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Review Article

Assessing Coastal Heritage Vulnerability to Sea-Level Rise in the Mediterranean: A Semi-Quantitative Review Towards Usable Knowledge and Integrated Adaptation Frameworks

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Abstract: Mediterranean coasts have one of the world's richest concentrations of cultural heritage, yet this legacy is increasingly threatened by sea-level rise (SLR), coastal erosion and storm impacts. Despite a growing number of local and thematic studies, regional syntheses remain scarce. This paper presents a semi-quantitative review of more than sixty peer-reviewed publications and institutional reports (2010–2024) addressing coastal heritage vulnerability in the Mediterranean. Drawing on a harmonised database, each study has been classified by country, heritage type, threat, temporal horizon and methodological approach, and evaluated through standardised severity (0–5) and risk (1–3) scales. Results reveal three interrelated dimensions of imbalance—geographical, methodological and temporal. Geographically, a pronounced north–south asymmetry persists: Italy, Spain and Greece concentrate more than half of all studies, while North Africa and the eastern Mediterranean remain under-represented. Methodologically, about 45% of works employ DEM-based geospatial modelling, 25% rely on field evidence, and only 10% address management or policy dimensions. Prospectively, most analyses project impacts to 2100 under high-emission scenarios, with more than 70% of assessed sites showing moderate-to-high vulnerability. Although comprehensive, the sample is not systematic, and geographic patterns partly reflect differences in research capacity rather than exposure. A critical weakness identified across the literature is the limited transfer of scientific results into usable frameworks for planners and heritage managers, underscoring the need for performance and usability assessment in future climate-adaptation research. Advancing this field requires standardised indicators, broader regional coverage, and stronger interdisciplinary integration between coastal science, archaeology and heritage management to inform effective adaptation strategies for safeguarding Mediterranean coastal heritage under accelerating climate change.

Keywords: Sea-level rise; Coastal heritage; Vulnerability assessment; Mediterranean basin; Integrated adaptation frameworks; Geospatial modelling; Archaeology; Coastal erosion; Climate change risk; Usable knowledge

Highlights:

- Research heavily concentrates in Italy, Spain, and Greece.
- Dominance of geospatial modelling over management and policy.
- Urgent need to transform scientific results into usable management tools.

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1. Introduction

Coastal heritage represents one of the most tangible records of human interaction with the sea. From ancient harbours and trading settlements to mediaeval fortifications and historic urban waterfronts, these sites embody millennia of cultural adaptation to changing coastlines. Yet today, sea-level rise (SLR) and related coastal hazards are emerging as some of the most critical threats to this shared legacy. Global projections anticipate a mean sea-level increase exceeding one metre by 2100 under high-emission scenarios, exposing thousands of low-lying heritage sites to recurrent flooding, erosion and eventual submersion. Although these risks are recognised in global assessments such as the UNESCO report Climate Change and World Heritage (Colette 2007) and subsequent modelling efforts (Marzeion & Levermann 2014; Reimann et al. 2018; Battisti et al. 2024), their regional expression in the Mediterranean remains poorly synthesised.

The Mediterranean basin constitutes an exceptional case: it concentrates one of the world's highest densities of coastal cultural assets—over 250 UNESCO World Heritage Sites are located within 10 km of the shoreline—while simultaneously exhibiting strong geomorphological sensitivity and rapid coastal development. Accelerated urbanisation, subsidence, and erosion have amplified exposure even in areas where relative sea-level change is moderate. Furthermore, the region's climatic and socio-economic gradients—from the densely urbanised northern coasts to the less monitored southern and eastern areas—make it a natural laboratory for studying the interplay between physical processes and heritage vulnerability. Despite the proliferation of site-specific studies, a comprehensive understanding of Mediterranean-scale patterns remains lacking.

Over the past two decades, research on coastal heritage vulnerability has evolved from qualitative inventories to quantitative, geospatially explicit models. Early works (e.g. Galili & Rosen, 2015; Colette, 2007) focused on descriptive assessments of archaeological loss or damage, whereas later studies applied digital elevation models (DEMs) to simulate flood scenarios for 2050 and 2100 (Ojeda-Zújar et al., 2011; Ojeda-Zújar et al., 2021; Antonioli et al., 2017; Rizzo et al., 2022; Sánchez et al., 2020). More recent contributions have shifted towards integrated frameworks, combining physical exposure, cultural value, and management capacity (Fatorić & Seekamp, 2017; Sesana et al., 2018; Daly et al., 2021). This evolution parallels current European initiatives aimed at developing user-driven tools for climate-informed maritime spatial planning and integrated seascape management. However, these approaches remain highly heterogeneous in spatial scale, methodological assumptions, and terminology. The absence of harmonised indicators—such as comparable SLR scenarios, temporal horizons or quantitative vulnerability indices—limits any meta-analytical synthesis and hinders the transfer of results to policy or management contexts. The United Nations Sendai Framework for Disaster Risk Reduction (2015–2030) provides an important international reference for linking climate-related hazards, risk governance and actionable adaptation strategies (Mizutori, 2020). By explicitly recognising cultural heritage as a component of societal resilience, the Framework offers a conceptual bridge between global climate adaptation agendas and the practical challenges faced by heritage managers. In this sense, Sendai helps frame the need to translate scientific assessments of coastal risk into usable knowledge and operational decision-making tools.

Existing reviews have generally adopted either a global perspective or a disciplinary focus, but none has systematically examined the Mediterranean as a unified heritage and climatic region. Most studies still emphasise the physical dimensions of risk—flooding, erosion and storm impacts—while socio-cultural, economic and governance aspects remain marginal (Fatorić & Seekamp 2017; Phillips 2015; Sesana et al. 2018; Roy et al., 2021). Moreover, geographical imbalances persist: Italy, Greece and Spain account for most published research, whereas the southern and eastern Mediterranean are notably underrepresented. This unevenness reflects broader disparities in data availability, monitoring capacity and institutional engagement with climate adaptation strategies.

Against this background, the present study conducts a systematic and semi-quantitative review of scientific literature addressing the vulnerability of Mediterranean coastal heritage to sea-level rise and related hazards between 2010 and 2024. This temporal frame was selected to capture the consolidation of quantitative and geospatial approaches that emerged after 2010, coinciding with the widespread availability of high-resolution DEMs, Copernicus datasets, and global sea-level projections (e.g. IPCC AR5, 2013; AR6, 2021). It also reflects the period during which climate–heritage research evolved from descriptive case studies to integrated vulnerability assessments, aligning with the analytical focus and temporal scope of current European initiatives. Drawing on a harmonised database of more than sixty peer-reviewed papers and institutional reports, the review pursues three main objectives: (1) to classify existing research by country, heritage type and methodological approach; (2) to evaluate the indicators, temporal horizons and risk metrics

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used to quantify exposure, and (3) to identify major thematic, spatial and methodological gaps that should guide future investigations.

In this review, the term vulnerability is used in an operational sense encompassing different but overlapping dimensions—exposure, susceptibility, and risk—as they appear in the reviewed literature. While many studies quantify exposure through topographic or spatial metrics (e.g. inundation extent or elevation thresholds), others address vulnerability more broadly by integrating cultural value, site condition or management capacity. A smaller subset explicitly estimates risk by combining hazard probability with potential impact. This distinction is essential, since terminological variability partly explains the methodological heterogeneity observed across Mediterranean case studies.

2. Materials and Methods

2.1. Literature selection and data sources

This review was based on a systematic search of peer-reviewed literature and institutional reports addressing the vulnerability of Mediterranean coastal heritage to sea-level rise (SLR) and related hazards. Searches were conducted in Web of Science, Scopus and Google Scholar using combinations of keywords such as 'sea-level rise', 'coastal heritage', 'archaeology', 'Mediterranean', 'vulnerability', and 'risk assessment'. Grey literature from UNESCO, ICCROM, ICOMOS and EU-funded projects was also included when it contained empirical or methodological information relevant to the topic.

To ensure temporal consistency, the survey covered the period 2010–2024, while including seminal precursors such as Colette (2007) that established the conceptual basis of climate-heritage risk. The geographical scope was restricted to studies explicitly referring to Mediterranean coastal environments, including adjacent islands and enclosed seas (Aegean, Adriatic, Tyrrhenian, Balearic). Only papers providing clear spatial or methodological information—for example, maps, DEM modelling or risk frameworks—were retained. Studies dealing exclusively with inland heritage, tourism or general climate awareness campaigns were excluded.

2.2. Database structure

All selected publications have been compiled into a relational database that constitutes the analytical backbone of this study. The database harmonises 63 peer-reviewed papers and reports published between 2010 and 2024, standardising them through a common set of metadata and semi-quantitative indicators. The purpose was not to create a bibliographic inventory but to enable a systematic comparison of heterogeneous studies addressing coastal heritage vulnerability under sea-level rise.

Each record integrates bibliographic, geographic, and methodological information with normalised variables describing heritage type, hazard, temporal horizon and methodological orientation. Two semi-quantitative indices—severity (0–5) and risk level (1–3)—were introduced to facilitate cross-comparison between studies employing different metrics or scales. This framework enables aggregation by country, heritage category or hazard type, while preserving qualitative notes on data sources, modelling procedures and management outcomes (Table 1).

Rather than replacing detailed case-by-case analysis, the database serves as a bridge between disciplinary approaches, revealing how physical modelling, archaeological assessment, and management studies intersect across the Mediterranean. The full dataset, including variable definitions and source references, is provided as supplementary material to ensure transparency and reproducibility.

2.3. Data harmonisation and classification

The reviewed literature employs a wide variety of metrics—from shoreline-retreat rates and elevation thresholds to qualitative vulnerability indices—reflecting disciplinary diversity but hindering direct comparison. Examples of such indicator-based approaches include the Coastal Vulnerability Index (CVI) frameworks applied along the Andalusian coast (Ojeda-Zújar et al., 2011; Fraile-Jurado et al., 2019), which combine geospatial exposure metrics with hazard and susceptibility factors. To overcome this heterogeneity, all studies were recoded using a single synthetic indicator: 'Percentage of coastal heritage sites exposed to sea-level rise by 2100 under a high-emission scenario (RCP 8.5 / SSP 5–8.5)'.

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This metric was selected as it represents the most recurrent and comparable framing across the corpus, allowing the aggregation of results originally expressed in different units or scales.

Where quantitative data were unavailable, qualitative expressions of risk were converted into equivalent categories on a 0–5 severity scale, calibrated according to the terminology used by the original authors (e.g. 'minor', 'moderate', 'severe'). For studies addressing multiple hazards, the dominant physical driver—typically sea-level rise or erosion—was recorded as the primary threat. Each publication was then classified into one of four overarching methodological categories (see Section 3.4): (1) geospatial/DEM-based modelling, (2) empirical or field-based evidence, (3) conceptual or methodological frameworks, and (4) management or policy applications. In addition, each record was categorised by heritage typology, distinguishing four thematic domains—archaeological sites, architectural or urban heritage, cultural landscapes and geoarchaeological contexts—to analyse how different heritage types are represented across the reviewed literature (see Section 3.2)

Table 1. Variables extracted, harmonised and analysed in the review, with definition and range of observed values

Field	Definition	Type	Range or Examples of Values Obtained
Country / Region	Geographic location of the study area	Categorical	Italy, Spain, Greece, Turkey, Tunisia, multi-country
Type of heritage	Category of coastal heritage affected	Categorical	Archaeological; Cultural landscape; Natural
Dominant threat	Main physical driver considered in the study	Categorical	Sea-level rise; Erosion; Storm surge; Subsidence
Temporal horizon	Year and scenario used for future projection	Mixed	Current; 2050; 2100; RCP 4.5; RCP 8.5; SSP 5–8.5
Methodological family	Overarching methodological orientation	Categorical	Geospatial modelling; Field/empirical; Conceptual
Indicator base	Metric used to express exposure or vulnerability	Numerical	"% of sites inundated"; "Area below +1 m"; "Shoreline retreat rate"; Composite indices
Extracted value	Main quantified result reported by the study	Numerical	2–82% of heritage sites exposed (SLR 2100 high scenario); retreat 0.1–1.2 m/yr; vulnerability indices 0.2–0.8
Severity (0–5)	Semi-quantitative translation of impact magnitude	Ordinal scale	0 = negligible; 5 = critical. Observed values: 2–4 most frequent
Risk level (1–3)	Synthetic index combining exposure, sensitivity, and adaptive capacity	Ordinal scale	1 = low; 3 = high. Most studies: 2–3
Data source detail	Notes on datasets used (DEM resolution, inventories, models)	Textual	LiDAR 1–5 m; SRTM 30 m; national heritage inventories; IPCC projections
Methodological notes	Qualitative information on techniques or assumptions	Textual	Model type; thresholds, validation approaches

This harmonisation process enabled both quantitative aggregation (e.g. frequencies by country or hazard type) and qualitative synthesis, revealing consistent trends in research focus and methodological evolution. However, the coexistence of multiple methodological approaches inevitably produces divergent representations of vulnerability. Geospatial models tend to quantify exposure in spatial terms; field studies describe observed degradation, and conceptual frameworks interpret vulnerability as a socio-cultural process. These differences are not merely procedural but episte-

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mological, leading to distinct outcomes that complicate direct comparison across studies. Beyond its descriptive function, the process also exposed how different disciplinary vocabularies—geomorphological, archaeological, or managerial—encode vulnerability in non-equivalent ways, an aspect discussed further in Section 4.

2.4. Limitations

Although systematic in design, this database does not claim exhaustiveness. The inclusion of grey literature and national reports remains uneven, particularly for the southern and eastern Mediterranean, where documentation is often scarce or inaccessible. Moreover, the diversity of spatial resolutions, temporal horizons and climate scenarios limits the feasibility of full numerical meta-analysis. Instead, a semi-quantitative comparative approach was adopted, favouring the identification of dominant methodological and spatial tendencies over statistical precision.

A further limitation concerns the interpretive translation of qualitative assessments into numerical categories, which inevitably simplifies complex risk narratives. Nevertheless, this step was essential to enable cross-disciplinary comparison and to visualise emerging patterns at the basin scale. The approach should therefore be viewed as exploratory rather than deterministic—an intermediate framework that connects disparate bodies of literature and lays the groundwork for future systematic meta-analyses.

3. Results

3.1. Geographic distribution of studies

The spatial coverage of the reviewed literature is markedly uneven. Approximately 60% of the 63 studies focus on the northern and central Mediterranean (Fig. 1), particularly Italy, Spain and Greece, which together host the largest concentration of UNESCO coastal heritage sites and the most active research institutions. Italy alone accounts for nearly a third of the total, reflecting its combination of extensive low-lying coastlines and a long archaeological record (Antonioli et al., 2017; Castagnino Berlinghieri et al., 2020; Aucelli et al., 2016).

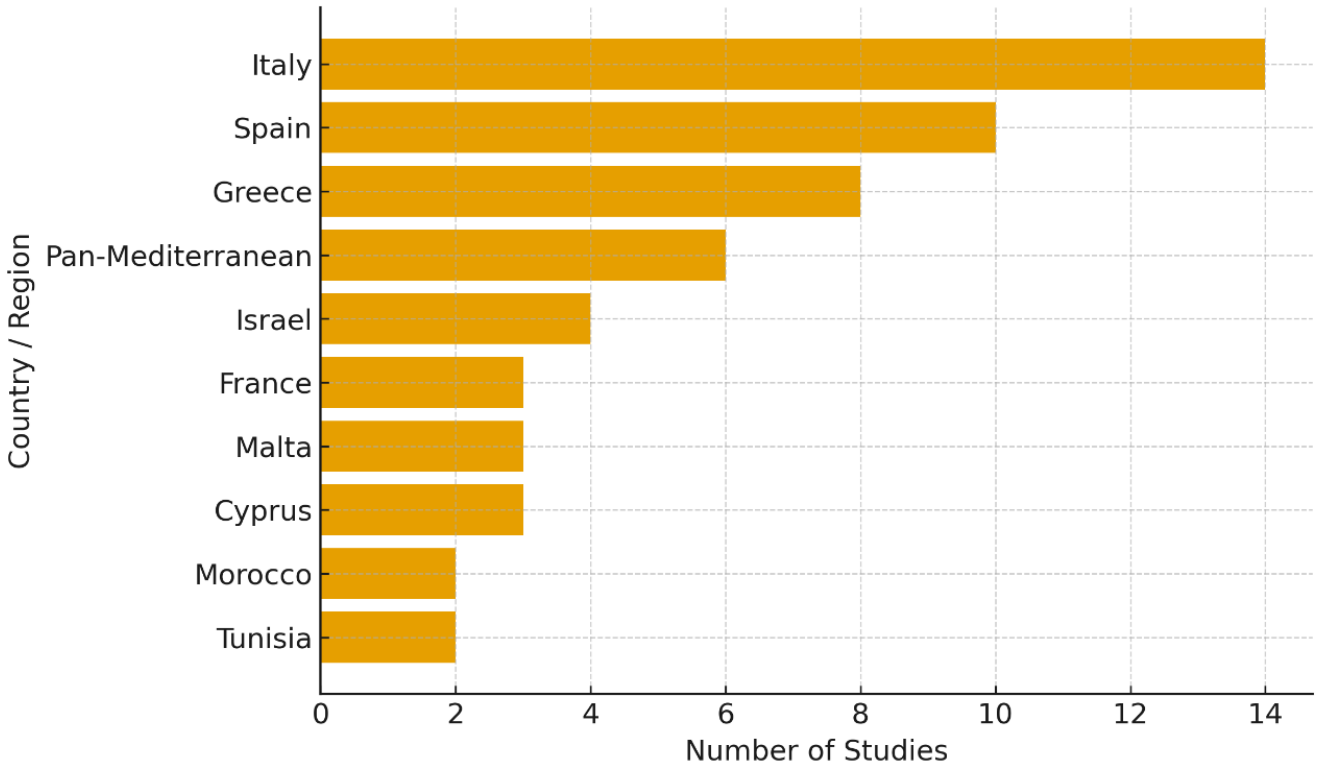

Figure 1. Geographical distribution of the reviewed studies (2010–2024)

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A smaller but growing cluster of works addresses the eastern Mediterranean, notably Israel and Cyprus (Galili & Rosen, 2010; Chalkidou et al., 2024), while only a few papers extend to Malta, Tunisia or Morocco. In contrast, the western and central sectors—particularly the Italian, Spanish and Greek coasts—remain dominant in the literature. Insular territories such as the Balearic Islands, Crete, Sardinia and Malta occupy an intermediate position: although geographically peripheral, they often act as focal points of research owing to their heritage density and clear exposure to coastal hazards. Pan-Mediterranean and cross-regional analyses—such as Reimann et al. (2018) and Colette (2007)—remain exceptional but provide essential comparative baselines. Overall, the spatial distribution of studies reveals a combined east–west and north–south imbalance, with the southern and eastern littorals and several insular regions still largely absent from quantitative assessments due to limited data availability and monitoring capacity.

3.2. Types of heritage studied

Overall, the literature remains dominated by tangible heritage approaches, with limited consideration of intangible or community-based values linked to coastal identities. The majority of research (more than 30%) concentrates on archaeological coastal sites—ancient ports, submerged settlements and coastal necropolises—whose visibility and material fragility make them emblematic indicators of climate exposure. Examples include the Israeli Phoenician sites analysed by Galili & Rosen (2010) and the Roman harbours of southern Italy examined by Palumbo et al. (2021) (Fig. 2).

Figure 2. Methodological typology of the reviewed studies

Approximately a quarter of the corpus targets urban and architectural heritage, historic waterfronts and fortifications especially (Rizzo et al., 2022; Capdevila & Oliver, 2020). Roughly 15% address cultural landscapes or mixed heritage areas combining natural and cultural components in broader coastal systems (e.g. wetlands, deltas, island environments). The remaining 15% encompass palaeoenvironmental or geological contexts relevant to heritage preservation and site formation (Antonioli et al., 2017).

3.3. Main threats and temporal horizons

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Coastal erosion and shoreline retreat constitute the predominant hazard, explicitly addressed in more than half of the studies. Across all records, sea-level rise (SLR) emerges as the second most frequent threat (25%), particularly along sedimentary plains and deltas. Most models adopt projection horizons of 2050 or 2100, often under the RCP 8.5 or equivalent high-impact scenarios (Reimann et al., 2018). Storm surge and compound hazards (SLR + wave action + subsidence) appear in roughly 15% of the papers, while humidity, salt crystallisation and temperature-related weathering account for the remainder. When reclassified by severity (0–5), over 70% of the entries scored 3 or higher, indicating moderate-to-critical risk levels for at least part of the study area. Although end-century projections dominate, a subset of empirical studies documents current erosion rates or recent flooding events, providing valuable ground truth for model validation.

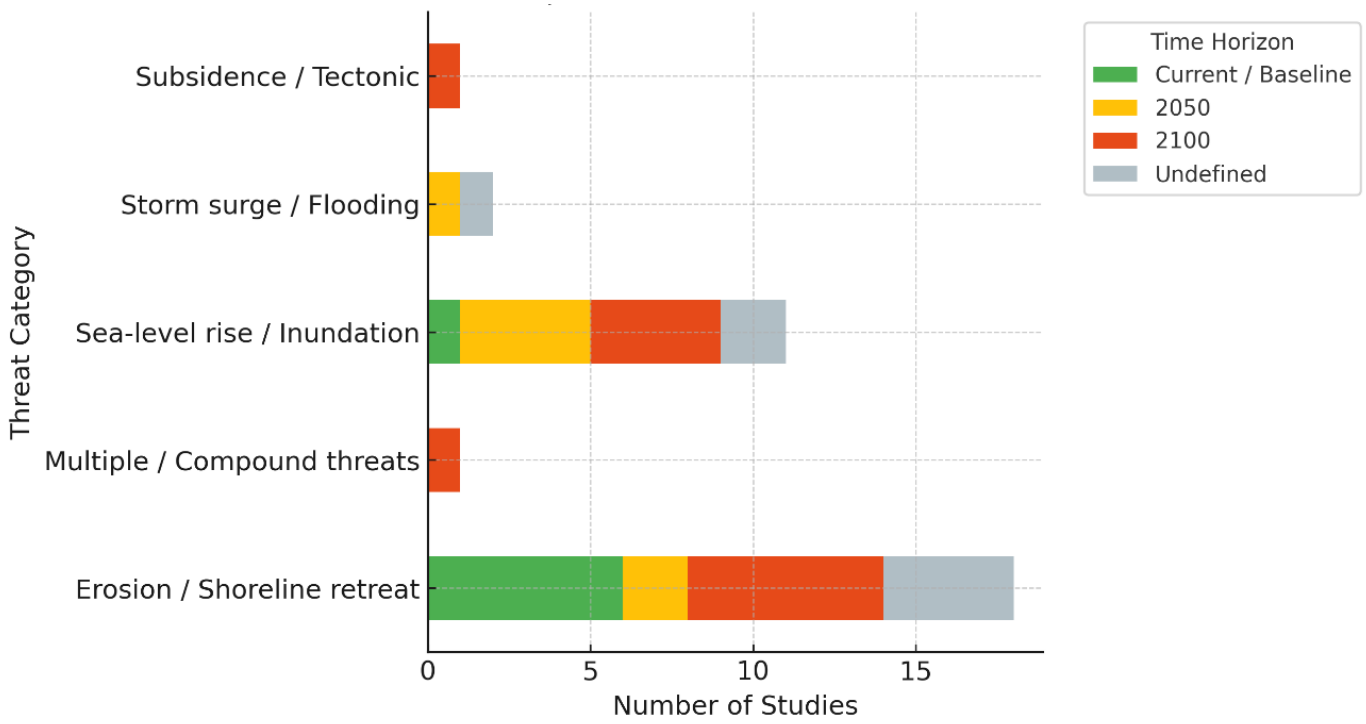

Figure 3. Main threats and temporal horizons in the reviewed studies (2010-2024)

3.4. Methodological approaches

The analysis of methodological approaches reveals four dominant families of studies, each reflecting a distinct epistemological orientation towards the assessment of coastal heritage vulnerability:

1. Geospatial and DEM-based modelling (45%): This group encompasses studies that quantify exposure through inundation or erosion mapping, often combining digital elevation models with sea-level scenarios and spatial overlays of heritage inventories. Representative examples include Reimann et al. (2018), Antonioli et al. (2017) and Rizzo et al. (2022). Regional-scale applications have also been implemented in southern Spain using cadastral and shoreline datasets to model near-future flood and erosion trends (Ojeda-Zújar et al., 2021; Díaz-Cuevas et al., 2020). Their outputs frequently express the proportion of heritage assets affected under specific scenarios, facilitating cross-comparison despite differences in spatial resolution or scenario assumptions. While these methods provide high technical precision, they tend to frame vulnerability as a cartographic rather than cultural condition.
2. Empirical and field-based analyses (25%): Derived from direct observation or geomorphological surveys, these works document measurable shoreline change, structural degradation or archaeological exposure (e.g. Galili & Rosen 2010; Palumbo et al. 2021). Their site-specific scope limits spatial generalisation but offers crucial empirical validation for modelled results. In several cases, field data have served to recalibrate exposure maps or refine inundation thresholds, underscoring the need for iterative feedback between physical measurement and spatial modelling.

3. Conceptual and methodological frameworks (20%): Studies such as Fatorić & Seekamp (2017) and Sesana et al. (2018) propose vulnerability indices, assessment protocols or adaptation guidelines applicable across regions. Although their qualitative orientation makes them less amenable to aggregation, they contribute decisively to methodological standardisation and to the articulation of shared conceptual vocabularies between disciplines. These works have been instrumental in reframing vulnerability as a dynamic process rather than a fixed state of exposure.
4. Management and policy-oriented studies (10%): A smaller but significant subset addresses adaptation planning, institutional capacity and heritage governance—particularly in insular and tourism-dependent contexts (e.g. Capdevila & Oliver, 2020). These papers often employ case-study methodologies that reveal the administrative and socio-political barriers to implementing adaptation strategies. Despite their limited number, they mark a shift towards more operational and decision-oriented research.

Taken together, these methodological families illustrate a gradual evolution from static inventories to integrated, multi-scalar analyses. However, full interdisciplinarity remains incipient: most studies still favour physical processes over cultural valuation, and management-oriented applications remain marginal. Strengthening the dialogue between these methodological domains is therefore essential for transforming vulnerability assessment from a descriptive exercise into a genuinely integrative tool for heritage resilience (Fig. 4).

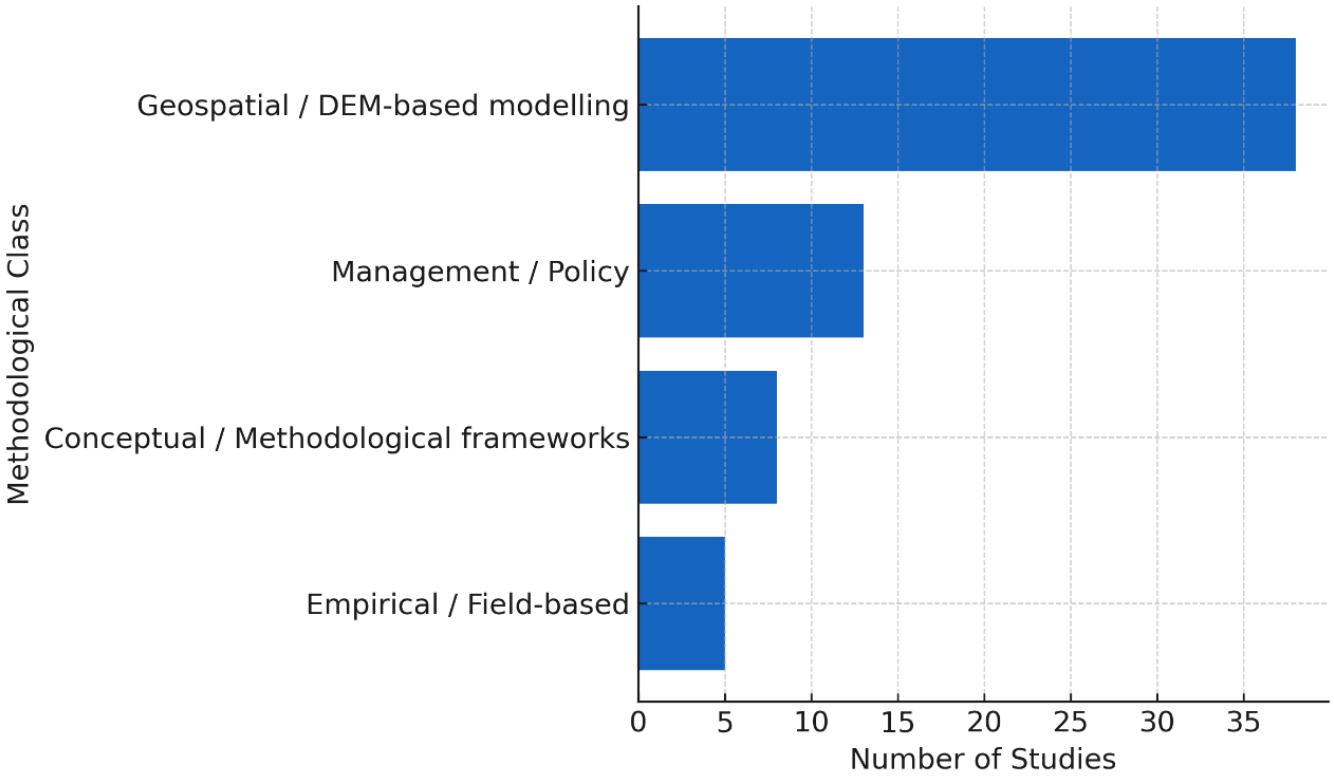

Figure 4. Methodological typology of reviewed studies

3.5. Summary of emerging patterns

When considered as a whole, the dataset reveals three interrelated tendencies that shape current research on Mediterranean coastal heritage vulnerability (Figure 5). Firstly, a pronounced geographical bias persists, with the northern Mediterranean—particularly Italy, Spain and Greece—accounting for the majority of published studies. This imbalance reflects uneven research infrastructure and heritage monitoring capacities rather than real differences in exposure, limiting the possibility of basin-wide synthesis.

Secondly, a methodological dominance of physically based modelling is evident, often accompanied by sophisticated DEM and GIS applications but only rarely by cultural or governance dimensions. The resulting picture is technically

detailed yet conceptually narrow, privileging exposure and inundation metrics over social, economic, or symbolic aspects of vulnerability. Thirdly, most works focus on long-term projections, especially RCP 8.5 scenarios for 2100, while short- and mid-term adaptation pathways remain underexplored. This temporal bias reduces the relevance of findings for policy and management, which operate on decadal rather than centennial timescales.

Beyond these tendencies, it is also striking that hardly any of the studies analysed provide usable outputs or communication pathways for end-users such as regional planners, heritage managers or local authorities. Despite their technical sophistication, the results are rarely incorporated into decision-making frameworks or practical adaptation tools, revealing a persistent gap between research production and societal uptake.

Taken together, these tendencies point to an emerging but still fragmented research field—one that combines scientific precision with limited cross-disciplinary dialogue. The semi-quantitative approach adopted in this review contributes to bridging this gap by providing a regional framework that links exposure, severity and cultural significance, offering a foundation for future comparative analyses and integrated adaptation strategies (Fig. 5).

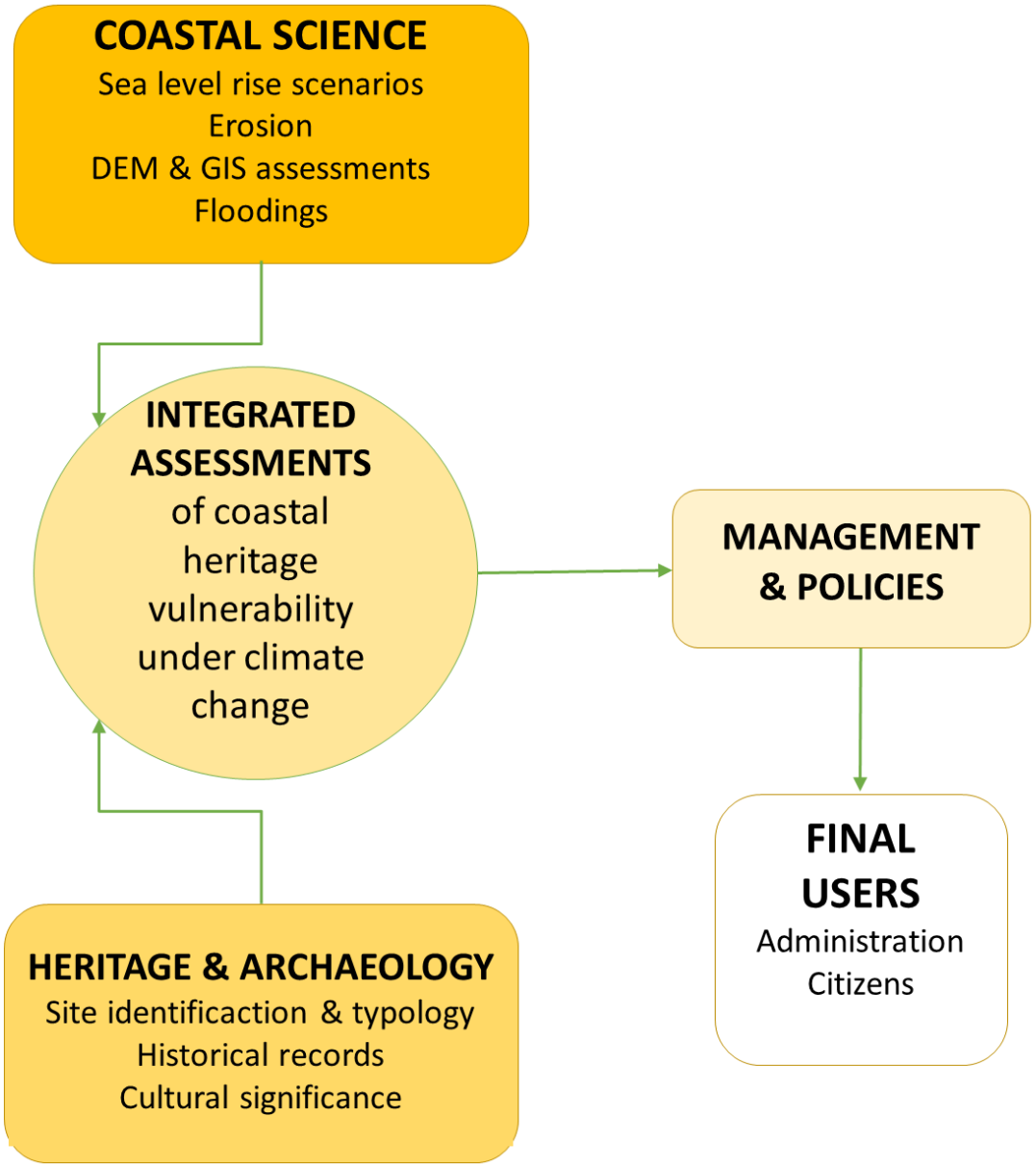

Figure 5. Conceptual framework for the integrated assessment of coastal heritage vulnerability under climate change. The diagram illustrates the interaction between coastal science and modelling, heritage and archaeology, management and policy, and final users. The colour scale—from dark yellow to white—represents the relative frequency of document types identified in the literature, with darker shades indicating higher frequency.

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4. Discussion

The present review demonstrates that research on Mediterranean coastal heritage vulnerability has expanded substantially over the past fifteen years, yet it remains methodologically fragmented and geographically uneven. While the compilation of more than sixty studies provides an unprecedented overview of existing approaches, the dataset should not be interpreted as fully systematic. Its heterogeneity—arising from differences in publication visibility, language and accessibility—implies that the apparent concentration of studies in certain countries partly reflects research capacity rather than actual exposure. Consequently, the geographical distribution of results must be interpreted with caution, since the scarcity of publications from the southern and eastern Mediterranean likely mirrors gaps in documentation rather than lower vulnerability.

This limitation, however, is in itself informative. The imbalance between well-represented (Italy, Spain, Greece) and under-represented regions (North Africa, the Eastern Mediterranean) reveals the structural asymmetry of research infrastructure and heritage monitoring systems across the basin. The absence of comparable data for large coastal stretches such as the Maghreb or the Middle East hinders regional synthesis and restricts the ability to design transnational adaptation strategies. Addressing this gap requires both investment in local capacity and the creation of shared data frameworks—for example, interoperable inventories linking cultural heritage databases with coastal hazard models.

Nevertheless, possible bias in the geographical origin of the reviewed studies must also be acknowledged. The results presented in Figure 1 should therefore be interpreted with caution, since this paper does not aim to provide a systematic review but rather a methodological and applied synthesis. The purpose is not to examine each contribution in depth, but to characterise and compare the prevailing types of research conducted on coastal heritage vulnerability

From a methodological standpoint, the results confirm that physical and geospatial modelling still dominate the field. The growing sophistication of DEM-based simulations has produced valuable quantitative insights, but these remain poorly connected to the cultural and social dimensions of heritage value. Few studies integrate exposure metrics with measures of historical significance, community attachment or governance capacity. This disconnect reinforces a 'technocratic' perception of vulnerability as a spatially measurable variable rather than a socio-cultural process. Following calls from heritage-climate scholarship (Fatorić & Seekamp, 2017; Sesana et al., 2018), future research should move towards interdisciplinary frameworks that couple physical risk modelling with cultural valuation and adaptive management.

As shown in Section 3.4, only about ten per cent of the analysed works explicitly address management or policy implementation, despite the widespread use of advanced geospatial or scenario-based tools. Many studies employ advanced geospatial or scenario-based approaches (Mejías-García & Fraile-Jurado, 2025), yet their results seldom inform heritage inventories, risk registers or site-specific adaptation strategies. This gap highlights a structural disconnection between the production of spatial knowledge and the institutional frameworks responsible for its application. Bridging this divide requires not only shared datasets but also the development of interdisciplinary languages capable of aligning scientific modelling with cultural value assessment.

Another key observation concerns the temporal framing of risk. The dominance of end-century projections (2100, RCP 8.5) has provided long-term scenarios but limited relevance for short- and mid-term decision-making. Very few studies explore adaptation pathways before 2050 or evaluate the effectiveness of implemented measures. Shifting part of the analytical focus toward operational timeframes—for example, within the next 20–30 years—could bridge the gap between academic projections and management needs.

The disciplinary composition of the reviewed literature also reveals a strong bias towards earth and environmental sciences, with comparatively little input from social sciences, heritage studies, or cultural geography. Therefore, vulnerability is often framed in physical or probabilistic terms, while social meanings, community attachment, and heritage perception remain underexplored. Future research could benefit from integrating participatory or ethnographic approaches that capture how local communities interpret, prioritise and respond to coastal change, complementing physically based risk assessments.

The heterogeneity of the reviewed studies illustrates the plurality of epistemic cultures surrounding coastal heritage research: geoscientists prioritise elevation and hazard metrics, archaeologists focus on site integrity and chronology, and heritage managers emphasise governance and funding. This diversity constitutes a major strength of the field, reflecting its interdisciplinary potential and the variety of perspectives through which vulnerability can be understood. The lack of systematic sampling also affects the possibility of quantitative synthesis. Although this review employs semi-

quantitative indicators (severity: 0–5; risk: 1–3), the diversity of original methodologies prevents full statistical meta-analysis.

A further weakness concerns the limited accessibility and operational uptake of research outputs by end users. Despite the increasing technical sophistication of modelling approaches, the vast majority of studies remain confined to academic dissemination channels and rarely provide interfaces, visualisations or guidance usable by heritage managers, planners or policymakers. This situation reinforces the divide between data production and decision-making, reducing the societal value of otherwise advanced research. Enhancing the communicability and usability of results—through participatory design, open platforms or targeted translation of scientific findings into management tools—should therefore be recognised as a central challenge for the next generation of coastal heritage vulnerability studies.

Another major challenge concerns the lack of standardised indicators for assessing coastal heritage vulnerability across countries. Existing studies employ heterogeneous criteria—ranging from purely topographic exposure indices to composite socio-ecological metrics—making cross-comparison difficult. The development of shared methodological protocols, ideally supported by an open regional database, would not only improve reproducibility but also foster the co-production of knowledge by scientists, heritage managers and policymakers across the Mediterranean basin.

In sum, the discussion highlights three interrelated challenges.

1. The need for systematic, balanced data collection across the Mediterranean to overcome geographical bias.
2. The imperative to connect physical and cultural dimensions of risk, moving beyond exposure mapping towards resilience assessment.
3. The importance of operational timeframes and adaptive governance, ensuring that vulnerability studies translate into actionable strategies.

By addressing these points, future research should transform the current patchwork of local studies into a coherent, region-wide framework for safeguarding Mediterranean coastal heritage under accelerating sea-level rise.

5. Conclusions

This review provides the first semi-quantitative synthesis of research addressing the vulnerability of Mediterranean coastal heritage to sea-level rise and related hazards. By analysing more than 60 publications produced between 2010 and 2024, it identifies the main spatial, thematic and methodological trends that define the current state of knowledge. Although the sample is broad, it is not systematic: the distribution of studies reflects research capacity and institutional visibility more than actual exposure or heritage density. The findings should therefore be understood as a representative, though uneven, cross-section of the scientific and professional landscape rather than a comprehensive inventory.

Three main conclusions emerge:

1. Geographical and institutional asymmetry. Research remains heavily concentrated in Italy, Spain and Greece, while large portions of the southern and eastern Mediterranean continue to be under-represented. This imbalance mirrors structural inequalities in research infrastructure and heritage monitoring systems. Addressing this will require sustained investment in local capacity building and the creation of interoperable databases capable of linking cultural heritage inventories with coastal hazard models at comparable resolutions.
2. Dominance of physical modelling and limited interdisciplinarity. The field continues to be driven by geospatial and DEM-based analyses, which have advanced the quantification of exposure but often neglect the cultural, social and governance dimensions of vulnerability. Achieving genuine interdisciplinarity demands frameworks that integrate physical risk metrics with heritage value assessment, community participation and adaptive management. Such integration would transform vulnerability mapping from a diagnostic exercise into a tool for resilience planning.
3. Methodological heterogeneity and future directions. The absence of standardised indicators, temporal horizons and reference scenarios constrains cross-comparison and limits the possibility of formal meta-analysis. Establishing common metrics of exposure and risk—applicable to both tangible and intangible heritage—is a necessary step towards a unified regional assessment framework. Harmonisation efforts should prioritise transparency, open data and replicable methodologies to strengthen both academic and policy relevance.

Beyond academic synthesis, this study underscores the urgency of developing operational tools to manage climate impacts on Mediterranean heritage. A regional observatory or open-access platform connecting heritage inventories, environmental data and adaptation strategies could provide an institutional foundation for this integration. In this sense, ongoing European initiatives aimed at developing user-driven tools for climate-informed maritime spatial planning and integrated seascape management illustrate how such a framework can be implemented in practice, linking scientific

datasets with decision-making tools for adaptation. Ultimately, the protection of coastal heritage under accelerating sea-level rise will depend on bridging scientific precision and social and cultural meaning, and on building sustained collaboration among researchers, practitioners and policy-makers across the Mediterranean basin.

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