

Review

# Flood Mitigation in Mediterranean Coastal Regions: Problems, Solutions, and Stakeholder Involvement

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**Abstract:** Flooding affects Mediterranean coastal areas, with negative impacts on regional populations and ecosystems. This paper reviews the causes and consequences of coastal flooding in European Mediterranean countries, common and advanced solutions implemented to mitigate flood risk, and the importance of stakeholder involvement in developing these solutions. Climate change, intensive urbanization, tourism, deforestation, wildfires, and erosion are the main causes of coastal flooding, leading to social and economic losses, degradation of ecosystems, and water and soil contamination due to saltwater intrusion. Various measures for mitigating urban coastal flooding have been implemented, including coastal barriers, infrastructural drainage systems, wetlands, and mobile dams. Development and implementation of such solutions should be performed in close collaboration with stakeholders, but their current engagement at the coordination and/or decision-making level does not allow full integration of local knowledge in flood mitigation projects. Various processes are used to engage stakeholders in coastal flood mitigation, but participatory approaches are required to integrate their perspectives into performance analysis of potential solutions. Such approaches would allow a balance to be reached between nature conservation, market forces, stakeholder needs, and decision-makers' priorities, resulting in development of innovative and sustainable mitigation solutions to enhance urban resilience to coastal flooding.

**Keywords:** coastal flooding; flood mitigation measures; stakeholder engagement; Mediterranean region



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## 1. Introduction

Flooding is one of the main natural hazards jeopardizing lives and properties of the people, and causing relevant economic losses [1]. Different types of floods have affected many regions worldwide, but within Europe, flash floods, river and lake flooding, cold-season floods and coastal floods are among the most common ones [2]. Due to the magnitude of societal impacts, several studies have been investigating different types and aspects of floods, such as the associated hydrological and hydraulic aspects [3], the environmental and societal consequences [4], and technical solutions to mitigate the problem [5]. Coastal floods, however, have been relatively less investigated comparing with other types of floods [6].

Coastal urban areas are critical regions for flooding [7–9]. This natural phenomenon threatens coastal communities, environmental resources, and infrastructures, increasing

their exposure and vulnerability to extreme hydro-climate conditions, such as heavy precipitation and sea level rise [10]. In Europe, the Mediterranean region has the highest population density within 50 km of the coast and is home to about 38.4% of the European population [11]. In this region, about 0.1–1.3 million people are affected by coastal flooding, suffering damage of approximately EUR 1 billion annually [12], of which EUR 5020.4 million is associated with damage to residential properties, EUR 589.3 million with damage to infrastructure, and EUR 4426.9 million with environmental damage [13].

In the Mediterranean region, the magnitude of long-term coastal floods (those occurring every 100 years) decreased in the period 1960–2015, but there was an increase in the frequency of short-term floods (i.e., those occurring every 2 years) [14]. A decrease from 68.9% to 50.2% in flood magnitude was recorded between 1990 and 2020 in the Mediterranean region, along with an increase of 0.51 m in sea level within coastal cities in southern Europe [15]. Mediterranean coastal cities experience 5–12% greater variability in flood frequency than other European Union (EU) coastal areas [16], depending on sea dynamics, anthropogenic interventions, and climate change [17]. Over the past decade, large coastal floods have severely affected Mediterranean countries such as Italy in 2009 [18], Greece in 2013 [19], Spain in 2015/2016 [20], and Portugal in 2020 [21].

According to the latest reports on climate change impacts, global warming in the Mediterranean region will range from 2.5 to 5.4 °C over the period 1908–2080 [22]. This increase will enhance people's exposure to flood events [23], resulting in loss of 0.7% of gross domestic product (GDP) in the EU territory [24]. These projections also apply to coastal areas, highlighting the need for improved coastal flood management in the Mediterranean region.

Besides increasing pressures from climate change, Mediterranean coastal cities also face intensive urbanization, with corresponding increases in flood hazard and environmental degradation [25]. Thus, it is critically important to enhance resilience by managing the capacity of coastal communities for implementing and adapting mitigation solutions [26]. Given the increasing coastal flood risk, there is an urgent need for measures to enhance the resilience of Mediterranean urban areas. Although various strategies to mitigate coastal flooding have been implemented in recent decades, the increasing challenges posed by climate change, coupled with rapid socioeconomic development, call for innovative approaches that make use of local knowledge and involve stakeholders [27].

This paper provides an overview of current flood problems along the European Mediterranean coast and their causes and main impacts, and presents four common and/or promising solutions implemented to date to mitigate coastal flooding. These solutions are illustrated using case studies from Portugal, Italy, Spain, and Greece (Figure 1), given their high susceptibility to coastal flooding, and because it is relevant to assess how different countries with similar coastal flooding problems respond in terms of strategies. The paper also examines how stakeholders are typically involved in flood mitigation strategies (decision-making) and discusses possible improvements for considering their interests and protection goals to benefit the entire community, but also the environment. This paper reviews and summarizes the scientific literature on causes, consequences and potential solutions to mitigate coastal flooding. This is needed to provide an overall vision of the problem, and support policy and decision making to face increasing coastal flood hazard arising e.g., from climate change. While the research has prompted the interest of scientists and engineers of water resources in seeking mitigation solutions especially in the countries of Northern Europe, less is known about urban coastal flood mitigation in the European Mediterranean countries.



**Figure 1.** European Mediterranean countries investigated in this manuscript.

## 2. Flooding in Mediterranean Coastal Areas

### 2.1. Main Causes

There are several causes of recent flooding along the European Mediterranean coast. Climate change in particular is considered a major driver of coastal flooding [28]. In the past century, sea level rose by 2–3 mm/year along the Atlantic and 1.5–2.5 mm/year along the Mediterranean coast [29]. The level of the Mediterranean Sea is estimated to rise at least 150 mm by 2050 [29] and 500–1000 mm by the end of the century [30], exacerbating coastal flooding risks.

Increasing population and intensive urbanization result in a high degree of land surface sealing [31,32]. Historically, coastal cities have been pools of economic, cultural, and infrastructural development, through their capacity to attract people and materials, especially following the opening of global markets [32]. On the Mediterranean coast, urban areas representing 20% of total coastal urbanization worldwide [33]. This is resulting in land degradation and associated decreases in nature's capacity to mitigate coastal flooding [34]. The level of urbanization of the Mediterranean coast is particularly high. In Portugal, Italy, Greece and Spain, most of the urban areas are located within the 10 km range from the shore, which is urbanized at an annual rate of 5.8% [30]. Even within the 10 km range, the proximity to the coast is associated with increasing urbanization pressure, extending over wide areas. On average, 34% of the national territory of these countries (over 696 km<sup>2</sup>) are included in the range of 300 m from the shore [31].

Tourism in coastal areas is one of the aggravating causes of intensive urbanization and flooding, since it involves massive land consumption to meet increasing accommodation needs for short periods [32]. During the tourist season, the regional population along the Mediterranean coast increases from 25% to 55% [33]. The increase in soil sealing due to infrastructural development deprives the natural coast of areas contributing to flood buffering, such as dunes [34], and enhances surface runoff due to lower storm-water infiltration and retention opportunities [35]. Tourism also increases the heat island effect due to massive use of infrastructure, affecting water heating and thus the frequency of floods [36]. Since Mediterranean coastal countries currently represent more than half of the total accommodation capacity in the EU and are projected to host 15–25% of the global tourist load by 2080 [36], the environmental pressure and flood hazard are expected to increase.

Deforestation and wildfires in coastal areas also contribute to coastal flooding in southern Europe [37], since they destroy the vegetative buffer zone between the waterfront and inland areas [37]. Coastal forests naturally absorb and contain flooding by regulating mean climate overheating of the site [38]. Vegetation removal leads to changes in the water cycle, particularly decreasing evapotranspiration, infiltration, and surface retention, and increasing surface runoff [38]. In recent years, large forest fires have frequently hit southern Europe, accounting for ~85% of the total annual burned area in southern Europe, with an average affected area of 700,000 ha per year [39]. In 2017, wildfires in Portugal took the life of 127 people, and affected a coastal peri-urban area of approximately 10,000 km<sup>2</sup> [40]. Typically, 80% of the socio-economic damages are caused by 2% of the fires in Mediterranean Europe, called ‘megafire events’ or large fires [40]. The wildfire problem in Mediterranean countries is linked with weather conditions characterized by long and dry summers, favored by extensive monocultures of highly flammable species such as pine and eucalypts grown using inappropriate management practices [40].

Increasing coastal flooding is also associated with coastal erosion, which contributes to destruction of coastal waterfront [41], increasing wave energy, tidal waves, and sediment and land cover changes [42]. Coastal erosion is driven by the balance between sediment interchange within the coastal zone (offshore, coastal, and inland) [43]. Wind erosion is an important driver of Mediterranean coastal erosion, which is expected to increase over the next 10–15 years [44]. However, urbanization and dam construction also influence coastal sediment dynamics by restricting sediment transportation, altering coastal morphology and its containment capacity and reaction to waves [43]. These factors lead to erosion rates that exceed sediment deposition rates, and a gradual lowering of the coast [44]. The coastline of Spain, Italy, Greece, and Portugal is currently retracting at an average annual rate of 0.36 m, causing the disappearance of 320 km<sup>2</sup> of waterfront and damaging a similar area of coastal ecosystems developed under low tides [42]. Since 2000, between 250 and 300 homes have had to be abandoned annually in these countries due to the imminent risk of coastal erosion, and another 3000 homes have had their market value fall by at least 10% [44]. The annual costs of coastal erosion averaged EUR 5400 million between 1990 and 2020 [42]. If additional flood mitigation measures are not implemented, loss of Mediterranean waterfronts due to coastal erosion will increase from 0.50 to 1.2 m/year by 2100 [44]. Thus, in order to protect coastal cities from erosion and flooding, it is imperative to counteract and manage their potential causes.

## 2.2. Main Consequences

Flooding affects the natural environment, but also has relevant social consequences for coastal inhabitants [45]. In Southern Europe, the 157 flood events reported between 1970 and 2006 affected 682 people and caused monetary losses to 560 people, disturbing 44% of the total population affected by flooding [46]. Flooding also involves potential health risks arising from sheltering in inadequate housing after the disaster and exacerbates chronic health conditions, including physical and mental ailments [47]. Experiencing a major natural flood disaster can worsen existing mental health conditions or contribute to new mental and interpersonal health problems. Significant increases in the level of post-traumatic stress disorder and other mental health problems are commonly reported, particularly during the months immediately following exposure to a natural disaster [48]. The duration of mental health problems may depend on the nature of the storm exposure and ongoing storm-related stressors, but has been reported to decrease within 18 months [49].

The economic consequences of floods along Mediterranean coasts comprise annual average losses of 1.4% for the inhabitants affected by coastal flooding [23]. By 2080, 775,000 to 5.5 million people are expected to be affected annually by coastal flooding, based on sea level rise projections of 0.80–0.88 m [23]. It is estimated that 85% of the damage costs along coasts are linked to vertical intrusion and infiltration of salt water driven by flooding, and subsequent contamination of coastal freshwater aquifers [50]. Salinization is one of the major degradation problems in the Mediterranean region, showing an increasing

trend, particularly in western Mediterranean countries [51]. There is a direct correlation between flooding events and salinization. Coastal flooding causes saline contamination of the soil, and organic carbon diffusion into deeper soil layers, affecting soil productivity. In fact, flooding acts mainly on the soils of grasslands and coastal forests, enhancing the desertification problems. Among the Southern European countries, those most affected and vulnerable to coastal flooding are Greece, Spain, Italy, and Portugal [52].

Coastal environments (the interface between land and sea) host about 40% of the main European Mediterranean ecosystems [53]. A natural consequence of flooding is destruction of dunes and coastal ecosystems [54]. Flooding has the ability to overhang coastal dunes, causing significant damage to approximately 160 m of inland coasts [55]. Particular damage is linked to environmental impoverishment, resulting in around 77% of annual habitat losses and 38% of annual economic losses due to destruction of beaches and dunes [56,57]. It is estimated that 45% of Mediterranean coastal dunes have been damaged or destroyed since 1900, while the remaining 55% have lost some natural characteristics [58]. In Southern Europe, loss of 2000–17,000 km<sup>2</sup> of coastlines, and their heritages, and an estimated economic loss of EUR 18 billion are projected for the period 1908–2080 [59]. Floods can introduce invasive species of flora and fauna, eventually changing the local ecosystem and biodiversity patterns [60].

### 3. Methods

#### 3.1. Sample and Data

To conduct the research, a database of over 100 scientific contributions was collected on the topic investigated. These contributions were then inserted in a database to support and demonstrate what has been reviewed in the literature. This has led to the possibility of identifying the causes, consequences and solutions within coastal urban areas in a single scientific panel. This operation of identifying observations on the aspects is mainly an exhaustive state of the art and the identification of significant and comparable mitigation practices.

#### 3.2. Matching Method

The identified mitigation solutions were analysed and compared on the basis of the similarity into three main dimensions: geographic, the economic and the environmental/climatic ones. In order to make the various projects presented methodologically more comparable, they have been discretized in the text based on the georeferenced mitigation strategy, based on the proposed solutions and based on the advantages and disadvantages observed for the defense from floods. This led to the creation of a comparison matrix between the different practices. The result of this phase is the emergence of a dominant dimension over the others which makes the area in which to direct the investigation accurately targeted.

#### 3.3. Model Specification

The examination group is composed of four defensive solutions that share common constants such as geographic, economic and environment, but a matching group based on specific criteria is built. First of all, the solutions investigated revealed a discriminating variable from the cultural point of view directly influencing the solution identified (natural logarithm). In order to avoid fluctuations in performance that could occur for a particular solution, each practice is combined with a technology and each of the respective constants has been combined with the type of stakeholder engagement mainly used.

#### 3.4. Variable and Data Description

After this reflection, it is interesting to place the different stakeholder participation strategies as a system within a further matrix, highlighting how communities, private developers and public institutions move with different goals towards common and shared benefits. Within the matrix, it is interesting to note the advantages and disadvantages and

how each of the strategies adopted is lacking compared to the needs. This will highlight the need to holistically combine these approaches to determine a virtuous strategy of participation (Figure 2).

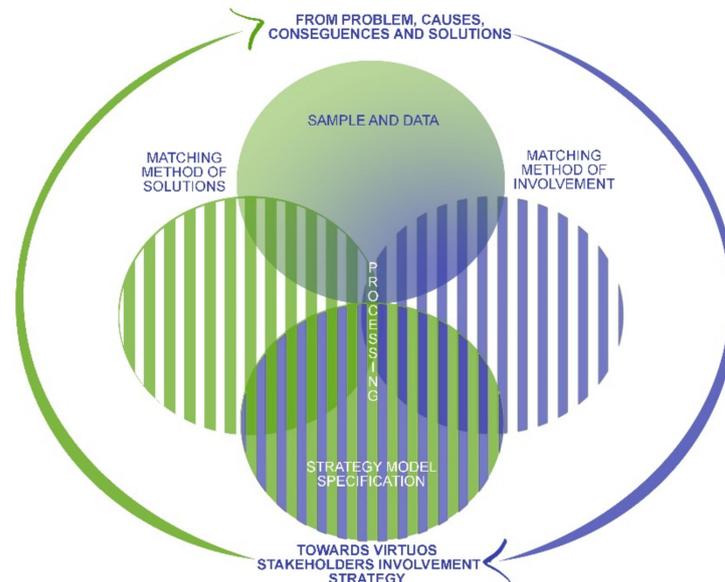


Figure 2. Methodological scheme.

#### 4. Flood Mitigation Solutions: Examples from Mediterranean Coastal Cities

Coastal management strategies and measures, including technological and nature-based solutions (NBS), have been developed and implemented in a number of southern European cities to mitigate flood hazards and enhance urban resilience to climate change [61,62]. There are different types/examples of flood mitigation solutions in Southern Europe and for this reason we select one from each country which is considered a successful practice from the technical point of view, based on the available literature e.g., [63–65]. Some of the most widely used and/or promising solutions include coastal barriers [66], dams [67], drainage systems [68,69], and mechanical wetlands [70,71]. This section describes these four solutions, including their main characteristics according to the approach used, the materials, the functioning of the solution, the impact on the territories, the operating capacity, advantages and disadvantages, using cases taken from four Southern European countries: Portugal, Spain, Greece and Italy. The presentation of the solutions does not follow any particular order, although it tends to show an increasing technological complexity. The analysis of the four solutions is based on the methodology described in Section 3, and is summarized in a matrix to help the reader to identify a close correspondence between the problem, solution and stakeholder involvement. The specificity of the places makes it possible to contribute to a theme that in Europe is less explored than river flooding, offering a contribution to scientific research on the subject. The reason of the selection of the four countries lies both in the similarity of climatic and economic aspects and in the diversity of the organizational dimension in response to floods. By exploiting the common starting condition, it is possible to compare the different solutions through a systemic scientific comparison that represents the respective defensive realities. This matrix highlights how different cultures return solutions linked to actor involvement.

##### 4.1. Coastal Barriers

One of the most common solutions to mitigate coastal floods are coastal barriers, which are landforms placed at the land-sea interface and consisting of hard engineering structures made of concrete or unconsolidated sediments (e.g., sand, gravel). The morphological typology of the sea front of the barrier is the most significant section due to its ability to

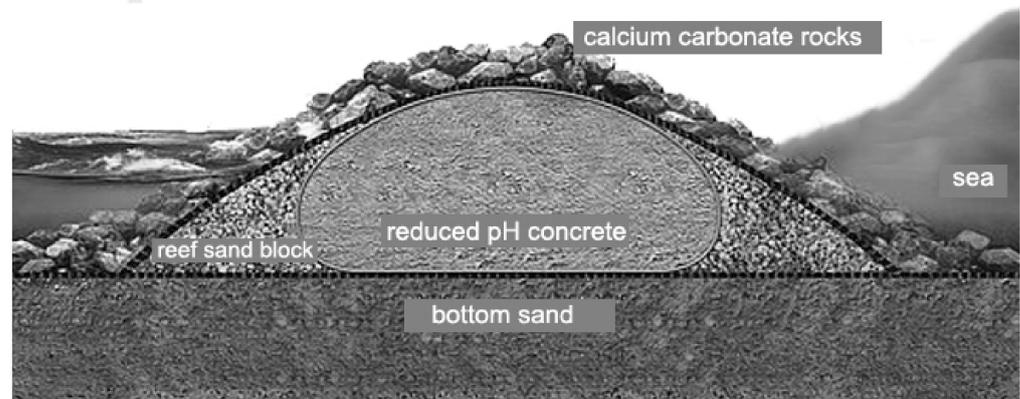
deflect the energy of the waves. For this reason, a conformation of smooth surfaces reflects the energy of the waves while an irregular surface disperses the direction and reflection of the waves. The latter may have the power to move the sand away or towards the mitigation structure which is why nourishment actions must be carried out [72] (Figure 3). Besides protecting against waves and sea level rise, these barriers also protect the coast against wind and tidal energy [72]. Additionally, they can buffer the mainland from the impact of storms, including associated landward aquatic habitats that are protected from direct waves and enclose a pond, marsh, or another aquatic habitat [73]. In recent years, coastal barriers have been developed and implemented by integrating some aspects of NBS, e.g., use of barriers made of calcium carbonate rock from coastal reef resting on a layer of reef sand-block with a core made of concrete with reduced pH (similar to that of the sea, pH 8.3) [74].



**Figure 3.** Example of a hard engineering coastal barrier (seawall). Image available as free commons at <http://www.geograph.org/gg/photo/685> (accessed on 27 July 2021).

Coastal barriers are widely used, for example in Portugal, whose coastline extends over 987 km and is characterized by sandy terrain undergoing severe erosion processes and flood events, marked by coastal retreat rates in some locations ranging from 6 to 8 m annually [75]. Climate change is recognized as the main cause of flooding in Portuguese coastal areas. It comprises sea level rise, increased frequency of storms, higher-intensity winds, stronger wave action, higher ocean surface temperature, and altered chemical composition of seawater [75]. In Portugal, coastal barriers are typically incorporated in urban planning to protect the coastal population against coastal floods and erosion [76]. Costa da Caparica, a low-lying sandy coastal plain located in the Tagus estuary and one of the Portuguese coastal cities most prone to erosion and flooding [74], provides an interesting example of how coastal barriers can integrate NBS with soft technologies (Figure 4). Design aspects of these barriers, including positioning, sizing, and inclination of the required number of barriers, are based on an analytical hierarchy process (AHP), using numerical models and geographic information system (GIS) [77].

Management of coastal barriers integrating NBS is linked with sea level monitoring. Integrated technological monitoring systems built in these barriers are equipped with a database for collection of quantitative data on sea water level, by comparing the state of the coast to each anomalous rise in the tide and determining how erosion of the barrier is progressing [77]. This system for monitoring tides and erosion of coastal barriers allows the efficiency of the implemented solution to be checked over time. Stakeholders can participate in system inspection and maintenance to enhance the effectiveness of the solution and to identify possible failures of the digital elements of the monitoring system [78].

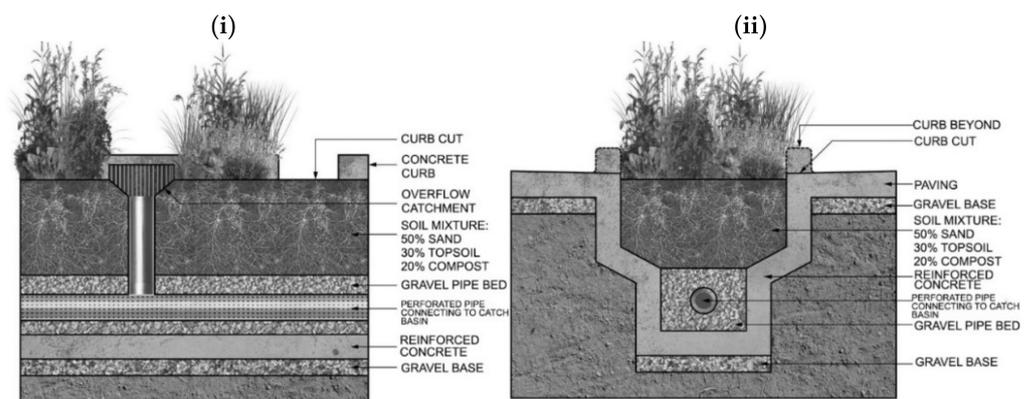


**Figure 4.** Schematic illustration of a coastal barrier incorporating nature-based solutions (NBS) implemented in Costa da Caparica, Portugal (adapted from <https://www.huesker.it/geosintetici/applicazioni/idraulica/> (accessed on 27 July 2021).

Coastal barriers in Costa da Caparica have decreased coastal retreat by 63%, reduced erosion by 32% and reduced sea advance by 5%, compared with the levels recorded prior to implementation of the solution [79]. A coastal protection intervention with coastal barriers is able to save and protect about 10–15 m of beach against erosion, allowing recovery of 10,000–15,000 m<sup>2</sup> of “new beach” [80]. However, these barriers can reduce beach access for swimming and tourism activities, and are susceptible to damage caused by high tides [81,82]. Coastal barriers are also rigid structures and are unable to adapt and respond interactively to natural and human-induced changes. Thus, they may fail to provide effective coastal protection over time. The advantages of using nature-based coastal barriers lie in their cost-effectiveness. Such solutions protect and enhance existing natural coastal ecosystems that host habitats and species of high cultural and commercial value. This maintains the attractiveness of local areas for tourists and the production level of the fish market. In addition, these solutions have the ability to absorb inorganic contaminants while protecting endangered species of juvenile fish and invertebrates, which supports viable fisheries [83].

#### 4.2. Infrastructural Drainage Systems

Some coastal flood mitigation solutions are based on draining the waves that hit the coast. These solutions apply integrated infrastructures to remove excess water as the average forfeiture load established at the site [84]. The most common types of infrastructural drainage systems are: (i) Green buffer zones consisting of native plants with a salt water filtering system underneath to sanitize and allow water use for greenery. The pluvial green buffer zone can collect coastal flooding at low slopes, reduce its velocity, and allow water to infiltrate through a porous surface instead of running over asphalt or concrete [85]; and (ii) bioswales consisting of typically vegetated, mulched, or xeriscaped channels designed to collect and transport flooding by removing debris carried by the waves. Bioswales and rain gardens can be used in urban areas to manage urban stormwater runoff (Figure 5). They are capable of absorbing 30% more saline water in the ground than a conventional lawn, and of reducing 70% of the overland flow from coastal flooding driven by high tides [86]. Bioswales can be incorporated into green infrastructures and help improve biodiversity and human comfort. They also include a filtering system to retain some contaminants. This type of system requires a pumping station to transport the flow to inland reservoirs for irrigation.



**Figure 5.** Schematic illustration of (i) a green buffer zones and (ii) a bioswale as infrastructural drainage systems (adapted from Nick McCullough, <https://nickgardenguy/> (accessed on 27 July 2021)).

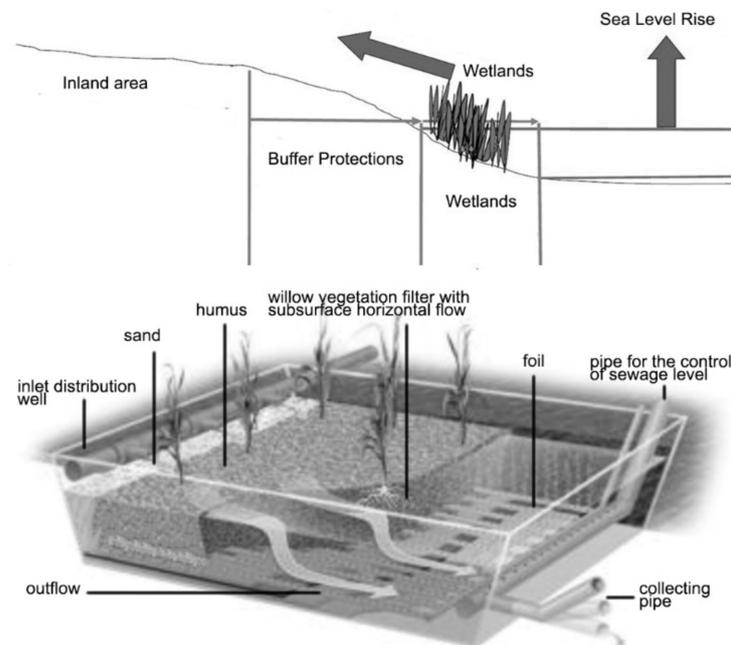
Infrastructural drainage systems have been widely used in urban coastal areas of Spain, for example, where flooding impacts the tourism sector and causes beach erosion, with long-term effects on coastal habitats. Barcelona, considered a flood-resilient city [87], has constructed green buffer zones and bioswales to manage urban stormwater and coastal flooding [87]. Inside the city, along the coast, 29 pumping stations, 24 rain-meters, 197 water level sensors, 44 locks, and 2900 auxiliary sensors are controlled automatically with communications via radio, 3G, broadband, and optical fiber [88]. These pumping stations are connected to 15 water containment deposit systems, each with the capacity to hold about 70,000 m<sup>3</sup> water [89]. The deposit systems are connected to large pipes and pumping systems that are capable of distributing the water to the city's sewage treatment plants [90,91]. While controlling excess wave flows and mitigating flood impacts, bioswales also lead to massive land transformation, with a great need for innovative technologies that can be difficult to operate in the event of malfunction during a flood event. The solution lies in its ability to handle large volumes of runoff, even where soils have very low hydraulic conductivity (about 1 mm/h), to remove pollutants when rainwater flows through bioswales, to recharge groundwater in grassy channels and dry marshes, and finally to be retrofitted, due to flexibility in location and size. The limitations of the solution lie in the difficulty of reversal and removal of the structure, the pollutant load and, above all, the maintenance operations and the accuracy of the flow forecast to be incorporated in the design phase [91].

#### 4.3. Mechanical Wetlands

Flood mitigation strategies in some Mediterranean coastal cities include large-scale hydraulic processes provided by mechanical wetlands, coupling natural and technological systems (Figure 6). Mechanical wetlands are used to absorb and filter water during flood events, acting as natural beds that purify the water of residual pollutants such as nitrates, heavy metals, pesticides, hydrocarbons, oils, and grease that has leaked onto road surfaces and pavements [92]. Mechanical wetlands recharge the groundwater and safeguard communities and ecosystems against flooding, thus protecting biodiversity [93].

In Greece, coastal flooding was aggravated by the intensive urbanization that occurred in the late 19th–early 20th century, for tourism development and agricultural expansion, which led to land degradation [94]. In Thessaloniki in northeastern Greece, an extensive network of wetlands and canals, drainage canals, and embankments to allow absorption and storage of coastal floods has been constructed [95]. The wetlands retain floodwater, which is then transported through the constructed canals into an underground drainage system where water moves from the coast to the hinterland [96]. This water transport reduces the level of flooding by temporarily storing part of the flood volume in under-

ground reservoirs that are generally built in adjacent mountainous areas, at altitudes up to 2400 m [95].



**Figure 6.** Schematic illustration of a mechanical wetland used for coastal flood mitigation in Thessaloniki, Greece (adapted from <http://www.csaexcavating.com/index.php/wetlands-system/> (accessed on 27 July 2021)).

Mechanical wetlands such as those implemented in Thessaloniki allow maximum water absorption of 45–85% of their size, depending on water salinity levels [97]. This flood mitigation solution creates a balance between flood control measures and environmental conservation practices, allowing the development of aquatic ecosystems on wetlands [97], while requiring massive transformation of coastal areas [98].

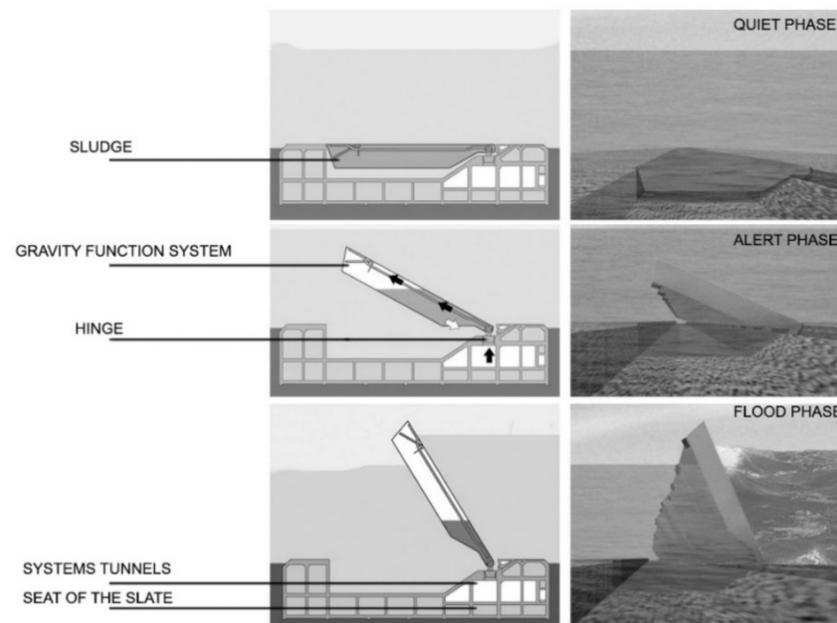
#### 4.4. Mobile Dams

A few flood mitigation strategies used in the Mediterranean region have aimed for a rethink, through constructive criticism of technological innovations, and present a model of coastal city redevelopment that seeks to integrate the protective avant-garde into its settlement system without further damage [99]. Dams or vertical gates, positioned along the coastline, are flood mitigation solutions that are partially or fully submerged in water, and can provide soil support and hydraulic sealing functions [100].

In Italy, the increasing frequency of coastal floods has been driven by an average sea level rise of 47 cm over the past 150 years [101], and sinking of the coast by natural and anthropogenic subsidence [102]. In Venice, the Italian coastal city most prone to flooding, the impacts of sea level rise are managed by mobile infrastructure called MOSE (Italian acronym for *MOdulo Sperimentale Elettromeccanico*) and by constructed esthetic landscapes with little impact on the environment, according to the community and local institutions [103].

The MOSE system consists of four retractable sluice gates and is considered the most integrative technology to the lagoon vision, as it is a ‘quiet phase’ technology (not visible when flooding is absent). Its operation ensures continuity of water exchange between the sea and the lagoon, to maintain the ecological balance [88]. MOSE is planned and operated in respect of the economic flows that govern the territory, by allowing ship passages (navigation of fishing vessels and tourist boats in the lagoon) when the gates are working. MOSE works in three phases: quiet, alert, and flood (Figure 7). The quiet phase is when the sea is flat and there is no flooding. In this phase, the MOSE gates are full of water

in normal tidal conditions and remain lying in the housing structure. The alert phase is when a weather alarm has been raised and the defensive system initiates a gravity function system before the flooding arrives. In the phase of high tides, the MOSE gates are emptied of water by introducing compressed air. The flood phase is when flooding arrives and the defensive system starts to operate. In this phase, the MOSE gates rise up to emerge from the waters.



**Figure 7.** Schematic illustration of mobile dams used for coastal flood mitigation in Venice, Italy, and associated management stages under different phases (adapted from <http://www.iitaly.org/> (accessed on 27 July 2021)).

Mobile infrastructures such as MOSE provide the scope to maintain the historical image of coastal cities, as they allow normal functioning of aquatic ecosystems by free coast-sea water exchanges in the absence of high tides and are only visible during flood events [104]. However, preventing electronic and mechanical failures in these systems is a great concern, requiring precise maintenance and adaptation of the defensive systems [105].

## 5. Stakeholder Engagement in Coastal Flood Mitigation Strategies

### 5.1. Approaches and Main Advantages

Effective solutions for coastal flood mitigation involve the re-design of urban areas, social profiles, and economic dynamics of coastal areas. The land transformations associated with implementation of flood mitigation solutions should enhance urban resilience to climate and socioeconomic changes, involve communities that are exposed to the impacts of both flood hazards and the implementation of solutions [106]. In contrast, flood mitigation strategies are typically considered as responsibility of public institutions and property developers (private developers) who acquire buildings or land for construction projects on the coast. Private developers aim to generate a profit, whereas governments aim to provide buildings for social and welfare reasons [107]. Participation by local communities must be viewed as being socially built on shared opinions, needs, and values. Community engagement in flood mitigation and management highlights inherent gaps in the shared responsibility between the local population and professionals, including decision makers [108]. Stakeholder engagement in the development, implementation, and maintenance of flood mitigation strategies and solutions can greatly support harmonization of the waterfront with the coastal urban structure, allowing it to preserve the identity and dynamics of local communities and natural environments [108].

To improve the effectiveness of flood mitigation strategies, it is necessary to ensure active collaboration between the experts developing the solutions and the local and regional communities who are affected by flood events or will be affected by the solution implemented [109]. In participatory planning, stakeholders are invited to collaborate with decision makers and scientists in analysis, planning, design, management, and evaluation of flood mitigation solutions [110]. However, in most cases, stakeholders are not involved in the decision-making process, as the importance of their (local) knowledge and the relevance of their involvement may not be fully perceived by the designers of the solutions and decision-makers [111]. This lack of community involvement in flood mitigation strategies along Mediterranean coastlines often hampers their understanding of the main causes, consequences, and vulnerabilities to flooding. Stakeholders are not usually involved in designing solutions or monitoring their functioning, and coastal communities are not informed about transformations and consequences associated with those solutions [112]. Additionally, clarification about the functioning of the defensive strategy to mitigate flood risks, and about its environmental and social consequences, is not always provided to local communities [112].

A potential reason for the ineffective stakeholder involvement in flood mitigation can be lacked of synergy between the actors involved in coastal management and protection [96]. Coastal flooding management can be an opportunity to effectively enhancing the relationship between various actors, but it is important to focus on different goals of stakeholder engagement, including [112]:

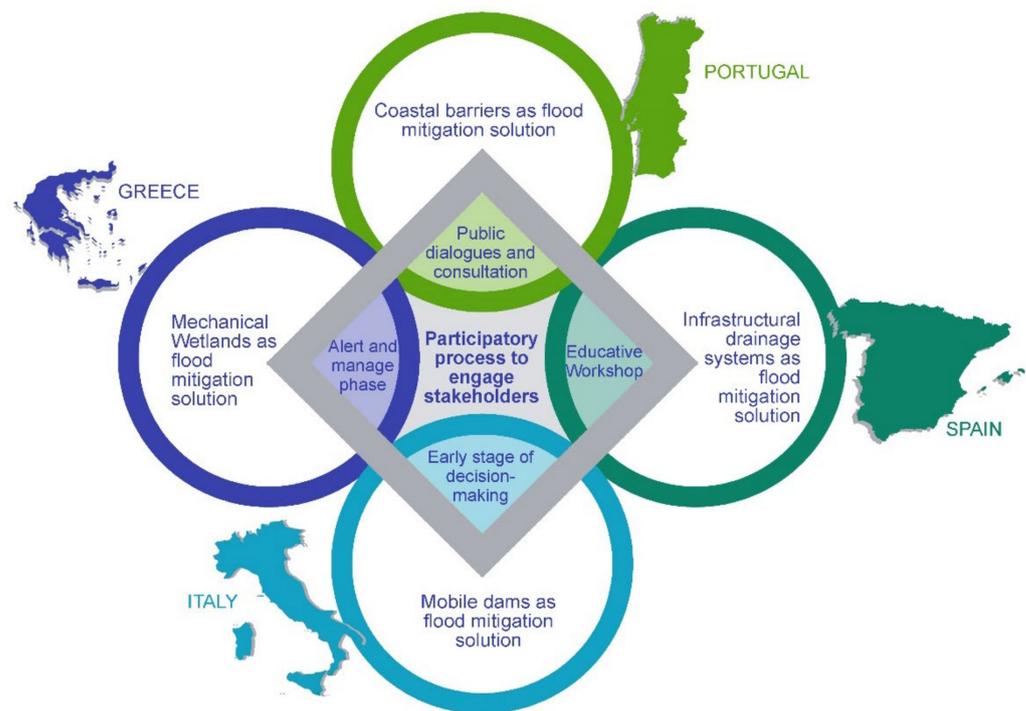
- Raising awareness about flood risks and impacts among stakeholders by collecting information on historical flood events, based on consultation between residents and qualified professionals (e.g., civil protection, politicians, NGOs, technical experts);
- Enhancing the sense of belonging to the coast, to promote care and maintenance of the coastline;
- Strengthening and responding to the needs of the local community by training them to face flood disasters and adapt to their impacts.

Through stakeholder participation, the collective actions for coastal management, based on shared principles, stimulate the co-evolutionary relationships between humans and nature in coastal built environments, by aligning stakeholder needs and values with the required performance of the coastal urban system. Enhancing the sense of belonging requires an interpretation of coasts as community resources, to link the intangible values of coastal identity to the tangible values of stakeholders [110]. The need to care for the coast and the important role it can play in protecting built environments should be considered by the community as a common good to be preserved. Stakeholder involvement can be interpreted as a way of creating shared values and collective benefits, and as a viable opportunity for discussing flood mitigation. The involvement of the community allows interactive consultations and discussions between stakeholders and decision-makers, initiating collaboration between stakeholders as a complex of multiple voices and perspectives [111].

Stakeholder engagement can influence settlement transformation, following a shared vision of ongoing and future changes and their potential consequences [112]. This would result in collective thinking and circular reuse of coastal areas by improving the landscape in which interventions are implemented [113]. It also overcomes the latent disparities between different groups, to guarantee an equitable distribution of possibilities and the satisfaction of individual actors' needs in order to respect the collective needs [99]. Participatory approaches for flood mitigation and management should involve multi-actor participation, bringing together community members, scientists, public administrations, and private industries to co-develop a systemic vision of coastal conditions by integrating different perspectives, goals, and interests [114].

### 5.2. Stakeholder Engagement in the Mediterranean Case Studies

Based on the type of stakeholder engagement process, a comparison matrix was constructed to show how the flood mitigation solutions vary according to the culture of the place and therefore how it is a discriminating form of intervention. Having assumed such an incisive role of the cultural aspect, by comparing the advantages and disadvantages of the various significant approaches, it was possible to act no longer by uniting similar elements but by the difference of missing elements. In fact, the thread that binds the various projects is that each of them fills the participatory gap of the previous strategy and therefore systematically determines the completeness of the process. An integrated vision of the environmental and social solutions adopted is shown in Figure 8.



**Figure 8.** Participatory process to engage stakeholders in coastal flood solutions implemented in some countries across the Mediterranean coastal region.

Different types of stakeholder engagement have been used in coastal flood mitigation. Table 1 summarizes the processes used in the case studies presented in Section 4, and their main advantages for different stakeholder groups.

In Costa da Caparica (first case in Table 1), the engagement process involved stakeholder participation in the design phase of coastal barriers through public debates organized in public meetings to let people explain their needs. This type of participation has the advantage of allowing community members to express their needs and demonstrate their potential willingness to state their opinions regarding the choice of flood defense strategy (Table 2). However, the community must not only be informed, but also educated, about the problem. This happens in order to provide reliable and incisive opinions in the process [115].

**Table 1.** Stakeholder engagement in the participatory process for the Mediterranean flood mitigation solutions in coastal areas presented in Section 3.

Mediterranean Flood Mitigation Solution	Stakeholder Engagement Techniques	Stakeholder Goals in the Participatory Process	Stakeholder Benefit/s from the Participatory Process
Coastal barriers (Costa da Caparica, Portugal)	<p>Stakeholders engaged through public dialogue during the project design phase.</p> <p><b>Advantages:</b> the dialogue allowed the community to be informed about the planning.</p> <p><b>Advantages:</b> lack of community public dissertation, impairing a structured awareness of the choices to be adopted.</p>	<p><b>Community:</b> Explain their needs;</p> <p><b>Advantages::</b> Establish a partnership between business and public investors;</p> <p><b>Advantages::</b> Plan the project to protect coastal ecosystems.</p>	<p><b>Community:</b> Participation and engagement;</p> <p><b>Advantages::</b> Testing new profitable strategies;</p> <p><b>Advantages::</b> Testing new inclusive strategies for flood defense.</p>
Infrastructural drainage systems (Barcelona, Spain)	<p>Stakeholders engaged through educational workshops in the project design phase. Involvement of the community in maintenance and management of the system, by reporting potential failures or malfunctions of the system.</p> <p><b>Advantages:</b> the community was informed about the solution, allowing development of a collective awareness of the transformations.</p> <p><b>Advantages:</b> the community did not have the opportunity to express its needs, neither to contribute to the choice of a specific solution that could have met both the latent social needs and the mitigation of floods.</p>	<p><b>Community:</b> Explain their preferences to aspire their needs;</p> <p><b>Advantages::</b> Establish a partnership between business and public investors to minimize project expenditure;</p> <p><b>Advantages::</b> Manage the project in compliance with administrative requirements.</p>	<p><b>Community:</b> Improving their life quality standards;</p> <p><b>Advantages::</b> Funding for the construction of private facilities for public use;</p> <p><b>Advantages::</b> Reduction of public economic pressure through private investment.</p>
Mobile dams (Venice, Italy)	<p>Stakeholders engaged in an early stage of the project through questionnaires, interviews, and meetings.</p> <p><b>Advantages:</b> the community contributed to the design choice through the scientific and structured expression of its needs.</p> <p><b>Advantages:</b> the community was not involved in the management and maintenance phase of the project.</p>	<p><b>Community:</b> Protect their identity by preserving the sense of belonging to a place;</p> <p><b>Advantages::</b> Maximize integration with existing resources;</p> <p><b>Advantages::</b> Manage the project in alignment with European Union policy directives.</p>	<p><b>Community:</b> Empowerment of community on the basis of shared values;</p> <p><b>Advantages::</b> Reducing adaptation costs;</p> <p><b>Advantages::</b> Adoption of sustainable strategies to protect local ecosystems.</p>
Mechanical wetlands (Thessaloniki, Greece)	<p>Stakeholders engaged in management of the alert phase of the system. The community also has the possibility to provide alerts about device failure.</p> <p><b>Advantages:</b> the community plays an active and pro-active role in risk management.</p> <p><b>Advantages:</b> the community was not involved in the early stages of the project, without being able to express themselves about the mitigation solution, given the bottom-up approach used.</p>	<p><b>Community:</b> Defend cultural heritage values;</p> <p><b>Advantages::</b> Enhance their business production;</p> <p><b>Advantages::</b> Enhance urban resilience to flooding.</p>	<p><b>Community:</b> New job opportunities;</p> <p><b>Advantages::</b> Reduction of management costs;</p> <p><b>Advantages::</b> Reduction of maintenance costs.</p>

Table 2. Matrix solution method.

Mediterranean Flood Mitigation Solution	Main Characteristics	Advantages	Disadvantages
Coastal barriers (Costa da Caparica, Portugal)	<ul style="list-style-type: none"> <li>Aim to provide flood wave attenuation.</li> <li>Incorporated in urban planning to protect the coastal population against coastal floods and erosion.</li> </ul>	<ul style="list-style-type: none"> <li>Buffer the mainland from the impact of storms.</li> <li>Improve landward aquatic habitats such as ponds, marshes, or other aquatic habitats.</li> <li>Ability of flooding event prevision through digital monitoring devices.</li> <li>Integration with models to predict offshore agitation and to project the shoreline.</li> </ul>	<ul style="list-style-type: none"> <li>Possible infrastructural damages in case of high tide.</li> <li>Interruption of navigation routes.</li> <li>Reduction of beach swimming accesses.</li> <li>No contribution for pollution control.</li> </ul>
Infrastructural drainage systems (Barcelona, Spain)	<ul style="list-style-type: none"> <li>Comprises pumping stations connected to water containment deposit systems, rain-meters, water level sensors, locks, and auxiliary sensors controlled automatically with communications via radio, 3G, broadband, and optical fiber.</li> <li>The deposit systems are connected to pipes and pumping systems which distribute the water to the city's sewage treatment plants.</li> </ul>	<ul style="list-style-type: none"> <li>Ability to handle large volumes of runoff providing flood wave attenuation.</li> <li>Transport of runoff to treatment plants, contributing for pollution control.</li> <li>Possibility to manage the system indirectly through activation of drainage mechanisms with geographic information systems that exploit mathematical and remote-control models.</li> </ul>	<ul style="list-style-type: none"> <li>Possibility of failure of the technology (e.g., pumping stations) during a flood.</li> <li>Difficulty in reversing and removing the structure.</li> <li>High maintenance operations.</li> </ul>
Mechanical wetlands (Thessaloniki, Greece)	<ul style="list-style-type: none"> <li>Include wetlands, drainage canals and embankments to allow absorption and storage of coastal floods.</li> <li>The water stored on the wetlands can be transported through the canals into an under-ground drainage system where water moves from the coast to the hinterland.</li> <li>The water is temporarily stored in reservoirs.</li> </ul>	<ul style="list-style-type: none"> <li>Balance between flood control measures and environmental conservation practices, allowing the development of aquatic ecosystems on wetlands.</li> <li>Positive contribution for pollution control.</li> </ul>	<ul style="list-style-type: none"> <li>Massive transformation of the coast.</li> <li>Difficult and expensive maintenance services.</li> </ul>
Mobile dams (Venice, Italy)	<ul style="list-style-type: none"> <li>Dam system consisting of four retractable sluice gates.</li> <li>Integrated in the lagoon landscape (not visible when flooding is absent).</li> <li>Ensures continuity of water exchange between the sea and the lagoon, to maintain the ecological balance.</li> </ul>	<ul style="list-style-type: none"> <li>Provides flood wave attenuation.</li> <li>Respect by the historical image of the city.</li> <li>Allow water flows and the maintenance of aquatic habitats.</li> </ul>	<ul style="list-style-type: none"> <li>Vulnerability of the technology to failure (e.g., electronic and/or mechanic).</li> </ul>

In the case of the infrastructural drainage systems in Barcelona (second case in Table 1), stakeholder participation in the design phase was based on informative and educational workshops. The workshops were organized by experts to explain how the solution could work and its goals, and what would happen in case of emergency. This conferred a general degree of knowledge that allowed the community to understand the proposed design choices and to conduct widespread monitoring operations with respect to obvious failures of operation. Nevertheless, the participants did not have an engrained capacity for choice, but were simply instructed about the planned design choice [116].

Stakeholder involvement in the case of mobile dams in Venice (third case in Table 1) took place in the early stages of the project design, through surveys, interviews, and meetings. The surveys were performed to let stakeholders familiarize with the site and its transformation. The interviews were used to raise public awareness about the process of transformation of the place. This allowed stakeholders to influence the choice of mitigation technology to be implemented.

In the case of mechanical wetlands in Thessaloniki (fourth case in Table 1), stakeholders were involved in the alert phase of the project through the possibility for reporting malfunctions or climate changes with the help of downloadable electronic applications, but not in the decision-making phase. This strategy allowed stakeholders to monitor the state of their cultural heritage, but not to express their opinion on the choice of the solution to be implemented [116].

True stakeholder engagement in flood mitigation strategies (as presented in Figure 6) facilitates identification of critical issues by strengthening social cohesion and increasing the capacity for innovative solutions. Through the participatory process, the community can better identify itself with the coastal space, and understand the flood risks and impacts of flood mitigation solutions to the community. Multi-actor stakeholder engagement provides the possibility for multiple actors to pursue their own goals, generating collective benefits in coastal protection and management. The ability of a community to attribute potential values to the coast allows them to play a decisive role in choosing the technology to be installed, integrating the economic, political, and cultural interests of decision-makers.

In some case studies, the possibility of stakeholders to influencing the choice of flood mitigation solution demonstrates the real involvement of the community in an early stage of the process. In these cases, the solution becomes a manifestation of the culture of the place, from both a product and a process perspective, which can be interpreted as an expression of a given society. It means that the transformations necessary to protect the existing culture must be compatible with the innovation necessary to protect the built environment. It involves incorporating the new needs of the users and the values they share, and drawing up sustainable development scenarios based on the interconnections between people, places and activities. The analysis of the cases carried out within the paper allowed us to be able to trace and select some comparable countries in terms of economic, climatic and geographic area. This similarity has determined a cluster of four comparable strategies, highlighting how the cultural dimension is an influencing factor (Figure 9).

The result of the review highlights how different stakeholder engagement strategies are strongly linked to the culture of the sites in which the mitigation solutions are implemented. The flood mitigation solution (which we will call  $Y(t)$ ) can be considered a function of the culture of the (which we will call  $X(c)$ ), some constant factors involving the geographical dimension ( $K_{ge}$ ), the economic dimension ( $K_{ec}$ ) and the environmental dimension ( $K_{en}$ ). For the Mediterranean countries, this can be expressed by the following proposed equation:

$$Y(t) = K_{ge}, K_{ec}, K_{en} \bullet X(c)$$

$Y(t)$  = flooding solution combined with specific technological mitigation approach

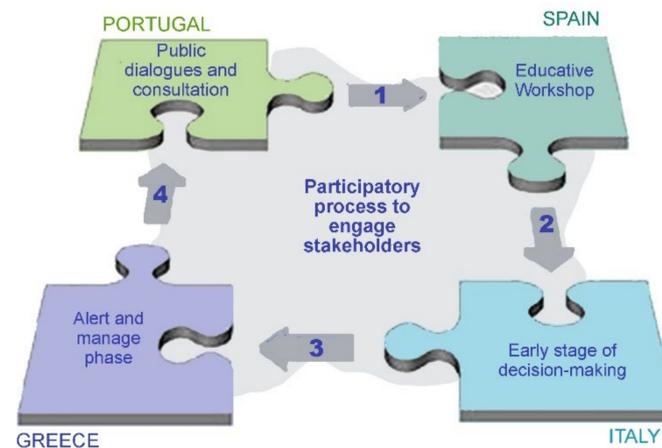
$K_{ge}$  = geographic constant (Mediterranean Coastal Country)

$K_{ec}$  = economic constant (Gross Domestic Product (GDP))

Ken = environmental constant (climate settings)

X (c) = cultural aspects

This observation opens the paper towards new research scenarios aimed at verifying the outcome of the review developed within this paper.



**Figure 9.** Participatory process to engage stakeholders in Mediterranean coastal flood solutions model.

## 6. Conclusions

Coastal areas comprise degraded environments driven by the huge pressure of settlements, with detrimental impacts for the ecosystems and threatening urban societies. This paper is a literature review of the main causes and consequences of coastal flooding in the European Mediterranean region, presents and characterizes some of the solutions implemented in coastal cities in the region, and highlights the importance of multi-actor stakeholder engagement in the different phases of flood management. Using four common/promising flood mitigation solutions implemented in some of the most vulnerable cities across the European Mediterranean coast, the paper discusses the advantages and disadvantages of the implemented solutions. The analysis, however, is based on qualitative information since quantitative data to assess the effectiveness of the solutions are lacking. Monitoring of implemented solutions should include data collection to allow quantification of the effectiveness of the solutions on flood mitigation, and assessments through cost-benefit analyses. This kind of information is of utmost importance to evaluate the performance of the implemented projects and support guidance in decision-making for coastal areas with similar biophysical characteristics and flooding problems. Flood defense and mitigation projects can provide exceptional opportunities to experiment with various innovative solutions based on multi-actor stakeholder engagement. Stakeholder involvement in flood mitigation processes could affect the coast by allowing their communities to improve strategies. This paper also discusses the advantages of a multi-actor stakeholder engagement process, and highlight the limitations in the approaches used in some of the coastal cities investigated. Coastal communities can help improve planning and management of coastal flooding strategies, namely through their engagement in problem definition, solution development, decision-making processes, solution implementation, monitoring, and maintenance. Integration of aims and visions of the public sector, private developers, and local communities must be considered to develop and implement integrative flood mitigation solutions that benefit the community. The advance made in this paper was co-considering the cultural dimension, social participation tools, and technological aspects of climate mitigation for flooding, opening up new scenarios for investigation. In fact, each case study reveals a specific solution that implies a different type of actor involvement, using tools typical of that culture.

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