SALINITY EFFECTS ON CULTURAL HERITAGE SITES WITH FOCUS ON THE TOMB OF THE KINGS IN PAPHOS - CYPRUS

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ABSTRACT

The impact of salt is a process that accelerates the degradation of historical sites or buildings, posing a major problem for coastal sites. Cyprus, an island rich in cultural heritage, experiences significant effects on its sites from sea salinity, as its eastern Mediterranean location is one of the most saline environments in the world.

This paper focuses on a preliminary investigation into the effects of salinity on cultural heritage sites, specifically the Tomb of the Kings, located on the southwest coast of Paphos, Cyprus, near the seashore and sea spray. The Tomb of the Kings, a UNESCO World Heritage site, consists of underground monumental burial structures carved out of solid rock, dating from the 4th century BCE to the 3rd century CE. The methodology used to measure the site's salinity levels includes both micro and macro approach, with in situ measurements, laboratory analysis, and remote sensing techniques to correlate and cross validate the results. The main purpose of this study is to create a salinity risk assessment framework, able to analyze how this phenomenon can affect the coastal heritage sites. Preliminary results have highlighted areas of higher and lower concentration of salts at the site, but further investigation is necessary to fully understand the behavior of salinity and its links to the degradation and conservation of the site of Tomb of the Kings.

Keywords: Remote Sensing, Satellite, Salinity, Conductivity, Acidity, Cultural Heritage

1. INTRODUCTION

1.1 Salinity effect on heritage sites: A significant threat

Salinity can become a major problem for heritage sites for various reasons. It significantly impacts the structural integrity of heritage monuments. It can accelerate the deterioration of building materials like erosion, corrosion, efflorescence and structural weakening. The crystallization of high salt concentration within the pores of the stone can cause expansion and therefore, cracking. Vulnerability of cultural artifacts can lead to cracking, staining and loss of identity. High salt concentrations also cause soil deterioration, vegetation loss, and landscape destabilization, compromising the integrity and aesthetic value of heritage sites [4].

Numerous investigations over the past two decades have explored how the marine environment contributes to the deterioration of buildings near the seashore. Marine aerosols consisting of inorganic salts and organic matter play a crucial role in the deterioration of buildings, including historical sites, located close to the sea. [6].

The most common salts observed on historical constructions near the sea are efflorescence on the surface and sub-efflorescence inside the pores of the stone [7]. This paper focuses on salinity effects on cultural heritage sites in Cyprus, specifically the Tomb of the Kings site located in Paphos. Salt concentrations are being identified at the site of the Tomb of the Kings and categorized into higher and lower levels of concentration. The intention of this paper is to create a risk assessment in the future which will relate the salt concentration from the sea on the site.

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1.2 Visual Observations

Salinity effect on buildings or sites cannot always be noticed. However, in many cases, they can be visually observed, especially on sites that are more exposed to saline environments. There are some characteristics of visual observations that indicate salinity effects such as crusting, cracking and spalling, peeling, surface roughness, loss of detail, biological growth and weathering patterns [4].

From field observations, it can be seen that salinity has a dramatic effect on the existing condition of the Tombs. It is important to mention that the site is located by the southwest coast of the city and is exposed to the salinity derived from the sea as wind blows from the northwest [5]. Very often, stone surface anomalies and roughness can be observed, and cracks and uneven holes appear frequently. In many other cases, it is clear that salt crystallization occurs on the surface of the stones. More specifically, whitened spots are visible randomly on the surface, and damaged parts of the monument have salt concentration around their perimeter. It is clear that salts are affecting the deterioration rate of the Tombs.

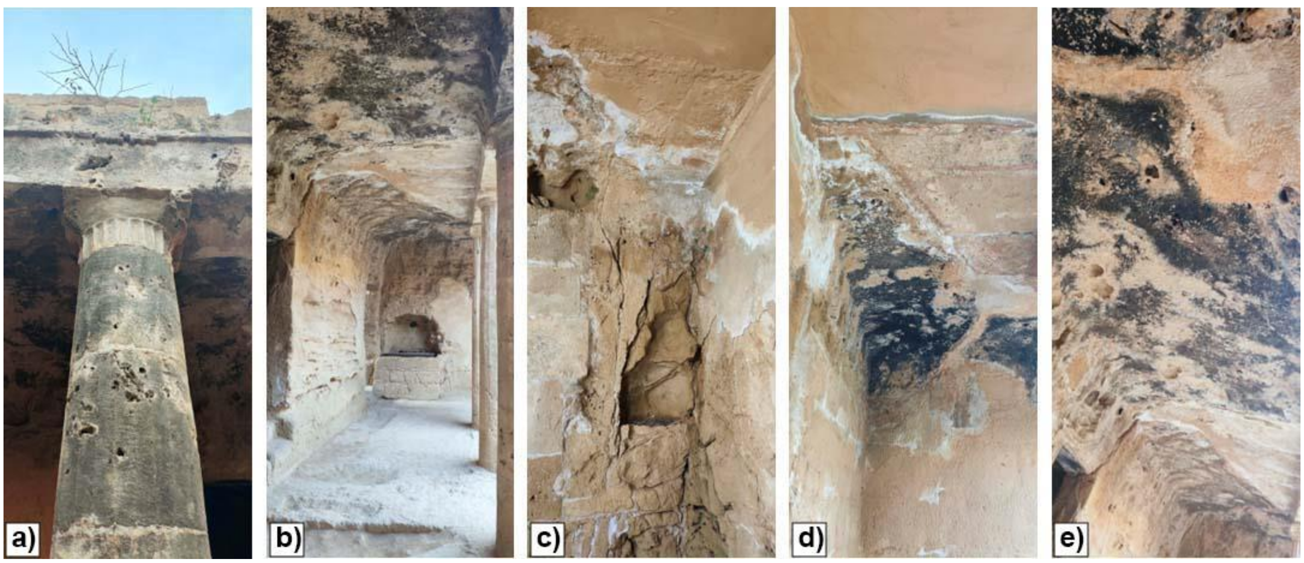

Figure 1. Observations of salt concentrations on Tomb 3. Uneven holes on the column of the Tomb (a). Weathering patterns on the ceiling of the Tomb (b). Salt crystallization and cracks in the top corner of the Tomb (c). Weathering patterns and salt crystallization on the top corner (d). Weather patterns on the ceiling of the Tomb (e).

2. METHODOLOGY

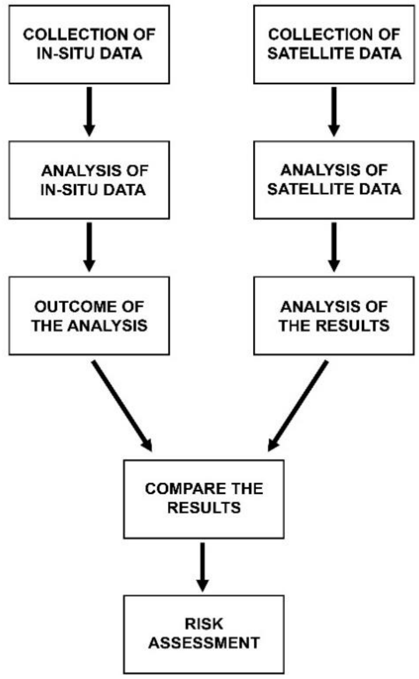

Figure 2. Methodology Diagram showing the process needed to reach the finalization of the risk assessment.

2.1 Description of sampling location

The first step of the methodology was data collection. Numbered gridded points were created on the map with 50 meters spacing between them. The grid was placed on the west side of the area where we assume that the site is exposed to sea salinity and covers a major part of the site as winds blow from the northwest side of the island and monuments are facing the west. This area consists of sandy ground, mainly located at the center and northwest side and low vegetated ground, located on the southern side with dense vegetation on the north side of the gridded area.

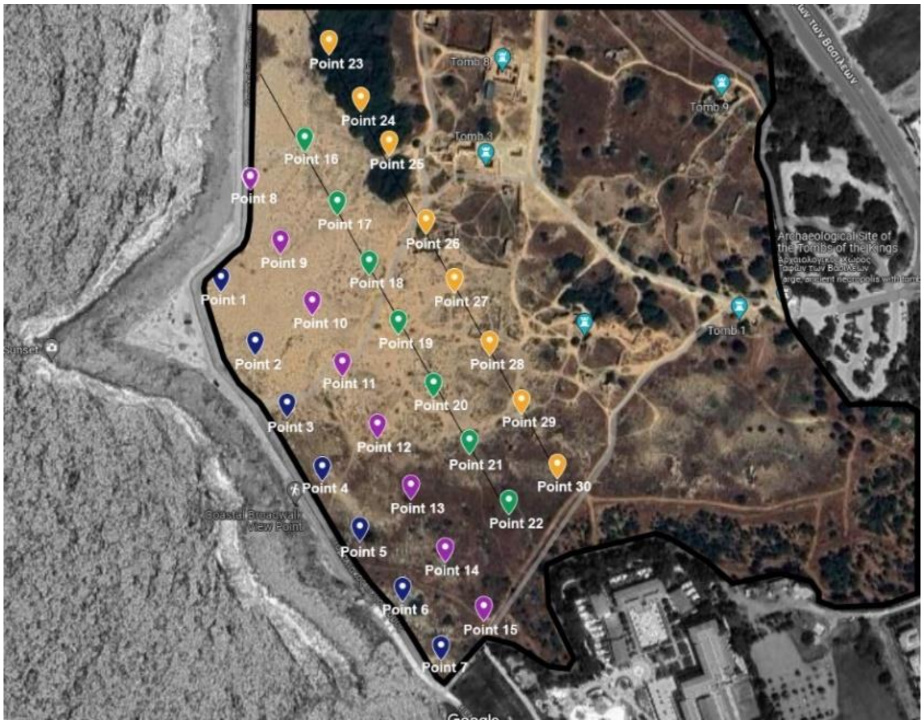

Figure 3. The map of the site with the creation of grid points of interest.

2.2 Collection of the samples

The next step was the collection of two samples from each of the points on the selected grid area. The first sample was taken from the surface of the ground and the second sample was taken from inside the ground between 5cm and 25cm in depth. The idea was to take the samples from the same depth (around 15cm deep), although this was not always possible in the field as in some areas, the ground was hard to penetrate and collect the sample. For this reason, the depth for collecting the samples was ranged between 5cm and 25cm.

Figure 44. Sample collection of the point numbered 16 from the surface (left) and 15 cm depth (right)

2.3 Analysis of the samples

The samples were taken into the laboratory where the aim was to measure the salinity from each of the gridded points of interest. Each sample was mixed with deionized water to measure the conductivity (μS/cm) and acidity (pH), which are two very important components that reveal the presence of salts. More specifically, 30ml of each sample were mixed with

170ml of deionized water, blended and the results obtained. This process, provided information on conductivity (µS/cm) and acidity (pH) from each point, allowing the creation of an initial map showing the different levels of salinity around the area.

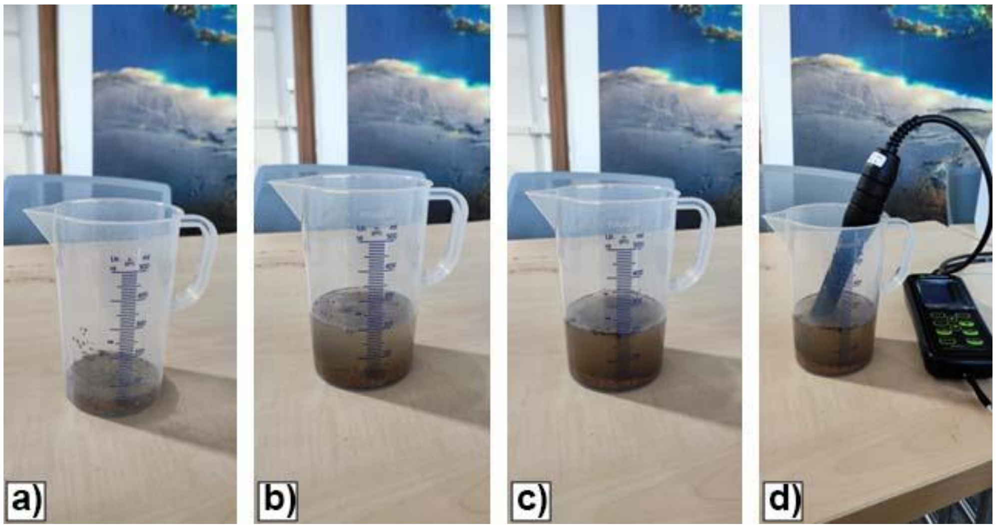

Figure 5. Analysis of the samples in the laboratory. 30ml of sample (a). 170ml of deionized water added (b). Sample and deionized water blended (c). Measurements collected with device (d).

Table 1. Sample results from the laboratory. Results from the surface on the left column and results from depth in the ground on the right column.

	SURFACE				DEEP		
	Temperature (°C)	Acidity (PH)	Conductivity (µs/cm)		Temperature (°C)	Acidity (PH)	Conductivity (µs/cm)
Point 1	24.6	9.54	105	Point 1	24.6	9.51	137
Point 2	24.5	9.54	106	Point 2	N/A	N/A	N/A
Point 3	24.5	9.59	79	Point 3	24.3	9.64	34
Point 4	24.2	9.24	84	Point 4	24.2	9.3	85
Point 5	24.3	8.66	223	Point 5	24.2	9.32	101
Point 6	24.3	8.41	120	Point 6	24.2	8.84	67
Point 7	24.3	8.97	149	Point 7	25	9.24	105
Point 8	24.6	9.44	150	Point 8	24.4	9.68	64
Point 9	24.5	9.46	63	Point 9	24.5	9.58	39
Point 10	24.6	9.4	24	Point 10	24.7	9.62	39
Point 11	25.1	9.63	39	Point 11	25.3	9.49	43
Point 12	25.5	9.3	65	Point 12	25.5	9.5	51
Point 13	25.5	9.22	143	Point 13	25.8	9.49	109
Point 14	25.9	9.08	111	Point 14	26	9.12	101
Point 15	26.1	8.91	131	Point 15	N/A	N/A	N/A
Point 16	26.3	9.59	64	Point 16	26.3	9.55	40
Point 17	26.2	9.32	79	Point 17	26.2	8.07	47
Point 18	26.3	9.39	51	Point 18	26.5	9.51	34
Point 19	26.8	9.61	39	Point 19	26.9	9.63	35
Point 20	27	9.4	39	Point 20	26.8	9.49	32
Point 21	24.5	8.88	114	Point 21	24.8	9.4	33
Point 22	25	8.88	100	Point 22	25	9.45	62
Point 23	N/A	N/A	N/A	Point 23	N/A	N/A	N/A
Point 24	N/A	N/A	N/A	Point 24	N/A	N/A	N/A
Point 25	25.2	9.45	66	Point 25	25.1	9.49	22
Point 26	25.2	9.59	49	Point 26	25.3	9.56	22
Point 27	25.3	9.48	40	Point 27	25.2	9.45	15
Point 28	25.3	9.4	42	Point 28	25.3	9.65	19
Point 29	25.5	9.18	54	Point 29	25.5	8.93	26
Point 30	25.7	9.01	112	Point 30	25.7	9.09	37

2.4 Collection and analyze of satellite data

Remote sensing methods were used to detect the salt concentration at a macro level for the entire extension of the archaeological site. The soil salinity index was used in the Copernicus browser with data from Sentinel-2. More specifically, bands B11 and B12 from Sentinel-2 satellite data were used to assess soil salinity. The width was set between 0.25 – 0.38.

Table 22. Bands of Sentinel-2 used for this remote sensing satellite analysis.

Band Number	Band Description	Wavelength Range (nm)	Resolution (m)
B11	Shortwave infrared 1 (SWIR1)	1565–1655	20
B12	Shortwave infrared 2 (SWIR2)	2100–2280	20

3. RESULTS

3.1 Results from sampling procedures

The results from the laboratory experiments, revealed high conductivity levels in the southern part of the area of interest, where the most vegetation exists and lower levels in the central and northern parts, where the sandy ground is located with an exception in the northwest point of the study area. On the other hand, the results showed higher acidity levels in the northern part and lower in the southern part of the area of interest.

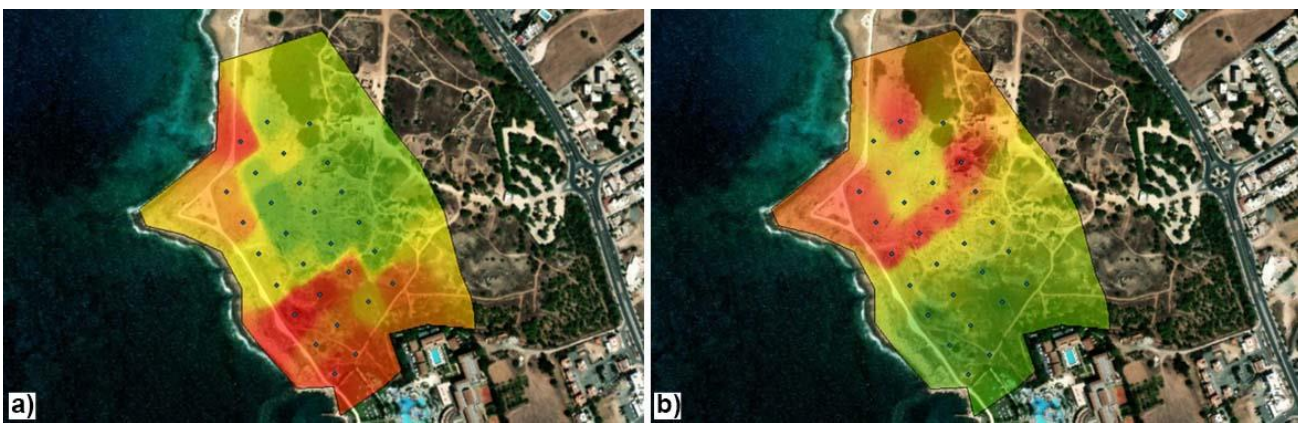

Figure 6. Results from the laboratory showing where lower and higher concentrations of Conductivity (μS/cm) and Acidity (pH) exist. The left-side image (a) shows Conductivity (μS/cm) levels. Red color indicates higher concentrations of conductivity, and green indicates less concentration of conductivity. The right-side image (b) shows Acidity (pH) levels. Red color indicates higher concentrations of acidity, and green indicates less concentration of acidity.

3.2 Results from remote sensing procedures

The results from remote sensing show higher soil salinity levels in the central and northern parts of the study area, and lower levels in the northeast and southern parts of the area of interest.

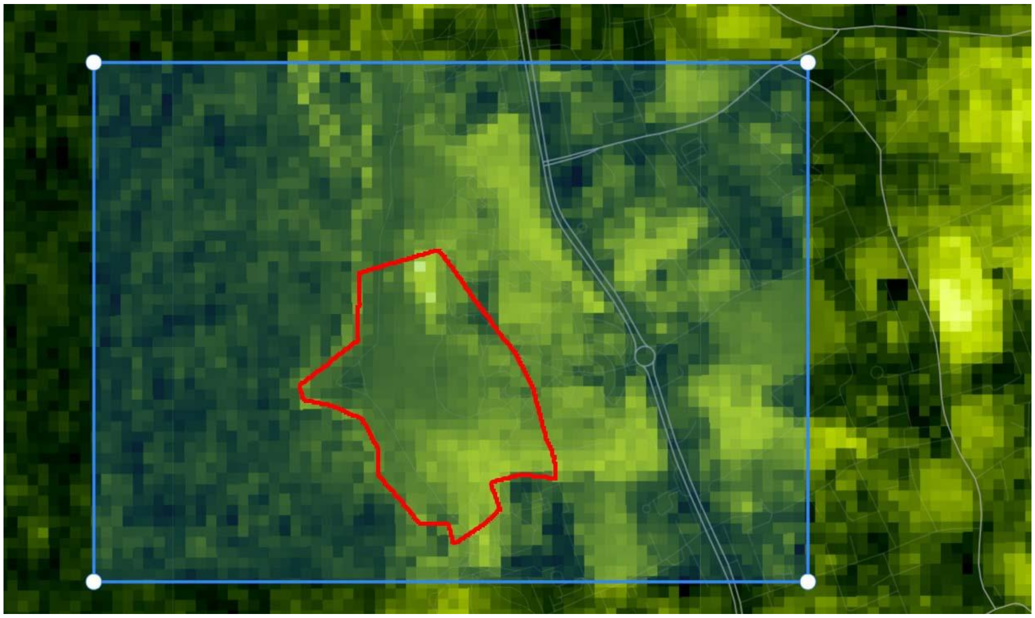

Figure 7. Satellite image from Sentinel-2 applied with the soil salinity index. Darker colors indicate a higher concentration of salinity, and lighter colors indicate lower concentrations of salinity levels on the site. The red outline indicates the Tomb of the King's site.

The acidity (pH) results from laboratory partially agree with the soil salinity image from the satellite, while the electrical Conductivity (μS/cm) does not. The differences between in situ sample collection and satellite imagery might be due to the collection methods used in the field. More specifically, the aim was to collect two samples from each point: one from the surface and one from 15cm deep. However, in many cases, it was not possible to collect the samples from a depth of 15cm due to obstacles in the soil, such as rocks or pebbles, leading to the collection of samples from shallower depths. Another reason for the differences in results is the daily touristic traffic at the site, which can affect the salinity on the soil surface as people walk around the site.

4. CONCLUSIONS

This process gathered some initial results related to salinity effects at the site of the Tombs of the Kings in Paphos. The outcomes show that the remote sensing and sampling procedures agree on higher concentrations of salts in the central part of the study area. On the other hand, the results show a gap in low conductivity and acidity in the sampling procedures which is opposite to the remote sensing results. More data needs to be collected to build solid outcomes, and further analysis and research should take place to fully understand the real impact of salinity on the existing monuments. The intension of this research is to create a risk assessment to understand the behavior of salinity at the site, which can be used as a future tool to relate the salinity effect on other cultural heritage sites on the island. With a correct understanding of the correlation between the use of remote sensing satellite technology and laboratory results, we can create a risk assessment map specifically for the Tomb of the Kings site initially, and later develop it for other cultural sites in the country, ultimately aiding in the conservation and protection of cultural heritage sites.

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