Journal of
Marine Science and Engineering

Article

An Index-Based Method to Assess the Resilience of Urban Areas to Coastal Flooding: The Case of Attica, Greece

Charalampos Nikolaos Roukounis [1], Vasiliki K. Tsoukala [2] and Vassilios A. Tsihrintzis [1,*]

1 Centre for the Assessment of Natural Hazards and Proactive Planning & Laboratory of Reclamation Works and Water Resources Management, School of Rural, Surveying and Geoinformatics Engineering, National Technical University of Athens, 9 Heroon Polytechniou Str., Zographou, 15780 Athens, Greece; babisrouk@gmail.com

2 Laboratory of Harbour Works, Department of Water Resources and Environmental Engineering, School of Civil Engineering, National Technical University of Athens, 9 Heroon Polytechniou Str., Zographou, 15780 Athens, Greece; v.tsoukala@hydro.civil.ntua.gr

* Correspondence: tsihrin@otenet.gr or tsihrin@survey.ntua.gr

Abstract: The aim of this study is to assess the resilience of coastal urban areas and their exposure to sea-level rise and coastal flooding, using the proposed Coastal Resilience Index (CResI). The CResI is an innovative combination of diverse characteristics. It includes 19 parameters and is implemented using GIS techniques. The parameters included in the CResI are classified into six category factors (geomorphology, flooding, wave exposition, land use, socioeconomic, and infrastructure/functional). The Analytic Hierarchy Process is used to assign weights and rank the parameters. The framework is tested in the southwest waterfront of the Athens Metropolitan Area in Greece. The study identified that around 25% of the coastal area could be at risk of coastal flooding in the upcoming years, including areas in both the metropolitan and suburban environments. As a result, the need for adaptation measures cannot be overlooked.

Keywords: Coastal Resilience Index; sea-level rise; coastal resilience assessment; coastal flooding; coastal infrastructure resilience

check for updates

Citation: Roukounis, C.N.; Tsoukala, V.K.; Tsihrintzis, V.A. An Index-Based Method to Assess the Resilience of Urban Areas to Coastal Flooding: The Case of Attica, Greece. *J. Mar. Sci. Eng.* **2023**, *11*, 1776. https://doi.org/10.3390/jmse11091776

Academic Editors: Athanassios A. Dimas, Nicholas Dodd, Theophanis V. Karambas, George Karatzas and Tiago Fazeres Ferradosa

Received: 7 August 2023
Revised: 30 August 2023
Accepted: 8 September 2023
Published: 11 September 2023

1. Introduction

Low-elevation coastal zones are home to 10% of the population [1]. These people are located up to 10 m above the present-day mean sea level (MSL), and they are subject to natural hazards such as sea-level rise (SLR) [2]. Climate change (CC) is an urgent issue in this era of constant challenges for humanity. Global warming has been primarily caused by human activities. The average temperature has risen by 1.0 ± 0.2 °C above pre-industrial levels and is expected to further rise by 1.5 °C between 2030 and 2052 if the current pace continues [3] and 2.8 °C by 2100 [4]. CC has a significant impact on the frequency and magnitude of storm surge events, and as such, it is expected to affect the infrastructure of coastal areas [5,6], while seaports, as the mainland–sea interface, will also be affected by climate change and human activities [7]. As a result, vulnerability assessment is a prerequisite for Integrated Coastal Zone Management (ICZM) [8].

The development of quantifiable and solidly identified variables is a way to assess vulnerability and analyze risk [9]. The use of index-based methods allows for the easy classification of alternatives during decision-making processes [10]. It is possible to visualize abstract concepts such as vulnerability and resilience in spatial scales using observable variables [11]. This approach allows for vague factors such as “social factors” to be identified and quantified with various parameters, e.g., age, education, and unemployment. [12]. Researchers have often assumed that people without wealth or resources are more likely to be affected by climate change [13]. The UN [14] has made it clear that climate change is a major concern for humanity.

Estimating the level of exposure, as well as vulnerability, is the first step to assess the level of resilience. Robust indices for estimating the exposure of coastal areas and assessing their vulnerability to CC were first proposed by [15] and then by [16]. The CVI [15] has been used as the basis for many indices that use a geophysical approach, while SoVI [17] was the guide for socioeconomic indices developed later. In the past, simple indices were used, and parameters were only one-dimensional. A total of 44 articles with applications of different types of coastal vulnerability and resilience indices were collected and reviewed by [18]. Some indices study only the physical and climatic characteristics of the areas, e.g., [19–23]; others, which are more complex, consider socioeconomic factors, e.g., [24–27]. The various approaches often present differences, especially in terms of the socioeconomic characteristics of each region, as the availability of data greatly influences research. Table 1 presents a summary of representative studies that implement vulnerability and resilience indices.

Table 1. Vulnerability and resilience indices found in the literature ([18], elaborated by the authors).

No.	Index	Authors
1	CVI (Coastal Vulnerability Index)	[15,16,20,28–40]
2	Sensitivity and Coastal Sensitivity Index	[19,21–23,41]
3	Composite (social, economic, environmental) Vulnerability Index	[7,26,42–48]
4	Social Vulnerability Index	[17,24,49–51]
5	PVI (Place Vulnerability Index)	[52]
6	Coastal Flood Vulnerability Index	[53–56]
7	Coastal Risk Index	[25,57–59]
8	Coastal Infrastructure Vulnerability Index	[60,61]
9	CORI (Coastal Resilience Index)	[27]

Even though there are similarities in parameter selection, it was not possible to find consistency across different approaches, especially when dealing with complex indices. Additionally, using indices appears to follow a static approach to address the human role in vulnerability and resilience assessment. However, human–environment interactions could be considered as a highly responsive and dynamic element, rather than a fixed, unchanging condition [62]. In an index-based approach, this could be reached by adding relevant parameters or by considering different future scenarios (e.g., RCP/SSP scenarios). The authors of [26,27,51] tried to fill the gap in the literature with indices matching different socioeconomic problems. However, in this direction, there is still room for improvement. Especially in climate change impact assessment, even state-of-the-art studies show inconsistencies when dealing with uncertainty in future projections [62]. In most literature, the spatial scale is either too broad (at a national level) or too narrow (in specific coastal segments), not taking into consideration crucial characteristics of the coastal urban areas and other relevant coastal infrastructure such as ports, marinas, fishing shelters, and waterfronts. This study tries to fill this gap with the development of a new Coastal Resilience Index.

In the context of this paper, a new index of coastal resilience to climate change (Coastal Resilience Index—CresI) is proposed after analyzing and identifying the gaps in the literature [18]. CResI is a single, unitless aggregated value aiming to assess the resilience of coastal urban and suburban areas to coastal flooding at the local level. The normalization of parameters provides a linear transformation that preserves the ranking and correlation structure of the original data while enabling the aggregation of parameters of different kinds and scales [63,64]. The southwest waterfront of Attica, Greece, is used as a case study. The proposed index is implemented using GIS techniques and assesses the ability of the study area to cope with the risk of coastal floods. In this way, CResI is developed by combining geomorphological and physical parameters from relevant indices to assess the level of exposure in the study area, as well as socioeconomic, land use, and technical parameters to assess its ability to mitigate and adapt to natural hazards. To achieve this, the research was not restricted to the characteristics of the seashore area, as in a significant part of the literature, but the case study was applied to a wider area. In order to assess resilience [27] of urban areas, it is vital to follow a holistic approach. This paper is structured in five sections. In Section 1, a short review of the vulnerability and resilience indices found in the literature is presented, emphasizing the main research gaps. In Section 2, the methodology for the development of CResI in a GIS environment, as well as the data collection process of the needed parameters, is described. In Section 3, the main results are illustrated, and they are discussed in Section 4. In Section 5, conclusions and suggestions for future research are presented.

2. Materials and Methods

2.1. Area of Concern

The coastal zone of the present study is located in Attica, Greece, and more specifically, in the southwest waterfront, between the port of Piraeus and the area of Vouliagmeni, with a total length of approximately 70 km. Figure 1 presents the study area. It includes urban, suburban, and rural areas, and both natural and artificial coastline, within the continuous Athens Urban Area, the financial capital of Greece. The port of Piraeus is one of the most important ports in Europe (Category I) included in the Core Network of the European Union (EU) and in the Motorways of the Sea. The study area also includes marinas with high capacity (i.e., Alimos Marina, Athens Marina, Flisvos Marina, Ag. Kosmas Marina, Zea Marina, Vouliagmeni Marina), transport infrastructure (highways, underground and suburban rail, tram, and bus stations), and other areas of high interest such as the Hellenikon Metropolitan Park that is under construction (Figure 1). The mean coordinates of the study area are lat: 37°52′47.2332″ N, lon: 23°46′9.2388″ E.

(**a**) (**b**)

Figure 1. (**a**) Study area; (**b**) areas of concern.

2.2. Data

The CResI consists of 19 parameters classified into six categories (i.e., geomorphology, flooding, wave exposition, socioeconomic, land use, infrastructure/functional), as shown in Table 2. The data for the evaluation of the CResI were collected as described below.

The most recent (2021) digital elevation model (DEM) (grid interval of 5 m) was provided by [65] and was used to estimate the elevation and calculate the slope of the coastal area. The number of extreme events was determined through an analysis of historical data provided by [66] and [67]. Areas of potential significant flood risk (APSFR) were obtained from GIS data provided by the Hellenic Ministry of Environment and Energy, derived from the Preliminary Flood Risk Assessment [68]. Soil and rock types were interpreted from geological maps of the Greek Institute of Geology and Mineral Exploration (scale 1:50.000) [69]. Furthermore, for the tidal range, published historical data were used [70], and future projections came from [70]. The mean significant wave height was used as an indicator of wave energy, available in [71]. However, to better evaluate the real conditions of the study area, and more specifically, waves due to southern winds, the maximum wave height was also used, derived from the same published data [72]. The rate of the absolute SLR was also abstracted from published data [73] using satellite measurements for the Mediterranean Sea. Land use data were obtained from the dataset of CORINE Land Cover [74]. Age, education level, and urban development information were obtained from the Hellenic Statistical Authority [75]. For the population density, the Global Human Settlement population grid (GHS-POP) data package from the European Joint Research Centre (JRC) [76] was used at a resolution of 250 m. Data on the transportation network were derived from the OpenstreetMap service [77], as well as from [78]. Adaptation planning and public awareness parameters were estimated by the authors after evaluating the national [79,80] and regional [81] plans for adaptation to climate change.

Table 2. CResI parameters and sources.

Classification	Parameter	Source
Coastal Landforms (CL)	Geotechnical Classification (GC)	[69]
Flooding (FL)	Flood Hazard Zones (FHZ)	[68,80]
	Slope (S)	[65]
	Sea-Level Rise (SLR)	[72]
Wave Exposition	Mean Significant Wave Height (MeanW)	[72]
	Max Significant Wave Height (MaxW)	[72]
	Tide Height (TD)	[70,71]
	Distance from the coast (D)	[77,78]
	Elevation (E)	[65]
	Number of extreme events (EE)	[66,67]
Socioeconomic	Age (population aged less than 9 and more than 70 years old) (A)	[75]
	Population Density (PD)	[76]
	Education Level (% of the population that has attended post-secondary education) (EL)	[75]
	Urban Development (% of population change within 10 years) (UD)	[75]
Land Use	Land Use (LU)	[74]
Infrastructure/Functional	Road Network (TN)	[77,78]
	Distance from hospitals/fire departments/police departments (DHPF)	[77,78]
	Level of community Awareness/Preparedness (AP1)	[78,80]
	Level of Public Natural Hazard Adaptation Planning (AP2)	[78,80]

2.3. Methodology

The methodology framework was structured in the following steps.

Step 1: Examination of the relevant literature and parameter selection. The first step to develop an effective framework for real-world cases is understanding and quantifying risk. After considering 44 relevant indices [18], CResI was formed based on both simpler (e.g., [15]) and more complex (e.g., [8,26,27,51]) indices. Nineteen (19) parameters were selected and classified into six (6) categories, as described below.

Step 2: Weights and ranks were assigned to the parameters using Multicriteria Decision Analysis (MCDA) by establishing a hierarchical structure and analyzing pairwise comparisons using the Analytic Hierarchy Process (AHP). The AHP is one of the most widely used MCDA methods. Introduced by [82], it is used for addressing complex semi-structured decision-making problems by setting weights to several options/scenarios regarding their importance. This method employs a hierarchic (or network) structure to represent the problem, and then, pairwise comparisons are used to build the relationships within that structure [83]. Saaty's [82] fundamental scale of preferences, which is a nine-point intensity scale of importance ranging from equal (1) importance to extreme (9) importance, can assist decision makers in carrying out pairwise comparisons.

For this purpose, pairwise comparison matrices are formed, where the relation, dominance, or equality between the element in row i and the element in column j is expressed by the ratio aij, as designated by the decision maker. The next step is a synthesis process, where the right principal eigenvector λmax values of the matrix are the weights (relative priorities). This matrix can be used in situations where the transitive property is valid. However, it is unlikely that it will occur in real-life situations. Therefore, AHP, as it is applied widely in the literature, is a trustworthy procedure. It can be repeated, and the decision maker is able to perform consistency checks and use both quantitative and qualitative data. Additionally, decision makers are facing difficulties in understanding slight differences among the alternatives, so AHP tends to solve these dilemmas [84,85]. The aforementioned reasons render AHP as a decent choice for the solution of multidimensional problems [86,87].

Step 3: The establishment of the required database was the first step in the development of the CResI through the compilation of geomorphological, flooding, wave exposition, socioeconomic, land use, and infrastructure/functional data. The database was processed through a GIS environment, using the ArcMap (v. 10.8) and ArcGIS Pro (v. 2.8). The ranking scheme for the evaluation of the parameters used was created after combining different approaches of widely used indices (e.g., [15–17], with later modifications (e.g., [21,24,33,50,88]), as well as more complex indices (e.g., [25–27,51]). The ranking refers to factors that affect the exposure (e.g., Mean–Max significant wave height), sensitivity (e.g., coastal landforms), and adaptive capacity (e.g., distance from hospitals, fire departments, police stations), which are crucial components of resilience in the coastal area. Therefore, low values of CResI refer to increased resilience, and high values refer to decreased resilience. A total of 19 parameters were used to create the CResI, as presented in Table 3. The final number of the parameters was also determined by data limitations that occurred during the research, and as a result, it can be modified for future research.

Table 3. Parameter classification table.

Classification	Parameter	Units	Categories					
			1	2	3	4	5	Thresholds Adapted from
Coastal Landforms (CL)	Geotechnical Classification	-	Rocky, high cliffs, seawalls	Medium cliffs and indented coast, bulkhead	Low cliffs, alluvial plain	Cobble beach, estuary lagoon	Sandy beach, mudflat, delta	[15,16] adapted to Greek case studies by [21,22,33,88]
Flooding (FL)	Flood Hazard Zones (FHZ)	-	Outside				Inside	Elaborated by authors
	Slope (S)	%	S ≥ 15	9 ≤ S < 15	6 ≤ S < 9	3 ≤ S < 6	S < 3	[15,16] adapted to Greek case studies by [21,22,33,88]
	Sea-Level Rise (SLR)	mm/y	SLR < 1.8	1.8 ≤ SLR < 2.5	2.5 ≤ SLR < 3.0	3.0 ≤ SLR < 3.4	SLR > 3.4	[15,16] adapted to Greek case studies by [21,22,33,88]

Table 3. *Cont.*

Classification	Parameter	Units	Categories 1	2	3	4	5	Thresholds Adapted from
Wave Exposition	Mean Significant Wave Height (MeanW)	m	MeanW < 0.30	0.3 ≤ MeanW < 0.6	0.6 ≤ MeanW < 0.9	0.9 ≤ MeanW < 1.2	MeanW > 1.20	[15,16] adapted to Greek case studies by [21,22,33,88]
	Max Significant Wave Height (MaxW)	m	MaxW < 3.0	3.0 ≤ MaxW < 5.0	5.0 ≤ MaxW < 6.0	6.0 ≤ MaxW < 6.9	MaxW > 6.9	[15,16] adapted to Greek case studies by [21,22,33,88]
	Tide Height (TD)	m	TD < 0.2	0.2 ≤ TD < 0.4	0.4 ≤ TD < 0.6	0.6 ≤ TD < 0.8	TD > 0.8	[40]
	Distance from the coast (D)	m	1500 < D ≤ 2000	1000 < D ≤ 1500	500 < D ≤ 1000	250 < D ≤ 500	D < 250	[25]
	Elevation (E)	m	E > 30	20 ≤ D < 30	10 ≤ D < 20	5 ≤ D < 10	E < 5	[20]
	Number of extreme events (EE)	No of events in the last 10 years	0 ≤ EE < 3	3 ≤ EE < 10	10 ≤ EE < 20	20 ≤ EE < 36	EE ≥ 36	[26]
Socioeconomic	Age (population aged less than 9 and more than 70 years old) (A)	%	A < 8	8 ≤ A < 14	14 ≤ A < 20	20 ≤ A < 25	A ≥ 25	[27]
	Population Density (PD)	Persons/km^2	PD < 1000	1000 ≤ PD < 2000	2000 ≤ PD < 10,000	10,000 ≤ PD < 20,000	A ≥ 20,000	[57] elaborated by authors
	Education Level (% of population that have attended post-secondary education) (EL)	%	EL ≥ 60	40 ≤ EL < 60	27 ≤ EL < 40	10 ≤ EL < 27	EL < 10	[25]
	Urban Development (% of population change within 10 years) (UD)	%	UD < 0.1	0.1 ≤ UD < 0.5	0.5 ≤ UD < 1.0	1.0 ≤ UD < 2.0	UD ≥ 2.0	[25]
Land Use	Land Use (LU)	-	Environmental protection area/natural habitat	Rural area	Residential Area	Commercial Area	Crucial Infrastructure and Industrial Area	[26])
Infrastructure/ Functional	Road Network (TN)	-	No roads/Minor Roads		Major Urban Roads		Highways	[27], Elaborated by authors
	Distance from hospitals/fire departments/police departments (DHPF)	m	DHPF < 250	250 ≤ DHPF < 500	500 ≤ DHPF < 750	750 ≤ DHPF < 1000	DHPF ≥ 1000	Elaborated by authors
	Level of community Awareness/Preparedness (AP1)	-	Aware/Prepared		Partially Aware/Prepared		Not aware/prepared	[25] Elaborated by authors
	Level of Public Natural Hazard Adaptation Planning (AP2)	-	Immediate Response		Adaptation Strategy not implemented yet		No Measures yet	Elaborated by authors

3. Results

AHP is implemented with pairwise comparison matrices A, where parameters are compared pairwise. Mathematically, the method is based on the solution of an eigenvalue problem [89]. The results of the pairwise comparisons are arranged in a matrix (A). Weights for the parameters are obtained with the normalization of the right eigenvector (w) of A, as in Equation (1), where λmax is the maximum eigenvalue of A:

$$[Aw] = \lambda \max[w] \tag{1}$$

The first (dominant) normalized right eigenvector of the matrix gives the ratio scale (weighting), and the eigenvalue determines the consistency ratio. The dominant eigenvalue λ of A is calculated using the power method [90].

Consistency is the most important measurement of the validity of the results of pairwise comparisons using the AHP [82,83]. The consistency of the AHP is determined using the value of the Consistency Index from the pairwise comparison table. For the calculation of the Consistency Index, the linear approach from [91] was implemented:

$$CI = \frac{\lambda - n}{2.7699\, n - 4.3513 - n} \tag{2}$$

The Consistency Index (CI) is a specialized index imported from AHP in order to explore possible inconsistencies in judgments. The acceptable amount of inconsistency is equal to or lower than 10% in the context of its imperceptible or not generally important influence on the results [83]. Pairwise comparisons of the criteria were carried out by the authors based on their experience on the methods and on the related literature. The aggregated pairwise comparison matrix is displayed in Table 4. The weight elicitation procedure was carried out using an Excel spreadsheet by [85], which is specialized for the AHP method. It is worth mentioning that the calculated Consistency Index (CI) was 3.8%.

Table 4. AHP aggregated pairwise comparison matrix.

Factor	Coastal Landforms	Flooding	Wave Exposition	Socioeconomic	Land Use	Functional	Normalized Principal Eigenvector%
Coastal Landforms	1.0000	0.2887	0.2500	0.2887	0.2887	0.2582	4.81
Flooding	3.4641	1.0000	1.0000	1.5811	1.4142	1.4142	20.80
Wave Exposition	4.0000	1.0000	1.0000	2.0000	2.0000	3.1623	28.47
Socioeconomic	3.4641	0.6325	0.5000	1.0000	0.2887	0.4082	10.50
Land Use	3.4641	0.7071	0.5000	3.4641	1.0000	0.5774	17.21
Functional	3.8730	0.7071	0.3162	2.4495	1.7321	1.0000	18.21

"Land use" was weighted higher in order to emphasize its role as a determinant of infrastructure location. AHP was also implemented for the weights among the parameters of each class. For the Flooding and the Infrastructure/Functional classes, each parameter was ranked equally; however, in the Wave Exposition and Socioeconomic classes, parameters such as the Max Significant Wave Height, Elevation, Population Density, and Urban Development were ranked with a higher relevant factor weight. The resulting weights of each parameter are shown in Table 5.

Table 5. Parameter weight elicitation.

Factor	Total Factor Weight (AHP) (%)	Parameters	Relevant Factor Weight (%)	Total Parameter Weight (%)
Coastal Landforms (CL)	4.8	Geotechnical Classification (GC)	100.00	4.80
Flooding (FL)	20.8	Flood Hazard Zones (FHZ)	33.33	6.93
		Slope (S)	33.33	6.93
		Sea-Level Rise (SLR)	33.33	6.93
Wave Exposition (WE)	28.5	Mean Significant Wave Height (MeanW)	11.60	3.31
		Max Significant Wave Height (MaxW)	26.70	7.61
		Tide Height (TD)	4.30	1.23
		Number of extreme events (EE)	12.90	3.68
		Distance from the coast (D)	18.60	5.30
		Elevation (E)	25.90	7.38
Socioeconomic (SE)	10.5	Age (A)	10.60	1.11
		Population Density (PD)	41.30	4.34
		Education Level (EL)	12.00	1.26
		Urban Development (UD)	36.00	3.78
Land Use (LU)	17.2	Land Use	17.20	17.20
Infrastructure/Functional (IF)	18.2	Road Network (TN)	25.00	4.55
		Distance from hospitals/fire departments/police departments (DHPF)	25.00	4.55
		Level of community Awareness/Preparedness (AP1)	25.00	4.55
		Level of Public Natural Hazard Adaptation Planning (AP2)	25.00	4.55

Based on the above, the formulation of the CResI is given by Equation (3):

$$\text{CResI} = 0.048\ \text{CL} + 0.208\ \text{FL} + 0.285\ \text{WE} + 0.105\ \text{SE} + 0.172\ \text{LU} + 0.182\ \text{IF} \quad (3)$$

$$\text{FL} = 0.3333\ \text{FHZ} + 0.3333\ \text{S} + 0.3333\ \text{SLR} \quad (4)$$

$$\text{WE} = 0.0331\ \text{MeanW} + 0.0761\ \text{MaxW} + 0.0123\ \text{TD} + 0.0368\ \text{TD} + 0.0530\ \text{D} + 0.0738\ \text{E} \quad (5)$$

$$\text{SE} = 0.1060\ \text{A} + 0.4130\ \text{PD} + 0.1200\ \text{EL} + 0.3600\ \text{UD} \quad (6)$$

$$\text{IF} = 0.2500\ \text{TN} + 0.2500\ \text{DHPF} + 0.2500\ \text{AP1} + 0.2500\ \text{AP2} \quad (7)$$

In the majority of the literature, indices are calculated using the arithmetic or geometric mean. The use of AHP to elicit weights to the parameters leads to a more realistic result, as each area has different characteristics. Using an arithmetic mean, all the weights would be assigned the same value (16.67%). In this case study, geotechnical classification is less significant, as it mostly includes urban areas with relevant infrastructure (e.g., seawalls). The physical factors (flooding and wave exposition), on the other hand, are ranked higher, with land use and infrastructure/functional factors close to the arithmetic mean weight level.

The database was processed in a GIS environment, creating a 100 × 100 m grid, since this resolution allowed the authors to take into consideration the various aspects of the urban system, such as land use, as well as characteristics of the coastal area (e.g., elevation and slope), that might lead to different results if a broader resolution was chosen. Furthermore, the 100 × 100 m resolution was more easily manageable within the GIS environment, and in addition, the available spatial data were not of finer resolution. Afterward, areas with an elevation higher than 30 m and more than 1000 m away from the coastline were excluded from the evaluation, as coastal flooding will not affect them. Meanwhile, the 1000 m zone from the coastline is enough to take into consideration the characteristics of the urban area. Thematic maps were created to visualize the rankings of each parameter, using the natural breaks (jenks) method, through GIS.

For the wider part of the coastal area, the geomorphology factor is low, as it includes areas with quay walls and coastal defense works (Figure 2). The rate of the absolute SLR was ranked in cat. 5 (+5 mm/year), abstracted from [72], as mentioned in Section 2. The flooding exposition factor is higher for many areas, as they are mostly flat or do not have significant slope and are included in flood hazard maps (Figure 3).

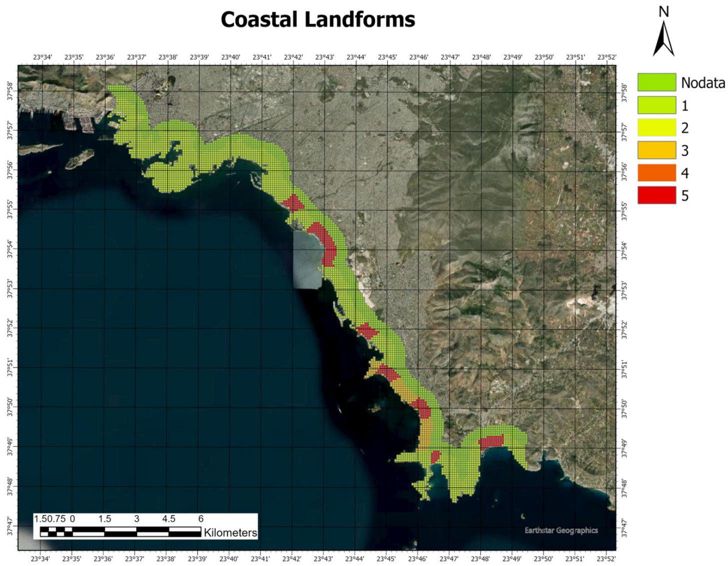
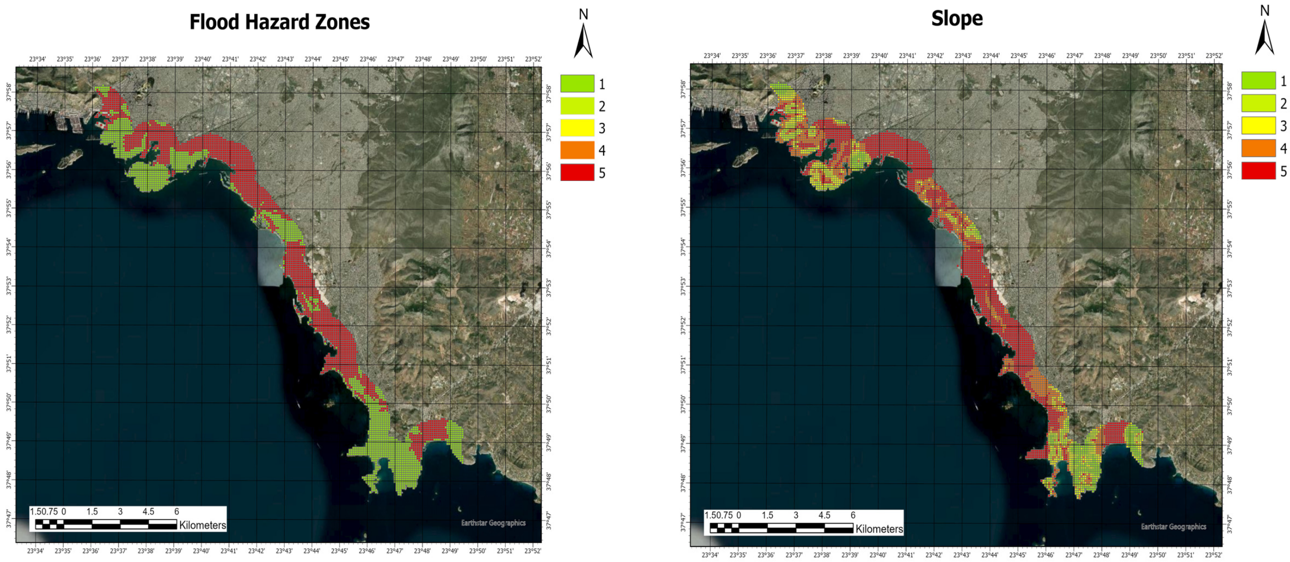
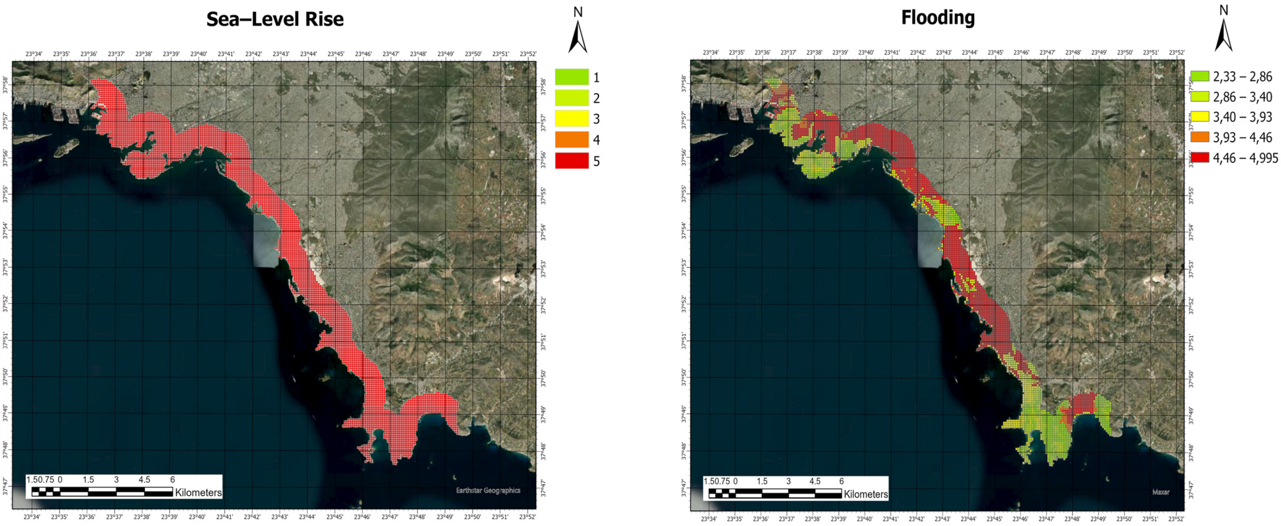


Figure 2. Exposure zonation based on the coastal landforms factor.



(**a**) (**b**)

Figure 3. *Cont.*



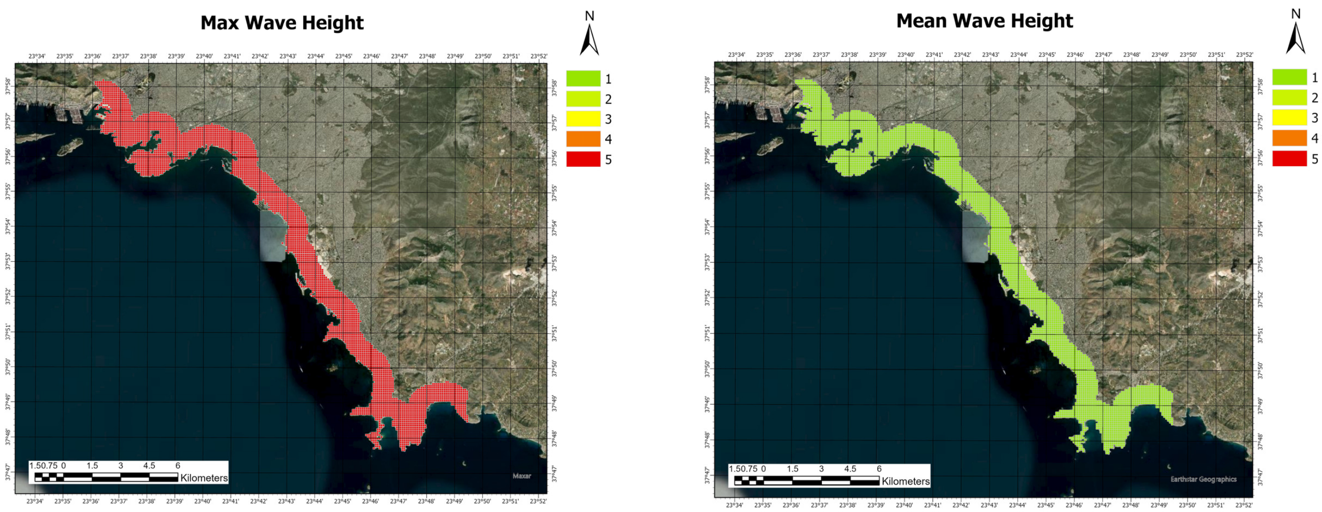
(c) (d)

Figure 3. Zonation of the study area based on (**a**) flood hazard zones; (**b**) slope; (**c**) SLR; (**d**) flooding factor.

Wave exposition was based on historical data, with a high max significant wave height (approx. 7.2 m) leading to higher values for the wave exposition factor. Meanwhile, as the tidal range in Greek seas is considered low (avg. 0.12 m for the east Mediterranean), this parameter is not significant for this case study. The wave exposition factor is relatively high for most part of the study area (Figure 4).

Furthermore, areas with a higher percentage of elderly people (age > 70 years) and young children (age < 9 years) are considered less resilient, while higher population density and urban development (e.g., Piraeus, Kallithea, Moschato) lead to lower values of resilience. However, the overall social factor of the CResI is considered medium (Figure 5).

The land use factor is higher for areas of economic importance, such as the port of Piraeus and nearby industrial areas and a noteworthy part of the coastal area (Figure 6).



(a) (b)

Figure 4. *Cont*.

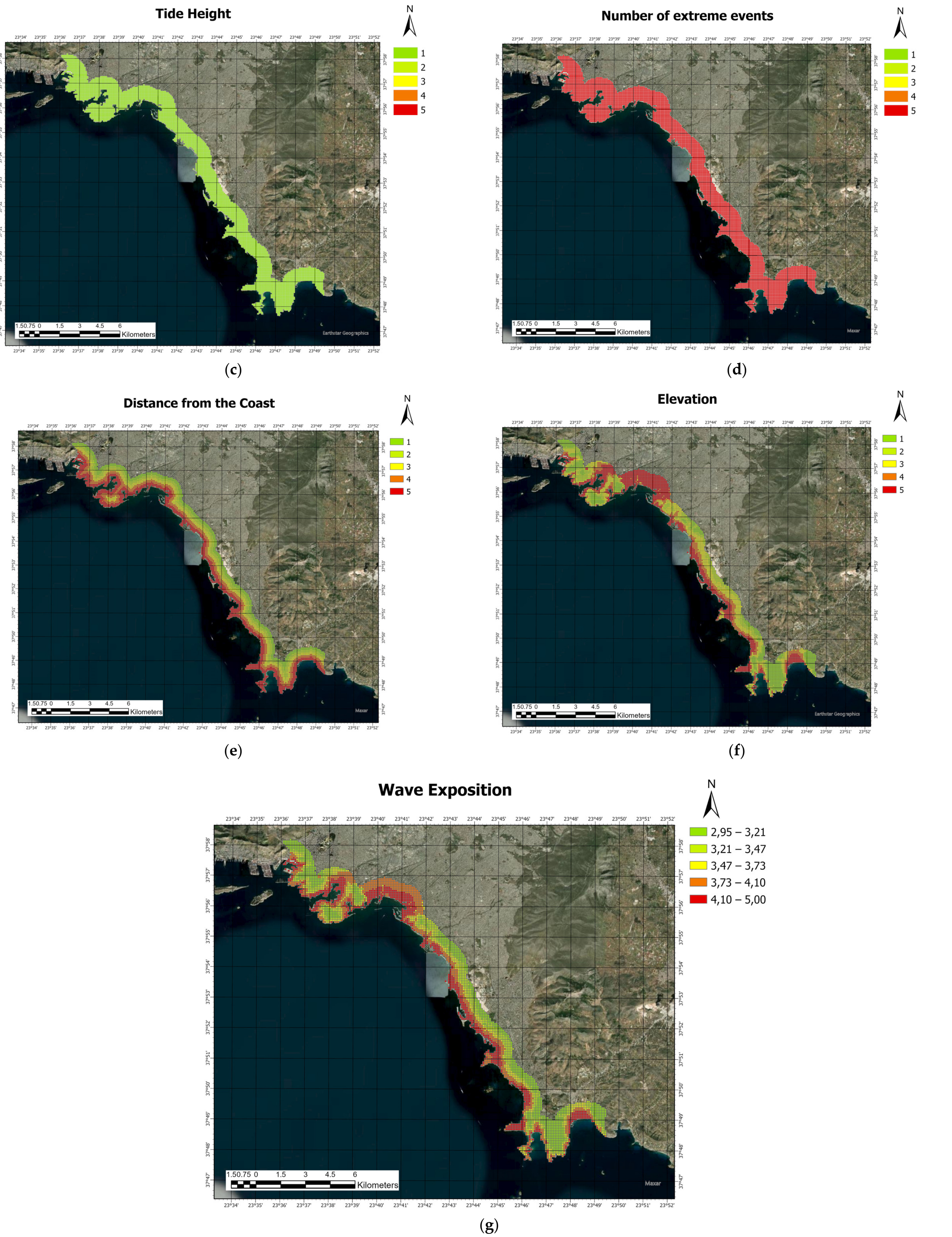


Figure 4. Zonation of the study area based on (**a**) mean wave height; (**b**) max wave height; (**c**) tide height; (**d**) number of extreme events; (**e**) distance from the coast; (**f**) elevation; (**g**) wave exposition factor.

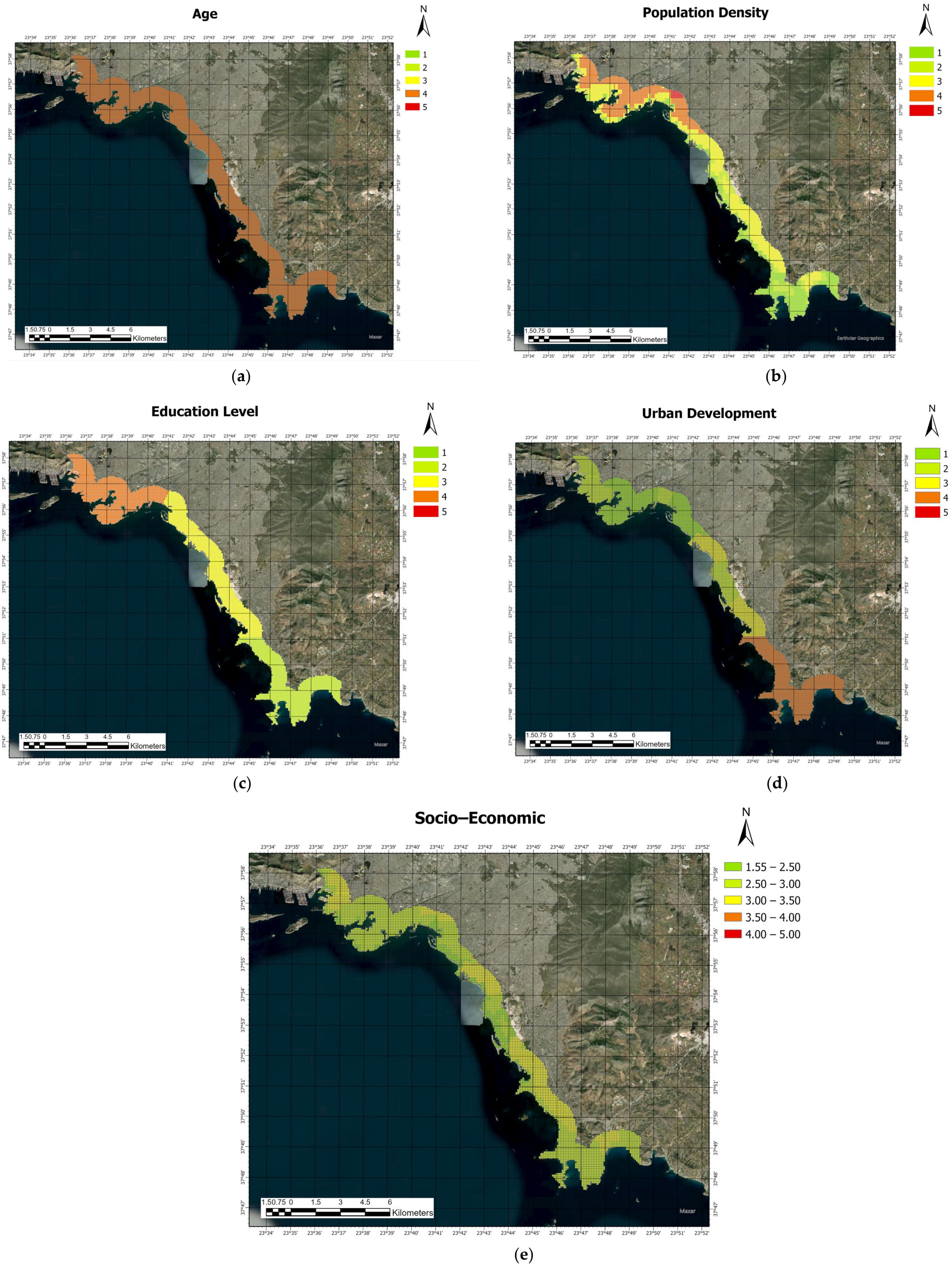


Figure 5. Zonation of the study area based on (**a**) age; (**b**) population density; (**c**) education level; (**d**) urban development; (**e**) socioeconomic exposure map.

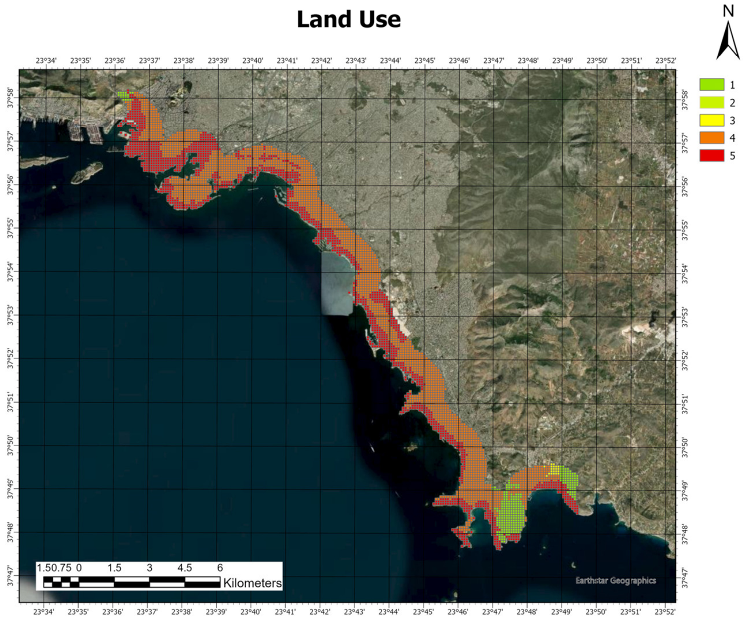
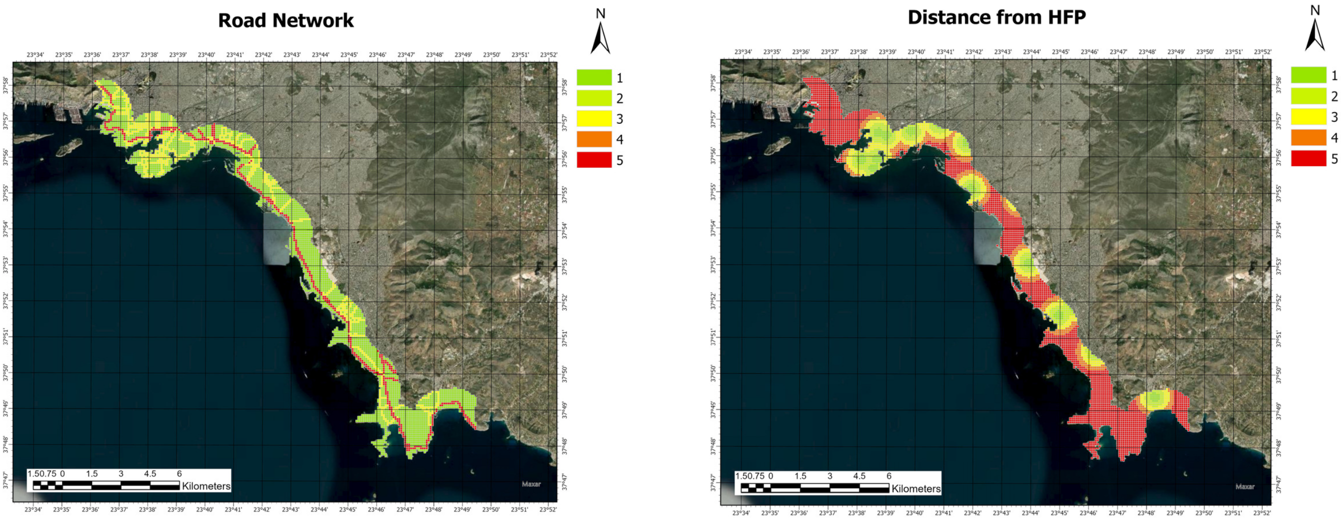


Figure 6. Exposure map based on land use classification.

Finally, existing infrastructure and adaptation measures were considered. The study area has a significant road network, and segments that include major roads have higher exposure than other areas, as they will be used for the evacuation of the study area in a natural disaster. The parameter indicating the distance from hospitals/fire departments/police departments was high for an important part of the study area, which was not expected for the Athens metropolitan area. The lower level of governmental adaptation planning and the lower population awareness/preparedness in areas with lower education levels were considered by the authors. Although research on climate change is highly advancing, adaptation and mitigation planning still requires improvement. The abovementioned parameters are shown in Figure 7.



(**a**) (**b**)

Figure 7. *Cont.*

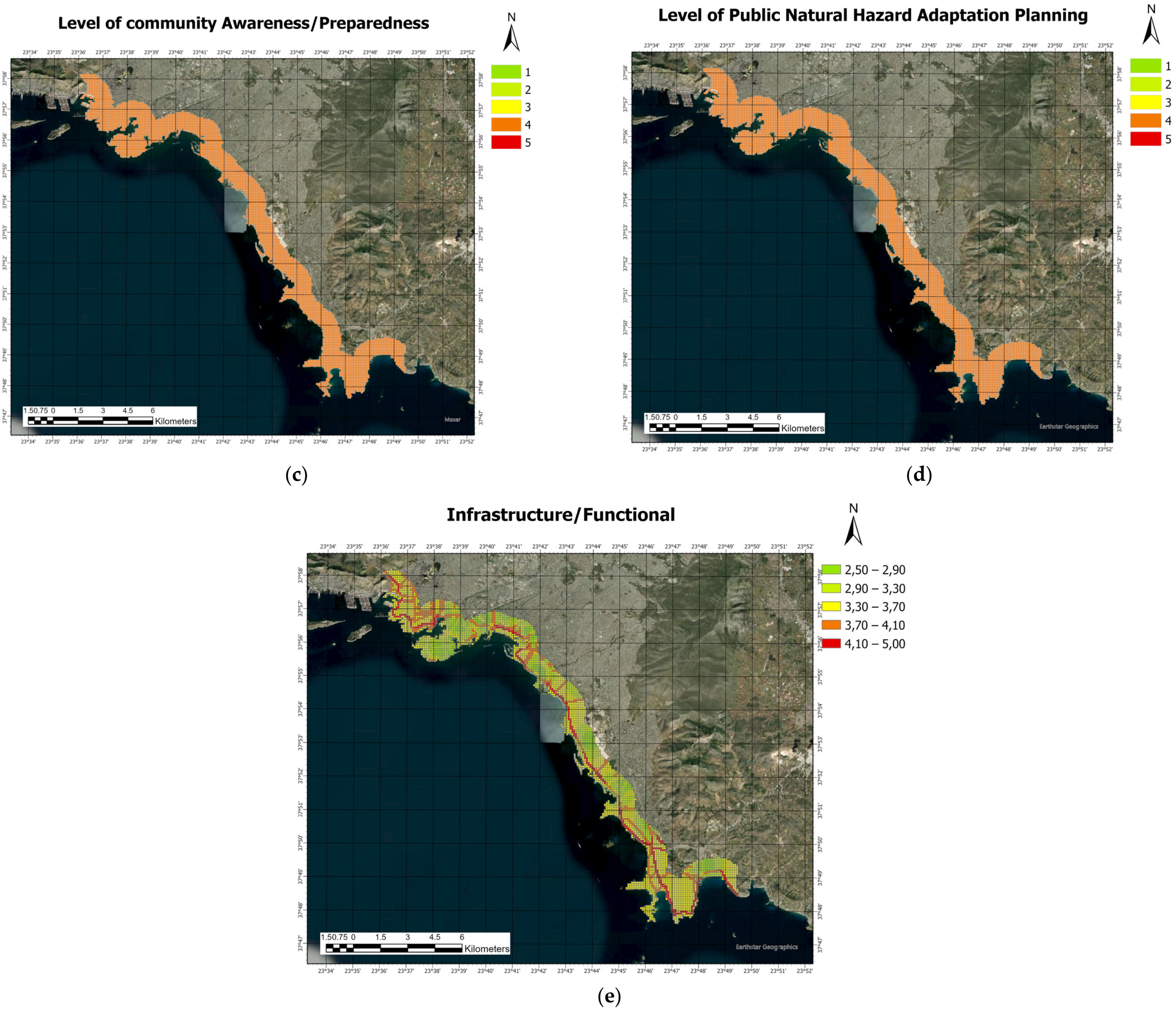


Figure 7. Zonation of the study area based on (**a**) road network; (**b**) distance from HFP; (**c**) community awareness; (**d**) level of public natural hazard adaptation planning; (**e**) infrastructure/functional factor.

Our findings indicate that a significant part (around 25%) of the coastal area is of level 4 (low-resilience) CResI. The resilience assessment of the study area is presented in the form of thematic maps. Low-resilience areas (CResI $\geq$ 4) include both residential and commercial/industrial areas, as well as major roads and streets (Figure 8a).

The suburban areas of Voula, Vari, and Vouliagmeni (Figure 8b), with high touristic interest and natural beauty, also have low resilience, mainly due to their geomorphology and wave exposition. Low-elevation areas near the Port of Piraeus, Faliro, Alimos (Figure 8d), Hellenikon and Glyfada (Figure 8c) are subject to higher coastal flood exposure. On the other hand, part of the coastal zone is elevated and as a result is not exposed to threats of sea-level rise.

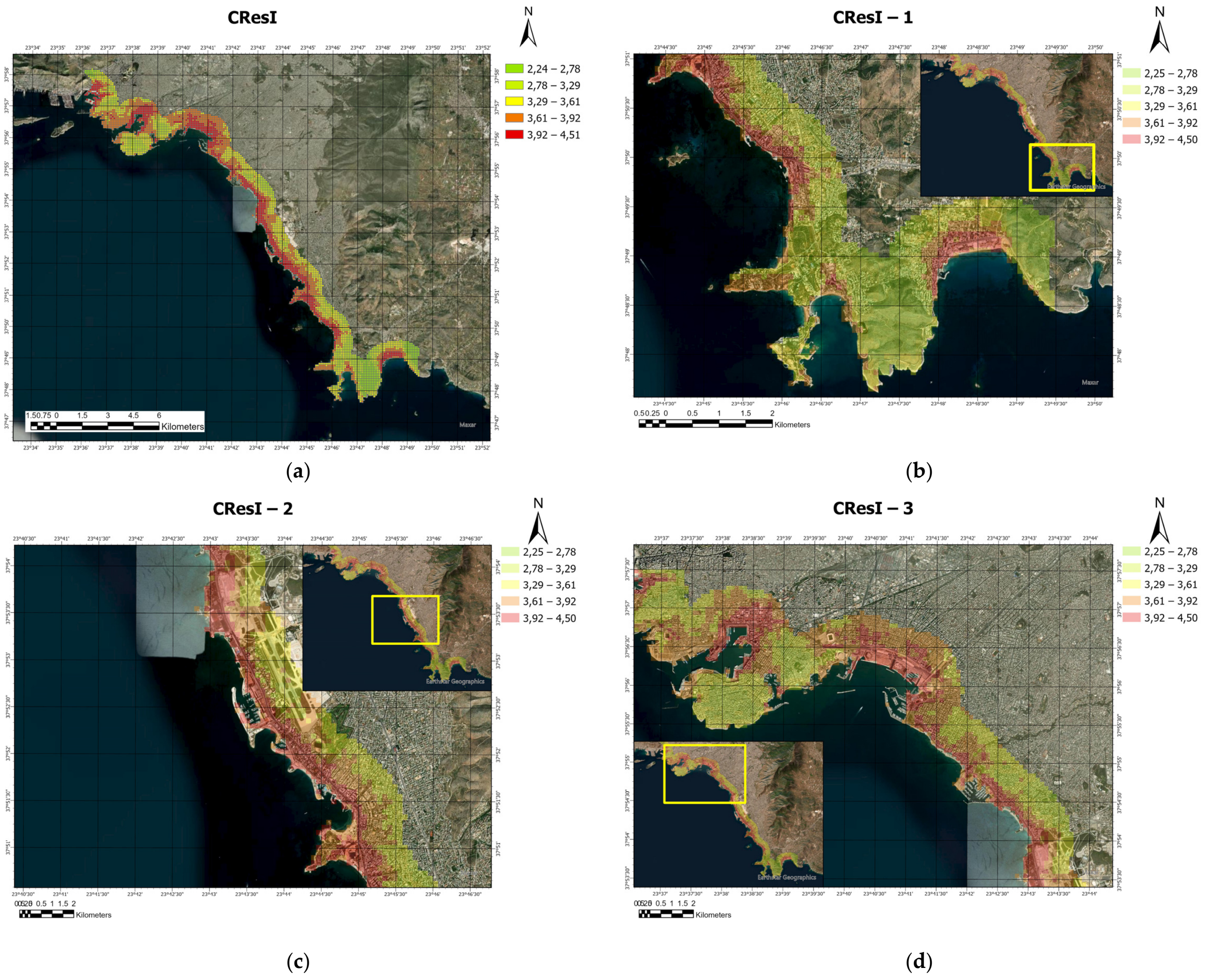


Figure 8. Zonation of the study area based on coastal resilience index (CResI) and areas of interest. (**a**) CResI map; (**b**) Vari, Voula, Vouliagmeni; (**c**) Hellenikon, Glyfada; (**d**) Port of Piraeus, Faliro, Alimos.

4. Discussion

The presented method has an advantage over existing studies in that it uses the advanced weighting and selection of indicators and provides a better prediction of future coastal flooding impacts. The method is applicable to areas that have not yet experienced the effects of SLR due to climate change, and it may be used not only by experts and policymakers but also by individuals and other stakeholders. The innovative aspects of the approach presented herein are the following: it addresses the concern raised by the UN [14] and highlighted by [18] about "who is vulnerable" rather than "what". Therefore, a more dynamic understanding of human–environment interactions is taken into consideration. Existing vulnerability and resilience approaches are modified to assess the resilience of coastal areas. This gives deeper insight into the interaction between socioeconomic characteristics and hazard dynamics. Previous researchers have focused on specific aspects of coastal vulnerability and resilience, either physical (e.g., CVI by [15,16] with adaptations (e.g., [8,21–23,28,36]) or social (e.g., [17,24,49,50]).

Also, other indices were applied on narrow areas of the coastline, not including crucial aspects of vulnerability, like the characteristics of urban areas. The approaches of Zan [26,50] used larger urban areas as case studies; however, their parameter selection could have taken into consideration more aspects of socioeconomic development. The transportation network has only recently been on the agenda of researchers [92,93]; however, such an important factor should be included in state-of-the-art studies. Parameters in the present study include features that have not been considered in any previous research, such as the distance from first hospitals, fire departments, police stations, community awareness/preparedness level, and future adaptation planning policy.

The parameters are selected after a robust review of the literature; therefore, the data size is significantly reduced. By categorizing them into clusters, all the features can be visualized in thematic maps. This method can also be implemented not only for climate change scenarios but also for different Socioeconomic Pathway (SSP) scenarios, as it includes diverse socioeconomic parameters. Also, it is highly adaptable to local conditions; thus, it can easily be transferred to other coastal areas.

5. Conclusions

Climate change is a crucial issue that this generation is already facing. The most accepted method to assess vulnerability or resilience to climate change is the index-based approach. Parameter selection may differ depending on the approach and data availability of each case study. The proposed index, CResI, could be useful for policymakers and local authorities. Through CResI, the areas in danger can be identified, as well as the level of exposure for individuals and communities at the local level. For this purpose, the southwest waterfront of Attica, Greece, was selected as a case study. Based on historical data, climate projections, socioeconomic characteristics, and the evaluation of the existing adaptation planning, thematic maps were created, and CResI values were identified on a spatial scale. Around 15% of the coastal area could be at risk of coastal flooding due to climate change in the next years, including areas in both the metropolitan and suburban environments. As a result, the urge for adaptation measures cannot be overlooked. Future research might include the addition of extra parameters into the CResI (e.g., capacity of touristic ports), the implementation of CResI for different climate scenarios, and the combination of RCP and SSP scenarios. CResI should also be implemented in other areas and compared to other climate change vulnerability–resilience indices. Collaboration with local authorities and policy makers would also be possible to gain access to additional data.

Author Contributions: Conceptualization, C.N.R. and V.A.T.; Methodology, C.N.R. and V.A.T.; Software, C.N.R.; Validation, C.N.R., V.K.T., and V.A.T.; Formal analysis, C.N.R.; Investigation, C.N.R. and V.A.T.; Resources, V.A.T.; Data curation, C.N.R.; Writing—original draft preparation, C.N.R.; Writing—review and editing, V.K.T. and V.A.T.; Visualization, C.N.R.; Supervision, V.A.T.; Project administration, V.A.T. All authors have read and agreed to the published version of the manuscript.

Funding: A graduate scholarship to C.N. Roukounis by the Research Committee of the National Technical University of Athens is greatly appreciated. The research is co-financed by Greece and the European Union (European Social Fund) through the Operational Program "Human Resources Development, Education and Lifelong Learning", 2014–2020, within the framework of the Action "Strengthening the human resources through the implementation of doctoral research—Sub-Action 2: Grant Programme of IKY scholarships to PhD candidates of Greek Universities".

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available upon reasonable request from the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Wahl, T.; Brown, S.; Haigh, I.; Nilsen, J. Coastal Sea Levels, Impacts, and Adaptation. *J. Mar. Sci. Eng.* **2018**, *6*, 19. [CrossRef]
2. McGranahan, G.; Balk, D.; Anderson, B. The rising tide: Assessing the risks of climate change and human settlements in low elevation coastal zones. *Environ. Urban.* **2007**, *19*, 17–37. [CrossRef]

3. IPCC. Global warming of 1.5 °C. An IPCC Special Report on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty; Masson-Delmotte, V., Zhai, P., Pörtner, H.O., Roberts, D., Skea, J., Shukla, P.R., Pirani, A., Moufouma-Okia, W., Péan, C., Pidcock, R.; et al., Eds.; 2018. Available online: https://www.ipcc.ch/site/assets/uploads/sites/2/2022/06/SR15_Full_Report_HR.pdf (accessed on 1 September 2023).
4. IPCC. Summary for Policymakers. In *Climate Change 2023: Synthesis Report. A Report of the Intergovernmental Panel on Climate Change. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*; Core Writing Team, Lee, H., Romero, J., Eds.; IPCC: Geneva, Switzerland, 2023; 36p, *in press*.
5. Tsoukala, V.; Chondros, M.; Kapelonis, Z.; Martzikos, N.; Lykou, A.; Belibassakis, K.; Makropoulos, C. An integrated wave modelling framework for extreme and rare events for climate change in coastal areas—The case of Rethymno, Crete. *Oceanologia* **2016**, *58*, 71–79. [CrossRef]
6. Afentoulis, V.; Kragiopoulou, E.; Skarlatou, E.; Moschos, E.; Lykou, A.; Makropoulos, C.; Tsoukala, V. Coastal processes assessment under extreme storm events using numerical modelling approaches. *Environ. Process.* **2017**, *4*, 731–747. [CrossRef]
7. Chalastani, V.; Pantelidis, A.; Tsaimou, C.; Tsoukala, V. Development of a Complex Vulnerability Index for Fishing Shelters—The Case of Cyprus. In Proceedings of the 7th Europe Congress of the International Association for Hydro-environment Engineering and Research (IAHR), Athens, Greece, 7–9 September 2022.
8. Tsaimou, C.; Kagkelis, G.; Papadimitriou, A.; Chalastani, V.; Sartampakos, P.; Chondros, M.; Tsoukala, V. Advanced Multi-Area Approach for Coastal Vulnerability Assessment. In Proceedings of the 7th Europe Congress of the International Association for Hydro-Environment Engineering and Research (IAHR), Athens, Greece, 7–9 September 2022.
9. Giannakidou, C.; Diakoulaki, D.; Memos, C.D. Vulnerability to Coastal Flooding of Industrial Urban Areas in Greece. *Environ. Process.* **2020**, *7*, 749–766. [CrossRef]
10. Brooks, N. Vulnerability, Risk and Adaptation: A conceptual Framework. Tyndall Centre for Climate Change Research. Working Paper 38. School of Environmental Sciences 2003, University of East Anglia, Norwich, UK. Available online: https://gsdrc.org/document-library/vulnerability-risk-and-adaptation-a-conceptual-framework (accessed on 20 May 2021).
11. Bevacqua, E.; Maraun, D.; Vousdoukas, M.I.; Voukouvalas, E.; Vrac, M.; Mentaschi, L.; Widmann, M. Higher probability of compound flooding from precipitation and storm surge in Europe under anthropogenic climate change. *Sci. Adv.* **2019**, *5*, eaaw5531. [CrossRef] [PubMed]
12. McIntosh, R.D.; Becker, A. Expert evaluation of open-data indicators of seaport vulnerability to climate and extreme weather impacts for U.S. North Atlantic ports. *Ocean Coast. Manag.* **2019**, *180*, 104911. [CrossRef]
13. Malone, E.L.; Engle, N.L. Evaluating regional vulnerability to climate change: Purposes and methods. *WIREs Clim. Change* **2011**, *2*, 462–474. [CrossRef]
14. United Nations. The Paris Agreement. Conference of the Parties, United Nations Framework Convention on Climate Change, Paris, November–December 2015. 2015. Available online: https://unfccc.int/sites/default/files/english_paris_agreement.pdf (accessed on 21 September 2020).
15. Gornitz, V. Global coastal hazards from future sea level rise. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* **1991**, *89*, 379–398. [CrossRef]
16. Thieler, E.R.; Hammar-Klose, E.S. National Assessment of Coastal Vulnerability to Sea-Level Rise. Open-File Report 1999, 179p. Available online: https://pubs.usgs.gov/dds/dds68/reports/gulfrep.pdf (accessed on 19 November 2020).
17. Cutter, S.L.; Boruff, B.J.; Shirley, W.L. Social Vulnerability to Environmental Hazards *. *Soc. Sci. Q.* **2003**, *84*, 242–261. [CrossRef]
18. Roukounis, C.N.; Tsihrintzis, V.A. Indices of Coastal Vulnerability to Climate Change: A Review. *Environ. Process.* **2022**, *9*, 29. [CrossRef]
19. Shaw, J.; Taylor, R.B.; Solomon, S.; Christian, H.A.; Forbes, D.L. Potential Impacts of Global Sea-Level Rise on Canadian Coasts. *Can. Geogr. /Le Géographe Can.* **1998**, *42*, 365–379. [CrossRef]
20. Mclaughlin, S.; Cooper, J.A.G. A multi-scale coastal vulnerability index: A tool for coastal managers? *Environ. Hazards* **2010**, *9*, 233–248. [CrossRef]
21. Karymbalis, E.; Chalkias, C.; Chalkias, G.; Grigoropoulou, E.; Manthos, G.; Ferentinou, M. Assessment of the sensitivity of the southern coast of the Gulf of Corinth (Peloponnese, Greece) to sea-level rise. *Open Geosci.* **2012**, *4*, 561–577. [CrossRef]
22. Tragaki, A.; Gallousi, C.; Karymbalis, E. Coastal Hazard Vulnerability Assessment Based on Geomorphic, Oceanographic and Demographic Parameters: The Case of the Peloponnese (Southern Greece). *Land* **2018**, *7*, 56. [CrossRef]
23. Zampazas, G.; Karymbalis, E.; Chalkias, C. Assessment of the sensitivity of Zakynthos Island (Ionian Sea, Western Greece) to climate change-induced coastal hazards. *Z. Für Geomorphol.* **2022**, *63*, 183–200. [CrossRef]
24. Tate, E.; Cutter, S.L.; Berry, M. Integrated Multihazard Mapping. *Environ. Plan. B Plan. Des.* **2010**, *37*, 646–663. [CrossRef]
25. Satta, A. An Index-Based Method to Assess Vulnerabilities and Risks of Mediterranean Coastal Zones to Multiple Hazards—Un Indice per la Valutazione delle Vulnerabilità e dei Rischi Generati da Multiple Pericolosità sulle zone Costiere del Mediterraneo. Ph.D. Thesis, Department of Economics Ca'Foscari University, Venice, Italy, 2014. [CrossRef]
26. Zanetti, V.; de Sousa Junior, W.; De Freitas, D. A Climate Change Vulnerability Index and Case Study in a Brazilian Coastal City. *Sustainability* **2016**, *8*, 811. [CrossRef]
27. Gargiulo, C.; Battarra, R.; Tremiterra, M.R. Coastal areas and climate change: A decision support tool for implementing adaptation measures. *Land Use Policy* **2020**, *91*, 104413. [CrossRef]

28. Pendleton, E.A.; Thieler, E.R.; Williams, S.J.; Beavers, R. Coastal Vulnerability Assessment of Cumberland Island National Seashore (CUIS) to Sea-Level Rise. 2004. Available online: https://pubs.usgs.gov/of/2004/1196/ofr20041196.pdf (accessed on 16 October 2020).
29. Rao, K.N.; Subraelu, P.; Rao, T.V.; Malini, B.H.; Ratheesh, R.; Bhattacharya, S.; Rajawat, A.S. Sea-level rise and coastal vulnerability: An assessment of Andhra Pradesh coast, India through remote sensing and GIS. *J. Coast. Conserv.* **2008**, *12*, 195–207. [CrossRef]
30. Doukakis, E. Coastal vulnerability and risk parameters. *Eur. Water* **2005**, *11*, 3–7.
31. Abuodha, P.A.; Woodroffe, C.D. Assessing vulnerability of coasts to climate change: A review of approaches and their application to the Australian coast. In *Proceedings of the GIS for the Coastal Zone: A Selection of Papers from CoastGIS 2006*; Woodroffe, C., Bruce, E., Poutinen, M., Furness, R., Eds.; University of Wollongong: Wollongong, Australia, 2006; p. 458. Available online: https://ro.uow.edu.au/cgi/viewcontent.cgi?article=1189&context=scipapers (accessed on 29 August 2023).
32. Devoy, R.J.N. Coastal Vulnerability and the Implications of Sea-Level Rise for Ireland. *J. Coast. Res.* **2008**, *242*, 325–341. [CrossRef]
33. Gaki-Papanastassiou, K.; Karymbalis, E.; Poulos, S.; Zouva, C. Coastal vulnerability assessment to sea-level rise based on geomorphological and oceanographical parameters: The case of Argolikos Gulf. *Hell. J. Geosci.* **2010**, *45*, 109–122.
34. Yin, J.; Yin, Z.; Wang, J.; Xu, S. National assessment of coastal vulnerability to sea-level rise for the Chinese coast. *J. Coast. Conserv.* **2012**, *16*, 123–133. [CrossRef]
35. Tibbetts, J.R.; van Proosdij, D. Development of a relative coastal vulnerability index in a macro-tidal environment for climate change adaptation. *J. Coast. Conserv.* **2013**, *17*, 775–797. [CrossRef]
36. Bonetti, J.; Klein, A.H.F.; Muler, M.; De Luca, C.B.; Silva, G.V.; Toldo, E.E., Jr.; Gonzalez, M. Spatial and numerical methodologies on coastal erosion and flooding risk assessment. In *Coastal Hazards*; Coastal Research Library Series; Finkl, C., Ed.; Springer: Dordrecht, The Netherlands, 2013; Chapter 16; pp. 423–442.
37. Addo, K.A. Assessing Coastal Vulnerability Index to Climate Change: The Case of Accra—Ghana. *J. Coast. Res.* **2013**, *165*, 1892–1897. [CrossRef]
38. Mani Murali, R.; Ankita, M.; Amrita, S.; Vethamony, P. Coastal vulnerability assessment of Puducherry coast, India, using the analytical hierarchical process. *Nat. Hazards Earth Syst. Sci.* **2013**, *13*, 3291–3311. [CrossRef]
39. Bagdanavičiūtė, I.; Kelpšaitė, L.; Soomere, T. Multi-criteria evaluation approach to coastal vulnerability index development in micro-tidal low-lying areas. *Ocean Coast. Manag.* **2015**, *104*, 124–135. [CrossRef]
40. Pantusa, D.; D'Alessandro, F.; Riefolo, L.; Principato, F.; Tomasicchio, G. Application of a Coastal Vulnerability Index. A Case Study along the Apulian Coastline, Italy. *Water* **2018**, *10*, 1218. [CrossRef]
41. Gzam, M.; Mansouri, B.; Gargouri, D.; Kharroubi, A. Assessment of the Coastal Sensitivity in the Southern Mediterranean Using the CSI. *Environ. Process.* **2022**, *9*, 39. [CrossRef]
42. Wu, S.; Yarnal, B.; Fisher, A. Vulnerability of coastal communities to sea-level rise: A case study of Cape May County, New Jersey, USA. *Clim. Res.* **2002**, *22*, 255–270. [CrossRef]
43. Briguglio, L.; Galea, W. Updating and Augmenting the Economic Vulnerability Index. In *Occasional Chapters on Islands and Small States*; Islands and Small States Institute of the University of Malta: Msida, Malta, 2003; Volume 4, pp. 1–15. Available online: https://www.um.edu.mt/library/oar/handle/123456789/18371 (accessed on 1 December 2020).
44. Chakraborty, J.; Tobin, G.A.; Montz, B.E. Population Evacuation: Assessing Spatial Variability in Geophysical Risk and Social Vulnerability to Natural Hazards. *Nat. Hazards Rev.* **2005**, *6*, 23–33. [CrossRef]
45. Li, K.; Li, G.S. Vulnerability assessment of storm surges in the coastal area of Guangdong Province. *Nat. Hazards Earth Syst. Sci.* **2011**, *11*, 2003–2010. [CrossRef]
46. Mackey, P.; Russell, M. Climate Change scenarios, sea level rise for Ca Mau, Kien Giang-Climate Change Impact and Adaptation Study in the Mekong Delta —Part A. In *Climate Change Vulnerability & Risk Assessment Study for Ca Mau and Kien Giang Provinces, Vietnam*; Institute of Meteorology, Hydrology and Environment of Vietnam (IMHEN): Hanoi, Vietnam, 2011; p. 250. Available online: https://www.adb.org/sites/default/files/project-documents/43295-012-tacr-03b_0.pdf (accessed on 2 September 2023).
47. Ahsan, M.N.; Warner, J. The socioeconomic vulnerability index: A pragmatic approach for assessing climate change led risks–A case study in the south-western coastal Bangladesh. *Int. J. Disaster Risk Reduct.* **2014**, *8*, 32–49. [CrossRef]
48. Edmonds, H.K.; Lovell, J.E.; Lovell, C.A.K. A new composite climate change vulnerability index. *Ecol. Indic.* **2020**, *117*, 106529. [CrossRef]
49. Kleinosky, L.R.; Yarnal, B.; Fisher, A. Vulnerability of Hampton Roads, Virginia to Storm-Surge Flooding and Sea-Level Rise. *Nat. Hazards* **2006**, *40*, 43–70. [CrossRef]
50. Guillard-Gonçalves, C.; Cutter, S.L.; Emrich, C.T.; Zêzere, J.L. Application of Social Vulnerability Index (SoVI) and delineation of natural risk zones in Greater Lisbon, Portugal. *J. Risk Res.* **2014**, *18*, 651–674. [CrossRef]
51. Toimil, A.; Losada, I.J.; Díaz-Simal, P.; Izaguirre, C.; Camus, P. Multi-sectoral, high-resolution assessment of climate change consequences of coastal flooding. *Clim. Change* **2017**, *145*, 431–444. [CrossRef]
52. Boruff, B.J.; Emrich, C.; Cutter, S.L. Erosion hazard vulnerability of US coastal counties. *J. Coast. Res.* **2005**, *215*, 932–942. [CrossRef]
53. Mendoza, E.T.; Jiménez, J.A. Regional vulnerability analysis of Catalan beaches to storms. *Proc. Inst. Civ. Eng.-Marit. Eng.* **2009**, *162*, 127–135. [CrossRef]
54. Balica, S.F.; Wright, N.G.; van der Meulen, F. A flood vulnerability index for coastal cities and its use in assessing climate change impacts. *Nat. Hazards* **2012**, *64*, 73–105. [CrossRef]

55. Kokkinos, D.; Prinos, P.; Galiatsatou, P. Assessment of coastal vulnerability for present and future climate conditions in coastal areas of the Aegean Sea. In Proceedings of the 11th International Conference on Hydroscience & Engineering, Hamburg, Germany, 28 September–2 October 2014. Available online: https://www.researchgate.net/publication/266561166 (accessed on 22 June 2021).
56. El-Zein, A.; Ahmed, T.; Tonmoy, F. Geophysical and social vulnerability to floods at municipal scale under climate change: The case of an inner-city suburb of Sydney. *Ecol. Indic.* **2021**, *121*, 106988. [CrossRef]
57. Satta, A.; Venturini, S.; Puddu, M.; Firth, J.; Lafitte, A. Strengthening the Knowledge Base on Regional Climate Variability and Change: Application of a Multi-Scale Coastal Risk Index at Regional and Local Scale in the Mediterranean. Plan Bleu Technical Report. September 2015. Available online: https://planbleu.org/wp-content/uploads/2020/04/multi-scale_coastal_risk_index_compressed.pdf (accessed on 10 January 2021).
58. Calil, J.; Reguero, B.G.; Zamora, A.R.; Losada, I.J.; Méndez, F.J. Comparative Coastal Risk Index (CCRI): A multidisciplinary risk index for Latin America and the Caribbean. *PLoS ONE* **2017**, *12*, e0187011. [CrossRef]
59. Hawchar, L.; Naughton, O.; Nolan, P.; Stewart, M.G.; Ryan, P.C. A GIS-based framework for high-level climate change risk assessment of critical infrastructure. *Clim. Risk Manag.* **2020**, *29*, 100235. [CrossRef]
60. Kantamaneni, K. Coastal infrastructure vulnerability: An integrated assessment model. *Nat. Hazards* **2016**, *84*, 139–154. [CrossRef]
61. Debortoli, N.S.; Clark, D.G.; Ford, J.D.; Sayles, J.S.; Diaconescu, E.P. An integrative climate change vulnerability index for Arctic aviation and marine transportation. *Nat. Commun.* **2019**, *10*, 2596. [CrossRef]
62. Innes, C.; Anand, M.; Bauch, C. The impact of human-environment interactions on the stability of forest-grassland mosaic ecosystems. *Sci. Rep.* **2013**, *2689*, 3. [CrossRef]
63. Gaur, A.; Simonovic, S.P. Towards Reducing Climate Change Impact Assessment Process Uncertainty. *Environ. Process.* **2015**, *2*, 275–290. [CrossRef]
64. Tran, L.T.; O'Neill, R.V.; Smith, E.R. Determine the most influencing stressors and the most susceptible resources for environmental integrated assessment. *Ecol Model.* **2009**, *220*, 2335–2340. [CrossRef]
65. Hellenic Cadastre Office. *Digital Elevation Model 5x5m*; Hellenic Cadastre Office: Athens, Greece, 2021.
66. Hellenic Centre for Marine Research. 2022. Available online: https://poseidon.hcmr.gr/ (accessed on 10 December 2022).
67. Hochman, A.; Marra, F.; Messori, G.; Pinto, J.G.; Raveh-Rubin, S.; Yosef, Y.; Zittis, G. Extreme weather and societal impacts in the eastern Mediterranean. *Earth Syst. Dyn.* **2022**, *13*, 749–777. [CrossRef]
68. Ministry of Environment and Energy (YPEN). Preliminary Flood Risk Assessment. 2012. Available online: https://floods.ypeka.gr/egyFloods/prokatarktiki_axiologisi/GR_PFRA_REPORT_V2_7.6.2013.pdf (accessed on 1 September 2023).
69. Greek Institute of Geology and Mineral Exploration (GIGME). Online Map, Data. Available online: https://gaia.igme.gr/portal/home/ (accessed on 21 July 2022).
70. Tsimplis, M.N. Tidal Oscillations in the Aegean and Ionian Seas. *Estuar. Coast. Shelf Sci.* **1994**, *39*, 201–208. [CrossRef]
71. Vousdoukas, M.I.; Mentaschi, L.; Voukouvalas, E.; Verlaan, M.; Feyen, L. Extreme sea levels on the rise along Europe's coasts. *Earth's Future* **2017**, *5*, 304–323. [CrossRef]
72. Soukissian, T.; Hatzinaki, M.; Korres, G.; Papadopoulos, A.; Kallos, G.; Anadranistakis, E. *Wind and Wave Atlas of the Hellenic Seas*; Hellenic Centre for Marine Research Publication: Heraklion, Greece, 2007; 300p, ISBN 978-960-86651-9-4.
73. Marcos, M.; Tsimplis, M.N.; Shaw, A.G.P. Sea level extremes in southern Europe. *J. Geophys. Res.* **2009**, *114*, C01007. [CrossRef]
74. Copernicus Land Monitoring Service (CLMS); European Environment Agency (EEA). CORINE Land Cover. Available online: https://land.copernicus.eu/ (accessed on 15 March 2022).
75. Hellenic Statistical Authority (ELSTAT) Population-Housing Census. Available online: https://www.statistics.gr/2011-census-pop-hous (accessed on 10 August 2021).
76. Schiavina, M.; Freire, S.; MacManus, K. *GHS-POP R2022A—GHS Population Grid Multitemporal (1975–2030)*; European Commission, Joint Research Centre (JRC): Brussels, Belgium, 2022. [CrossRef]
77. OpenStreetMap Contributors. OpenStreetMap Foundation: Cambridge, UK; 2021. Available online: https://openstreetmap.org (accessed on 1 February 2022).
78. Open Data Greece. Available online: https://geodata.gov.gr/ (accessed on 4 March 2023).
79. Ministry of Environment and Energy (YPEN). National Energy and Climate Plan (NECP). 2016. Available online: https://ypen.gov.gr/wp-content/uploads/legacy/Files/Klimatiki%20Allagi/Prosarmogi/20160406_ESPKA_teliko.pdf (accessed on 2 December 2022).
80. Ministry of Environment and Energy (YPEN). Online Geospatial Information Portal. 2021. Available online: http://mapsportal.ypen.gr/ (accessed on 1 August 2022).
81. Adens, S.A.; Regional Adaptation Plan to Climate Change. Attica Region. 2021. Available online: https://www.patt.gov.gr/koinonia/perivallon/pespka/pespka_ye1/ (accessed on 20 December 2021).
82. Saaty, R.W. The analytic hierarchy process—What it is and how it is used. *Math. Model.* **1987**, *9*, 161–176. [CrossRef]
83. Saaty, T.L. Making and validating complex decisions with the AHP/ANP. *J. Syst. Sci. Syst. Eng.* **2005**, *14*, 1–36. [CrossRef]
84. Mau-Crimmins, T.; de Steiguer, J.E.; Dennis, D. AHP as a means for improving public participation: A pre–post experiment with university students. *For. Policy Econ.* **2005**, *7*, 501–514. [CrossRef]
85. Lepetu, J.P. The use of analytic hierarchy process (AHP) for stakeholder preference analysis: A case study from Kasane Forest Reserve, Botswana. *J. Soil Sci. Environ. Manag.* **2012**, *3*, 237–251.

86. Roukounis, C.N.; Karambas, T.; Aretoulis, G. Multicriteria Decision Making for Water Aerodromes Allocation in Greece. In Proceedings of the 7th Transport Research Arena TRA 2018, Vienna, Austria, 16–19 April 2018.
87. Roukounis, C.N.; Aretoulis, G.; Karambas, T. A Combination of PROMETHEE and Goal Programming Methods for the Evaluation of Water Airport Connections. *Int. J. Decis. Support Syst. Technol.* **2020**, *12*, 50–66. [CrossRef]
88. Vandarakis, D.; Panagiotopoulos, I.P.; Loukaidi, V.; Hatiris, G.-A.; Drakopoulou, P.; Kikaki, A.; Gad, F.-K.; Petrakis, S.; Malliouri, D.I.; Chatzinaki, M.; et al. Assessment of the Coastal Vulnerability to the Ongoing Sea Level Rise for the Exquisite Rhodes Island (SE Aegean Sea, Greece). *Water* **2021**, *13*, 2169. [CrossRef]
89. Goepel, K.D. Implementation of an Online Software Tool for the Analytic Hierarchy Process (AHP-OS). *Int. J. the Anal. Hierarchy Process* **2018**, *10*, 469–487. [CrossRef]
90. Larsen, R. *Elementary Linear Algebra*; Cengage Learning: Boston, MA, USA, 2013.
91. Alonso, J.A.; Lamata, T. Consistency in the Analytic Hierarchy Process: A new approach. *Int. J. Uncertain. Fuzziness Knowl.-Based Syst.* **2006**, *14*, 445–459. [CrossRef]
92. Rizzo, A.; Vandelli, V.; Buhagiar, G.; Micallef, A.S.; Soldati, M. Coastal Vulnerability Assessment along the North-Eastern Sector of Gozo Island (Malta, Mediterranean Sea). *Water* **2020**, *12*, 1405. [CrossRef]
93. Šimac, Z.; Lončar, N.; Faivre, S. Overview of Coastal Vulnerability Indices with Reference to Physical Characteristics of the Croatian Coast of Istria. *Hydrology* **2023**, *10*, 14. [CrossRef]