ASSESSING COASTAL VULNERABILITY TO SEA LEVEL RISE: THE CASE STUDY OF SLOVENIA

Mojca Poklar
University of Primorska, Faculty of Humanities,
Titov trg 5, SI – 6000 Koper, Slovenia;
mojca.poklar@fhs.upr.si

Valentina Brečko Grubar
University of Primorska, Faculty of Humanities,
Titov trg 5, SI – 6000 Koper, Slovenia;
valentina.brecko.grubar@fhs.upr.si

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mojca.poklar@fhs.upr.si
VALENTINA BREČKO GRUBAR
University of Primorska,
Faculty of Humanities,
Titov trg 5, SI – 6000 Koper, Slovenia;
valentina.brecko.grubar@fhs.upr.si

Abstract

The sea level rise, as a result of climate change, is inevitable and will represent one of the greatest challenges for the coastal regions in the coming years. Therefore, the need to assess and monitor the vulnerability of the coastal regions to these hazards has been of growing interest and has also been highlighted in many recent studies. In this context, the main goal of this paper is to analyse and map the vulnerability of the Slovenian coast to sea level rise, a coastal area historically known to be highly susceptible to coastal flooding and erosion. Since there is no single method for measuring vulnerability, we chose to use an index-based approach that expresses coastal vulnerability through a one-dimensional vulnerability index. The study was conducted using a combination of the Physical Vulnerability Index (PVI) and GIS methods to assess the physical parameters of the coastal region (elevation, coastal slope, coastal orientation, bathymetry, presence/absence of protective structures, beach width, and geomorphological processes) and classify them into five categories of coastal vulnerability. The results show that 7.5% of the coastline can be classified as highly vulnerable and 2.5% as very highly vulnerable.

Keywords: coastal zone, physical vulnerability index (PVI), geographic information systems (GIS), Slovenia.

1 Introduction

The world's coastal areas cover only 4% of the Earth's total land area (Barbier, 2013), but although they represent only a small portion of the urbanized land, they are dynamic and complex multifunctional systems that provide multiple ecosystem services of environmental, economic, social, cultural and recreational value (ETC CCA, 2011). Due to population growth, urbanization, and various development activities over the past century, coastal processes in these areas have changed so that the provision of these services is declining (De Serio et al., 2018). Climate change adds additional pressure on these areas by increasing the vulnerability of already highly vulnerable areas (ETC CCA, 2011). Most coastal areas around the world are already facing the impacts of climate change, which include global sea level rise. Global mean sea level reconstructions based on tide gauge observations show a rise of 21 cm from 1900 to 2020 with an average rate of 1.7 mm/year and an accelerated rise of 3.7 mm/year in the period 2006-2018 (European Environment Agency, 2022).

According to the estimates by the Intergovernmental Panel for Climate Change (IPCC), the sea levels are likely to rise by up to 1 m by 2100, and in any case by no less than 0.5 m (Church et al., 2013), while some other predictions anticipate that by the year 2100 the sea level should rise from 0.9 m to 1.5 m (Nuccitelli, 2018). This phenomenon, which cannot be prevented, is likely to lead to permanent inundations of low-lying regions, land loss due to higher erosion rates, saltwater intrusion and damage to the built environment from extreme events (e.g. storm surges) (Church et al., 2013), which could have an even greater impact on the provision of ecosystem services when coupled to high concentration of people and socio-economic activities in coastal areas.

1.1 Vulnerability of coastal areas

Therefore, assessing the vulnerability of coastal areas to climate change is a topic of growing interest (Pantusa et al., 2018). Due to increasing human pressure on coasts and the threats posed by sea level rise, a number of different methodological approaches to coastal vulnerability assessment have been developed over the last three decades. These fall into four main categories, which include index-based methods, indicator-based approaches, GIS-based decision support systems and methods based on dynamic computer models (ETC CCA, 2011). The most common and probably the most widely used is the Coastal Vulnerability Index (CVI), an index-based method introduced by Gornitz (1991) and Gornitz, White and Cushman (1991). It is based on the calculation of an index combining a number of variables that affect the vulnerability of coastal areas. Each variable is ranked on a scale from 1 (lowest level) to 5 (highest level) to express its contribution to coastal vulnerability. After ranking, the CVI is calculated as the square root of the product of the ranking factors divided by the number of variables considered. The method divides the coastline into different segments and assigns a rank value and a vulnerability index to each of these segments, so that the relative vulnerability of the different coastal sections (segments) of a coastal area can be assessed (Gornitz, 1991).

This methodology was later modified to adapt the index to the particular coastal area and used by different researchers around the world (Diez, Perillo and Piccolo, 2007; Aboudha and Woodroffe 2010; De Serio et al. 2018; Pantusa et al. 2018; Mohamed 2020; Rocha, Antunes in Catita 2020; Sekovski et al. 2020).

1.2 Purpose and goals

However, a CVI has never been calculated for the Slovenian coast, a coastal area historically known to be highly susceptible to coastal flooding and erosion. Sea level monitoring in Slovenia shows that the sea level has risen by 10 cm in the last 50 years, i.e. by 1.7 mm per year. However, in the last 20 years, the rise is even higher than the European and world averages (Kovačič, Kolega and Brečko Grubar, 2019; Agencija RS za okolje, 2022).

Most of the Slovenian coast represents the abrasive type of coast, where different erosion driving forces prevail. Although most of the cliffs are in a mature form where abrasion is limited to occasional extreme storm events and the main erosion factors are rain erosion and weathering with occasional landslides, some of the cliffs, characterized by almost vertical walls and narrow shingle beaches at their toe, are subject to constant erosion by the waves, with the sea undercutting their steep slopes and forming marine notches (Vahtar, 2002). Although most of the coastline is protected by artificial structures, the stretches of low coast are flooded several times a year during of high tides. The area exposed to regular annual flooding covers 220 hectares, most of which is within the saltpans of Strunjan and Sečovlje, while extreme flooding affects over 600 hectares of land (Kovačič, Kolega and Brečko Grubar, 2019).

In this context, the main objective of this study is to quantitatively assess the vulnerability of the Slovenian coast to sea level rise. Our aim is to illustrate a relatively simple but efficient method for assessing the coastal vulnerability using the CVI and thus to verify the applicability of the methodology proposed by Gornitz (1991) in the analysis of the Slovenian coast.

2 Study area

The study area covers the Slovenian coast at the northern top of the Mediterranean, along the Gulf of Trieste, which is the northernmost part of the Adriatic Sea. The Gulf is a relatively small (approx. 570 km2) and shallow marginal sea with an average depth of 16.4 m. It is a geologically young sea, formed after the last glacial maximum with the onset of the Holocene transgression (Trobec et al. 2018), when river mouths were flooded by the sea, wide bays were formed, and the intervening ridges became peninsulas exposed to abrasion.

The Gulf of Trieste is shared by the three countries: Italy (65%), Slovenia (32%) and Croatia (3%) (Orožen Adamič, 2002). The Slovenian coast, from the Gulf of Sv. Jernej on the border with Italy to the mouth of the Dragonja on the border with Croatia, is only 46.6 kilometres long. Despite its shortness, it is very highly varied. It is a ria coast and can be divided into three types from a lithological point of view: limestone coasts, which make up 11% of the coast and are thus the least represented type of coast, occurring only near Izola; flysch coasts, which make up 60% of the coast; and coasts with alluvial and Holocene sediments, which occur along the alluvial plains and occupy 29% of the coast (Orožen Adamič, 1990).

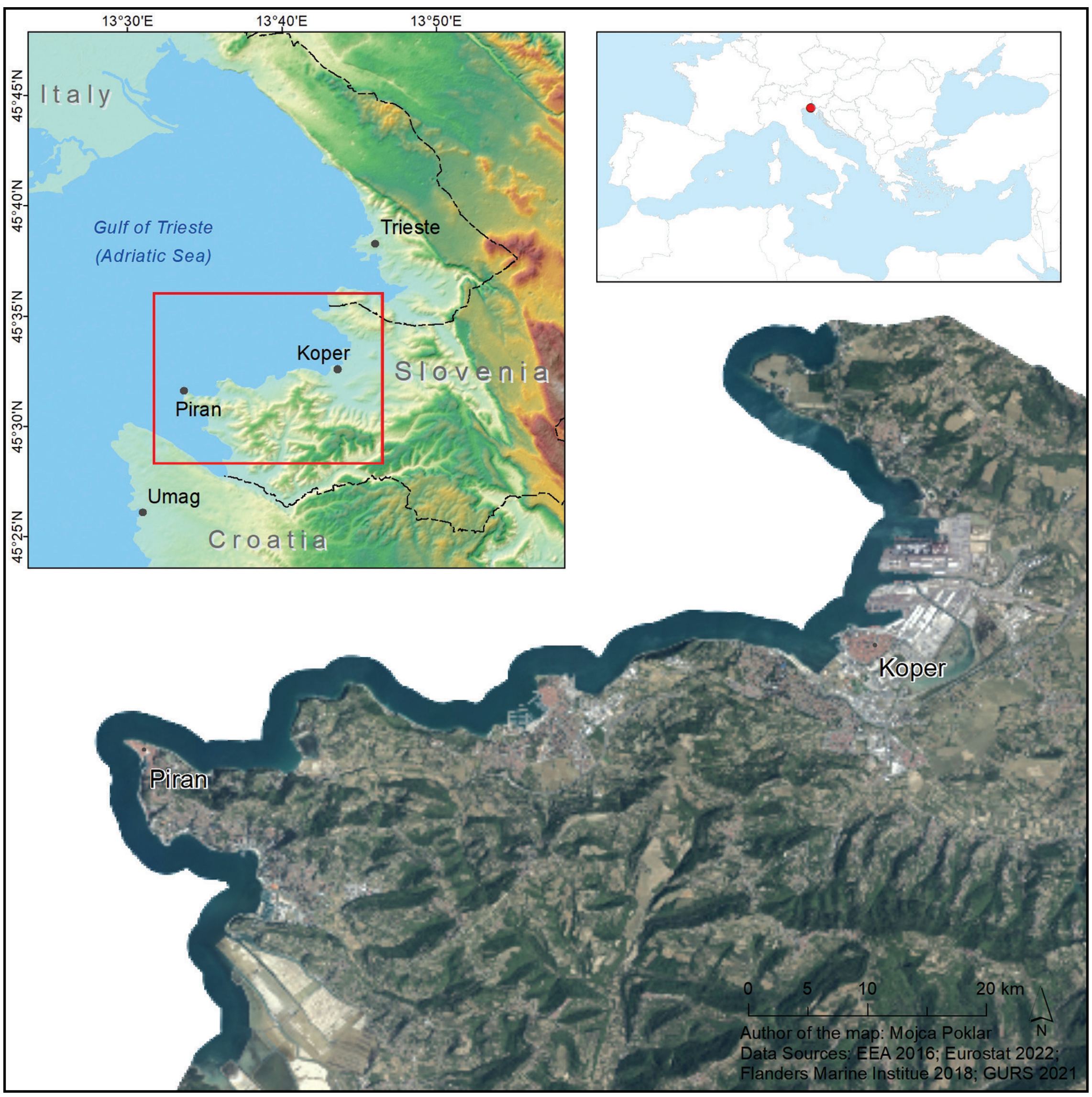

Figure 1: Map of the study area.

Most of the Slovenian coast represents the abrasive type of coast, characterized by extremely high slopes and dominated by the cliffs of marl and sandstone. The layers of sandstone emerge from the walls (turbidite limestone breccia is rare), which is more resistant and usually breaks off in larger pieces, while the marl weathers into gravel. Some of the cliffs reach a height of almost 80 m and are the highest flysch cliffs on the Adriatic (Orožen Adamič, 1990; Natek, Repe and Stepišnik, 2018).

In addition to the abrasive type, there is also the accumulative type of coast, which is formed by the deposition of large quantities of fine sediments by rivers. Rivers such as the Soča River and, to a lesser extent, the Dragonja River, the Rižana River and the Badaševica River, have created alluvial plains by depositing sediments, facing a shallow sea with a muddy, gently sloping seabed (Vahtar, 2002). The coastal plains are for the most part highly changed by human activities, which is a consequence of the extremely intensive urbanization of the Slovenian coastal area, reflected in the population density (more than 1500 inhabitants/km2 in the coastal settlements of Koper, Izola and Piran) and a large number of different socio-economic activities such as tourism, transport, industry and commerce (Koderman, Razpet and Poklar, 2021).

An important feature of the Slovenian sea is its shallowness. The average depth is 18.7 m, with the deepest point at 37.2 m at Punta in Piran. Along the Slovenian coast, the seabed slopes rapidly, albeit unevenly. The underwater slope is divided by folds, steep steps and abrasion terraces created by the gradual rise of sea level (Ogrin and Plut, 2009). Compared to the rest of the Adriatic, the surface sea currents are much weaker and their direction and speed are closely tied to the weather situation of the moment, while in contrast to the currents, the effects of the tides are stronger than elsewhere in the Adriatic, with the largest difference between low and high tide being more than 180 cm (Richter, 2005; Brečko Grubar, 2010).

3 Data

Data play an important role in vulnerability assessment, as the level of detail (national, regional or local scale), the spatio-temporal availability of data and their resolution strongly influence the methods to be used (Rocha, Antunes and Catita, 2020). In this study, seven physical variables were selected to assess the vulnerability of the Slovenian coast. The data sources with their accuracy and reference period are listed in Table 1.

Figure 2: The high, abrasive type (a) and the accumulative type (b) of the coast in Slovenia (photography by: Valentina Brečko Grubar, 2022 (a); Krajinski park Sečoveljske soline, 2017 (b)).

Table 1: Data used in the study and its source and reference period.

Variable	Data Source	Data accuracy	Period of Reference
Coastal elevation (m)	LIDAR/DEM (0.5 m) from Slovenian Environment Agency	0.5 m	2020
Coastal slope (°)	derived from DEM	0.5 m	2020
Orientation of the coast (azimuth)	derived from DEM	10 m	2020
Seabed slope (°)	sonar data/DBM (0.5 m) from Harpha sea, d.o.o. Koper	0.5 m	2016
Coastline covered by (artificial) protection structures	Orthophoto from the Surveying and Mapping Authority of the Republic of Slovenia / Field work and Mapping (GPS measurements)	0.25m / 1m	2021/2022
Beach width	Institute for Water of the Republic of Slovenia	0.5 m	2013
Geomorphological processes	Field work and Mapping (GPS measurements)	1 m	2022

The data used in this study are mostly from different national institutions (e.g., the Surveying and Mapping Authority of the Republic of Slovenia, Slovenian Environment Agency—ARSO, Institute for Water of the Republic of Slovenia), while for some variables (geomorphological processes, coastline covered by artificial protection structures) data collection in the field was necessary to obtain up-to-date information.

All spatial data are in the coordinate reference system Slovenia 1996 / Slovene National Grid (EPSG: 3794). A geospatial database, built in a Geographic Information System (GIS), was created to store all spatial data, facilitating the spatial data harmonization.

4 Methods

The methodology for this study is shown in Figure 2. Based on the literature review of different methodological approaches and the identification of available spatial and nonspatial data, we first identified some key variables that could contribute to the vulnerability of the Slovenian coast. Seven physical variables were selected to determine the Physical Vulnerability Index (PVI). As some authors argue that the CVI needs to take into account both physical and socio-economic variables and in this study only physical variables are considered, we called the index PVI instead of CVI. All these parameters were implemented in a GIS and subjected to various spatial analyses to calculate the vulnerability scores of the variables. Finally, the PVI was calculated using a slightly modified formulation of that presented by Gornitz (1991). The whole procedure was based on the implementation of the relevant data in a GIS, which was used for data collection, processing and finally mapping of the results. The software used for this study was ArcGIS® 10.7.

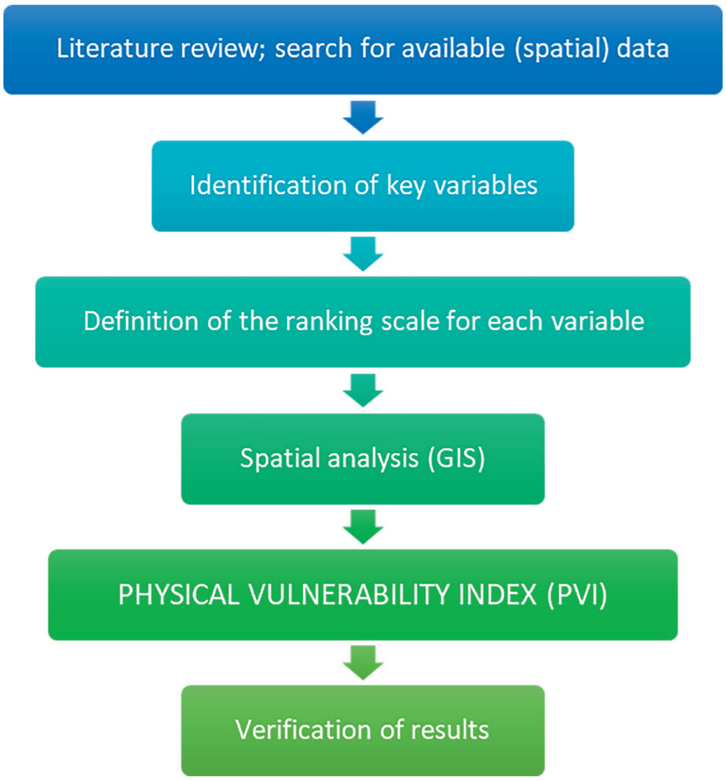

Figure 3: Flowchart illustrating the methodology used in this study.

Finally, the accuracy and reliability of the vulnerability assessment results were verified in the field and compared to current conditions and previous research results at several sites. The study area was surveyed using an aerial vehicle, with aerial photographs taken at specific locations.

4.1 Variables selection and vulnerability ranking

The selection of variables to be included in the calculation of the PVI was based on an extensive literature review and the availability of spatial and nonspatial data for the Slovenian coast. As mentioned above, seven physical variables were selected for the assessment of the PVI. These are (a) coastal elevation, (b) coastal slope, (c) orientation of the coast, (d) seabed slope, (e) coastline covered by artificial protection structures, (f) beach width and (g) geomorphological processes. Relative sea level change, mean significant wave height and mean tidal range, which are normally considered in other coastal vulnerability studies, were not selected because their influence is uniform in the study area.

Based on the literature reviews and discussions with experts, vulnerability scores from 1 to 5 were assigned to the values of each variable, with 1 being the lowest contribution to vulnerability and 5 being the highest. Table 2 shows the range of vulnerability for the seven variables. All these variables were implemented in a GIS where the extraction of the values for each variable was performed.

Table 2: Vulnerability ranking assigned for physical variables.

Variables	Coastal Vulnerability Ranking				
	Very low (1)	**Low (2)**	**Moderate (3)**	**High (4)**	**Very high (5)**
Coastal elevation (m)	> 179	115–179	60–115	30–60	< 30
Coastal slope (°)	2.3–5.7	5.7–9.8	9.8–15.7	15.7–24.5	24.5–38.1
Orientation of the coast	E	-	NW, W, SW	NE, N	SE, S
Seabed slope (°)	0.43–2.71	2.71–4.27	4.27–5.72	5.72–7.81	7.81–12.44
Coastline covered by artificial protection structures (%)	80–100	60–80	40–60	20–40	0–20
Beach width (m)	> 10	7.5–10	5–7.5	0–5	0
Geomorphological processes	areas without cliffs	mature cliff (completely covered with vegetation)	mature cliff (partly, in the lower part covered with vegetation)	active cliff (no visible rock shelters, erosion gullies, etc.)	active cliff (visible rock shelters, erosion gullies, etc.)

The first variable considered in the calculation of the PVI is the coastal elevation (a). It is defined as the average elevation (m) of an area above mean sea level. The elevation in the study area ranges from -0.7 m to 44 m. High elevations make the coast less vulnerable, while low elevations make it highly vulnerable. In this study, coastal elevation data was derived from a digital elevation model (DEM) with a horizontal resolution of 0.5 m, which was created from LIDAR data.

The second variable considered in the analysis is coastal slope (b). It is an indicator of the relative vulnerability to flooding and the potential retreat of the coastline. Coastal slope was derived from the DEM. It was defined as the average slope from the coastline to 100 m inland. Coastal slope varies from a few degrees on beaches, where lower vulnerability scores have been assigned to coastal segments, to very steep or vertical cliffs with higher vulnerability scores where extreme erosion or rock falls are possible.

The orientation of the coast (c) is determined by the compass direction in which the slope faces for each location. It was derived from the DEM, by performing an aspect analysis. In contrast to the slope analysis, it was calculated on DEM with a resolution of 10 m. The reason for this is that the DEM with a resolution of 0.5 m would produce an aspect surface that is too fragmented, as the orientation is calculated for each cell individually and does not give us a picture of the general (predominant) orientation of the coast in a given area. The orientation of the coast is related to the exposure of the coastline to wind-generated waves. The winds that statistically generate the largest waves on the Slovenian coast are three, namely *jugo* (S and SE), *burja* (NE) and *tramontana* (N, NW). These coastal orientations were ranked as very highly, highly and moderately vulnerable respectively.

The seabed slope (d) variable is related to the ability of the coast to dissipate wave energy and reduce the impact on the coastline. It was defined as the average slope from the coastline to 100 m seaward. Along the Slovenian coast, the seabed descends rapidly, albeit unevenly. The flatter the nearshore area, the greater its ability to dissipate wave energy and reduce the impact on the coastline. On steep underwater slopes, large waves can break on the beach with greater force than on shallow slopes. The seabed slope in the study area ranges from 0.43° to 12.44°. Steeper seabed was associated with high vulnerability, while flatter seabed was associated with moderate and lower vulnerability. In this study, seabed slope data was derived from a digital bathymetric model (DBM) with a horizontal resolution of 0.5 m, which was created from sonar data.

The presence of artificial protection structures (e) was manually digitised using the orthophoto of the Surveying and Mapping Authority of the Republic of Slovenia. Despite its high resolution (0.25 m), there were coastal segments where protection structures were not fully visible and therefore difficult to determine. In these cases, the protection structures were captured on site, using the mobile application Mergin Maps. The vulnerability scores were assigned based on the percentage of the coastline in each segment covered by the artificial protection structures, with smaller percentages associated with higher vulnerability and vice versa.

Beach width (f) is another variable related to the ability to dissipate wave energy. The beach areas were defined and marked as polygons, with their width calculated as the difference between mean sea level and mean higher high waters using the ArcGIS Digital Shoreline Analysis System (DSAS) tool, which is normally used to calculate the coastline change rate. The beach width ranged from 0 m to 80.33 m, with a mean beach width of 3.3 m. A wider beach has a greater ability to dissipate the wave energy and to reduce the impact of extreme events. Therefore, beaches narrower than 5 m were classified as highly vulnerable, while beaches wider than 7.5 m were recognised as segments with low vulnerability.

Since the classified parameters of coastal elevation, coastal slope, orientation of the coast and seabed slope refer to the actual coastal topography given by a recent digital terrain model (DEM from 2020 and DBM from 2016) without any future morphodynamics, the PVI only assesses the actual coastal vulnerability to the future threat of sea level rise. This means that future coastal erosion cannot be directly considered in the current vulnerability assessments, but only indirectly through physical parameters of the geology and geomorphological processes in the PVI formulation (Rocha, Antunes and Catita, 2020). As the Slovenian coast is geologically relatively uniform, the geological structure does not play a decisive role in shaping the surface in most parts of the study area. The bedrock is mainly Eocene flysch with alternating layers of marl and sandstone (Natek, Repe and Stepišnik, 2018). For this reason, instead of geology, we have considered geomorphological processes (g), which deal with coastal morphology due to marine processes and landscape evolution. They represent the response of the coast to both erosion and sea level rise. The geomorphological processes were identified and captured on site, using the mobile application Mergin Maps. The vulnerability scores were assigned based on the presence or absence of geomorphological processes and their characteristics. Active cliffs with visible rock shelters, erosion gullies and other geomorphological forms were classified as highly vulnerable, whereas mature cliffs, partly or fully covered with vegetation were assigned lower vulnerability scores.

4.2 Segmentation of the coast and calculation of the PVI

When ranking the coastline based on variables that determine vulnerability, it is useful to first divide the coastline into different sections. In this way, we can identify high priority areas for vulnerability reduction (Nguyen et al., 2016). In this respect, the study area was divided into 214 segments ("sectors") for the coastal vulnerability assessment. These segments have an approximate length of 200 m, while the landward/seaward boundary for each segment was chosen to be 100 m from te coastline.

The PVI was calculated for each segment. It was obtained by taking the square root of the product of the vulnerability scores assigned to each variable divided by the total number of variables:

$$PVI=\sqrt[2]{(a\times b\times c\times d\times e\times f\times g)/7}$$

where a = Coastal elevation, b = Coastal slope, c = Orientation of the coast, d = Seabed slope, e = Coastline covered by artificial protection structures, f = Beach width, g = Geomorphological processes. The PVI values were then normalised to a scale of 1 to 5 according to the formula:

$$N(vi)=((vi-Vmin)/(Vmax-Vmin))\times 5$$

where $N(vi)$ is the normalized vulnerability value vi for variable V, $Vmin$ is the minimum value for variable V, and the $Vmax$ is the maximum value for variable V.

5 Results and discussion

5.1 Vulnerability scores based on variables

The vulnerability scores for each variable, assigned to each of the 214 coastline sections based on the vulnerability classification in Table 2 are shown in the Figure 4.

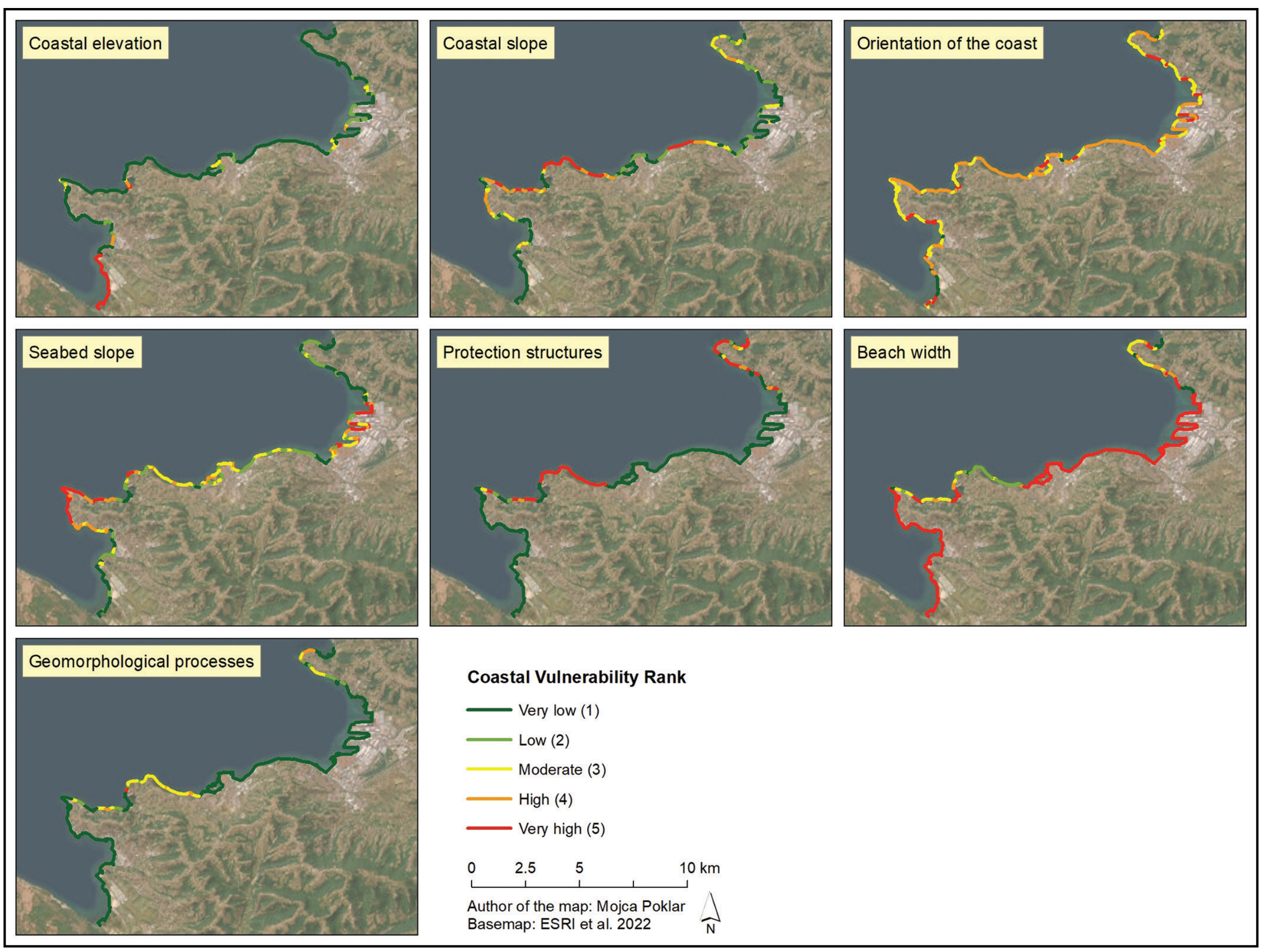

Figure 4: Map showing vulnerability values for each variable for each segment in the study area.

We can see that not all seven variables affect the coastal vulnerability of the study area in the same way. According to the coastal elevation, the results of the vulnerability evaluation show that low coasts, where saltpans and artificial lagoons have been developed, are mainly observed and are therefore very vulnerable. They account for 8.4% of the total coastline. In contrast, higher elevations with very low vulnerability cover 80% of the total study area. Coastal slope varies from a few degrees on beaches, where lower vulnerability values have been assigned to coastal sections, to very steep or vertical cliffs with a higher vulnerability ranking where extreme erosion or rock falls are possible. A good third of the coast is classified as moderate to highly vulnerable (14% moderate, 10% high and 12% very high vulnerability). Depending on the orientation of the coast, moderate to very high vulnerable areas are those under the influence of winds that statistically cause the largest waves on the Slovenian coast. These areas are south, south-east, north-east, north and north-west oriented and together account for 96% of the coastline, with almost half of the coastline classified as highly or very highly vulnerable. The remaining 4% of the coastline, consisting mainly of the coast in Sečovlje (SW of the study area), was ranked with low vulnerability as the coast there is resistant to wave attack due to its location. Along the Slovenian coast, the seabed descends rapidly, albeit unevenly. The seabed slope in the study area ranges from 0.43° to 12.44°. Slopes of more than 7.81°, classified as very highly vulnerable, account for almost 20% of the total coastline and are found in the port of Koper (artificial deepening of the seabed) and around the Punta in Piran, where the lowest point of the Slovenian sea is located. According to the presence of artificial protection structures, a large part of the Slovenian coast (76%) is categorized as very low vulnerable. This includes the artificial coastline in the port of Koper, from Koper to Izola and south of the town of Piran. In contrast, the abrasive type of coastline, where natural coasts can still be found, was classified as very highly vulnerable. It accounted for 20% of the entire coastline. Beach width is the variable that has the largest percentage of very high vulnerability scores. Most of the coastline (about 74%) is ranked as very highly vulnerable. These segments are artificial stretches of coastline without beaches. 4% of the coastline is highly vulnerable, 10% shows moderate vulnerability, while 7% and 5% is classified with low and very low vulnerability respectively. On the other hand, geomorphological processes is the variable that has the largest percentage of very low vulnerability scores. The identification and ranking of the geomorphological processes was carried out on the cliffs, so that the areas without cliffs, which make up most of the Slovenian coast, were assigned a very low vulnerability score. These areas account for 81% of all the coastline. As many of the existing cliffs on the Slovenian coast are in mature form and partly or fully covered with vegetation, their contribution to vulnerability is relatively low. On the other hand, active cliffs with visible rock shelters and erosion gullies have been classified as highly and very highly vulnerable. They comprise only 4% of the coastline.

5.2 Final vulnerability score

The final vulnerability scores for each variable and for each segment are shown in Figure 5 for all segments.

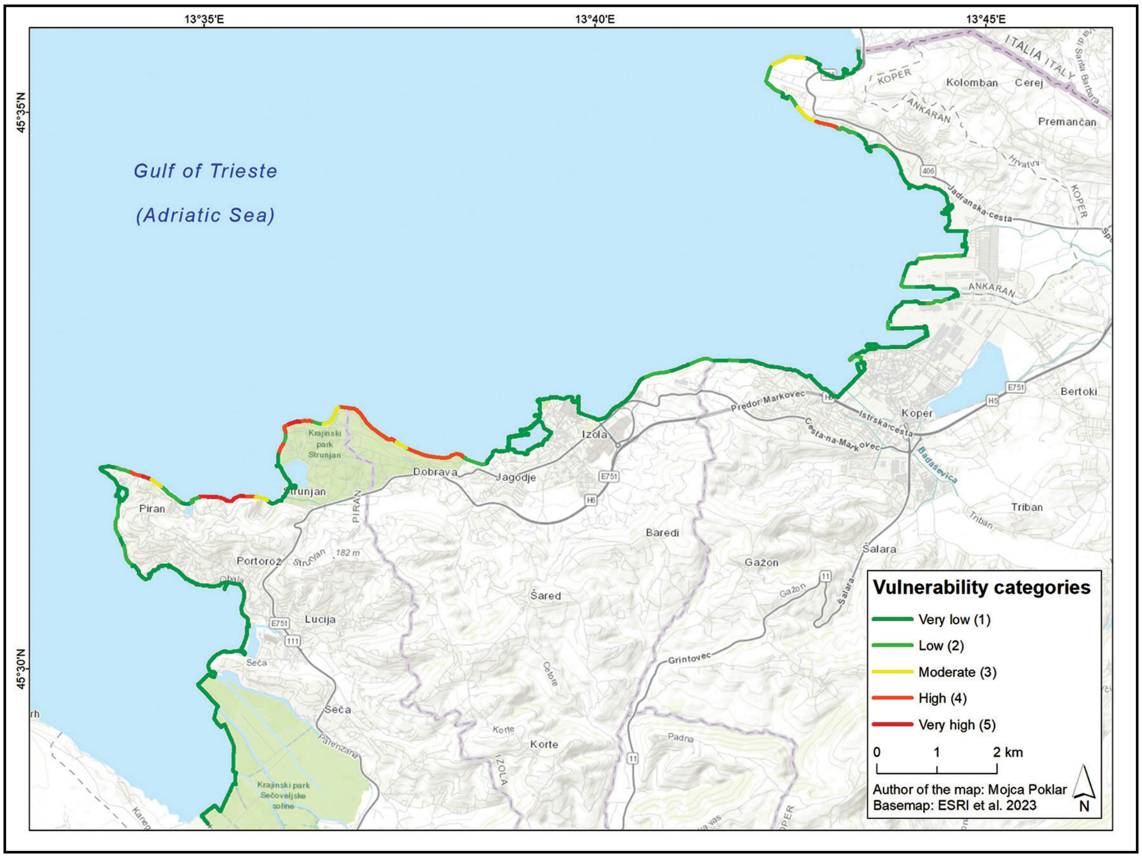

Figure 5: Map showing final vulnerability scores for each segment in the study area.

The results show that 7.5% of the coastline can be classified as highly vulnerable and 2.5% as very highly vulnerable. The highest vulnerability to sea level rise is shown on the abrasive coastline with steep and crumbling cliffs of marl and sandstone in the northern part of Piran, Pacug and Strunjan. These areas are characterised by greater slopes of the terrain, both landward and seaward of the coastline and a mostly northerly orientation of the coast, which is exposed to frequent and strong northerly and north-easterly winds. The coastline here is in an almost natural state, lacking the presence of artificial protection structures to reduce erosion. In fact, these almost vertical cliffs are exposed to constant erosion by waves and rock falls, which is reflected in various geomorphological processes. All these factors contribute to the highest vulnerability to sea level rise. The extensive and steep cliff of Belvedere in Izola was only classified as highly vulnerable, mainly because of the greater width of gravel beaches at its toe, reducing the impact of the extreme events.

The cliffs in the south-western and in the northern part of Debeli rtič, Ankaran and some parts between the already mentioned cliffs in Piran, Pacug and Strunjan are in a mature state, where wave erosion is limited only to occasional extreme storm events. The terrain here is not as steep, and there are slopes of the seabed that are considered less vulnerable. These areas, representing 4.1% of the coastline, are classified with moderate vulnerability.

Most of the low and very low vulnerability scores are assigned to those segments on the accumulative type of coast with coastal plains facing a shallow sea with muddy, gently shelving seabed. The coastal plains are mostly heavily modified by human activities, so these sections are largely protected by artificial structures which contribute to flood attenuation.

6 Conclusion

The PVI is a useful method for the assessing the relative physical vulnerability of a coastline to the impacts of climate change. The proposed method is quite simple to implement, repeatable and widely applicable and allows vulnerability maps to be obtained quickly for a 'first assessment'.

However, there are still some considerations in defining a more accurate index to model the vulnerability of the Slovenian coast. Due to the different role of individual parameters in calculating the vulnerability of high, abrasive type of coast and low, accumulative type of coast, it would make sense to carry out separate PVI calculations in which the individual variables are weighted differently. The vulnerability of the abrasive type of coast is mainly related to abrasion processes and cliff retreat, while the vulnerability of the accumulative type of coast is related to flooding or sea spreading to the lowlands and estuaries. The increase in vulnerability of both types will be strongly influenced by sea level rise, and the impacts of each parameter considered in the PVI will vary.

Consideration of the socio-economic factors in vulnerability assessment is also important, as we assess the coastal vulnerability from an anthropocentric perspective. Here we have in mind the material damage that will occur in the future due to more intense abrasion processes and flood events. As a result of the retreat of the cliffs, some buildings located near or at the edge of the cliffs are already at risk, for example the church in Piran, the natural vegetation and cultivated areas on the Debeli rtič peninsula or above the cliffs in Strunjan. With the rise of the sea level, especially at high tide and increased wave action, mature cliffs, which today are only reshaped by geomorphological processes or are mostly covered by vegetation, will also come within the reach of the sea. The "reactivation" of abrasively active cliffs will increase soil erosion, cause property damage, affect plant and animal habitats at the edge of the cliffs, and threaten the tourist use of the beaches.

During the highest tides, which occur more frequently during the full and new moon in the autumn months, the lower parts of the coast have already been flooded by the sea in the past. The most affected are the town of Piran, where a densely populated area extends along the coast, and the areas of the former salt pans in Sečovlje and Strunjan, which are now protected natural areas with significant cultural heritage. As the sea level rise, the frequent annual floods will be comparable to the current extreme floods. This means that parts of the coastal strip along the low coast would be permanently below the sea level, leading to changes in coastal ecosystems and even loss of habitat for fish, birds and plants. During high tide, the floodplain would expand greatly. Even if the land were dry at low tide, its use would be very limited and unsuitable for agriculture because of contamination of the soil with salt. The protected wetlands on the Slovenian coast (Škocjanski zatok Nature Reserve, Sečovlje Saltpans Landscape Park and Stjuža in Strunjan Landscape Park), would also completely "disappear" once and for all.

In order to adapt to the future conditions, knowledge of coastal vulnerability is very important. This is the only way to reduce the negative impacts and the resulting damage to people and their activities. The aim of our future research is therefore to validate the proposed index by comparing it with the more complex numerical models in order to make the index a useful tool for coastal planning and management. This includes (1) weighting the key parameters of vulnerability assessment, based on the Analytic Hierarchy Process;

(2) taking into account socio-economic or anthropological parameters such as land use, population and water management to finally calculate the Integrated Coastal Vulnerability Index; and (3) deriving two different indices, one assessing vulnerability in terms of erosion and the other in terms of flooding. Although further improvements in the methodology are needed to assess coastal vulnerability to sea level rise in Slovenia, the present results are an important contribution to the identification of coastal vulnerability.

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