A COMPARATIVE ANALYSIS OF THE YACHT MARINAS' VULNERABILITY TO SEA LEVEL RISE BY USING AN INTEGRATED VULNERABILITY INDEX

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Abstract
This study aims to analyse the vulnerability of yacht marinas in Bodrum to sea level rise (SLR) compound impacts using seven spatial physical and eight socio-economic parameters. A new integrated marina vulnerability index (IMVI) was developed as a composition of the physical coastal vulnerability index (PCVI) and non-physical marina vulnerability index (MVI). To determine vulnerability values, coastal vulnerability index approach was used. A geo-database was created using spatial and tabular data collected from different data source. The PCVI parameters were converted to a 1-5 scale by using geographic information systems analysis (GIS) (subset, buffer, slope, reclass, map algebra), and PCVI values were calculated. The MVI parameters were converted to a 1-5 scale by using the natural break classification method, and MVI values were calculated. Both PCVI and MVI results were presented as maps and tabular values using a scale of 1 (Very Low Vulnerability) to 5 (Very High Vulnerability). The results provide comparative vulnerability analyses of seven marinas, using the PCVI and MVI, individually and, their combination with IMVI. The findings showed that the physical vulnerability of marinas was generally higher than their socio-economic vulnerability. While the physically very high vulnerability marinas are Turgutreis, Yalikavak and Ortakent, the marina with very low socio-economic vulnerability is Ortakent. According to IMVI results, Turgutreis, Yalikavak and Milta are the vulnerable marinas both physically and socio-economically. Consequently, this study potentially brings a new perspective to research on SLR-induced climate impacts not only for marinas but also for cargo ports.

1 INTRODUCTION

Climate change poses a significant risk of exacerbating coastal hazards by amplifying the frequency and severity of coastal storms, accelerating the pace of sea level rise (SLR), worsening coastal erosion processes, and inundating low-lying coastal areas (New Jersey Department of Environmental Protection, 2011). The SLR is known one of the biggest global problem of climate change that can cause environmental, social, economic challenges for coastal communities (Sierra et al., 2016; IPCC, 2022). It threatens countries with high population densities and economic activity in coastal areas (Kuleli, 2010). According to the IPCC (2022), the SLR, which is continuing and accelerating, will damage coastal ecosystems and coastal infrastructures, particularly in low-lying zones.

Infrastructure located in coastal areas as a result of socio-economic development are vulnerable to climate impacts, particularly the SLR (IPCC, 2022; Innocenti and Musco, 2023; Sierra et al., 2023). As a coastal infrastructure, yacht marinas are vulnerable to SLR-induced climate impacts such as rising coastal waters, coastal erosion, and coastal flooding due to their role in the socio-economic development, particularly for economies engine by maritime recreational activities (Kuleli and Bayazit, 2023). Vulnerability is defined as "the propensity or predisposition to be adversely affected" (IPCC, 2014). Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt (IPCC, 2014). Determining the vulnerability level of infrastructures to SLR-induced climate impacts is significant for planning and establishing adaptation strategies for coastal communities. Although there are many studies on coastal vulnerability, a few of them focused on the vulnerability of transportation infrastructures including seaports, airports etc. are limited (Sierra et al., 2016; Monioudi et al., 2018; Kantamaneni, 2016). Since seaports are located in coastal areas, they will experience impacts associated with coastal hazards due to the SLR (Becker et al., 2013; Messner et al., 2013; Sanchez-Arcilla et al., 2016; Sierra et al., 2023). Therefore, recently numerous number of studies have focused on assess seaport vulnerability to the SLR-induced climate change impacts (Messner et al., 2013; Becker et al., 2018; Christodoulou, 2019), while there is a lack of studies focusing on yacht marinas (Lazarus and Ziros, 2021). According to Lazaruz and Ziros (2021), *"Marinas, and the yachts within them, constitute hotspots of exposure to coastal hazard concentrations of high-value economic assets densely packed behind concrete breakwaters".* Yacht marinas are crucial component of maritime tourism which is a highly dynamic sector and has cumulative direct and indirect effects on coastal region's economy (Perez-Labajos and Blanco, 2006).

In previous studies four different methods were applied when evaluating vulnerability of a coastal area and infrastructures within the coastal area. These are index-based; indicator-based; GID-based decision support systems and dynamic computer models (Ramieri et al, 2011; Rani, et al., 2015; Dey and Mazumder, 2023). Previous studies on vulnerability of facilities and infrastructures such as roads, airports, seaports, fire stations, touristic assets due to SLR-induced climate impacts have assessed the vulnerability mostly based on climate projections, flood modelling, inundation risk and storm risksbased on SLR scenarios (Mase et al. 2013; Chhetri et al., 2015; Sanchez-Arcilla et al., 2016; Monioudi et al., 2018; Christodoulou et al., 2019; Izaguirre et al., 2020; Sierra et al., 2023). According to Koroglu et al. (2019), the CVI is one of the simplest and commonly used methods to assess coastal vulnerability to the SLR-induced impacts such as coastal erosion. It is also recognized as a useful tool that contribute the decision making process in adaptation and planning for climate resilient policies (Koroglu et al., 2019). Therefore, in this study, the CVI method, developed first by Gornitz (1991), then by Gornitz et al. (1994) and Thieler and Hammar-Klose (2000) was used to analyse coastal vulnerability of yacht marinas. The original CVI is composed to six physical variables, however currently studies on the assessment of coastal vulnerability have been utilized integrated approaches by modifying the CVI using non-physical (social, economic etc.) parameters in addition to the physical parameters (Mani Murali et al., 2013; Djouder and Boutiba, 2017; Behera, 2019; Koroglu et al., 2019; Charuka et al., 2023; Dey and Mazumder, 2023). There is a need for integrated index-based vulnerability assessment which include both physical and socio-economic characteristics of coastal areas to assess important infrastructures.

In this study, the objective is to analyse the vulnerability of yacht marinas to SLR-induced climate impacts, in a comparative manner. To do this, an integrated marina vulnerability index (IMVI) was developed by combining physical coastal vulnerability index (PCVI) including seven physical parameters and non-physical marina vulnerability index (MVI), including eight non-physical (socio-economic) marina parameters. Seven marinas, Yalikavak, Turgutreis, Ortakent, Bitez, Gumbet, Milta and Bodrum Kale were analysed in the study area, Bodrum. To determine vulnerability values, the CVI methodology, developed by Gornitz (1991), was utilized. A geo-database was created using spatial and tabular data collected from different data source. The PCVI parameters, which are geology, coastal slope, relief, relative sea level change, shoreline erosion/accretion, mean tide range, mean wave height were converted to a 1-5 scale by using geographic information systems analysis (subset, buffer, slope, reclass, map algebra), and PCVI values were calculated. The MVI parameters which are (berthing capacity, berthing length, service area (land), gross mooring capacity, berthing/mooring fees, berthing income, number of employees, and number of services) were converted to a 1-5 scale by using the natural break classification method, and MVI values were calculated. Results were presented as maps and tabular values using a scale of 1 (Very Low Vulnerability) to 5 (Very High Vulnerability). According to the results, each marina was evaluated comparative to the others based on PCVI, MVI and IMVI values. In this study, for the first time an integrated coastal vulnerability index specific to marinas has been developed and applied for a marina-dense coastal area. Marina-specified socio-economic parameters have been used for marina vulnerability assessment, in addition to the physical CVI assessment. As a benchmarking tool, the IMVI can be utilized when prioritization of strategies and funds for adaptation solutions to SLR due to climate change impacts for marinas and other ports.

2 STUDY AREA

The study area encompasses seven yacht marinas in Bodrum which is a Peninsula in south-western the Aegean Sea (Fig. 1). Bodrum is a coastal district as a part of Aegean Region of Turkiye, with 125 km of coastline, covers an area of 689 km^2. It is characterized by its unique geographical features, including its coastline, natural bays, and historical significance, attracting both local and international visitors. The resident population is 198,335 in 2023 (TURKSTAT, 2023), however, the number of visitors reach 1 million stays in the tourist season (from May to December), and might be 2 million visitors. Its economy is based on tourism and maritime tourism forms the basis of its recreational resources.

Fig. 1 Study area map, the Bodrum Peninsula and seven yacht marinas.

As an Aegean coastal destination, Bodrum is a yacht marina-dense area. Turgutreis, Yalikavak, and Milta are five-anchor-awarded marinas, operated by the private sector. Bodrum Kale, Gumbet, Bitez, and Ortakent have different sizes and functions, operated by the Municipality. Turgutreis, situated on the western coast of the peninsula, is one of the largest marinas in the region, catering to a diverse range of vessels and offering various amenities and services. Yalikavak, located to the north, is another prominent marina known for its modern infrastructure and high-end facilities. Milta and Bodrum Kale marinas, situated closer to the town center of Bodrum, attract both local boaters and international visitors with their convenient locations and historical surroundings. Gumbet and Bitez marinas, positioned in relatively sheltered bays, cater to smaller vessels and provide a more tranquil setting compared to the larger marinas. Ortakent marina, located towards the eastern end of the peninsula, offers a more secluded experience with its picturesque surroundings and smaller scale.

Bodrum provides a wide range of services and facilities for maritime and coastal tourism activities in the region. Apart from those marinas studied in this paper, there are several small piers and docking areas for small crafts and fishing boats, a cruise port, a shipyard complex covering more than 50 boats and yacht producer and there are marine suppliers in the area, contributing significantly to the local economy. In addition, the study area has geographic and economic importance for the Mediterranean region where the majority of the World’s yacht activity takes place (EC 2016(a); EC 2016(b)). It meets a significant demand not only for regional yachting activities but also at the international level.

Despite its importance in the yachting and cruise industry, seaports and marinas in Bodrum Peninsula is physically vulnerable to climate change impacts, particularly the SLR (Kuleli and Bayazit, 2023). The vulnerability of yacht marinas to SLR is of significant concern due to their proximity to the coast and the potential impacts on infrastructure, operations, and the local economy. So, Bodrum with its diverse array of marinas, and socio-economic importance makes it an ideal study area for assessing not only the physical but also the socio-economic vulnerability of marinas to the SLR.

3 MATERIAL AND METHODS

In this study an integrated marina vulnerability index methodology was used based on coastal vulnerability index (CVI) approach, to determine vulnerability level of yacht marinas to SLR-induced climate impacts. In this section, the data, methods and techniques used for the required analyses to meet the aim of this study were explained. The workflow of the methodology used in this study shown as in the Figure 2.

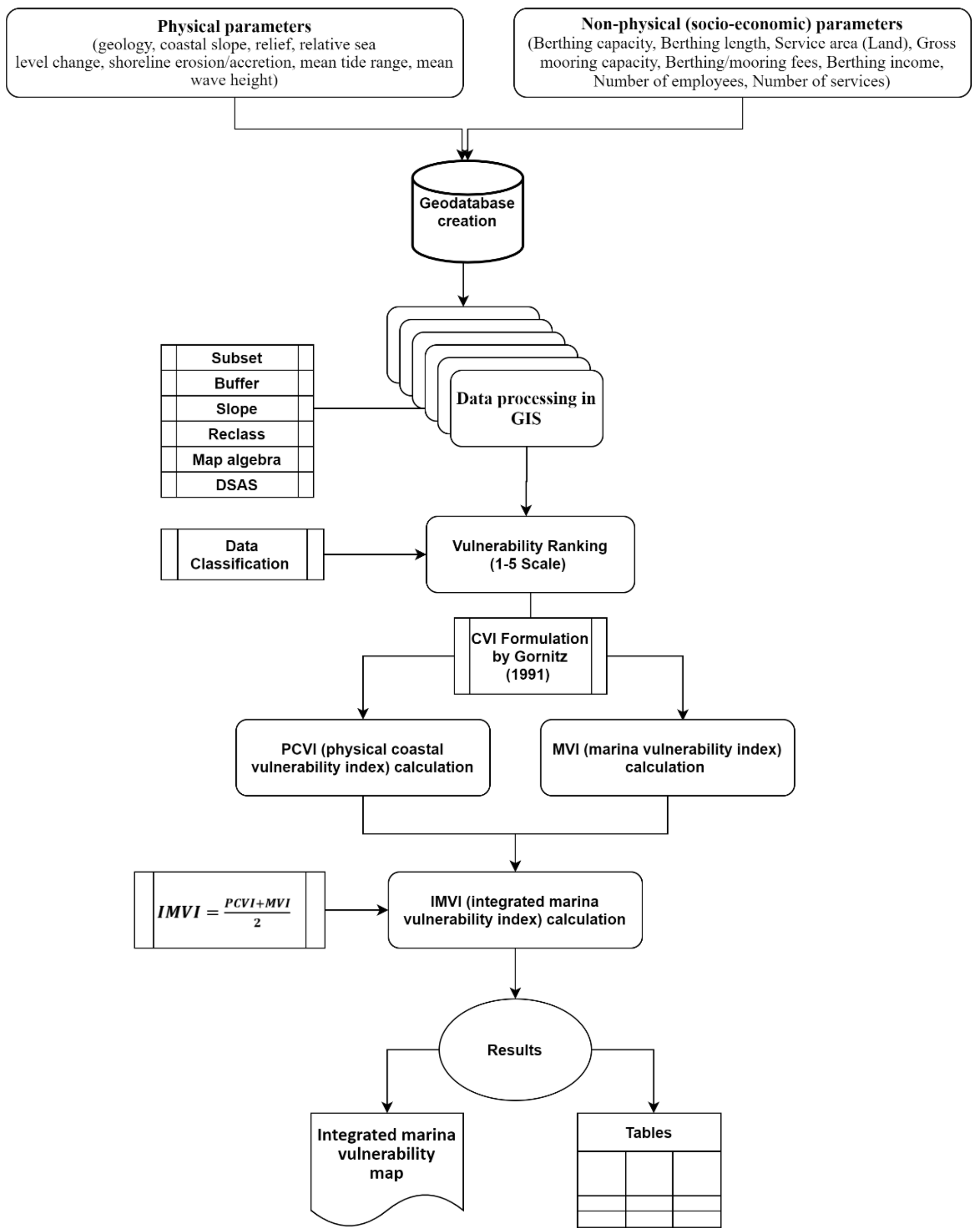

Fig. 2 Workflow of the study methodology.

The data used for the analyses of marina vulnerability are divided into two groups, physical (spatial) and non-physical (socioeconomic). As shown in Table 1, seven physical and eight socio-economic parameters were obtained from different data sources and used in the analyses.

	Parameters	Data Source
Physical parameters	Geology	Processing and digitising from Mineral Research and Exploration General Directorate (MTA) GeoScience Map Viewer
	Coastal Slope	Processing from Shuttle Radar Topography Mission (SRTM) dataset
	Relief	From SRTM (NASA JPL, 2013; SRTM, 2018)
	Relative sea level change	3.3±1.1 mm/yr from Kuleli (2010), Caldwell et al. (2015), Zlotnicki et al. (2019), CMS (2021), TUDES (2022), SLE (2022)
	Shoreline erosion/accretion	-1 - +1 m/yr from Landsat 8 images from USGS (2022)
	Mean tide range	0.2-0.3 m from TUDES (2022), Sayre et al. (2018, 2021), ECU (2022)
	Mean wave height	1.1-2.0 m from Özhan & Abdalla (2002), Sayre et al. (2018, 2021), CMS (2022), ECU (2022)
Non-physical parameters	Berthing capacity	Marina Survey
	Berthing length	Marina Survey and Google Earth
	Service area (Land)	Marina Survey and Google Earth
	Gross mooring capacity	Marina Survey
	Berthing/mooring fees	Marina Survey
	Berthing income	Marina Survey
	Number of employees	Marina Survey
	Number of services	Marina Survey and The Yacht Harbour Association (TYHA)

Table 1 Data table.

3.1. Physical parameters

Seven physical parameters including geology, coastal slope, relief, relative sea level change, shoreline erosion/accretion, mean tide range, mean wave height were used to determine the PCVI and to calculate the PCVI values, which indicate physical vulnerability level of yacht marinas to SLR-induced climate impacts. To calculate the PCVI values, the data were extracted by the grids of 30x30 meter in size, and 1 km inland from the coastline was considered.

Geology

The geology variable identifies generalized rock type and is present for all coastal grid cells within the database. Geological data was extracted from Geoscience Map Viewer presented at the Mineral Research and Exploration of the Directorate General (MTA) and Akbas et al. (2011).

Coastal slope

The coastal slope is one of the determinant variables that significantly impacts vulnerability to periodic flooding, SLR, and erosion in a coastal area (Rani et al., 2015). Therefore, measuring and assessing the coastal slope is important in assessing vulnerability which is determined by dividing the amount of elevation change by the amount of horizontal distance covered, then multiplying the result by 100. Slope percent was calculated and reclassified, using the Space Shuttle Radar Topography (SRTM) data set (1 arc-second, 30 meters) (SRTM, 2018).

Relief

Gornitz (1991) stated that the hazard decreases progressively for higher average elevations. Relief is the variation in elevation or height of the land surface along coastal areas. Higher relief values often indicate areas that are more resilient to coastal erosion and inundation, as they may feature elevated landforms that provide natural protection against wave action, storm surges, and SLR. Relief was calculated and reclassified, using the Space Shuttle Radar Topography (SRTM) data set (SRTM, 2018) (1 arc-second, 30 meters) (USGS, 2020).

Relative sea level change

Relative sea level change is a variable that is determined based on the change in annual mean water elevation over time (Emery and Aubrey, 1991). It is measured using water level monitoring stations located along a coasts, usually placed on piers, measure the sea level relative to a nearby geodetic benchmark. The relative sea level change data provides historical records (such as last 50-100 years). In this study, the data was obtained the National Sea Level Monitoring System of Turkiye (TUDES, 2023)

Shoreline erosion/accretion

To assess coastal erosion and accretion, End Point Rate (EPR) values were calculated using Sentinel-2 images (10m resolution) from ESA (2023). Images from August 30, 2023 and August 20, 2018, along with a 2014 shoreline from Google Earth, were analysed with Digital Shoreline Analysis System (DSAS) software. This approach reveals erosion and accretion rates in meters/year. Shorelines were analysed for erosion and accretion using transects (500m long, 250m apart) generated by DSAS software. This free tool calculates shoreline dynamics based on historical data (Thieler et al., 2005; Himmelstoss, 2021). The EPR which divides shoreline movement by the time between data points, was chosen for its simplicity and data efficiency (Himmelstoss, 2021).

Mean tide range

Mean tide range simply means the difference in height between high and low tides. It closely connected to the risks of both permanent and occasional flooding along coastlines. A larger tidal range often means stronger tidal currents, which can lead to more significant erosion and sediment movement along the coastline. Coastlines with high tidal ranges, typically exceeding 4 meters, are more prone to vulnerability compared to those with smaller tidal ranges (Gornitz, 1991). According to Shaw et al., (1998) and Gornitz (1991) if a coastal area has a high tidal range, it is considered as a highly vulnerable area. In this study, the mean tide range was obtained from National Sea Level Monitoring System of Türkiye, shortly TUDES (TUDES, 2023).

Mean wave height

Mean wave height is an indicator of wave energy and it plays a pivotal role in driving coastal sediment transport, erosion/accretion rate. It is a key factor in understanding coastal dynamics (Chakaruka et al., 2023). Mean wave height data within the research area was gathered from diverse sources, such as Özhan et al. (2002), CMS (2022), and Sayre et al. (2018, 2021).

3.2. Non-physical parameters

Eight non-physical parameters including berthing capacity, berthing length, service area (land), gross mooring capacity, berthing/mooring fees, berthing income, number of employees, and number of services were used to determine the MVI and to calculate the MVI values, which indicate socio-economic vulnerability level of yacht marinas to SLR-induced climate impacts. To calculate the MVI values, the data of the following parameters were collected from primary and secondary sources. Primarily sources are marina managers and authorities in the study area. A simple Word document, which includes a data table with blanks was sent to the marina managers, by e-mail. The necessary data was collected from seven marinas through both e-mail, telephone, and official correspondence. Also, cross check was applied for service area on land, gross mooring capacity and berthing length using Google Earth Pro's distance and space calculate tool. Secondary sources which are marina websites and The Yacht Harbour Association (TYHA) were utilized for applying cross-checks for the data related to the number of services provided by each marina. Finally, all collected data and information were added to the geodatabase which was created before for the computation of the operations of PCVI in GIS.

Berthing capacity

This parameter refers to the maximum number of boats or yachts that a marina can accommodate theoretically at any given time, measured in number of yachts (n.). A higher berthing capacity means the marina can generate more revenue by accommodating more vessels. It also indicates the level of demand for boating services in the region. Regions with marinas with large berthing capacities can attract more visitors and yachting enthusiasts, contributing to local economies through increased tourism spending and related services.

Berthing length

It represents the linear distance along the waterfront where boats and yachts can be safely moored, measured in meters (m.). A longer berthing length indicates a greater capacity to accommodate vessels of various sizes and types. It is a critical factor in determining the marina's capability to host larger boats and cater to diverse boating needs. Moreover, a sufficient berthing length enhances the marina's attractiveness to boat owners and visitors, supporting economic activities such as tourism, recreation, and marine services. Additionally, an extensive berthing length signifies potential for increased revenue generation through berthing fees and related services, contributing to the overall economic vitality of the marina and its surrounding region.

Service area (Land)

This represents the land allocated for marina operations, including amenities such as restaurants, repair shops, fuel stations, retail outlets, and recreational areas, measured in square meters. The size of this area is critical for offering diverse services, enhancing user experience, and attracting visitors. In regions with high demand for commercial land, a larger service area provides a competitive edge. It allows for the development of upscale amenities, attracting high-end clientele and stimulating economic activity.

Gross mooring capacity

This represents the spatial sea area allocated for marina activities, including manoeuvring, berthing, and anchoring areas, measured in square meters. Similar to the concept of the service area on land, it determines the available space for boats and yachts to dock safely at sea within the marina. It's crucial for accommodating boats and yachts safely at sea, ensuring smooth operations, and enhancing safety. A larger capacity attracts more boat owners and visitors, supporting maritime activities and stimulating economic growth in the region.

Berthing/mooring fees

These are the charges imposed on boat owners for utilizing berthing or mooring facilities at the marina. Revenue generated from berthing/mooring fees constitutes a significant portion of the marina's income. The fee structure can influence the marina's competitiveness and attractiveness to boat owners, impacting its overall financial performance. Additionally, lower fees may attract more boaters and stimulate economic activity in the region by encouraging increased boat traffic and visitor spending. Price policies may vary from marina to marina depending on factors such as boat size, boat type, length of stay and service quality. For this reason, in order to obtain standard data that can be measured and compared, the mooring fee considered an annual fee was requested from marinas for an area of 30 m^2 sea zone.

Berthing income

This represents the total income generated by the marina from berthing fees charged to boat owners. Berthing income is a crucial revenue stream for marina operators, supporting operational expenses, maintenance costs, and investment in facility upgrades. A steady and growing berthing income contributes to the financial sustainability of the marina and its ability to withstand economic fluctuations. Moreover, it indirectly benefits the regional economy by supporting jobs, infrastructure development, and tourism promotion efforts. Marina income was determined based on the calculation made by the authors, not on data received directly from the marinas. This parameter is obtained by multiplying the sea area allocated by the marina management for berthing and mooring uses for boats and yachts by the annual mooring fee.

Number of employees

This refers to the total workforce employed by the marina, including administrative staff, maintenance personnel, security guards, and service providers. The number of employees reflects the marina's operational scale and its contribution to local employment opportunities. A higher number of employees indicate a larger workforce supporting marina operations and servicing the needs of boat owners and visitors. Additionally, marinas can serve as significant employers in coastal communities, stimulating economic growth and enhancing livelihoods. The number of employees in the marina may vary depending on the intensity of use in summer and winter seasons. In this study, the total number of full-time workers throughout the year was considered.

Number of services

This represents the variety and quality of services offered by the marina to boat owners and visitors, measured by numbers (n.). The quality of services is out of the scope. Services may include boat maintenance and repair, bunkering, provisioning, concierge services, recreational activities, and hospitality amenities. A diverse range of services enhances the marina's appeal to customers and contributes to a positive user experience. It also promotes local economic development by creating opportunities for service providers and entrepreneurs to establish businesses within or around the marina, thereby enriching the region's tourism and hospitality as well as ship repairing and maintenance sectors.

Once the data collected, then a geodatabase was created that includes all data collected by using a GIS software. The physical data have spatial feature that were stored, prepared, processed, and reclassified in GIS platform, while socio-economic marina data are tabular so prepared and processed in a spreadsheet then transferred to the GIS platform. The GIS methods and tools including subset, buffer, slope, reclass, map algebra and DSAS were used for the analyses. Analyses were carried out on boundaries covered along the coastline with a 1 km buffer zone from the shoreline.

The index values were calculated based on the CVI formulation which will be explained in the next paragraphs. Parameter index values from 1 to 5 were determined using data classification methods such as equal interval and natural breaks according to the nature of the data and analysis. The physical parameters were classified from 1 to 5 using five equal interval breaks. Parameter index values show its vulnerability levels (1: Very Low, 2: Low, 3: Moderate, 4: High, 5: Very High). The data of non-physical parameters were classified using Jenks optimization (natural breaks), from 1 to 5 by dividing them into five intervals. Natural breaks is statistical data classification method which divide data into classes using an algorithm which calculates groupings of data values based on the data distribution (Jenks, 1967). All data classifications were performed in the GIS platform. Table 2 shows the unit and the intervals that match the vulnerability level of each parameter a marina has. Ranking or scoring criteria of physical parameters were obtained from Gornitz (1990) and Gornitz (1991). Except geology parameter, the physical parameters from the table were obtained from previous study of the authors (Kuleli and Bayazit, 2023).

	Parameters	Unit	Very Low (1)	Low (2)	Moderate (3)	High (4)	Very High (5)
Physical parameters	Geology	-	Plutonic, volcanic, high-medium grade metamorphics	Low grade metamorphics, sand-stones and conglomerates, metamorphics rocks	Most sedimentary rocks	Coarse, poorly sorted, unconsolidated sediments	Fine, consolidated sediment, ice
	Coastal Slope	%	>12	8-12	4-8	2-4	<2
	Relief	m	>30	21-30	11-20	6-10	0-5
	Relative sea level change	mm/yr	<-1	-1.0-0.9	1.0-2.0	2.1-4.0	>4.0
	Shoreline erosion/accretion	m/yr	>2.0	1.0-2.0	-1 - +1	-1.1 - -2.0	<-2
	Mean tide range	m	<1.0	1.0-1.9	2.0-4.0	4.1-6.0	>6.0
	Mean wave height	m	<1.1	1.1-2.0	2.0-2.25	2.25-2.60	>2.60
Non- physical parameters	Berthing capacity	n.	<= 35	35.000001-200	200.000001-260	260.000001-425	425.000001-620
	Berthing length	m	<= 208	208.000001-1,264	1,264.000001-1,566	1,566.000001-2,611	2,611.000001-4,030
	Service area (Land)	Sq.m.	0,000000	n/a	0,000001-9,750	9,750-10,000	10,000-25,000
	Gross mooring capacity	Sqm.	<= 3,730	3,730.000001-34,026	34,026.000001-51,294	51,294.000001-75,000	75,000.000001-170,598
	Berthing/mooring fees	€ per 30 sqm	<= 11	11.000001-14	14.000001-45	45.000001-79	79.00001-255
	Berthing income	€	<= 294,670	294,670.000001-741,037	741,037.000001-1,020,780	1,020,780.000001-7,676,910	7,676,910.000001-25,836,200
	Number of employees	n.	5-7	7.000001-10	10.000001-31	31.000001-76	76.000001-102
	Number of services	n	<= 3	3.000001-4	4.000001-5	5.000001-28	28.00001-33

(% per cent; mm/yr; milimeter/year; m/yr; meter/year; m. meter; Sqm. Square meter; €: euro; n. number)

Table 2 Vulnerability levels in 1-5 scale and ranges corresponding to parameter values.

3.3. Calculation of integrated marina vulnerability index (IMVI)

The calculation procedure of the IMVI provides a new index based marina vulnerability assessment model, modified from the CVI. It is a composition of as a result of integration of both physical and non-physical (socio-economic) parameters. The CVI approach was utilized because it is recognized the most simplistic and commonly used methodology in coastal vulnerability researches (Koroglu et al., 2019). Most of the vulnerability assessments were done by adapting Gornitz (1990)'s methodology (Rani et al., 2015). Several CVI modifications by integrating the geophysical and socioeconomic parameters in order to obtain a multi-scale vulnerability assessment have been studied for coastal areas (Nageswara Rao et al., 2009; Mani Muralli et al., 2013; Rani et al., 2015).

The IMVI values are obtained as a result of the arithmetic mean of the physical coastal vulnerability index (PCVI), and non-physical marina vulnerability index (MVI). Therefore, before calculating the IMVI values the PCVI and MVI were calculated, separately, using the CVI method, and then combined.

Formulation of the PMVI and MVI are shown in the Equation 1 and 2.

$$PCVI = \sqrt{\frac{p_1 \times p_2 \times p_3 \times p_4 \times p_5 \times p_6 \times p_7}{7}} \quad \text{(Equation 1)}$$

where PCVI is the physical vulnerability index value, each p denotes parameter value obtained from relevant scale (1-5) give in Table 2;

p_1=-Geology
p_2= Coastal slope
p_3= Relief
p_4= Relative sea level change
p_5= Shoreline erosion / accretion
p_6= Mean tide range
p_7= Mean wave height

$$MVI = \sqrt{\frac{m_1 \times m_2 \times m_3 \times m_4 \times m_5 \times m_6 \times m_7 \times m_8}{7}} \quad \text{(Equation 2)}$$

where MVI is the marina vulnerability index value, each m denotes parameter value obtained from relevant scale (1-5) give in Table 2;

m_1= Berthing capacity
m_2= Berthing lenght
m_3= Service area (Land)
m_4= Gross mooring capacity
m_5= Berthing/mooring fees
m_6= Berthing income
m_7= Number of employees
m_8= Number of services

Next step is to calculate the (IMVI). It is calculated using arithmetic mean of the PCVI and MVI shown as below:

$$IMVI = \frac{PCVI + MVI}{2} \quad \text{(Equation 3)}$$

The IMVI values determined using the Equation 3 were also classified in GIS platform, from 1 to 5 using five equal interval breaks. The result of the IMVI indicate the vulnerability level of the marina according to both physical and socioeconomic variables to SLR-induced climate change impacts. The findings of the PCVI, MVI and ultimately IMVI results were used to make a comparative assessment which are discussed in the results and discussion section.

4 RESULTS AND DISCUSSION

In this study, we assessed the vulnerability level of each marinas comparatively to climate change impacts derived from SLR. As highlighted in the methodology section, IMVI model, was developed and applied to seven marinas located in Bodrum (Turkiye). Marinas in the research area are Yalikavak, Turgutreis, Ortakent, Bitez, Gumbet, Milta and Bodrum Kale. The IMVI values were determined using the PCV) including seven physical parameters (geology, coastal slope, relief, relative sea level change, shoreline erosion/accretion, mean tide range, mean wave height) and the MVI, including eight non-physical (socio-economic) marina-specific parameters (berthing capacity, berthing length, service area (land), gross mooring capacity, berthing/mooring fees, berthing income, number of employees, number of services). As a result, the relative vulnerability levels of each marina were detected according the values of the PCVI, MVI and their combination which is IMVI. In this section, the results obtained from the application of the IMVI methodology (see Fig. 2) were presented.

Physical dynamics are the geo-physical characteristics of their location, while the non-physical parameters characterize the market economic value and regional importance of each marina. Non-physical parameters were used to calculate the MVI values, which indicate the socio-economic vulnerability of marinas. Table 3 shows the data of non-physical parameters which was gathered from different sources (Table 1).

	Berthing capacity	Berthing length	Service area	Gross mooring capacity	Berthing/ mooring fees	Berthing income	N. of employees	N. of service
Bitez	260	1264	0	34026	30	1020780	10	3
Bodrum Kale	230	1566	0	67367	11	741037	31	5
Gumbet	200	1027	0	51294	14	718116	7	4
Milta	425	2611	25000	75000	255	19125000	102	28
Ortakent	35	208	0	3730	79	294670	5	3
Turgutreis	532	3468	9750	129181	200	25836200	76	31
Yalikavak	620	4030	10000	170598	45	7676910	95	33
Parameter units are as illustrated in Table 2.								

Table 3 Non-physical (socio-economic) parameter values corresponding by each marina.

Using the findings shown in Table 3, vulnerability levels in socioeconomic terms were assigned on a 1-5 scale ranking corresponding to the range within which these values meet (See Table 2). Table 4 shows the results of parameter index values that contribute to the MVI values.

	Berthing capacity	Berthing length	Service area	Gross mooring capacity	Berthing/ mooring fees	Berthing income	N. of employees	N. of service
Bitez	3	2	1	2	3	3	2	1
Bodrum Kale	3	3	1	4	1	2	3	3
Gumbet	2	2	1	3	2	2	1	2
Milta	4	4	5	4	5	5	5	4
Ortakent	1	1	1	1	4	1	1	1
Turgutreis	5	5	3	5	5	5	4	5
Yalikavak	5	5	4	5	3	4	5	5
Parameter index values showed levels of vulnerability which are 1: Very low, 2: low; 3: moderate; 4: high; 5: very high corresponding to the relevant ranges as illustrated in Table 2.								

Table 4 Parameter index values of the MVI in 1-5 scale.

The results in Table 4 are non-physical parameter index values, ranked from 1 to 5 which were determined according to the ranges (see table 2) corresponding to data in Table 3. The first column of the Table 4 shows the name of marinas. MVI was calculated using the parameter index values shown in the row corresponding to the marina. However, the results presented in Table 4 can also provide information about the relative status of each marina with respect to a parameter. For example, Ortakent is a small-scale marina that generates low income despite its high mooring fees. On the other hand, Turgutreis is relatively one of the most valuable marinas in the region according to socio-economic parameter values. For this reason, from a socio-economic perspective, Turgutreis can be considered a much more vulnerable marina than Ortakent if adequate precautions are not taken. In previous studies that conducted socio-economic vulnerability index for a coastal area or infrastructure, it was accepted that as the capacity and number of coastal infrastructures and their criticality level for a coastal region increase, the level of social vulnerability will also increase (Cutter et al., 2003; Mahapatra et al., 2015; Tano et al., 2018). In this study, similar logic was used when determining parameter ranges and corresponding vulnerability ranks. If a marina's income, yacht capacity or number of services provided are relatively higher than others, its socio-economic vulnerability is also high.

The results showed that the location of the marinas and the areas in their immediate surroundings had high and very high vulnerability in terms of seven physical parameters. Particularly the slope and elevation results, it was seen that the marina areas are evaluated as flat or low plains. Ortakent, Turgutreis and Yalıkavak are the marinas located in the lowest sloping areas while Gumbet and Bitez have highest elevation and slope. The slope and elevation of coastal land are considered one of the most influential factors determining vulnerability to SLR-induced climate change impacts, and exposure to hazards such as inundation, and coastal flooding (Dawson et al. 2009; Kaliraj and Chandrasekar 2012; Minar et al. 2013; Kuleli and Bayazit, 2023). According to the geology findings, it was observed that the locations where marinas are located have andesite rock type. However, Milta is the unseparated quaternary; Bitez marble; Gumbet andazite; Ortakent, Turgutreis and Yalikavak are unseparated quaternary and pyroclastic rocks; Yalıkavak has also unseparated quaternary soils. The index values of each physical parameter for each grid was calculated accordingly the scale given in Table 2. And the PCVI results were illustrated as a map (Figure 3)

Figure 3 is the result map that include both PCVI and MVI findings, obtained from the spatial analyses of parameters' index values of seven physical and eight non-physical parameters using various GIS methods (as highlighted in method section) in accordance with the Equation 1 and Equation 2. The map shows two result: First, spatial distribution of physical coastal vulnerability index (PCVI) toward the hinterland of seven marinas, according to the 1-5 scale. The boundaries cover along the coastline with a 1 km buffer zone from the shoreline. There is no standard buffer zone determination criteria in coastal research, so in line with the scope and purpose of this study, it was considered that an area of 1 km would be sufficient. Second, as point-display distribution of marina socio-economic vulnerability (MVI) of seven marinas, according to the 1-5 scale.

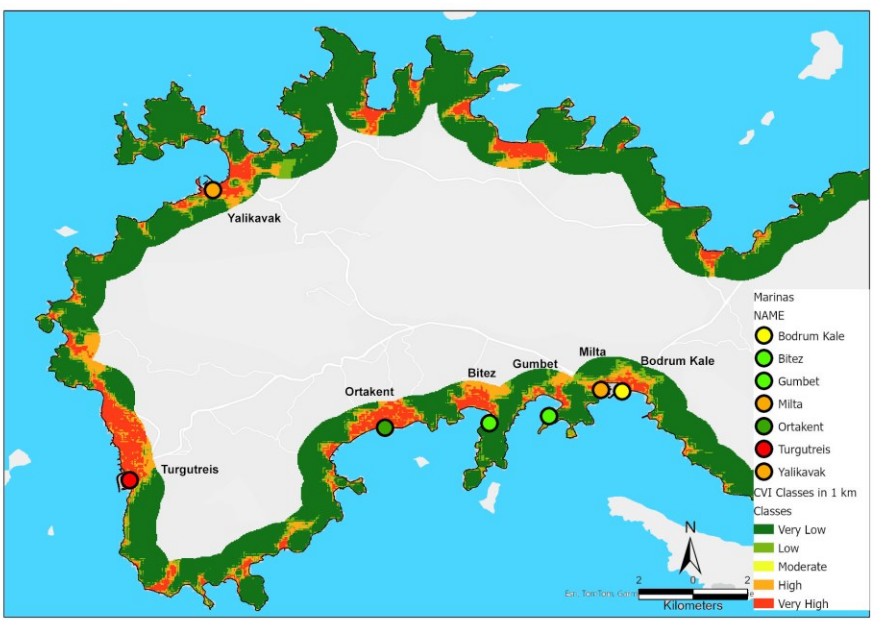

Fig. 3 Integrated marina vulnerability map, including physical coastal vulnerability (PCVI) and non-physical (socio-economic) marina vulnerability (MVI) for seven marina in the study area.

The *round icon* in Figure 3 indicates the geographical location of each marina examined. However, the *color* of the round icon indicates the colours corresponding to the MVI values of marinas determined according to eight socio-economic parameters. Each colour in the round icon indicates a different level of socio-economic vulnerability. Meaning of colors are the level of vulnerability to SLR-induced impacts, red: MVI=5, very vulnerability; orange: MVI=4; high vulnerability; yellow: MVI=3; moderate vulnerability; green: MVI=2; low vulnerability; dark green: MVI=1; very low vulnerability. Accordingly, Turgutreis is very highly vulnerable (round icon, red; MVI=5) in socio-economic terms. Yalikavak and Milta are highly vulnerable (round icon, orange; MVI=4) in socio-economic terms. Gumbet, Bitez and Ortakent are marinas with low and very low vulnerable in terms of socio-economic parameters. These results point out that marinas with relatively higher socio-economic regional and sectoral value, such as Turgutreis, Yalıkavak and Milta, are prone to be more vulnerable to the threats of SLR caused by climate change. However, the level of socio-economic vulnerability is a finding that will gain meaning with the physical vulnerability level of the area where the marina is located, according to the physical coastal dynamics.

In the study area, the PCVI value of the region examined as a buffer area of 1 km from the coastline is expressed with pixel values spread over the study area on the map (see Fig. 3). The meanings of these values on the colour scale show the physical vulnerability level of the location and surroundings of each marina. Red: PCVI=5, very vulnerability; orange: PCVI =4; high vulnerability; yellow: PCVI =3; moderate vulnerability; green: PCVI =2; low vulnerability; dark green: PCVI =1; very low vulnerability. According to the PCVI results, Turgutreis, Yalikavak and Ortakent were found to be very highly vulnerability marinas, depending on the physical coastal characteristics of their location (PCVI=5). Milta and Bodrum Kale are high vulnerability (PCVI=4). Gumbet and Bitez are vulnerable at moderate level (PCVI=3).

The higher PCVI of a marina means that the marina is located in a vulnerable coastal area that is susceptible to coastal hazards such as coastal flooding, coastal erosion, saltwater intrusion, rising coastal water, storm damage due to its rising frequency and intensity (Wang and Marsooli, 2021). Marinas that are superior in socio-economic indicators such as the facilities they offer and the income and employment they provide can be considered vulnerable in terms of exposure to these hazards that may occur (Tano et al., 2018). Rising population density, port and tourism activities increase the level of socio-economic vulnerability (Rani et al., 2015). Therefore, the high MVI values have the effect of increasing the overall vulnerability level of marinas.

Figure 3 does not include the IMVI values, because the assessment of IMVI results would be beneficial for specific cases when prioritization is a need due to limited budget or time for immediate adaptation. IMVI results show physical coastal vulnerability outcomes induced (magnified or reduced) by the level of socio-economic vulnerability. So it may also provide the degree of exposure of a marina to the SLR-induced climate change impacts of physical spatial and socio-economic factors. Table 5 shows the summary of PCVI and MVI values and then the combination of both values that determined the IMVI values.

	Coastal vulnerability in physical terms		Marina vulnerability in socioeconomic terms		Integrated marina vulnerability	
	PCVI Value	Level	MVI Value	Level	IMVI Value	Level
Bitez	3	Moderate	2	Low	1	Very low
Bodrum Kale	4	High	3	Moderate	3	Moderate
Gumbet	3	Moderate	2	Low	1	Very low
Milta	4	High	4	High	4	High
Ortakent	5	Very high	1	Very low	2	Low
Turgutreis	5	Very high	5	Very high	5	Very high
Yalikavak	5	Very high	4	High	5	Very high

Table 5 Vulnerability levels of marinas based the PCVI, MVI and IMVI values in 1-5 scale.

The results of this study, as summarized in the Figure 3 provide a comparative analysis of the level of vulnerability of marinas to climate change impacts especially the SLR, based on both their physical and non-physical dynamics. According to the findings in the scientific literature, considering not only physical factors but also socioeconomic variables is significant in the vulnerability assessment process (Poompavai and

Ramalingam 2013; Jana and Bhattacharya 2013; Rani et. al., 2015).Physical vulnerability in an area are usually used to give a quick indication of coastal vulnerability (Palmer et al., 2011). However, socio-economic features of coastal infrastructures are also needed for a holistic vulnerability assessment that provides implications for both natural and human systems. For instance; it was observed that Yalıkavak, Turgutreis and Milta showed consistency both physical and socio-economic vulnerability levels. It means that, these top three marinas are superior than others in terms of socio-economic parameters such as yacht capacity (both in the sea and the land), number of services and employment it proves in the region, incomes, are also marinas with high and very high physical vulnerability. So it might mean that preventive and protective actions and plans should be required for these marinas for the hazards due to climate change impacts. On the other hand, Ortakent is notable as a marina with very high physical vulnerability but very low non-physical vulnerability. It means that Ortakent has a less socio-economic importance for the region according to the eight parameters used in this study. Other marinas have similar situation are Bitez, Bodrum Kale and Gumbet marinas, but less distance between the results of PCVI and MVI. In this case, IMVI results (Table 5) can provide information to decision makers about which marinas with high levels of physical vulnerability should be prioritized in adaptation plans and strategies. For example, a priority ranking can be made among marinas showing similar levels of physical vulnerability, according to criteria such as contribution to the regional economy and sectoral importance.

Although it provided important findings, this study has limitations. The most important factor determining the boundaries of the study is the availability of common data required for the comparative analysis of the selected marinas. Additionally, this research conducted on a peninsula scale can also be conducted on a larger scale for areas with different geographical and administrative borders. Future studies reproduce the IMVI model in this study by adding different non-physical variables related to marinas.

In conclusion, the key infrastructure such as seaports, roads, and commercial and touristic sites are prone to threats by erosion, coastal flooding, and storm surges etc. due to SLR-induced climate impacts. Although the coastal zone is a financial engine for economic development, the zone and infrastructures within the coastal zone are vulnerable to SLR. This study presents a new integrated index methodology, the IMVI to assess the relative vulnerability level of yacht marinas. The IMVI approach can be modified by future studies and can be used as decisive criteria for adaptation strategies toward resilience in the economy and the community. It has the potential to advance the current understanding of determining the vulnerability to SLR-driven climate impacts not only for marinas but also for transportation infrastructures such as commercial cargo ports and shipyards.

5 REFERENCES

Akbas, B.; Akdeniz, N.; Aksay, A.; et al. *1:1.250.000 scaled Geological Map of Turkey* [online]. Ankara: General Directorate of Mineral Exploration and Research, 2011[Accessed: 13 May 2024]. Available at: https://www.mta.gov.tr/en/maps/geological-1250000.

Becker, AH.; Acciaro, M.; Asariotis, R.; et al. A note on climate change adaptation for seaports: a challenge for global ports, a challenge for global society. *Climatic Change* [online]. 2013, vol. 120, p. 683–695[Accessed: 13 Many 2024]. Available at: https://doi.org/10.1007/s10584-013-0843-z.

Becker, A.; Ng, A.K.Y.; McEvoy, D. and Mullett, J. Implications of climate change for shipping: Ports and supply chains. *WIREs Climate Change* [online]. 2018, vol. 9, no. 2, p. 508[Accessed: 13 May 2024]. Available at: https://doi.org/10.1002/wcc.508.

Behera, R.; Kar, A.; Das, MR. and Panda, PP. GIS-based vulnerability mapping of the coastal stretch from Puri to Konark in Odisha using analytical hierarchy process. *Natural* Hazards [online]. 2019, vol. 96, p. 731–751[Accessed: 13 May 2024]. Available at: https://doi.org/10.1007/s11069-018-03566-0.

Charuka, B.; Angnuureng, DB.; Brempong, EK.; Agblorti, SKM.; Agyakwa, KTA. Assessment of the integrated coastal vulnerability index of Ghana toward future coastal infrastructure investment plans. *Ocean and Coastal Management* [online]. 2023, vol. 244, p. 106804[Accessed: 13 may 2024]. Available at: https://doi.org/10.1016/j.ocecoaman.2023.106804.

Chhetri, P.; Corcoran, J.; Gekara, V.; Maddox, C. and McEvoy, D. Seaport resilience to climate change: mapping vulnerability to sea-level rise, *Journal of Spatial Science* [online]. 2015, vol. 60, no. 1, p. 65-78[Accessed: 13 May 2024]. Available at: https://doi: 10.1080/14498596.2014.943311.

Christodoulou, A.; Christidis, P. and Demirel, H. Sea-level rise in ports: a wider focus on impacts. *Maritime Econ Logist* [online]. 2019, vol. 21, p. 482–496[Accessed: 13 May 2024]. Available at: https://link.springer.com/article/10.1057/s41278-018-0114-z.

Copernicus Marine In Situ Tac Data Management Team. *Copernicus Marine in situ TAC - physical parameters list* [online]. 2024[Accessed: 13 May 2024]. Available at: https://doi.org/10.13155/53381.

Cutter, S.L.; Boruff, B.; Shirley, W.L. Social vulnerability to environmental hazards. *Social Science Quarterly [*online].2003*, vol.*84, no. 2, p. 242–261[Accessed: 13 May 2024]. Available at: https://doi.org/10.1111/1540-6237.8402002.

Dawson RJ.; Dickson ME.; Nicholls RJ.; Hall JW.; Walkden MJ.; Stansby P.; Jordan, A. Integrated analysis of risks of coastal flooding and cliff erosion under scenarios of long term change. *Climate Change* [online]. 2009, vol. 95, p. 249–288[Accessed: 13 May 2024]. Available at: https://doi.org/10.1007/s10584-008-9532-8.

Dey, J. and Mazumder, S. Development of an integrated coastal vulnerability index and its application to the low-lying Mandarmani–Dadanpatrabar coastal sector, India. *Natural Hazards* [online]. 2023, vol. 116, p. 3243–3273 [Accessed: 13 May 2024]. Available at: https://doi.org/10.1007/s11069-022-05805-x.

Djouder, F. and Boutiba, M. Vulnerability assessment of coastal areas to sea level rise from the physical and socioeconomic parameters: case of the Gulf Coast of Bejaia, Algeria. *Arabian Journal of Geosciences.* 2017, vol.10, no. 299[Accessed: 13 May 2024]. Available at: https://doi.org/10.1007/s12517-017-3062-5.

Emery, K.O. and Aubrey, DG. *Sea Levels, Land Levels, and Tide Gauges*. New York: Springer-Verlag, 1991. ISBN-13:978-1-4613-9103-6.

European Commission, Directorate-General for Maritime Affairs and Fisheries (EC). *Assessment of the impact of business development improvements around nautical tourism. Final Report* [online]. Publications Office*,* 2017[Accessed: 13 May 2024]. Available at: https://data.europa.eu/doi/10.2771/26485.

European Commission, Executive Agency for Small and Medium-sized Enterprises (EC). *Study on specific challenges for a sustainable development of coastal and maritime tourism in Europe. Final Report* [online]. Publications Office, 2016[Accessed: 13 May 2024]. Available at: https://data.europa.eu/doi/10.2826/94993.

Gornitz, V. M. Vulnerability of the East coast, U.S.A. to future sea level rise. *Journal of Coastal Research* [online]. 1990, p. 201–237[Accessed: 13 May 2024]. Available at: http://www.jstor.org/stable/44868636.

Gornitz, V. Global coastal hazards from future sea level rise. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* [online].1991*,* vol. 89, no. 4, p. 379–398[Accessed: 13 May 2024]. Available at: https://doi.org/10.1016/0031-0182(91)90173-O.

Gornitz, V.M.; Daniels, R.C.; White, T.W.; Birdwell, K.R. The development of a coastal risk assessment database: vulnerability to sea-level rise in the U.S. southeast. *Journal of Coastal Research* [online*]*. 1994, no. 12, p. 327–338[Accessed: 13 May 2024]. Available at: http://www.jstor.org/stable/25735608.

Himmelstoss, E.A.; Henderson, R.E.; Kratzmann, M.G. and Farris, A.S. *Digital Shoreline Analysis System (DSAS) version 5.1 user guide* [online]. Reston, VA: U.S. Geological Survey, 2021[Accessed: 13 May 2024]. Available at: https://doi.org/10.3133/ofr20211091.

Innocenti, A. and Musco, F. Land–Sea Interactions: A spatial planning perspective. *Sustainability* [online]. 2023, vol. 15, no. 12, p. 9446[Accessed: 13 May 2024]. Available at: https://doi.org/10.3390/su15129446.

Intergovernmental Panel on Climate Change (IPCC).WGII AR5 glossary. In: *Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [online]. Tokyo, Japan: International Association of Ports and Harbors, 2014[Accessed: 13 May 2024]. Available at: https://www.ipcc.ch/report/ar5/wg2/.

Intergovernmental Panel on Climate Change (IPCC). Climate change 2022: Impacts, adaptation and vulnerability. Contribution of Working Group II. In: *Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [online]. Cambridge, UK and New York, NY, USA: Cambridge University Press, 2022. 3056 p[Accessed: 13 May 2024]. Available at: https: //doi.org/10.1017/9781009325844. https://www.ipcc.ch/report/ar6/wg2/.

Izaguirre, C.; Losada, IJ, Camus, P.; Vigh, JL. And Stenek, V. Climate change risk to global port operations. *Nature Climate Change* [online]. 2020, vol. 11, p. 14–20[Accessed: 13 May 2024]. Available at: https://doi.org/10.1038/s41558-020-00937-z.

Jana, A. ; Bhattacharya, A.K. Assessment of coastal erosion vulnerability around Midnapur-Balasore Coast, Eastern India using integrated remote sensing and GIS techniques. *Journal of Indian Society of Remote Sensing* [online]. 2013, vol. 41, p. 675–686[Accessed: 13 May 2024]. Available at: https://doi.org/10.1007/s12524-012-0251-2i.

Jenks, George F. The data model concept in statistical mapping. *International Yearbook of Cartography*. 1967, vol. 7, p. 186-190.

Kaliraj, S. and Chandrasekar, N. Geo-processing model on coastal vulnerability index to explore risk zone along the south west coast of Tamilnadu. *Int J Earth Sci Eng.* 2012, vol. 5, p. 1138–1147.

Kantamaneni, K. Coastal infrastructure vulnerability: an integrated assessment model. *Natural Hazards* [online]. 2016, vol. 84, p. 139–154[Accessed: 13 May 2024]. Available at: https://doi.org/10.1007/s11069-016-2413-y.

Koroglu, A.; Ranasinghe, R.; Jimenez, JA and Dostgheib, A. Comparison of Coastal Vulnerability Index applications for Barcelona Province. *Ocean & Coastal Management* [online]. 2019, vol. 178, p. 104799[Accessed: 13 May 2024]. Available at: https://doi.org/10.1016/j.ocecoaman.2019.05.001.

Kuleli T. City-Based Risk Assessment of sea level rise using topographic and census data for the Turkish Coastal Zone. *Estuaries and Coasts* [online]. 2010, vol. 33, p. 640-651[Accessed: 13 May 2024]. Available at: https://doi.org/10.1007/s12237-009-9248-7.

Kuleli T. Quantitative analysis of shoreline changes at the Mediterranean Coast in Turkey. *Environ Monit Assess* [online]. 2010, vol. 167, p. 387–397[Accessed: 13 May 2023]. Available at: https://doi.org/10.1007/s10661-009-1057-8.

Kuleli and Bayazit. Site analysis of maritime transportation infrastructures by using the Coastal Vulnerability Index Approach: The case of Bodrum Peninsula. *Marine Science and Technology Bulletin* [online]. 2023, vol. 12, no. 2, p. 142-155[Accessed: 13 May 2024]. Available at: https://doi.org/10.33714/masteb.1260897.

Lazarus, ED. and Ziros, LA. Yachts and marinas as hotspots of coastal risk. *Anthropocene Coasts* [online]. 2021, vol. 4, p. 61–76[Accessed: 13 May 2024]. Available at: https://dx.doi.org/10.1139/anc-2020-0012.

Mahapatra, M.; Ramakrishnan, R.; Rajawat, AS. Coastal vulnerability assessment using analytical hierarchical process for South Gujarat coast, India. *Natural Hazards* [online]. 2015 vol. 76, p. 139–159[Accessed: 13 May 2024]. Available at: https://doi.org/10.1007/s11069-014-1491-y.

Mani Muralli, R.; Ankita, M.; Amrita, S. and Vethamony, P. Coastal vulnerability assessment of Puducherry coast, India, using the analytical hierarchical process. *Nat. Hazards Earth Syst. Sci*. [online]. 2013 vol. 13, no. 12, p. 3291–3311[Accessed: 13 May 2024]. Available at: https://doi.org/10.5194/nhess-13-3291-2013.

Mase, H.; Tsujio, D.; Yasuda, T.; Mori, N. Stability analysis of composite breakwater with wave-dissipating blocks considering increase in sea levels, surges and waves due to climate change. *Ocean Eng.* [online]. 2013, vol. 71, p. 58–65[Accessed: 13 May 2024]. Available at: https://doi.org/10.1016/j.oceaneng.2012.12.037.

Messner, S.; Moran L.; Reub G. and Campbell, J. Climate change and sea level rise impacts at ports and a consistent methodology to evaluate vulnerability and risk. *WIT Transactions on Ecology and the Environment* [online]. 2013, vol. 169[Accessed: 13 May 2024]. Available at: https://doi.org/10.2495/CP130131.

Minar, M. H.; Belal Hossain, M. & Shamsuddin, M. D. Climate change and coastal zone of Bangladesh: Vulnerability, resilience and adaptability. *Middle-East Journal of Scientific Research* [online]. 2013, vol. 13, no. 1, p. 114-120[Accessed: 13 May 2024]. Available at: https://doi.org/10.5829/idosi.mejsr.2013.13.1.64121.

Monioudi, I. N.; Asariotis R.; Becker, A.; et al. Climate change impacts on critical international transportation assets of Caribbean Small Island Developing States (SIDS): The case of Jamaica and Saint Lucia. *Regional Environmental Change* [online]. 2018, vol. 18, p. 2211–2225[Accessed: 13 May 2024]. Available at: https://doi.org/10.1007/s10113-018-1360-4.

Nageswara Rao, K.; Subraelu, P.; Venkateswara Rao, T.; et al. Sealevel rise and coastal vulnerability: an assessment of Andhra Pradesh coast, India through remote sensing and GIS, J. *Coast. Conserv*. [online]. 2009, vol. 12, p. 195–207[Accessed: 13 May 2024]. Available at: https://doi.org/10.1007/s11852-009-0042-2.

New Jersey Department of Environmental Protection. Office of Coastal Management. *New Jersey's Coastal Community vulnerability assessment and mapping protocol* [online]. Office of Coastal Management, 2011.[Accessed: 13 May 2024]. Available at: https://www.nj.gov/dep/cmp/docs/ccvamp-final.pdf.

Özhan, E. & Abdalla, S. *Türkiye kıyıları rüzgar ve derin deniz dalga atlası. MedCoast – Orta Doğu Teknik Üniversitesi, Sürüm 1.0*, 2002, 445 s. ISBN: 975429190X, 9789754291902. [*Turkey coast wind and deep sea wave atlas. MedCoast – Middle East Technical University, Version 1.0,* 2002, 445p. ISBN: 975429190X, 9789754291902].

Palmer, B.J.; Van der Elst, R.; Mackay, F.; et al. Preliminary coastal vulnerability assessment for KwaZulu-natal, South Africa. *J. Coast Res.*[online]. 2011, p. 1390–1395[Accessed: 13 May 2024]. Available at: https://www.jstor.org/stable/26482403.

Poompavai, V. and Ramalingam, M. Geospatial analysis for coastal risk assessment to cyclones. *Journal of The Indian Society of Remote Sensing* [online]. 2013, vol. 41, p. 157–176[Accessed: 13 May 2024]. Available at: doi:10.1007/s12524-011-0198-8.

Ramieri, E. et al. *Methods for assessing coastal vulnerability to climate change: Technical Paper 1/2011* [online]. Bologna, ETC CCA, 2011[Accessed: 13 May 2024]. Available at: https://tuit.cat/dFMeY.

Rani, NNV.; Satyanarayana, ANV and Blaskaran, PK. Coastal vulnerability assessment studies over India: a review. *Nat Hazards* [online]. 2015, vol. 77, p. 405–428[Accessed: 13 May 2024]. Available at: https://doi.org/ 10.1007/s11069-015-1597-x.

Perez-Labajos, C. and Blanco, B. Leisure Ports Planning. *Journal of Maritime Research* [online]. 2006, vol. III, no. 2, p. 67-82[Accessed: 14 May 2024]. Available at: https://www.jmr.unican.es/index.php/jmr/article/view/56/53.

Sanchez-Arcilla, A. et al. A review of potential physical impacts on harbours in the Mediterranean Sea under climate change. *Reg Environ Change* [online]. 2016 vol. 16, p. 2471–2484[Accessed: 24 May 2024]. Available at: https://doi.org/10.1007/s10113-016-0972-9.

Sayre, R., Noble, S.; Hamann, S.; Smith, R.; et al. A new 30 meter resolution global shoreline vector and associated global islands database for the development of standardized global ecological coastal units. *Journal of Operational Oceanography* [online]. 2018, vol. 12, Issue sup2: Ocean Observing for Societal Benefit, p. S47-S56[Accessed: 14 May 2024]. Available at: https://doi.org/10.1080/1755876X.2018.1529714.

Sierra J.P. et al. Vulnerability of Catalan (NW Mediterranean) ports to wave overtopping due to different scenarios of sea level rise. *Reg Environ Change* [online]. 2016, vol. 16, p. 1457–1468[Accessed: 14 May 2024]. Available at: https://doi.org/10.1007/s10113-015-0879-x.

Sierra JP.; Sanchez-Arcilla A.; Gironella X.; Gracia V.; Altomare C.; Mosso C.; Gonzalez-Marco D.; Gomez J.; Barcelo, M. and Barahona, C. Impact of climate change on berthing areas in ports of the Balearic Islands: adaptation measures. *Front. Mar. Sci.* [online]. 2023, vol. 10, p. 1124763[Accessed: 14 May 2024]. Available at: https://doi.org/10.3389/fmars.2023.1124763.

Tano, R.A.; Aman, A.; Toualy, E.; Kouadio, Y.K.; François-Xavier, B.B.D. and Addo, K.A. Development of an Integrated Coastal Vulnerability Index for the Ivorian Coast in West Africa. *Journal of Environmental Protection* [online]. 2018, vol. 9, no. 11, p. 1171-1184[Accessed: 14 May 2024]. Available at: https://doi.org/10.4236/jep.2018.911073.

The Yacht Harbour Association (TYHA). Find a marina. In: *The Yacht Harbour Association's website* [online]. TYHA, 2024[Accessed: 14 May 2024]. Available at: https://www.tyha.co.uk/marina-listing#advancedsearch.

Thieler, E.R.; Hammar-Klose, E.S. *National Assessment of Coastal Vulnerability to Future Sea-Level Rise: Preliminary results for the U.S. Pacific Coast: U.S. Geological Survey, Open-File Report 00-178* [online]. USGS, 2000[Accessed: 14 May 2024]. Available at: https://pubs.usgs.gov/of/2000/of00-178/.

Thieler, E. R.; Himmelstoss, E. A.; Zichichi, J. L. & Miller, T. L. *Digital Shoreline Analysis System (DSAS) version 3.0: an ArcGIS extension for calculating shoreline change: US Geol Surv Open-File Rep, 2005-1304* [online]. USGS, 2005[Accessed: 14 May 2024]. Available at: https://doi.org/10.3133/ofr20051304.

TUDES (Türkiye Ulusal Deniz Seviyesi İzleme Sistemi). *Sea Level Observations* [online]. 2022[Accessed: Dec 20]. Available at: https://tudes.harita.gov.tr/.

U.S. Geological Survey. Earth Resources Observation and Science (EROS) Center. *USGS EROS Archive - Digital Elevation - Shuttle Radar Topography Mission (SRTM) 1 Arc-Second Global* [online]. 2018[Accessed: 14 May 2024]. Available at: https://doi.org/10.5066/F7PR7TFT.

Wang, Y. and Marsooli, R. Dynamic modelling of sea-level rise impact on coastal flood hazard and vulnerability in New York City's built environment. *Coastal Engineering* [online]. 2021, vol.169, p. 103980[Accessed: 14 May 2024]. Available at: https://doi.org/10.1016/j.coastaleng.2021.103980.