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Hazard ranking of the UNESCO world heritage sites (WHSs) in Europe by multicriteria analysis

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Received 21 March 2019
Revised 12 December 2019
Accepted 12 February 2020

Abstract

Purpose – Aim of this paper is to evaluate the reliability of UNESCO Periodic Reports for the assessment of hazards affecting the UNESCO world heritage sites (WHSs) and to rank the most critical WHSs in Europe through multicriteria analysis.

Design/methodology/approach – The Periodic Reports represent the available continental-scale knowledge on hazards that threaten the WHSs in Europe and include 13 different natural threats. The information included in these reports has been first validated with high-quality data available in Italy for volcanoes, landslides, and earthquakes. Starting from the Periodic Reports, a multicriteria hazard analysis has been developed by using the analytical hierarchy procedure (AHP) approach. This analysis allows to identify and to rank the most critical WHSs at the European scale.

Findings – The data provided by Periodic Reports are demonstrated to be a good starting point for a continental-scale analysis of the actual distribution of natural threats affecting WHSs in Europe. The Periodic Reports appear to be reliable enough for a first-order assessment of hazards. The general overview of the hazard at the European scale shows high value of hazard index in the Eastern Mediterranean area and Balkans, due to a combination of earthquakes and landslides. The most at danger cultural site is in Bosnia and Herzegovina, while the most at danger natural site is Norway.

Originality/value – The paper gives a contribution to improve the continental-scale knowledge on hazards affecting the UNESCO heritage sites. The assessment of hazard inside the WHSs is an important task for the preservation of cultural and natural heritage, and it is important for UNESCO to achieve some of its goals. Through this research, European WHSs have been ranked according to their degree of hazard.

Keywords UNESCO Periodic Reports, UNESCO WHSs, Natural threats, Hazard assessment, Europe, Analytical hierarchy procedure

Paper type Research paper

1. Introduction

UNESCO world heritage sites (referred as WHSs in the paper) are monuments, groups of building sites that are of outstanding universal value from the point of view of history, art, or science. These may be natural features such as geological and physiographical formations or natural sites

Data used in this work were acquired during the PROTHEGO (PROTection of European Cultural HEritage from GeO-hazards) project, in the framework of the Joint Programming Initiative on Cultural Heritage and Global Change (JPICH) – HERITAGE PLUS, under ERA-NET Plus and the Seventh Framework Programme (FP7) of the European Commission (http://www.prothego.eu/, last access 06/12/2019).

that are of outstanding universal value from the point of view of science, conservation, or natural beauty (UNESCO World Heritage Centre, 2017). Their identification, conservation, and protection are very important to convey to future generations what our impacts on Earth and the beauty of the Earth itself have been (UNESCO World Heritage Centre, 2017).

Hence, assessing natural risk in these areas is important for the management and the conservation of these sites (Leask and Fyall, 2006; Lollino and Audisio, 2006; Paolini *et al.*, 2012) and other cultural heritage sites (Taboroff, 2000; Waller, 2003; Delmonaco *et al.*, 2005; Sabbioni *et al.*, 2010; Spizzichino *et al.*, 2013), Based on the literature, a number of guiding principles are suggested for the improvement of management plans and the integration of hazard and risk in cultural heritage (e.g. Stovel, 1998; Taboroff, 2000; Taboroff, 2003; ICCROM UNESCO, IUCN ICOMOS, 2010; Michalski and Pedersoli, 2016), With the aim to reduce the risks on world heritage properties from natural and human-made disasters, these research studies provide methodologies to identify, assess, and mitigate disasters (ICCROM UNESCO, IUCN ICOMOS, 2010; Michalski and Pedersoli, 2016), Recently, Pavlova *et al.* (2015) and Osipova *et al.* (2017) presented a global-scale analysis of geological hazards at world heritage sites; despite this, a detailed overview at continental scale in Europe is still missing for WHSs. Such overview may be useful to characterize the hazards that actually affect the sites and to assign a possible rank to the sites based on risk. This ranking may help to prioritize the interventions and future allocation of funds independently from the State Parties' request. UNESCO, or each State Party, could establish management plans and set up report systems on the state of conservation of heritage sites based on the associated risk level. UNESCO could give international assistance and cooperation in scientific, financial, artistic, and technical terms. At least, based on an objective analysis, UNESCO could define and suggest policies for protection, conservation, presentation, and transmission to future generations of the cultural and natural heritage witness.

This research aims at presenting a continental-scale analysis, based on a simple multicriteria approach, which allows to identify the European sites with high level of risk based on available data.

Multicriteria analysis has been widely used for risk assessment associated to natural hazards. At European scale, different projects have been developed, such as EC TIGRA project 1997 (Delmonaco *et al.*, 1999); TEMRAP (The European Multi-Hazard Risk Assessment Project) (Delmonaco *et al.*, 2003); DDRM (France) multirisk approach (DRM-Délégation aux Risques Majeurs, 1990); ESPON 2005 multihazard approach (Schmidt-Thomé, 2005); JRC – Multirisk Approach: an integrated assessment of weather-driven natural risk in Europe (Barredo *et al.*, 2005); ARMONIA Project (Delmonaco *et al.*, 2006); and MATRIX Project (https://cordis.europa.eu/project/id/265138/it). In addition to these European projects, some international approaches were developed, such as: FEMA (Federal Emergency Management Agency) multirisk approach (United States, Federal Emergency Management Agency, 2003); the methodology of disaster management in Tajikistan (Granger, 2001); the global risk analysis impact-weighted multihazard disaster hotspot index (Dilley *et al.*, 2005); the approach proposed by Geoscience Australia (Dwyer *et al.*, 2004). Other works include: the New Zealand RiskScape developed by GNS Science and NIWA (Gallina *et al.*, 2016); the CAPRA project (https://ecapra.org/; Gallina *et al.*, 2016); the CLUVA project (https://cordis.europa.eu/project/rcn/96934/factsheet/en); and the PRIM project (Lari *et al.*, 2009).

In this paper, we apply a multicriteria methodology at European scale considering multiple hazards using the analytic hierarchy process (AHP) methodology. The AHP methodology is a multicriteria decision-making (MCDM) approach (Ho, 2008). Because of its great flexibility and wide applicability, integrated AHP approaches have been studied extensively for the last 20 years in different fields (Ho and Ma, 2018). Many research studies aimed at evaluating natural hazards and geo-environmental problems using the AHP technique can be found in literature (e.g. Dai *et al.*, 2001; Wu *et al.*, 2004; Chen *et al.*, 2011; Bathrellos *et al.*, 2012; Chang and Chao, 2012; Tsai *et al.*, 2012).

In this paper, the hazard distribution in Europe was evaluated on the basis of Periodic Reports. Then the reliability of Periodic Reports information has been validated in Italy, for which high-quality inventories for volcano, earthquake, and landslide hazards are available. Finally, a methodology for multicriteria analysis is presented to rank the level of hazard of the WHSs at the European scale.

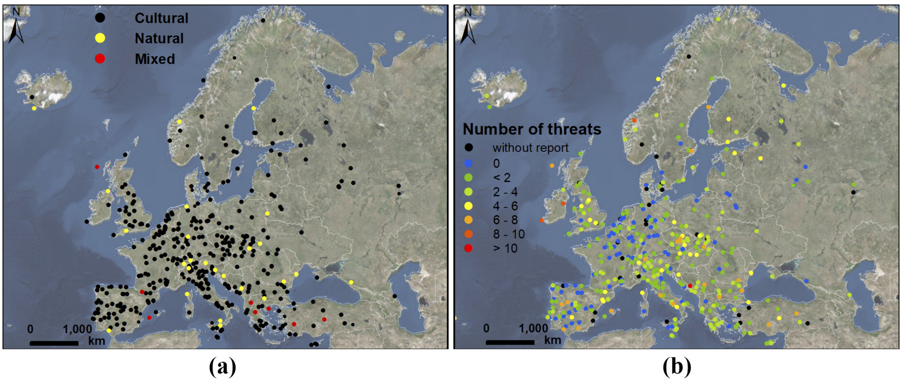
2. WHSs and Periodic Reports

436 WHSs exist in the European continent as of May 2016 (Figure 1a). The official reference of the sites is the UNESCO WHL webpage (http://whc.unesco.org/en/list/), with maps and documents available for download.

For each WHS, the State Parties are invited to submit a Periodic Report relative to the state of conservation of the world heritage properties located on their territories (https://whc.unesco.org/en/periodicreporting/; Pavlova *et al.*, 2015).

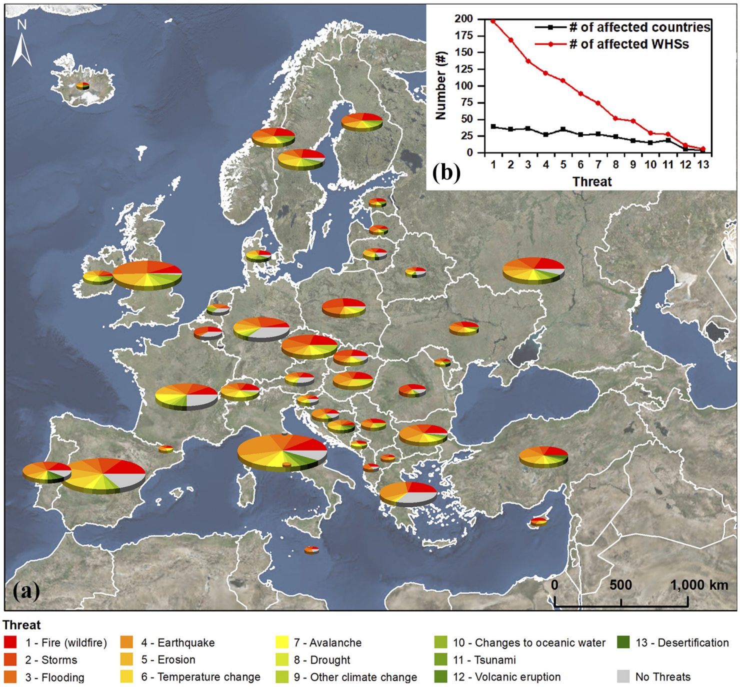
The methodology is based on a self-assessment of the state of conservation through a questionnaire. The Periodic Report consists of two sections: Section I on the implementation of the World Heritage Convention on a national level; and Section II on the state of conservation of each world heritage property (UNESCO World Heritage Centre, 2012). States Parties may request support from the Advisory Bodies and the UNESCO Secretariat, which may also commission further expert advice. The World Heritage Committee formulates recommendations to State Parties at the regional level. Action Plans are formulated through a collaborative process, which often involves site managers, Advisory Bodies, and the World Heritage Centre. The process lasts for a period of approximately six years.

In this paper, Chapter 3 of section II (Factors affecting the property) of the “Second Cycle” of Periodic Report in Europe (2008–2015) has been considered and analyzed. Among all the factors, the analysis includes 13 factors belonging to the “Climate change and severe weather events” and “Sudden ecological or geological events” groups (Figure 2), The first group is composed of storms (including tornadoes, hurricanes/cyclones, gales, hail, lightning, river/stream overflows, extreme tides), flooding, drought, desertification, changes to oceanic waters (including changes to water flow and circulation patterns at local, regional, or global scale, changes to pH, changes to ocean temperature), temperature change, and other climate change impacts. The second group is composed of volcanic eruptions, earthquakes, tsunami/tidal waves, avalanches/landslides, erosion and siltation/deposition, and wildfires. This list was established by the World Heritage Committee following a two-year consultation process



Source(s): Maps sourced from ArcGIS software (2019)

Figure 1. (a) WHSs inside the European continent in May 2016; (b) number of threats affecting the WHSs based on the Periodic Reports



Note(s): The size of the pie charts is a function of how many times the threats affect the WHSs of each country and the number of sites without threats

Figure 2.
(a) Distribution of the considered threats inside the European countries; (b) the plot reports the number of affected countries and sites for each threat, classified according to the legend of Figure 2a. Maps sourced from ArcGIS software (2019)

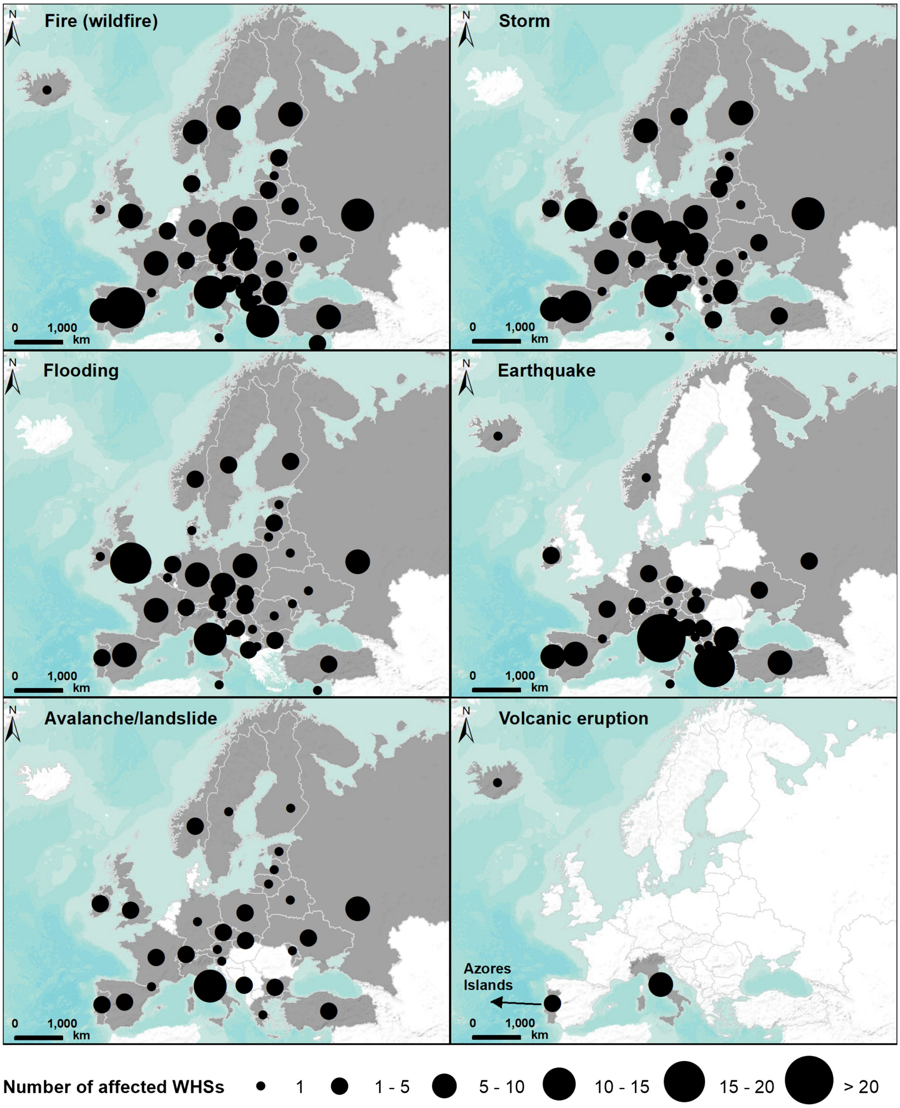
with experts in both fields of natural and cultural heritage (https://whc.unesco.org/en/reflectionyear/).

Most of the WHSs are composed of more than one property (i.e. the site nominated and inscribed inside the World Heritage List), sometimes located in different countries (transboundary sites). The Periodic Report is produced for the whole site also for multipart sites, without any specification about the distribution of hazard among the proprieties.

Periodic Reports are available for 406 (93.2 percent) out of 436 WHSs (Figure 1b). Among these, 23 percent do not show any threat affecting the area, while the remaining 70 percent show at least one threat. The most frequent threats are fire (i.e. wildfire), storms, flooding, earthquakes, and erosion (Figure 2). The spatial distribution of threats among the European countries is variable and depends on geodynamic, meteo-climatic, and geomorphological conditions (Figure 3). For instance, fire, storm, and flooding are evenly spread in the whole European continent, while avalanche/landslides, earthquakes, and volcanoes are more localized, especially in the Mediterranean countries.

3. Validation of Periodic Reports

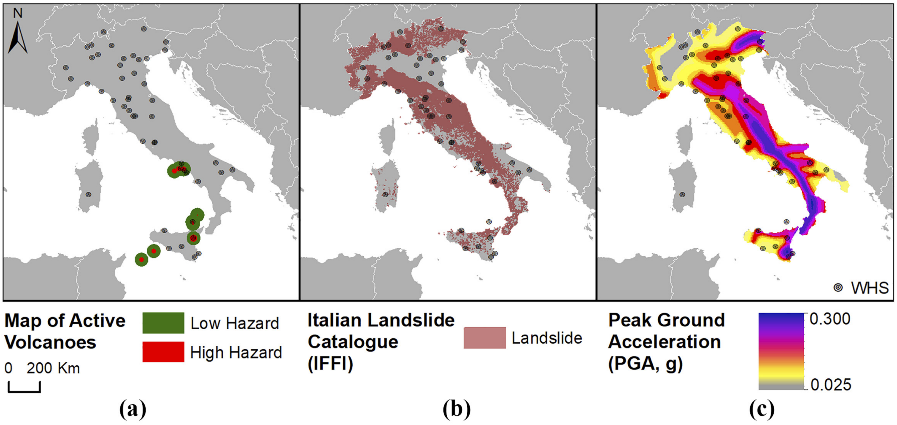
To validate the reliability of hazards identified on the basis of the Periodic Reports, we performed a detailed analysis on the Italian sites for which high-quality hazard inventories are available (Figure 4). In particular, three threats among the list are considered: volcanoes, earthquakes, and landslides.



Note(s): The size of the dot is a function of the number of affected WHSs in each country. Countries with at least one site affected by the threat are coloured in gray

Figure 3. Distribution of six selected threats inside the European countries

For each threat, we assessed the number of sites actually affected, according to high–quality data, and we compared this number with the information of the Periodic Reports through a contingency matrix (Table I). This matrix allows to visualize the WHSs correctly classified by both methods as affected (True Positive, TP) or not affected (True Negative, TN) by any hazard, and the sites that are incorrectly classified by Periodic Reports, either because considered wrongly affected (False Positive, FP) or not affected (False Negative, FN) by any



Note(s): (a) map of the active volcanoes hazard in Italy (Loughlin et al., 2015); (b) Italian landslide catalogue (IFFI, 2010); (c) seismic hazard map of Italy expressed in terms of peak ground acceleration (PGA, g) with a 10 percent probability of exceedance in 50 years (Working Group MPS, 2004; Tr = 475years), Italian WHSs are also reported (black square)

Figure 4.
Italian national-scale hazard inventories

Table I.
Meaning of contingency table adopted in this study

		UNESCO reports	
		No hazard	Hazard
High-quality information	No hazard	TN, True negative	FP, False positive
	Hazard	FN, False negative	TP, True positive

Note(s): In row, the classification based on high-quality treat information, which we consider the truth for the validation of the classification based on Periodic Reports (in column)

hazard. The overall accuracy (or Percent Correct) of the classification is computed as (Frattini *et al.*, 2010):

$$\frac{TP + TN}{(TP + TN + FN + FP)}$$

3.1 Volcanic hazard

The map of the active volcanoes of Europe (Loughlin *et al.*, 2015) reports nine areas in Italy potentially affected by volcanic activity (Figure 4a), For each volcano, two buffer zones are defined: an area with high hazard associated to the area supposedly affected by lava, pyroclastic flows, tephra, and volcanic ash; and an area with low hazard associated to the maximum propagation of the volcanic ash only (http://annuario.isprambiente.it/).

Comparing these data with the Periodic Reports, we found that 98 percent of the WHSs are correctly classified as affected by volcanic hazard according to the Periodic Reports (Table II). The only false negative is Costiera Amalfitana site, which appears to be without volcanic hazard according to the Period Report, but actually lies within the Vesuvius ash fall impact zone (low hazard buffer).

3.2 Landslide hazard

The Italian Landslide Catalogue IFFI, 2010 has been used for the characterization of landslide hazard (Trigila *et al.*, 2010, Figure 4b). This inventory was compiled since 1999 with the aim of identifying and mapping landslides throughout Italy on the basis of standardized criteria, and it includes over 480,000 landslides.

In this analysis, the site is considered as actually affected by landsliding if: (1) at least one landslide lies within the WHS area (either property or buffer zone) (Table IIIa); or (2) more than 1 percent of the area is affected by landslides (Table IIIb).

From Contingency Table IIIa, 67 percent of the WHSs are correctly classified as affected by landslide hazard according to the Periodic Reports. In particular, the Periodic Reports tend to underestimate the landslide hazard, as demonstrate by a high rate of false negative (61.9 percent). The same results are observed in Table IIIb, with 65 percent of the WHSs correctly classified as affected by landslide hazard, and a false negative rate of 64.7 percent.

3.3 Earthquake hazard

The seismic hazard map of Italy, expressed in terms of peak ground acceleration (PGA, g) with a 10 percent probability of exceedance in 50 years (Working Group MPS, 2004; Tr = 475years), has been used for seismic hazard (Figure 4c). A site has been defined as affected by seismic hazard if the PGA at the site is greater than 0.15 g. 73 percent of the WHSs are properly classified as affected by earthquake hazard according to the Periodic Reports (Table IV). Also in this case, a certain number of sites are misclassified, five of which as false negatives (i.e. Early Christian Monuments of Ravenna, Prehistoric Pile Dwellings around the Alps, Arab–Norman Palermo and the Cathedral Churches of Cefalú and Monreale, and the

		UNESCO reports	
		No hazard	Hazard
Catalogue of active volcanoes	No hazard	42 (100%)	0 (0%)
	Hazard	1 (14.3%)	6 (85.7%)
Overall accuracy = 98%			

Note(s): Only one site is classified as affected by volcanic hazard by the catalogue of active volcanoes and not affected by the UNESCO Periodic Reports. Values in parenthesis are percent with respect to row totals

Table II. Contingency table reporting how many Italian WHSs are affected or not by volcanic hazard according to Periodic Reports and the European catalogue of active volcanoes (Loughlin *et al.*, 2015)

		UNESCO reports	
(a)		No hazard	Hazard
IFFI (≥1 landslide inside WHS	No Hazard	24 (88.9%)	3 (11.1%)
	Hazard	13 (61.9%)	9 (38.1%)
Overall accuracy = 67%			

		UNESCO reports	
(b)		No hazard	Hazard
IFFI (≥1% WHS area affected by landslides)	No hazard	26 (81.2%)	6 (18.7%)
	Hazard	11 (64.7%)	6 (35.3%)
Overall accuracy = 65%			

Note(s): With respect to the Italian Landslide Catalogue IFFI, 2010 based on the presence of one landslide (a) and based on the percentage of area affected by landslides with a 1 percent of the area threshold value (b), respectively. Values in parenthesis are percent with respect to row totals

Table III. Contingency tables reporting if each Italian WHS is affected or not by landslide hazard according to Periodic Reports

Dolomites). For example, an earthquake with a magnitude of 4.6 affected the city of Ravenna on January 15, 2019.

4. Multicriteria method for WHSs hazard analysis

Hazard is defined here as a process that may cause loss of life, injury/other health impacts, property damage, social and economic disruption, or environmental degradation (UNISDR terminology, Assembly *et al.*, 2016) and does not account for probability. In order to calculate a multihazard index for ranking the WHSs, the different threats were aggregated through a weighted sum:

$$H_{pr} = \sum (H_i P_i) \tag{1}$$

where H_{pr} is the Periodic Report–based multihazard index, H the presence/absence [0,1] of a threat that affects a specific site as from the relative Periodic Report, and P the mean weight derived from the AHP methodology (Table V).

The AHP (Saaty, 1987) is an extensively used technique for multiattribute decision-making. AHP enables the breakdown of a problem into hierarchy where both qualitative and quantitative aspects of an issue are included in the evaluation process. The opinion of different experts about the dominance of hazards is extracted by means of pairwise comparisons. In this comparison, the value 1 indicates equality between two processes while 9 indicates that one process is absolutely more important than another. The weights are obtained by rescaling between 0 and 1 the eigenvectors relative to the maximum eigenvalue for the matrix of the coefficients, resulting from the pairwise comparisons. The internal

Table IV. Contingency table reporting if each Italian WHS is affected or not by seismic hazard according to Periodic Reports and the Italian seismic hazard map (PGA > 0.15g) (Working Group MPS, 2004)

		UNESCO reports	
		No hazard	Hazard
PGA > 0.15g	No hazard	18 (69.2%)	8 (30.8%)
	Hazard	5 (21.7%)	18 (78.3%)
Overall accuracy = 73%			

Note(s): Values in parenthesis are percent with respect to row totals

Table V. Normalized weights computed as the mean of the values assigned through AHP approach by expert judgment and relative standard deviation

Threat	Mean weight	Standard deviation	Coefficient of variation
Earthquake	0.193	0.075	39%
Volcanic eruption	0.193	0.055	28%
Avalanche/landslide	0.131	0.072	55%
Flooding	0.109	0.043	39%
Tsunami/tidal wave	0.1	0.063	63%
Storm	0.064	0.044	69%
Change to oceanic water	0.056	0.035	63%
Fire (wildfire)	0.049	0.033	67%
Desertification	0.024	0.035	146%
Erosion and siltation/deposition	0.024	0.047	196%
Drought	0.023	0.026	113%
Temperature change	0.019	0.031	163%
Other climate change impacts	0.016	0.025	156%

Note(s): Coefficient of variation is the ratio between the standard deviation and the mean weight, is shown in percentage coherence of the expert's attribution is controlled by the consistency ratio (CR), which is given by the ratio between the consistency index (CI) and the random consistency index (RI). The first is calculated as:

$$CI = (\lambda - n)/(n - 1) \quad 2$$

where λ is the maximum eigenvalue of the matrix and n represents the size of the matrix itself (n = 13 in this paper). RI is a value associated to the size of the matrix and amounts to 1.5551 for a matrix with 13 elements (Alonso and Lamata, 2006). Different thresholds of CR are associated to different sizes of the matrix. In particular, if the size of the matrix is higher than five elements, the suggested CR threshold is 10 percent (Saaty, 1987).

A panel of 16 experts from partner institutions of the JPICH PROTHEGO project (PROTection of European Cultural HEritage from GeO-hazards, available at: http://www.prothego.eu/) was involved. In order to compare the different hazards, the experts have been asked to judge the relative importance keeping in mind events with a magnitude corresponding to the same reference return period (i.e. 100 years for all the threats). Among the 16 experts, 10 reached the CR target and were used to estimate the weights (Table V). For each threat, the normalized weight is computed as the mean of the values assigned through AHP approach by expert judgment.

The coefficient of variation (i.e. the ratio between the standard deviation and the mean weight) of the weights ranges from 28 percent to 196 percent, showing variable degree of uncertainty in the opinion of the experts about the weighs for the different threats. In particular, the uncertainty is greater for those threats that are more difficult to quantify in terms of physical effect, such as temperature change or other climate change impacts. For other threats with a more quantifiable effects on WHSs, such as volcanic eruptions and earthquakes, the coefficient of variation decreases below 40 percent.

The results of the multihazard index for the European WHSs are presented in Figure 5, and Table VI lists the most at danger cultural and natural sites. The Mediterranean area and Balkans show the greatest concentration of WHSs with high level of hazard, while Central Europe seems to show the lowest amount of threats potentially affecting the WHSs. The highest value of hazard for cultural heritage is 0.677 (Old Bridge Area of the Old City of Mostar, Bosnia and Herzegovina). For natural heritage, the most at danger site (West Norwegian Fjords – Geirangerfjord and Nærøyfjord, Norway) has a value of 0.745. In both cases, the hazard is relative to a scale with a maximum value of 1, which would occur in case all the 13 threats are affecting the site.

A general overview of the H_{pr} distribution is reported in Figure 6 for European countries with more than one WHS. For some of them, the statistics is not representative due to the low number of WHSs within their borders (e.g. Ireland, Holy See). Ten countries show at least one cultural heritage site with an index higher than 0.5 (Figure 6a). Among the countries with more cultural heritage sites, the distribution of H_{pr} is significantly shifted toward lower values for France and Germany with respect to Italy, Spain, and the United Kingdom. Interestingly, some countries show a large spread of hazard values, possibly due to complex morphological settings leading to significant diversification of hazard within the country (e.g. Italy and Spain). From Figure 6b it is possible to appreciate the low number of natural heritage sites in each country. Due to the presence of only one natural heritage site in Norway, the most at danger European natural heritage site is not shown in the graph.

5. Discussion and conclusion

The assessment of hazard inside the WHSs is important for the preservation of cultural and natural heritage, and it is important for UNESCO to achieve some of its goals, such as: (1) to ensure the protection of natural and cultural heritage at European scale; (2) to provide

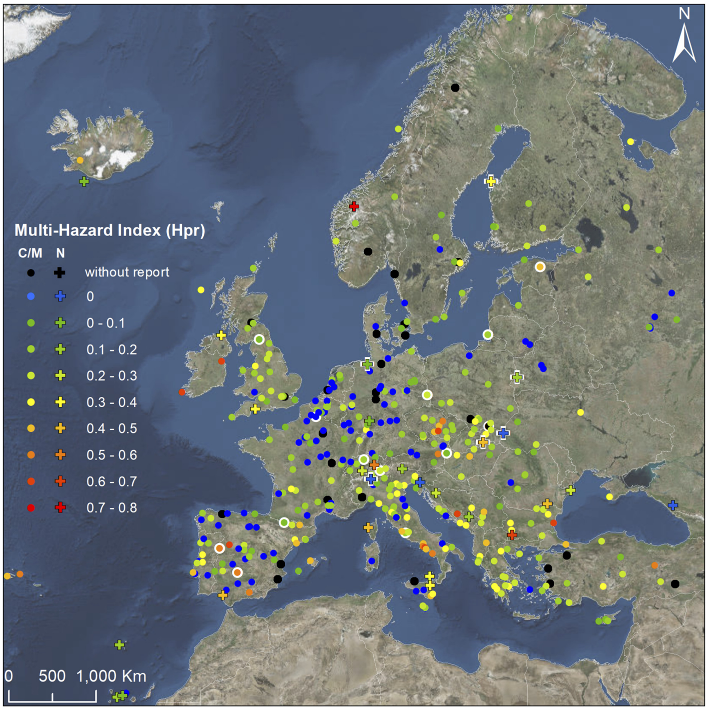


Figure 5. Classification of the 436 WHSs on the European continent based on the multihazard index (H_{pr}, eq.1)

Note(s): The sites have been divided into cultural and mixed sites (C/M–dot) and natural sites (N–cross). The white halo indicates the transboundary property.
Maps sourced from ArcGIS software (2019)

emergency assistance for heritage sites in immediate danger, besides technical assistance and professional training, for the sites with a high risk; (3) to support States Parties' public awareness-building activities for heritage conservation, showing the level of risk that may affect the heritage sites; (4) to encourage international cooperation in the conservation and protection of world's cultural and natural heritage threatened by a high risk.

In this study, the data provided by Periodic Reports are demonstrated to be a valuable starting point for a continental-scale analysis of the actual distribution of natural threats that affect the cultural and natural WHSs in Europe. Periodic Reports represent the perception that individual State Parties have regarding threats that affect their heritage sites, and they are extremely useful because they allow a synoptic and comparative view of these threats among the different countries. However, the available data present some shortcomings that need to be taken into account when evaluating the hazards: (1) some sites still miss the Periodic Report; (2) the Periodic Reports are developed by each State Party, causing overestimation or underestimation of site specific risks, due to a different risk perception (Pavlova *et al.*, 2015); (3) the Periodic Report is compiled for the whole site, which is a strong limitation in case of transboundary properties (e.g. Struve Geodetic Arc Sites, present in 10 states), or site with the property divided in more than one part (e.g. the Routes of Santiago de Compostela in France encompasses 78 buildings). In these cases, in fact, a hazard affecting a part of a site is associated to all the properties within the same site. As an example, the threat

Type	Rank	Site name	Country name	H_{pr}
Cultural and mixed site	1	Old Bridge Area of the Old City of Mostar	Bosnia and Herzegovina	0.677
	2	Archaeological ensemble of the bend of the Boyne	Ireland	0.668
	3	Archaeological areas of Pompeii, Herculaneum, and Torre Annunziata	Italy	0.654
	4	Sceilg Mhichíl	Ireland	0.626
	5	Ancient City of Nessebar	Bulgaria	0.617
	6	Jewish Quarter, and St Procopius' Basilica in Třebíč	Czechia	0.605
	7	Old city of Salamanca	Spain	0.605
	8	Central Zone of the town of Angra do Heroismo in the Azores	Portugal	0.599
	9	Litomyšl Castle	Czechia	0.569
	10	Great Mosque and Hospital of Divrigi	Turkey	0.548
Natural site	1	West Norwegian Fjords – Geirangerfjord and Nærøyfjord	Norway	0.745
	2	Pirin National Park	Bulgaria	0.612
	3	Swiss Tectonic Arena Sardona	Switzerland	0.515
	4	Caves of Aggtelek Karst and Slovak Karst*	Hungary, Slovakia	0.481
	5	Gulf of Porto: Calanche of Piana, Gulf of Girolata, Scandola Reserve	France	0.478
	6	Doñana National Park	Spain	0.441
	7	Pitons, cirques and remparts of Reunion Island	France	0.437
	8	Srebarna Nature Reserve	Bulgaria	0.419
	9	Mount Etna	Italy	0.386
	10	Isole Eolie (Aeolian Islands)	Italy	0.348

Note(s): The first 10 sites with the higher potential hazard in Europe are shown for both cultural and mixed sites (*C/M*) and natural sites (*N*), *transboundary property

Table VI. Ranking of the WHSs according to the AHP approach

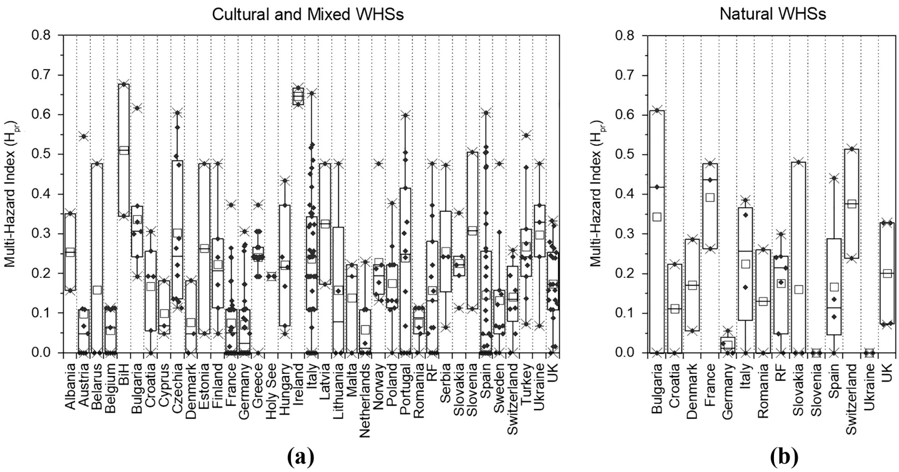


Figure 6. Distribution of the multihazard index (H_{pr}) for countries with more than one WHS; (a) cultural and mixed WHSs and (b) natural WHSs. BiH = Bosnia and Herzegovina; RF = Russian federation; and UK = United Kingdom of Great Britain and Northern Ireland

of tsunami is attributed to all the Struve Geodetic Arc Sites, even if most of them are located far inland.

The validation of the Periodic Report information with high-quality hazard data sets available for the Italian sites supports the reliability of Periodic Reports for an initial characterization of potential hazard in WHSs in Europe. In particular, the reliability is higher for volcanic hazard, which is strongly constrained by the location of few well-known volcanos, and lower for landslide hazard that is characterized by many small and spatially diffused phenomena, the perception of which strongly depends on the skill of the experts in charge of Periodic Reports compilation.

In order to become a more reliable tool for understanding and comparing at European scale the potential risks that affect the WHSs, it could be extremely useful that Periodic Reports follow more objective and standardized guidelines, also including information about events or other data that could confirm the actual impact of the threats. Moreover, the Periodic Reports should be done for the individual sites in the case of transboundary properties or for site with the property divided in more than one part and located in an extended area.

The ranking of WHSs at the European scale was done by defining a multihazard index (H_{pr}) through the AHP procedure. The method has been developed without considering the differences existing among the heritage types (e.g. cultural vs natural sites, built areas vs cultural landscapes), and therefore, it does not account for the potential damage of the threats, which also depends on the specific vulnerability of the WHSs. This implies that the actual level of risk to the cultural and natural Heritage sites is not accounted in this analysis since it depends on site-specific conditions that are beyond the aim of this paper.

The AHP methodology adopted for the ranking of the WHSs is affected by some weaknesses that, however, do not invalidate its validity for the purposes of the paper. In addition to the subjectivity of the expert judgments, the AHP methodology assigns equal importance to each individual's priority vectors and ranking and ignores the disparities in expert's profiles (Cascetta *et al.*, 2015). This may be an issue when involving different groups of decision-makers, experts, and stakeholders. In our case study, the 16 experts involved in the AHP belong to similar fields with a common background and partially obviate this weakness. Rank reversal is another typical issue with the AHP ranking (Belton and Gear, 1983) and should be considered carefully. It defines the changes in the order of the judgment alternatives when a new judgment alternative is added to the analysis. In this paper, this issue has been not experienced since no change associated to the alternatives has been applied. When the number of the levels in the hierarchy increases, the number of pair comparisons also increases, so that building the AHP model takes much more time and effort and possibly introduces further inconsistencies due to decrease in concentration (Lockett *et al.*, 1986). This may be an issue for our case study where 13 alternatives are used. In contrast to the method proposed by Saaty (2003) to improve the consistency judgments and transform an inconsistent matrix to a near consistent one, in this paper no transformation was adopted. This decreased the level of consistency, but allowed to maintain the original expert judgments without any alteration.

The uncertainty of the weight in the AHP procedure is strongly linked to the degree of knowledge of the experts on the considered threats and on the perception that these threats can constitute an actual hazard on a WHS. For these reasons, threats such as temperature change or erosion show a high degree of uncertainty, due to the dispersion of the scores. Experts considered these threats either predominant or negligible compared to the other threats. In contrast, for threats such as volcanoes, whose effects and consequences are well known and quantifiable, the uncertainty associated with the score decreases significantly. From this point of view, this research also provides an insight into the degree of confidence of researchers on the threats affecting the WHSs and our environment at larger scale.

The outcome of the study, in terms of threats recognized as potentially more harmful, could help UNESCO to better characterize them inside each WHS. Periodic Reports could collect data specific to these threats. In this perspective, it will be necessary to expand the panel of experts involved in defining the weights associated with each threat. For different WHSs (i.e. cultural, natural, or mixed site), different sets of threats could be considered for a more specific characterization of the hazards affecting the WHSs.

The general overview of the hazard at the European scale shows high value of H_{pr} in the Eastern Mediterranean area and Balkans, due to a combination of earthquake and landslide hazards. As shown in Figure 3, these threats, characterized by a high weight in AHP methodology, are dominant in these areas. Despite the high number of WHSs, Germany, France, and Spain present a high percentage of sites for which Periodic Reports do not mention any threat affecting the sites. In these cases, a critical review of the existing Periodic Reports is suggested to avoid shortcomings.

Highlights

(1) Periodic Reports represent the available continental-scale knowledge on threats affecting UNESCO World Heritage Sites (WHSs);

(2) Periodic Reports data are validated with high-quality data available in Italy;

(3) Multicriteria analysis is proposed to rank the most critical WHSs in Europe.

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