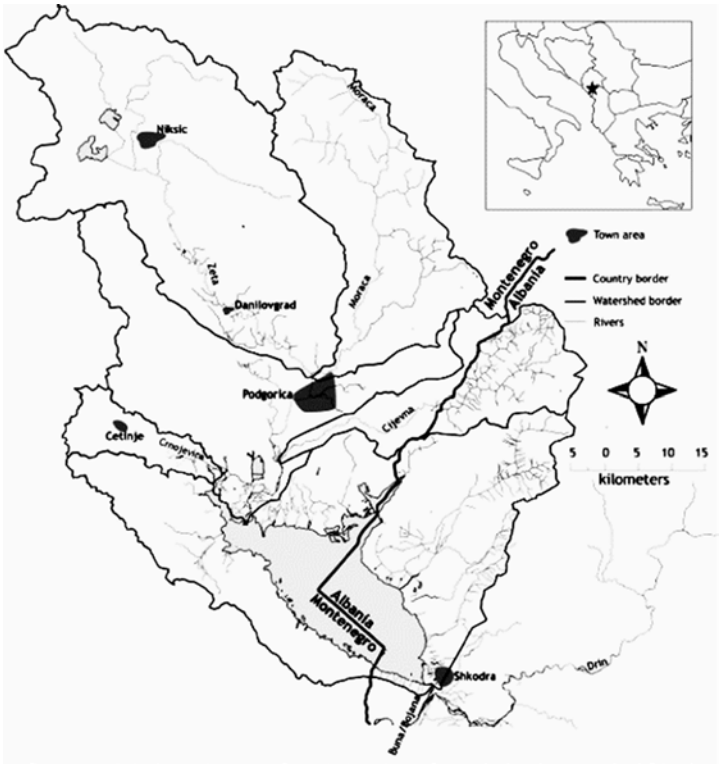

Figure 1.The Lake Shkodra watershed and location of Lead Mosque

In its present state the building itself is seriously affected by weathering factors, and among all by the frequently happen floods. FURTHERMORE, the location of the building is favouring an increased presence of water humidity that along with other environmental factors (physical - chemical, biological) are seriously threatening the structure of the building including internal and external parts.

Water circulation in stones and water flow between stones and atmosphere or ground are one of the main driving factors in the complex degradation processes of historical monuments. Water plays a fundamental role in the phenomena of stone deterioration (Reyes et al., 2009; Corvo*et al*., 2010). It is well known that porous building material absorbs and desorbs water as a function of weather conditions (temperature, relative humidity and rainwater). Following the INTERACTION, the fluxes of water within the stone affect the behaviour of the material and can be responsible for its deterioration. The weak action of condensed water on the stone surface, particularly if compared with that of rain was reported by different authors (Reyes *et al*., 2009; Corvo*et al*., 2010; Zendri*et al*. 2001); however, condensed water facilitates dissolution of pollutants and their chemical action on the stone.

At the wider scale, among the largest current threats to the natural heritage of the Balkan region is a wave of planned hydropower stations. Hydropower dams have a significant impact on the river ecosystem and the longitudinal continuum for living organisms and sediments. They can also negatively impact wild terrestrial animals including large carnivores living in mountain fringes within the Dinaric

Arc. This leads to a loss of ecological integrity, river degradation, and consequently a decrease in biodiversity (Schwartz, 2012; Shumka, 2015). Current state of the are in vicinity of the Lead Mosque is affected by various impacts (Filipovic, 1981; MoE, 2002; Cullaj*et al*., 2005; Neziri*et al*, 2006; REC, 2006; UNDP, 2014; Shumka, 2015)

Material and Method

The experimental tests through temperature and humidity were determined using data loggers from selected walls of Lead Mosque. Air temperature and relative humidity were measured every 30 min and processed to obtain average, maximum, and minimum monthly data. The flood history was also considered following archival data of Institute of Geo-science in Tirana. The EL-CC-2 Cold Chain Humidity and Temperature Data Logger were used for measuring and recording temperature and humidity with internal sensors. The device has own capacity of storing 65,200 total readings onto non-volatile internal memory, non-replaceable battery with 12 months typical battery life.

Results and Discussions

The conservation and restoration of architecture and art monuments in Albania has been considered as an interdisciplinary approach (Shumka*et al*., 2017; Meksi, 1988). The scientific research on deterioration of works of art is known for over several decades, while in the last decades the surveys and proposals for adequate conservation techniques of monuments have significantly advanced (Shumka*et al*., 2017). During the past decade studies reveal that in post byzantine churches of Albania fungal attacks appear when improper conditions of maintenance, humidity variation exist and other environmental factors for the churches (Shumka, 2013; Shumka*et al*., 2017). Frequently floods and increased high humidity (Figure 2, Figure 3 and Table 1) are directly influencing and considered as main degradation factor towards the stone walls and entire mosque structure. The operation practices of hydropower plant on Drini river cascade and increased rate of precipitations (Table 1) stands on a base of other affecting factors.

Figure 2. The flood area and flooded Lead mosque 24th March 2018

Table 1. Main climate data for the Lake Shkodra area

	2017									2018		
Parameter	Apr	May	Jul	Jun	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Humidity %	70	64	57	46	38	58	65	67	67	78	83	85
Max. Temperature (°C)	21	27	33	35	36	26	22	15	11	12	14	17
Avg. Temperature (°C)	18	24	30	32	33	23	19	13	9	10	11	14
Min. Temperature (°C)	13	19	25	27	27	19	14	10	7	5	3	9
Rain (mm)	144.9	107.4	5	6.7	7.1	93	87.8	453.2	507.3	196	339	310

Following the data presented in the Table 1, the maximum value of humidity has been recorded in March 2018 (85%), while the minimum value of the last year has been measured in August 2017 (38%). The daily values of humidity (13th October 2017 and14th January 1018) shower high values of 81 and 82% in January with respective time of measurement at 07 00 in morning and 18 00 in evening (Figure 3). The same parameter in October 2017 was recording lower values and respectively 67 and 72 at the same time of data logger operation.

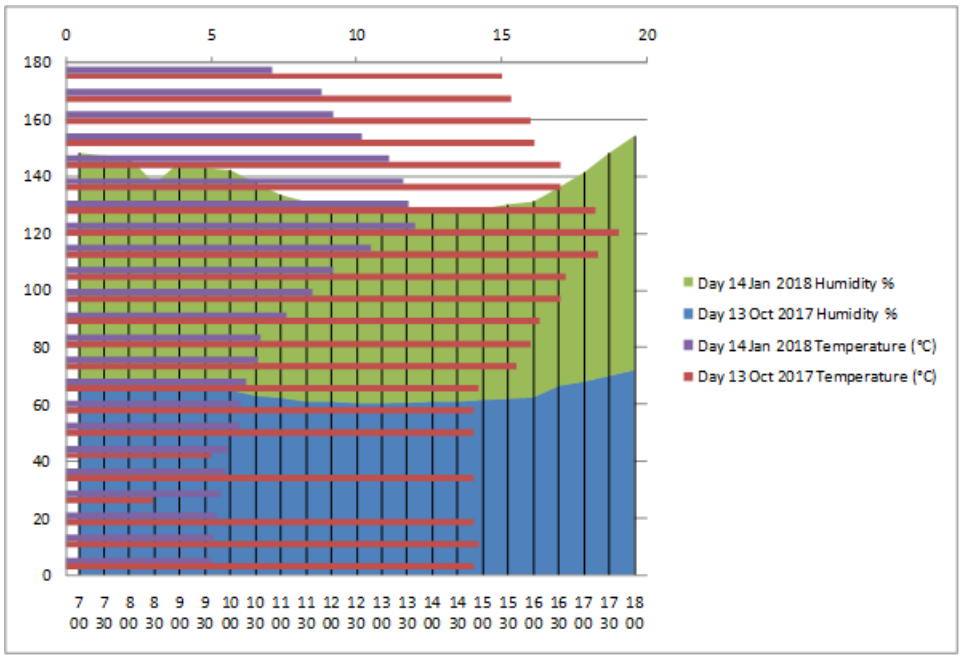

Figure 3. Values of relative humidity (%) and temperature (°C) during two days of experimental testing

The hourly values of the relative humidity and temperature oscillations were significantly different from the other areas of Albania, and particularly from those situate din the continental part of the country. The vulnerability of the area and those contexts of the mosque are directly affected by the climate change as it is an increasing threat to both nature and entire area which have narrow variation of the amplitude for, particularly temperature and water regime. According to Joksimović *et al*. (2008) in the Adriatic Sea and adjacent area there is indication of changes attributed to climate change reflected in different features.

Figure 4. Traces of weathering factors influence and acceleration biological degradation in Lead Mosque

The increased values of precipitation, relative humidity and temperature oscillations are evidenced during site visits (Figure 4), while these weathering factors are directly influencing in an accelerated biodegradation. On entire wall structure clearly there are two phenomenons: heavily damaged wall and connection sites, and secondly bio-invasion one.

As a conclusion, it can be confirmed that this monument is seriously threaten by the weathering factors and there is limited maintenance effort. In order to preserve it is an urgent need to: (i) undertake a rehabilitation plan with clearly defined measures; (ii) mitigation measures against the flood has to be considered as an integral part of the wider area; (iii) mosque mitigation measures has to be designed

from the engineering prospective and (iv) well-coordinated operational program of hydropower operation has to be advanced.

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