Article

Analysing the Vulnerability State of The Cultural Heritage by Geomorphological and Geophysical Methods: A Case Study on The Black Sea Coast, The Roman Edifice With Mosaic Site of Constanta, Romania

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Abstract: Heritage monuments are religious, historical, strategic or civil edifices and could be deteriorated, even damaged due to their exposure to natural and human induced processes. The Roman Edifice with Mosaic (II-IV A.D.), the largest one in Eastern Europe is an ancient civil edifice built on the steep cliff in the western part of Black Sea, Constanța, Romania and being exposed to geomorphological and hydrogeological processes is affected by degradation. The main objective of this paper is to assess the current state of this ancient historical site in relation with the environmental instability in order to offer scientific support for rehabilitation process through interdisciplinary and non-destructive methods. Geophysical methods had been applied to analyze comparatively the spatial variations and flows of groundwater around Roman Mosaic over 10 years. Geomorphological hazards had been inventoried and mapped. The results emphasize the state of degradation of the roman mosaic pavement and ancient walls mainly through high variations of the deposits moisture due to poor maintenance which caused suffusion, slip processes, bring the mosaic into highly vulnerability range. Zoning vulnerability map of the Roman Mosaic environment is a necessary tool for continuously improvement of risk management because emphasize clearly the sectors which still confronting with hazards.

Keywords: cultural heritage; Roman Mosaic; geomorphological hazard; geophysical survey; geo-morphological methods; vulnerability zoning

1. Introduction

Over the history, a series of edifices had been built as a result of certain strategic, economic, social or religious requirements, edifices which nowadays are included in the national or world heritage. The value of these sites is given by a certain combination between their architectural features, notoriety, uniqueness, greatness and legends [(1), (2) (3) (4)]. Often, cultural, historical, archaeological sites had been used as nucleus of cities growth, extended to the present period [(5) (6) (7) (8)]. The changes, even those contemporaneous ones were added along with the urban development are responsible for disturbances to the natural environment balance with different responses from the historical edifices. Urban development (new constructions, sewage system and urban water supply systems the growing number of inhabitants and urban tourists generates different responses from the natural environment prone to the instability phenomena nearby cultural heritage sites as a result of increasing of the impact on heritage sites [(9), (10), (11), (12) (13)]. Subject of extensive reconstruction and consolidation, many historical, archaeological sites are still currently threatened by specific natural hazards driven by climatic, hydrodynamic and gravitational factors [(14), (15), (16), (17), (18), (19)].

Our paper is focusing on one of these fragile sites having a high exposure to natural and human changes threats. The Roman Edifice with Mosaic of Constanta (II-IV A.D.), an ancient spot facing urban environmental changes is located in Dobrogea Region, in eastern part of Romania. This heritage site was accidentally discovered, in 1959, precisely due to urban sprawl of Constanta town. The remains and mosaic degradations were not only caused by the damages through centuries and by the passage of time when they were buried, but also by the works carried out in the modern period to develop the Constanta residential area and harbor which is overlap on the ancient port Tomis [(21), (22), (23), (24), (25) (25), (27)]. This example underlines the importance of effectively preserving archaeological vestiges, especially in such dynamic environments as urban ones [(28), (29)].

Our approach to assessing the current and local vulnerability of the Roman Edifice with Mosaic, consist in analysis of all components likely to cause instability of relict front cliff which is the geomorphological support for The Roman Edifice with Mosaic, starting from the hypothesis that the main factors which induce that instability of mosaic pavement are anthropogenic ones.

The interdisciplinary approach, combining geophysical methods with topographical measurements and geomorphological mapping, helps to identify and assess geomorphological hazards, responsible for the reshape of the land surface, with rapid impact on ancient vestiges condition [(30), (31), (32), (33), (34), (35), (36)].

The main aims of this work are: 1) to inventory the spatial vulnerabilities of Roman Edifice with Mosaic from Constanța as a result of relation between the heritage monument and the geomorphological environment in its capacity of support; 2) to identify the anthropogenic impact sources that human changes have on it in order to assess current unsteady state and to analyze the types and scale of instability monument; 3) to provide valuable informational inputs in order to improve the environmental rehabilitation of surroundings of this cultural heritage.

Regional Settings

Among the historical touristic attractions from south-east side of Romania, there is a cultural heritage known as The Roman Edifice with Mosaic assembly from Constanta (IV A.D.), located in east side of the low tableland South Dobrogea (Figure 1 a), along Black Sea front cliff shaped as an abrasion terrace in the south-western side of a peninsula, situated between the harbor of Constanta and the tourist port of Tomis (Figure 1 b).

As a result of the smooth relief of tableland, the low elevations (25 – 200 m) (Figure 2 a), but especially the vicinity of the Black Sea shore, the Dobrogea Plateau, which was part of the historical Roman province Scythia Minor, represents one of the old Geto-Dacian dwelling areas on the territory of Romania, knowing throughout history different influences (Scythian, Slavic, Bulgarian, etc.) and colonizations (Greek, Roman, Ottoman).

Among the vestiges of the fortress-cities built in Dobrogea along the Danube and the Black Sea shore and which remained testimonies of historical transformations, commercial and defensive military strategies, is also the fortress and port of Tomis. It was built over the Sarmatian limestones deposits and Quaternary loess deposits of peninsula of Constanța [(37)].

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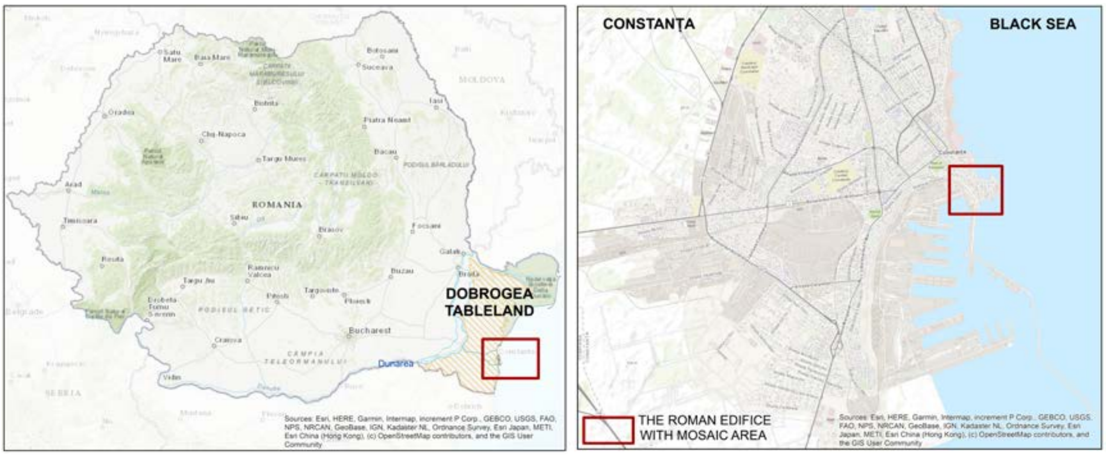

(**a**) (**b**)

Figure 1. Geographical settings of interest site: (a) in the south-east of Romania, on the eastern side of Dobrogea tableland, (b) a peninsula lies in north of the largest harbor of Romania, city of Constanța.

Its south-western side is anthropogenically reshaped since the first centuries AD by the construction of a few anthropogenic terraces used for ancient civil constructions and the harbor of Tomis. The Roman Mosaic Edifice housed the storage and commercial spaces related to ancient port.

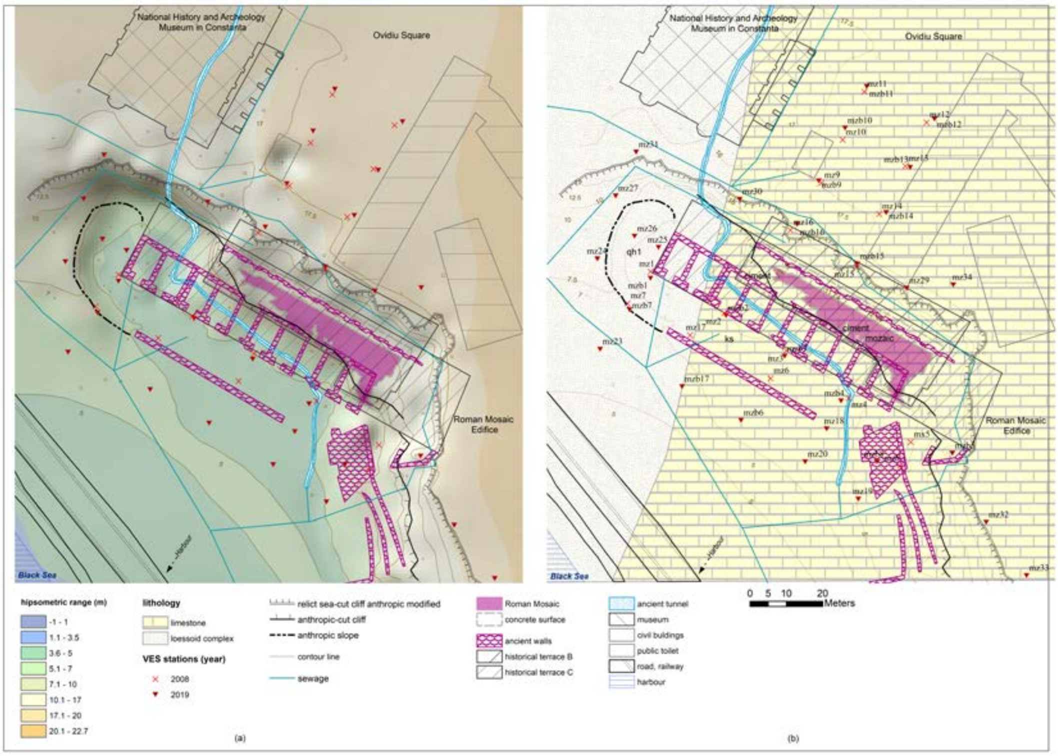

Figure 2. The Roman Edifice with Mosaic area (a) hypsometry and (b) lithological deposits.

The Roman Edifice with Mosaic was built on four anthropic terraces on the Black Sea front cliff, including one terrace below actual ground level (Figure 3). The upper terrace is the level of ancient town Tomis, the second terrace with mosaic pavement was built on loess sedimentary layer, the third terrace, an indoor hall with ancient wall soldering cliff (L=100) and vaulted warehouses, was erected on thin loess sedimentary layer and limestone and the lowest terrace with commercial pavilions, built on limestone (Figure 2 b),

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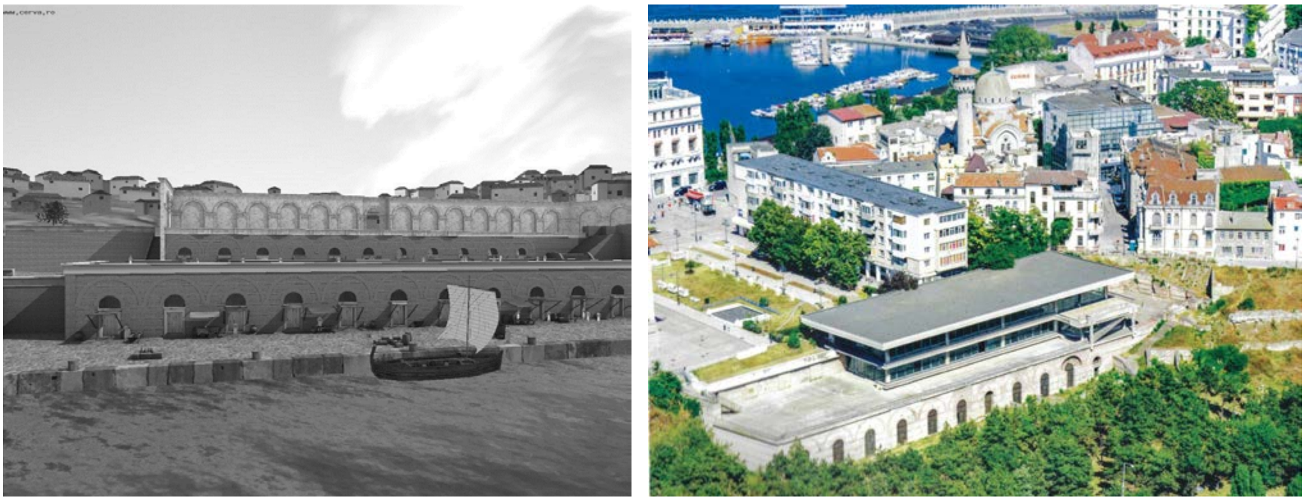
nowadays being an underground level (37). Under the lowest terrace there are a few segments of a roman gallery.

Figure 3. The Roman Edifice with Mosaic built on four anthropic terraces on the Black Sea front cliff.

It was an important public, commercial, political and cultural place in the ancient city of Tomis (38) (Figure 4), being the largest archeological complex with mosaic pavement (2040 m²) from south - east of Europe and until nowadays, only about 820 m² have been preserved and protected by a concrete hall [(25)]. Nowadays, public and residential buildings were constructed to the north and north-eastern part of the ancient edifice.



(a) (**b**)

Figure 4. (a) Virtual reconstitution of the Roman Edifice with Mosaic (38) and (b) nowadays visualization of the edifice (Association for the Salvation of Cultural Heritage in Dobrogea, 2022 https://patrimoniuldobrogean.ro/en/the-roman-mosaic-edifice/).

Abrasion terrace and front cliff are outcropping in Quaternary loess deposits, Sarmatian limestones (Figure 2 b) with thin intercalation of clay, marl, marine sand layers. Subsequently, as result of the expansions of the built environment, anthropogenic deposits (fillings) were added. The tectono-stratigraphic structure of these deposits is tabular towards monocline, discordant and faulted (39).

Climatic conditions generate a severe deficit of air humidity due to low rainfall (300-450 mm/year), related to high values of temperature (annual average is 10.0°-11.5°C) and, as result, 600-700 mm/year evapo-transpiration values are recorded.

Ample variations of values of sedimentary deposits moisture are not strongly correlated with meteorological conditions, but can be interdependent by municipality sewage networks efficiency, yielding a slowly but continuously damage status of the mosaic pavement. Municipality sewage and water supply networks of Constanta provide other moistening sources of ground foundation of interest site, through leakages and water seepages.

As a consequence, the Roman Edifice with Mosaic was damaged due to geomorphological and hydrogeological processes through slow sliding movements of a quite large sector of the relict abrasion cliff (Figure 5 a, b).

(**a**) (**b**)

Figure 5. Degradation of (a) the roman mosaic pavement through geomorphological and hydrogeological processes (2019), (b) detail of the most damaged part of mosaic pavement and ancient wall.

Therefore, the mosaic pavement, the ancient wall and the retaining walls were affected by: leakages, local failures, suffusion, erosion and differential settlements.

2. Materials and Methods

All methods applied in this study are non-invasive for natural environment and heritage site.

The study is the result of an interdisciplinary research consisted in topographic measurements, geophysical surveys, mapping and geomorphological analysis in order to identify the sources of the instability of surrounding area of the Roman Edifices with Mosaic and archeological plans, geographical and geological maps and ortho-plans have been included in a GIS analysis and related to geophysical assessment. (Table 1).

Table 1. Data base map.

Map	Editors	scale	year
L-35-142-A-d-3	DTM. MANRSR	1:10 000	1975
Map of Constanta City	Ionescu Dobrogianu	1:9 000	1931
The Roman Edifice with Mosaic plan	V. Canarache	1:500	1959-1966
Map of Ovidiu Square plan	National Research-Development Institute for Land Improvements-ISPIF	1:500	1970
Orthophoto imagery Old imagery	ISPIF	1:15 000	2011

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Field surveys was made in 2008 and 2019, with the propose of inventorying, mapping and analyzing the natural and anthropogenic factors of wide degradation degree of roman mosaic during last decades. The field surveys had been done in the summer time when the moisture degree usually reflects high amplitude of variations of air humidity.

There are important implications of variations of climate parameters in the geoelectrical survey readings and thus, in order to reduce the gaps determined by these variations, we chose that the geophysical measurements be carried out in similar time intervals from a meteorological point of view in the two years. Comparing the meteorological data such as temperature, relative humidity and air pressure during the days when geoelectrical surveys were done, it follows that meteorological parameters considered was rather stable without wide variations throughout surveys in ten years rank: the values of air temperature varied between 24° and 31°C, low range of air pressure, between 1006 mb and 1014 mb, and 40 – 55% air humidity.

Field investigations carried out: topographical survey, to map the recent shape of the morphological surface, using Sokkia 660 Total Station; geoelectrical survey (Figure 1 b, c), to highlight the natural ground moisture and leakages; geomorphological mapping, to inventory the natural and anthropic features and to assess the geomorphic hazards issues of the Roman Edifice with Mosaic (Table 2).

Table 2. Filed Investigations made in 2008 and 2019.

Field measurements	Mosaic pavement	Down to cliff	Above the edifice
Topographical survey	50 points	150 points	110 points
Vertical Electrical Sound (VES)			
2008	-	17 stations	-
2009	-	17 stations*	17 stations
Self-Potential (SP)	180 points along 3 the survey lines	-	-
Inventory and mapping			
2008	-	-	-
2009	1	1	1

* Geophysical survey records were carried out at the same stations in these two years.

(**a**)

(**b**)

Figure 6. (a) Vertical electric soundings (VES) readings made in front of roman edifice and (b) self-potential surveys made on roman mosaic pavement.

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Topographic measurements along with older topographical maps (Table 1) had been used to collect accurate elevation data and to generate a large-scale DEM in order to reassemble the actual detailed shape of terrain which support the mosaic edifice, man-made landforms included, in order to mapping microrelief, shallow deposits and active geomorphic processes (gravitational and hydrodynamic).

Geoelectrical surveys consist in two methods: vertical electric soundings (VES) and self-potential (SP) in order to establish lithological features, ground water levels depth, water sources categories, infiltrations and exfiltrations, and furthermore, to assess the related geomorphic hazards.

Geoelectrical measurement points network was designed taking into account two criteria: the relatively uniform spatial distribution of measurement points, so that the geoelectrical images would have the same accuracy of the information, and the correspondence between measurement points with known vulnerable points of the edifice.

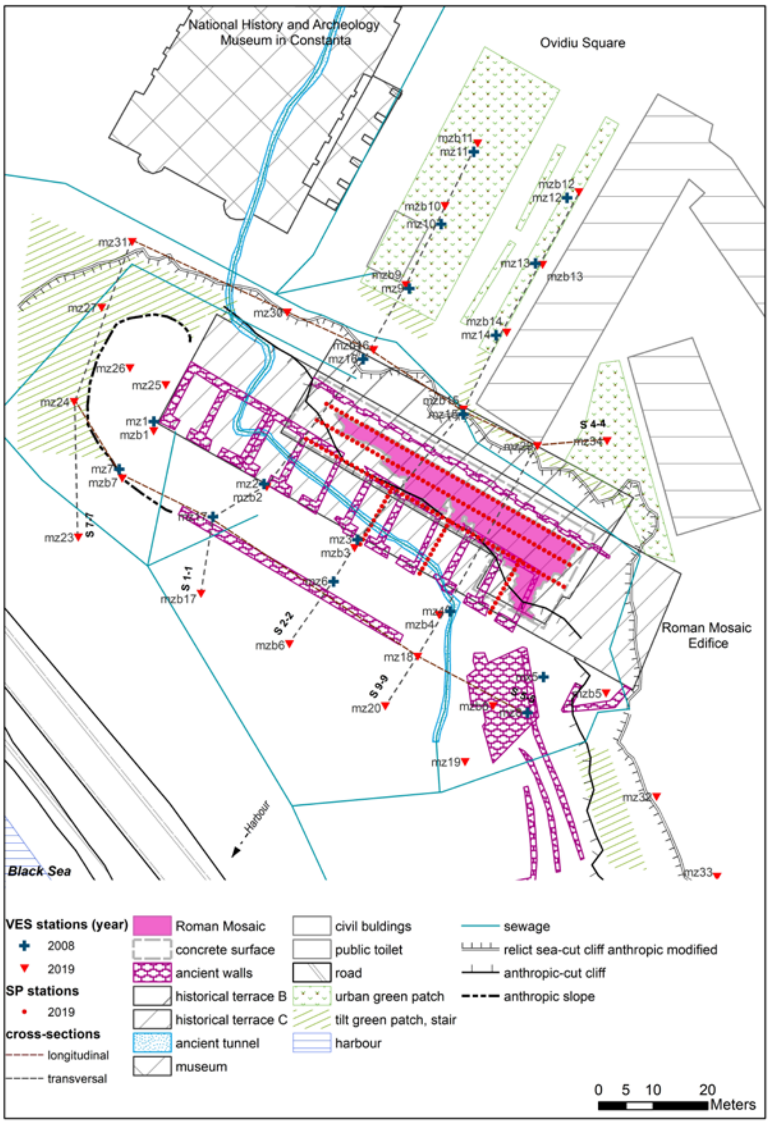

Figure 7. Spatial distribution of geophysical surveys stations and longitudinal and transversal cross-sections (S n-n).

The vertical electric soundings (VES) were made using Super Sting R1 IP AGI down the cliff from the edifice with mosaic in 2008 (17 VES) and repeated its in 2019 and above

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of roman edifice in 2019 (34 VES). Survey depth of vertical electric soundings was 12 meters in 2008 and 20 meters in 2019 with a view to intercept the lower terrace of edifice and the hydrostatic levels (Table 2 and Figure 7).

Specific calculation method of resistivity for non-cohesive and porous rocks was applied since the penetration current depth (sounding curves) is smaller (AB/3):

$$\rho a = k\frac{\Delta V_{MN}}{I_{AB}}, \text{ where} \tag{1}$$

k is Schlumberger geometric factor related to the distance coefficient AB (electrodes) and

$$k = \frac{AM \cdot AN}{MN} \cdot \frac{\pi}{2} \tag{2}$$

ΔV measured at MN slot and IAB, slot AB is

$$\frac{AB}{3}, \text{ if} \tag{3}$$

there are non-cohesive rocks.

Self-potential method emphasizes the underground water flow. Self-potential network survey consists in 1 m^2 cells and were applied only on mosaic pavement and vaulted rooms, the ancient warehouses bellow the mosaic pavement, along 3 survey lines (Figure 6 b). The obtained data of self-potential method were processed and analyzed in MATLAB and ArcMap 10.6 software. The resulted maps indicate the self-potential effect images from the surface of investigated ancient rooms and reveal the infiltrations and exfiltrations.

Data analysis using QGis 3.4, ArcGIS 10.6, Surfer 8 were done to outline the dynamic of the morphological and the geoelectrical parameters.

Morphometric analysis was performed by means of spatial distribution of slope and hypsometry parameters; the maps were generated based on the contours (with 2.5 meters equidistance) extracted from topographic map 1:10.000 (1975) corroborated with DEM obtained from interpolating points recorded by topographic measurements. The analysis of superficial deposits and geomorphological processes was carried out following detailed geomorphological mapping based on field observations and imagery at different scale.

The interpolation of geophysical, lithological, geomorphologic parameters allows us to set up the spatial distribution of the different degrees of vulnerability of the Roman Edifice with mosaic related to the surface's geomorphologic and hydrogeological hazards. The geomorphological vulnerability map depicting those areas can have vary degree of damage from the occurrence of geomorphological hazards. Accordingly with the idea that the vulnerability is the key for risk mitigation [(40)], it is necessary to understand the spatial distribution of surfaces hazards prone. Geomorphological hazards, morphometrical parameters (such as slope degree, hypsometry), geophysical parameters, categorized in different classes were mapped being considered important factors for the vulnerability assessment. The vulnerability factors preliminary identified, have become attributes for vulnerability map, ones they have gotten scores depending on their magnitude and their contribution (ones of them having an essential contribution than other). Using the different contribution weight of the factors in vulnerability of the ancient edifice, the weighted average was applied and finally converted to percentage.

$$V = \frac{\sum_{i=1}^{n} fi \cdot pi}{\sum_{i=1}^{n} pi}, \text{ where}$$

V is vulnerability,

f_i is considered factors

p_i is the weight of the factors in vulnerability of old edifice.

3. Results

3.1. Pattern of moisture deposits dynamic identified through geophysical methods

A great spatial distribution of the different status of deposits related to the edge of the relict sea cliff and toe slope was highlighted through geoelectrical assessment. The moisture of mosaic foundation ground may be from different sources as phreatic levels, pluvial, seepage, sewage, or it is influenced by buried walls, ruined buildings and aqueducts.

The size of the investigation area where the resistivity methods was applied, has undergone changes from 2008 to 2019, in the attempt to pinpoint the sources of infiltrations and the causes of the increased morphodynamic in recent decade.

Sixteen longitudinal profiles and cross sections on sea front cliff and mosaic pavement were made (six of them are illustrated in figures bellow) using vertical electric sounding (VES) at 12 – 20 meters depth, with the purpose of inventorying the mosaic degradation sources.

The phreatic water levels had been identified into shallow deposits at 3 - 4 meters depth, then, at 7-8 meters depth and the ground-water level was located bellow 17 meters at the base of loess and silty sand deposits, above some thin clay layers.

The geoelectrical survey results highlight the natural ground moisture and leakages which are a critical issue for the surrounding area of the mosaic edifice, through dynamic of hydro-morphological and anthropogenical processes.

The apparent resistivity values (ar) measured in 2019 are locally more than 30 times greater than 2008 values both in superficial layers and in depth (Table 3.). Regarding the range between the minimum and maximum values recorded, they are about 100 times higher in the two years analyzed. The ratios of the minimum and maximum values recorded on the whole study area in 2008 and 2019 vary varies from 1.54 to 3.8. The variations of standard deviation values that are in scale of hundreds (anomalies), are greater in 2019, with a ratio of 2.28 than 2008. Consequently, we focused on anomalies since they may indicate, either supplementary moisture or natural and anthropic discharge from hydrogeological system, both sources of mosaic damages.

Table 3. Minimum, maximum, mean and standard deviation of apparent resistivity (ar) values.

apparent resistivity	ar 2008	ar 2019	ar 2019/2008
Minimum	9.17891	34.4707	3.8
Maximum	600	918.84	1.54
Mean	84.15488	309.713	3.68
Standard deviation	110.053	249.8555	2.28

To determine variability of geoelectrical data we had designed longitudinal and transversal geomorphological and geoelectrical cross sections on each side of ancient mosaic pavement and through it.

First step of our geophysical research was focused especially on the leakages from seepage water system and water supply and on analysis of the spatial distribution of resistivity values at different depths, in order to find out inflow and outflow levels in surrounding deposits of mosaic pavement. We notice some thin layer with higher moisture variations at 1.5 meters depth and at 3-4 meters. The superficial water infiltration level highlighted in the cross profiles (Figure 7, 8 and 9) at 3-4 meters depth is outlined by rapid changes of direction of the apparent resistivity curves.

The hydrostatic level located at 16-18 meters is not influenced by sewerage in 2019 compared to 2008.

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We notice some isolated areas in north side of mosaic with high moisture degrees of deposits and fillings, highlighted by low apparent resistivity values (Figure 8).

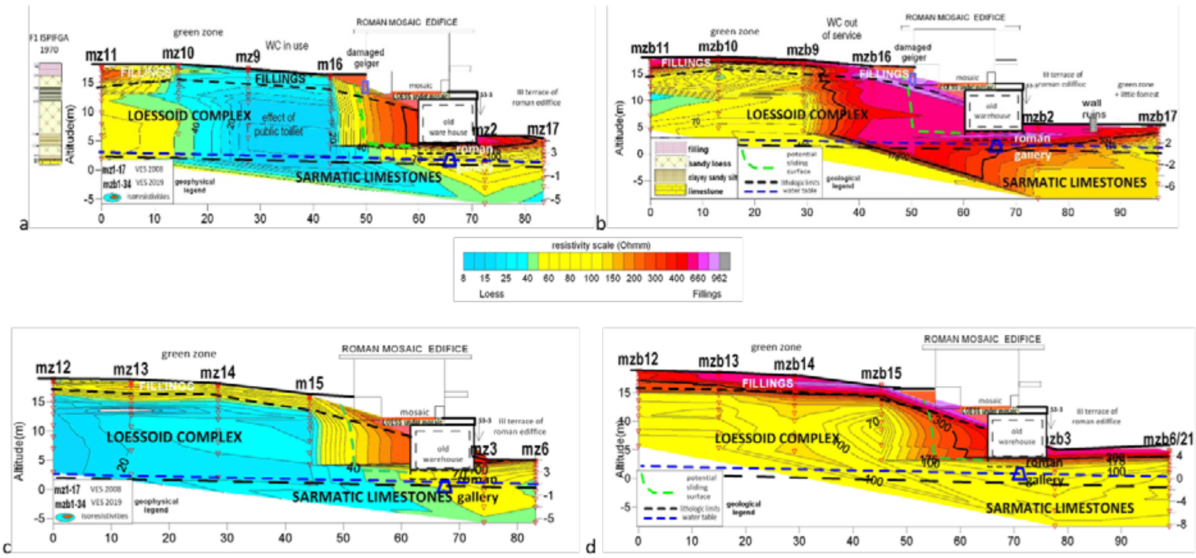

Figure 8. Geophysical and geomorphological cross sections through the Edifice with Mosaic, scale 1:600, (a) S1-1 /2008, (b) Sb1 -1/2019, (c) S2-2/2008, (d) Sb2 -2/2019, NNE – SSW orientations.

An interesting maximum contrast of resistivity values between 2019 and 2008 is a local anomaly area located below mz9 (Figure 8 a) and mzb9 (Figure 8 b) VES measurement points. In 2008 the resulting values of apparent resistivity had been calculated at the 8 – 50 Ohm range proving heightened infiltrations. By comparison, in 2019 the infiltrations were lower, even though the values of apparent resistivity were still quite reduced because of the remanent moisture (50 – 150 Ohm). The shape of the apparent resistivity contours is totally different shaped. This fact is clearly underlined by the different appearance of the apparent resistivity curves shown on the cross-sections (Figure 8).

The infiltration and sewage groundwater-induced (2008) had generated a slide surface along the front cliff, pushing towards ancient walls, and some ripples had appeared on mosaic pavement. Both phreatic levels were affected by the leakages then. The shape of the apparent resistivity contours obtains in 2019 reveals significant realignment of the underground-water processes to the hydrogeological pattern. In fact, it is quite visible around the 500 – 600 Ohm range one of the natural emergences at 4-5 m depth (Figure 8).

Bellow the ancient edifice, at a lower altitude, the resistivity values are increasing (40 – 180 Ohm in 2008 and 100 – 360 Ohm in 2019), as the effect of some gaps due to the presence of ruins of Roman gallery, fillings and landings from the groundwater levels (Figure 8 a, b, c, d and 9 b).

Two infiltrations sources at 4 – 8 meters depth still remain active into the cliff sector above the mosaic pavement (Figure 8 a, c and 9 a). Regarding the nature of these sources, it is obviously linked by museum and residential buildings, but in depth there is no other water sources as water supply or water seepage. The shape of apparent resistivity curves indicates buried anthropic structure: in fact, remains of an aqueduct and a roman tunnel influenced the direction of underground infiltration flow directions. More over between these two water sewage sources, behind of the mosaic pavement, there is a sector with high porosity of the deposits which is emphasize by over 500 Ohm apparent resistivity (Figure 9 a), which facilitates the high variation of moisture deposits.

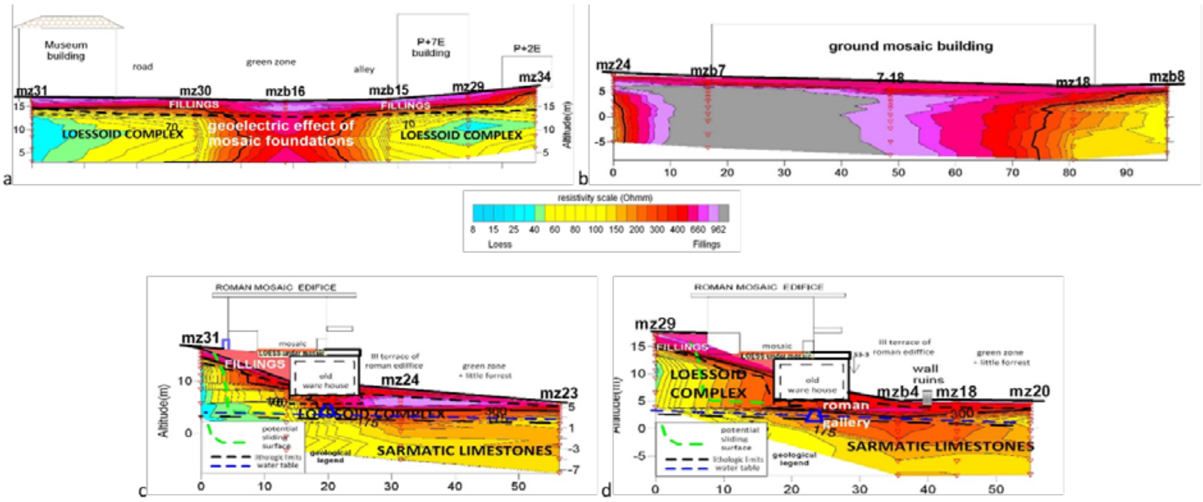

Figure 9. Geophysical and geomorphological cross sections side to the Edifice with Mosaic, scale 1:600, (a) S4-4 WNW – ESE, (b) S5-5 WNW – ESE, (c) Sb 7 – 7 NNE – SSW, (d) Sb9-9 NNE-SSW.

The second step of the geophysical research was to identify also other causes of the damages. The assessment of apparent resistivity recorded at 4 meters depth reveals different status for those two years of investigations. The focused analysis on geophysical measured parameters in 2008 (8 – 200 Ohmm), when the apparent resistivity values were from 5 to almost 40 times smaller than the values obtain through measurement in 2019 (40 – 900 Ohmm), indicate o strong variation of deposits moisture unrelated to weather conditions, but linked to anthropical sources. The lower values of apparent resistivity (2008) indicate high moisture of deposits characterized by aggressive chemistry of water seepage (Figure 10 a) and higher apparent resistivity values (2019) may highlight either dry deposits or underground flows with lower chemistry (Figure 9 b).

The effect of the museum foundations and residence building (remanence of leakages into ground foundation) towards the front of the ancient edifice is outlined by minimum resistivity (8 – 150 Ohmm), on both sides of the edifice, and it is maintained until the bottom of the slope. The maximum values of the apparent resistivity, more than 300 Ohmm, characterize the central area of the old edifice and it is given by the concrete alley, water rainfall percolation and rapid underground water into local deposits (Figure 9 a). This fact is obviously down the edifice, where the over 600 Ohmm (Figure 9 b, mz 24 and mz 7) curves correspond to the "barrier" effect of the buried walls for pluvial water. A local disturbance is observed in the vicinity of the buried Roman gallery, where sandy-clay fraction remains are accumulated; some shadings of polluted underground water flows is recorded through lower apparent resistivity (100 – 200 Ohmm) (Figure 9 c, d).

3.2. Inflows and outflows from the system of mosaic pavement through self-potential method

Self-potential survey had applied only on the second and third anthropic terraces cut off in relict sea cliff (B and C). Beyond other interesting data provided by this method, the most important aspect revealed was the direction of underground water flows, meaning the location of infiltration and exfiltration areas. High underground moisture variations can be observed between the ancient wall and the edge line of mosaic pavement (Figure 10 a). Self-potential low values show high density of shallow cracks in mosaic. Infiltration phenomena are identified along edge line of pavement. Exfiltration of water/fluids from civil buildings infrastructure placed north-east of ancient walls (ancient terrace) are indicated by SP high values.

The exfiltration reports more moisture in relation to the absorption capacity of the mosaic pavement and loess floor (Figure 10 b). The phenomenon comes from the different granulometry /particle size of the mosaic infrastructure (ancient human-shaped thin layer of compacted loess).

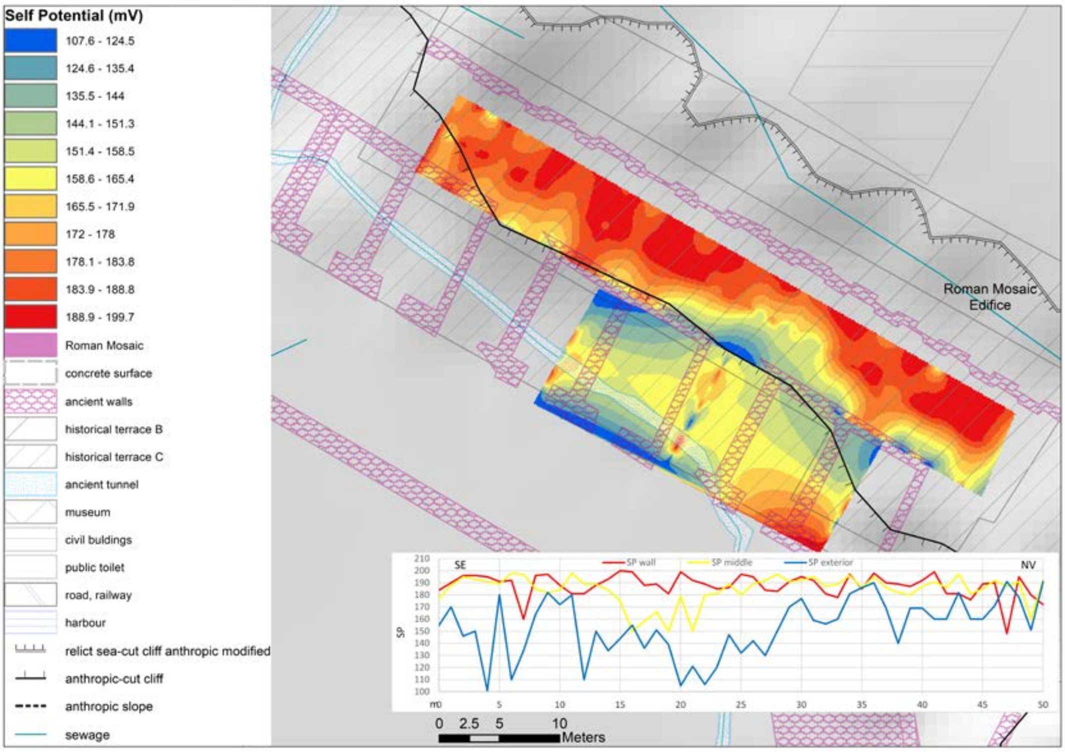

Figure 10. Spatial self-potential (a) over the mosaic pavement and ancient warehouse, (b) variations of self-potential along mosaic pavement from north-west to south-east (2019).

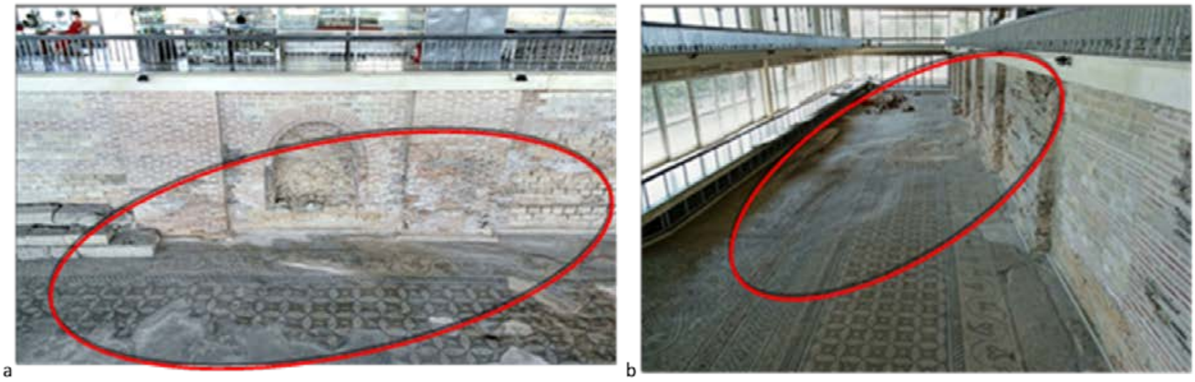

Figure 11. Damages to the roman mosaic pavement: (a) cracks and (b) slip on ripple surface.

The circulation of water and shallow slide movements from the north-east to the south-west part of the mosaic had result a lot of thin cracks which have proved the dynamic of mosaic pavement, though maximum variations of self-potential values (Figure 11).

3.3. Geomorphological results

The results of the geoelectrical analysis facilitated the understanding of shallow geomorphic processes in order to map and assess the current morphodynamic. Two different morphodynamical systems, emphasized by geomorphological map (Figure 12), were imposed by the two types of surfaces: front cliff and plateau of peninsula, on which the archaeological site is overlaid. The edifice was built on an abrasion slope, with 17°-25° decline and uneven edge, but it`s dynamics were greatly influenced by the plateau above (2 meters high than the upper edifice level).

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The porous nature of surface deposits (anthropic fillings, loess) in which the plateau is carved leads the infiltration of water and active underground circulation. As result, suffusion processes are wide spread and topographic surface is affected.

The civil constructions and traffic network (roads, alleys) placed on this plateau, nearby the roman edifice, have increased the creeping and slip processes inside the shallow deposits. This phenomenon is observed through dense network of cracks with several centimeters step and over one meters length, both in the retain wall of first level and on the mosaic pavement (Figure 11 a).

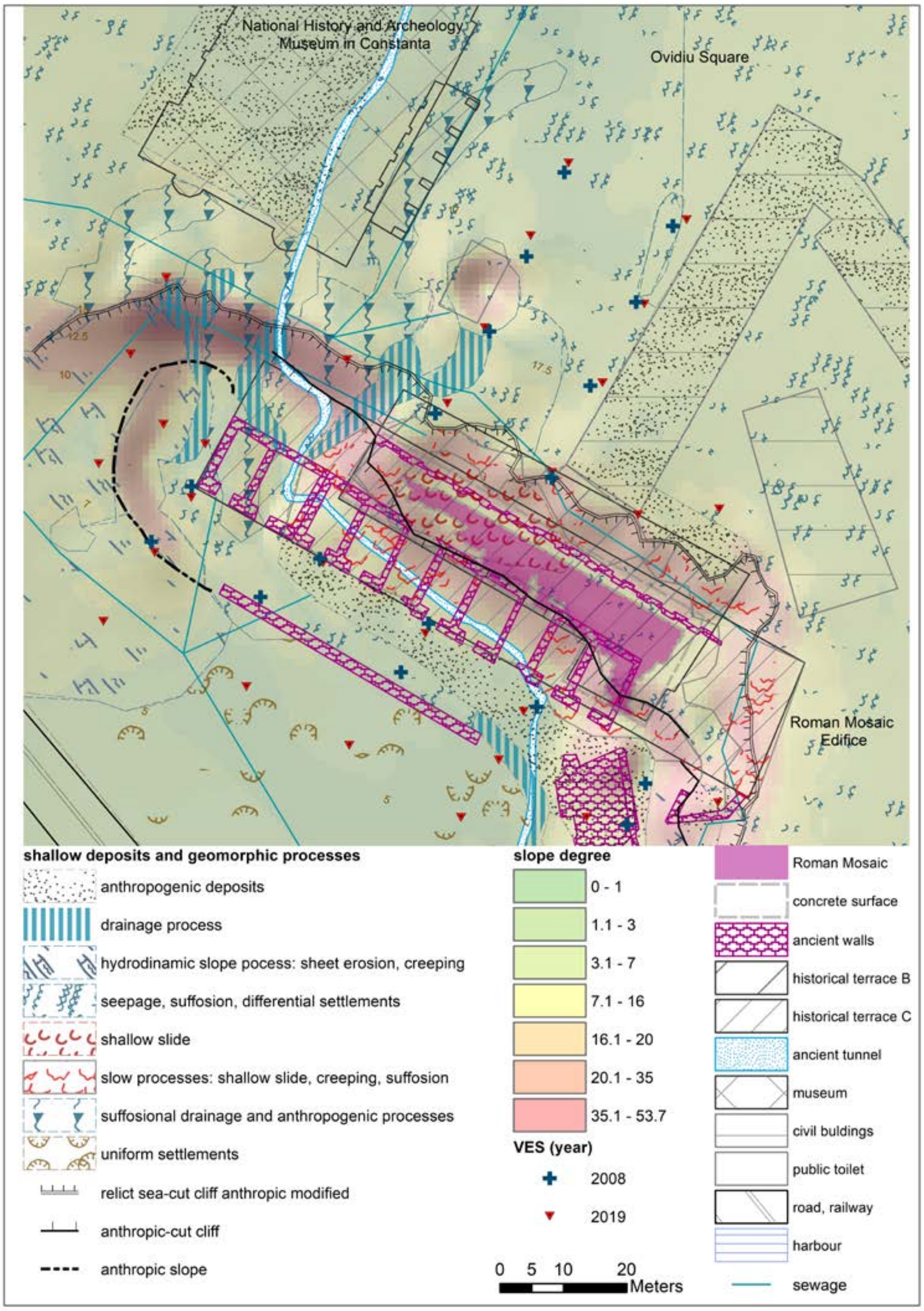

Figure 12. Geomorphological processes and shallow deposits corelated with slope degree.

The high density of cracks nearby the main edifice entrance is correlated with the increased moisture of the filling layers caused by the sewerage network and leakages from a public toilet located in front of the edifice.

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At the plateau level, some negative microrelief in loess (micro-depressions) with high density along the cliff edge as well as the edifice (Figure 12). Rainwater stagnates in some of larger micro-depressions frequently at north from the main entrance in edifice. In this way the moisture of the shallow deposits increases by prolonged infiltrations and, most important, the surface run-off water flows towards the cliff and many rills are developed. Therefore, the erosion through concentrated currents is more pronounced on the western side of the edifice, where deep rills, arranged in the amphitheater, wiped out a sector of front cliff. The rills expanded regressively by pushing the edge of slope toward north-east, have contributed to the deterioration of the ancient walls from III and IV level of the edifice (Figure 12).

The increased moisture linked with the anthropogenic sources mentioned above (sewerage, WC), combined with the intercalations of thin clays and marls, explains the shallow slides which have repeatedly damaged the western half of the edifice, being most likely the main cause of the advanced degradation of the mosaic (Figure 12 b). At the base of the steep slope, stagnant water was detected, accumulated from the rills behind the ancient wall, which maintains a permanent wetness of the walls between the ancient warehouse rooms at the lower (IV) level of the edifice.

4. Discussion

Related with deterioration of mosaic pavement we identified, beside natural factors, other potential sources of water leakages such as: public toilet and inappropriate maintenance sewage system.

We were interested to assess those land patches with different rate of the active processes and their implications into vulnerability zoning and to provide a model of exposure of mosaic to degradation in order to improve the stability of the Roman Edifice with mosaic. We have focused on those natural and anthropogenic components that had have a recently more dynamic, bringing the Edifice with mosaic into highly vulnerability range.

The sewage water, suffusion, creeping and differential settlement hazards (depending on each other) and the occurrence of a potential slip surface of the cutting cliff behind the mosaic pavement level had defined two areas in north-west and north-east are more vulnerable along the mosaic pavement. Due to the lack of engineering drains (which should be located between front cliff and roman walls of ancient terraces) the infiltrations through ancient walls and exfiltration flows on mosaic pavement are permanent processes.

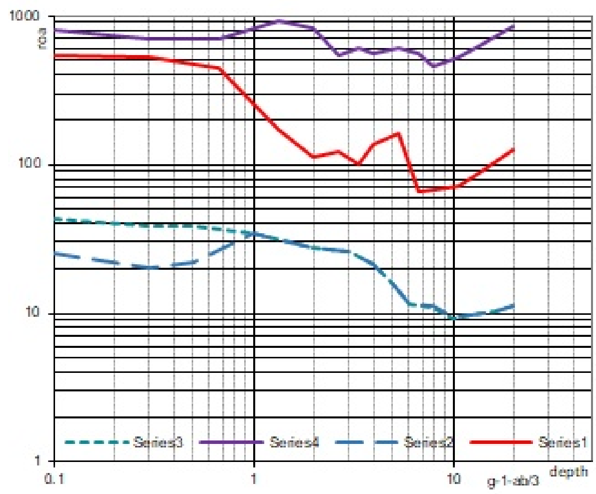

Figure 13. Example for anomalies outline by VES 9 and 16 curves, 2008 (blue and turquoise lines) and 2019 (red and purple lines).

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Figure 13, based on data from Table 4, shows a good example on how the anomalies can lead to a pretty accurate detection of leakage areas.

Table 4. The recorded anomalies are identified at the same levels, namely the maximum values are at shallow depths, indicating changes induced by human activity and the minimum values at 7-8 meters, corresponding to the hydrostatic level.

ar ab/3	ar mzb16 / 2019	ar mz 16/ 2008	ar mzb9/2019	ar mz 9/2008
0.1	800	43	544	25
0.3	700	39	522	20
0.67	706.80	38.30	**447.64**	**21.73**
1.33	**918.84**	**34.54**	171.99	34.54
2	824.70	27.24	112.71	27.24
2.67	544.28	26.01	123.70	26.01
3.33	614.22	21.56	101.08	21.56
4	561.55	15.48	134.77	15.48
5.33	600.84	11.42	160.22	11.42
6.67	564.07	10.84	**65.81**	11.29
8	**451.60**	**9.18**	67.74	**9.53**
10.7	529.55	9.66	70.61	9.66
13.33	627.95	10.31	87.91	10.31
20	848.00	11.31	127.20	11.31

The shapes of the chart lines above emphasize opposite behavior regarding the response of the lithological environment of two vertical electric soundings.

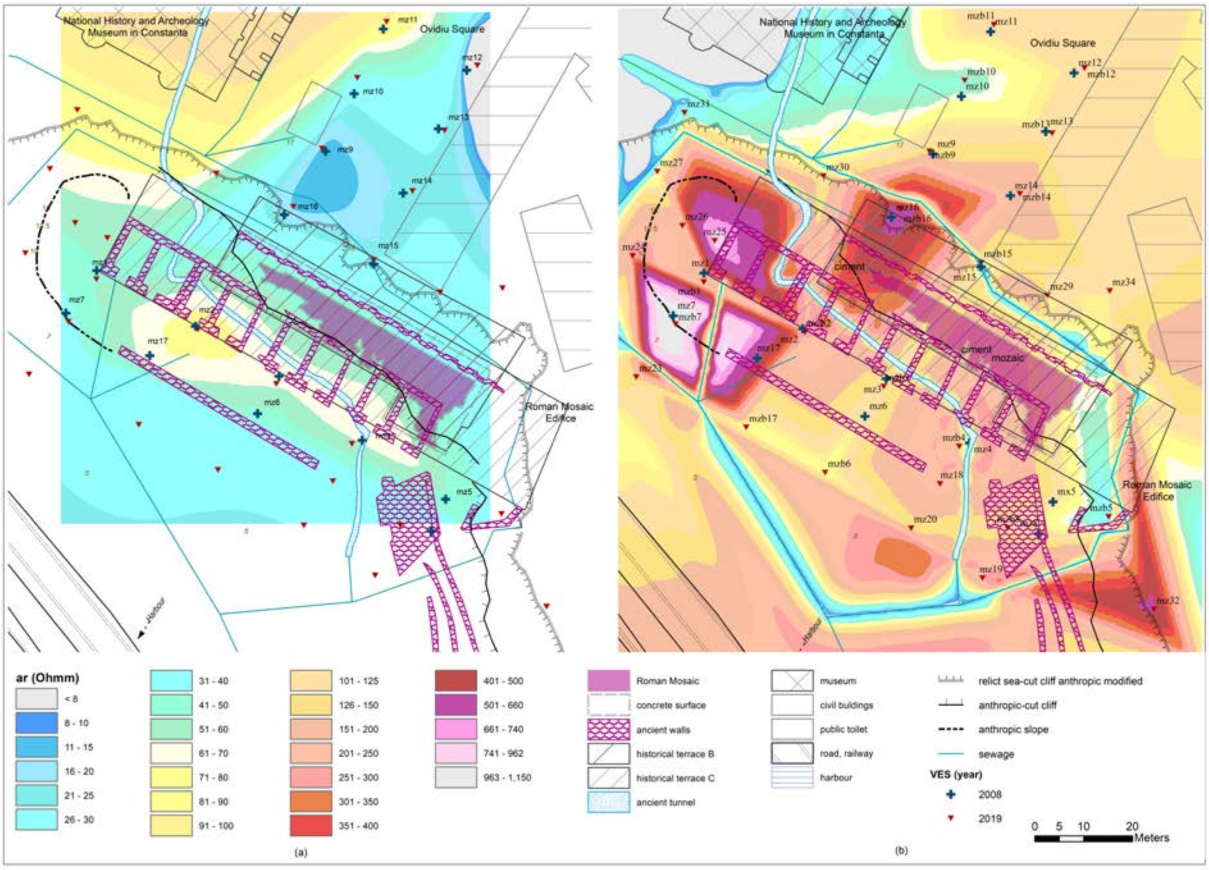

Figure 14. Spatial variations of apparent resistivity at 4 meters depth below surface (ground foundation of The Edifice with Mosaic) recorded in (a) 2008 and (b) 2019.

In order to analyze the spatial variability of resistivity values in 2008 and 2019, from all resistivity measurements we chose two different depths of investigations at 1.5 m

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depth, where fills are influenced by meteorological variations, pluvial water and green spaces watering of nearby and at 3-4 m depth since the damages on ancient retaining wall and mosaic pavement are quite visible beginning from this level down.

The local administrative authority was noticed regarding the necessary repairs works and these were done. Ten years after, the degradation of mosaic pavement and surrounding roman ruin buildings is still active.

In fact, in 2008, the leakages from civil sewage system on north-east part of edifice with mosaic are the primary sources of the infiltration into the edifice with mosaic ground and a potential sliding surface is drawn at the discordance line between fillings and loess complex, also along the foundation of concrete building which protect the edifice with mosaic and where stagnant water shed lies into negative microrelief. The leakages of sewage water with low resistivity are very aggressive and the ground moisture pass through the ancient walls, inappropriate mended with cement, as it shown at the entire front of edifice (Figure 10 a and Figure 9 a, c).

Eleven years later, the deposits are dryer than they were in 2008. The infiltrations and leakages from civil seepage system are stopped by restricting and outing of service of public toilet nearby and rehabilitation of the civil sewage. Therefore, there are no more leakages until 2019.

Certain residual water seepage with aggressive chemistry (polluted) still remains into geological environment. We had repeated and extended the measurements which are locally over 30 times higher on average than the values from 2008. This means that there are no longer infiltrations and the deposits have a low moisture degree, or the moisture is given by the pluvial water (low chemistry), but still there are great variations of it. So, the question was: what is the source of the persisting degradation of mosaic? The water supply and pluvial water outflowed with high resistivity values, just impose washout of tills and generate suffusion. The infiltrations, outflows and moisture pathways are yet active.

The field survey from 2019 reveal some side-effects induced by the drying process, such as the washing out of the fine particle fraction, easily seen in the transversal geomorphological and geoelectrical cross sections (Figure 8 and 9). Despite the high range of apparent resistivity values which indicate dry shallow ground foundation or reduced pluvial water underground flows, the geomorphic processes continue to be active, meaning that the underground water and moisture pathways still exist, continuing to be active.

The hypothesis is validated by removing the comparable data values from the measurements from two years ago and highlighting the extremes through ratios of the apparent resistivity values from 2019 to those from 2008. Thus, the distribution of the high values of ratios allows the identification of vulnerability points that overlap with sources of moisture of deposits, having the most pronounced dynamics.

Starting from the observation that the values of the apparent resistivity are mostly higher in 2019 reflecting a reduced moisture compared to those of 2008, we calculated the values of the ratios in order to identify the anomalies of the apparent resistivity. We chose to point out the anomalies using the first cross section S1-1 which is the most representative for the instability of mosaic pavement (Figure 15). The spatial variation of the ratios of the 2019 to 2008 measurements values indicates anomalies, through high values, identified next to VES 9 and 16, behind the mosaic pavement. The maximum values were recorded at depths of 5 m (12.5 m above sea level) and 11 m (5.5 m above sea level), indicating the points at which the fluctuations in the dynamics of underground water flows and leakages are maximum between the two repetitive measurements. Within the loess deposits there is a thin and weak sandy layer can increase the infiltrating waters rate (elevation 12 m) and thus the mosaic vulnerability. However, the variation of ratios values can express more, namely, it can allow delimitation, including in-depth, of two areas of the superficial strata affected by that hydrogeological dynamic/instability. The shape of these two areas of shallow hydrogeological instability indicates a thinning towards inland (north-east) and an expansion towards mosaic edifice (south-west), also in-depth, more

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precisely, to the mosaic pavement and to the warehouse. It can be associated with Roman gallery.

The highest values of the over unity ratios point out reduced moisture of the deposits in 2019, compared to 2008, located in front cliff and into fillings layers and at the level of loess-like deposits, due to their porosity and specific dynamics, thus becoming the most unstable.

The values of the subunit ratios identified only under the terrace surface of peninsula, at 7-8 m depth, reveal in 2019 compared to 2008 higher humidity and natural circulation at the base of the loess deposit, as a consequence of the repair works done to the wastewater collection system.

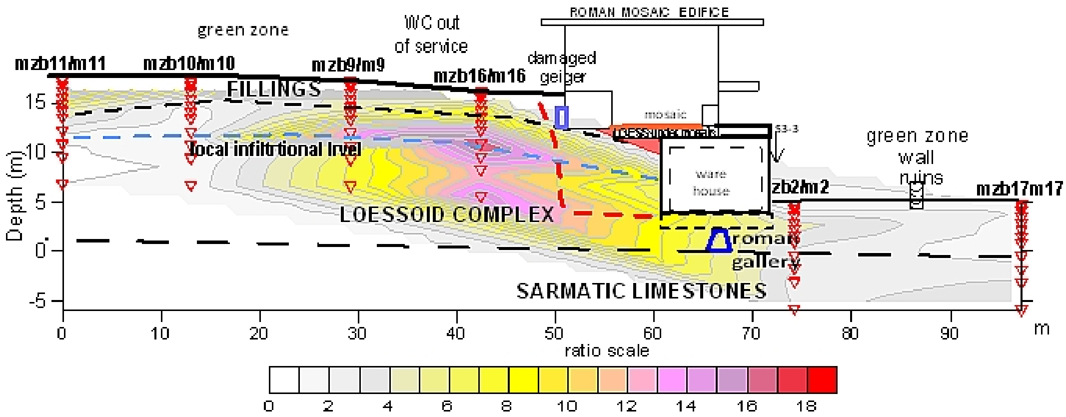

Figure 15. Cross-sections S 1-1: variation of ratios 2019/2008 surveys data points out through high values, areas with increased dynamics of ground-water flows and geomorphological processes.

Although, there is a good correlation between moisture deposits and sliding movements, in this case the issue is the connection between dry deposits and continuously and slowly individual movements of fine particles. It points out that morphodynamical mechanism of creeping, suffusion is combined with differential settlements. These movements are reflecting on instability of loess deposit from foundation of mosaic pavement with strong impact on it. The pluvial water outflowed with high resistivity values, just impose washout of tills; this fine sedimentary deposit is amassed into front cliff and below the ancient wall generating high pressure on mosaic pavement.

We had have demonstrated that even if there are great features changes into environment which hosts the cultural heritage of Roman Edifice with Mosaic regarding the moisture of deposits and fillings, the engineering works of the wastewater systems, the reducing human impact, the hydrogeological and geomorphological processes continue to exert various pressure on the edifice, increasingly causing damages to the mosaic pavement.

We'd reviewed and corroborated the surveys data and we noticed a remanence impact of the considered factors, as well as the local geomorphological hazards continuing to be active long time after some anthropogenic and hydrogeological factors were reduced. In case of vulnerable components, such as fillings, loess deposits, ancient walls mosaic, sewage, microclimate buried walls, they were analyzed regarding their amplitude of dynamic and sequential evolution.

Comparing these results with topographical and geomorphological mapping we noticed a very sensitive relation between cracks (density and orientation), differential settlements (localization, elevation and shape) on mosaic pavement with self-potential minimum and maximum values. Even if the moisture of deposits, fillings and buried ruined buildings became lower in time, the hydrodynamic and morphodynamic processes are slowly but active, having impact in other way the mosaic pavement.

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Zoning vulnerability of the environment around the cultural heritage of Roman Edifice with Mosaic (Figure 16) is a key feature of an improvement risk management and emphasize clearly the sectors which still confronting natural and anthropogenic geomorphological and hydrogeological hazards.

The vulnerability assessment highlights the critical condition areas that characterize the mosaic pavement and its northern, central, and east sides. Higher vulnerability overlaps on the mosaic pavement and north, north-west, and east surroundings of it. The low vulnerability of the area from the north-east side of the mosaic pavement is due to the effect of a historical pluvial drain sewer parallel with the north-east ancient wall [(24)] which provides a higher degree of protection of mosaic pavement from its immediate environment. The other area with low vulnerabilities is located at the south, southwest, and west of mosaic pavement and can be related to the repair works of the sewage system, and as result, the humidity variations of the roman gallery became lower.

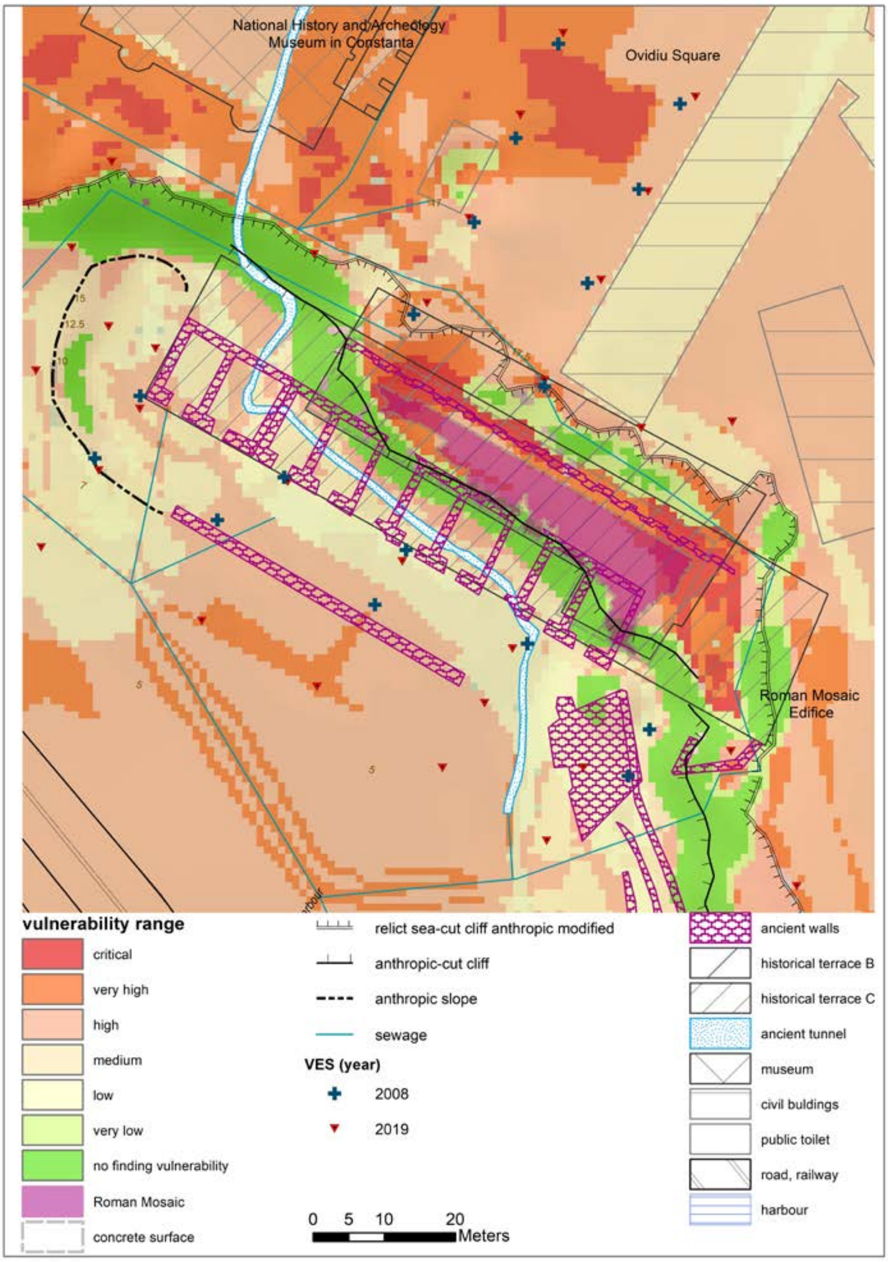

Figure 16. Hydrogeological and geomorphological vulnerability (2019).

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Over decades an improper maintenance of concrete building with the role to protect the ancient mosaic has contributed partially to increasing damages of the Roman Edifice with Mosaic.

5. Conclusions

Variations of deposits moisture and of the sewage water in foundation of The Roman Edifice with Mosaic during the last decades and of the geomorphological hazards at large scale were confirmed through non-destructive geophysical and geomorphological methods. Low resistivity values of filling and loess deposits indicate leakages from civil sewage system, close to museum and civil buildings. Water seepage–induced processes are revelated by medium resistivity values of loess and limestone deposits. High values of resistivity indicate dry deposits; the cracks in mosaic and natural deposits can be distinguished.

The comparative analysis of The Roman Edifice with Mosaic condition between the 2008 and 2019, stands out multiple sources of infiltrations and exfiltrations, natural and anthropogenical, as well. Despite of decreasing of leakages and anthropogenic water sources due to the engineering drains effect, the suffusion processes and differential settlements of the shallow sedimentary deposits persist. The removing of the seepage nearby mosaic and also the pluvial water effect led to increasing of the apparent resistivity. As a result, more intense hydrogeological process continues to damage the mosaic pavement such as differential settlements of the natural and anthropic deposits underlying the mosaic. A side-effect of the high humidity degree of the microclimate in the building which protect the mosaic is the increasing of the hydrostatic pressure into the ancient walls. From this level down in depth, it is recommendable to perform engineering drains (between the cutting front and ancient walls) to collect the ground – water and moisture and to discharge them beyond the ancient edifice, at the bottom of consolidate slope, for a proper maintenance.

However, the high humidity of temporary infiltration (at least from the past 20-30 years) causes suffusion, on the one hand, and slip processes on the other hand. Such geomorphological hazards, suffusion and differential settlements are related to hydrogeological mechanisms, which are slowly, but continuously and with seasonally dynamic. The consequences reverberate through rippling mosaic pavement and remains of ancient walls.

In addition, the high pressure of human activities (tourism included) related with local features of the cliff magnify the danger of degradation of the largest Roman Mosaic in Eastern Europe.

The results of geomorphological hazards analysis should increase the understanding of behavior of a cultural heritage into fragile environment condition with the purpose to continuously improvement of the risk management.

The environmental rehabilitation and protection of cultural heritage against compound natural and anthropogenic hazards reflect the care of society for historical monuments and should be a paramount concern to the local and central authorities.

6. Patents

Author Contributions:

Conceptualization, A.A.T., M.V., M.M., G.M. and D.C.; methodology, M.M., A.A.T. and M.V.; software, A.A.T., M.M.; validation, A.A.T., M. V., M.M, M.A., G.M., R. P., M. M., and D. C.; formal analysis, A.A.T.; investigation, A. A.T., M.M. and M.V.; resources, M.V. M.M., R.P. and M.A.; data curation, A.A,T. M.M. and M.A; writing—original draft preparation, A.A.T., M.M, and M.V.; writing—review and editing, A. A.T., D.C, G.M.; visualization, D.C.; supervision, A.A.T., D.C., M.A and M.V.; project administration, A.A.T. and D.C; funding acquisition, D.C., M.M, M.V. and R.P.

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