Mapping Natural and Activity-Induced Hazards for Water Heritage in Italian Seaports

Elena Cantatore(✉), Mariella De Fino, Margherita Lasorella, and Fabio Fatiguso

Politecnico di Bari, 70126 Bari, Italy
elena.cantatore@poliba.it

Abstract. Hazard mapping for built heritage in seaports is essential due to the coexistence of natural events and anthropogenic activity-based. Hydro-geomorphological features and human-induced effects are diversely distributed, and both affect the preservation of valuable architectural, archaeological, industrial and infrastructural assets in administrative seaport boundaries. However, in the Italian context, the ongoing process of cataloguing heritage may limit the effectiveness of assessment and preservation strategies.

This paper presents the first findings of hazard identification in Italian seaports as part of the national research project RE^{3}WORK. The study focuses on the assessment of seaports' susceptibility to natural and anthropogenic hazards to support the safe and sustainable reuse of their built heritage. By combining data on geographical location, port activities and systematic built heritage inventory, recurrences in natural and activity-induced hazards are identified at national scale, also thanks to national hazard maps and an international database of industrial-based hazards classification. As the main outcomes, flooding and explosion caused by industrial and civil navigation are identified as dominant hazards in seaports. A more detailed investigation is conducted at the regional scale, focusing on Apulia, South Italy, to examine site-specific hazard interactions. The analysis links the spatial distribution of built heritage with flood vulnerability and port activities, revealing local variations in hazard proneness. Findings highlight the predominant role of ship-related activities as explosion source, while also demonstrating the limitations of regional flood vulnerability mapping in effectively assessing built heritage exposure to natural hazards.

Keyword: Water built Heritage · seaport · natural and anthropogenic risks · Apulian ports

1 Introduction

Risk mapping constitutes a pivotal activity in the preventive phases of the hazard risk management process. Identifying hazard types and understanding the potential proneness of certain areas to these hazards are the main basis for establishing a robust structure for risk management [1–3].

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At a global scale, hazard mapping aims to identify the types of hazards affecting territorial areas with varying intensities or occurrences to categorise and measure vulnerable areas [4]. Another level of hazard mapping involves a more detailed analysis at smaller territorial scales, characterised by similar geographical conditions but local specificities. This approach seeks to define possible local variations in hazards, combine them with physical and social vulnerabilities, and prioritise interventions at the appropriate scale [5, 6]. In both activities, risk mapping begins with identifying hazard types as a preliminary step to conducting risk analysis and management. Globally, several initiatives have been undertaken to record disastrous events and determine recurrence patterns. This is particularly relevant for hazards related to climate change processes that affect regions worldwide, including natural phenomena (i.e., Intergovernmental Panel on Climate Change – IPCC classification activities) [7]. Other classifications focus on different types of disasters, encompassing both natural and anthropogenic hazards and threats (i.e. classification by United Nations Office for Disaster Risk Reduction – UNDRR, Centre for Research on the Epidemiology of Disasters – CRED and the related EMDAT database) [8, 9]. Here, the purpose is to support national and international risk assessment and management efforts, enhancing local resilience.

In this framework, built heritage represents a weak element in disaster risk management. As outlined below, policymakers must control potential exposure at the physical level to conduct thorough analyses and implement strategies for risk mitigation. However, beyond well-documented architectural heritage, many undiscovered or unlisted ones pose challenges to risk management at both broad and local scales [10–12].

Risk mapping activities for architectural and cultural heritage are not new and have already been the focus of several projects.

At the European level, the Shelter and STORM projects represent two significant examples [13, 14]. In these projects, scientists and technicians collaborated to develop specific operational tools to assist policymakers in selecting mitigation strategies and potential reuse activities for particular case studies exposed to natural hazards. A common feature of these applications is the necessity of studying the varying levels of vulnerability of selected case studies across Europe. These efforts aim to establish classifications of strategies and promote general or specific guidelines for action, addressing both the preservation and reuse of heritage sites at risk from natural hazards while also fostering social and cultural resilience. However, in both projects, the focus is on listed architectural heritage.

In Italy, a significant initiative is the “Carta del Rischio” [15, 16]. Here, public and scientific institutions have collaborated to systematise three key dimensions of risk for national cultural heritage: potential exposure, state of vulnerability, and hazard type. These dimensions converge towards different levels of risk within the national territory. Risk classes are assessed in terms of potential cultural heritage loss, facilitating risk mapping on a broad scale to establish intervention priorities for heritage preservation. The identification of risk levels is integrated into a national WebGIS which maps Italian architectural and cultural heritage and qualifies them according to vulnerability levels (e.g., state of conservation), potential exposure (e.g., geomorphological vulnerability, seismic frequency), and hazard type. This is achieved with contributions from national and regional bodies specialising in natural hazard assessment, including Civil Protection,

Italian Institute for Environmental Protection and Research (ISPRA), National Institute of Geophysics and Volcanology (INGV), and regional Basin Authorities.

Despite the broad scale of analysis, "Carta del Rischio" is linked to the metadata of "Vincoli in Rete," which catalogues all listed and registered cultural heritage sites and architectures. However, the census of cultural heritage remains an ongoing and slow process. Recent studies have highlighted how this situation may impact recovery and preservation efforts for architectural heritage in seaport areas [17], particularly along the Italian coastline. The multi-dimensional nature of national and regional regulations for coastal management and protection, the diverse range of activities within the ports, and the historical evolution and transformation of port infrastructure hinder the identification and safeguarding of architectural and built heritage. Given this complexity, identifying built cultural heritage is a crucial first step in its documentation, while risk mapping for port areas is essential for their preservation, as it helps assess potential hazards and threats to which these sites may be exposed.

In this framework, the paper presents preliminary findings related to the hazards and threats identification of Italian ports currently managed by the Port System Authorities – AdSP, as part of the activities for the project RE^{3}WORK – REsilient REtrofitting and REuse of Water heritage and built environments: multi-objective Optimization for RisK mitigation and cultural enhancement. Specifically, the study focuses on preliminary activities aimed at determining possible hazard proneness of sites to provide suitable and secure reuse of architectural heritage in Italian AdSP ports – the so-called Water built Heritage (WH). This is achieved through a coherent and structured analysis of possible mitigation actions combined with integrated and conservation-oriented interventions. In detail, the study begins with an analysis of Italian coast proneness to natural hazards and the recurrence of related disastrous events in AdSP seaports due to port activities. The most recurrent hazards are identified in line with national-scale analyses. A specific focus on Apulian ports further examines local exposure to these hazards, linking WH to local geomorphological and typological features and distribution of port activities.

To this end, the paper is structured in the following sections:

- A background of previous scientific activities in risk mapping for coastal heritage and the associated aims of the RE^{3}WORK project (Sect. 2).
- The general framework and the detailed goals of the paper contents for Italian seaports coherent with the RE^{3}WORK project activities (Sect. 3).
- Preliminary results in hazards identification at national (Sect. 4.1) and mapping at local scale (Sect. 4.2), with a specific focus on the WH in Apulian seaports.

2 Background

Seaports are complex urban areas where multiple governmental entities and activities coexist. Due to historical development, both built historical and cultural heritage are present in these areas, with ports functioning as active or inactive architectural elements in their current state. This is a common characteristic of many port areas that have already been analysed in previous studies, particularly in relation to hazard proneness. In detail, focusing on the most recent activities in risk mapping activities on coastal built heritage, two main classes of hazards can be identified:

– Natural hazards, which consider both the geographical position of the studied territories (e.g., landslide, flood) [18, 19] and relative position with the sea (e.g. coastal erosion, sea level rise) [20–23].
– Hazards induced by human activities, resulting from local or territorial events (e.g., oil spills, ship accidents) [24, 25], as well as global processes (e.g., rising temperatures, water pollution) [26, 27].

In addition to governmental complexity, these two classes of hazards highlight the multidimensionality of ports, where commercial, strategic, and touristic activities coexist within a defined perimeter of the broader urban built environment. In this context, hazard identification and mapping for built heritage in ports reflect two key aspects:

– The positioning of seaports in terms of morpho-hydro-geographical conditions, which locally WH due to natural environmental factors (e.g., geomorphological features, climate).
– The type of activities conducted within ports, which may directly or indirectly contribute to the occurrence of disastrous events.

Both aspects must be properly correlated with the sea, which acts as a direct or indirect stressor for natural and anthropogenic hazards affecting WH.

Given these considerations, the hazard mapping for Italian ports managed by the AdSP in the RE^{3}WORK project begins with a rapid methodology designed to identify the most common hazards. This approach serves as a preliminary basis for analysing the relationship between WH and ports, with a particular focus on port activities, morpho-typologies, materials, and construction techniques. These characteristics help describe WH's inherent vulnerabilities or resilience, providing a foundation for a more detailed risk assessment. To this end, the analysis builds on the preliminary port cataloguing phase reported in [17]. This phase includes the ports' identification, geographical details gathering, and the activities' categorisation within seaports, as the primary dataset for developing a geographically referenced hazard recurrence database. In line with these objectives, three levels of data collection and analysis have been pursued:

– Level I—A census of all AdSP administrative areas, starting with basic information about their location and main activities.
– Level II—A census of WH in multi-activity port areas, enriching the ViR dataset by identifying WH entities within port environments.
– Level III—A locally focused analysis that integrates detailed information on activities, WH distribution within ports, construction techniques, materials, and functions associated with WH.

Based on these levels of information, subsequent national, local, and WH-specific risk analyses can be conducted, ensuring a comprehensive mapping of national and activities-induced hazards within their local contexts. Following, the most recurrent are identified and related to seaport samples and analysed in depth at the local scale for the reduced sample in the Apulian region.

3 General Framework and Goals

In line with the overview and previous thematic relevance of these issues, two dimensions of hazard classes are identified, leveraging two different databases and previous phenomenological analyses. Specifically:

- Natural hazards (H_Cl.1), referring to environmental, geophysical, or climatological events, regardless of whether they are induced by natural site conditions (e.g., earthquakes) or other factors (e.g., heatwaves). These hazards are derived from metadata related to the national territory, accessible via the National Geoportal. The geoportal allows data visualisation but does not enable metadata export. However, by classifying data into relevant macro-domains, it has been possible to identify the most significant hazards for the territory, such as earthquakes, landslides, and floods. Hazards related to air pollution and potential climatological risks are excluded, as they are associated with slow-onset scenarios and are therefore not considered relevant to the project's aims.
- Anthropogenic threats (H_Cl.2) caused by the use of or activities within the identified sites. In this case, the relationships between threats and ports are structured by linking the classification of port activities with the anthropogenic risk classes identified in the EM-DAT database[1] [9], which categorises anthropogenic threats as technological and complex risks. This database is managed by the CRED [28].

These classes of hazards, along with the associated databases, are integrated with the different levels of detail collected in Levels I, II, and III to achieve two main goals:

- Identification of the hazard types, calibrated to geographical details and predominant activities in port environments (Sect. 4.1, Level I content). Information on anthropogenic hazards (H_Cl.2) is derived from the classification of port activities and the EM-DAT classification of technological threats. Simultaneously, port administrative perimeters and national thematic metadata are combined to analyse the recurrence of relevant natural hazards (H_Cl.1) on the national scale.
- Preliminary hazard/threat proneness mapping at the WH scale, aligned with the typologies identified in the previous step (Sect. 4.2). Here, selected case studies from Level II are assessed based on the types of activities and hazards identified earlier. This step involves integrating details on WH locations and the distribution of activities within port areas (details from Level III).

All data collected and external open-source metadata are managed within a GIS-based environment to facilitate geographical-level data management.

To illustrate these objectives, Fig. 1 summarises the data used, including those catalogued in Levels I, II, and III, as well as metadata accessed for natural and activity-induced hazards, ensuring coherence with the scale of outcomes presented in this work.

[1] https://doc.emdat.be/docs/data-structure-and-content/disaster-classification-system/.

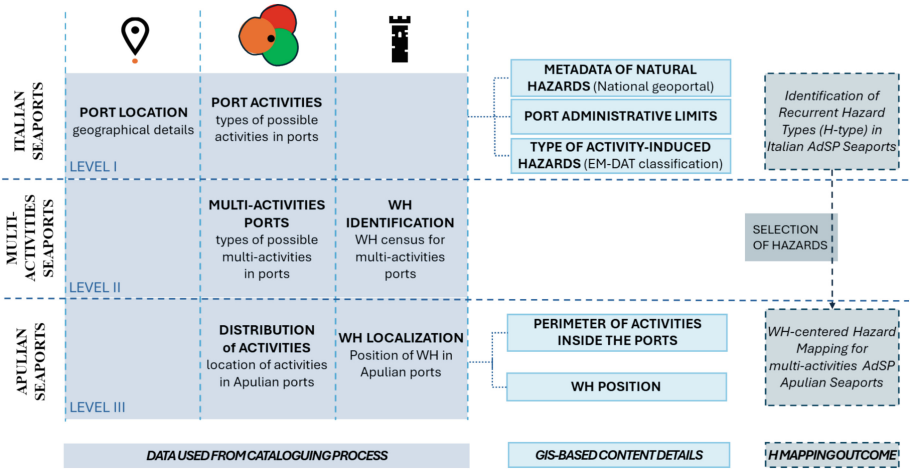

Fig. 1. Structure of data and metadata used to identify Hazard proneness of seaports from national to regional scale, combining three levels of data collected for seaports and WH census

4 Results in Hazard and Threat Mapping for Italian AdSP Ports

4.1 The Identification of Recurrent Threats and Hazards

Data gathering in Level I involved a 63-item sample of Italian AdSP port sites, distributed along the Italian coasts [17]. Using their geographical details, port sites were integrated into the GIS environment to set up the database and enhance them with external natural hazard metadata and the related threat types, also linking these with the associated activities.

Each port's administrative boundary was merged with metadata related to regional hydrogeological, territorial landslide, and national seismic vulnerability mapping in accordance with the details in Table 1.

The initial outcomes of the GIS analysis highlight the significance of hazard mapping activities in the ports. Specifically, the overlapping of port boundaries with all hazard vulnerability layers reveals several key patterns (Fig. 2).

The first relates to the seismic vulnerabilities of sites, which vary significantly, covering all the classes defined by national regulations (where 1 represents the highest level of vulnerability and 4 the lowest). In contrast, landslide vulnerability shows limited variation in significance for port areas, with few cases of critical geomorphological vulnerabilities when comparing external and inner port boundaries. Regarding the final hazard mapping aspect, flood vulnerability in ports exhibits a distinct distribution within administrative recurrences. Local dependency on administrative perimeters is evident when comparing the inner and outer results of the process, particularly in identifying high-vulnerability classifications for hydrogeological proneness. A critical analysis of these outcomes suggests that the management or absence of flood-related measures within port boundaries may require further investigation at a higher scale of analysis. Simultaneously, the key outcomes indicate that hydrogeological flood vulnerability in ports is a significant hazard warranting further exploration at the port scale.

Table 1. Thematic metadata used for the identification of natural hazard proneness analysis at the Italian AdSP ports

Thematic layer hazard type	*Opendata source*
Landslide	http://wms.pcn.minambiente.it/ogc?map=/ms_ogc/WMS_v1.3/Vettoriali/PAI_rischio.map
Seismic	http://wms.pcn.minambiente.it/ogc?map=/ms_ogc/WMS_v1.3/raster/IGM_25000.map
Flooding	http://wms.pcn.minambiente.it/ogc?map=/ms_ogc/WMS_v1.3/Vettoriali/Alluvioni_Classi_di_Rischio.map

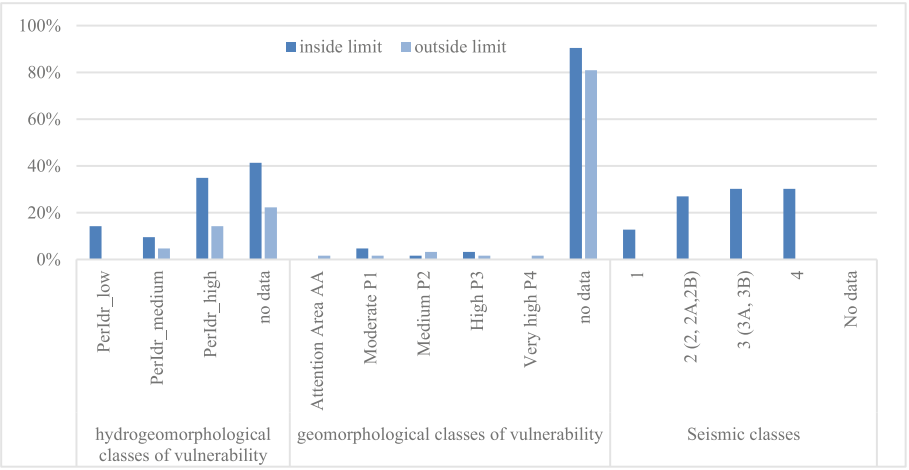

Fig. 2. Distribution in % of natural hazard proneness of the 63-item sample of AdSP seaports in classes of territorial vulnerability to hydro-geomorphological (flooding), geomorphological (landslide) and seismic hazards

The second level of outcomes pertains to activity-induced hazard identification. Based on the census carried out in Level I, Table 2 summarises the recurring activities and their frequency across all sampled ports. Additionally, Table 2 illustrates the multi-activity levels in the analysed ports, reflecting possible interferences between activities and threats. Industrial production, shipbuilding, civil navigation, leisure navigation, mercantile operations, and fish landing are linked to the EM-DAT threat types. The structured relationships between activities and EM-DAT threat classification are summarised in Table 3, providing a coherent correlation.

The integration of metadata into the GIS database for 63 ports facilitates the analysis of activity-induced hazards and their potential recurrences. Given the prevalence of multi-activity operations and the multidimensional nature of activity interferences, the counting process considers only the number of ports affected by each identified threat. This approach is essential to prevent the overestimation of hazard intensities, which can

Table 2. Type of activities and their recurrences in the 63-item sample of the analysed ports as single and multi-function levels

Type of activities	*n. of sites*	*Multi-function levels*	*n. of sites*
Industrial production	35	2 activities	3
Shipbuilding	31	3 activities	12
Civil navigation	47	4 activities	18
Leisure navigation	56	more than 4 activities	28
Mercantile	55		
Fish landing operations	42		

vary significantly depending on the spatial arrangement of activities within each port sub-area. In line with this approach, Fig. 3 presents the results, emphasising the prominence of threats associated with water-related activities, such as poisoning and shipping accidents, as well as industrial-based threats that arise from interactions between water activities and production processes (e.g., fire, explosion, and chemical/oil spills). A unique case involves a disused port where structural collapse is unrelated to ongoing activities but rather to physical and/or technological obsolescence.

Table 3. Relationship between seaports activities and EM-DAT type of threat defined for the Italian cases

EM-DAT type of Threat / *Activity type*	*Chemical spill*	*Gas leak*	*Oil spill*	*Radiation*	*Poisoning*	*Collapse*	*Explosion*	*Fire*	*Transport accident (Rail)*	*Transport accident (Water)*
Industrial production	x	x	x	x	x	x	x	x		x
Shipbuilding			x			x	x	x	x	x
Civil navigation							x	x		x
Leisure navigation								x		x
Merchant shipping						x	x	x		x
Fish landing	x				x			x		x

As first outcomes of these preliminary activities, two key classes of hazards emerge as focal points for further detailed analysis in WH conservation: the natural susceptibility of port areas to hydro-morphological vulnerabilities, particularly flooding, and the susceptibility to explosions resulting from industrial processes and ship accidents. The proneness of Italian seaports to these hazards requires further detailed assessment at the local scale, examining how the spatial distribution of activities and WH may interact.

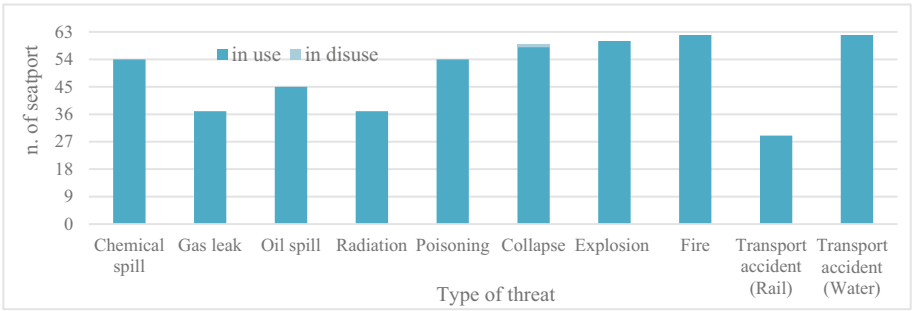

Fig. 3. Distribution of the 63-item sample of AdSP seaports in types of threats, as identified in EM-DAT and merged with seaport activities

Additionally, physical distances should be considered to determine how local conditions may extend the hazard susceptibility of other WH assets.

4.2 The Identification of Recurrent Hazards in Seaports for WH. First Outcomes in the Apulian Cases

Considering the second goal to be achieved in the hazard mapping process for Italian AdSP ports, the relationship between the WH census and site proneness is determined for a limited set of seaports, aligning with the requirements of the RE^{3}WORK project. This limited sample includes seaports characterised by a high level of multi-activity (three or more), relevance to the selected activity-induced (explosions from industrial activities and ship accidents), and/or proneness to the identified natural hazard (hydro-geomorphological proneness to flooding), as well as the presence of WH. For these ports, the WH census begins with the Vincoli in Rete (ViR) list, and it is refined through site analysis and administrative port documents, enhancing knowledge and WH cataloguing for the project's objectives. Table 4 presents the reduced list of ports and the associated number of WH assets within each port, highlighting the census results. For these ports, spatial recurrences of natural and activity-induced hazards mapping is necessary. To achieve this, the process involves merging the spatial distribution of functional areas in each port with the coordinates of the identified WH items. Thus, outcomes of the Apulian case studies are presented. Following the operational details discussed in Sect. 3, this second step uses WH coordinates, national maps of hydro-geomorphological vulnerabilities, and the distribution of port activities.

The geographical hazard mapping for the Apulian case studies indicates zero direct interferences between flooding and single WH. However, local proximities to flood-prone areas are observed in the cases of Taranto and Brindisi (Fig. 4), making them the most representative examples of this natural hazard.

On the other hand, the activity-induced hazard mapping for WH items reveals more significant findings for Apulian cases. Specifically, as summarised in Fig. 5, most identified WH items are located within port sub-areas dedicated to mercantile and civil navigation activities. This reduces their presence in industrial or production zones, emphasising

Table 4. List of selected multi-activities AdSP seaports and number of WH assets considering items already censed in Vincoli in Rete (ViR) platform and external ones

Seaport name	*n. WH items*	*ViR*	*Other*	*Seaport name*	*n. WH items*	*ViR*	*Other*
Porto di Genova	39	27	12	Porto di Licata	2	0	2
Porto di Savona	11	1	10	Porto di Augusta	8	6	2
Porto di La Spezia	11	9	2	Porto di Catania	6	2	4
Porto di Livorno	27	3	24	Porto di Bari	5	0	5
Porto di Portoferraio	7	6	1	Porto di Brindisi	17	11	6
Porto di Civitavecchia	9	8	1	Porto di Barletta	3	1	2
Porto di Napoli	15	5	10	Porto di Termoli	2	2	0
Porto di Castellamare di Stabia	4	1	3	Porto di Taranto	5	0	5
Porto di Crotone	2	0	2	Porto di Ancona	22	14	8
Porto di Cagliari	9	9	0	Porto di Ravenna	9	1	8
Porto di Olbia	3	3	0	Porto di Venezia	32	25	6
Porto di Palermo	18	2	16	Porto di Trieste	70	49	21
Porto di Porto Empedocle	8	2	6	Porto di Messina	8	3	5
Porto di Trapani	3	1	2				

the primary role of these activities in threat-induced evaluation. As a result, all identified WHs are linked to the main local activities to determine interferences and potential explosion sources. In these cases, sources depend on ship activities (navigation and mercantile operations) as the most probable starting events. Specifically, all identified WHs are connected to possible explosion sources, considering activities along mercantile docks and civil navigation docks and routes, with physical proximity acting as a key factor in enhancing WH proneness to overpressure [29]. To quantify this, minimum distances between mercantile docks, civil navigation routes, and WH location are calculated within the GIS environment, leading to the final results discussed in Table 5.

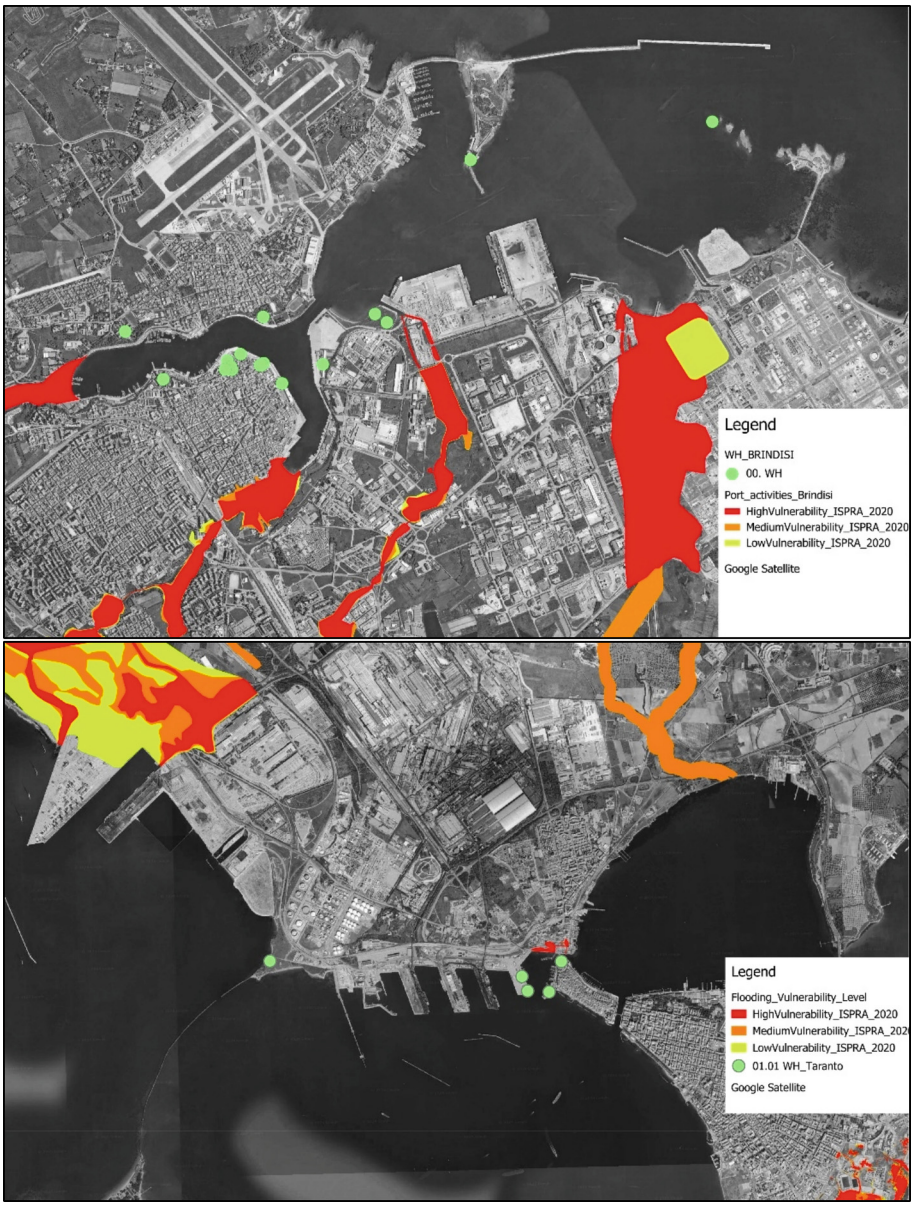

Fig. 4. Details of hydro-geomorphological vulnerability levels and WH distribution within the seaports of Brindisi (top) and Taranto (bottom)

In detail, distance classes are defined based on the following criteria:

– The same ship type is considered for both explosion collisions and mercantile activities, as explained by [29].

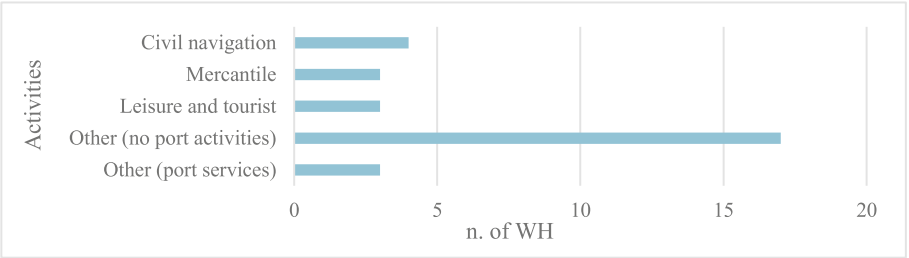

Fig. 5. Quantitative distribution of items in specific sub-areas of Apulian AdSP ports' activities

– Key ranges of overpressure (measured in bars) corresponding to potential damage to building structures.
– Key ranges of overpressure (measured in bars) with potential effects on people.

The same WH sample within the selected Apulian ports is categorised according to distance ranges (Table 5), highlighting the significance of explosion proneness in relation to physical distances from potential explosion sources.

Table 5. Equivalent critical distance for overpressure threshold and related effects determined for the explosion of an LPG-fueled ship as in [29]

Distance [m]	*Overpressure thresholds [bar]*	*Effect*
<100	0,37	Threshold on effects in disruption
100–160	0,20 – 0,37	Serious damages
160–240	0,13 – 0,20	Moderate damages
240–800	0,03 – 0,13	No damages on structure, effects on people
>800	<0,03	Fragile break (window, plasters)

Figure 6 illustrates their distribution, identifying critical physical distances in line with the explosion source locations. This highlights the feasibility of conducting in-depth analyses of explosion effects on WH as a tangible and significant hazard (see Fig. 7 for detailed seaport analyses of Brindisi and Taranto).

5 Discussion of Results

The use of national and regional thematic maps of natural hazards is a powerful tool for exploring large territories, aligning with the scale and level of detail in their processing. In this study, their application to Italian seaports has demonstrated their potential in identifying recurrent hazards in coastal areas and determining priority hazards for further focus at a broader scale. The prominence of flooding, resulting from the coastal positioning and the proximity to the sea, is an expected outcome at the site level.

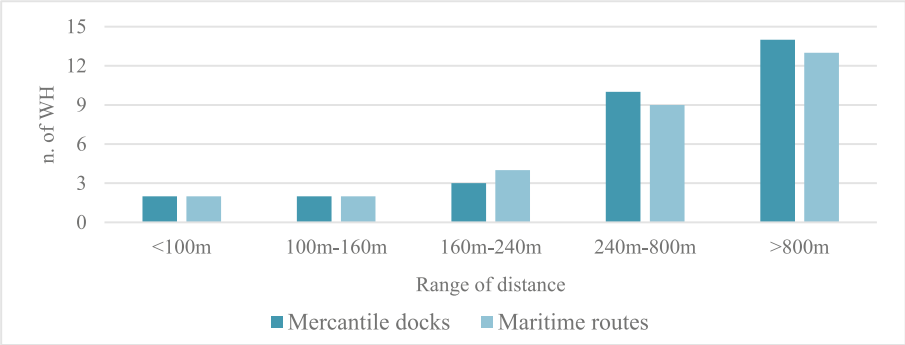

Fig. 6. Distribution of WH assets in the equivalent critical classes of distance from the explosion source as in Table 5

However, the local interactions with vulnerable hydro-geomorphological sub-areas are insufficient to definitively assess WH hazard proneness, necessitating detailed local evaluations. This aligns with existing Italian territorial mapping carried out by national and regional experts in collaboration with public administrations to catalogue built and unbuilt cultural heritage. However, as the analysis of these coastal areas has shown, many architecturally, historically, or socially significant structures remain absent from listing heritage inventories. This lack of recognition suggests a potentially lower level of attention at the national scale, consequently limiting opportunities for their protection and preservation. Addressing this uncertainty requires local-scale assessments by port administrations, which must be supported in identifying WH assets. The importance of this census activity was underscored when the knowledge-gathering phase for selected ports revealed that more than 40% of WH (Table 4) could potentially enrich the metadata of the national "Carta del Rischio", thereby expanding opportunities for managing this heritage at risk on a national level.

Conversely, the multi-activity nature of the analysed Italian ports has highlighted the recurrence of certain activity-induced hazards, primarily linked to shipping activities (mercantile and civil navigation) and industrial production. In this context, the preliminary phase of anthropogenic hazard identification has expanded beyond natural ones, incorporating threats linked to port activities, currently excluded from national and regional mapping within the "Carta del Rischio".

The identification of both hazards and threats at a broad scale presents an opportunity to examine the WH located within Apulian seaports, providing preliminary insights into site-specific risk conditions. For these sites, flood proneness necessitates more detailed, downscaled mapping to refine the quality of regional and national geomorphological datasets. Simultaneously, in both the hazard assessments, the identified WH will be evaluated by parameters and features that define their physical vulnerabilities. These vulnerabilities will be classified into different heritage types to ensure a comprehensive approach that will allow the extension of local and in-depth analysis to the national scale, increasing the potential impact.

The diversity of WH types - ranging from industrial heritage and landmarks to buildings, warehouses, and lighthouses -, alongside the variety of construction materials



Fig. 7. Details of activities and WH distribution within the seaports of Brindisi (top) and Taranto (bottom), highlighting possible explosion sources

and techniques (e.g., masonry, steel, concrete structures), necessitates a categorisation of equivalent or combined vulnerability classes. Such classifications will enable the assessment and testing of mitigation strategies, facilitate evaluations of resilience variations concerning risk exposure, and allow for the extrapolation of findings to comparable WH types.

6 Conclusions

This study presents a preliminary hazard mapping framework for the water built heritage in Italian seaports, integrating both natural and anthropogenic dimensions of possible stressors. Through the identification of hydro-geomorphological vulnerabilities and human activity-induced threats, the research highlights the recurrent hazards for Italian seaports, particularly flooding and explosion.

The findings indicate that flooding, while expected due to the geographical setting of ports, requires downscaled mapping to address site-specific vulnerabilities, overcoming regional and territorial analysis to allow a heritage-based risk analysis. Meanwhile, the analysis of anthropogenic threats reveals the significant role of shipping activities, particularly mercantile and civil navigation, in increasing explosion proneness in proximity to the water built heritage.

The study also underlines the necessity of a comprehensive built heritage census in port areas, as a significant portion of historical and culturally relevant architecture that are still uncatalogued at the national level for risk assessment purposes. This gap in documentation limits effective risk management and conservation strategies, reinforcing the need for targeted heritage recognition initiatives by port administrations.

Future research should focus on refining hazard and risk mapping methodologies by integrating detailed vulnerability and exposure assessments. This is fully in line with current trends in the behavioural-based risk assessment, where the users and physical vulnerability of places are evaluated, by means of agent-based modelling and dynamic risk scenario-based simulations [30–32]. Additionally, the development of mitigation strategies tailored to the specific heritage typologies identified in ports will be crucial for enhancing resilience and ensuring the sustainable preservation of water heritage in Italian seaports. These activities will be pursued as complementary outcomes to support policymakers in risk communication actions with users, including inhabitants and potential tourists involved in the newest use of such water built heritage, as well as seaport users during daily activities [33, 34].

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References

1. Sagara, J., Saito, K.: Risk Assessment and Hazard Mapping (2013). Accessed 21 March 2025. https://www.preventionweb.net/files/29163_drmkn511.pdf
2. Pimentel, J., et al.: Risk assessment and hazard mapping technique in the project for strengthening national strategy of integrated natural disaster risk management. Int. J. Erosion Control Eng. **13**(1), 35–47 (2020)
3. Ward, P.J., et al.: The need for mapping, modeling, and predicting flood hazard and risk at the global scale. In: Global Flood Hazard: Applications in Modeling, Mapping, and Forecasting, pp. 1–15 (2018). https://doi.org/10.1002/9781119217886.ch1
4. Intergovernmental Panel on Climate Change (IPCC): Key Risks across Sectors and Regions. In: Climate Change 2022 – Impacts, Adaptation and Vulnerability: Working Group II Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, pp. 2411–2538. Cambridge University Press (2023). https://doi.org/10.1017/9781009325844.025
5. Sarwar, J., Khan, S.A., Azmat, M., Khan, F.: An application of hybrid bagging - Boosting decision trees ensemble model for riverine flood susceptibility mapping and regional risk delineation. Water Resour. Manage **39**(2), 547–577 (2025). https://doi.org/10.1007/s11269-024-03995-6
6. Abdo, H.G., et al.: Multi-criteria analysis and geospatial applications-based mapping flood vulnerable areas: a case study from the eastern Mediterranean. Nat. Hazards **121**(1), 1003–1031 (2025). https://doi.org/10.1007/s11069-024-06864-y
7. IPCC, Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press (2021)
8. United Nation: Hazard Definition and Classification Review. Technical Report (2020)
9. Centre for Research on the Epidemiology of Disasters: EM-DAT The International Disaster Database. https://public.emdat.be/. Accessed 21 March 2025
10. Li, M.: Disaster risk management of cultural heritage: a global scale analysis of characteristics, multiple hazards, lessons learned from historical disasters, and issues in current DRR measures in world heritage sites. Int. J. Disaster Risk Reduct. **110** (2024). https://doi.org/10.1016/j.ijdrr.2024.104633
11. Brandano, M.G., Conti, C., Modica, M., Urso, G.: Mapping cultural heritage sites at risk: a support tool for heritage sites management. J. Urban Manage. (2025). https://doi.org/10.1016/j.jum.2025.01.007
12. Eze, E., Petersen, M., Siegmund, A.: Enhancing protection motivation for disaster preparedness among actors at UNESCO-designated heritage sites in Africa. Int. J. Disaster Risk Reduct. **109** (2024). https://doi.org/10.1016/j.ijdrr.2024.104599
13. STORM Project [Online]. https://www.storm-project.eu/en/project/. Accessed 21 March 2025
14. Ripp, M., Egusquiza, A., Lückerath, D.: Urban heritage resilience: an integrated and operationable definition from the SHELTER and ARCH Projects. Land, **13**(12) (2024). https://doi.org/10.3390/land13122052
15. Fiorani, D., Cacace, C.: The risk map as a tool for conservation managing of historical centres. ArcHistoR **13**(7), 1542–1563 (2020). https://doi.org/10.14633/AHR282
16. Ministero della Cultura: Carta del Rischio. http://www.cartadelrischio.beniculturali.it/. Accessed 21 March 2025

17. Cassano, F., De Fino, M., Cantatore, E., Fatiguso, F.: Unveiling the water built heritage: preliminary results towards a systematic cataloguing of Italian ports. In: Corrao, R., Campisi, T., Colajanni, S., Saeli, M., Vinci, C. (eds) Proceedings of the 11th International Conference of Ar.Tec. (Scientific Society of Architectural Engineering). Colloqui.AT.e 2024. Lecture Notes in Civil Engineering, vol 610. Springer, Cham (2025). https://doi.org/10.1007/978-3-031-71855-7_11
18. Kefi, C., Bakouche, H., El Asmi, A. M.: Climate-induced vulnerability and conservation strategies for coastal heritage sites in the southern Mediterranean Sea using integrated remote sensing and flood modeling. Regional Stud. Marine Sci. **77** (2024). https://doi.org/10.1016/j.rsma.2024.103618
19. Zaccariello, G., Tesser, E., Piovesan, R., Antonelli, F.: The (Building) stones of venice under threat: a study about their deterioration between climate change and land subsidence. Sustainability (Switzerland) **16**(11) (2024). https://doi.org/10.3390/su16114701
20. Westley, K., et al.: Climate change and coastal archaeology in the Middle East and North Africa: assessing past impacts and future threats. J. Island Coastal Archaeol. **18**(2), 251–283 (2023). https://doi.org/10.1080/15564894.2021.1955778
21. Chalkidou, S., Georgiadis, C., Roustanis, T., Patias, P.: A methodology for identifying coastal cultural heritage assets exposed to future sea level rise scenarios. Applied Sciences (Switzerland), **14**(16) (2024). https://doi.org/10.3390/app14167210
22. Zengin, E.: Inundation risk assessment of Eastern Mediterranean Coastal archaeological and historical sites of Türkiye and Greece. Environ. Monitor. Assess. **195**(8) (2023). https://doi.org/10.1007/s10661-023-11549-3
23. Graham, E.: Drone survey to monitor erosion impacts on coastal archaeological sites. J. Field Archaeol. **50**(1), 22–41 (2025). https://doi.org/10.1080/00934690.2024.2439224
24. Zanier, G., Palma, M., Petronio, A., Roman, F., Armenio, V.: Oil spill scenarios in the Kotor Bay: results from high resolution numerical simulations. J. Marine Sci. Eng. **7**(2) (2019). https://doi.org/10.3390/jmse7020054
25. Medda, A., Serra, P., Mandas, M., Fancello, G.: A risk prediction model for Maritime accidents. WMU J. Marit. Aff. **23**(3), 415–436 (2024). https://doi.org/10.1007/s13437-024-00337-6
26. Haydous, F., et al.: Unraveling the levels of emerging contaminants along the eastern Mediterranean Sea. Sci. Reports **15**(1) (2025). https://doi.org/10.1038/s41598-025-89027-8
27. Saraiva, N.B., Pereira, L.D., Gaspar, A.R., Costa, J.J.: Measurement of particulate matter in a heritage building using optical counters: Long-term and spatial analyses. Sci. Total Environ. **862** (2023). https://doi.org/10.1016/j.scitotenv.2022.160747
28. EM-DAT: Disaster Classification. [Online] www.emdat.be/classification. Accessed 21 March 2025
29. Martino, A., Fatiguso, F., De Tommasi, G., Casal, J.: Accidental impacts on historical and architectural heritage in port areas: the case of brindisi. Int. J. Arch. Heritage **11**(2), 219–228 (2017). https://doi.org/10.1080/15583058.2016.1204486
30. Muhammad, A., et al.: Integrated tsunami risk framework considering agent-based evacuation modelling: the case of Saga, Kochi Prefecture, Japan. Int. J. Disaster Risk Reduct. **101**, 104193 (2024). https://doi.org/10.1016/j.ijdrr.2023.104193
31. Quagliarini, E., Bernardini, G., Romano, G., D'Orazio, M.: Users' vulnerability and exposure in Public Open Spaces (squares): a novel way for accounting them in multi-risk scenarios. Cities **133**, 104160 (2023). https://doi.org/10.1016/j.cities.2022.104160
32. Zlateski, A., Lucesoli, M., Bernardini, G., Ferreira, T.M.: Integrating human behaviour and building vulnerability for the assessment and mitigation of seismic risk in historic centres: proposal of a holistic human-centred simulation-based approach. Int. J. Disaster Risk Reduct. **43**, 101392 (2020). https://doi.org/10.1016/j.ijdrr.2019.101392

33. Santoro, S., Totaro, V., Lovreglio, R., Camarda, D., Iacobellis, V., Fratino, U.: Risk perception and knowledge of protective measures for flood risk planning. the case study of Brindisi (Puglia region). Safety Sci. **153**, 105791 (2022). https://doi.org/10.1016/j.ssci.2022.105791
34. Yin, J., Khan, R.U., Afzaal, M., Nawaz, R., Shanshan, X., Jamal, A.: A fuzzy bayesian quantitative risk assessment for language and communication induced accidents in maritime operations. Ocean Coastal Manage. **259** (2024). https://doi.org/10.1016/j.ocecoaman.2024.107449