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Climate Monitoring and Damage Assessment Model: A Case Study from the Praetorium at Umm El-Jimal Archaeological Site, Jordan

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Abstract

Umm el-Jimal is a Byzantine- Nabetean archeological site located on the edge of the southern Hawran plain. The site is notable among Jordan's premier archaeological sites for its wealth of Late Antique ruins. The architectural forms are illustrated in the ruins of the site by ground plans, the construction of the super structures of the buildings, their ornament, the girder arch, the corbel courses, and roofing slabs. There are principal details and constructive principles developed in the purely lithic architecture in basalt at Umm el-Jimal and these are not common in the architecture of Hawran.

The objective of this study is to carry out a detailed microclimate monitoring program in order to provide reliable information on the measurement and characteristics of the stone decay problem at Umm el-Jimal. Relative humidity, temperature, and the level of pollution (CO_2) will be measured for a limited period of time.

This study is focused on the Praetorium – one of the structures at Umm el-Jimal which enables us to determine elements that accelerate destruction. The Praetorium gives a glance at the damage to the stone in Umm el-Jimal, which is affected by microclimate. Climate changes such as the rise in the percentage of relative humidity during winter and humidity decline during summer, and vice versa with temperature all result in damages to the site. Both relative humidity and temperature appear in different types of mechanical, alteration, and solution decay forms at the site. In addition, it is notable that Umm el-Jimal suffers from high levels of CO_2, which contributes to the increasing growth of micro-organisms on stone surface, which accelerates many types of damage to the stone. Therefore, it is necessary to have a comprehensive conservation plan for the preservation of the site from loss and destruction in addition to the need for removing the damaged or deteriorated crust by using non-destructive methods as much as possible.

Keywords: Umm el-Jimal, microclimate, damage assessment, relative humidity, temperature, CO_2 and conservation plan

1. Introduction

1.1. General Introduction

Umm el-Jimal is a large settlement near the northern border of Jordan and is located in the semiarid region of north Jordan – on the edge of the basalt plain. It was created by prehistoric volcanic eruptions from the slopes of the Jebel Druze (De Vries, 1990). The ruins of Umm el-Jimal are situated at twenty kilometers from Mafraq, where the pipeline and road from Iraq cut the Hijaz railway on the way to Haifa city on the Mediterranean Sea (Horsfield, 1937).

Figure 1. Umm el-Jimal location (Google Earth, 2016).

Umm el-Jimal is situated in semi-arid steppe, 25km south of Busra and 40km southwest of Salkhad. This is the point where the southern Hawran plain meets al-harra, the formidable basalt plateau of north-eastern Transjordan. This remote lava city is interspersed with pockets of soil and vegetation. Today, the city hosts a few villages including Sabha and Umm al-Quttayn, which were built-up around the Late Antique ruins as local Bedouins settled, and as a result of the scattering of Druze families (Brown, 2009).

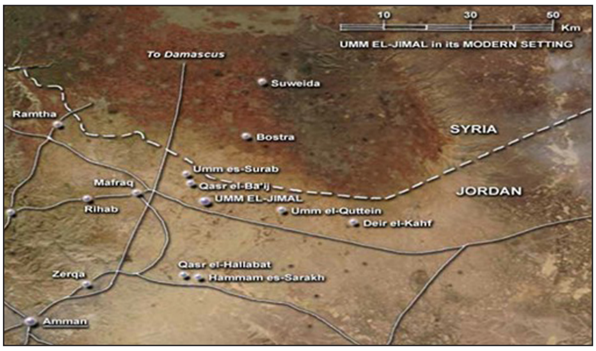

Figure 2. Umm el-Jimal location (Umm el-Jimal Project, 2016)

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Umm el-Jimal ranks second after Petra and Jerash in the state of preservation among Jordan's archaeological sites (De Vries, 1981). The city is considered as a substantial town compared with many of its neighboring towns (Kennedy, 2013).

In the Roman, Byzantine, and Umayyad periods, the desert population of Northern Jordan created a comfortable human habitat in the apparently hostile environment of the basaltic frontier. Umm el-Jimal formed more fertile parts of the basaltic regions where sparse agricultural resources were exploited and distributed along the Roman-Byzantine Arabic region. This also formed a secure buffer to prevent nomadic and military incursions into Syria and Palestine (De Vries, 1985).

Umm el-Jimal was occupied for 700 years from the 1st Century AD to the 8th Century AD. It was, then, completely abandoned and after that was occupied during the 20th century (De Vries, 1990). Umm el-Jimal has undergone several occupations in the Late Nabataean Roman, Byzantine and Umayyad periods (De Vries, 1995). It was finally reoccupied by the Druze who expanded their territories beyond their mountain to the North, and found Umm el-Jimal an attractive place to remodel (De Vries, 1990).

The landscape of the town resembles a rough parallelogram from south to north (Horsfield, 1937), with 800 meters in length and 500 meters in width. The site encompassed more than 150 buildings grouped into three irregular clusters (Whitcomb, 1996). However, some of the buildings had been destroyed for different reasons, while other structures still exist.

People who lived at Umm el-Jimal built a town of laboriously chiseled basalt ashlars and long beams (Brown, 2009). The town of Umm el-Jimal encompassed doorways and alleys that lead from room to room, and from building to building, reaching up to three or four stories high (Al-Kurdi, 2014). The town was surrounded by walls from four destinations and five gates. These held within them praetorians, churches, houses, several reservoirs, a channel system, civil buildings, stairways, barracks, and a number of other features. All of these features were scattered throughout the town, which contravened a late antiquity pattern (Obeidat, 2002).

Umm el-Jimal has many inscriptions found throughout the rubble of the buildings, churches and graves. The inscriptions are lingually diverse including Nabataean, Latin, Greek, Safaitic, and Arabic inscriptions written on basalt rocks. The inclusion of the various inscriptions facilitates the determination of the history of the site. Furthermore, the multilingual inscriptions allow the absolute dates of some of the structures at the site to be detected. Also, the inscriptions facilitate the understanding of the development of the Arabic language and provide information on who settled at this site (Obeidat, 2002).

1.2. Architecture of Umm el-Jimal

Since the Late Roman, Byzantine and Umayyad periods, Umm el-Jimal has had dozens of prosperous rural towns and villages scattered on the plains between Dera'a to the west and Deir el-Kahf to the east (De Vries, 1990).

The architecture of Umm el-Jimal has given it a unique stability through the one-hundred and eight of the town's structures which once stood three stories in height (Brown, 2009). Moreover, there were fifteen churches, a water system and barracks distributed at the site (Obeidat, 2002). These were grouped in compact masses, in the east, west and north, and a scattered group was found down the middle of the structure of the city (Horsfield, 1937). Further walls of structures run every direction without plan or order (Al-Kurdi, 2014).

Umm el-Jimal is built completely from basalt. Basalt exhibits a high structural resistance against erosion, climate and time (Al-Kurdi, 2014). People who occupied the site used special techniques to support the buildings and give more space to the structures, such as corbelling, the the cantilevered stairway rough wall finish, the building quality, doorway and window treatment, and lintel relieving illustrated by the circular window relief and double lintel relief (Obeidat, 2002).

Umm el-Jimal, has none of the formal lay-out or architecture which distinguished Syrian Graeco-Roman cities of the 2nd and 3rd centuries A.D. Although contiguous and contemporary with them (Horsfield, 1937), Umm el-Jimal is a non-grid town. The place is planned without frills or carving on any kind of its buildings. The churches present a far greater variety of ground plans and superstructure than can be found in any part of the surrounding area (Butler, 1913).

The houses of Umm el-Jimal consist of a single or more than one room, which overlooks a courtyard; some houses share walls (Obeidat, 2002). The houses are of two large arched stories at the front, but houses with four stories of narrow chambers are also common throughout the ruins (Al-Kurdi, 2014). Some of the houses were covered internally and externally with coatings of stucco, finished with a polished surface on walls. It should be noted that doors and window shutters were made of basalt (Horsfield, 1937), but unfortunately, people who reoccupied the site during the Umayyad period robbed and badly damaged some portions of the Byzantine buildings, such as the walls of the rooms (De Vries, 1995).

Churches of Umm el-Jimal appear in various types. Some of the churches can be identified by inscriptions upon the surface of the structure, like that of Numerianos. Others may be distinct through the observation of their architectural form, such as the cathedral church, of a basilica type built in 557 A.D. Furthermore, churches that include multiple arcades in their structure can also be found, such as the Chapel of the Barracks. The last type of churches to be found at Umm el-Jimal is known as the "hall type". This type is demonstrated by the churches of Julianos, built in 345 A.D., and of the Maeschos. The halls of these churches include roofs with black basaltic long beams and girder arches to carry the flat roofs. The largest church at Umm el-Jimal is known as the "cathedral church". The cathedral church is 23 meters in length and 25 meters in width. On the other hand, the smallest church is referred to as the "southeast church" which is 10 meters in length and 8 meters in width. In general, the churches of Umm el-Jimal are distinct in that they lack excessive decorations, while only a few are found at the base and capital of the columns which support the arches.in addition to some minor religious symbols carved on the walls (Horsfield, 1937).

Remarkably, the tribes who reoccupied the site during the 20th century changed the purpose of some ruins. They used the site as a campground, where domestic courtyards provided corrals and additional walled pens which could easily be created from the scatter of stones that littered the site (Brown, 2009).

2. Case Study

The Praetorium (371 A.D) is situated near the west wall, south of the Gate of Commodus, and beside the broad, open, space that extends through the middle of the city. Its major axis lies eastwards and westwards. It is a great courtyard, originally enclosed within a high wall. In the southwest angle of this yard, and extending for some distance along its western wall, is a row of residences of the same period, following the same general style, as the main building (Butler, 1913).

Figure 3. Front Façade of Praetorium, Umm el-Jimal (by researcher, 2016)

The plan of the Praetorium is a parallelogram divided longitudinally into two main sections; one to the south subdivided into three main apartments, and one to the north having five smaller divisions. The middle division of the three main apartments consists of a square atrium noricum. The south wall of the atrium contains the principal entrance to the building and two large windows above two rectangular niches. In the eastern wall of the atrium, to the right as one enters, is a single doorway between two pilasters which correspond to the columns (Obeidat, 2002).

The Praetorium is composed of two-storey superstructures. This is evident upon the observation of the ground-plan, with the aid of the parts of the building that are still in situ, and by the observation of the fallen parts (De Vries, 1993).

3. Literature Review

Butler, De Vries, and the Department of Antiquities of Jordan are principal investigators responsible for the start of the excavation project in 1905 continuing to present day. Butler started the excavation of the site in 1905. De Vries continued the excavation work at Umm el-Jimal during 1972. As such with any project, many archaeologists and specialists are involved in the actual excavations and subsequent studies and analysis required for publication.

Haddad (1991) presented an analytical study for nine of the Byzantine churches, in order to contrast the differences of the internal and external details of the structures. Moreover, Haddad made a comparison of the churches at Umm el-Jimal site, and those in the surrounding areas in Syria and Jordan. The ability to identify the differences and similarities among the churches allowed for the determination of approximate dates of the Churches. The study helped current researchers compare the structures for digital reconstruction and the theories on how the buildings were destroyed through time and were then introduced as a three-dimensional model.

In 2002, Dunn provided a new study of mortars and concretes from an Umm el-Jimal structure. Her study depended on the collection of many samples taken from random structures of Umm el-Jimal. She used many types of analysis such as Insoluble Residue Analysis, Grain Size Analysis, X-Ray Diffraction analysis, ICP Mass Spectroscopy, Petrographic and Microscopical Analysis. The formulation result gave the original mortar and concrete specific degrees of physical strength and durability, in addition to the effect of the geological origin of the raw materials. The evidence allowed Dunn to provide an explanation for the way through which the former inhabitants of Umm el-Jimal processed it, and how technology changed over time. Finally, Dunn used the results based on the analysis to create a comprehensive management plan of the site.

Smith et al., (2008) developed a way to evaluate damage done to stone using salt weathering simulated and salt-based durability tests which have largely relied on weight loss after each weathering cycle. One must take into consideration properties that are affected by environmentally-driven thermal and moisture cycles and association variation in relative humidity, and how stone reacts with atmospheric pollutants. In order to properly monitor the environmental agents, researchers have to use a specific environmental monitoring sensor. The apparatus is put into the stone and is left for a period of time. During this time, the change of physical properties of the stone will be observed and recorded.

Abo Ali (2012) created a development and marketing plan for Umm el-Jimal site. Abu Ali illustrated how individuals may utilize the site for cultural resources, by exploring the heritage or structure, like those of the Nabatean Temple, Barracks and many others. He submitted a comprehensive study of natural and human resources located around the site as clarification of how they can be explicated. These actions can be set into place to serve as promotion of Umm el-Jimal as a tourist destination.

4. Methodology

The current study relies on a theoretical as well as a practical approach as follows:

1. The theoretical approach: during this phase of the study, the researchers reviewed all the previous studies of Umm al-Jimal that are of a historical and archaeological significance in order to understand the detailed aspects of the site. After utilizing the practical approach, the researchers re-studied the results of the diagrams obtained from the devices. This allowed the researchers to evaluate the changes that occurred on site according to SWOT analysis and determine the strengths and weaknesses. Furthermore, this can contribute and aid in the drafting of opportunities to preserve Umm el-Jimal against decay by the determination of possible intervention techniques to

protect the site of Umm el-Jimal against threats which may deprive it of being a tourist destination. Lastly, together, the researchers would be able to set up a comprehensive conservation plan that may be applied at the site, based on the results from the practical approach.

2. The practical approach: This approach included several steps.

The first step entailed carrying out several fieldwork visits to the site for the assessment of stone decay. Also, the completion of a comprehensive environment-monitoring program in order to determine the risks threatening the site using two Gemini Tiny tag loggers. These loggers are installed at the site for several months to monitor three parameters of the microclimate. The readings of the loggers will then be discussed to link how these parameters have an effect on the damaging of the stone. Finally, fieldwork observation will be conducted to assess the decay of some features at site that are not visible to the naked eye. Such assessment will record the types and degree of damage; the degree of damage will be evaluated on a scale from one to five.

The reason behind choosing such types of loggers is mainly because they are designed for tough locations and they are ideal for external environmental monitoring due to their waterproofing qualities and their large detection range. The temperature ranges of these loggers are between -30 and 50º C, and the relative humidity ranges are from 0 to 100 %. Also, these loggers are capable of recording more than 15,000 readings, which means that they can run unattended for more than twenty months if set up to record one reading every hour (Gemini Data Loggers, 2015).

5. Microclimate Condition Assessment

The sustainability and preservation of the historical and cultural heritage preserved in stone required studies of the intrinsic and extrinsic deterioration factors causing the decay of such materials. The intrinsic factors include the composition and internal architecture. On the other hand, extrinsic factors such as the environmental conditions where the structure is located, and the microclimate affecting particular stones in the buildings (Rives and Talegón, 2006).

The first investigation of Umm el-Jimal considered the **microclimate**, such as temperature, relative humidity and pollution, which are significant factors within the stonework, and have a major influence on the patterns of salt movement. Subsequently, the type and severity of salt-induced decay, which means chances for salt to deliquesce, crystallize, hydrate or dehydrate on porous building materials when interacting with microclimate regimes, are not easy to control and harder to reverse (Smith et al., 2008; Hoyos et al., 1998).

5.1. Temperature and Relative Humidity Readings

Tinytag logger Pluse 2 (TGP / 4500) was placed at certain sites in the buildings, and measured automatically. The device provided continuous recordings of the temperature and relative humidity over two periods of time. The first period was in winter and lasted from December, 2015 to March, 2016, while the second period took place for a shorter span of time during the summer season.

Data retrieved from the first duration of temperature recordings show a maximum value of 24.4 °C, while the minimum value was 2.6 °C, and reached an average of 12.5 °C. The relative humidity recorded during the period varied from 23.8 %, to 76.3 %.

For the majority of the duration of monitoring, relative humidity was recorded at rates above 52.5 %. The next table and graph summarize the most important data regarding the readings.

Table 1. Important data regarding readings at Umm el-Jimal.

Property	Temperature	Relative Humidity
Type	TGP-4500	TGP-4500
Logging started	December1, 2015 12:10 PM	December1, 2015 12:10 PM
Logging ended	February 29, 2016 5:50 PM	February 29, 2016 5:50 PM
Logging duration	92 days 5 hours 39 minutes	92 days 5 hours 39 minutes
Interval between readings	10 minutes	10 minutes
Number of readings	16307	16307
Minimum readings	2.6 °C	23.8 % RH
Maximum readings	24.4 °C	76.3 %RH
Average readings	12.5 °C	52.5 % RH

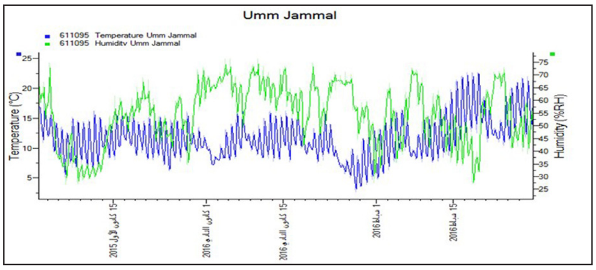

Figure 4. Peculiarities of temperature and relative humidity at Umm el-Jimal took place in winter.

The results of temperatures and relative humidity recordings from various readings logged for three individual durations are shown in Figures 4, 5, and 6.

1. During the first period of monitoring (December 1, 2015 to December 31, 2015) temperature reached a maximum of 17.5 °C and a minimum of 5.1 °C, with an average reading at about 11.5 °C.

During this period, temperature readings varied greatly, which gave a large difference between the maximum and minimum temperatures recorded. Relative humidity fluctuated greatly and was unstable ranging between humid and very dry. The maximum reading of relative humidity was 74.7 % and the minimum reading was 26.6 %, with an average reading of 49.1%

2. The second duration of monitoring at the site took place from (January 1, 2016 to January 31, 2016). The maximum temperature reading decreased to 16.6 °C. The minimum reading in all the periods of monitoring was recorded at 2.6 °C, so the average reading of temperature also decreased to be around 10.1 °C. As the temperature decreased, the relative humidity increased. The maximum reading of relative humidity was recorded at 76.3 %, and the minimum reading was 27.3 %, with an average of 60.8 %.

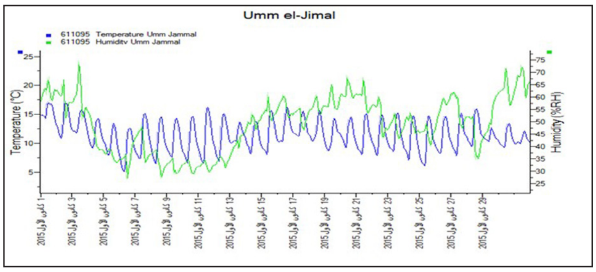

Figure 5. Temperature and relative humidity readings from data logger for the first duration of monitoring at Umm el-Jimal.

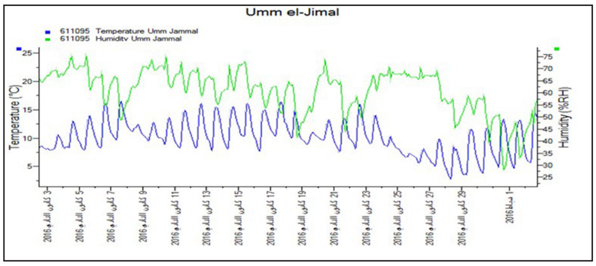

Figure 6. Temperature and relative humidity readings from data logger for the second duration of monitoring at Umm el-Jimal.

3. The third duration of monitoring at the site lasted from (February 1, 2016 to February 29, 2016). The maximum temperature was 24.4 °C, and the minimum reading was 6.2 °C, so the average reading of temperature was around 15.2 °C. The maximum recorded rate of relative humidity was 73.1 % and the minimum reading was 23.8 %, with an average of 48.2 %; humidity fluctuated greatly and was unstable ranging between humid and very dry.

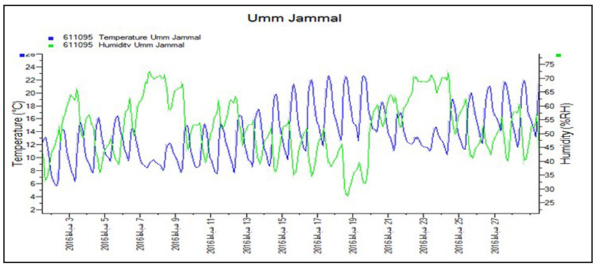

Figure 7. Temperature and relative humidity readings from data logger for third duration of monitoring at Umm el-Jimal.

After exhibiting the results of the readings from the logged research, a day was chosen to discuss the behavior of two parameters of microclimates. The day chosen was in winter on December 1st, 2016, as shown in the next table:

Table 2. Temperature and relative humidity readings and behavior during one day (December 1, 2016).

Parameters	Duration	from	to	Dec/inc
Temperature	(12:00 - 08:00) AM	6.0 °C	3.8 °C	Decrease
	08:10 AM- 03:00 PM	4.1 °C	11.8 °C	Increase
	(03:10 – 11:50) PM	11.1 °C	6.08 °C	Decrease
Relative Humidity	(12:00 - 09:00) AM	57.4 %	59.6 %	Increase
	(09:10 - 10:00)AM	59.1 %	59.6 %	Increase
	(10:10 – 05:00) PM	59.1 %	38.5%	Decrease
	(05:10 – 11:50) PM	38.3 %	49.4%	Increase

After monitoring temperature and relative humidity for one day, the researches showed the variations of these two parameters over the period of a whole week starting on February 14, 2016 until February 20, 2016 (figure 7, a and b). A maximum temperature of 22.7 °C and a minimum reading of 8.6 °C were recorded. Therefore, the average temperature was approximately 16.3 °C. The maximum relative humidity reached 61.4 % and the minimum recorded reading was 27.1 %, with an average rate of relative humidity at 44.3 %.

The following graph shows the daily variations that occurred over the period of one week as an individual unit.

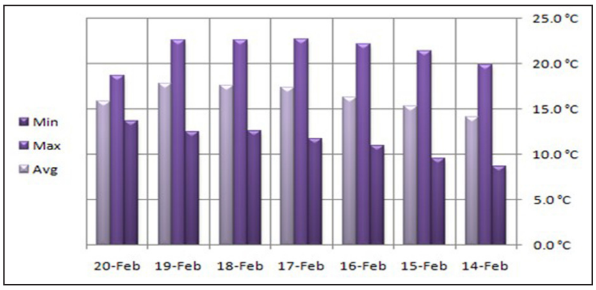

Figure 8a. Maximum, minimum, and average temperature readings from (February 14-20, 2016).

4. The Fourth duration: Data retrieved from the second duration of monitoring were for a shorter period of time during summer lasting only from June to July of 2016. Temperature records show a maximum value of 37.9 °C, while the minimum value was 19.9 °C, and reached an average of 29.1°C. The relative humidity recorded during the period varies from 33.3 % as the minimum value, to 58.4 % as the maximum value. For the majority of duration, the relative humidity recorded was above 18.0 %. The next table and graph summarize the most important data regarding the readings.

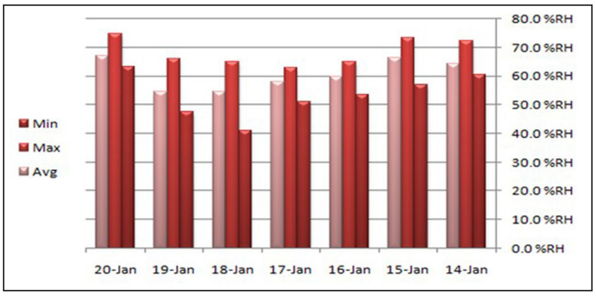

Figure 8b. Maximum, minimum, and average relative humidity readings from (February 14-20, 2016).

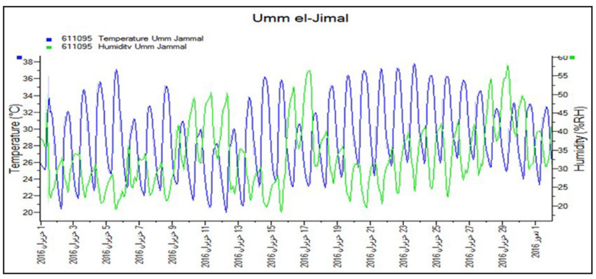

Figure 9. Maximum, minimum, and average relative humidity readings from (February 14-20, 2016).

As an example of the weekly behavior of microclimate during summer at Umm el-Jimal, the researchers chose to exhibit the recordings for one week, that is from June 6, 2016 to June 12, 2016. During this week, the maximum temperature reading was 35.2 °C. The minimum temperature in all the periods of monitoring was recorded at 19.9 °C, and the average reading of temperature was around 26.8 °C. As the temperature increased, relative humidity decreased. The maximum reading of relative humidity was recorded at 50.9 %, and the minimum reading was at 21.2 %, while the average reading was 33.8 %.

Table 3. Important data regarding the readings at Umm el-Jimal in summer.

Interval	10 minutes	10 minutes
Number of Readings	6639	6639
Statistics Start Time	1 June 2016	1 June 2016
Statistics End Time	1 July 2016	1 July 2016
Minimum Reading	19.9 °C	18.0 %RH
Maximum Reading	37.9 °C	58.4 %RH
Average Reading	29.1 °C	33.3 %RH

Table 4. Maximum, minimum, and average temperature and relative humidity readings from (June 6-12, 2016).

Date	Temperature			Relative Humidity		
	Min	Max	Avg	Min	Max	Avg
6/June/2016	22.9 °C	31.3 °C	27.2 °C	22.2%	38.3 %	28.5 %
7/June/2016	21.8 °C	32.8 °C	27.7 °C	22.5 %	34.2 %	28.5 %
8/June/2016	22.5 °C	35.2 °C	29.0 °C	21.1 %	31.9 %	26.7 %
9/June/2016	23.3 °C	30.9 °C	27.1 °C	28.0 %	43.6 %	35.1 %
10/June/2016	21.4 °C	30.0 °C	26.0 °C	31.4 %	49.4 %	41.2 %
11/June/2016	20.5 °C	28.3 °C	24.9 °C	32.1 %	50.7 %	41.7 %
12/June/2016	19.9 °C	30.1 °C	25.6 °C	23.1 %	50.9 %	35.3 %

5.2. Carbon Dioxide (CO_2)

The data on carbon dioxide were collected using TGE-0011 Tinytag CO_2 Logger. The reason behind the choice of this type of logger is that it records a range of 0 to 5,000ppm, and can be used in more specialized applications. TGE-0011 Tinytag CO_2 Logger is capable of working in a temperature range of -20°C to +60°. In addition, the device is distinct in its self-calibrating system. The logger uses a self-calibrating NDIR sensor. This uses an infrared source to accurately measure the carbon dioxide concentrations. Over time, the properties of the infrared source will change, so the sensor uses a second infrared source, which is only powered up occasionally, to calibrate the first. The patented measurement technique allows for excellent long-term accuracy and stability. Moreover, the logger has a discreet case housed in a small, neutral colored, low profile case. The logger can be wall-mounted for unobtrusive use in an office or workplace applications (Gemini Data Loggers, 2015).

TGE-0011 Tinytag CO_2 Logger was placed at certain sites in the buildings, and measured automatically. The device provided continuous recordings of CO_2 levels. The period of measurement took place from December 1, 2015 to June 30, 2016. The CO_2 recorded during this period varied from 0 ppm as the minimum value, to 910 ppm as the maximum value with an average reading at about 640 ppm. The next table and graph summarize the most important data regarding the readings.

The researcher separated the readings of the data logged during the monitoring behaviors for one day, one week, and monthly. This results in notably more accurate readings due to an increase in the variation in the data available. A discussion of the level of CO_2 for the duration of one day is given bellow:

The researchers picked up the device on May 5, 2016 and noted the changes that have occurred regarding CO_2 levels during one day. The CO_2 readings have not varied during this day, which gave a similar approximation in the change between the maximum and minimum CO_2 levels that were recorded. The maximum CO_2 reading was 630 ppm, and the minimum reading was 580 ppm, while the average reading of CO_2 was about 600 ppm.

Table 4. Maximum, minimum, and average temperature and relative humidity readings from (June 6-12, 2016).

Property	CO_2 Concentration
Logging Started	December 1, 2015
Logging Ended	June 30, 2016
Logging Duration	215 days 11 hours 29 minutes
Interval	10 minutes
Number of Readings	32614
Minimum Reading	0 ppm
Maximum Reading	910 ppm
Average Reading	640 ppm

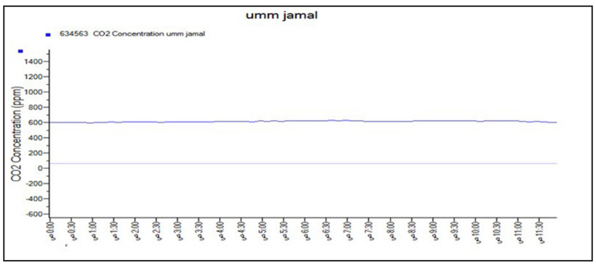

Figure 10. Levels of CO_2 at Umm el-Jimal for 215 days.

Weekly levels of CO_2 can be very different from one day to another as shown in the next graph. During the two days, the maximum CO_2 level for this week reached 640 ppm, while the minimum level was around 550 ppm. These two readings are not much different from one another, so the average CO_2 level was around 580.

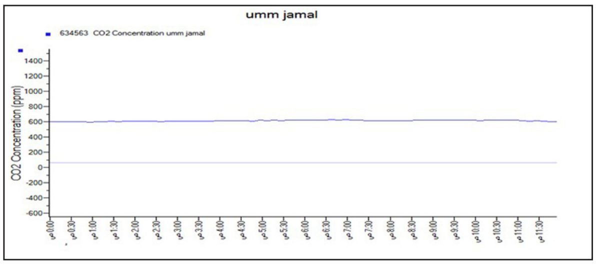

Figure 11. Diagram combining CO_2 readings from the data logger for one day.

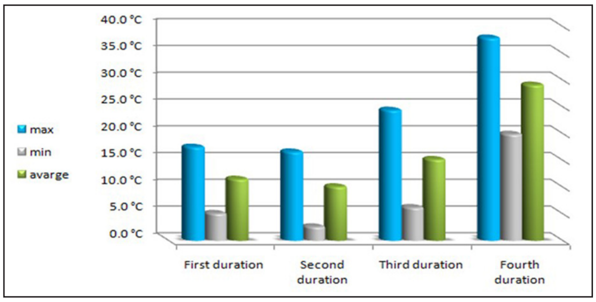

Figure 12. Maximum, minimum, and average CO_2 readings for the period (April 20-26, 2016).

5.3. Summary of Umm el-Jimal Microclimate Condition

The changes monitored at Umm el-Jimal can be identified as microclimate conditions and behavior (temperature, relative humidity and CO_2). It is knwon that humidity is inversely proportional to temperature. This means that an increase in one factor leads to a decrease in the other. During the four months of the monitoring, temperature and relative humidity showed differences between the lowest values and the highest values that were very irregular for the same month. The observed rates during one month differed from humid to dry. Afterwards, when data were compared for different months, they showed rates of convergence.

At Umm el-Jimal, December displayed a microclimate with low temperatures and high humidity that exceeded the average rate of 50 %. In the following month of January, the relative humidity rates amounted to about 60 %, with temperatures declining to an average of 10 °C. The microclimate can be described as humid with moderate temperatures, while the last month of the winter period showed a steady rise in temperature, reaching 20 C. Throughout the monitored period, the researchers observed a decrease in relative humidity to less than 48 %. The microclimate can be described as humid with moderate heat.

The following two figures (23 and 24) illustrate the differences and fluctuations of maximum, minimum, and average observed data of temperature and relative humidity at Umm el-Jimal.

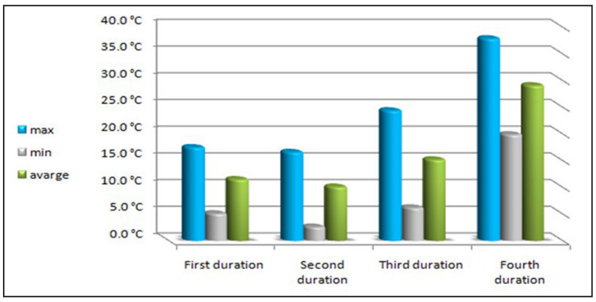

Figure 13. Maximum, minimum, and average temperature readings for four months of monitoring.

During the last month of the summer period, temperatures were very high, reaching about 38 C. This in turn led to a very low relative humidity, reaching a very dry rate of 18 % during that month. The rates were moderate reaching almost 33%.

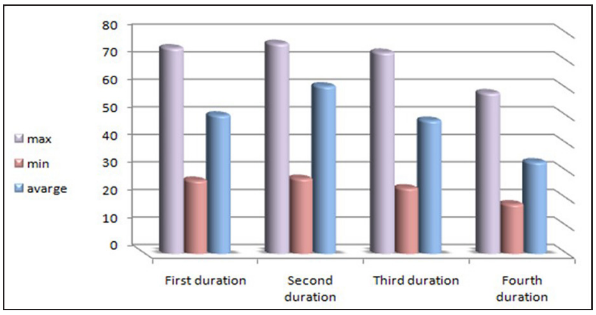

Figure 14. Maximum, minimum, and average relative humidity readings for four months of monitoring.

From the results of the measurements of the CO_2 concentration over the period of seven months, it can concluded that CO_2 levels were consistently high during this period. As seen in the next figure, the maximum and minimum levels of carbon dioxide varied for each month. The maximum levels of CO_2 measured in Umm el-Jimal (910 ppm) were reached during February. The minimum values were (551 ppm) and were recorded during June. It is important to note that the zero values were excluded as this device may have been removed from its power outages during these periods. Therefore, the CO_2 concentration rate is very high, usually around 640 ppm.

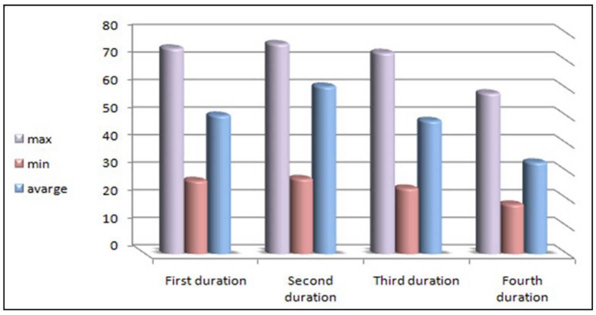

Figure 15. Maximum, minimum, and average CO_2 readings during seven months of monitoring.

The fluctuations in temperature, relative humidity, and CO_2 rates caused the basalt stone buildings of Umm el-Jimal to suffer. The microclimate changes affected the stability of the historic buildings at this site. These changes affected both the internal structures through the movement of salts through the pores, and the external ones through the accumulation of pollutants on the surface which resulted in changes in colors and shape.

6. Stone Decay at Umm el-Jimal

After investigation of the structures at Umm el-Jimal discussed earlier, the most important causes of the decay of stones are displayed following Smith's classification system. It becomes evident that a simpler and a more convenient system is needed in order to facilitate the assessment of the risks to some of the structures in Umm el-Jimal, and find a simpler way to represent these decay patterns in the form of photographic images.

A flow chart is shown as a way to distinguish between the types of stone decay. Each major type of decay is represented in a rectangle that carries a specific color. In addition, the following branches of the decay types hold a character key to follow the chart more easily. The following images have rectangles of colors that correspond to those in the flow chart. Those rectangles are enlarged so that the details are seen more easily.

Table 5. Classification of stone decay editied by the researchers.

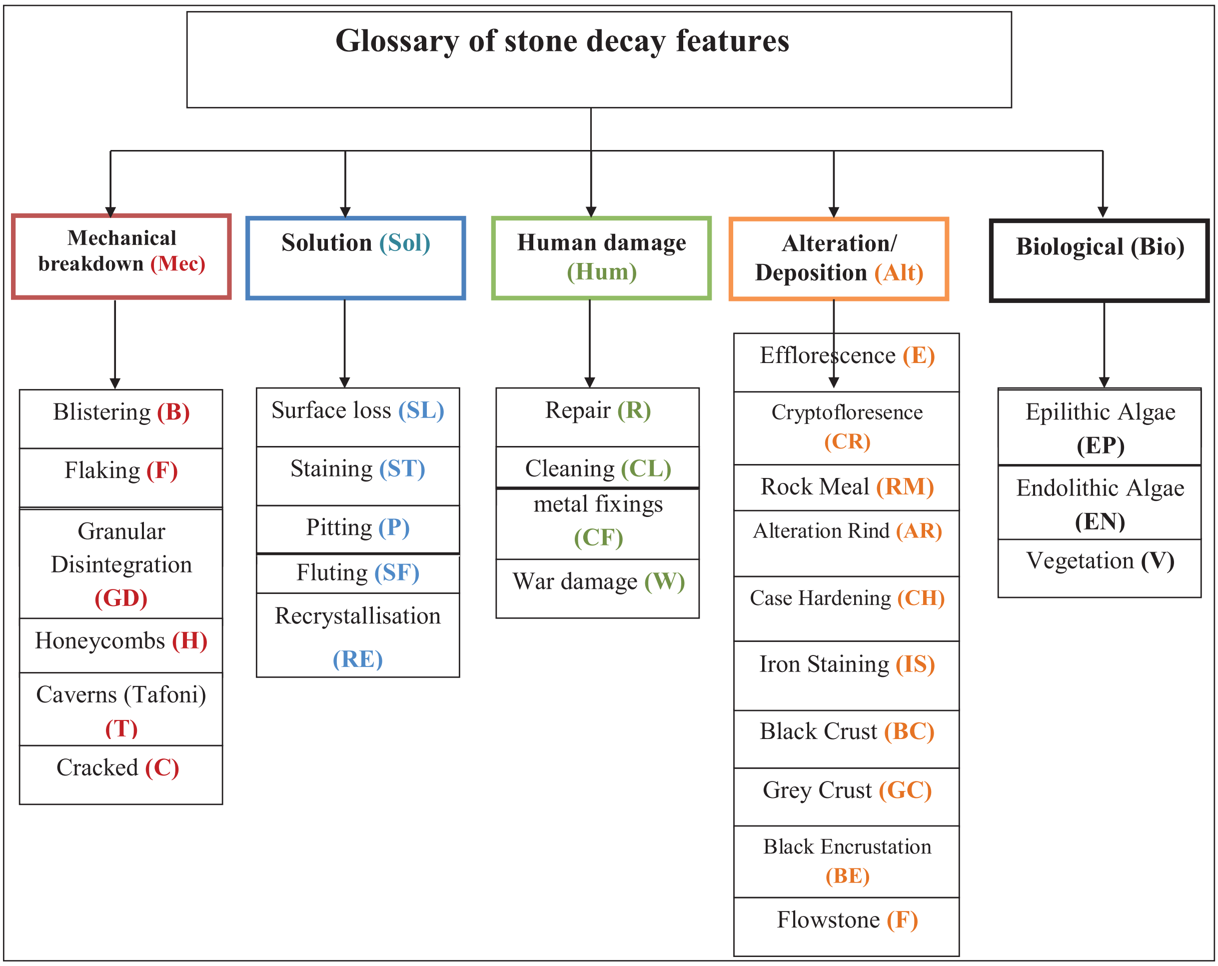

Table 6. Stone decay feature of front façade Praetorium, Umm el-Jimal.

Types of stone decay of front façade of Praetorium		
		
		
Human Damage? (HU) Repair (R) Scale (1-5): 2	Mechanical breakdown (MB) Scaling (S) Scale (1-5): 3	Biological (Bio) Vegetation (V) Scale (1-5): 2
Photo taken by Researcher, 2016		

Table 7. Stone decay feature of other façade of Praetorium, Umm el-Jimal.

<table>
<tr><th colspan="3">Types of stone decay inside of Praetorium</th></tr>
<tr><td colspan="3"></td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td>Alteration (Alt)
Efflorescence (E)
Scale (1-5): 2</td><td>Alteration (Alt)
Efflorescence (E)
Scale (1-5): 2</td><td>Alteration (Alt)
Black crust (BC)
Scale (1-5): 3</td></tr>
<tr><td colspan="3">Photo taken by Researcher, 2016</td></tr>
</table>

Table 8. Stone decay feature inside of Praetorium, Umm el-Jimal.

Types of stone decay inside of Praetorium		
		
		
Alteration (Alt) Black Encrustation (BE) Scale (1-5): 1	Solution (Sol) Pitting (P) Scale (1-5): 2	Solution (Sol) Pitting (P) Scale (1-5): 2
Photo taken by Researcher, 2016		

6. Conclusions

The researchers of this study took part in several fieldwork assignments after installing devices at Umm el-Jimal. The results of monitoring over a period of seven months allowed the researchers to determine the factors that threaten the survival of Umm el-Jimal archaeological heritage site. These factors can greatly influence the site structure and damage it permanently.

The temperature at Umm el-Jimal affects the stones of the site in two ways. Fluctuations in temperature during one day or one month may cause an acceleration of fatigue in susceptible materials, which results in a frequent expansion and contraction of the stones. In order to collect evidence on the expansion and contraction of the stones in Umm el-Jimal, the researchers observed the readings of the loggers; In winter, the maximum temperature reached 24.4 °C, and the minimum was around 2.6 °C. This shows a large difference in temperature. Regarding evidence on the changes occurring during one day, the maximum temperature reached 35.9 °C, while the minimum reading was 23.5 °C –

which indicates an unstable temperature. This fluctuation is relevant to the structural stability of the buildings bevause it induces a number of weathering mechanisms, particularly speaking, cracks and scaling. Furthermore, this may affect the structures significantly, and cause a collapse in the bonds between particles and or between layers.

The increasing temperatures and the rotting, increased the biological growth of micro-organisms. Usually, their growth increases at temperatures ranging from 20 °C to 35 °C; this range is generally favorable to the micro-organisms' metabolic activity (Camffuo, 1998). Such conditions were present at Umm el-Jimal. During June, the recorded temperature in Umm el-Jimal was no less than 20 °C. In winter, the logger recorded many readings around 20 °C. These temperatures led to a notable growth of micro-organisms across a wide area on the surface of the structures. Several micro-organisms such as the special lichen cover the surface of materials, which enhances the deposition of airborne particulate matters.

Changes in relative humidity during the day and seasonally were also considered in this study. The standard rates of relative humidity are between 30-40 %, but a greater proportion of relative humidity had been recorded at Umm el-Jimal reaching an average of 52 % during the first three months of monitoring. The maximum relative humidity recorded reached 76.3%. On average, relative humidity was recorded at 33.3 %. During June, it was recorded at 18% - which is less than that of the international standards. Thus, the results demonstrate high and fluctuating levels of relative humidity which can have an effect on dissolving crystallized salts, movement, and change contributing to the formation of decay. The changes also played a role in the increase of decay features at the site which usually include pitting, staining, surface loss, case hardening, and efflorescence.

In reference to pollutants, the researchers monitored the level of CO_2 as an important factor which contributes to the contamination at Umm el-Jimal. The site witnesseed a high level of CO_2 during the seven months of monitoring reaching up to 550 ppm while the standard limit of CO_2 in the atmosphere is 450 ppm. The level is remarkable on the surface, with the emergence of black and grey crust in many blocks of stone at the site. The reasons behind the high levels of CO_2 may be attributed to the location of Umm el-Jimal in al Mafraq semi-industrial region which houses plenty of factories in addition to the fact that Umm el-Jimal is located near a highway with heavy traffic. Furthermore, the high CO_2 levels are generated also by the behavior of local communities in the area who build outdoor campfires, which is, another factor that influences the degeneration of the structure of the wall.

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