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RESEARCH ARTICLE

Site analysis of maritime transportation infrastructures by using the Coastal Vulnerability Index approach: The case of Bodrum Peninsula

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ABSTRACT

In this research, site locations of marina-type maritime transportation infrastructure (MTI) in the Bodrum Peninsula were analyzed using the coastal vulnerability index (CVI) approach. For the calculation of CVI, six parameters; coastal slope, relief, relative sea level change, shoreline erosion/accretion, mean tide range, and mean wave height were used in accordance with the method. After the data collected from different data sources were transferred into a geo-database, basic geographical information systems analyses were applied (reclass, buffer, subset, slope, overlay, classify, count, map algebra, etc.). CVI results have been presented as maps and tabular values using a scale of 1 (Very Low) to 5 (Very High). Thus, the vulnerability level of the MTI site locations was determined. According to the determined results, it was founded that, Ortakent and Turgutreis were Very High (red-5); Yalıkavak, Milta and Kale MTIs are High (orange-4); Cruise Port, Gumbet and Bitez were found to have Moderate (yellow-3) CVI values. In this research, the CVI approach was applied by evaluating the physical site location characteristics of marina-type MTI, for the first time applied in the Bodrum Peninsula, where there is a high density of marina. For adaptation strategies for existing MTIs, more investigations should be realized from the functional, economic, social, and ecosystem points of view. From the managerial point of view, it can be said that small marinas or municipal berthing facilities with a state ownership model are advised to work together with other marinas in the region if they exist. The CVI-methodology should also utilize for the site selection of any type of maritime transportation infrastructure.

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Introduction

Maritime transportation infrastructures (MTIs) are among the most important physical infrastructures built to meet the expected usage demands from coastal areas. In general, an MTI differs according to its usage purpose, ownership model, type of service it provides, type of vessel, and cargo it serves (DLH, 2010a, 2010b). The MTIs constitute coastal infrastructures for transport, maritime tourism, and other purposes such as fishing and military. The MTIs including commercial cargo ports (container ports, general cargo ports, chemical terminals, etc.), passenger ports, and special purpose ports (such as fishing) are defined as "seaports" which are logistic and industrial transportation nodes (Notteboom et al., 2022). Depending on their functions, the number and density of MTIs in a region and the site location characteristics in the coastal area may differ from each other. For example, although the number of seaports is less than the number of marina-type MTIs in a region, the area surrounding a seaport and its hinterland needed for trade operations requires more space than a marina-type MTI.

In the field of vulnerability assessment, climate change risks, planning, and policies for adaptation, studies have been conducted for seaports, especially for major commercial ports (Becker et al., 2010, 2012, 2016; Messner et al., 2013; IPCC, 2014; Monioudi et al., 2018; Christodoulou et al., 2019; Hanson & Nicholls, 2020; Sweeney & Becker, 2020; UN, 2020; Izaguirre et al., 2021) because of a strategic role in the global trade system. However, marina-type MITs including modern marinas, yacht ports, municipal berthing facilities are often overlooked despite their high economic value (Lazarus & Ziros, 2021). However, there is a crucial gap in the literature in the field of coastal vulnerability analysis of marina-type MTIs which host recreational and maritime activities as well as valuable physical assets (Lazarus & Ziros, 2021).

In course of time, the physical characteristics of the selected site for an MTI can also create challenges or convenience for its existence and operational activities. The coastal zone of Bangladesh is a good example of this. Because, according to Minar et al. (2013), Bangladesh has an extremely flat, low-lying coastal type, and it has been determined that in the event of a one-meter SLR, about 18% of the country's total land area and all MTIs could be inundated. MTI sites can range in size from a small dock with a few ten boats or small crafts to a very large port of over hundreds of yachts or ships. The major physical site characteristics include coastal landforms, land use, bathymetry, tidal range, wave, relief, slope, climate, availability of land transportation, etc. (DLH, 2010b; Golestani & Amiri, 2021). Both seaports and marina-type MTIs are built in coastal zones due to their functions. Coastal areas are considered highly vulnerable hot points by climate change worldwide (IPCC, 2019; Fox-Kemper et al., 2021). It is commonly accepted that the most important observed and expected physical impacts of climate change on the coastal areas are SLR; the permanent inundation of low-lying urban areas and physical infrastructures; augmented flooding because of extreme weather conditions such as storm surges; saltwater intrusion to coastal groundwater; high erosion on coastlines, beaches, cliffs, and wetlands (Fox-Kemper et al., 2021).

Many populated cities, residential areas, and transportation infrastructure in the world are located on low-lying coastal plains, and these coastal areas are among the regions that can be directly affected in the case of SLR because of climate change. Therefore, knowing the coastal areas' vulnerability because of SLR is of great importance in terms of taking necessary precautions and developing policies to deal with risks. Gornitz (1991) and Gornitz et al. (1994) developed the coastal vulnerability index (CVI) approach as a "site" analysis in order to determine vulnerability in the case of SLR. This method has been used by many researchers to evaluate the vulnerability of coastal areas in the world. According to Koroglu et al. (2019) and Cogswell et al. (2018), approximately 30% of the analyses about coastal vulnerability utilized the CVI method. Different tools such as geographical information systems, computer models, mapping tools and index-based approach as CVI have been used at different spatial and temporal scales to analyze vulnerability in coastal areas (Ramieri et al., 2011) Generally, the CVI-based approach has been developed for fast assessment and visualization in different areas and spatial scales based on available datasets to quantify and analyze the level of vulnerability of coastal areas to the effects of SLR.

In this research, site locations of marina-type MTI in the Bodrum Peninsula were analyzed using the CVI approach. The aim of the research is to determine the vulnerability level of the site locations with existing MTIs according to the CVI. Thus, the analysis was carried out according to the internationally accepted CVI method to determine the vulnerability level of the sites where marina-type MTIs are located, which is seen as a deficiency in the literature. For the calculation of CVI, six parameters were used in accordance with the method. These parameters are; coastal slope, relief, relative sea level change, shoreline erosion and accretion, mean tide range, and mean wave height. After the data collected from different data sources were transferred into a geo-database, basic GIS analyses were applied (reclass, buffer, subset, slope, overlay, classify, count, map algebra, etc.). CVI results have been presented as maps and tabular values using a scale of 1 (Very Low) to 5 (Very High). Thus, the vulnerability level of the MTI site locations was determined. According to the determined results, MTI locations at each CVI level were analyzed, evaluated, and recommendations were developed.

Material and Methods

Research Area

Bodrum Peninsula was chosen as the research area (Figure 1). It is located in the South Aegean region of Turkey and is a world-famous tourism area. Bodrum has a very rich marina-type MTIs including modern marinas, yacht ports and berthing facilities with small and large mooring capacities for various size of boats and a cruise port. Apart from these, there are quite small and local piers of various sizes. In addition, there are shipyards in Icmeler and Yalıkavak that specialized in manufacturing, maintaining and repairing touristic boats and yachts. While the total resident population of Bodrum district in 2022 is 187.284, during the summer seasons, especially during the peak season for tourism, the total population can sometimes exceed 1.500.000 (TUIK, 2022).

In order to conduct site location analyses based on the CVI method, a peninsular coastal area rather than a mainland coastal area was considered for the first time, where there is a high density of marina-type MTIs. So, the Bodrum Peninsula can be seen as a pilot study in the application of the CVI approach for the field of MTIs. The marina-type MTIs included in the site analyses are Bodrum Cruise Port, Bodrum (Kale) Yacht Port, Milta Marina, Gumbet Yatch Port, Bitez Yatch Port, Ortakent Marina, Turgutreis Marina, and Yalıkvak Marina, which are located throughout the Peninsula (Figure 1).

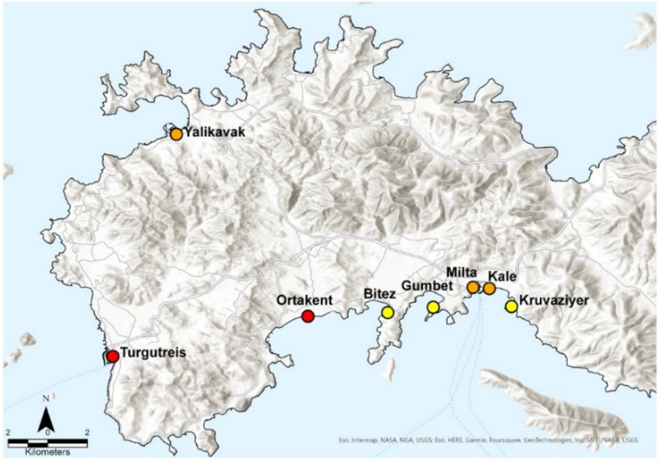

Figure 1. Research area. Bodrum Peninsula

Data and Methods

In this research, the variables, data types, and data sources used to determine the CVI and evaluate marina-type MTIs sites are shown in Table 1.

Space Shuttle Radar Topography (SRTM) data set (SRTM, 2018) (1 arc-second, 30 meters) was used to determine the coastal relief and coastal slope variables (USGS, 2020).

In order to determine the shoreline erosion/accretion variable, the 8th band images of the Landsat 8 satellite on two different dates (16.09.2013 and 27.10.2022) were used with a resolution of 15 meters.

The Mean Tide Range variable was determined, according to Turkish National Sea Level Monitoring System (TUDES, 2022) observations, and near-time literature such as Sayre et al. (2018, 2021), and Ecological Coastal Units (ECU) (2022).

Table 1. CVI variables and data sources

Variables (a_n)	**Data Source**
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)

According to Özhan & Abdalla (2002), the mean wave height variable was retrieved from three samples point which is very close to the research area. The geographical coordinates (Lat-Long) of these points are; 27.10 E-37.25 N, and 27.40 E-37.25 N, and 27.40 E-37.00 N. Also, cross check was performed using data of 1km global coastline segments and segment midpoints database (ECU, 2022). The workflow diagram of the methodology is shown in Figure 2.

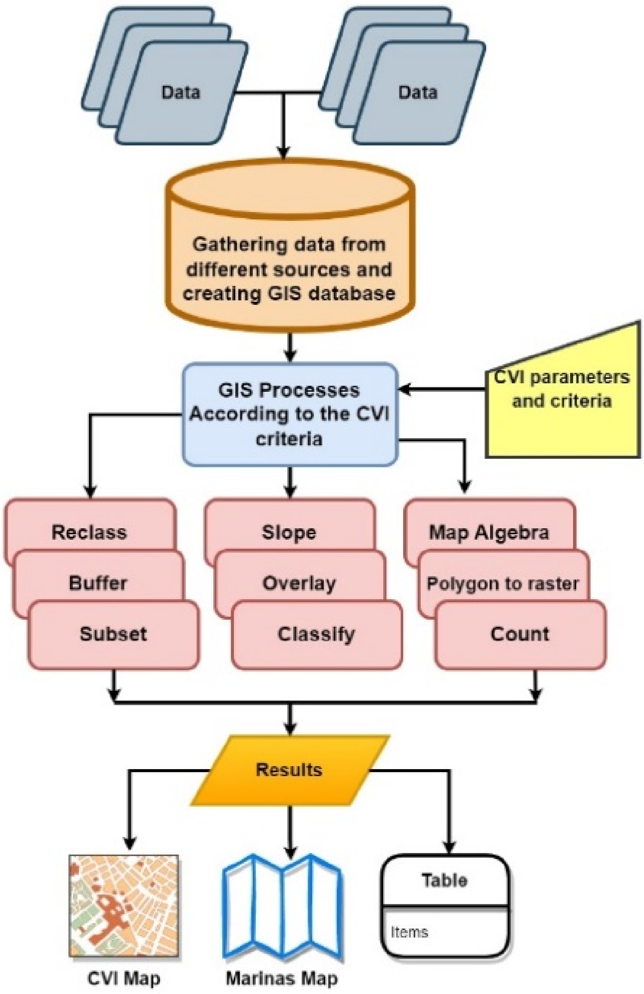

Figure 2. Workflow diagram of the methodology

As a first step, a geo-database was created in which all the data obtained from different sources were gathered together in order to make the data suitable for analysis. A GIS software was used for geo-database creation.

The second step is the preparation of the CVI variables. Coastal Vulnerability Index (CVI), which was also used in this research, is the most common index-based assessment method used to determine SLR-inducted coastal vulnerability. Many of the CVI methods commonly used for assessing coastal zone vulnerability were adapted from Gornitz (1990, 1991), which evaluated the US coastline on a national scale (Koroglu et al., 2019). Thereafter, Shaw et al. (1998) and Gornitz (1991) added the geology variable to the CVI calculations. In this research, the CVI values have been calculated with the following variables (a_n) according to Eq. (1);

$$CVI = \sqrt{\frac{a_1 \times a_2 \times a_3 \times a_4 \times_5 \ldots \times a_n}{n}} \quad (1)$$

a_1: Coastal slope
a_2: Relief
a_3: Relative sea level change
a_4: Shoreline erosion / accretion
a_5: Mean tide range
a_6: Mean wave height

Variables are classified from 1 to 5 by dividing them into 5 equal intervals as follows, and the ranking table of variables of the selected method was given in Table 2; 1: Very Low, 2: Low, 3: Moderate, 4: High, 5: Very High.

According to the CVI variables scale, the method of obtaining the values of each variable by using GIS software has been explained in detail below.

Grids for analysis: Grid resolution directly affects CVI analysis results. For this reason, it is necessary to determine the grid size that represents the variables in the most accurate way

Table 2. Coastal Vulnerability Index (CVI) ranking scale from Gornitz (1990, 1991)

Variable	Unit	Very Low 1	Low 2	Moderate 3	High 4	Very High 5
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

and gives the most accurate analysis result. In the literature, it is seen that many different sizes are used for grid resolution and there is no standard for grid resolution. For example, Gornitz et al. (1994), who introduced the CVI method, used 0.25-degree grids in a coastal hazards database study for the US Gulf Coast in 1994. In determining the grid resolution, the resolution of the data used and the length of the coastal area should be considered and an expert opinion should be taken into account. In this research, a grid network of 30×30 m in size, 250 m inward from the coastline, was created to cover the shoreline in the research area to evaluate the coastal vulnerability (Figure 3). The data of all the variables were extracted by the grids to calculate the CVI using Gornitz (1990) and Gornitz (1991) method.

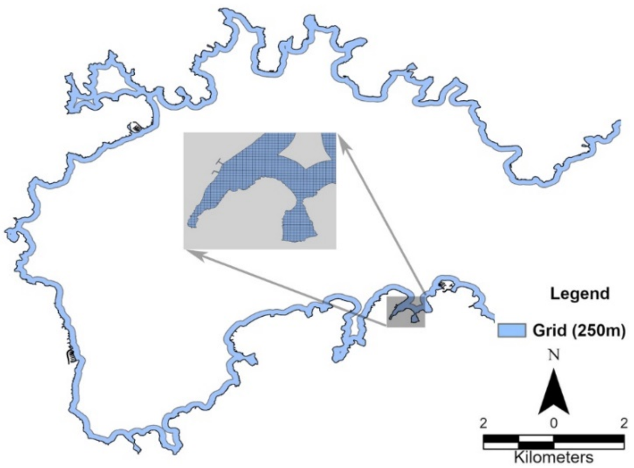

Figure 3. Grids for analysis

Coastal Slope: Using SRTM data, first the slope was calculated, then the slope map was reclassified according to the ranges shown in Table 2, and a new slope raster image consisting of values ranging from 1-5 was obtained. Percent slope Eq. (2) as follows (DeYoung, 2022);

$$Slope\% = \frac{Rise}{Run} x100 \qquad (2)$$

In this equation, *Rise* is land elevation, and *Run* is distance.

Relief: Relief refers to the coastal land elevation. SRTM coastal land elevation data was reclassified according to the ranges shown in Table 2, and a new relief raster image consisting of values ranging from 1-5 was obtained.

Relative sea level change: The data acquired from the data sources specified in Table 1 were converted to raster format and a new relative sea level change raster image consisting of values ranging from 1-5 was obtained.

Shoreline erosion/accretion: To detect shoreline changes in the research area the 8th band images of the Landsat 8 satellite on two different dates (16.09.2013 and 27.10.2022) were used with a resolution of 15 meters. By using the automatic detection of shoreline change method (Kuleli et al., 2011), the Normalized Difference Water Index (NDWI), the areas with change were determined by overlaying the shorelines of two different dates. The Normalized Difference Water Index (NDWI) Eq. (3) as follows (Xu, 2005);

$$NDWI = \frac{(Band3-Band5)}{(Band3+Band5)} \qquad (3)$$

Using this Eq. (3), the images were made suitable for separating the land and sea areas. Thus, the coastline and the sea border were clarified and it was examined whether there was a difference between the obtained coastlines.

Mean tide range: The data acquired from the data sources specified in Table 1 were converted to raster format and a new mean tide range raster image consisting of values ranging from 1-5 was obtained.

Mean wave height: The data acquired from the data sources specified in Table 1 were converted to raster format and a new mean wave height raster image consisting of values ranging from 1-5 was obtained.

Calculation and mapping of CVI value: According to the formula in Eq. (1), the raster maps of each variable were calculated using the map algebra function. The obtained CVI map was reclassified according to values between 1 and 5. Equal interval formula Eq. (4) is used in classification (Campbell & Shin, 2011).

$$Interval = \frac{Range\_of\_Data}{Number\_of\_Classes} = \frac{(HighestValue-LowestValue)}{Number\_of\_Classes} \qquad (4)$$

For example, if 5 classes will be created for values ranging from 0 to 50, the class ranges will be as Table 3;

Table 3. Example for equal interval classification

$$\boldsymbol{Interval = \frac{(50-0)}{5} = 10}$$

Value	**Class**
1	0-10
2	11-20
3	21-30
4	31-40
5	41-50

After the CVI map and its statistical distribution were created, the marina-type MTI sites were overlapped with the CVI map and the sites were evaluated according to their CVI classes. The results are presented as maps, graphs and tables.

Results

In this research, according to the CVI method, site analysis was performed for eight marina-type MTIs in the Bodrum peninsula. These are Bodrum Cruise Port, Bodrum (Kale) Yacht Port, Milta Marina, Gumbet Yatch Port, Bitez Yatch Port, Ortakent Marina, Turgutreis Marina, and Yalıkvak Marina. The CVI values of the marina-type MTI sites in Bodrum were determined by using coastal slope, relief, relative sea level change, shoreline erosion and accretion, mean tide range and mean wave height data, and various GIS methods and formulas. The results of the analyses were presented separately on the basis of variables, CVI values, and MTI sites.

First, the analysis results obtained in terms of relief and slope were explained. The slope can be evaluated as a distance-dependent function of the terrain height (Eq. 2). If the terrain elevation suddenly rises over short distances, the slope also rises. Such land areas are evaluated as steep terrain. Conversely, if the land elevation gradually rises over long distances, the slope decreases. Such land areas are evaluated as flat or low plains. Relief and slope maps classified according to the CVI scale in Table 2 were determined as in Figure 4 and Figure 5. It has been found that MTIs in the research area are generally located naturally in low plains and low-sloping areas.

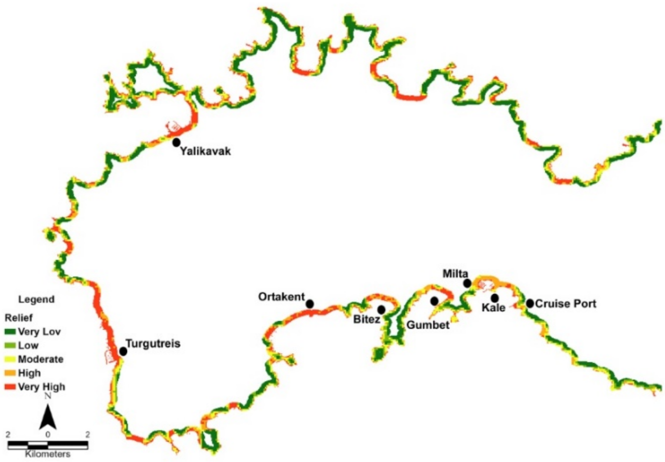

Figure 4. According to the CVI scale, relief map in the research area

In order to better understand site location characteristics of marina-type MTIs in the research area in terms of relief and slope, the slope and relief values of the site are given in Table 4. According to these results, Gümbet, Bitez, and Cruise Port are the three marina-type MTIs located in the highest coastal elevation and steepest slopes, respectively. On the other hand, the first three MTIs located in the lowest coastal elevation and flat slopes are Ortakent, Turgutreis, and Yalıkavak, respectively.

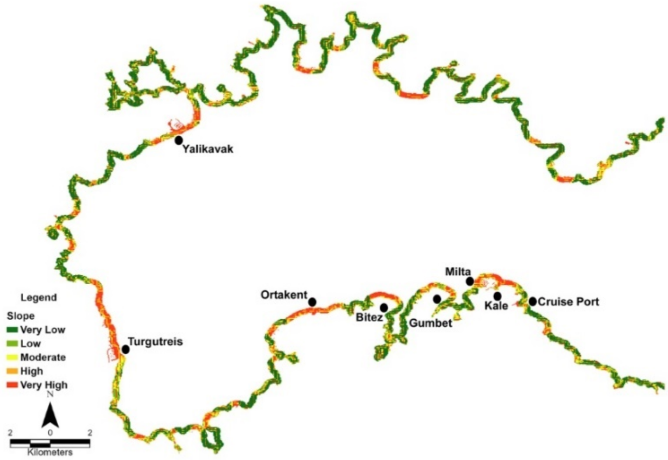

Figure 5. According to the CVI scale, slope map in the research area

Table 4. The distance of reaching a 10m land elevation from the coastal line to the land side, and the average ground slope for each marina-type MTI site

MTI	Land Elevation (m)	Distance From Coastline (m)	Slope (%)
Gümbet	10	23	43.48
Bitez	10	30	33.33
Cruise Port	10	65	15.38
Milta	10	251	3.98
Kale	10	564	1.77
Yalıkavak	10	632	1.58
Turgutreis	10	764	1.31
Ortakent	10	1140	0.88

Relative sea level change (RSLC): According to the data sources in Table 1, the RSLC value in the entire research area was determined as 3.3±1.1 maximum. This RSLC value corresponds to the High (4) value according to the CVI classification (Figure 6). Therefore, the RSLC value in the CVI for the entire sites where marina-type MTIs are located, was evaluated as High (4).

Shoreline erosion/accretion (SEA): SEA was determined by using satellite images of two different dates noted in the method section. In the last ten years, it has been determined that the shoreline in the research area is stable and there is no erosion or accretion. According to the CVI scale table (Table 2), the Moderate (3) value was used for areas with stable shorelines such as the research area (Figure 7). Therefore, the SE-A value in the CVI for the entire sites where marina-type MTIs are located, was evaluated as Moderate (3).

Figure 6. According to the CVI scale, relative sea level change map in the research area.

Figure 7. Maps showing CVI values for shoreline erosion/accretion.

Mean tide range and ***Mean wave height:*** According to the data obtained from the ECU (2022) and other sources in Table 1, the MTR and MWH distribution maps in the research area was created Thus, lower and upper limits were determined for the values that MTR and MWH can take according to the CVI scale. According to the CVI scale, it was determined that the MTR distribution was <1.0 and had a Very Low (1) value, the MWH distribution was between 1.1-2.0 and had and Low (2) value. Therefore, the MTR value in the CVI for the entire sites where marina-type MTIs are located, was evaluated as Very Low (1) (Figure 8), and the MWH value was evaluated as Low (2) (Figure 9).

Figure 8. Maps showing CVI values for mean tide range

Figure 9. Maps showing CVI values for mean wave height

Results of Calculation and mapping of CVI value for MTI: The CVI value was calculated for the entire research area by using all six variables and Eq. (1). It was seen that relief (elevation) and slope, two of the six variables used in calculating CVI for the entire research area, were the most determinant. The calculated raw CVI values were found to range between 2 and10. According to the CVI ranking/classification, raw CVI values were reclassified between 1 and 5 by using an equal interval procedure in Eq. (4), and the result CVI map was obtained (Figure 10). It was observed that marina-type MTI sites in the research area were distributed in regions with red (Very High), orange (High) and yellow (Moderate) CVI values.

When the CVI result map and the marina-type MTI site map were overlapped, the CVI values corresponding to the sites where the marina-type MTIs are located were also determined (Figure 10). According to this overlay analysis, Ortakent and Turgutreis were Very High (red); Yalıkavak, Milta and Kale MTIs are High (orange); Cruise Port, Gumbet and Bitez were found to have Moderate (yellow) CVI values (Table 5).

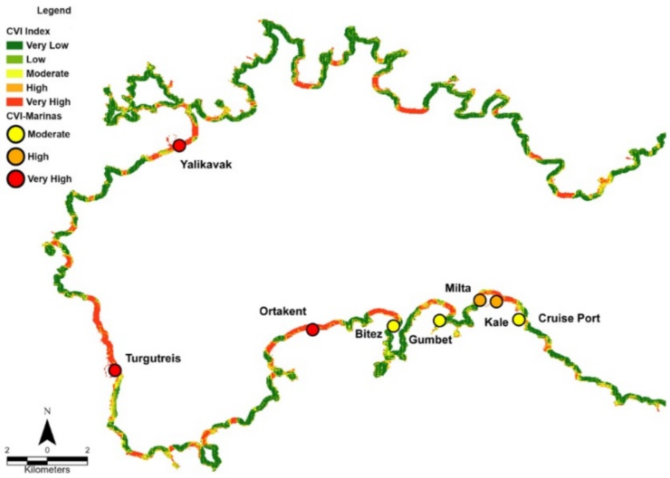

Figure 10. Distribution of the CVI value for the whole peninsula and CVI values of site location of the marine-type MTIs

Table 5. CVI values of the site location of MTI

Maritime Transportation Infrastructure	CVI Value
Cruise port	3 (Moderate)
Gümbet	3 (Moderate)
Bitez	3 (Moderate)
Kale-Bodrum	4 (High)
Milta	4 (High)
Ortakent	5 (Very High)
Turgut Reis	5 (Very Heigh)
Yalıkavak	5 (Very Heigh)

As the overall result of the site location analysis of maritime transportation infrastructure according to CVI, Ortakent, Turgutreis and Yalıkavak which have "very high vulnerability" values in terms of size and location are among the MTIs in the Bodrum peninsula; those with "high vulnerability" values are Milta, and Bodrum-kale; Bitez, Gümbet and the cruise port are the ones with "moderate vulnerability" value.

Discussion

In this research, the site vulnerability of marina-type MTIs including modern marinas, yacht ports, municipal berthing facilities and cruise ports located in Bodrum Peninsula was analyzed and evaluated based on the CVI method. The overall result of the site location analysis of marina-type MTIs based on the CVI method showed that Ortakent and Turgutreis Marinas were the marinas located in the most vulnerable sites. Relative to them, the site location of Bodrum (Kale) Yatch Port, Yalıkavak and Milta Marina were found the second most vulnerable. Besides, Bodrum Cruise Port, Gumbet, and Bitez Yatch Ports were the MTIs located in the least vulnerable sites, relative to the other marina-type MTIs in Bodrum. It has been observed that the most decisive variables on the vulnerability levels of the marina-type MTIs in the Bodrum Peninsula are slope and relief. According to the slope and relief variables, Bodrum Cruise Port, Gumbet, and Bitez Yacht Ports are located in steep terrain locations. So, sites where they are located noteworthy were moderately vulnerable and relatively resistant based on their CVI values. In addition, Milta Marina can be considered relatively less vulnerable against the SLR-induced effects in terms of its higher slope, comparing to Bodrum (Kale) Yacht Port and Yalikavak Marina, which are located in highly vulnerable sites. On the other hand, Ortakent Yacht Port and Turgutreis Marina are relatively the most disadvantaged MTIs due to being built on a flat (low plain) location. Therefore, Ortakent and Turgutreis would be exposed to relatively the greatest physical effects due to climate impacts such as coastal flooding and extreme SLR, waves, and winds, storm surges, etc.

Unlike commercial ports, for marina-type MTIs, effective transportation between the commercial centers in its hinterland and the marina is not crucial. In order for a marina-type MTIs to fulfil its functions, it needs a sheltered and sufficient boat mooring capacity at sea, and a certain dock area in the land area depending on the demand for maintenance-repair works and wintering or other services. Most municipal berthing facilities do not even have any land space but have marina power, lightning, and water supply box-like devices. In the course of time, expanding a seaport hinterland can be needed depending on global trade volume. To expand a seaport in order to obtain a larger handling capacity, step terrain sites would increase construction costs. However, to fulfil its function, a marina needs more maritime space than a hinterland. Therefore, building or being located in low plain sites would not be the priority for marina-type MTIs. In general, while choosing a location for any type of MTI, it is preferred that the hinterland is as flat as possible, has less slope and has a transportation connection (UN, 1992; Murphy et al., 1992; Glatte, 2015). However, according to the evaluation realized with the CVI-approach, the areas where the MTIs are located with low land and low slope hinterland would be more fragile and more vulnerable against the SLR.

The CVI-based investigation is critical for existing MTIs. It determines how vulnerable a marina is based on its own site location characteristics. It also provides information to shed light on adaptation processes. In this research, CVI-based methods were used to evaluate the site location of existing marina-type MTIs in Bodrum Peninsula. It was seen that Gumbet and Bitez Yacht Ports were built in an advantageous site, however, Ortakent would be needed adaptation solutions. The cruise port was built on a steep terrain site, which may limit expanding of the port but provide the port resistance against SLR-induced coastal vulnerability. For large marinas located in a low-lying coastal area such as Turgutreis, coastal vulnerability is very high so adaptation solutions should be taken as soon as possible. Climate and vulnerability analysis in order to provide information for policymakers who will take adaptation strategies for existing MTIs can be utilized the literature on commercial ports, but should take into account the characteristics specified to marina-type MTIs, such as yacht ports (Lazarus & Ziros, 2021). Some applications have been developed to increase the resistance to inundation and flooding of areas where MTIs are located (Messner et al., 2013). Elevating, defending, and relocating or retreating are the three major adaptation solutions (Cheong, 2011; Aerts et al., 2014). When determining which climate adaptation measures will be taken for existing coastal systems, using a combination approach site and situation characteristics for each MTI should be considered.

There is a need for more researches to determine adaptation strategies for marina-type MTIs which are located in low-lying coastal areas and therefore vulnerable to climate impacts. For a more adaptable marina by implying one of the adaptation solutions (protect, elevate, or relocate) which involves near and long term planning for hard and soft interventions requires to make a cost-benefit analysis, utilizing site and situation specific characteristics of MTIs. For marinas, yacht mooring facilities, and cruise ports, which are located in SRL-vulnerable sites based on CVI, one or a combination of more adaptation solutions can be adopted depending on site location characteristics, port characteristics based on its function and capacity, and its socio-economic importance in its region. Future studies may also evaluate the site location of a new location using the CVI approach for site selection of MTIs. According to Nguyen et al. (2021), decisions are mostly given by politic-based decision makers, and an assessment of the physical variables of the selected site would be carried out after that. However, for the benefit of the region physical site characteristics should be taken into account for a sustainable MTI's site selection (PIANC, 2019; Nguyen et al., 2021; Taneja & Oosterwegel, 2022). It is expected that this study will encourage authorities and policy-makers to include the CVI methodology in the site selection criteria.

The limitation of this research is derived from the nature of the CVI method. The simple and widely used first version of CVI approach includes only physical variables. The first version of CVI approach does not include socio-economic variables such as the number of the affected population, number of buildings, infrastructure, economic sectors or economic costs (Gornitz et al., 1993; Cooper & McLaughlin, 1998; ETC/ACC, 2010a, 2010b). Therefore, the CVI approach, first used by Gornitz (1991), has continued to be developed, with some researchers incorporating socio-economic variables into the formula (Cutter et al., 2003; Kleinosky et al., 2007; Ergin et al., 2008; Tate et al., 2010; Guillard-Gonçalves et al., 2015; Tragaki et al., 2018). The CVI-method for site location analysis of existing or new building decisions of marinas utilizing socio-economic variables can be modified. Future studies are advised to apply CVI-method to the MTIs considering marina dynamics such as mooring capacities, number of services provided, and socio-economic dynamics such as transportation facilities such as roadways and population adjacent to the marina.

Conclusion

Yachting and cruising activities represent a large part of marine and coastal industry which constitute the significant economic value for the most Mediterranean countries. Marinas and cruise ports are essential facilities for these activities. Marinas and cruise ports facilitate marine and coastal tourism. Marinas-like MTIs are critical coastal infrastructures located on shorelines so are highly vulnerable to coastal risks, and host valuable assets which are yachts. Coastal risks could affect marina facilities such as slipways, boatyards, stores, chandlery, shops and areas adjacent to marinas such as roadways. The vulnerability and risk profile of each marina-type coastal infrastructure would be different based on its physical and functional qualities. In this research, the CVI approach was applied by evaluating the physical site location characteristics of marina-type MTI, for the first time applied in the Bodrum Peninsula, where there is a high density of marina. For adaptation strategies for existing MTIs, more investigations should be realized from the functional, economic, social, and ecosystem points of view. From the social point of view, for large and complex marinas disruption of roads to the marina or harbor could affect the movement of people and service movements around the marina. From the ecosystem point of view via floodwaters, contaminants existing at various sites, such as slipways, and maintenance-repair areas within the marina could flow into the sea or contaminate rising groundwater. From the managerial point of view, it can be said that small marinas or municipal berthing facilities with a state ownership model are advised to work together with other marinas in the region if exist. The CVI-methodology should also be utilized for the site selection of any type of maritime transportation infrastructures.

Compliance With Ethical Standards

Authors' Contributions

Please provide contributions of authors for the paper. Use first letters of name and surnames. See below for an example.
TK: Manuscript design, Field sampling, Laboratory experiments, Draft checking.
ŞB: Writing, Statistical analyses, Draft checking, Reading, Editing.
Both authors read and approved the final manuscript.

Conflict of Interest

The authors declare that there is no conflict of interest.

Ethical Approval

For this type of study, formal consent is not required.

Data Availability Statements

1) Relief and digital elevation data:

- SRTM data: NASA JPL (2013). NASA Shuttle Radar Topography Mission Global 1 arc second number [Data set]. NASA EOSDIS Land Processes DAAC. Accessed 2022-11-29 from https://doi.org/10.5067/MEaSUREs/SRTM/SRTMGL1N.003

- SRTM 1 Arc-Second Global elevation data offer worldwide coverage of void filled data at a resolution of 1 arc-second (30 meters) and provide open distribution of this high-resolution global data set (https://doi.org/10.5066/F7PR7TFT).

2) Mean tide range and mean wave height data:

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3) All other data generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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