Cultural heritage management and monitoring using remote sensing data and GIS: The case study of Paphos area, Cyprus.

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Abstract

Cultural heritage (CH) sites are threatened from a variety of natural and anthropogenic factors. Innovative and cost effective tools for systematic monitoring of landscapes and CH sites are needed to protect them. Towards this direction, the article presents a multidisciplinary approach, based on remote sensing techniques and Geographical Information System (GIS) analysis, in order to assess the overall risk in the Paphos district (Cyprus). Paphos region has a great deal of archaeological sites and isolated monuments, which reflect the long history of the area, while some of them are also listed in the UNESCO catalogue of World Cultural Heritage sites. Several natural and anthropogenic hazards have been mapped using different remote sensing data and methodologies. All data were gathered from satellite images and satellite products. The results from each hazard were imported into a GIS environment in order to examine the overall risk assessment based on the Analytic Hierarchy Process (AHP) methodology. The results found that the methodology applied was effective enough in the understanding of the current conservation circumstances of the monuments in relation to their environment as well as predicting the future development of the present hazards.

1. Introduction

Cultural heritage (CH) monuments and sites are endangered by anthropogenic and natural threats such as earthquakes,flooding,fires and urbanization, with prevention actions sometimes being the only remedy (Jones, 1986; Stovel, 1998; Jokilehto, 2000; Wang, 2015; Rainieri et al., 2013; Drdácký, 2007). CH sector seeks innovative and cost effective tools for systematic monitoring so as to protect and preserve CH sites, monuments and landscapes. In this framework, gathering data and information for vast areas can be time consuming and expensive, while sometimes data collection procedure might not be possible due to the lack of the appropriate equipment and tools.

In contrast, remote sensing technologies have shown a great potential as an important tool for the protection and prevention of monuments and sites (Spreafico et al., 2015; Agapiou et al., 2015; Cigna et al., 2014; Banerjee & Srivastava, 2013). In the last two decades, the development of ground, aerial and space technologies has successfully been applied to several CH applications (Casana et al., 2014; Agapiou et al., 2014; Chase et al., 2011; Deroin et al., 2011; Giardino, 2011; Lasaponara & Masini, 2009; Garrison et al., 2008; Lasaponara & Masini, 2006). The technological achievements of space technology, such as higher spatial resolution and hyperspectral data, offer new opportunities for future archaeological discoveries (Sarris et al., 2013; Giacomo Di, Ditaranto & Scardozzi, 2011; Aqdus et al., 2008; De Laet et al., 2007; Cavalli et al., 2007).

Satellite remote sensing has become a common tool of investigation, prediction and forecast of environmental change and scenarios through the development of GIS-based models and decision-support instruments that have further improved and considerably supported decision-making strategies (Ayad, 2005; Hadjimitsis et al., 2011). By combining satellite remote sensing techniques with GIS, CH sites can be efficiently monitored in a reliable, repetitive, non-invasive, rapid and cost-effective way (Alexakis et al., 2011).

Satellite imagery can provide a quick and relatively low cost approach for monitoring natural and anthropogenic hazards over large and inaccessible areas (Youssef et al., 2015; Kaiser et al., 2014; Pradhan, 2010; Rahman, Shi & Chongf, 2009; Biswajeet & Saro, 2007). It should be noticed however that the availability of cloud free satellite images for operational projects is critical. Mediterranean countries are ideal for the use of optical remote sensing data as they are characterized by clear weather conditions with availability of cloud-free images.

The aim of this paper is to present a methodological framework based solely on remote sensing data and GIS analysis in order to extract valuable information regarding natural and anthropogenic hazards as well as to assess the overall risk for CH sites and monuments located in the Paphos district. Based on a variety of remote sensing data including low, medium and high resolution images (e.g. MODIS; Landsat; QuickBird), as well as ready satellite products (e.g. ASTER Global Digital Elevation Model, ASTER GDEM) each hazard examined in this paper has been analysed while the overall risk was estimated based on the Analytic Hierarchy Process (AHP) methodology. In contrary to previous studies (Hadjimitsis et al., 2011) where the authors have used archive information for each hazard for a limited number of sites (8 sites), the methodology presented here indicates that each hazard can be re-evaluated after a short period if deemed necessary (e.g. if stakeholders require updated information relative to specific monument) applied for a wider area and sites. Therefore the overall benefit from the proposed approach is highlighted by the fact that the overall risk assessment of an area can be re-estimated based on new satellite data.

2. Study area

Cyprus is an island located to the eastern corner of Mediterranean Sea. Its strategic geographical position between Europe, the Middle East and Africa has made it important since antiquity, which is reflected in the numerous archaeological sites and monuments to be found on the island (Maier & Karageorghis, 1984; Daszewski & Michaelides, 1989; Fejfer, 1995; Christou, 2008; Andreou, 2008). The present case study concerns the Paphos district, which covers a total area of 1393 km^2 of the western part of the island. The Paphos district was chosen as a case study since it presents a unique geomorphology combining different microclimates. The district extends from NW to SW Cyprus along the coast line. Another part of the district extends towards the hinterland covering part of the mountainous area of Troodos. Furthermore, the Paphos district was selected since it combines both UNESCO World Heritage Monuments (e.g. Paphos town, “Tombs of the Kings” ancient necropolis) as well as isolated monuments in inaccessible areas (e.g. Paphos region, church of Panagia Xorteni). Moreover, monuments and cultural heritage sites in Paphos can be found both in urban and rural areas, in low elevation (nearly sea level) and high elevation (mountain-peaks), near and far from the coastlines, forests. These two main geographical configurations of Paphos district, namely the coastline and the mountain areas, provide different study parameters within the research's framework, thus permitting comparison through the analytical methodologies applied, as these are described further in the Methodology and resources section of the paper.

Prior to the risk assessment analysis, the known archaeological sites and monuments were registered in a local cartographic projection of Cyprus. Archaeological excavation reports and maps were digitized and used in combination with high resolution satellite images. More than 170 monuments and sites listed by the Department of Antiquities of Cyprus as protected monuments have been mapped with high accuracy in Paphos district (Fig. 1). In order to map these monuments and sites, located in the Paphos district, the "Cyprus Archaeological Digitization Programme" database of the Department of Antiquities of Cyprus was explored upon special permission. In addition, local cadastral maps have been also used so as to geo-reference these sites.

3. Methodology and resources

3.1. Methodology

A series of risk maps regarding both anthropogenic (urban sprawl, modern road network, drainage network, fires) and environmental hazards (landslides, erosion, salinity, neotectonic activity) of CH sites in the Paphos district were created. Four methodological steps were applied in order to evaluate each hazard as well as to classify the monuments under study according to their overall vulnerability. The overall methodology is presented in Fig. 2.

3.1.1. Step 1. Identification of the risk

Initially the potential hazards of the case study area were defined. Both natural and anthropogenic hazards were examined and evaluated. The hazards were divided into two main categories: (a) natural (landslides; erosion; salinity and neotectonic activity) and (b) anthropogenic (urban sprawl; modern road network; drainage network and fires).

3.1.2. Step 2. Profile hazards

The creation of a spatial “hazard” database was followed based on the available remote sensing data. For each hazard defined in Step 1, satellite images and remote sensing products as shown in Table 1 were used and analysed. The data were initially geo-referenced into a common geodetic system (WGS'84, 36N) using standard techniques (control points from digital maps).

3.1.3. Step 3. Risk analysis

Following the identification of the risks, the necessary remote sensing data (either satellite images or satellite derived products) were collected to be further analysed with spatial tools in a GIS environment. The AHP (Analytic Hierarchy Process) methodology, introduced by Saaty (1980) was used in order to compare the different factors and their relative importance. AHP method has been widely used in remote sensing applications (Oikonomidis et al., 2015; Pourghasemi et al., 2012). The AHP is a multi-criteria objective decision-making approach that allows the user to arrive at a scale of preferences drawn from a set of alternatives. According to Ramanathan (2001), some of the main advantages of AHP method over other multi-criteria methods, such as point allocation and multi-attribute utility theory, are its flexibility, its ability to check inconsistencies and its appeal to decision makers. Moreover AHP is considered to reduce bias in decision making and supports group decision-making through consensus by calculating the geometric mean of the individual pairwise comparisons (Zahir, 1999).

In AHP methodology, the final weight of significance for each factor can be defined using the Eigen-vectors of a square reciprocal matrix of pair-wise comparisons between the different factors. Once the pairwise comparison matrix is obtained, there is a need to summarize the preferences so that each factor can be assigned a proper relative importance. Based on Saaty (1980) a certain value is assigned to all the different pairs on a scale from 1 to 9, with 1 as “not important at all” to 9 as “extremely important”. Finally, the total value of the sum weights of all rows was estimated and the final division of this value with the sums of each factor provided the final normalized weight of each individual factor.

3.1.4. Step 4. Evaluation of the risk

The final step involved an overall evaluation of all the risks regarding the selected archaeological sites and monuments. The evaluation was based on in situ observations to CH sites.

3.2. Resources

For the aims of this study a multidisciplinary approach was applied. Remote sensing data from various sources were processed, in order to determine each hazard. Table 1 indicates the satellite data sources used in this study as well as some characteristics of the sensors. Low resolution MODIS images have been used in order to retrieve Burned Areas over the Paphos region. In addition medium resolution Landsat 5 TM and 7 ETM+ have been analysed for monitoring urban expansion, landslides, salinity and road network. High resolution QuickBird images have explored for calculating landslides and erosion parameters. Calibrated DMSP–OLS night-time data set for 2010 has been also used for mapping urban areas in Paphos district while ASTER GDEM has been exploited for detecting neotectonic activity as well as mapping the drainage network.

4. Natural and anthropogenic hazards

In the study, eight different factors (as shown in Fig. 2andTable 1) with possible influence on the monuments were incorporated in the final GIS model and analysed for their potential contribution in the development of the final Hazard Assessment map. The appropriate remote sensing data set for each hazard as shown in Table 1were used. A brief description of the analysis for each factor is mentioned below.

4.1. Natural factors

4.1.1. Landslides

Landslides are considered to be one of the most extreme natural hazards worldwide, causing both human losses and severe damages to the modern facilities. Human interventions to the landscape, geomorphologic processes and climatic phenomena could trigger the occurrence of landslides. Factors that can trigger landslide episodes include proximity to active faults, geological formations, fracture zones, degree and high curvature of slopes and water conditions (Theilen-Willige 2007).

For estimating landslide hazard several known historic landslide phenomena were mapped through in situ field visits (broader Paphos area) and recording of landslide occurrence. Satellite imagery of medium and high spatial resolution such as Landsat TM/ETM+ and QuickBird was acquired and pre-processed in order to extract the road network of the area, faults and land use/land cover. All these data were incorporated into the final landslide hazard model. Following, topographic characteristics such as relative relief, slope, aspect and surface hydrological information were extracted from the ASTER GDEM (30 m resolution) of the target area.

The above factors were then implemented into a GIS environment and were reclassified with various ratings for their contribution to possible landslide phenomena. The extracted landslide hazard map was validated for its accuracy with the existing landslide occurrences in the study area. Following, the initial hazard map was transformed to landslide hazard zonation map (LHZM). Therefore, the digital GIS layer was reclassified in a GIS environment according to natural breaks method into five major classes: very high hazard, high hazard, moderate hazard, low hazard and extremely low hazard (Alexakis et al., 2013). The first two classes were considered as the primary areas with high risk value to the monuments (Fig. 3a).

4.1.2. Erosion

Soil erosion is considered as a major environmental problem since it seriously threatens natural resources, agriculture and the environment (Rahman et al., 2009). Recently, there has been a growing awareness of the problems directly related to erosion in the broader Mediterranean region. The widespread occurrence and importance of accelerated erosion in the Mediterranean region have driven to the development of models at scales ranging from individual farm fields to vast catchment areas and different types of administrative areas. To determine erosion, the RUSLE equation is used, which estimates soil loss from a hill-slope caused by raindrop impact and overland flow (inter-rill erosion), plus rill erosion and it does not estimate gully or stream-channel erosion. The RUSLE equation incorporates five different factors concerning rainfall (R), soil erodibility (K), slope length and steepness (LS), cove management (C) and support practice (P) (Eq. 1).

$$A = R*K*L*S*P \qquad (1)$$

To estimate soil erosion in the area rain-gauge stations, soil map, slope, terrace areas, vegetated areas and other parameters were also used or calculated. The final erosion hazard map was developed into the GIS environment based on Eq. (1)using Boolean Geometry. In order to smooth the speckle phenomenon in the final RUSLE grid file, a 3 × 3 majority filter was applied. Two final RUSLE map was then reclassified into two main categories: the areas where the soil loss is greater than the mean value soil loss of the whole district and the areas where the soil loss is less than the mean value soil loss. According to the final results (Fig. 3b) the vast majority of sites are established in the first category.

4.1.3. Salinity

The cultural heritage sites located near the coastline may be threatened by shoreline erosion and salt-decay (Robinson et al., 2010). For this purpose, buffer zones indicating the proximity of cultural heritage sites along the coastline were included in the GIS database (Fig. 3c). Thus, the distance from the coastline was categorized into four different classes based on the distance from the sea as follows: 0–200 m distance from the sea; 200–500 m distance; 500–1000 m distance and more than 1 km distance from the sea.

4.1.4. Neotectonic activity

Geomorphological characteristics of the surface can highlight important information that can be associated with tectonically active areas. Such areas can be exposed in a higher degree to the occurrence of large earthquakes. The evaluation of the geomorphological characteristics at some extent can manage and mitigate the consequences of such a hazard. One of the main parameters to be considered in the hazard analysis herein is the use of DEMs in order to extract geomorphometric and morphotectonic information. The spatial distribution maps, extracted from DEMs using GIS, provide useful information as their interpretation can indicate potential zones of tectonic uplift and/or tilting which determine: i) the presence of tectonic activity spatial distribution within the entire study area and ii) identification of zones of still higher susceptibility to active tectonics. The data derived from a DEM were particularly useful for the calculation of geomorphic indices and extraction of geomorphometric information that can be associated with the determination of tectonic activity such as slope, amplitude relief, stream length gradient, topographic wetness index, drainage density, stream frequency, elevation relief ratio and lineament density/frequency

(Anderson & Kneale, 1982; Awasthi et al., 2002; Ayalew et al., 2004; Boroushaki & Malczewski, 2008).

The extraction of geomorphic indices and information that can be associated with active tectonics aspects was evaluated. The stages of the approach consisted of: i) using Analytical Hierarchy Process (AHP) in order to extract the criteria weights, ii) applying Weighted Linear Combination in order to achieve an overall priority rating/ranking of the factors to be used in the assessment of neotectonic activity and iii) assess the neotectonic activity and create a final distribution map regarding the degree of active tectonics. Based on the weighting–ranking system for the neotectonic activity values, within the range of 0–100, reclassification was applied to the final map. The final classification consisted of five classes: i) very low; ii) low; iii) moderate; iv) high and v) very high. The classes where based on natural breaks in the cumulative frequency histogram (Ayalew et al., 2004).The final neotectonic activity map revealed areas which are characterized by a high to very high degree of tectonic activity (see Fig. 3d) (Argyriou et al., 2014)).

4.2. Anthropogenic factors

4.2.1. Urban sprawl phenomenon

Urbanization processes as a result of population growth, migration and infrastructure initiatives have a direct impact to the cultural heritage sites. Urban expansion is considered to be one of the major threats for monuments in this area. The building boom in Paphos was relatively sudden and abrupt, due to large population movements during the '80 in the undeveloped areas of the period. Extensive construction and building development have taken place, and several areas of archaeological interest suffered from the widespread urban growth. The archaeological sites that suffered the most from urban expansion and building boom during the '80s in the centre of modern Paphos area are the ancient necropolises.

A multi-temporal satellite database was examined for monitoring urban expansion in the area of Paphos over the last 40 years. Multispectral Landsat TM/ETM+ images and the radiance calibrated DMSP–OLS night-time data set for 2010 were also used.

The classification results from the Landsat imagery displays a complex urban footprint of a coalescent urban core and a complex, sprawling suburban to splinter development in rural areas. The classification results were then examined to evaluate the urban expansion in the vicinity of the cultural heritage sites of Paphos (Agapiou et al., 2015).Fig. 3e indicates the urban areas for the year 2010.

4.2.2. Proximity of cultural heritage sites to modern road network

Proximity of cultural heritage sites to the local road network was another anthropogenic hazard taken into account. Air pollution nearby highways or town centres very often exceeds the regular limits and therefore can slowly deteriorate cultural heritage monuments.

Moreover, accessibility of an archaeological area by the existing road network can promote future urban expansion with negative consequences to the preservation of cultural heritage sites. The major road network of Paphos district was created in digital format in GIS environment through the extensive digitization of topographic maps. Following, buffer zones of 250 m were created around the main road network, in order to examine the proximity of cultural heritage sites to the network. A value of one was assigned to the areas (zones) of more than 250 m away from the road network and a value of zero was assigned to the areas (zones) within a distance of 250 m from the road network (Fig. 3f).

4.2.3. Drainage network proximity

In order to incorporate the parameter of “Drainage network Proximity” the drainage network of Paphos district was digitized with the complementary use of cadastral maps and DEM. Then the network according to Strahler's order system was classified. Following, a buffer zone of 50 m was constructed around each part of the drainage network (Fig. 3g).

4.2.4. Fires

Fires constitute a diachronic threat for all the archaeological sites. Thus a number of historic fires in Paphos district were recorded based on “MODIS Active Fire Data” (Davies et al., 2009) for the period 2010 until 2013, and then incorporated into a GIS environment as point vectors. Following, a buffer zone of 500 m was assigned around each point in order to delineate the potential vulnerable areas (Fig. 3h).

5. Overall risk assessment: AHP approach

The above mentioned eight different factors were incorporated in the final GIS model and analysed for their potential contribution in the development of the final Hazard Assessment map. In order to evaluate the above named hazards and to arrive to an overall map, the Analytic Hierarchy Process (AHP) method was applied. According to AHP methodology, a pair-wise comparison of the contribution of each factor was established. Specifically, answers of several experts were collected on the reciprocal matrix, and the appropriate eigenvector solution method was employed to calculate the factor weightings. The results (see Table 2) revealed the high importance of tectonic activity and urban sprawl phenomenon in the model development. After the calculation of the normalized weights, the consistency of the responses was checked by calculating the consistency ratio (CR). For that reason, the consistency index (CI) was calculated according to Eq 2.

$$\mathrm{CI} = \frac{\lambda\mathrm{max} - \mathrm{n}}{\mathrm{n} - 1} = \frac{9.656 - 9}{9 - 1} = 0.082 \qquad (2)$$

where λmax is the largest eigenvector and n is the number of criteria used in the study. The final consistency ratio (CR) was estimated through Eq. (3):

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} = \frac{0.12}{1.45} = 0.082 \qquad (3)$$

where RI = random consistency index. For the case of eight different factors, it is equal to 1.45. If the ratio exceeds 0.1, the set of judgments may be too inconsistent to be reliable. However, in practice, CRs of little more than 0.1 are accepted and the extracted weight values are considered as reliable (Alexakis et al., 2013).

The final hazard map (Fig. 4a) was constructed by summing up (through Boolean operators) the product of each category, which has been rated accordingly for its subcategories, in GIS environment. Following, the initial hazard map was transformed to landslide hazard zonation map (LHZM). Thus, the digital GIS layer was reclassified, in GIS environment according to natural breaks method, into five major classes: very high hazard, high hazard, moderate hazard, low hazard and extremely low hazard.

Following the construction of the final map, the results revealed that 33% of the total archaeological sites in Paphos are situated in “high hazard” areas (HH) and 9% are situated in “very high hazard” areas (VHH). The eastern part of Paphos district (the area around Statos village, Fig. 4b) was shown to be a considerably high risk area. In addition, the GIS system revealed that the UNESCO heritage site of “Nea Paphos” (Fig. 4c), as well as the nearby site of the ancient necropolis “Tombs of the Kings”, is situated on HH and VHH areas, due to the extreme pressure from urban sprawl phenomenon and their exposure to salinity erosion.

6. Discussion

Nowadays, CH sector is facing challenges including the decrease of the available public budgets while at the same time global warming and climate change, such as the occurrence of extreme weather events, can put cultural heritage in great risk. At the same time CH sector seeks innovative and cost effective tools for protection of monuments and sites.

While CH sites and monuments are continually threatened by anthropogenic and/or natural hazards, local authorities need to prioritize threats and allocate their budget. Therefore authorities need to have reliable information regarding the risk status of CH sites, rather than information regarding isolated case studies. The overall hazard map, as shown in this study, can be used by such stakeholders to understand the overall risk index and take actions respectively.

The overall hazard map of Paphos district (Fig. 5a) has been observed in various archaeological sites of the area through in situ inspection. Indeed, the salinity problem of the monuments located along the coastline is patently clear and visible with the naked eye. In some cases the situation seems to question more crucial issues as a consequence of the deterioration due to salinity and hive formation, such as static stability of the monuments as well as the permanent loss of historic and aesthetic aspects of the monuments. Both “Tombs of the Kings” as well as the “Castle of Paphos”, two important archaeological sites in this area (Fig. 5a and b respectively) are facing the aforesaid problems. Another example is the necropolis of Anavargos village in the outskirts of Nea Paphos, suffering both from urban sprawl pressure, as well as of the proximity of the modern road network passing very close to the protected site (Fig. 5c). As it was found from the classification results, urban land coverage in the vicinity of cultural heritage sites has been increased during the period 1984–2010 (Agapiou et al. 2015). A more detailed observation of the results indicates that urban expansion has been increased by 350% during the last 35 years. As it was found from an almost 4% of the land cover in 1984, urban areas were increased to 7% in 1990, 11% in 2000 and 14% in 2010.

7. Conclusion

Anthropogenic hazards can contribute to the damage of precious archaeological monuments and immovable cultural remains while environmental factors such as erosion and landslides can create intense and severe damages to cultural heritage sites.

The applied methodology utilized data from different sources in combination with state of the art technologies. Satellite remote sensing and GIS successfully resolved the problem of an integrated and multi-layer monitoring system for a vast area rich in cultural heritage sites, simultaneously.

The results of this study can be used as a road map for taking specific actions regarding the protection and/or consequent restoration of the archaeological monuments. It is crucial to mention that almost 40% of the archaeological sites considered in this study obtained a classification of HH and VHH monuments, clarifying the need to take certain actions for the protection and preservation of the monuments. The pilot application for Paphos district could be the basis for a wider monitoring platform covering the whole island. In this case other environmental and natural hazards could be considered such as the impact of air pollution (Agapiou et al., 2013) and agricultural pressure. The latest is related with the pollution of soils due to intensive agricultural activities, soil erosion or even with the use of modern and heavier machinery used for agricultural purposes, destroying in this way buried archaeological remains (i.e. un-excavated sites).

Remote sensing techniques used in the study revealed the regional setting of Paphos's archaeological sites/monuments and assisted in cultural resource management. Remote sensing management of cultural heritage in a landscape scale is proved to be cost effective, time-saving and much more efficient than traditional ways of observing and monitoring large areas.

It should be emphasized that the spatial GIS tools and the methodologicalflowchart that were used in the present study are flexible to be modified for different environments and regions since AHP methodology is adjustable based on parameters/factors and/or weights of significance in order to have an even more specific understanding of the risk areas; thereby, being a useful tool for the management of cultural heritage monuments and sites.

In conclusion, it should be stated that remote sensing data sets and the technological tools used in the study, provide a non-destructive, cost effective and systematic method for management and monitoring cultural heritage sites.

Acknowledgements

The results reported here are based on findings of the project “ΑΕΙΦΟΡΙΑ/ΚΟΙΑΦ/0311(ΒΙΕ)/06”: Managing Cultural Heritage Sites through Space and ground Technologies using Geographical Information Systems: A Pilot application at the archaeological sites of Paphos. The project is co-funded by the Republic of Cyprus and the European Regional Development Funds (ΑΕΙΦΟΡΙΑ/ΚΟΙΑΦ/0311(ΒΙΕ)/06). Thanks are given to the Remote Sensing and Geo-Environment Laboratory of the Department of Civil Engineering & Geomatics at the Cyprus University of Technology for its continuous support (http://www.cut.ac.cy). The authors would like to thank the Director of the Department of Antiquities Dr. Maria Hadjicosti for her permission to access the data of the Department.

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Figures:

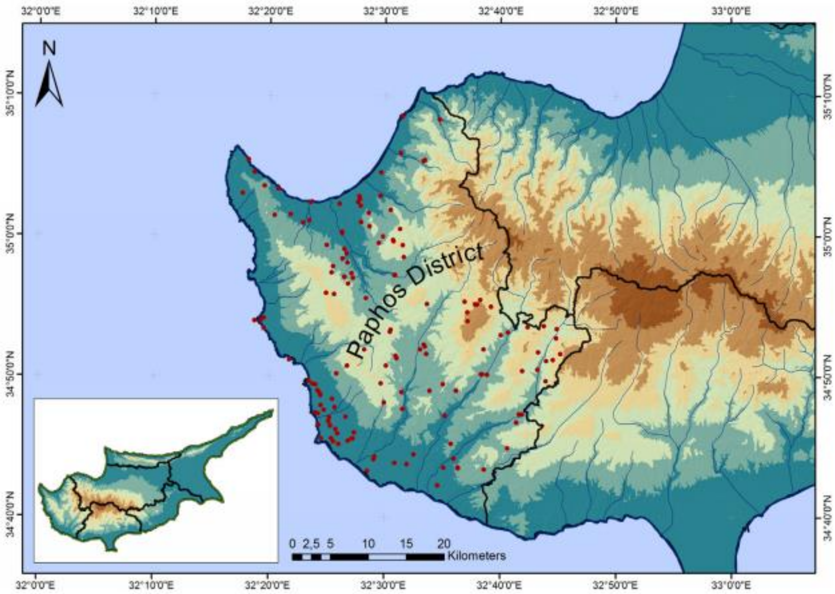

Fig. 1. Map showing the case study area (Paphos district, Cyprus).

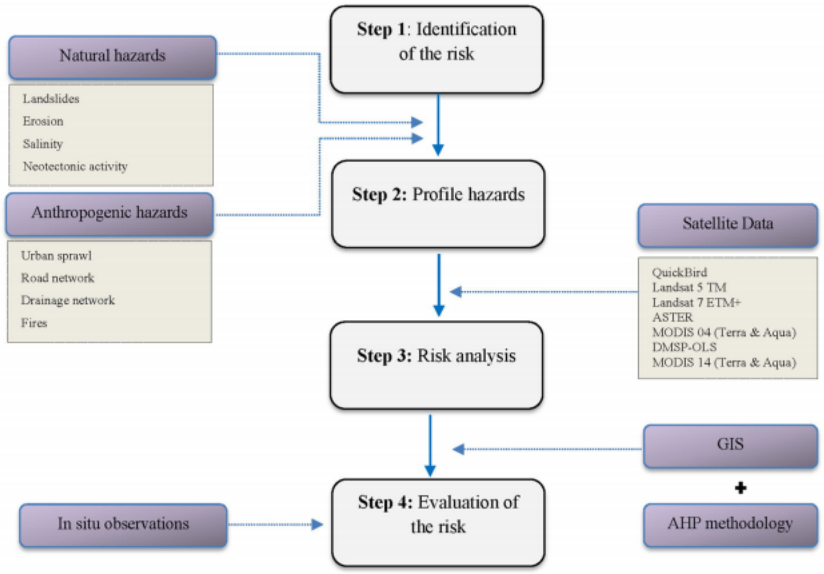

Fig. 2. Methodological diagram of the paper.

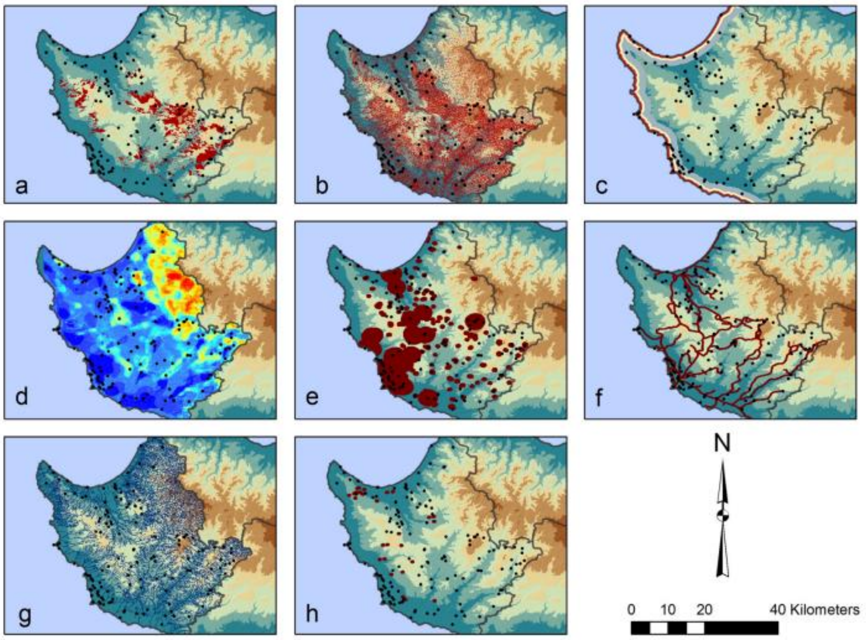

Fig. 3. Map indicating the different anthropogenic and natural hazards over Paphos district. (a) Landslide map: very high hazard and high hazard areas are indicated with red; (b) Erosion map: areas where the soil loss is greater than the mean value soil loss of the whole district are indicated with red; (c) Salinity map: areas close to the sea are indicated with red; (d) Tectonic activity: high and very high hazard areas are indicated with red; (e) Urban expansion; (f) Road network proximity (250 m); (g) Drainage network (50 m buffer zone) and (h) Fire map observed during the period 2010–2013. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

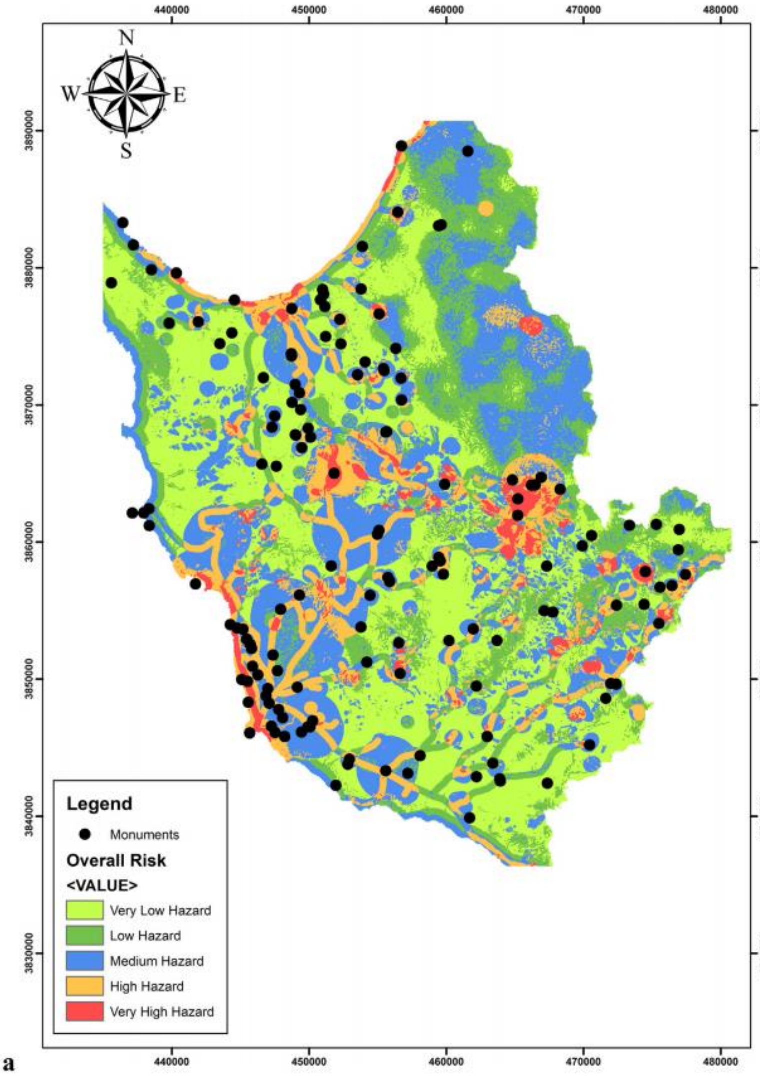

Fig. 4. a) Overall hazard map for Paphos area (monuments in circle). The final map is classified into 5 final classes of hazard. b) Detail of risk map in Statos village broader area (the reddish tones indicate the areas of high risk). c) Detail of risk map in broader Paphos area. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

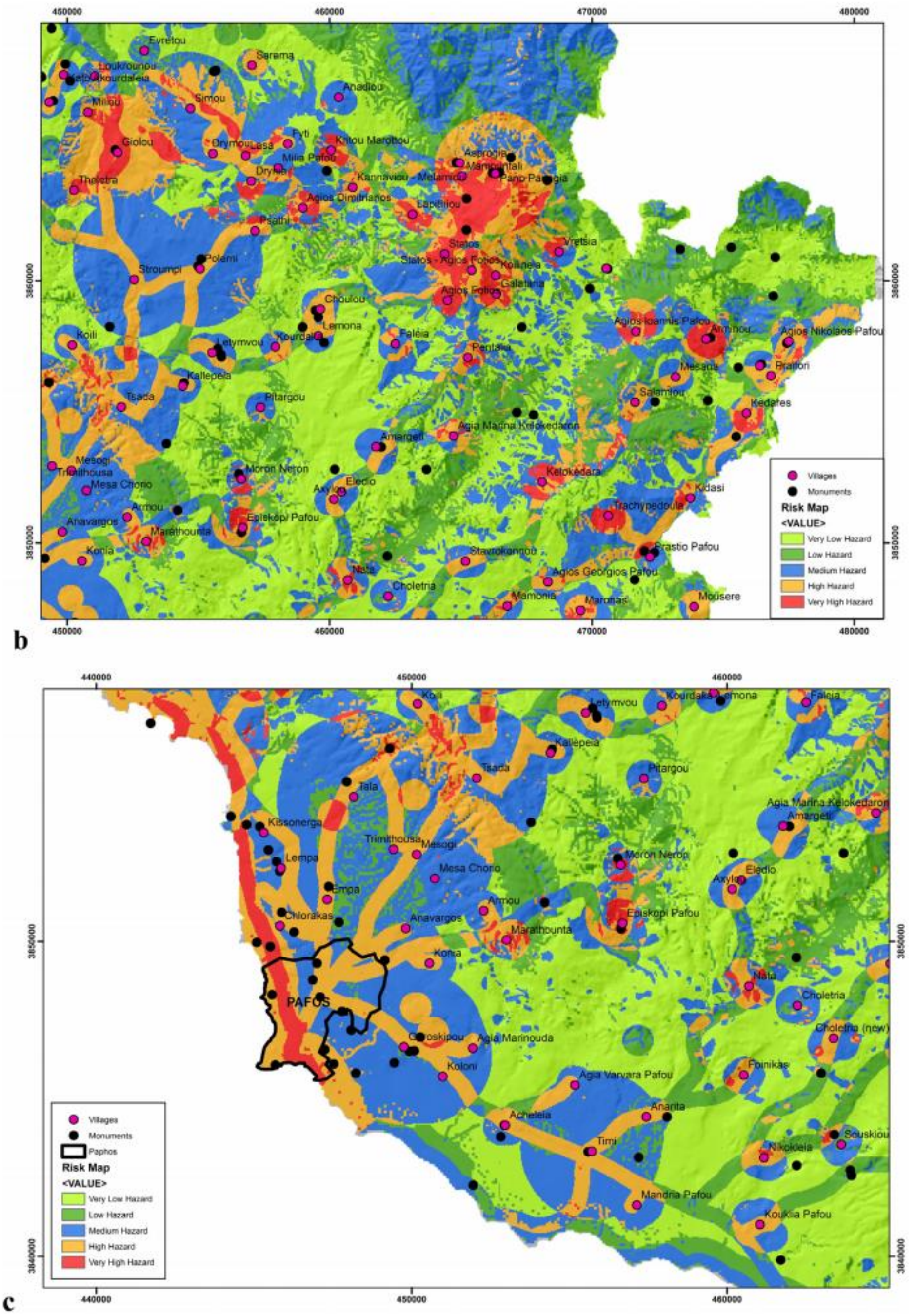

Fig. 4 (*continued*).

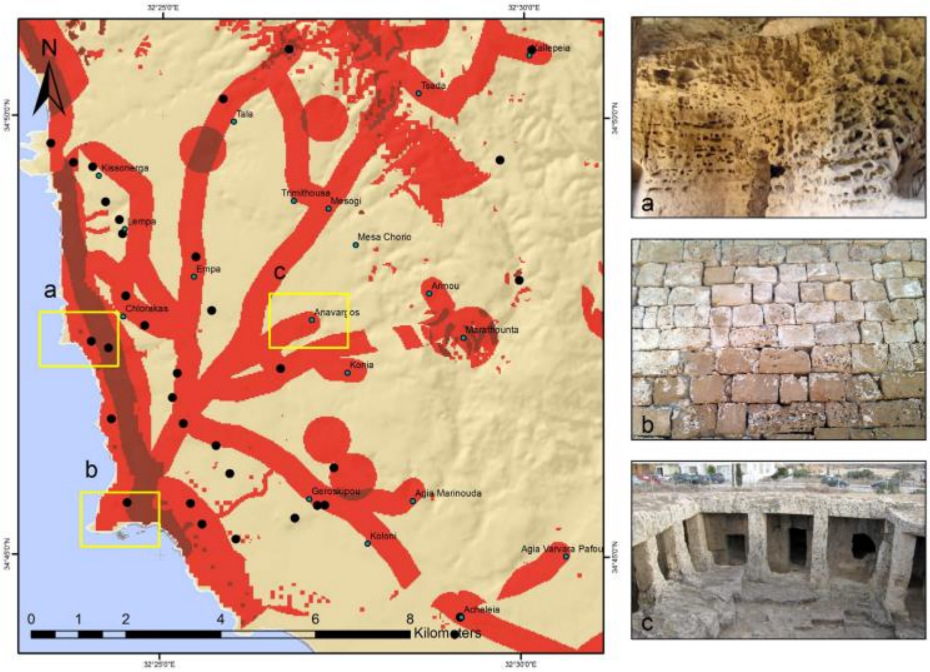

Fig. 5. Examples of monuments in threat. a–b) Detail of deterioration in one of the tombs in the "Tomb of the Kings" necropolis (a) and Castle of Paphos (b) due to salinity and alveolization. c) Archaeological site of Anavargos village in the vicinity of road network and urban areas.

Tables:

Table 1
Satellite data used for each hazard.

No	Satellite data	Hazard used	Spatial resolution	Spectral resolution
1	QuickBird	Landslides Erosion	1 m (PAN) 4 m (Vis–NIR)	Vis–NIR
2	Landsat 5 TM	Landslides Salinity Urban expansion	15 m (PAN) 30 m (Vis–NIR)	Vis–IR-Thermal
3	Landsat 7 ETM +	Landslides Urban expansion Road network	15 m (PAN) 30 m (Vis–NIR)	Vis–IR-Thermal
4	ASTER	Neotectonic activity Drainage network	15 m (ASTER GDEM)	-
5	MODIS 04 (Terra & Aqua)	Aerosol optical thickness	1 km	-
6	DMSP–OLS	Urban expansion	0.56 km	Vis–IR-Thermal
7	MODIS 14 (Terra & Aqua)	Fires	500 m	IR-Thermal

Table 2
Extraction of weights for each factor with the use of AHP methodology.

No	Factor	Tectonic	Urban	Landslides	Salinity	Fires	Roads	Erosion	Rivers	Sum	Weights
1	Tectonic	1	3	5	7	5	7	5	7	40	0.293
2	Urban	0.33	1	3	3	3	3	3	3	19.33	0.141
3	Landslides	0.2	0.33	1	3	3	3	5	3	18.53	0.136
4	Salinity	0.14	0.33	0.33	1	0.33	0.2	0.33	3	18.12	0.132
5	Fires	0.2	0.33	0.33	3	1	3	3	3	13.86	0.101
6	Roads	0.14	0.33	0.33	5	0.33	1	0.33	5	12.46	0.091
7	Erosion	0.2	0.33	0.2	3	0.33	3	1	3	11.06	0.081
8	Rivers	0.14	0.33	0.33	0.33	0.33	0.2	0.33	1	2.99	0.021