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Review Article

Floods Countermeasures by Hybrid Appraches with Hard and Natural Engineering and Flooding events at Mediterranean Coasts

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Abstract

Floodings can seriously affect coastal regions, endangering human life and causing geomorphological changes, with important consequences for urban infrastructures, harbour facilities, coastal tourism infrastructures, agriculture of coastal areas, fishery acivities, and transports. Factors causing flood events include climate change as in the case of increases in the probability and intensity of precipitations, sea level rise, coastal erosion, land subsidence, increased river flow, deforestation, wildfires, and an intensive urbanization with important changes in the uses of coasts. The phenomenon of flood hazard is expected to increase in the next years. In order to protect coastal areas, hard engineering infrastructures as concrete seawalls, breakwaters, groins, or dikes, have often been used, although they are quite expensive to build and maintain, and can deteriorate coastal vegetation. Green infrastructures, although mostly present in zones at low density, provide nature-based coastal protection and can be represented by restored or conserved coastal wetlands to produce natural buffer from storms, such as wetlands, barrier islands, reefs, mangrove and marsh ecosystems. In the last years it has emerged that each of these two approaches has problems when used alone, thus suggesting the use of hybrid infrastructures combining hard and green engineered structures. Hybrid infrastructures combine both hard and soft engineering strategies, evidencing high ratio of benefits to costs with low residual risk. As an example of a hybrid infrastructure, coastal embankments as hard infrastructure have been combined with green infrastructures as shallow beaches, coastal forests, rice paddies and dunes. The combination of hard and green technologies in hybrid approaches has shown to be effective in preventing disasters derived from flooding in coastal areas. The Mediterranean Basin presents a high coastal vulnerability, with prevalence of low elevation zones as shallow sedimentary coasts, dunes, reefs, lagoons, estuaries and deltas. Mediterranean climate is characterized by unique morphological characteristics causing complex interactions between precipitation increases and lower antecedent soil moisture, leading to threshold effects in the catchments responses. Flooding can affect Mediterranean coastal areas with negative impacts on populations and ecosystems. Given the increasing coastal flood risk, there is an urgent need for measures to enhance the resilience of Mediterranean urban areas. Various measures for mitigating urban coastal flooding have been implemented in the european coasts of Mediterranea Sea, including coastal barriers, infrastructural drainage systems, wetlands, and mobile dams. Although various strategies to mitigate coastal flooding have been implemented in recent decades, further investigations are necessary in order to face with the increasing challenges posed by climate change, coupled with a rapid socioeconomic development. Innovative approaches are necessary that rely on local knowledge and request the intevention of stakeholders. In this mini-review, a description of innovative hybrid engineering approaches for protection of coasts from flooding effects has been reported, along with a description of sensitive areas of Mediterranean coasts, related engineering interventions and possible future countermeasures.

Keywords: Coasts; Flooding; Climate change; Hard engineering; Natural interventions; Hybrid procedures; Mediterranean basin

1.Introduction

Coasts are defined as that parts of the sea which are significantly affected by the land, and the parts of the land, which are significantly affected by the sea. The limit of coasts towards the sea is considered to include the continental shelf and, as a rule, is defined as including the depths to 200 m, and the limit toward the land is established within 100 km from the coastline. Coasts thus enclose the coastal sea, the coastal land, coastal flora and fauna, and humans living in these zones [1].

Flooding is one of the most serious hazard that can occur near the coast. Coastal flood is defined as the overflow of water higher than normal levels along the coast and represents a serious phenomenon in terms of environmental and structural damages, economic losses, and consequences for human health [2].

Concerning causes of flooding, climate change strongly influences sea level rise increase likely causing storm surge increases and an increment in the degree of shoreline erosion, giving rise to the origin of these events at coasts. Sea level rise will increase in a range from 10 to 20 cm by 2050, causing an increase in intensities of natural events such as storm surges [2, 3, 4]. Climate change can cause storm surge phenomena that in turn can induce coastal flooding, beach erosion, deterioration of coastal vegetation, degradation of agricultural activities, saltwater intrusion in coastal lagoon and aquifers. Moreover, storm surges can damage coastal infrastructures as ports, sea walls, roads and railways, industry, and also residential, touristic and commercial structures, along with animals and human lives [4]. Sea level rise acceleration represents an important hazard for coasts, potentially generating storm-surge flooding and wave attack, with induced geomorphological changes and damages for harbour facilities, coastal tourism facilities, houses, and human lives [5]. Effects of sea level rise coupled to groundwater extraction, can cause the phenomenon of subsidence, with an increase in salinity of groundwater and inclusion of brackish water [6]. Citizens living at coast, especially those from lowlands, can have consequence from these conditions caused by climate change.

Occurrences of flooding are also influenced by human activities or development that does not consider the principles of environmental conservation. Spaces are often utilized without consideration of their capabilities, exceeding their water carrying capacities. Moreover, vegetation removal close to coasts represents a cause of soil fragility and these areas become more prone to flooding. Coastal vegetation, including trees, slows down rain movement, absorbs water from the soil allowing more significant infiltration into the ground reducing surface run-off, stabilises existing sediment and traps new sediment, raising the height of the land above sea level, absorbs wave energy, reducing wave impact and erosion, and reduces the distance waves travel onshore before their power is exhausted [7]. Scarce maintenance procedures of dams and other strutcutes present at coasts as systems of protection, can further worst the effects of floods events, maybe in combination with other reported above causes [7].

Socio-economic development, although of extreme importance for the coastal areas, can have consequences in causing an increase of the flooding phenomena, as in presence of a growing demand for new lands to accommodate growing population and the industrial facilities, with a marked impact on fragile coastal eco-systems. Moreover, long-term ground subsidence evolution, topographic changes, and morphological variation of the coastal regions can contribute to trigger of coastal flooding events [8]. Coastal areas have registered an important growth in term of population, with the higher concentration within 5 km with higher population at an elevation below 20 m [9]. Areas at coast can offer resources, trading opportunities and possibilities of occupation, thus allowing human settlements and tourism activities to increase and flooding can cause disastrous immense societal and economic negative effects [8, 10]. Causes of coastal flooding are reported in Table 1, pointing out aspects related to climate change, human activities and socio-economic development as the most significant drivers.

General factors	Specific factors	References
Climate change	Sea level rise; Land subsidence; Intensification of storm surges; Wave attack increase	[2, 3, 4, 5, 6]
Human activities	Vegetation removal; Poor maintenance of dams and other structures; Improper flood control systems	[7]
Socio-economic development	Rapid urbanization; Human settlements increase; Tourism activities extention	[8, 10]

Table 1: Causes of coastal flooding

In the future, flood hazard is expected to increase and related consequences are expected to expand as well, likely depending on the effects of climate change, including sea level rise, land subsidence, increases in frequence and intensity of storms, augmented peak of discharge in rivers flowing into coastal zones, and due to a continuous socioeconomic development. If the 20th century recorded an unprecedented population expansion and a revolution in the ways of life and work, with enhanced and renewed uses of coastal areas, the 21st century evidences challenges related to climate change, including floods. Due to increases of sea level rise, of socioeconomic development, and of resident populations, coastal flood impacts are expected to increase significantly during the 21st century [11].

Coastal areas furnish advantages to the world population in terms of social, economic, and environmental aspects [12]. The presence of climate change drives affecting storm surges, extreme wave conditions, and flooding, can lead to significant alterations in coastal hydrodynamics [13]. It is noteworty to highlight that the sustainable transformation of the threatened coastal regions is also recognized in the Global Agenda for Sustainable Development 2030, with recommendations to focus on measures making cities and human settlements inclusive, safe, long-lasting, and sustainable, and soliciting the participation of policy makers, stakeholders, and authorities to face with the consequences of climate change at coasts [14].

Coastal flooding is a complex phenomenon evidencing a combination of events contributing to the final goal and highlighting the need of a coral monitoring approach in order to control the different elements of the process such as water depths. This approach can give important information, considering that coastal flooding is usually caused by high water levels, maybe caused by tides and storm surges, along with waves, which can lead to the exceeding of coastal defences and inundation of low-lying areas, potentially causing serious damages [15]. An important parameter to be measured is the shoreline dynamic, as a proxy of the stabilty of coastal environmet, with detection of flooding events as ultimate goal. Moreover, urban development and coastal sediments change pathways needs to be detected, as they could give important information on coastal flooding [16].

In this mini-review, flooding phenomena treatening coasts are described and engineering approaches are reported, emphasizing the positive role the hybrid engineering can have, in using combinations of hard engineering and nature-based solutions, offering an efficace protection and a sustainable approch. The flooding in the Mediterranean coasts is moreover described, along with cases describing enginering interventions.

2. Engineering hard and soft infrastructures for flooding control

In order to reduce the risks of flooding in coastal areas and to increase coastal defence, hard (or grey) engineering infrastructures have been adopted. In the meantime, nature-based solutions (or green) engineering infrastructures, with ecosystem-based elements, have been tested [17].

Hard infrastructures, comprehending concrete sea walls, is the most frequently method of approach to protect coastal communities from flooding. Hard engineering infrastructures are expression of the conventional engineering, and they include constructions such concrete sea wall, breakwaters, groins, or dikes. In spite of their well known advantages and warranty of protection, this approach is expensive to build, needs procedure to be maintained, and can cause deterioration of coastal vegetation. On the other hand, soft infrastructure, as can be represented by restored or conserved mangrove and marsh ecosystems, delivers nature-based coastal protection but in comparatively lower density coastal areas. Soft infrastructures base their approach on restoring or conserving coastal wetlands to dispose of natural protection from storms, such as wetlands, barrier islands, and reefs [18].

Protection of coasts represents an important question for human well-being. Hard engineering approaches can give greater level of protection as respect to the other countermeasures, that alleviates speed of waves, tsunamis, prevents erosion, withstands storm events soon after seawalls are built and provides stable protection for two to three decades. Moreover, these structures offer a great understanding of techniques and of effects, by allowing policy makers to perform cost-benefit analysis. Again, this approach requests significant engineering expertise [17]. Some consequences from the use of hard engineering infrastructures have emerged, as in the case of loss of coastal habitats. Coastal habitat loss can be caused by installed hard engineering infrastructures, as they have negative effects on other ecosystem services, in which coasts and surrounding area such as beaches provide. The hard infrastructures can have high installation and maintenance coasts, they thus require detailed studies and additional elements to mitigate the effets of sea level rise. These structures weaken with time. A societal aspect resides in the lack of community involvement, leading to safety misanderstandings and disaster risks [17].

Considering that the great and serious concern of coastal flooding will increase in frequency and in intensity in the future, due to higher evidences of climate change phenomena, and coupled with sea level rise, the need to find sustainable coastal protection solutions has emerged [18]. Coastal protection by soft and more natural approaches were highlighted as possible sustainable solutions. Soft engineering infrastructures can offer co-benefits of coastal protection, aesthetic seascape, recreational use, coastal habitats with many species. Soft engineeing approaches present lower cost as respect to the other methods, evidence adaptation to unexpected events, as they may keep pace with climate change, and sea level rise. Soft engineering approaches can represent ideal solutions in respecting the natural processes, nevertheless, they have also evidenced criticalities. Ambiguous effects have been highlighted by coastal soft engineering infrastructures, due to the fact that limited understanding and limited uniformity of protection levels were evidenced, due to topography, vegetation, and soils characteristics. Concerning time for maturing forests, it is noteoworty to highlight that it needs about 20 years to mature for sufficien protection. Cases of pine wilt diseases have been evidenced, suggesting that damages by diseases and pest can occur, altering the soft intervention procedures facing to coastal flooding. Moreover, soft enginerring can be subjected to societal crimes and dumping, evidencing the need of an approriate maintenence of these green infrastructures [17].

3. Hybrid engineering facing with coastal flooding events

Hard infrastructures showed the capability to reduce the risk of flooding effects at coastal zones and soft infrastructure were adopted for coastal defense. The results have evidenced that the separate use of hard or of soft infrastructures highlights limitations in counteracting the intensity and frequency of flooding hazards [19, 20].

Taking into account these concerns derived from the use of separate techniques, construction of hybrid infrastructure, which have the characteristics of both structures, by combining heavy and soft engineering infrastructures, are thus receiving growing attention. In a hybrid approach, as in the case of coupling a storm-surge barrier with a coastal wetland, efficiency outperforms both hard and soft strategies offering low residual risks, high benefits in term of coasts, and reduction in the number of disasters. An example of a hybrid infrastructure in the coastal zone is represented by a combination of coastal embankments as gray infrastructure and shallow beaches, coastal forests, rice paddies, and dunes as green infrastructure. Procedures for coastal embankments construction take into account past disaster documentation and disaster extent [21]. It is noteworthy to highlight that methods of hybrid infrastructures in coastal areas still need to be evaluated and their effectiveness must be tested accurately, in being a quite new approach [22].

During a flooding event, hard infrastructures can reduce the flood risk, although a residual risk can still be present. A residual flood risk can originate from low-probable events as very strong storm surges. In these circumstances, the residual risk can be further reduced by combining the hard infrastructues with the coastal wetland strategies, forming a hybrid strategy. Soft, or green, strategies as wet-proofing and coastal wetland growing, can play a critical role in flood risk management and can maintain the ecosystems, providing carbon sequestration, biodiversity, and aesthetic value. It thus emerges that flood risk can be reduced significantly through hard protection approches, as storm-surge barriers and, in the meantime, soft infrastructures, as in the case of wetlands, may have advantages, but can give still a residual risk by 2100. These analyses suggest that managing flood risk requires a multi-scale approach, without considering only the use of a single kind of procedures [2, 23].

Procedures of hybridization of engineered structures and wetland restoration practices, if compared with separated hard and soft approaches, have evidenced about 70% of successful hybrid infrastructures. It is noteworthy to highlight that the hybrid approach can take into account both ecological and hydrological changes. It is thus expected that the development of future hybrid infrastructures in mitigating coastal flood risks will give important results [18].

Hybrid engineering infrastructures can offer advantages consisting in a greater protection along with other co-benefits, as the fact that these infrastructures may require less space than natural approaches alone. Moreover, hybrid engineering can give innovative coastal design and planning, evidencing features compatible with resilience and aesthetic values [17]. In the meantime, several disadvantages of hybrid infrastructures, in particular the availability of little data and limited expertise, need to be explored in depth. This approach requires more research regarding potential effects, and may require more space to introduce both, hard and soft, systems [17]. An example of hybrid coastal infrastructures is described in Figure 1, with a view from above (Figure 1A) of a coast presenting a hard infrastructure constituted by a sea wall coupled with a soft infrastrucure represented by a coastal forest. Both these engineering infrastructures can thus protect the village near the coast and the hinterland from the effects of flooding events. A side view (Figure 1B) of this hybrid intervention highligts that sea wall pemits sediment accretion and sand accumulation, thus protecting coastal settlements and hinterland. On the other hand, coastal forest allows wind and waves intensity mitigation and the development of an habitat hosting animals and migratory birds.

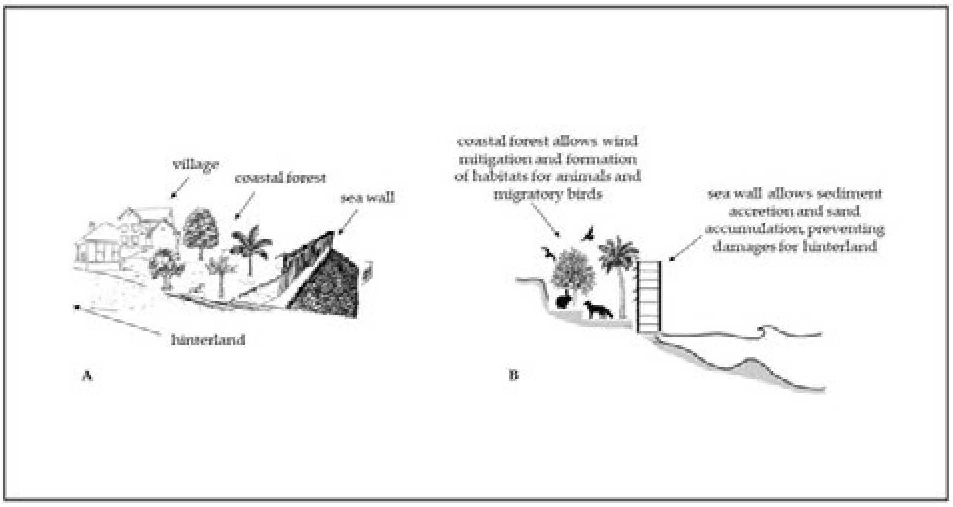

Figure 1: Hybrid infrastructure for coastal protection from flooding, composed by combination of hard engineering infrastructure (sea wall) and soft engineering infrastructure (coastal forest). A) view from above; B) side view.

4. Mediterranean Sea coastal flooding

Mediterranean is an enclosed sea with a long coastline of over 46000 km, consisting of rocky coast in a percentage of about 54% and of sedimentary coast at a percentage of 46%. Sedimentary coasts are at risk of climate change effects, moreover, due to the fact that the Mediterranean occupies an active geological plate boundary, subsidence can be a common phenomenon [24]. Half of coastline in the Mediterranean Basin is characterized by low-lying sedimentary coasts evidencing beaches, dunes, reefs, lagoons, estuaries and deltas. The low elevation coastal zones consist in areas bordering the coast that are less than 10 m above sea level [25]. In the Mediterranean Basin, the low elevation coastal zones represent 20% of the total coastal area [24]. In this area, the sedimentary coasts are mainly originated by biogenic material of both terrestrial and marine origin. Terrestrial sediments are discharged into the Mediterranean Sea by rivers with deltas, and construction of dams in river catchments in recent years, has significantly reduced the sediment transport of rivers to the coastlines. By diminishing the fuvial discharge contribute, the downstream plains can suffer from severe shoreline retreat and coastal aquifer salinization. Another aspect affecting the Mediterranean area is represented by subsidence of coastal land, originating by sediment compression caused by building loads, dredging activities in harbors, modifications in coastal sediment supply, and extraction of subsurface resources. Moreover, the Mediterranean basin is interested by an increment in climate aridity, changes in land use, pollution and declining biodiversity. These condition can trigger important changes in the wetlands and vegetation coverages of coasts, inducing desert expansion toward the North African coasts and the in-land regression of alpine forests in southern Europe [24].

The climate of the area including the Mediterranean Sea and the surrounding areas is determined by the interaction between middle latitude climate and subtropical circulation regimes. Moreover, the complex morphology of the area, with mountain chains and land-sea contrasts, confers peculiarities to Mediterranea area, and this region has been classified as one of the main climate change hotspots, meaning that it is one of the most responsive zones to climate change [26]. Due to climate change impacts, global warming in the Mediterranean region will range from 2.5°C to 5.4°C over the period 1908–2080. Levels of sea level rise of 1.5-2.5 mm year^{-1} have been registered along the Mediterranean coast and the level of the Mediterranean Sea is estimated to rise at least 150 mm by 2050 and 500–1000 mm by the end of the century, amplifying coastal flooding risks [27]. The Mediterranean Sea acts as a large source of moisture and the presence of steep slopes at coastal areas can induce rapid uplift of moist and unstable air, may trigger condensation and convective instability processes [28].

The Mediterranean region has the highest population density within 50 km of the coast, as an example, in the central Mediterranean basin, the semi-arid areas of the North African coasts are rapidly evolving over the last few decades and these coastal regions are highly urbanized [16]. Coasts represent the area of highest population concentration, and Mediterranean coasts are highly populated by millions of people distributed in about 30 countries in Africa, Asia, and Europe. Humans prefer to concentrate in the coastal zones of the world, and populations of coastal areas grow more rapidly than the global average. The populations pesent at coasts can induce important changes to the coastal environment, with increasing pressure on coastal resources and increasing exposure to coastal hazards like erosion, flooding and salinity intrusion, furter exacerbated by upcoming climate change. The Mediterranean is a good example of a coastal region where human stresses are already significant and continue to grow, also due to combination of urban disaster zones and environmental hot spots in the Mediterranean Basin [29]. In these contexts, increasing population and intensive urbanization in coastal cities, along with people and materials concentration, favored economic, cultural, and infrastructural development of coastal cities. On the Mediterranean coast, these changes resulted in land degradation and in decreases of natural resilience to coastal flooding. The level of urbanization of the Mediterranean coast is particularly high, with Greece, Italy, Portugal and Spain, showing most of the urban areas located within the 10 km range from the shore, with increasing urbanization pressure on coastal areas [30].

Coastal plains of the Mediterranean basin, although representing a limited area, can be subjected to intense agricultural activities that have developed through the years, often after interventions of wetlands reclamation. Agricultural procedures can modify coastal environments of the Mediterranean basin, as all types of agricultural practices and land use can diffuse pollution of water. The pressures of development of agricultural land can be very significant, in particular on the narrow coastal strip bordered by desert regions on the southern coast of Mediterranean. The main pressures conferred by agriculture include soil erosion and nutrient surplus, in case of excessive fertilisers use. In other coastal sites of Mediteranean basin, agricultural pressures exert their influences at large river basins like the Rhône and the Po Basins [31].

Consequences of combination of diffeent conditions in the Mediterranean coastal areas, including climate change, intensive urbanization, tourism impact, deforestation, wildfires, and erosion, can trigger flooding events. These events are causes of social and economic losses, degradation of ecosystems, and water and soil contamination due to saltwater intrusion. Risks of coastal flood events will increase in the next years in the Mediterranean basin, thus there is an urgent need for countermeasures to enhance coasts safety and resilience.

Different infrastructures for coastal flooding consequences mitigating have been improved, including coastal barriers, infrastructural drainage systems, wetlands, and mobile dams. Thus, such approaches can represent innovative and sustainable mitigation solutions to enhance urban resilience to coastal flooding [30].

Table 2 reports studies conducted at Mediterranean coasts investigating flooding events examples and related adopted countermeasures, or reporting the assessment of the coasts conducted to evaluate the need of hard, soft or hybrid engineering infrastructures. These studies are aimed to protect coastal sites evidencing potential flood threatens. Coasts of countries from the South Europe, North Africa, Middle East and from the Western Mediterranean have been evaluated in terms of vulnerability to climate change, sea level rise, storm suges, rain, wave actions, subsidence, and/or susceptibility to population increase and the development of urbanization and of tourism, and/or sites damaged by interventions as dams that could have introduced further problems with loss of sediments and of vegetation. These investigations were adopted, to a later extent, to evaluate flooding events probability and to adopt preventive countermeasures.

Table 2 reports examples of sites subjected to flooding where different countermeasures have been adopted for coastal protection, from site characterization to the introduction of different kind of protection infrastructures. In Egypt, cement barriers in the coastal area near the city of Alexandria have been builted, thus adopting flooding countermeasures of hard enginering. Nevertheless, these conventional methods evidenced a partial efficiency against flooding [32]. Another hard engineering approach consisting in infrastructure with retractive sluice gates called MOSE *MOdulo Sperimentale Elettromeccanico* was adopted to protect the city of Venice in Italy from frequent flooding events. This approach highlighted positive results and the impact on the environment was mitigated by aesthetic landscape [30]. Heavy engineering approches were adopted in Morocco, at the site El Gharb Plain, where protection from floods was realized by dams. In this site, further investigations are conducted aimed to introducing soft infrastructures along with dams [33]. In Syria, the cities of Lattakia and Tortous, hosting maritime cultural heritages, have gained floods protection by heavy infrastructures represented by dams construction [34]. Examples of soft engineering approaches have been adopted in France to protect the city of Marseille from flooding events, by restoration of the dune system. The depletion of waves forces operated by dunes showed reduction of flood events probabilities and respect the natural environment [35]. The foredunes restoration soft engineering procedures were also adopted in Italy, in the coasts of North Adriatic Sea. This system was efficient in terms of coasts protection from floods and evidenced the need of maintenance procedures to be observed [36]. In Israel, the soft approach of coastline nourishment was introduce to protect Haifa Bay, although a poor durability of the nourishment was evidenced [37]. This example of soft engineering approach was efficient and the obtained results were compared with other nourishment projects along the Mediterranean beaches of Italy, France and Spain, evidencing some concerns in terms of stability of the system [37]. Hybrid engineering approaches have been adopted in Greece, gaining protection from floods of coast near the city of Thessaloniki with a system of wetlands, drainage and embankment, allowing a balance between flood control measures and environmental conservation practices, although the efficiency was not very high [30]. In Portugal, coastal erosion and floods threatens in the site Costa da Caparica have been efficiently reduced by a hybrid approach constituted by coastal barriers with integrated nature based solutions [38]. Hybrid engineering solutions have also been adopted in Spain at Coast of Granada, with bioswales and rain drainage allowing reduction of the impacts of flooding events [39].

Country	Site/Area	Event	Scientific/Engineering Approach	References
Albania	Bay of Lalzit	Wave run-up	Coastal vulnerability evaluation against inundation risk	[40]
Algeria	Bab El Oued	Flooding	Analyzing the influence of urbanization and the meteorological hazard	[41, 42]
Algeria	M'zab Valley	Flooding	Evaluation of effects at the UNESCO World Heritage Site	[33, 41]
Algeria, Croatia, Greece, Italy, Tunisia	UNESCO World Heritage Sites at Mediterranean Coasts	Flood risk	Evaluation of adaptation measures	[43]
Algeria, Egypt, Libya, Morocco, Tunisia	Middle East	Erosion, ecosystem damages	Erosion, ecosystem damages	[44]
Balearic Islands	Coasts	Sea level rise, potential coastal flooding and potential beach erosion	Investigation on chemical, physical	[45]
Croatia	Coast of Istria	Coasts exposed to waves, high tides, and storm surges	Coastal vulnerability evaluation	[46]
Cyprus	Cypriot beaches	Beach erosion due to storm events	Assessment of beach retreat/erosion at a regional (island) scale under mean sea level and storm events and its application at the touristic island	[47]

Egypt	Alexandria	Flooding	Cement barrier placed against rising water levels near the citadel	[32, 48]
Egypt	Salloum	Flooding	Evaluation of impacts of urban growth, extreme climate, and mismanagement	[49]
Egypt	Nile Delta	Flooding and shoreline retreat	Preliminary evaluation of causes (damming and urbanization)	[24]
France	Marseille	Coastal erosion	Restoration of the dune system by accepting the natural evolution	[35]
France, Italy, Spain	Western Mediterranean Area	Flooding at floodplain areas	Definition of an appropriate spatial planning process finalized to the resilience of the population	[50]
Greece	Thessaloniki	Flooding	Wetlands, drainage canals and embankments	[30, 51]
Greece	Lamia	Seasonal flash-flooding and high sedimentation	Evaluation for using natural and sustainable measures (green) or combining green with grey elements (hybrid)	[52]
Greece	Chalastra plain, Central Macedonia	High vulnerability to floods and land subsidence	Evaluation of effects of sea river outfow	[20]
Israel	Haifa Bay	Storms and erosion	Coastline nourishment, mitigation of coastal erosion	[37]
Italy	Venice Lagoon	Increasing frequence and risk of coastal floods	Infrastructure with retractive sluice gates corredated by aesthetic landscape and investigation for adapting to sea level rise	[20, 30, 53, 54]
Italy	Emilia Romagna	Flooding	Damages and causes evaluation	[55]
Italy	North Adriatic Sea	Flooding	Foredune restoration	[36]
Italy	Calabrian Coasts	Flooding	Hydrological simulations	[28]
Italy	Basento River Mounth	Coastal erosion and beach retreat	Identification of mitigation measures	[30]
Italy	Calabaia Beach, Calabrian Coast	Flooding, costal erosion	The results of this study can be useful to design further sea defense structures	[14]
Italy	Eastern Liguria Area	Flooding	Evaluation of geo-hydrological risk and uncontrolled building	[56]
Italy	Coasts of North Adriatic Region, the Gulf of Taranto and Sardinia	Coastal erosion and increases of the risk of flooding	Definition of maps of flooding scenarios for futue interventions	[57]
Italy	Scilla and Monasterace, Calabria	Flooding	Coastal flooding hazards evaluation	[58]
Lebanon	Beirut	Coastal informal settlements	Planning specifications and quality aspects	[59]
Libya	Coast of Tripoli	Flooding and shoreline retreat	Preliminary evaluation of causes (damming and urbanization)	[24]
Libya	Derna	Flooding	Description of phenomenon	[33]
Morocco	El Gharb Plain	Flooding	Dam flood protection	[60]
Morocco	Ourika Valley	Flooding	Flood risk management	[33, 61]
Portugal	Costa da Caparica	Coastal erosion and flooding	Coastal barrier with integrated nature based solutions	[30, 38]

Spain	Coast of Granada	Erosion, landloss, flooding, salinization, stormwater runoff	Bioswales and rain garden	[30, 39, 62]
Spain	Ebro Delta at Coast of Catalunya	High vulnerability to storms and tides and coastal retreat and erosion	Evaluation of response measures	[20]
Spain	Maresme Coast	Flooding	Quantification of artificial stream-channel modifications and registered urban expansion effects on flood hazards	[63]
Syria	Lattakia	Presence of conditions for flood events	Construction of dam	[34]
Syria	Tortous	Climate change, acceleration of the global sea level rise, high population density and investment in coastal areas	Surface dams have been constructed	[34, 64]
Tunisia	Bizerte	Sea level rise	Preparation of mid to long-term coastal adaptation	[35]
Tunisia	Gulf of Tunis	Flooding and shoreline retreat	Preliminary evaluation of causes (damming and urbanization)	[24]
Tunisia	Gabes	Flooding	Analyses of the principal flooding causes and impacts	[65]
Turkey	Karasu	Sea level rise	Assessment of the risk of a low-lying coastal area	[66]

Table 2: Flooding sites and flooding events examples in Mediterranean coasts

5. Conclusions

Hybrid infrastructures, combining hard engineering infrastructures to soft infrastructures based on nature, can offer an interesting approach to face with the threatens originated from coastal floods. In the next years, increasing challenges posed by climate change, coupled with a rapid socioeconomic development, will cause serious consequences for human health and for the health of the environment. Further research and investigation are thus necessary in order to face with these challenges. Innovative approaches are necessary, always relying on local knowledge and requesting the intevention of policymakers for protection of coasts from flooding effects in the future.

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