COASTAL VULNERABILITY ASSESSMENT FOR MERSİN AND İSKENDERUN BAYS, NORTHEASTERN MEDITERRANEAN

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FAHRİ AYKUT

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submitted by **FAHRİ AYKUT** in partial fulfillment of the requirements for the degree of **Master of Science in Oceanography, Middle East Technical University** by,

Prof. Dr. Barış SALİHOĞLU
Director, Institute of Marine Sciences of **METU** ________________

Assoc. Prof. Dr. Bettina FACH SALİHOĞLU
Head of the Department, Oceanography**, METU-IMS** ________________

Assist. Prof. Dr. Devrim TEZCAN
Supervisor, Marine Geology and Geophysics**, METU-IMS** ________________

Examining Committee Members:

Assoc. Prof. Dr. Bettina FACH SALİHOĞLU
Oceanography, METU-IMS ________________

Assist. Prof. Dr. Devrim TEZCAN
Marine Geology and Geophysics**,** METU-IMS ________________

Assist. Prof. Dr. Fulya YÜCESOY ERYILMAZ
Geological Eng., Mersin University ________________

Date: 15.02.2021

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name Last name : Fahri Aykut

Signature :

ABSTRACT

COASTAL VULNERABILITY ASSESSMENT FOR MERSIN AND İSKENDERUN BAYS, NORTHEASTERN MEDITERRANEAN

Aykut, Fahri
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Coasts are sensitive and dynamic areas against natural influences such as waves, winds, currents, and tides. Pressure of human activities also accelerate the change of coasts. Climate change and global sea level rise are other factors affecting the coasts. Therefore, the identification and protection of coasts, which are important in terms of socio-economically and natural environment, becomes an important issue.

One of the main purposes of this study is to classify Mersin and İskenderun bays coasts according to their vulnerability to natural forces and anthropogenic factors using the Coastal Vulnerability Index (CVI) methods. In this study, five different CVI methods are used to evaluate the vulnerability of coasts.

To easily adapt all these method a Geographic Informations System (GIS) tool has been developed. This GIS tool will facilitate researchers for CVI calculations. In addition, this tool will help decision makers to take the necessary precautions to protect coasts and to increase their resistance to natural and human effects on the coasts.

According to the coastal vulnerability analyses, 151 km of the coastal zone is classified as very high vulnerable, 147 km as high vulnerable, 153 km as moderate vulnerable and 138 km as low vulnerable. In this study, the main parameters to affect the vulnerability are the coastal slope, land-use and population. High and very high vulnerable coasts occurred in coastal plains with low slope, weak geological and geomorphlogical structures, high socio-economic values. These high and very high vulnerable coasts are mainly located between Silifke and Yumurtalık coasts.

Keywords: Coastal Vulnerability Index, Vulnerability, Mersin, GIS

ÖZ

KUZEYDOĞU AKDENİZ MERSİN VE İSKENDERUN KÖRFEZLERİ İÇİN KIYISAL KIRILGANLIK DEĞERLENDİRMESİ

Aykut, Fahri
Yüksek Lisans, Oşinografi
Tez Yöneticisi: Dr. Öğr. Üyesi Devrim Tezcan

Şubat 2021, 108 sayfa

Kıyılar, dalga, rüzgar, akıntı, gel-git gibi doğal etkilere karşı hassas ve değişken alanlardır. İnsan aktiviteleri de kıyılar üzerinde baskı oluşturarak kıyıların değişimini hızlandırmaktadır. İklim değişikliği ve küresel su seviyesi yükselmesi de kıyıları etkileyen diğer faktörlerdir. Dolayısıyla, sosyo-ekonomik ve doğal çevre açısından önemli olarak kıyıların tanımlanması ve korunması önemli bir konu haline gelmektedir.

Bu çalışmanın temel amaçlarından birisi, Mersin ve İskenderun Körfezi kıyılarını Kıyısal Kırılganlık İndeksi (KKİ) yöntemleri kullanılarak, doğal kuvvetlere ve insan kaynaklı faktörlere karşı kırılganlıklarına göre sınıflandırmaktır. Bu çalışmada kıyıların kırılganlığını değerlendirmek için beş farklı KKİ yöntemi kullanılmıştır.

Tüm KKİ yöntemlerine kolayca uyum sağlayabilmek için bir Coğrafi Bilgi Sistemi (CBS) aracı geliştirilmiştir. Bu CBS aracı, araştırmacıların KKİ hesaplamalarını kolaylaştıracaktır. Ayrıca bu araç kıyıların doğal ve insan etkilerine karşı dirençlerinin arttırılması ve kıyıların korunması için gerekli önlemler alınmasında karar vericilere yardımcı olacaktır.

Kıyısal kırılganlık analizlerine göre, çalışma bölgesinin 151 km'si çok yüksek derecede, 147 km'si yüksek derecede, 153 km'si orta derecede ve 138 km'si düşük derecede kırılgan olarak sınıflandırılmıştır. Bu çalışmada kırılganlığı etkileyen temel parametreler kıyısal eğim, arazi kullanımı ve nüfustur. Yüksek ve çok yüksek derecede kırılgan olan kıyılar, düşük eğimli, jeolojik ve jeomorfolojik yapıları zayıf, sosyo-ekonomik değerleri yüksek kıyı ovalarında bulunmaktadır. Bu yüksek ve çok yüksek kırılgan kıyılar genellikle Silifke ve Yumurtalık kıyıları arasında yer almaktadır.

Anahtar Kelimeler: Kıyısal Kırılganlık İndeksi, Kırılganlık, Mersin, CBS

Dedicated to my family

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INTRODUCTION

1.1. Coasts

Coastal zones are the most important areas for human and economic activities and ecosystem. Vulnerability of the coastal zones against the natural impacts should be carefully examined to protect the nature of the coasts. A significant part (~37%) of the global population live in the coastal zone (The Ocean Conference, UN, 2017). Similarly, the population density of the coastal zones in Turkey is intense; about 45 million people (54.8 % of the Turkey population) live in coastal cities.

Coasts have significant resources for economic activities. For instance, coastal waters are the highways of the global trade. About 90 percent of the global goods are transported by ship (WOR, 2017). In addition, marine and coastal tourism is a significant economic sector. Recreational activities such as swimming, fishing, surfing, boating attract make the coasts an important tourist destination. It is reported coastal and maritime tourism is the Europe's largest tourism sub-sector and also the largest single maritime economic activity in terms of jobs (3,2 million jobs) and value added (over 180 billion Euros) in EU countries in 2014 (EC Report 2016). Moreover, fisheries sector is a key contributor to the global economy. It is estimated that 90% of fishing vessels are operated in coastal waters. The General Fisheries Commission for the Mediterranean (GFCM) estimated that Mediterranean fisheries had a collective worth of US$3.2 billion in 2016 (Randone et al., 2017). The coastal areas with alluvial accumulation plains provide favorable soil and climatic conditions for more productive agriculture. Furthermore, coastal agriculture provides food and also livelihood support to coastal populations.

The coastal areas are important not only for high economical value but also biologically. As being a transition zone between sea and land, they encompass great species diversity which play a significant role for ecosystems. They provide nourishment for a wide range of biodiversity such as important bird populations, mangroves and seagrass, which provide nursery grounds for fish.

The coastal zones are sensible and dynamic habitats. There are shaped continuously by natural forces such as wind, waves, tides, and currents. They are also under pressure of human activities. Climate changes related drivers result in more severe and often natural events such as storms. This vulnerability of the coastal areas to these natural impacts increase with the human related drivers such as uncontrolled land use, unbalanced population density, environmental pollution and misuse of coastal resources.

1.2. Climate change

Climate is defined as the conditions of atmosphere including temperature, precipitation, and wind. Although most of discussions focus the last centuries climate change, the climate has oscillated throughout the history of the earth. Climate change evidences are preserved in marine and lake sediments and ice sheets. The cores drilled through the ice sheets produced a record of polar temperatures and atmospheric composition for the last 800,000 years in Antarctica (Figure 1.1; Lüthi et al., 2008). About 3.2-kilometer continuous ice core from Antarctica contains a record of past atmospheric concentrations of carbon dioxide and methane as the ice accumulates.

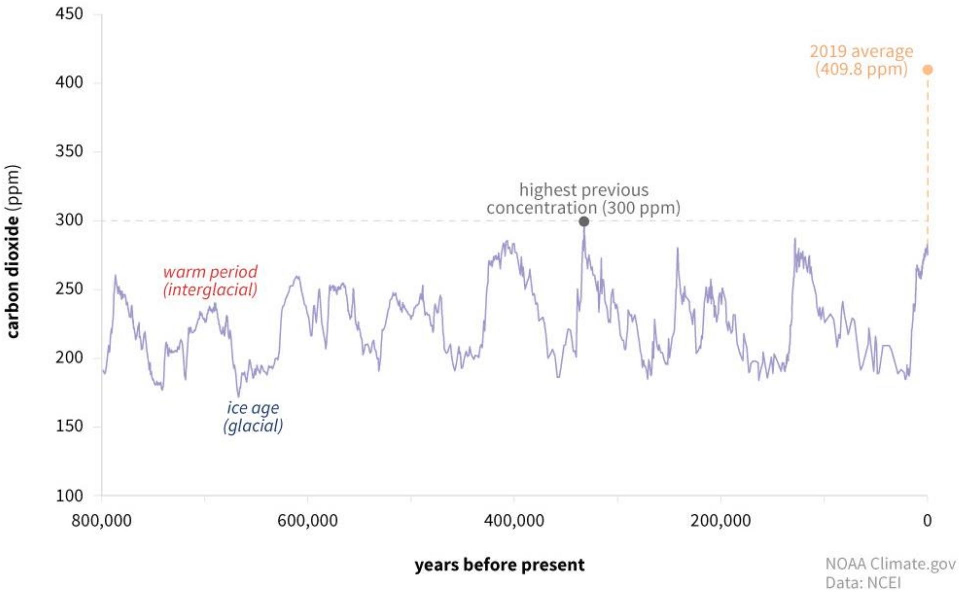


Figure 1.1. Carbon Dioxide (CO_2) record of the past 800,000 years (from Lüthi et al., 2008).

The temperatures anomalies show that several cycles of glacial-interglacial periods occurred in the last 800,000 years. The last glacial period ended up about 11,000 years ago and the Holocene, the most recent interglacial period, started.

The variations in climate have been affected by many natural factors such as the changes in solar energy, variations in Earth's orbit, volcanic eruptions, and even the movement of tectonic plates. Although these natural factors are the main contributors of the past-climate changes, human activities have accelerated the changes in climate including warming.

Intergovernmental Panel on Climate Change (IPCC), established in 1988, is a worldwide group of atmospheric and climate scientists sponsored by the United Nations Environment Programme and the World Meteorological Organization. IPCC has studied the human effects on climate change and global warming. IPCC reports (2007, 2014) show that anthropogenic greenhouse gas emissions have increased since the pre-industrial era (Figure 1.2). It is thought that some gases such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) cause the Earth to overheat by preventing the reflection of the radiation from the Sun to space and trapping the heat in the Earth's atmosphere. Humans are altering global climate and they are producing significant impacts on physical and biological systems worldwide by adding emissions to the atmosphere (IPCC, 2014).

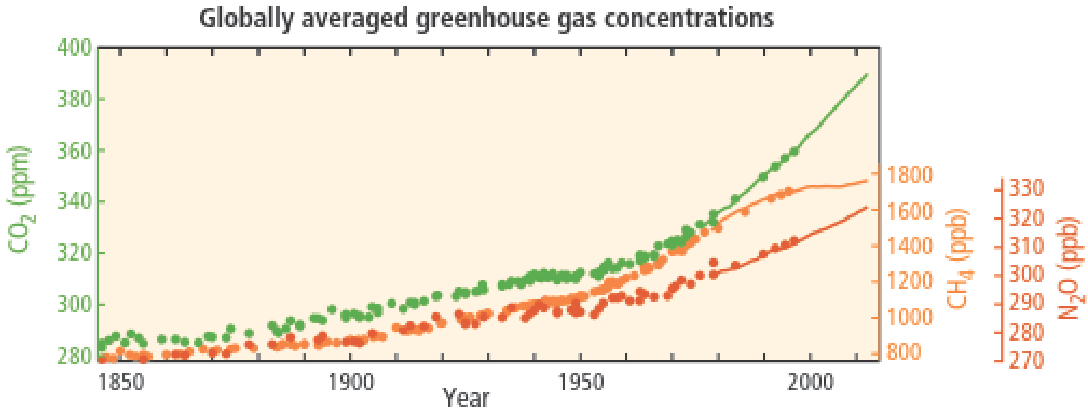


Figure 1.2. Atmospheric concentrations of the heat trapping gases. Green line and dots represent carbon dioxide (CO_2) concentration, orange line and dots represent methane (CH_4) concentration, red lines and dots represent nitrous oxide (N_2O) concentration. Lines determined from direct atmospheric measurements. Dots determined from ice core data. (IPCC, 2014)

As a result of the climate change, the globally average surface temperature has increased 0.85 C° over the period 1880 to 2012 (Figure 1.3). In addition, ocean warming dominates the increase in energy stored in the global climate system and it accounts for more than 90% of the energy accumulated between 1971 and 2010 (IPCC, 2014). As a result of global warming, it has been observed in different events such as melting of ice sheets, decreasing snow cover extent and earlier blooming of plants in spring (Karl et al., 2009).

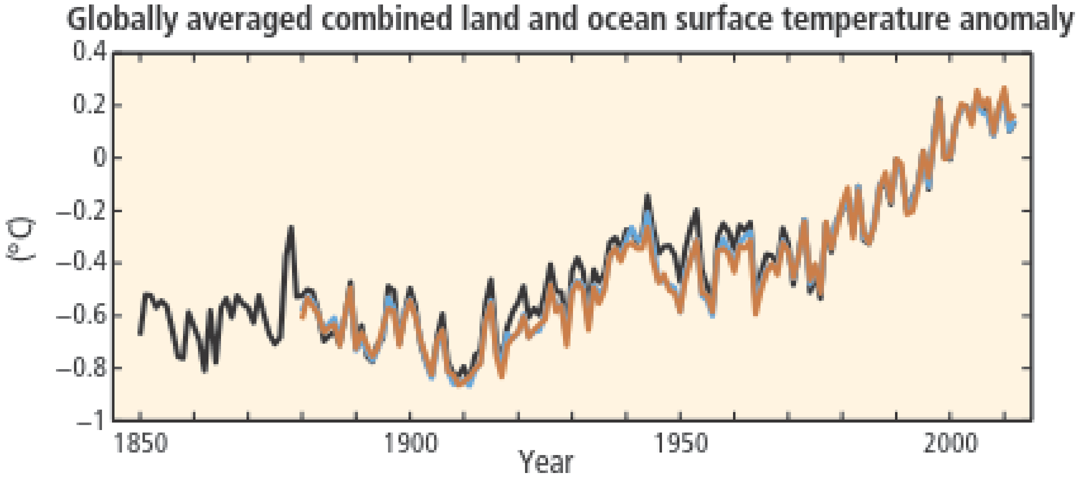


Figure 1.3. Globally averaged combined land and ocean surface temperature anomaly in 1850 to 2012. Lines with different colours show different data sets. (IPCC, 2014)

1.3. The impacts of the Climate Change

The coastal zones are under threat of many natural and anthropogenic factors. Climate change increase the effects of natural impacts such as sea level rise, ocean temperature. The potential impacts of the climate changes are presented in Figure 1.4. Climate change has many direct and indirect impacts on the environment as well as humans.

The change of the precipitation patterns is one of the consequences of climate change. Precipitation is related to atmospheric circulation patterns, presence of moisture and land surface effects. As the first two of these factors affected by temperature, global warming is expected to change precipitation patterns.

Global warming will intensify the Earth’s water cycle and will increase the evaporation. Increased evaporation will result in more frequent and intense storms, but will also contribute to drying over some land areas.

As a result of the increasing carbon dioxide concentration in the atmosphere, an increase of the wetland production is observed. In addition, because the ocean absorbs carbon dioxide from the atmosphere, sea water becomes less alkaline and this phenomenon is called ocean acidification. It affects the process of calcification by which living things create shells and skeletons in the coastal zone. Moreover, it adversely affects some plankton species and coral reefs (Karl et al., 2009).

Increasing the ocean surface temperature is another impact of the climate change. As a result of the increasing the sea surface temperature, a rapid growth in the algae population is observed, and this causes large amounts of nutrients to enter the water system, depletion of oxygen levels and blocking the sunlight from reaching other organisms. On the other hand, increases in sea surface temperature make a stress for coral reefs. Therefore, algae which provide 90% of the energy of corals, are extracted from the coral tissues (Dove and Hoegh-Guldberg, 2006). Corals turn white when they lose their algae. This process is called coral bleaching. Coral bleaching may cause corals to die (Karl et al., 2009).

With climate change, extreme wind events, higher ocean waves and more intense storms have been observed. These changes affect the coastal areas negatively. Major impacts are beach rotation, benthic damage, infrastructure damages and storm surges in the coastal zones (Figure 1.4; Short and Woodroffe, 2009)

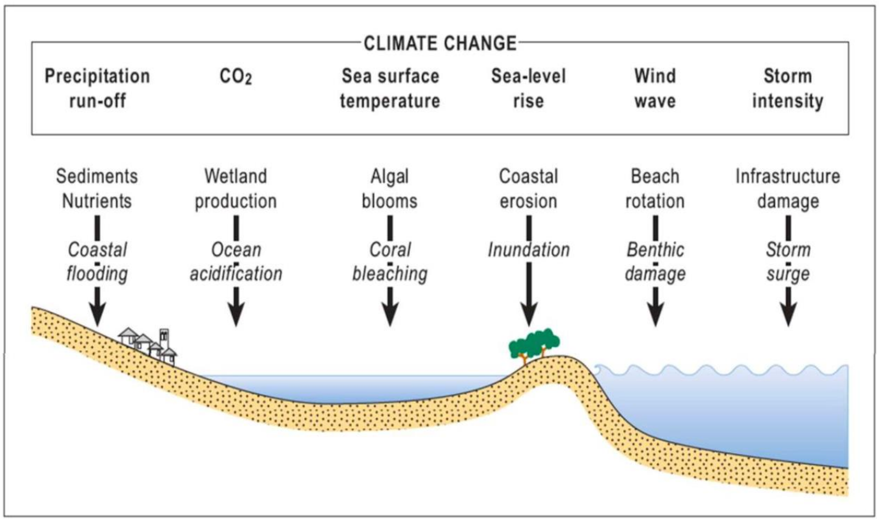


Figure 1.4. The potential impacts of the climate changes on coastal zones (Short and Woodroffe, 2009)

1.3.1. Sea Level Rise

One of the important impacts of climate changes on coastal areas is sea-level rise. The main cause of the sea level rise is the global warming. Because of the global warming, the glaciers and the ice sheets are melting and adding water to the ocean that rise the sea level. On the other hand, as the sea water warms, the volume of the ocean is expanding. This process is called thermal expansion.

Coastal zones are among the most vulnerable areas to climate change. Sea level rise, as one of the most critical climate change impacts, has a wide range of physical and ecological effects on coastal zones. These include inundation, flood and storm damage, loss of wetlands, erosion, saltwater intrusion and rising water tables. Higher sea water temperatures, changes in precipitation patterns and changes in storm tracks, frequency and intensity are the other climate impacts that affect coastal systems.

Escalation of coastal erosion and increased risk of inundation as a result of sea level rise combined with storm surge may lead to loss of habitat in ecosystems, as well as damage and loss in settlements and infrastructure. Although sea level rise is a major driver, other climatic and non-climatic stresses should be considered within a vulnerability and adaptation assessment. Rising sea surface temperatures, changing current systems and water mass properties and acidification may also change the costal structure as well as the biodiversity of coastal species. Rapidly growing population and economy within the coastal zone also increase the vulnerability of the coastal systems. The assessment of the risks and vulnerability of the coastal systems are essential for coastal managers to deal with these impacts.

IPCC produced some greenhouse gas concentration scenarios. Greenhouse gas concentration path is defined as a Representative Concentration Pathway (RCP). There are several RCP scenarios which are used for the future climate predictions. These future predictions are relative to past observations (IPCC, 2014). According to RCP 2.6, the carbon dioxide (CO_2) emissions start declining by 2020 and go to zero by 2100. Future predictions show that the global sea level will be higher than

40 cm than present sea level, according to RCP 2.6 which is the most optimistic scenario. On the other hand, RCP.8.5, which is the worst scenario, indicates that CO_2 emissions continue to rise throughout the 2100. According to RCP 8.5, the global sea level in 2100 will be 1 meter higher than the sea level in 2000 (Figure 1.5). Consequently, even the most optimistic scenario suggest that the sea level will continue to rise throughout the 2100. In addition, Figure 1.5 indicate that even if the precautions are taken now, mitigation of the sea level will show their effect after many years.

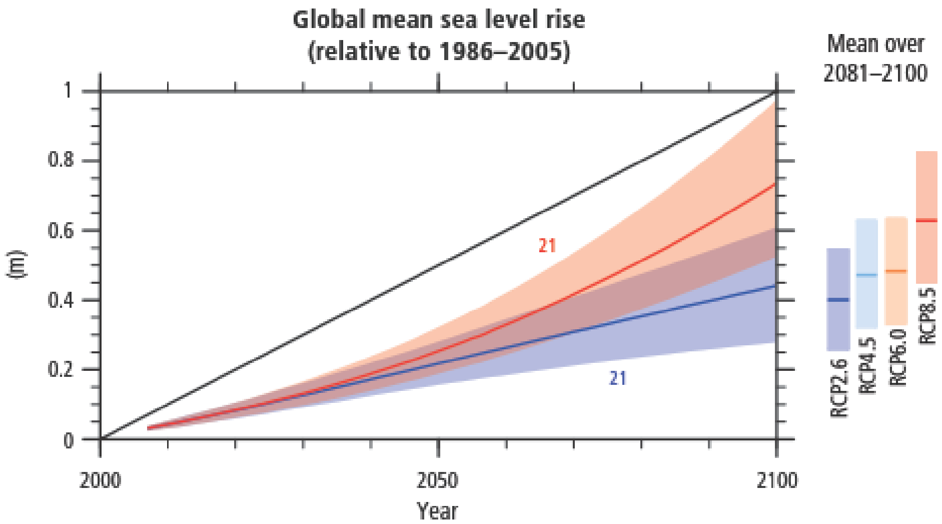


Figure 1.5. IPCC Climate Change: 2014 Synthesis Report Sea-level Rise Future Projections

Sea Level Rise will affect millions of people because there would be many impacts which are coastal inundation, erosion, unexpected natural events, saltwater intrusion into groundwater and some threats for coastal resources, of it. While the global temperature increasing, seawater has expanded, glaciers have melted, therefore Sea Level risen and observed unusual natural patterns. These changes have some effects on human and natural systems.

1.4. Coastal Vulnerability

Coastal zones are under pressure of many natural and human induced impacts. Understanding the effects of these impacts is important to protect the coasts. The impacts need to be carefully analyzed to assess how they affect/damage the coastal zones. To do that coastal zones should be identified and classified regarding their vulnerability to natural and anthropogenic forces.

Although there are many definitions, the vulnerability to climate change is generally described as a function of the exposure, sensitivity and adaptive capacity. According to IPCC, a system is vulnerable if it is exposed and sensitive to the effects of climate change and has only limited adaptive capacity (IPCC, 2007). Here we define the vulnerability for the coastal zones is a degree of capacity to cope with the consequences of climate change and accelerated sea level rise based on IPCC (2007) definition.

To assess the coastal vulnerability several indices have been developed (Gornitz 1990, Gornitz et al. 1997, Thieler and Hammar-Klose, 1999). The main objective of the index approach in these methods is to simply the complex and related parameters that are represented with different data types (McLaughlin and Cooper., 2010). The physical properties of the coastal areas such as elevation, slope is quantitative. However, some other physical properties such as lithology, geomorphology can be expressed qualitatively. Similarly, the human related coastal zone properties can be represented either quantitatively (population, income) or qualitatively (cultural heritage, land-use). In this way, the authorities such as the decision-makers, coastal managers can use the index methods as a management tool. Although the vulnerability to climate change includes many impacts, here we assessed the vulnerability to sea level rise and weather events such as storm surges.

1.4.1. Coastal Vulnerability Index (CVI)

Coastal Vulnerability Index (CVI) is a tool for classification of the coastal areas regarding their vulnerability. CVI methods use physical and socio-economic parameters to calculate the vulnerability of the coast against the sea level rise. Using the CVI methods, coastal regions can be compared or ranked based on their vulnerability. Therefore, CVI can be used as a coastal zone management tool, because it transformed many parameter's data to information.

In one of the pioneering studies, Gornitz (1990) use seven physical parameters (elevation, local subsidence trend, geology, geomorphology, mean shoreline displacement, maximum wave height and mean tidal range) to assess the vulnerability of the east coasts of US for future sea level rise. It was explained that the CVI can be calculated as either the sum or product of the parameters (Gornitz, 1990). After trying several indices, four CVI formulas were developed in the study (CVI_1 ; (1.1), CVI_2; (1.2) CVI_3; (1.3) and CVI_5; (1.5)). The statistical comparison of the results of these four CVI methods indicates a very high degree of correlation. Therefore, it was concluded that each of the CVI methods can be used as an indicator of coastal hazards. After that, the last CVI of method of Gornitz (1990), the square root of the geometric mean, was used to calculate the coastal vulnerability of the all US coast (Gornitz, 1991; (1.5)).

Gornitz et al. (1997) developed two more formulas (CVI_4; (1.4) and CVI_6; (1.6)) to calculate the CVI. They indicated that the CVI_6 method showed lower sensitivity overall to misclassification errors and missing data (Gornitz et al., 1997).

$$CVI_1 = \frac{(X_1 * X_2 * X_3 * X_4 * \ldots \ldots X_n)}{n} \tag{1.1}$$

$$CVI_2 = \frac{\left(X_1 * X_2 * {}^{1}\!/_{2}\,(X_3 + X_4)\right) * X_5 * {}^{1}\!/_{2}\,(X_6 + X_7))}{n-2} \tag{1.2}$$

$$CVI_3 = \frac{(X_1{}^2 * X_2{}^2 * X_3{}^2 * X_4{}^2 * \ldots \ldots X_n{}^2)}{n} \quad (1.3)$$

$$CVI_4 = \frac{(X_1 * X_2 * X_3 * X_4 * \ldots \ldots X_n)}{5^{(n-4)}} \quad (1.4)$$

$$CVI_5 = [\, CVI_1 \,]^{1/2} \quad (1.5)$$

$$CVI_6 = 4X_1 + 4X_2 + 2(X_3 + X_4) + 4X_5 + 2(X_6 + X_7) \quad (1.6)$$

Where, n is the parameter numbers, X1 is the mean elevation, X2 is the Local subsidence trend, X3 is the geology, X4 is the geomorphology, X5 is the mean shoreline displacement, X6 is the maximum wave height, X7 is the mean tidal range.

Although, there are numerous studies with different parameters and CVI calculation methods, the study by Gornitz (1990) is one of the most important studies regarding CVI that assesses the East Coasts of U.S.A.

Thieler and Hammar-Klose (1999) adapted the CVI_5 method of Gornitz (1990) with different parameters to assess the vulnerability of the coasts of the US. They used six parameters: coastal geomorphology, coastal slope, historical shoreline change, mean tidal change, mean wave height and rate of sea-level rise. They indicated that these selected parameters to calculate the CVI are more accessible and applicable for vulnerability assessments. Due to the availability of data for the parameters Thieler and Hammar-Klose (1999) method has been commonly used by many researchers around the world such as Greece (Gaki-Papanastassiou et al., 2010), Ghana (Addo, 2013), Alaska (Gorokhovic et al., 2014), India (Kunte et al., 2014), Argentina (Diez et al., 2007).

Some of the researchers applied the modified version of the Thieler and Hammar-Klose (1999) method. For instance, Gorokhovic et al. (2014) considered three physical parameters (geomorphology, coastal slope and shoreline erosion) were sufficient for vulnerability analysis in Alaska. On the other hand, Kunte et al. (2014) increased the number of parameters by adding two new socio-economic parameters: the sum of population and tourism density.

The methods developed by Gornitz (1990), Gornitz et al. (1997) and Thieler and Hammar- Klose (2000) include only physical variables. However, it is reported that the vulnerability is also influenced by socio-economic factors (Boruff et al., 2005). Szlafsztein and Sterr (2007) assessed the vulnerability using both physical and socio-economic factors in Brazil. It is reported that socio-economic changes happen more rapidly than the natural or physical changes (Szlafsztein and Sterr, 2007). Kunte et al. (2014) used not only seven physical and geologic parameters but also used population and tourist density as socio economic parameters for vulnerability index in Goa, India. It was stated that those parameters are important for Goa coasts because of the state's growing population and significance of the tourism for the Goa's economy (Kunte et al., 2014). As a result, the study aimed to make a model which would be useful for policy and decision-makers.

Mclaughlin and Cooper (2010) used a CVI sub index method which slightly differs from the other formulas. They defined the vulnerability as a function of coastal characteristics (geology, shoreline type, elevation, etc.), coastal forcing (wave height, tidal range, etc.) and socio-economic parameters (population, cultural heritage, roads, etc.) forming three sub-indices for CVI. Each sub-index is calculated first by the sum of the vulnerability score of each variable, then the results are worked out as a percentage of the range of scores for normalization. Since some sub-indices may have more parameters than others, the normalization is necessary to obtain equal contribution from each sub-index. The final coastal vulnerability is computed by averaging the percentage scores of three sub-indices (Mclaughlin and Cooper, 2010).

Palmer et al (2011) developed a CVI method by sum of the variables. The five variables that they defined as the most suitable indicators for coastal vulnerability assessment in South Africa are beach width, dune width, distance to the 20m isobath, percentage rocky outcrop and distance (width) of vegetation behind the back beach. They also described the first three variables as the most critical indicators for highly vulnerable sites. In order to emphasize these variables, Palmer et al (2011) added an additional weighting of 4 if they all three have high scores. Also, they added another weighting (4) for the area where estuarine mouths exist.

Denner et al. (2015) applied the method in Palmer et al (2011) with a little modification. They replaced one of the critical parameters, the distance to the 20m isobath with a parameter for coastal slope. They explained that as the Loughor Estuary in South Wales, UK is subject to different coastal processes, the coastal slope is more critical (Denner et al., 2015).

Özyurt and Ergin (2010), developed CVI-SLR method. In this method, parameters are divided into 2 groups which are human influence parameters and physical parameters. Physical parameters are rate of sea level rise, geomorphology, coastal slope, significant wave height, sediment budget, tidal range, proximity to coast, type of aquifer, depth to ground water level above sea, river discharge and water depth at downstream. Human influence parameters are reduction of sediment supply, river flow regulation, engineered frontage, groundwater consumption, land use pattern, natural protection degradation, coastal protection structures. This method uses parameters to calculate 5 sub-indexes that are impacts of sea level rise. These sub-indexes are coastal erosion, flooding due to storm surge, inundation, salt water intrusion to groundwater resources and salt water intrusion to river/estuary. Physical and human influenced parameters which affect the sub-indexes are evaluated separately. For example, inundation sub index was calculated with rate of sea level rise, coastal slope and tidal range (physical parameters), natural protection degradation and coastal protection structures (human influenced parameters) ranking values. So unlike other methods, this method highlights the most vulnerable areas by directly matching numerical and qualitative data with specific physical effects (Özyurt and Ergin, 2010). In Indonesia, Joesidawati et al. (2019), use the CVI-SLR method to develop vulnerability model of the effect of SLR and to describe the magnitude of the impact of SLR in Tuban Regency coasts. CVI-SLR method is generally performed in local study areas because of the specified parameters used for the calculation of the sub-indexes. For this reason, this method was not used in this study. This method was not used in this study, since it is difficult to collect special parameters data such as sediment budget, depth to groundwater level above sea, river flow regulation in the smaller scale study areas.

1.5. Study Area

The study area covers the coastal zone of the Cilician Basin (Iskenderun Bay and Mersin Bay) in North-Eastern Mediterranean (Figure 1.6). The study area includes the coastal parts of Mersin, Adana and Hatay provinces. These provinces are important for natural environment, human population and economic potential of the region.

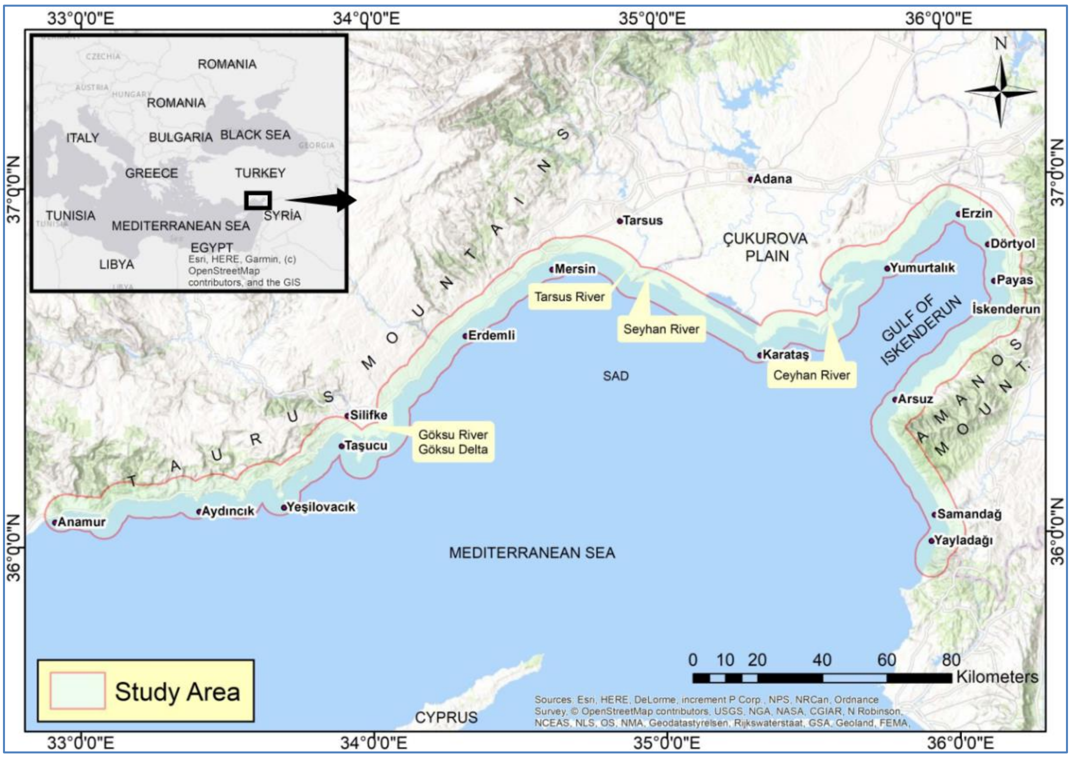


Figure 1.6. Study Area

The Taurus Mountains extend along the coast. Between these mountains and the sea, there are important flat areas such as Çukurova and Göksu. Çukurova has been formed by alluvial deposits that transported from Seyhan, Ceyhan and Tarsus rivers. The Göksu Delta is a coastal plain formed by the alluvium carried by the Göksu River. These plains have important lagoons, wetlands and areas that accommodate to some endangered animals. In Hatay province, Amanos mountains lies in North-South direction. There are plains such as Erzin, Dörtyol, Payas and Arsuz plain in the coastal regions between Amanos mountains and the sea.

The total length of the coastline of the study area is about 600 km. The study coastline is located between Anamur and Samandağ (Figure 1.6).

1.5.1. Population

The study area is a significant area regarding the high population density. The total population of the 3 provinces represents about 7% of the population of Turkey and more than 50% of the population of the Mediterranean region (Figure 1.7). Flat areas between the sea and mountains (Taurus and Amanos) are narrow in Mersin, Iskenderun and Arsuz. For this reason, high populated cities are located at coastal zone. In addition, population of the Mersin, Karatas, Tarsus, Yumurtalık, Arsuz and Samandağ coasts, is doubled in the summer season due to secondary residences.

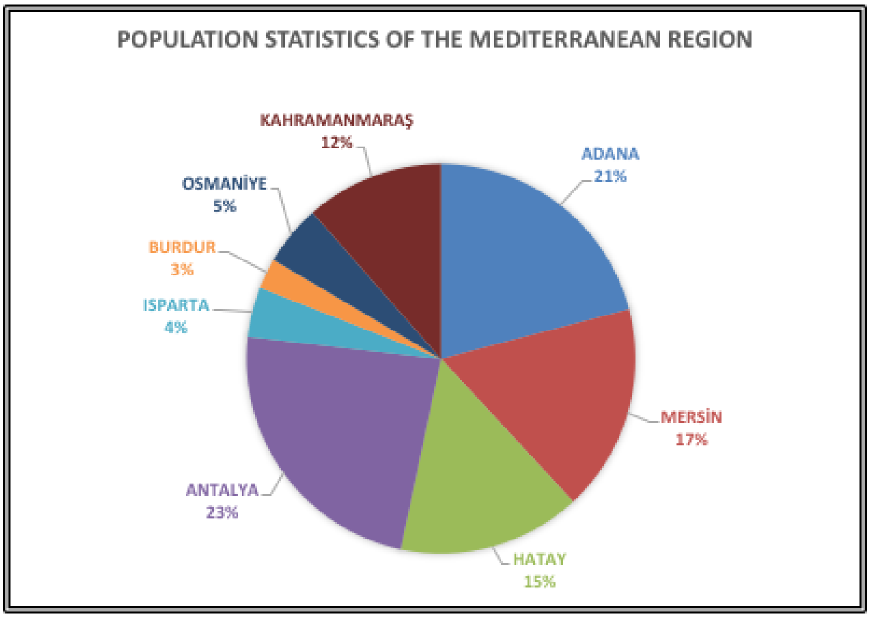


Figure 1.7. Population statistics in the Mediterranean region. (Turkish Statistical Institute (TSI), 2019a)

1.5.2. Economic potential

The region has important economic sectors such as agriculture, tourism, fisheries, industry and transportation. For instance, this region is a suitable area for agriculture, due to convenient climate conditions, large and fertile alluvial plains. Agricultural activities contribute significantly to the national economy. Products with high economic value such as citrus fruits, strawberry, watermelon and banana are produced in this region. For example, 73% of citrus production in Turkey is carried out in this region (Figure 1.8).

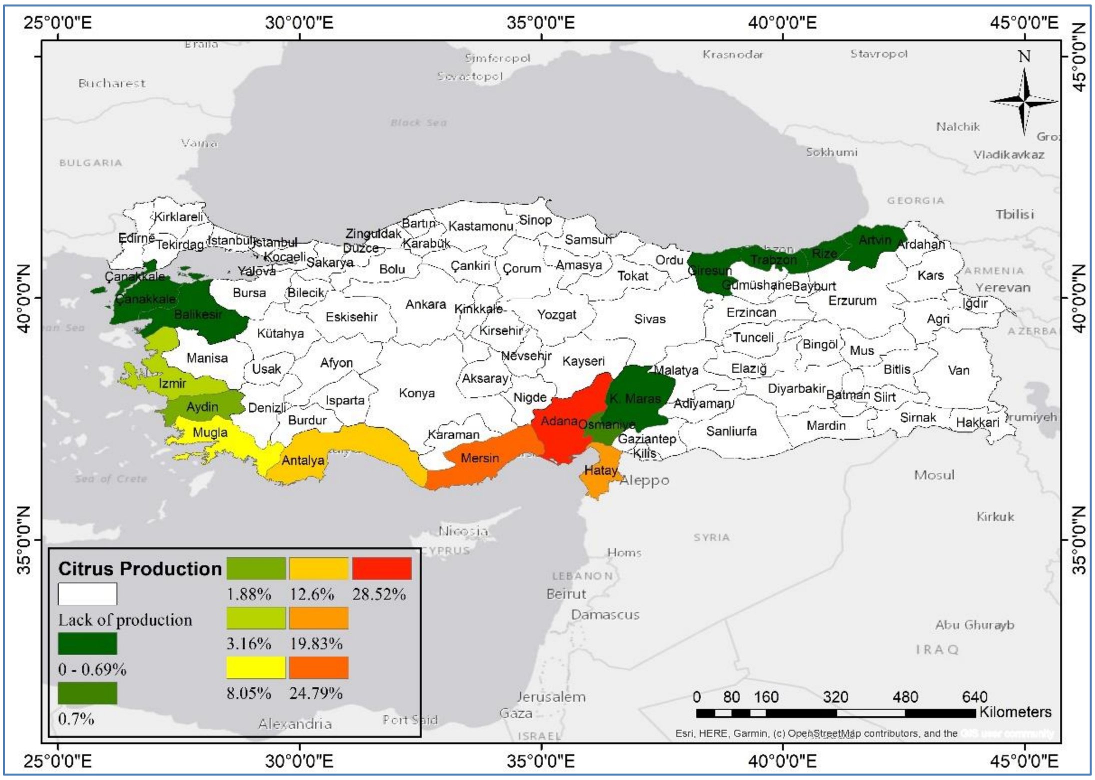


Figure 1.8. Citrus Production in 2018 according to provinces (Turkish Statistical Institute, citrus production in provinces, 2018)

Total coastline of the study region is about 600 km. Hence, there are many recreational and attractive areas for tourists. In addition, the number of sunny days is higher than other coastal regions which causes the favorable climatic conditions. Due to the long summer seasons, this region became a more preferred area for vacations. According to tourism statistics in 2018, There are 469 tourist facilities in Mersin. Hence, Mersin is the 4th city regarding the number of tourist facilities in Turkey. In addition, it is the 8th largest capacity province according to its bed capacity (Ministry of Culture and Tourism, 2018). In addition, there are many secondary residences on the coasts of Mersin, Adana and Hatay. Visitors from the neighboring cities spend the summer season in these secondary residences. The secondary residences are concentrated mainly along the Mersin coast. Karataş, Arsuz, Samandag, Tarsus coasts are other regions where secondary residences are intense.

Maritime transportation is another significant economic sector for the study area. There are several international ports, piers and oil pipeline buoys for oil storage facilities. For instance, Mersin International port is the 2nd harbour regarding the container handling in Turkey (Figure 1.9).

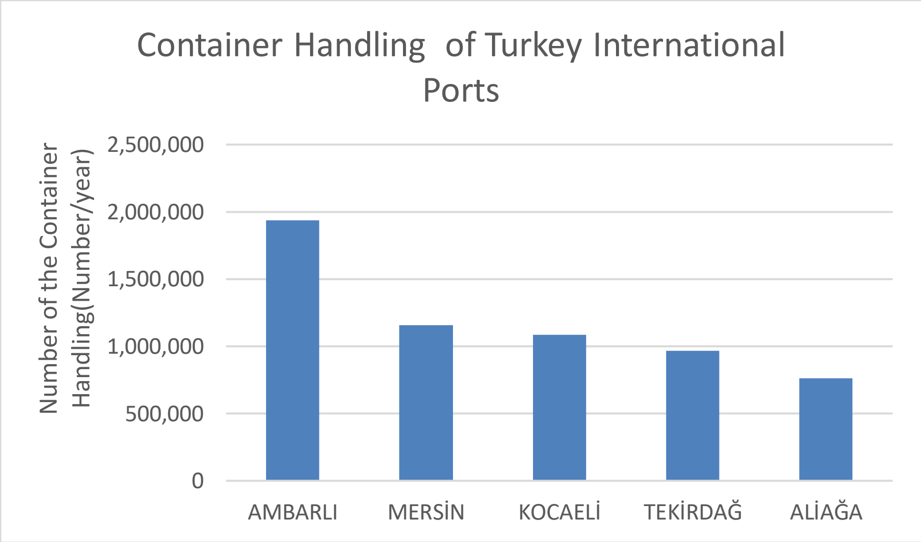


Figure 1.9. Number of the container handling of Turkey ports in 2019 (Ministry of Transport and Infrastructure of the Republic of Turkey, 2019)

In addition, Botas, Iskenderun and Mersin port regions are in first 5^{th} in terms of total cargo volume of Turkey ports (Figure 1.10). A significant increase of cargo volume of these international ports is expected in the future.

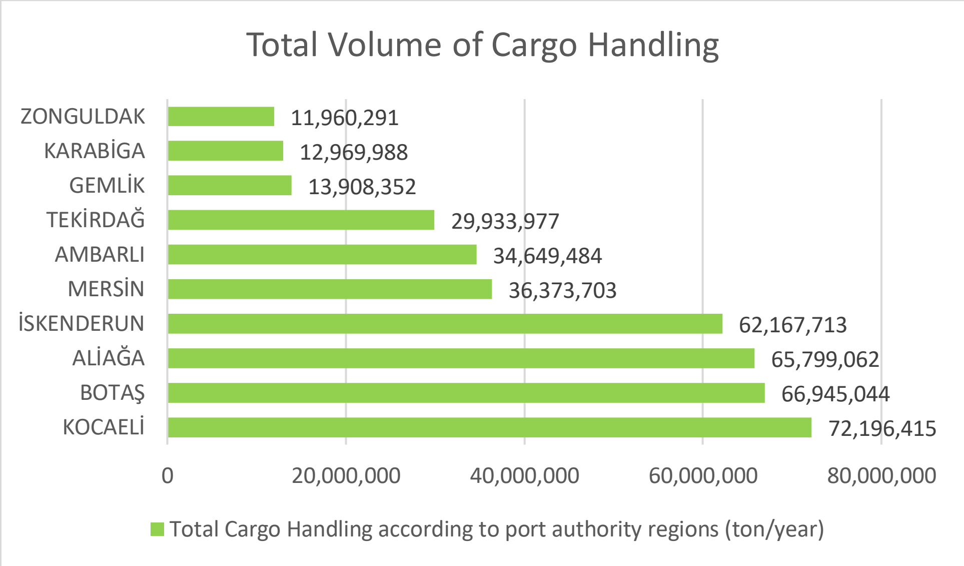


Figure 1.10. Total cargo handling volume of Turkey ports in 2019. (Ministry of Transport and Infrastructure of the Republic of Turkey, 2019)

1.6. Aim of the study

The main aim of the study is to assess the coastal vulnerability for coastal zone management in the study area which extends from Anamur to Samandağ. For this purpose, physical and socio-economic data related to the coastal zones have been compiled. The coastal vulnerability index is calculated with different methods and can be used for Integrated Coastal Zone Management (ICZM) to help reducing negative impacts of the climate change as well as the human activities on coastal zone. This index will provide information for local authorities and decision makers to manage the coastal zone and to use marine resources effectively.

The other aim of this study is to discuss the results of the different coastal vulnerability index methods. Five different methods have been used to calculate the coastal vulnerability index. All of these methods use physical parameters such as coastal slope, geomorphology, mean tidal range, but only three of them use the socio-economic parameters. They also differ from each other by the contribution of socio-economic parameters to coastal vulnerability index. In this way, it is aimed to see the difference between the methods to decide which one or more are suitable for the study area.

The final aim of the study is to develop GIS Model tool to assess the vulnerability for any coastal area. The end-users will be able to calculate easily the vulnerability using all the five methods with this GIS Model tool.

CHAPTER 2

MATERIAL and METHODS

The coastal vulnerability can be identified by evaluating the resilience of the coast to the effects of some physical processes such as sea level rise, extreme weather events, storm surges. These processes can damage the coast in various ways. The physical properties of the coast and the human activities on the coastal zone strongly affects the vulnerability.

The assess the coastal vulnerability several methods were developed. The details of these methods will be given in the next section. A powerful GIS software, ArcGIS Desktop is used to apply these methods on Cilicia Basin coast. To easily adapt these methods in different places with different parameters, new geoprocessing tools were created in ArcGIS environment. Tools are designed with Model Builder tool in ArcGIS and modified using Python. These tools can be executed in a sequence, feeding the output of one tool to the input of another. To use these CVI tools, the coast is dividing into cells of which the size can be assigned by users. Therefore, users will be able to assign different cell size; big sized cells than means coarse resolution can be used for a long coastline, and small sized high-resolution cells can better describe short coastline.

2.1. Parameters and Data Source

Coastal Vulnerability Index (CVI) method use ranked parameters according to their relative vulnerability to natural events such as erosion, inundation, flooding and sea level rising. Several CVI methods were developed for the needs of different places. These methods use different physical and socio-economic parameters to calculate the CVI values.

In this study, five different CVI assessment methods were applied and tested for the study area. Each method uses physical and/or socio-economic parameters to assess coastal vulnerability. All parameters and data sources are described below. Vulnerability ranking tables are shown in the results section.

2.1.1. Coastal Slope Data

Coastal slope is an important parameter when considering the inundation, erosion and sea level rise.

Shuttle Radar Topography Mission (SRTM) was an international space mission to obtain high resolution land elevation data (Farr et al., 2007). SRTM offers a 1 Arc-Second resolution (about 30m) elevation data that covers about 80% of the land surface on the earth (Figure 2.1). The data is freely available at https://www2.jpl.nasa.gov/srtm/. Coastal slope was computed from the SRTM elevation data (Figure 2.2). The Slope tool in ArcMAP calculates the maximum rate of change in value from that cell to its neighbors. It identifies the steepness of the terrain; The lower the slope value, the flatter the terrain; the higher the slope value, the steeper the terrain (https://desktop.arcgis.com/en/arcmap/latest/tools/spatial-analyst-toolbox/how-slope-works.htm).

In the slope map (Figure 2.2), low values indicate the flat areas like Çukurova plain, on the other hand steeper slopes show the mountainous or hilly terrains.

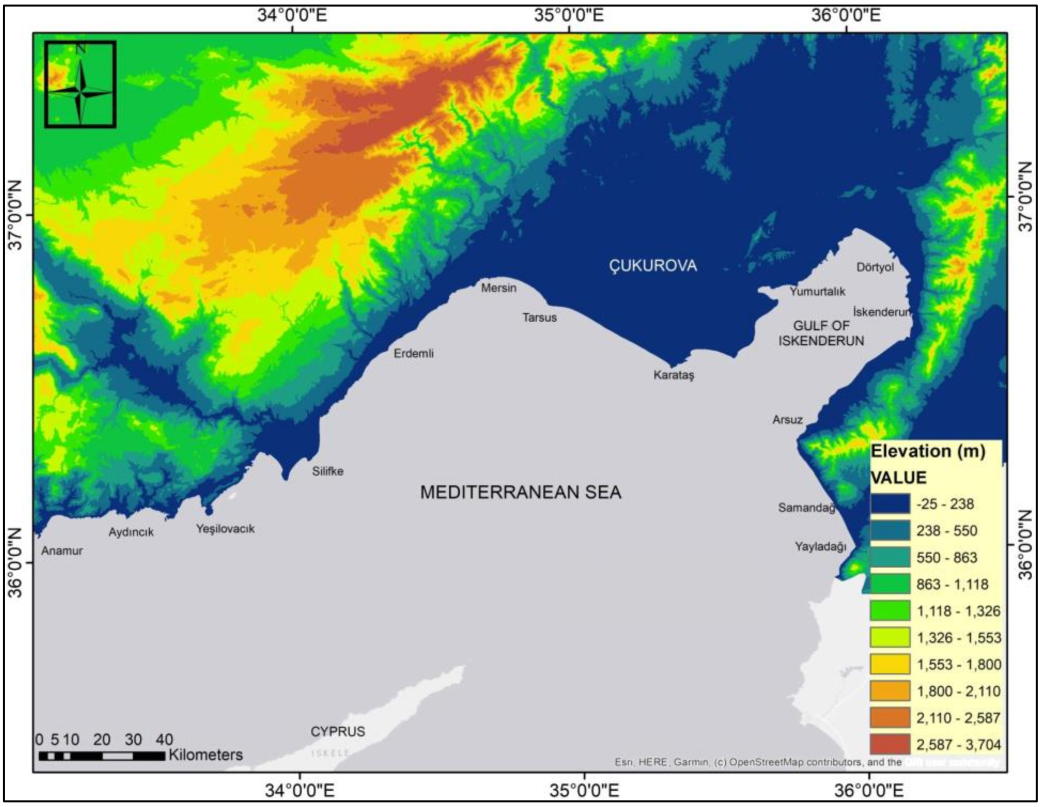


Figure 2.1. SRTM Digital Elevation Model Map

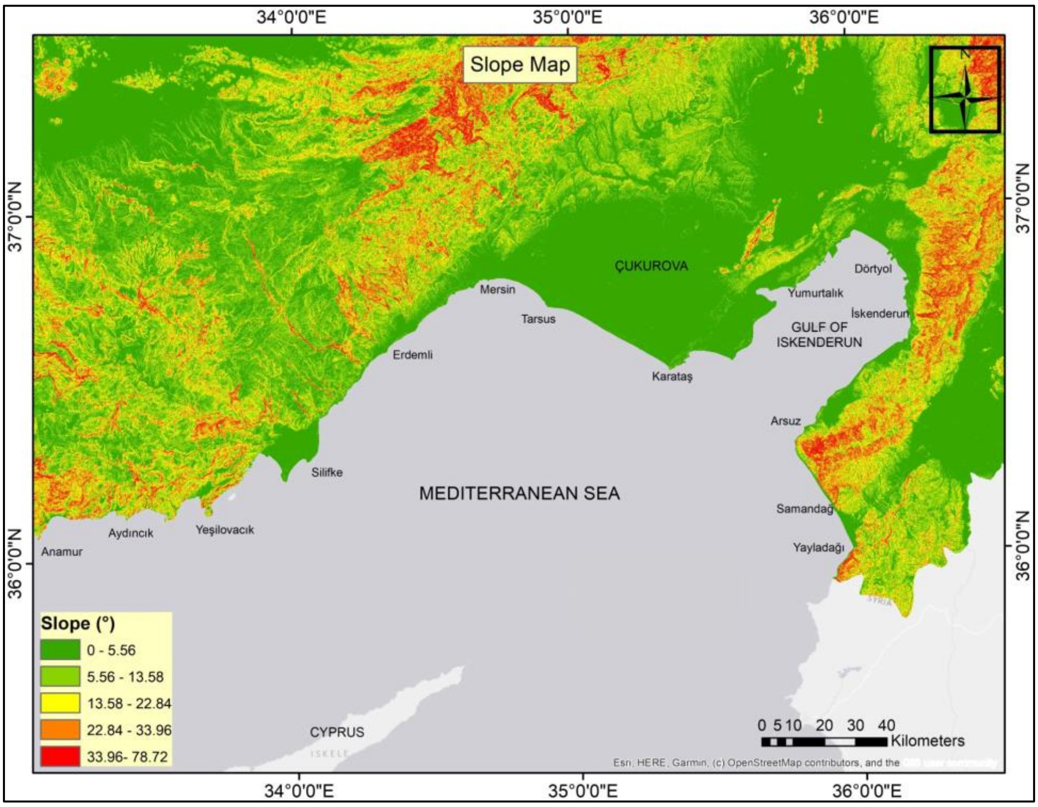


Figure 2.2. Slope Map of the Study Area

2.1.2. Geomorphology Data

The geomorphology data is obtained from satellite images in Google Earth (Figure 2.3). The estuaries and deltas, alluvial plains and cliff are defined as geomorphologic landforms for this study. These landforms that located at the coastal zones were digitized on satellite images. The digitized polygons were then transformed to gridded data set to be used in ArcMap for the CVI calculations.

Figure 2.3. Geomorphologic landforms digitized from the Google Earth Satellite Images. Red polygons show the rocky and cliff areas, orange polygons show beaches, dark green polygons show estuaries, lagoon and deltas, light green polygons show the alluvial plains.

2.1.3. Geology

The geology parameter includes the general rock types of the study area. Rock types are related to the resistance to coastal erosion in terms of hardness of minerals. For instance, coastal areas with beach, dunes and alluvium fan geologic formations have less resistance to erosion. On the other hand, ophiolitic rocks are hardest and most resistant geological formations in the study area. Therefore, the beach and dunes coasts are considered more vulnerable to natural hazards than the coast with ophiolitic rocks.

Geology data is obtained from the "GeoScience MapViewer and Drawing Editor" operated by General Directorate of Mineral Research and Exploration (Figure 2.4). Geological formations were digitized using the polygon tool in this application and exported in kml format. This kml formatted file were imported in the GIS environment to use in coastal vulnerability assessments. The simplified geologic formations used in this study is shown in Figure 2.6.

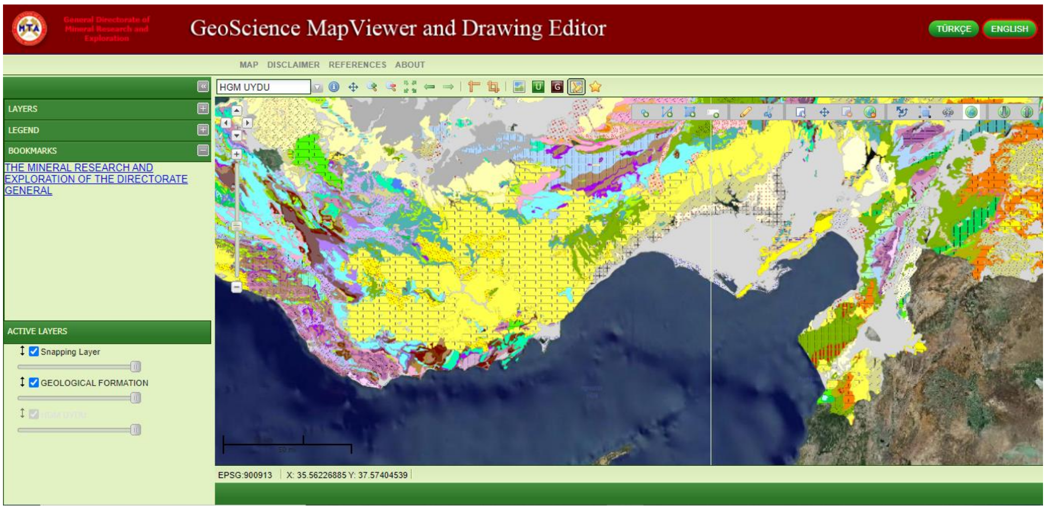


Figure 2.4. Geology data editor from General Directorate of Mineral Research and Exploration (http://yerbilimleri.mta.gov.tr/anasayfa.aspx)

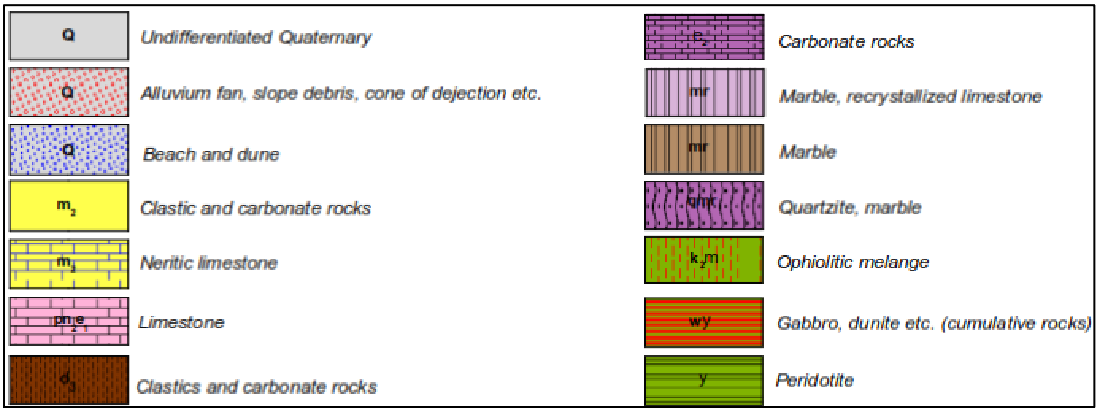


Figure 2.5. Main geological formations of the “GeoScience MapViewer and Drawing Editor” in the study area (Figure 2.4).

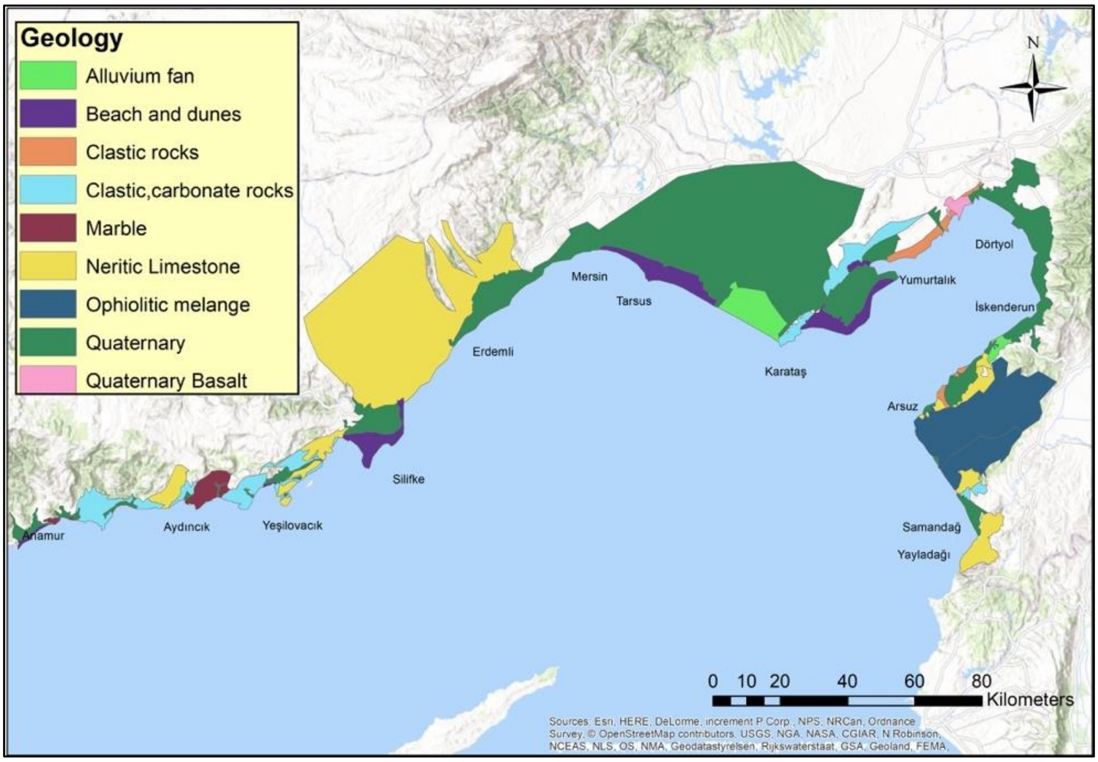


Figure 2.6. Simplified geologic formations of the study area

2.1.4. Shoreline Erosion/Accretion Rate

The shoreline erosion/accretion parameter is obtained from the historical trend of coastline change. The sandy coasts, especially the beaches experience sediment movements. The removal of sediments indicates erosion and the sediment deposition suggests accretion. The shoreline erosion/accretion rate data is derived from historical satellite images by using Google Earth.

The erosion and accretion dataset are assessed by means of several satellite images between 1984 and 2020 in Google Earth. The digitized shorelines for different years are compared to each other to identify the erosive and depositional areas. Shoreline change is generally observed around the river mouths and fine sand beaches in the study area. An example of coastline changes in two different years is shown in Figure 2.7 and the interpretation in Figure 2.8.

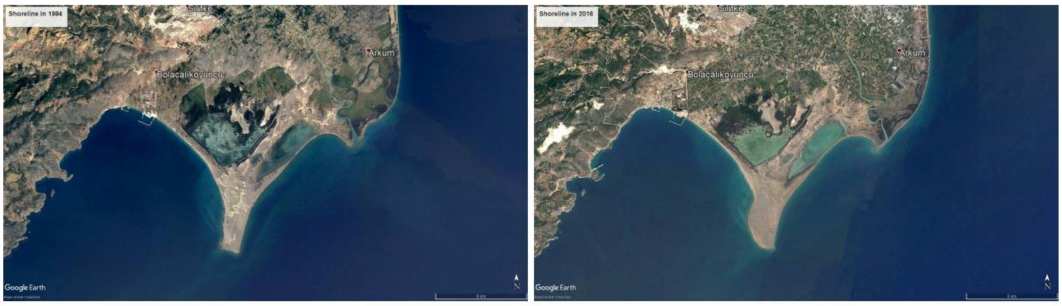


Figure 2.7. An example of shoreline changes in Göksu Delta. Google Earth Satellite images in 1984 (Left), and 2016 (Right).

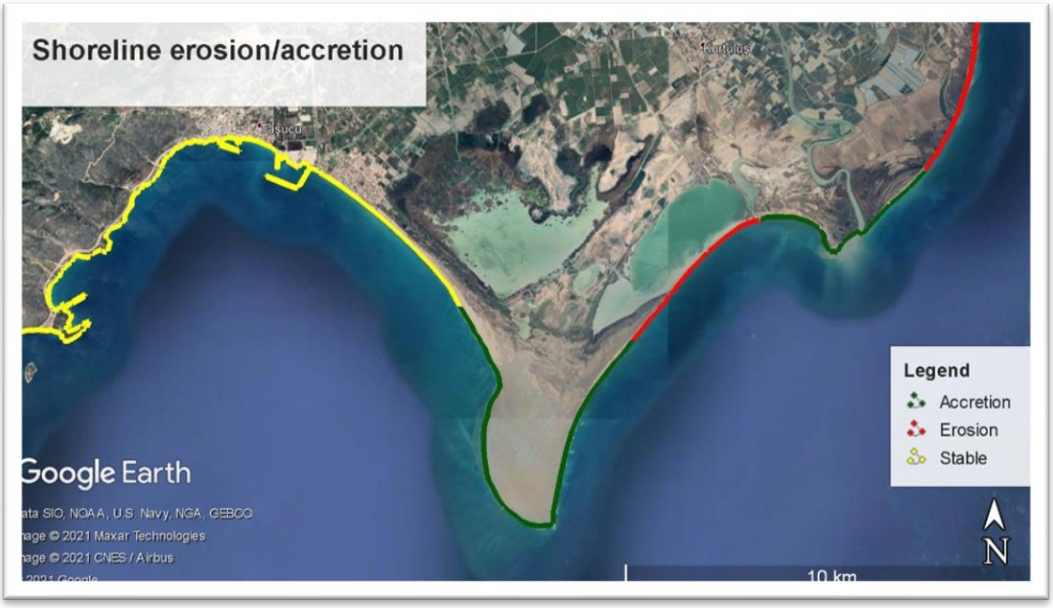


Figure 2.8. Coastal areas classified according to their historical changes in coastlines like coastal areas in Göksu delta.

2.1.5. Mean Wave Height

Waves are the one of main factors of coastal sediment transportation which drive coastal erosion and deposition. Significant mean wave height is used as a parameter for coastal vulnerability. As a result of wave height increasing, wave energy will increase. Therefore, waves, which have high energy, transport more coastal sediment. Hence, coastal areas, which are exposed to high wave heights, more vulnerable than low wave heights.

For the study area significant wave height data is found in Zodiatis et al. (2014). Zodiatis et al. (2014) used an integrated very high resolution atmospheric/wave modeling system for simulating the atmospheric circulation and the sea waves evolution in the area over a period of ten years (2001-2010) to investigate the wave energy potential in the Levantine Basin, Eastern Mediterranean. The statistical analysis of 10 years mean significant wave height is shown in Figure 2.9. However, the result is very coarse. Moreover, there is no in-situ measurements for the Cilician Basin to justify the results.

Although significant wave height is accepted one of the fundamental parameters of coastal vulnerability, a good quality significant wave height data for the coastal zone in the study area is unavailable. However, a Ph.D. study (Buyruk, 2019) that investigated the wind and wave climates in Turkish coasts, calculated the mean maximum wave height and monthly mean wave height data for 180 stations of which 17 are located in our study area (Figure 2.10). The data is shown in Table 2.1. The data conforms with the significant wave high data of Zodiatis et al. (2014).

Monthly mean wave height data (Buyruk, 2019) is used for coastal vulnerability index calculations in this study.

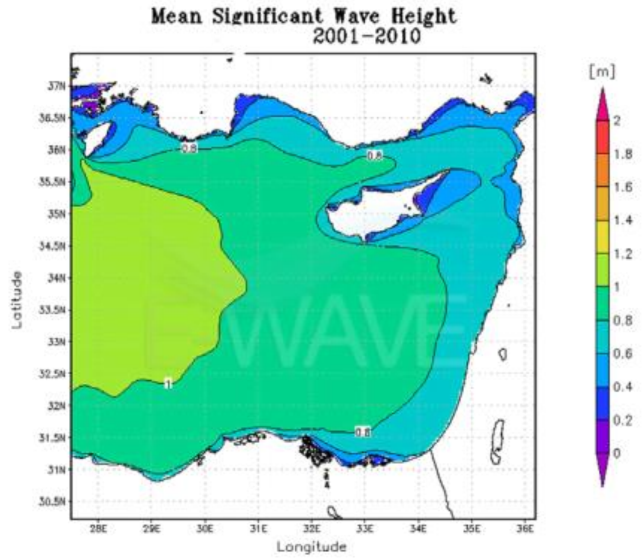


Figure 2.9. The 10 years means significant wave height in Eastern Mediterranean based on statistical analysis (from Zodiatis et al. (2014)).

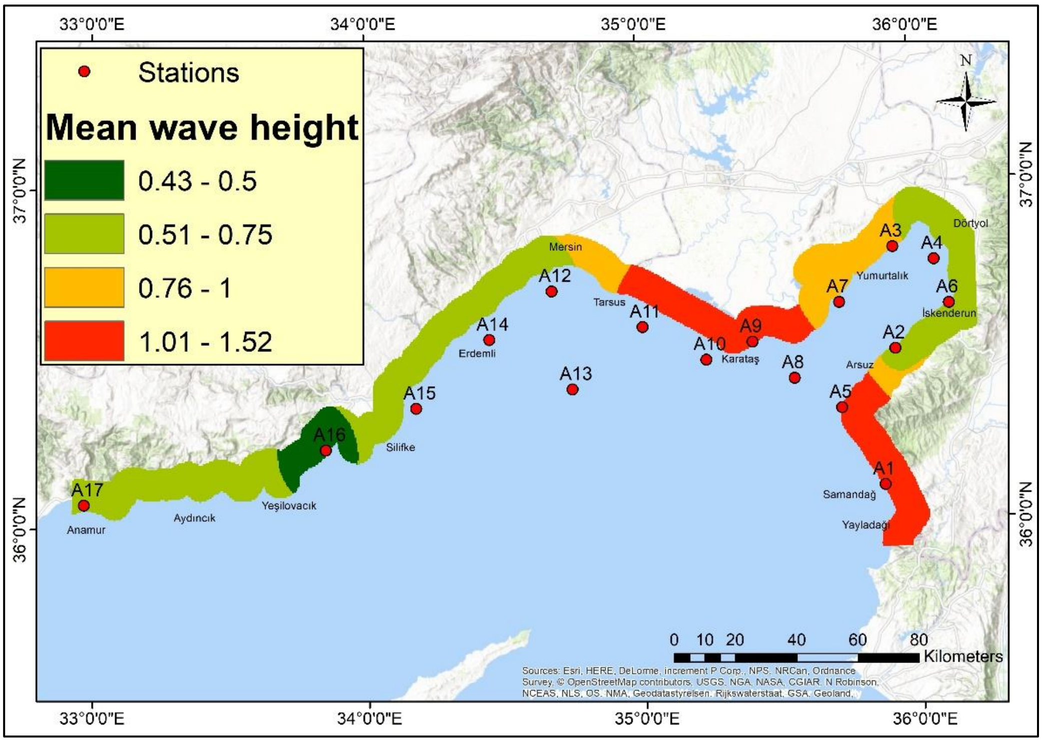


Figure 2.10. Location of 17 station in Buyruk, 2019 research and interpolated mean wave height model was digitized according to the data.

Table 2.1. The monthly mean wave height data for the study area from Buyruk (2019). Monthly mean wave height data obtained as a result of applying CEM method to ECMWF operational archive wind data.

Point	Station	Longitude (E)	Latitude (N)	Monthly Mean Wave Height (m)
A1	Samandağ	36.1	35.88	1.11
A2	İskenderun	36.5	35.93	0.62
A3	Yumurtalık	36.8	35.93	0.7
A4	Dörtyol	36.76	36.08	0.59
A5	Antakya	36.33	35.73	0.95
A6	İskenderun	36.63	36.13	0.56
A7	Yumurtalık	36.64	35.73	0.94
A8	Karataş	36.42	35.56	1.05
A9	Karataş	36.53	35.41	0.91
A10	Karataş	36.48	35.24	0.91
A11	Karataş	36.58	35.01	0.78
A12	Mersin	36.69	34.68	0.66
A13	Alata-Erdemli	36.4	34.75	0.93
A14	Alata-Erdemli	36.55	34.45	0.75
A15	Silifke	36.35	34.18	0.83
A16	Silifke	36.23	33.85	0.97
A17	Anamur	36.07	32.97	1.7

2.1.6. Mean Tidal Range

Tides are rise and fall of sea levels caused by gravitational forces between the moon and the sun. Tidal range is the vertical difference between the low tide and high tide.

Tide-gauge data is obtained from Turkish National Sea Level Monitoring System (TUDES). The network includes 18 Tide gauge stations to collect automatic sea level data and other physical parameters (Simav et al, 2012; Figure 2.11). Four of these tide gauge stations are located in our study area: Iskenderun, Erdemli, Tasucu and Bozyazı (Figure 2.11).

The last 5-years sea level data for the Iskenderun, Erdemli, and Bozyazı stations are presented in Figure 2.12. Erdemli and Bozyazı stations have 45 cm difference between hide and low tides on average. İskenderun tide-gauge station has measured about 60 cm difference between hide and low tides.

Figure 2.11. TUDES (Turkish National Sea Level Monitoring System) Stations in Turkey (Simav et al, 2012).

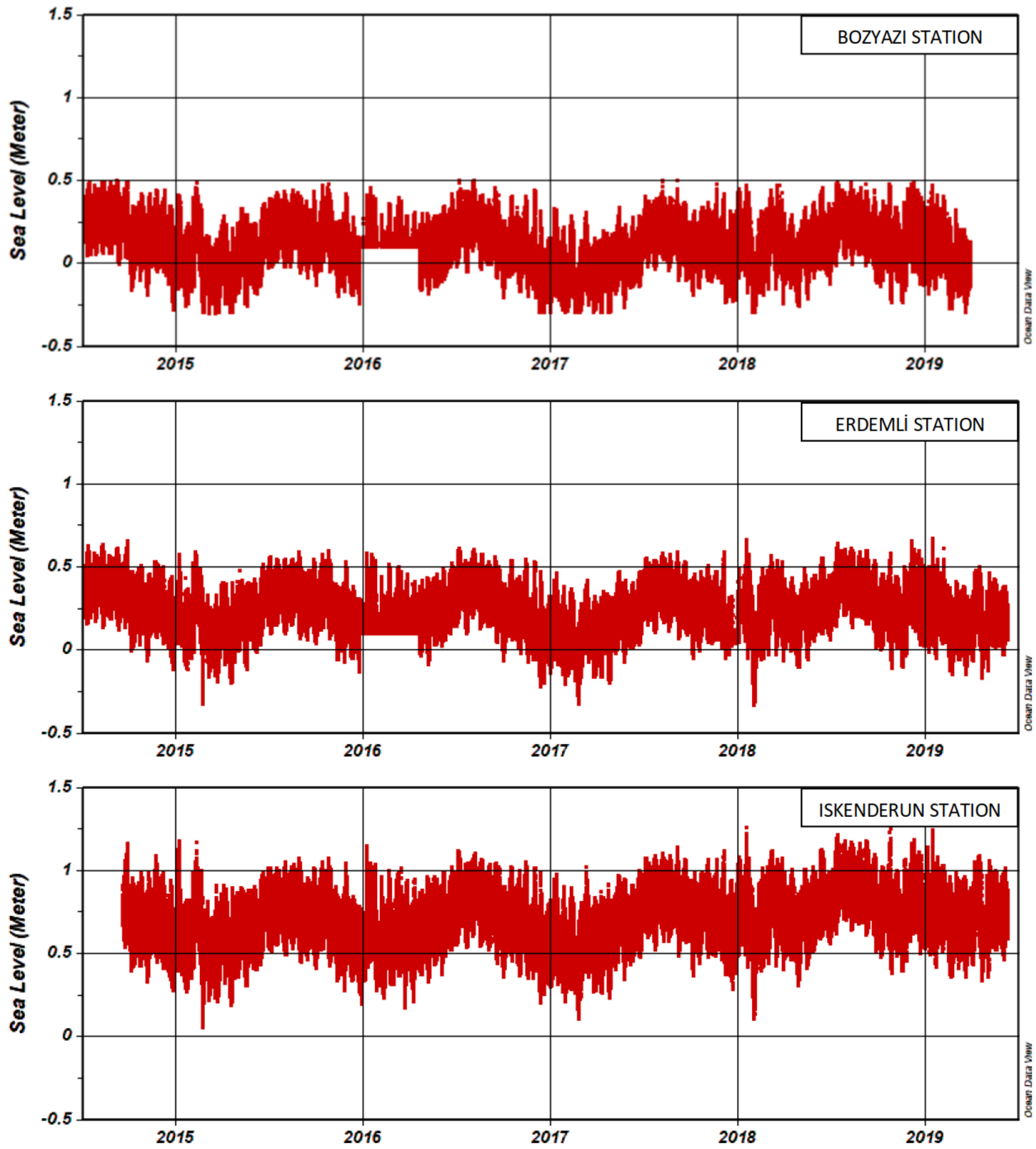


Figure 2.12. Sea level time series data in Bozyazı, Erdemli and İskenderun tide-gauge stations.

2.1.7. Relative Sea Level Change

Sea level rise has not similar trends all around the world because of some effects such as atmospheric pressure, steric effect and local land movement. These effects have different contributions to sea level depending on the geographical position. Sea level is changing at different rates in different coastal regions as a result of these effects. The local sea level change is known as relative sea level change including the local effects in addition to the global sea level change.

The long-term evaluation of satellite altimetry data indicates a continuous sea level rise in the Eastern Mediterranean (Cazenave et al., 2001; Hebib and Mahdi, 2019). Hebib and Mahdi (2019) concludes that the coastal Mediterranean Sea level has risen during the period of the altimetry era (1993–2015) with a clear increasing trend in the Eastern Mediterranean basin (Figure 2.13). It is reported that the average rate of the sea level rise is approximately 20 mm/year in Eastern Mediterranean and 5-10 mm/year in Western Mediterranan (Cazenave et al., 2001).

On the other hand, the tectonics and stratigraphic studies indicate the differential tectonic subsidence in the Cilician basin (Aksu et al, 1992). The average subsidence rates are computed 0.26 m/kyear for Cilicia Basin and 0.3 m/kyear for Iskenderun Basin (Aksu et al, 1992).

The subsidence increases the effects of the sea level rise in the coastal zones of the study area. Therefore, the relative sea level rise is considered as significant parameter to increase the coastal vulnerability.

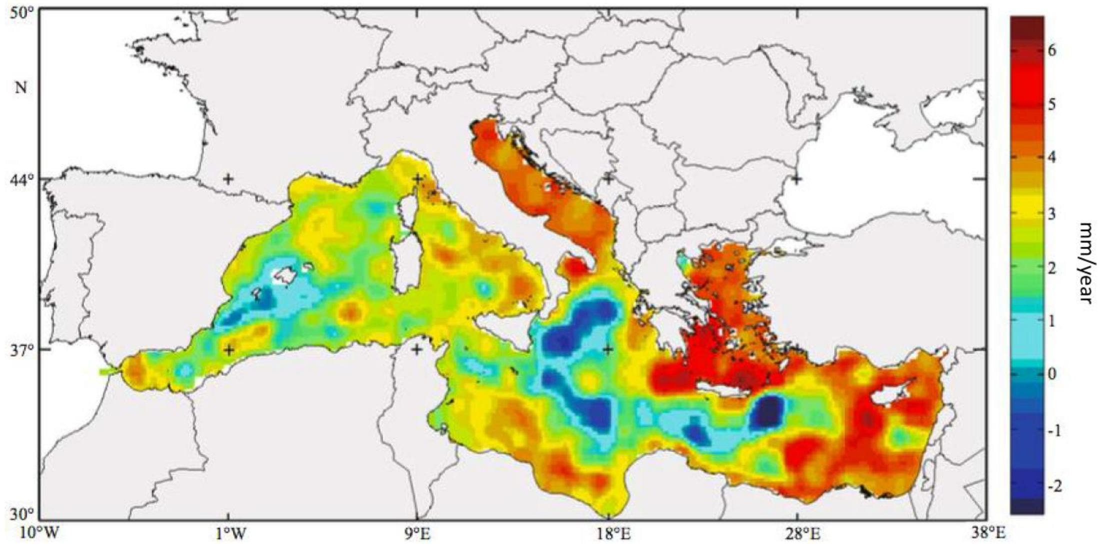


Figure 2.13. Rates of the Mediterranean Sea level change in mm/year between January 1993 and December 2015 (from Hebib and Mahdi, 2019)

2.1.8. Population

Population is one of the most important socio-economic variables about the coastal vulnerability. There are two different considerations about the impacts of the population. Firstly, population can have negative impacts on the coastal sites, because human pressure affects environment. Therefore, coastal areas that have high population, are more vulnerable than the other areas. However, other idea claimed that high population can be decreased the vulnerability. Because, in densely populated areas there are more infrastructures or sources to protect the environment from SLR and other natural hazards. Nevertheless, first approach can be more convenient for the study area. Although, sources and infrastructures try to protect coastal environment from the SLR and natural hazards, there are huge human pressures in the coastal areas. Hence, these sources and infrastructures are not enough for the protection.

Population data is obtained from the Turkish Statistical Institute (2015). The data is published as a gridded data set from the GIS portal of the Ministry of Environment and Urbanization (Figure 2.14; Figure 2.15)

The data is given the population density per km^2. To use in this study the data is resampled to 0.01 km^2.

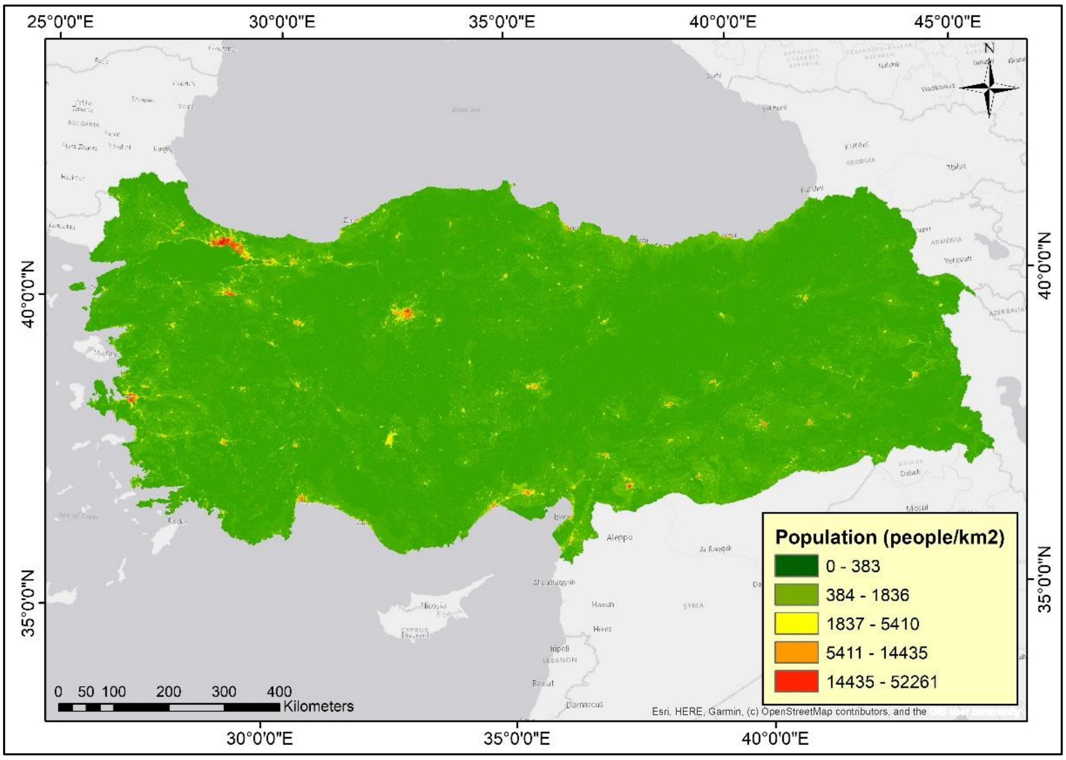


Figure 2.14. Population Map of the Turkey in 2015 (Turkish Statistical Institute)

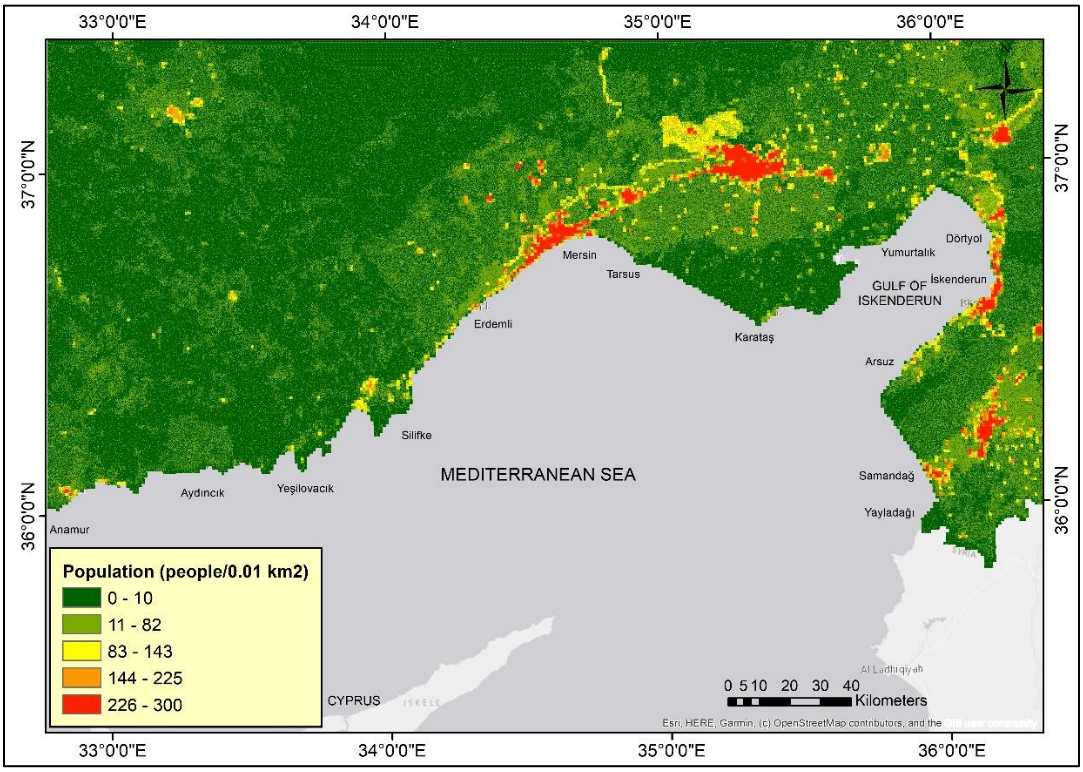


Figure 2.15. Population map of the Study Area in 2015 (Turkish Statistical Institute).

2.1.9. Land-use

Another socio-economic parameter for vulnerability index is land-use. According to land usage such as human and economic activities, some part of coastal areas may be vulnerable to SLR. For instance, continuous urban areas are riskier to flood or inundation events than rural areas regarding to population number.

Coastal areas should be evaluated according to their economical values. For example, industrial units, continuous urban, touristic places and agricultural lands have high economic values. Therefore, if there will be any natural or anthropogenic hazards in these places, these can be damaged more than other land use types. Hence, coastal areas classified according to their usages.

Land-use data is derived from satellite using the Google Earth software (Figure 2.16). All coastal areas were digitized regarding their usages. Coastal areas are classified as agricultural land, beach, continuous urban areas, discontinuous urban areas, forests, industrial units, lagoons, ports or piers, unclaimed areas and water bodies. For the vulnerability index, these land-use types are divided into five categories considering their vulnerability to SLR.

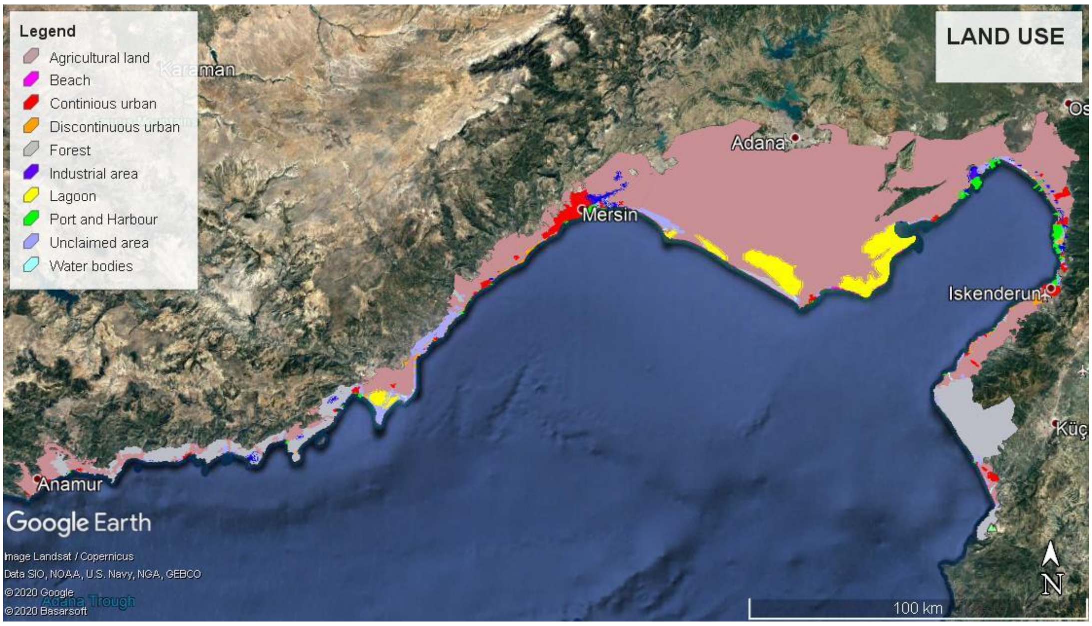


Figure 2.16. Land-use types digitized in Google Earth software.

2.1.10. Roads

The roads have a major role in human and economic activities in Turkey. There is a total of 68 231 km road network that are motorways, state highways and provincial roads in Turkey. Especially, along the coast of the Mediterranean the roads are very close to the coastline because of the geomorphology (Figure 2.17). The short distance to the sea makes the roads vulnerable to the flood or inundation events and SLR.

Because of the economic value, the roads are considered as an important socio-economic parameter for the coastal vulnerability.

The roads data is obtained as a shapefile from Mapcruzin.com. The shapefile is a vector format that can be used directly in ArcGIS environment. Only the main roads such as D400 are used for the vulnerability index calculation.

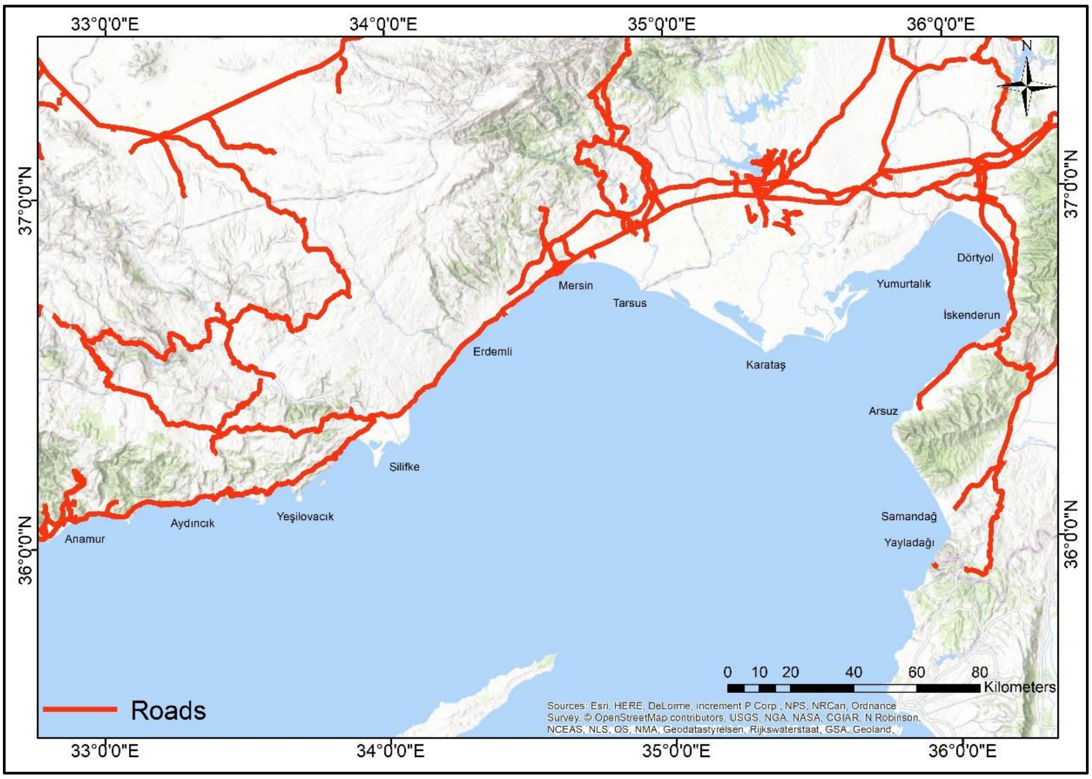


Figure 2.17. Road network of the study area (Data source: www.mapcruzin.com and www.OpenStreetMap.org)

2.1.11. Protected Areas

Nature and natural resources are under threat because of the usage unconscious and uncontrolled usage of the resources. Therefore, protection of the natural areas has become an important issue for different organizations and governmental bodies.

Protected areas are defined as a geographical place which are managed in accordance with legislations in order to protect biological diversity, natural and related cultural resources by International Union for Conservation of Nature (IUCN).

In Turkey, legislations for the protection of protected areas are implemented by the Ministry of Environment and Urbanization and Ministry of Agriculture and Forestry. These protected areas classified as National Park, Nature Park, Nature Monument, Nature Conservation Area, Wild Life Conservation Area, Ramsar Area, Wetland, Protection Forest, City Forest, Gene Conservation Forest, Seed Orchard and Seed Stands. The number distributions of the different types of protected areas shown in Figure 2.18.

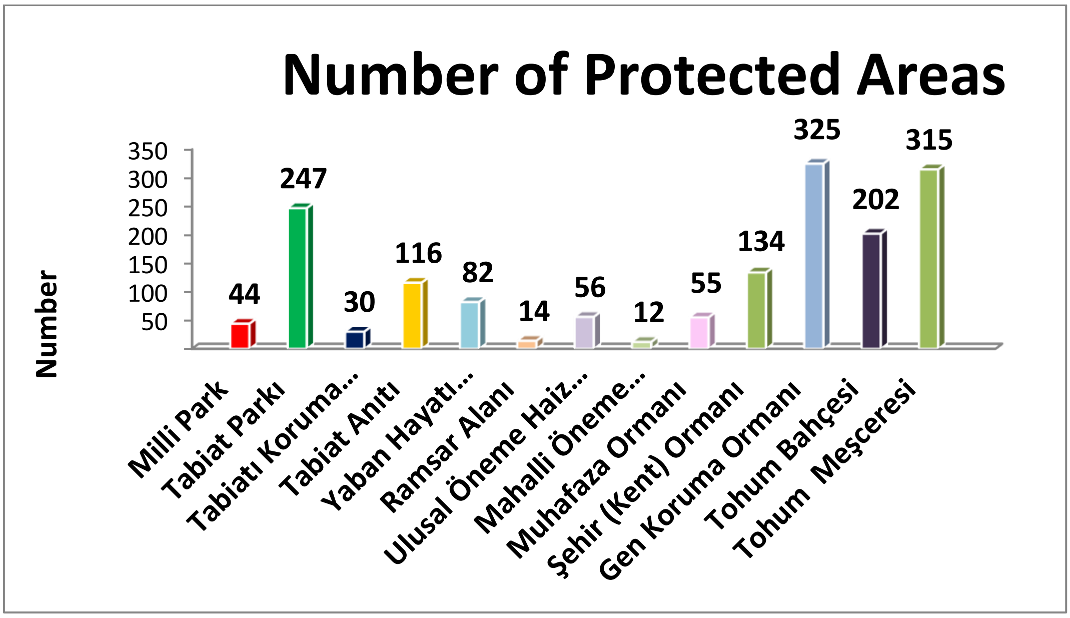


Figure 2.18. Number of protected areas in Turkey (Turkish Statistical Institute ,2019b)

There are several protected areas in the study area based on the information taken from the GIS portal of the Ministry of Environment and Urbanization. Wild life conservation sites, national parks, nature parks and also two RAMSAR sites exist along the coast of the study area (Figure 2.19).

Protected areas data is published as polygon shapefiles in the GIS portal.

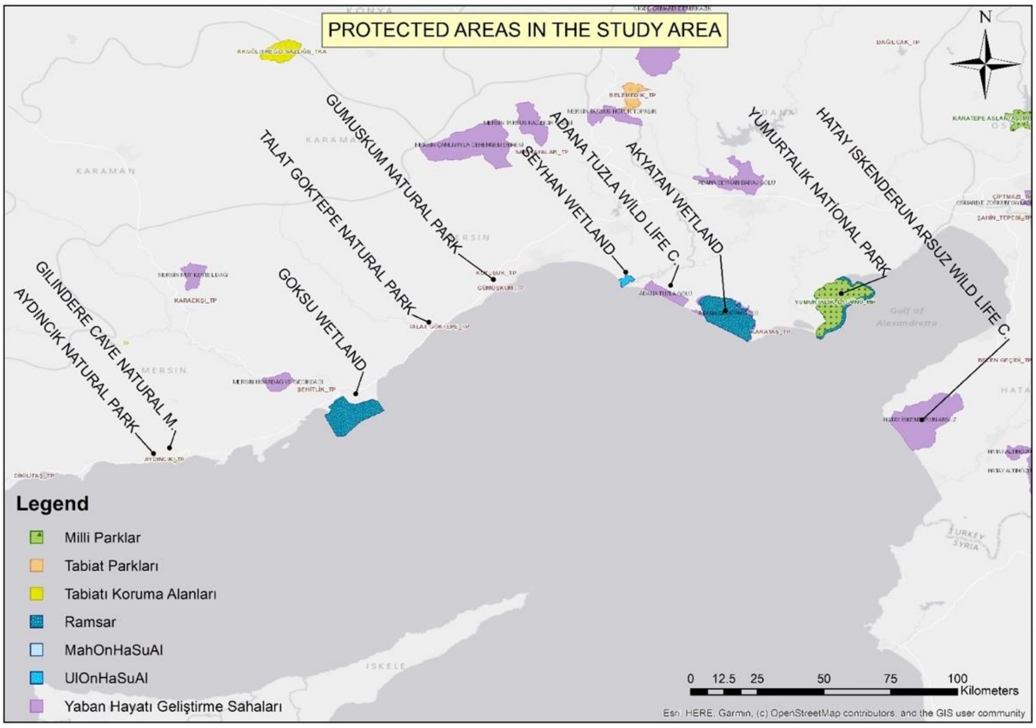


Figure 2.19. Protected Area map of the study area (from the GIS portal of the Ministry of Environment and Urbanization).

2.2. CVI methods

Coastal vulnerability is calculated based on physical and socio-economical parameters. Although there are many different, the most common physical parameters are coastal geomorphology, coastal slope, mean wave high, tides, relative sea level rise rate and sediment erosion/accretion rate. In addition, socio economic parameters are used for the CVI assessments. However, parameters such as land use, protected areas, roads and population are the most preferred socio-economic parameters for CVI assessments.

The approaches for the different methods are given in the introduction part. Among many different CVI calculation methods, five of them were applied in this study. These five methods are different from each other according to parameters and the calculation formulas.

2.2.1. Thieler and Hammar-Klose method

The Thieler and Hammar-Klose method was developed for the vulnerability assessment of the US coasts (Thieler and Hammar Klose, 2000). This method is based on a research by Gornitz et al. (1990). However, Thieler and Hammar Klose method used just 6 physical parameters to assess the coastal vulnerability (2.1)

$$CVI = \sqrt{\frac{(a * b * c * d * e * f)}{6}} \tag{2.1}$$

Where a is the geomorphology, b is the coastal slope, c is the relative sea level rise rate, d is the shoreline erosion/accretion rate, e is the mean tidal range and f is the mean wave height.

An advantage of this method is that these physical parameters used in this method, can be obtained from various sources relatively easily. For this reason, this method has been used for many coastal vulnerability studies around the world. One of the disadvantages of this method is that the only physical parameters are used to assess the coastal vulnerability. Another disadvantage is the lack of weighting coefficients; all the parameters have same degree of importance.

2.2.2. $\mathbf{CVI_6}$ method

CVI_6 is a weighted method to calculate the coastal vulnerability index (Gornitz et al., 1997). CVI_6 method includes 7 physical parameters. In this method, the parameters have weighting coefficients (2 or 4) according to their contribution to vulnerability (2.2).

$$CVI_6 = 4X_1 + 4X_2 + 2(X_3 + X_4) + 4X_5 + 2(X_6 + X_7) \qquad (2.2)$$

Where X_1 is the mean elevation or coastal slope, X_2 is the Local subsidence trend or relative sea level rise rate, X_3 is the geology, X_4 is the geomorphology, X_5 is the mean shoreline displacement or shoreline erosion-accretion rate, X_6 is the maximum wave height, X_7 is the mean tidal range.

Gornitz et al. (1997) used mean elevation as a parameter for CVI calculation. Although the slope is calculated from the elevation data, coastal slope is most preferable parameter in recent vulnerability studies. The reason is that coastal slope allows to evaluate not only the relative risk of inundation, but also the potential rapidity of shoreline retreat (Denner et al., 2015). Coastal areas where have low slope values should retreat faster than steeper coasts. Similarly, coastal slope parameter is used for the CVI calculation instead of elevation data in this study.

The main difference between CVI_6 method and Thieler and Hammar Klose method, is the mathematical operations to calculate the vulnerability index. CVI results are calculated by multiplying the parameters in Thieler and Hammar Klose, whereas the results are computed by summing the parameters in CVI_6 method. Gornitz et al. (1997) claimed that the CVI_6 method is less sensitive to misclassification errors and missing data than the product of the parameters.

2.2.3. Relative CVI method

Relative CVI method (Palmer et al., 2011) uses physical parameters and 2 additional weighting parameters for the coastal vulnerability analysis. The physical parameters are selected based on the properties of the study areas. For instance, Palmer et al. (2011) described that the distance to 20 m isobaths are one of the most important parameters for vulnerability in South Africa. However, Denner et al. (2015) changed this parameter to coastal slope based on the physical properties of the study area in South Wales, UK.

According to this method if the three critical parameters defined specifically for the study area have high scores, an additional weighting of 4 is added. Also, if there are high vulnerability areas such as estuaries or river mouths, another weighting score (4) for the area is added. In this study, the parameters for the Relative CVI method were defined as geomorphology, coastal slope, relative sea level rise rate, shoreline erosion/ accretion rate, mean tidal range and mean wave height similar to the previous methods. As a critical socio-economic parameter, the protected areas were selected for additional weighting score. In other words, if a cell intersects a protected area, additional weighting score of 4 is added (2.3).

$$Relative\ CVI = a + b + c + d + e + f + g \qquad (2.3)$$

Where a is the geomorphology, b is the coastal slope, c is the relative sea level rise rate, d is the shoreline erosion/accretion rate, e is the mean tidal range, f is the mean wave height, g is the additional weighting score is the cell intersects a protected area.

2.2.4. Total Vulnerability Index

Total vulnerability Index method differs from the previous method in the evaluation of socio-economic parameters (Szlafsztein and Sterr., 2007). In this method the physical and the socio-economic parameters are assessed separately, then, coastal vulnerability is calculated by taking the average.

The reason to assess the physical and the socio-economic parameters separately is to remove the artificial effects of the number of variables. For instance, if the number of the physical parameters are more than number of the socio-economic parameters, physical parameters may affect the CVI results more.

$$\sum PhysicalProcessVariables = w_1x_1 + w_2x_2 + \ldots + w_nx_n \tag{2.4}$$

$$\sum Socio - economicVariables = w_ay_1 + w_by_2 + \ldots + w_my_m \tag{2.5}$$

$$Physical\ Vulnerability\ Index = \sum PhysicalProcessVariables \,/\, \text{Number of PhysicalProcessVariables} \tag{2.6}$$

$$Socioeconomic\ Vulnerability\ Index = \sum SocioeconomicVariables \,/\, \text{Number of SocioeconomicVariables} \tag{2.7}$$

$$Total\ VI = \frac{\sum PhysicalVulnerabilityIndex + \sum SocioeconomicVulnerabilityIndex}{2} \tag{2.8}$$

Where, X_n is the physical parameters, Y_m is the socio-economic variables, n is the number of the physical parameters, m is the number of the socio-economic parameters, W is the weighting coefficient factors which are defined different for each parameter.

Another difference of this method are the weighting coefficients of the parameters. All the physical and socio-economic parameters are assigned a coefficient based on their degree of the contribution to the coastal vulnerability. The range of the coefficients value is defined between 0 and 0.5. The weighting coefficients are determined by considering the effects of parameters on coastal vulnerability in the study area usually by expert opinions. More critical parameters have higher values than others. The weighting coefficient used in this study are given in Table 2.2.

Table 2.2. Weighting coefficients of the parameters used in this study for the total vulnerability index method

Parameters	Weights
Coastal Slope	0.5
Relative Sea Level Rise	0.3
Geomorphology	0.4
Geology	0.2
Shoreline Erosion/accretion rate	0.2
Mean Tidal Range	0.3
Mean Wave Height	0.3
Population	0.4
Protected Areas	0.5
Road	0.1
Land use	0.5

2.2.5. CVI Sub-Index

CVI Sub-Index method was developed by Mclaughlin and Cooper (2010) to assess coastal vulnerability at different scales such as local, national and global. This method uses physical and socio-economic parameters such as the previous method. Mclaughlin and Cooper (2010) suggested also to assess the physical and socio-economic parameters separately. Moreover, they also separate the physical parameters into two classes: Coastal Characteristic (geology, elevation,etc.) and Coastal Forcing (Significant wave height, tidal range,etc.).

The parameters are evaluated as separate sub-indices at first (2.9). Each sub- index has several parameters. Vulnerability score of the parameters are summed for each sub-index separately then normalized by using the maximum and minimum scores sub-indexes can have. Then the sum of the parameters evaluated a percentage of the vulnerability score range for each sub-index (2.10). Then percentage of sub-indexes summed and the result divided by three for Coastal Vulnerability Index (2.11).

The parameters have not weighting coefficients in this method, because according to Mclaughlin and Cooper (2010), weighting can have subjective judgements that strongly affects the CVI result.

$$\text{Addition of sub-index}_a = X_1 + X_2 + X_3 + X_4 + X_5 + \ldots + X_n \tag{2.9}$$

$$\text{CVI sub} - \text{index}_a = \frac{[\text{Addition of sub} - \text{index}] - \text{Minimum}_{\text{addition of sub}-\text{index}}}{\text{Maximum}_{\text{addition of sub}-\text{index}} - \text{Minimum}_{\text{addition of sub}-\text{index}}} \text{ x } 100 \tag{2.10}$$

$$\text{CVI Sub} - \text{Index} = \frac{\text{CVI sub} - \text{index}_a + \text{CVI sub} - \text{index}_b + \text{CVI sub} - \text{index}_c}{3} \tag{2.11}$$

Where, X_1 is the one of the parameters in a sub-index, n is the number of the parameters in sub index$_a$, CVI sub-index$_a$ is the coastal forcing sub index, CVI sub-index$_b$ is the coastal characteristics sub index, CVI sub-index$_c$ is the socio-economic sub index.In this study, we used three sub-indices. (Table 2.3)

Table 2.3 Sub-indices and their parameters

Sub-Index	Parameters
Coastal Characteristic	Coastal Slope Geomorphology Geology Shoreline Erosion/Accretion Rate
Coastal Forcing	Mean Wave Height Mean Tidal Range Relative Sea Level Rise
Socio-Economic	Population Land-Use Roads Protected Areas

CHAPTER 3

RESULTS

In this study, we use five different CVI calculation methods to identify the coastal vulnerability of Mersin and Iskenderun Bays. All these methods use the physical properties of the coast to define the vulnerability. The physical properties include coastal slope, geomorphology, shoreline erosion/accretion rate, significant wave height, mean tidal range and relative sea level change rate. Moreover, some of them use also socio-economic parameters in addition to physical parameters. Socio-economic parameters are land use, population, protected areas and roads. The vulnerability of 100m x 100m cells was calculated within 500 meters along about 600 km of the coast of study area with GIS tool.

3.1. GIS Model Tool

A special GIS tool has been developed for this study to calculate the CVI values. This tool has capabilities to resample and reclassify the data, create a coastal zone mask and calculate the index value for coastal vulnerability with five different methods (Figure 3.1). The calculation of Coastal Vulnerability Index can be complicated: the method, the diversity of the data, the expected resolution of vulnerability, the resolution of the data, the weighting coefficients, the width of the mask are could/should be defined over and over. To overcome this complexity, a GIS tool have been developed using ModelBuilder application and python script language in ArcGIS (Figure 3.2). ModelBuilder is a visual programming language for building geoprocessing workflows (https://desktop.arcgis.com/en/arcmap/latest/analyze/modelbuilder/what-is-modelbuilder.htm).

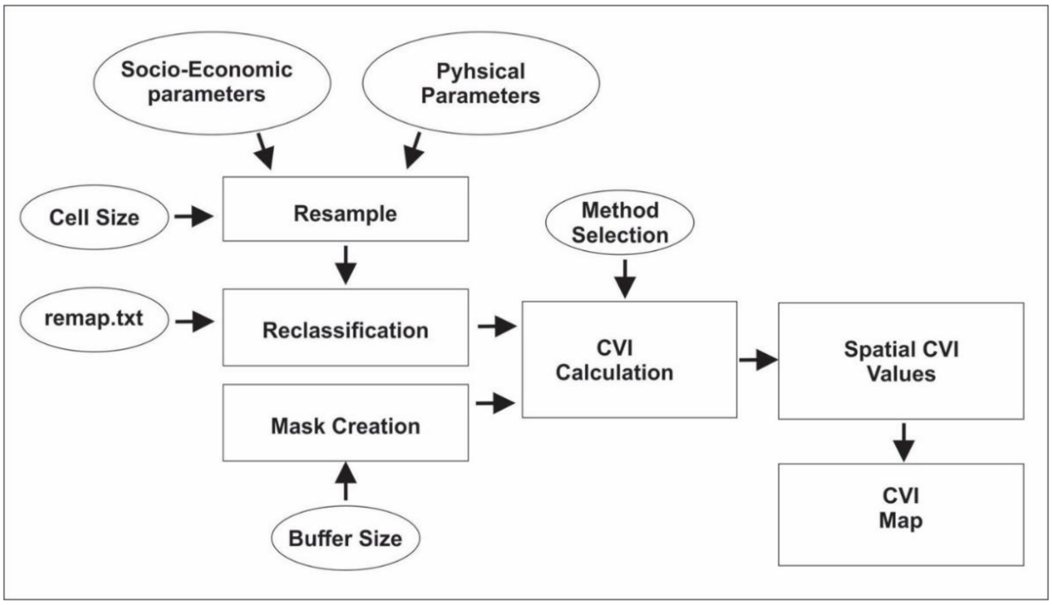


Figure 3.1. Simplified structure of the GIS model tool

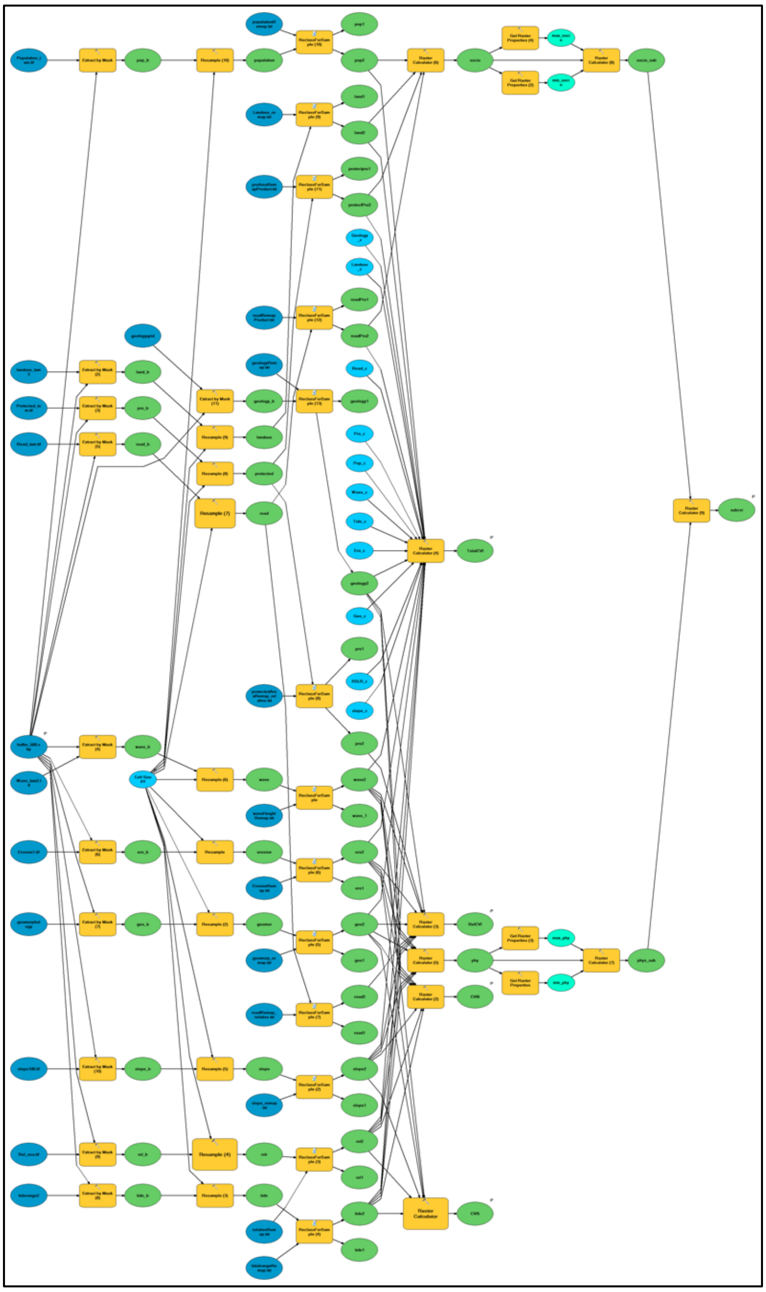


Figure 3.2. The diagram of the developed CVI calculation tool in ModelBuilder

3.1.1. Raster Data

Raster data is defined as a matrix of cells or pixels organized into rows and columns where each cell contains a value represent information such as elevation. Raster can be a digital aerial photograph, satellite images, digital pictures or thematic maps (https://desktop.arcgis.com/en/arcmap/10.3/manage-data/raster-and-images/what-is-raster-data.htm). Raster data can include both quantitative and qualitative data or information. For instance, elevation raster data have elevation values from the earth's surface. On the other hand, land use thematic raster files have land cover categories such as agriculture, forest and settlements. The area or surface represented by each cell consist of the same width and height. It is an equal part of the entire working area represented by a raster. For instance, a raster representing population may cover an area of 100 square kilometers. If there were 100 cells in this population raster, each cell would represent 1 square kilometer of equal width and height which is 1km x 1km. In this study, all parameter's data was transformed raster formats due to their simple data structure and the ability to analyze complex datasets of raster files. In the GIS tool, parameter's data inputs should be raster form to calculate CVI values.

3.1.2. Resampling

The physical and socio-economic data can be at any resolution. To use them in CVI calculation with a predefined resolution, they should be resampled first (Figure 3.1). Resampling is the process of interpolating pixel values while transforming raster data set. This ArcGIS tool is used when the pixel size changes (https://desktop.arcgis.com/en/arcmap/10.3/tools/environments/resampling-method.htm). Because the CVI calculations are made by using the pixels of the overlapping parameter's raster data in mathematical expressions, it is important for CVI calculations that the pixels of all parameters are at the same size. In this study, the cell size is defined 100 meters. All the parameter's data converted 100 m x 100 m raster data files. However, the cell size can be changed by users with the GIS tool. There are some methods to resample the raster files such as nearest, bilinear and cubic. In this study, nearest resampling method was used, since it will not change the values of the cells while the interpolation process. In addition, this nearest is the fastest interpolation method.

3.1.3. Reclassify

The parameter's raster data files have different kinds of values or attributes. The coastal slope, mean wave height, mean tidal range, and population parameters were considered quantitively. For instance, the coastal slope data has values between 0 and 78 degrees. Mean wave height values are between 0 and 1.52 meters. On the other hand, other parameters were considered qualitatively. For example, geomorphology data has 4 geomorphological landforms such as beach and alluvial plains. Land use parameter has 10 different types of usage such as industrial units, continuous urban, agricultural land. In order to use all these parameters in the Coastal Vulnerability Index calculations, they should be classified a common index, from 1 to 4 in this study, according to their values or attributes. This process is called as Reclassification. Reclassification tool change cell values to alternative (new) values in a raster. It is generally used to simplify the information in a raster or regroup raster values (https://pro.arcgis.com/en/pro-app/latest/tool-reference/spatial-analyst/understanding-reclassification.htm). For example, there are 10 classes in terms of land use. Some similar land uses can be grouped into a group.

In this study, reclassifications are based on the user input for each parameter. The new values for the parameters should be determined by users in remap.txt files (Figure 3.1). In the first line of the these remap.txt files, reclass field name in the raster dataset must be specified. In the second line, the number of the new classes number should be written. Then, old values and new values of the raster file should be written respectively on the lines with a space between them. An example of the remap.txt file for the land use parameter is shown in Figure 3.3.

In addition, raster files with numerical values can be classified according to value intervals. For example, raster values of coastal slope parameter were classified between 0-1, 1-4, 4-10, 10-90 intervals. In this case, minimum and maximum values of the intervals should be written in old values section with a space between them. Coastal slope remap.txt files in this study is shown in Figure 3.4.

Separate remap.txt files for all parameters should be determined by users. Reclassification tool creates new raster files for all parameters according to their remap.txt files. These raster files have values between 1 and 4 and they become ready for mathematical operations of CVI calculations.

```
CLASS
10
Agriculture 3
Beach 3
Continuous 4
Discontinuous 3
Forest 2
Industrial 4
Lagoon 2
Port 4
Unclaimed 1
Waterbodies 1
```

Figure 3.3 Remap.txt file of the land use parameter’s raster file. First line represents the field name. Second line indicates the number of the new classes. Other lines represent the old values and new values of the raster pixels.

```
Value
4
0 1 4
1 4 3
4 10 2
10 90 1
```

Figure 3.4 Remap.txt file of the coastal slope parameter's raster file. First line represents the field name. Second line indicates the number of the new classes. Other lines represent the old interval values and new values of the raster pixels.

3.1.4. Buffer

Another user input is buffer size in this GIS model tool. Buffer is for creating the polygons between the coastline to a specified distance from this coastline. In this study buffer size was selected 500 meters landward (Figure 3.5). All parameter’s raster files are restricted by this buffer polygon. With the buffer polygon the raster data of all parameters should be in the same boundaries and overlap.

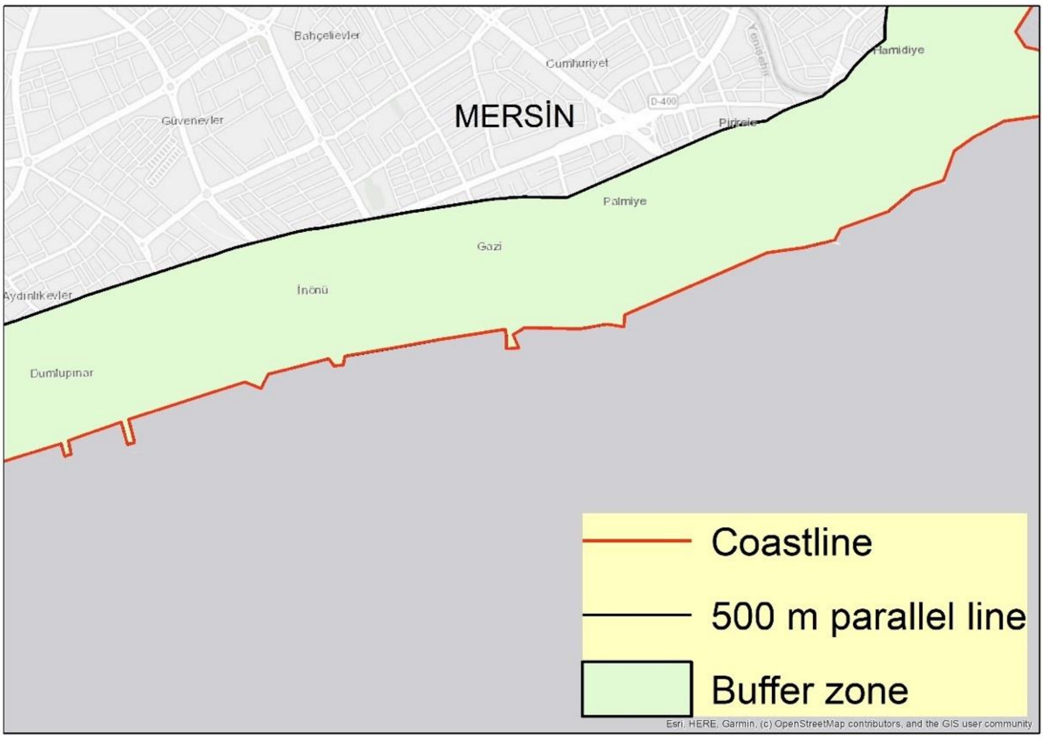


Figure 3.5 An example of the buffer zone for this study. Red line represents the coastline. Black line represents the 500 meters parallel to the coastline. Blue area represents the buffer zone.

3.1.5. CVI Calculations

After the previous data processing, the raster data of all parameters that have values between 1 and 4 are ready to calculate the CVI values. The CVI values are calculated with Raster Calculator tool. Raster calculator tool is used to make mathematical operations using multiple raster data. In other words, this tool mathematically evaluates the values of cells in the same location in multiple raster. As an example, the value of two raster cells is summed and the new value of that cell is calculated for the output raster file. All of the CVI method's values were calculated with this tool (Figure 3.6). However, the calculation of the CVI values of either one method or all the methods can be selected from the GIS tool that has been developed for this study.

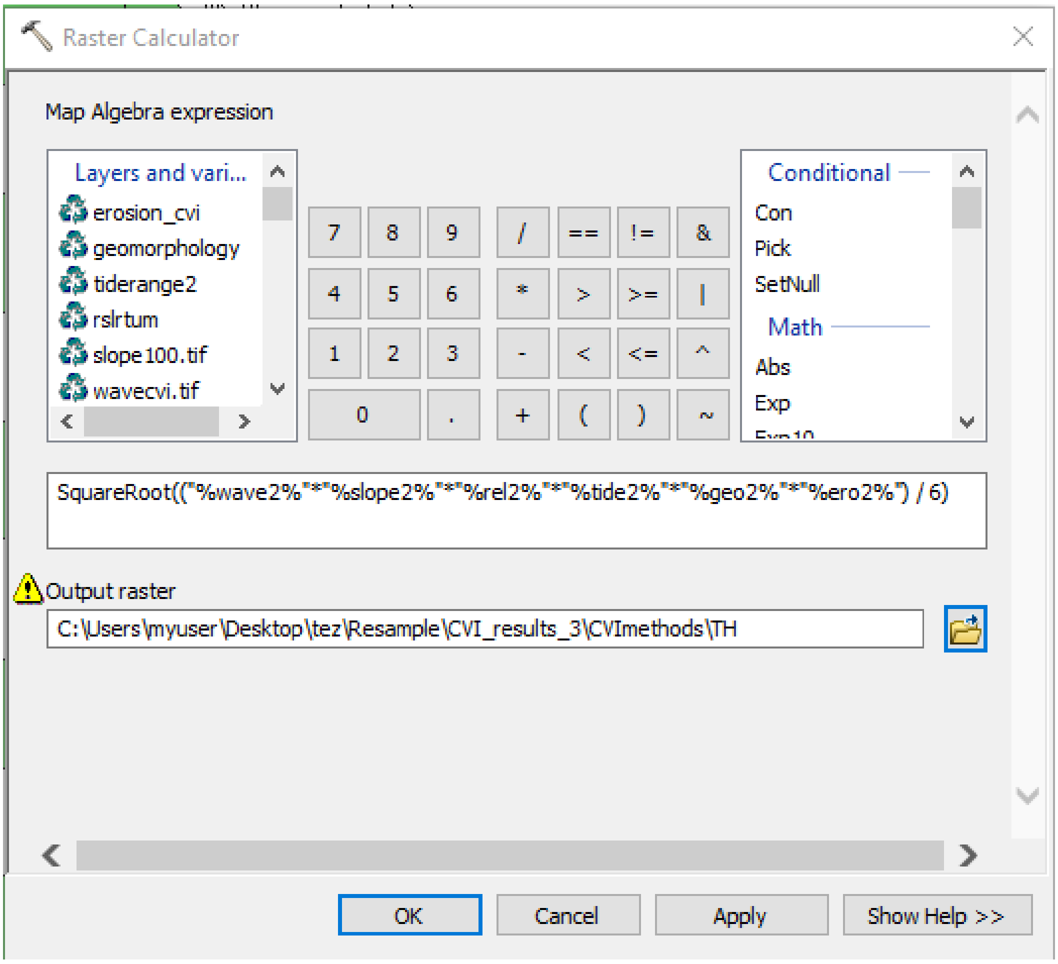


Figure 3.6 Raster calculator tool interface. The raster files that can be used for calculations are shown in the upper left. On the upper right, there are mathematical operators. The formula for the Thieler and Hammar-Klose method is shown in the middle row. The bottom line includes the output location.

The calculated CVI values are classified to create a CVI map for each method (Figure 3.1). In the process of producing CVI maps, all CVI values have been assigned to a coastline both for a better view and to express the coastline. In other words, the raster file with the specified coastline and CVI values is overlaid and all calculated CVI values are displayed on the coastline. In addition, after statistical calculations of CVI result raster files and coastline are made, tables are created for each parameter and CVI calculation method results. Therefore, the distributions of vulnerability classes are calculated automatically in the developed GIS tool. Moreover, this tool can accept user input such as the classification table for each dataset, the ranking range. An interface is created for user interaction (Figure 3.7).

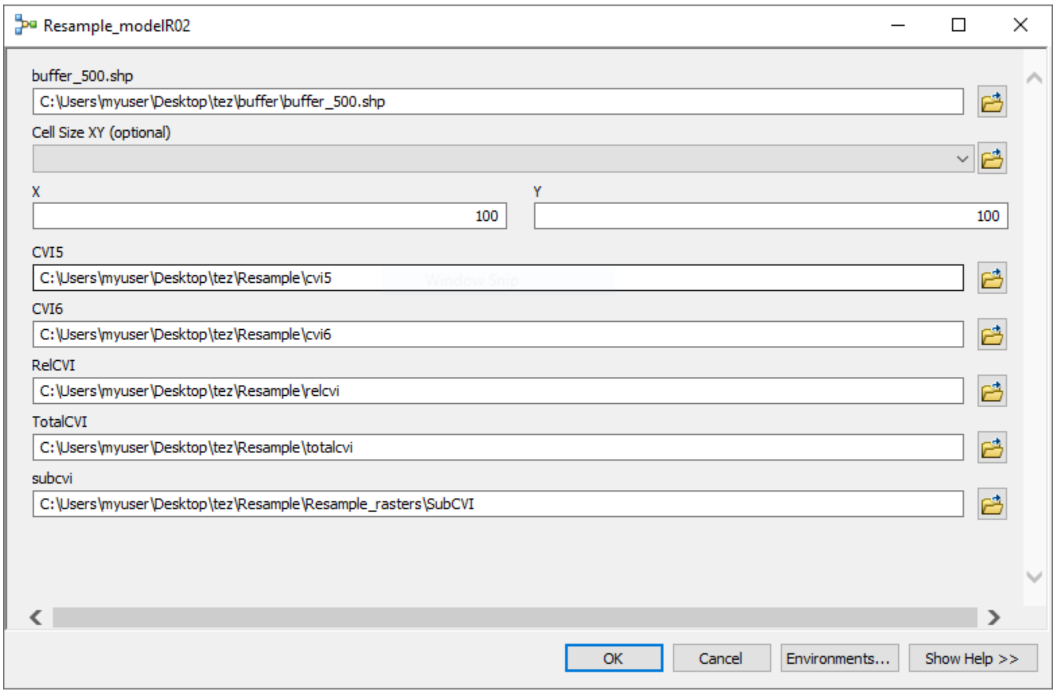


Figure 3.7. The GIS tool interface

3.2. Physical Parameters

The vulnerability ranges of the physical parameters are given in Table 3.1. The previous studies listed in introduction part were mainly used to determine the ranges. Some of the ranges were determined based on the expert opinions. The parameters with numeric values are divided into 4 ranges. Some parameters were evaluated in 4 classes, while others were evaluated in 3 or 2 classes.

Coastal slope is an important parameter when considering the inundation and sea level rise. Coastal areas that have gentle slope retreat easily than steeper coastal areas. In coastal plains larger areas will be affected than steeper areas by inundation and rising of the sea level. Thus, coastal areas that have gentle slope values are more vulnerable than steeper coasts. The gentle slope is considered as very high vulnerable and moderate slope (>10) is considered as low vulnerable (Table 3.1).

Geology parameter identifies rock types of the coastal areas according to their resistance to natural effects. High resistance rock types such as ophiolitic, are considered as low vulnerable. Coastal areas with beach and dune rock types are ranked as very high vulnerable (Table 3.1).

The shoreline change parameter is an indicator that demonstrates the vulnerability of coasts to natural hazards. Some studies in the literature, Erosion/accretion parameter is evaluated quantitively (mm/ year). In our study, this parameter was ranked qualitatively such as Diez et al. (2007). Historical satellite images were used to describe the coastline change in the study area. As a result of this comparison, some areas have significant erosion, some relatively little. Areas with high erosion rate evaluated as very high vulnerable and low erosion rate as high vulnerable. On the other hand, depositional or accretionary coastal areas are less vulnerable than others. Thus, they were ranked as low vulnerable.

Mean wave height is depending on the wave energy potential. For this reason, coastal areas with larger mean wave height have more vulnerable to erosion. Mean wave height less than 0.5 meters are ranked as low vulnerable. On the other hand, areas that have more than 1 meters Mean wave height are considered as very high vulnerable areas.

Although the high tidal range is defined as highly vulnerable transport in respect to sediment transport capacity in some studies (Gornitz et al., 1994; Diez et al., 2007; Yin et al., 2012; Duriyapong and Nakhapakorn, 2011; Addo, 2013), we believe that low tidal range is the most vulnerable as the sea-level is always close the high tide level that increase the erosion because of the waves and storm surge. This idea is also supported by many studies (Gaki- Papanastassiou et al., 2010; Karymbalis et al., 2012; Gorokhovich et al., 2014) including one study in Göksu Delta (Ozyurt and Ergin, 2010). Therefore, areas with a tidal range of less than 0.5 meters were classified as very high vulnerable.

Sea level rise is a threat for the coastal areas. Satellite altimetry data shows clearly the significant sea level rise in the Eastern Mediterranean (Figure 2.13). Relative sea level rise includes also local effects in the coastal areas. Different rates of subsidence, an important local effect for the sea level, are reported in the study area (Aksu et al, 1992). The relative sea level is ranked based on the subsidence rates.

Table 3.1. The vulnerability classification of physical parameters

Parameters/Vulnerability	Low	Moderate	High	Very high
	1	2	3	4
Coastal Slope (%)	>10	10-4	4-1	1-0
Geomorphology	Cliff, Rocky	Alluvial Plains	Beach	Estuary, Delta, Lagoon
Geology	Ophiolitic Rocks	Neritic Limestone, Clastic and carbonate rocks, Quaternary Basalt, Marble	Alluvium Fan, Undifferentiated Quaternary	Beach and Dunes
Shoreline Erosion/Accretion (m)	Accretion	Stable	Minor Erosion	Major Erosion
Mean Wave Height (m)	<0.5	0.5-0.75	0.75-1	>1
Mean Tidal Range (m)	> 1	0.75-1	0.5-0.75	<0.5
Relative Sea Level Change		Low subsidence	Subsidence	High Subsidence

3.2.1. Coastal Slope

The coastal slope parameter identifies the relative risk of inundation or flooding and potential rapidity of coastline retreat (Nageswara Rao et al., 2008). Low-sloping coastal areas are retreated faster than steeper areas. In the study area, there are many low-sloping plains between the mountains and the sea. In west coasts of the Mersin and east coasts of the Hatay, steeper coasts exist.

Entire study area was classified according to their slope values (Figure 3.8). The Taurus mountains are very close to the sea in the western parts of the study area. Between Anamur and Silifke, the mountains lie along the coast creating steep slope. Göksu River has formed a low slope alluvial plain, Göksu Delta, between Taşucu and Silifke. Afterward, the distance between the Taurus mountains and the sea increases towards Mersin. Then, very wide Çukurova plain start covering the coast between Mersin and Dörtyol. Relatively narrow coastal plains exist in Iskenderun and Arsuz at the base of steep Amanos mountains. In the eastern part of the study area, Amanos mountains extend to the sea around Samandağ and Yayladağı. Thus, the slope is very high on these coasts.

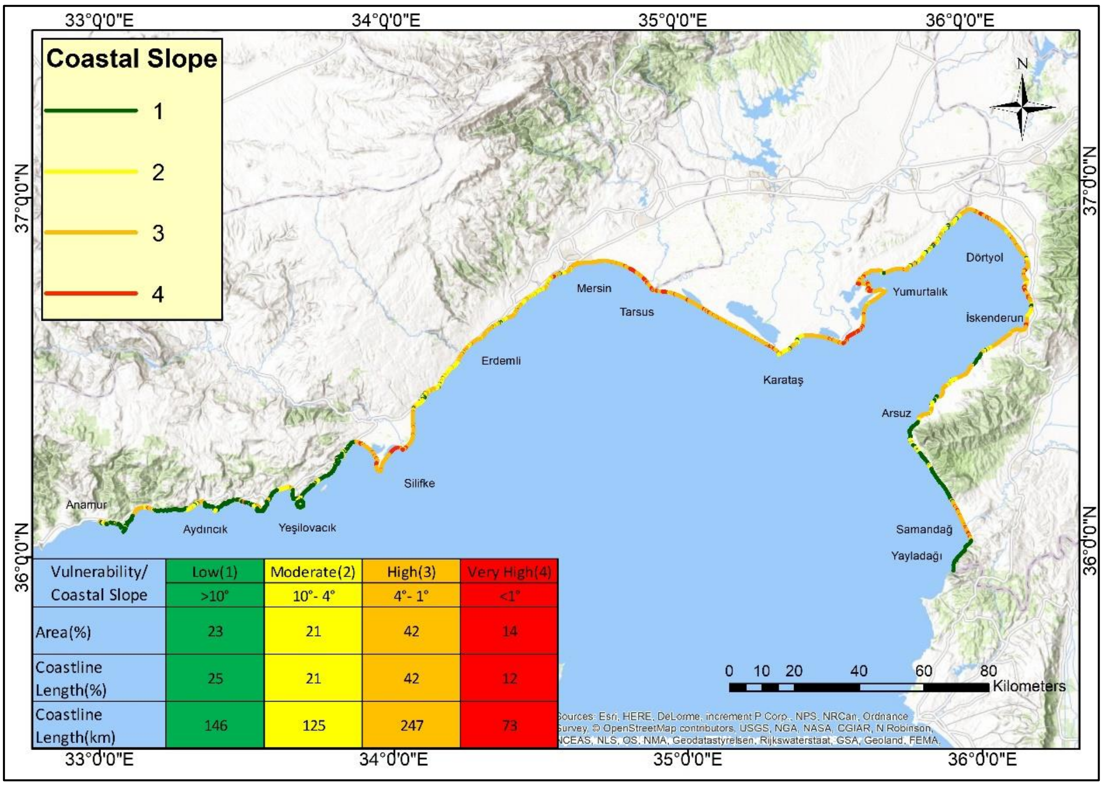
Coastal plains with slopes less than 1° were considered as very high vulnerable corresponding to the 12% (~73 km) of the coastline in the study area. These very high vulnerable areas are located in Silifke coast (Goksu Delta), Tarsus coasts (around Seyhan river mouth) and Yumurtalık coast (Figure 3.8).

The 42% (about 247 km) of the coastline is characterized as high vulnerable where the slope values range from 1 to 4 degrees. These high vulnerable areas are mainly the coastal plains.

Coasts with a slope between 4 and 10 degrees exhibits about 21% (~125 km) of the entire coastline. These areas are classified as moderate vulnerable.

146 km of the coastline (%25) was considered as low vulnerable. Coastal cliffs or rocky coasts with slopes higher than 10° were classified as low vulnerable areas. The low vulnerable coasts in terms of slope, are generally present in the west (such as

Aydıncık, Yeşilovacık) and east (Samandag, Yayladağı) sides of the study area (Figure 3.8).



Vulnerability/ Coastal Slope	Low(1)	Moderate(2)	High(3)	Very High(4)
	>10°	10°- 4°	4°- 1°	<1°
Area(%)	23	21	42	14
Coastline Length(%)	25	21	42	12
Coastline Length(km)	146	125	247	73

Figure 3.8. Coastal vulnerability classification based on slope parameter. The classes range, the coastal areas (%) and coastline length (% and km) are given in inset table.

3.2.1. Geomorphology

Coastal areas have different degree of the resistance to natural forces, according to their landforms. The erodible areas such as an estuary or a delta have highest risk. On the other hand, strength landforms such as rocks and cliffs, have low sensitivity and low risk regarding the erosion.

The 35% (~208 km) of the shoreline is categorized as low vulnerable in terms of geomorphology (Figure 3.9). These coastal areas are mainly located around Yeşilovacık, Aydıncık, between Erdemli and Silifke, Karataş, Samandağ and Yayladağı. In these areas rocky and cliff landforms exist.

Alluvial plains, which are evaluated as moderate vulnerable, represent the 42% (about 250 km) of the coastline in the study area. Alluvial plains are the most common landform in the study area. Mersin, Yumurtalık, Dörtyol, Arsuz plains and some parts of the Samandağ coasts are considered as moderate vulnerable (Figure 3.9).

About 81 km (13%) of the entire coast is defined as beach in terms of geomorphology. These beaches are ranked as high vulnerable because of their sensible nature. Most of the distribution of the beachs are appeared in Göksu Delta (Silifke), some areas between Mersin and Karataş and some parts of Yumurtalık (Figure 3.9).

Coastal areas with high erodible landforms (estuary, lagoon,delta) are categorized as very high vulnerable. These areas especially appear around the wetlands in Yumurtalık, Tarsus and Silifke. Estuary, lagoon and delta landformes occupy about 10% of the entire shoreline which corresponds about 60 km of the coastline (Figure 3.9).

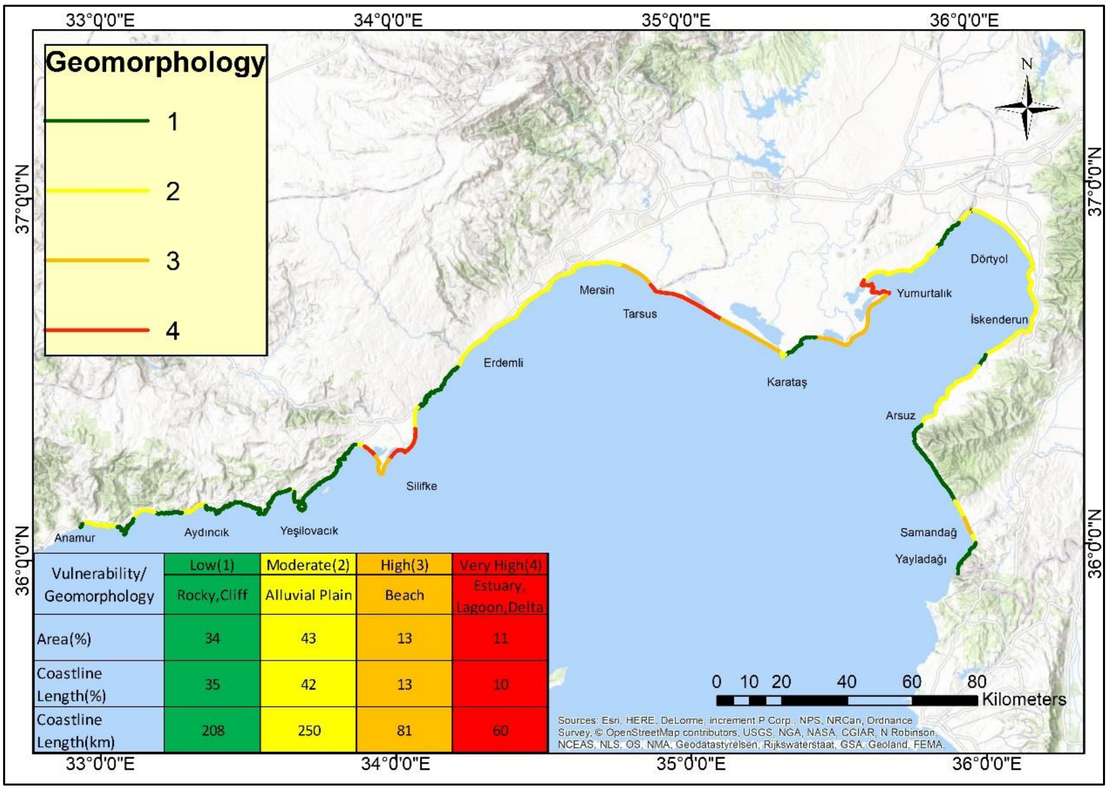


Figure 3.9. Coastal vulnerability map based on geomorphology. The geomorphological landforms and corresponding vulnerability classes are given in inset table.

3.2.2. Geology

Geology parameter is related to the resistance of the geological formations in coastal areas. Ophiolitic, metamorphic, volcanic and sedimentary are observed often in the study area. The region is classified according to resistance of these rock types. For instance, areas with ophiolitic rocks have the highest resistance to natural hazards. Thus, these areas classified as low vulnerable. Beach and dunes which are sedimentary rocks, are ranked as very high vulnerable because of their sensitivity to natural forces.

Coastal areas with ophiolitic rock characteristics are considered as low vulnerable due to their substantial geological features. Low vulnerable coastlines represent about 4% (~25 km) of the total length of shoreline. These kind landforms exist on the coasts between Samandağ and Arsuz (Figure 3.10).

The 38% (about 227 km) of the study area is classified as moderate vulnerable in terms of geology. These geological features are neritic limestone, clastic, carbonate rocks, basalt and marble. The distribution of the moderate vulnerable areas is generally located in the western part of the study area (Aydıncık, Yeşilovacık, areas between Erdemli and Silifke). Some part of Karataş coasts, area between the Yumurtalık and Dörtyol and Yayladağı coasts are also considered as moderate vulnerable (Figure 3.10).

Alluvial fan and undifferentiated quaternary sedimentary rocks are classified as high vulnerable in terms of geology. These rock types comprise about %37(~222 km) of the entire coastline. High vulnerable areas are placed in Mersin, Karataş, Dörtyol, İskenderun, and some parts of Samandağ coasts (Figure 3.10).

The 21% of the study area is defined as very high vulnerable. Beach and dune rocks type is the most insubstantial geologic feature in the study area. They are generally located around the lagoons and deltas. The most prominent high vulnerable areas are in Silifke (Göksu Delta), Tarsus (coasts around the Seyhan River mouth, and Yumurtalık coasts (Figure 3.10).

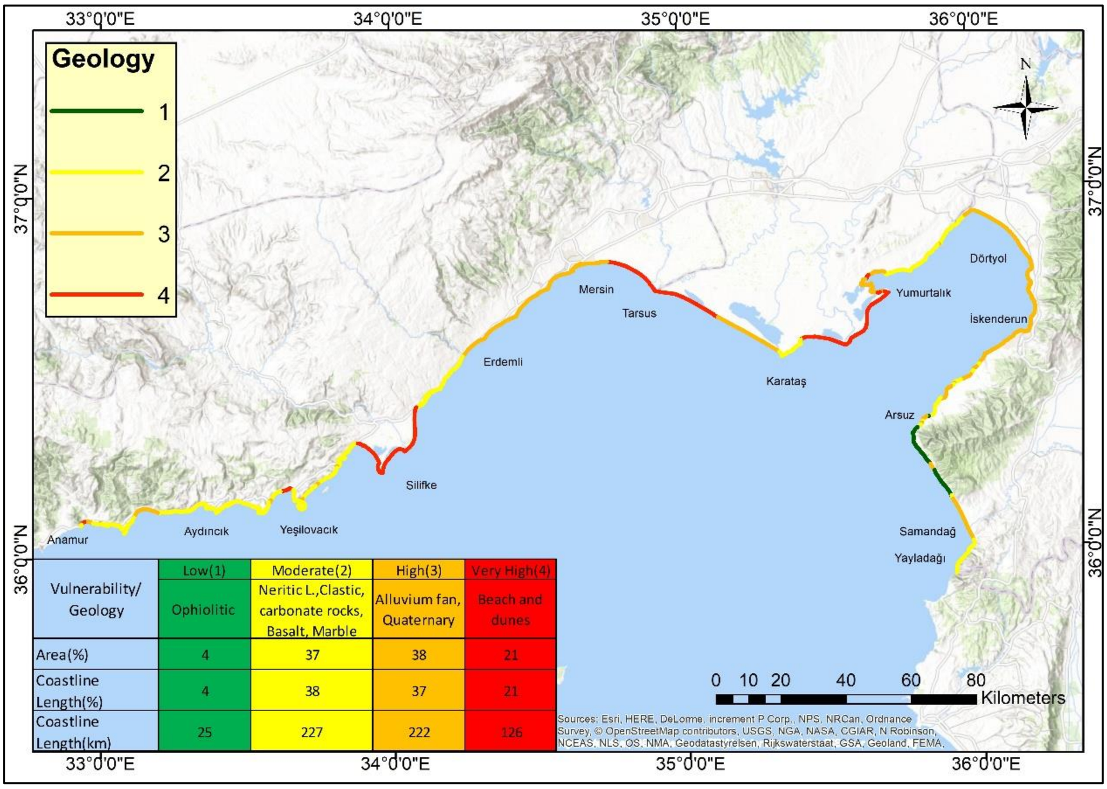


Figure 3.10. Geology classification map of the study area

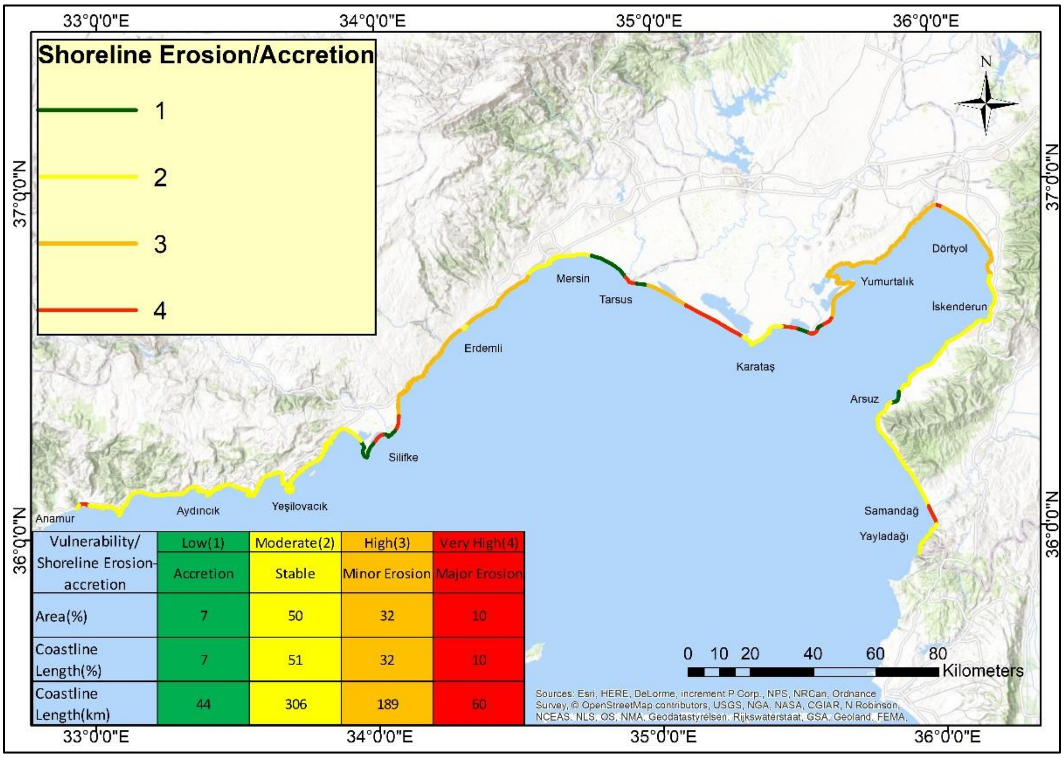
3.2.3. Shoreline erosion/accretion rate

The shorelines in different years were digitized from the satellite images from different years (1984, 1994, 2004, 2014 and last satellite images). The changes in the coasts were evaluated by comparing these shorelines. After the comparison, erosive, depositional and stable coasts are classified qualitatively classified in the study area.

Accretional areas, classified as low vulnerable, correspond to 7% of the coastline (about 44 km). These areas are located mainly in Göksu Delta, Mersin, Tarsus, Yumurtalık and İskenderun coasts. Some part of Göksu delta coasts, Tarsus coasts and Yumurtalık coasts are evaluated as depositional areas as a result of the accumulation of sediments transported by Göksu, Seyhan and Ceyhan rivers, respectively (Figure 3.11).

Coastal areas with shoreline high rate of erosion are categorized as very high vulnerable areas. These areas represent about 10% (~60km) of the total coastline (Figure 3.11). Erosional areas are located mainly in Göksu delta, Seyhan river mouth in Tarsus, in the coastal part of the Akyatan Lagoon (between the Karataş and Tarsus). The coastal areas where only a minor erosion observed are ranked as high vulnerable that corresponds 32% of the coastline (Figure 3.11).

The vulnerability of the longest (51% =~306 km) part of the coastline in the study area is defined as moderate vulnerable. In this part the sediment movement is stable, it wasn’t observed a permanent deposition or erosion (Figure 3.11).



Vulnerability/ Shoreline Erosion-accretion	Low(1) Accretion	Moderate(2) Stable	High(3) Minor Erosion	Very High(4) Major Erosion
Area(%)	7	50	32	10
Coastline Length(%)	7	51	32	10
Coastline Length(km)	44	306	189	60

Figure 3.11. Shoreline Erosion/accretion classification map.

3.2.4. Mean Wave Height

The coastal vulnerability based on mean wave height are represented in four classes based on the data (Table 2.1).

About 8% (~ 46 km) of the coastline is characterized as low vulnerable where the wave height values are less than 0.5 meters. Figure 3.12 shows that the low vulnerability areas are located only in Taşucu bay.

About 317 km of the coastline (~52%) is considered as moderate vulnerable. Coastal plains such as Göksu Delta and Çukurova are examples of the areas of moderate vulnerability. Despite the high slope values, the coastal zone between Anamur and Taşucu is also moderate vulnerable to waves. The reason is the lack of natural protection against the waves from the open sea.

The high vulnerable areas, about 17% (103 km) of the coastline are located in the Yumurtalık side of the inner İskenderun Bay and at the Kazanlı beach located between Seyhan River's mouth and Mersin city.

The very high vulnerability (22%: 134 km of the coastline) is observed at two edges of the İskenderun Bay. It is believed that this is mainly related to the direction of prevailing wind.

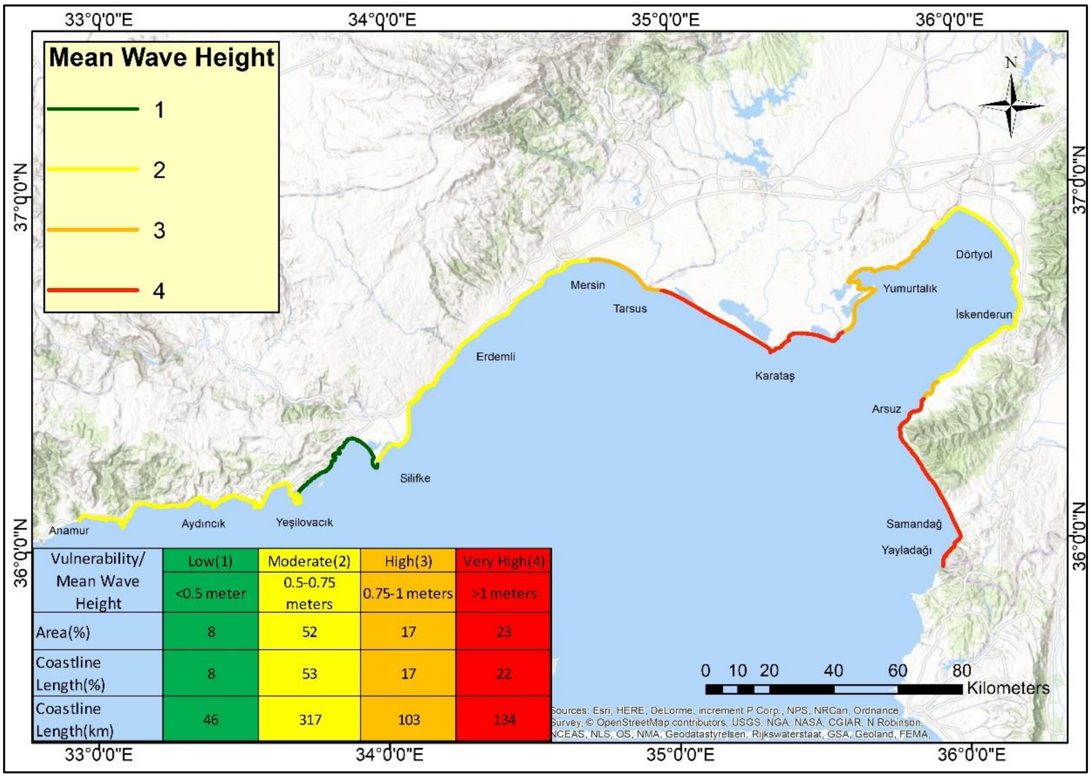


Figure 3.12. Coastal vulnerability classification based on mean wave height values.

3.2.5. Mean Tidal Range

Study area is considered as a micro tidal coastal region based on the short range between high and low tides (Figure 2.12). As the sea level is always close to the high tide, low tidal range increase the risk of erosion and inundation related to the storm surges. For this reason, the low tidal range is considered as more vulnerable for the coastal zones.

Based on the data from the tide-gauge stations, two vulnerability classes are defined in the study area. The eastern part of the study area including İskenderun Bay is considered as high vulnerable (41%, about 247 km of the coastline). The coast from Anamur to Karataş, 59% of the coastline (~352 km) is categorized as very high vulnerable (Figure 3.13)

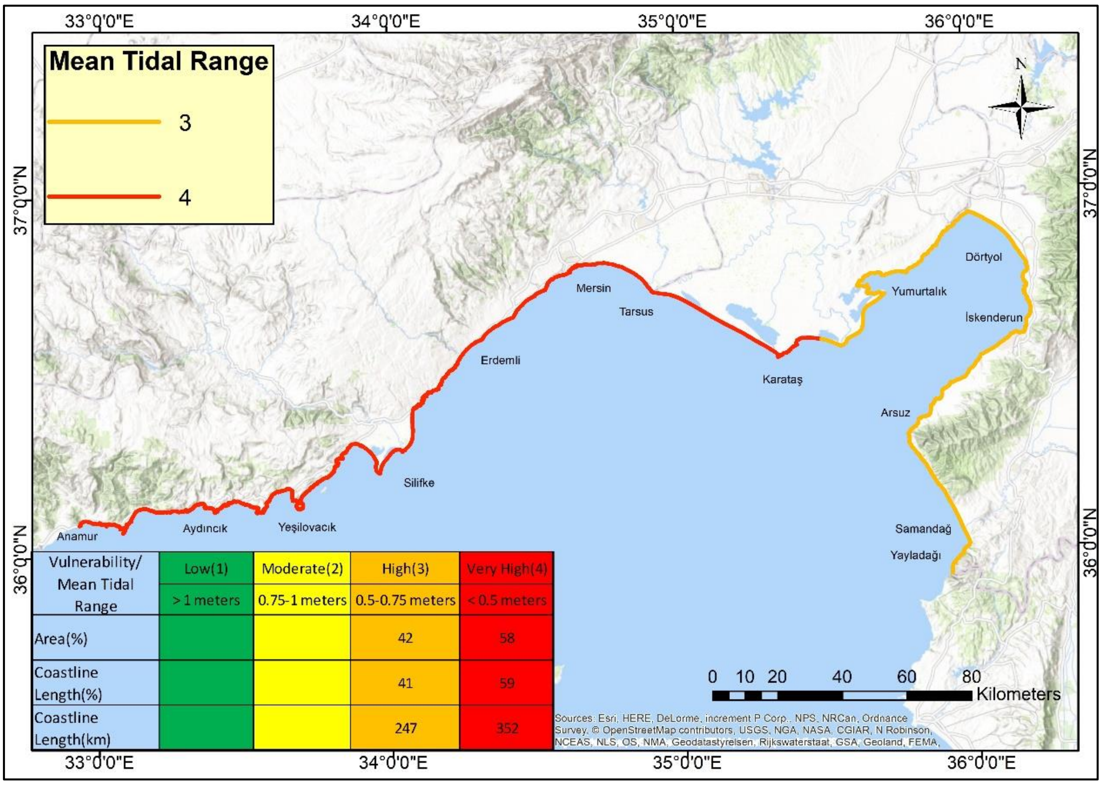


Figure 3.13. Mean tidal range map based on the Turkish National Sea Level Monitoring System data.

3.2.6. Relative Sea Level Change

As one of the main impacts of the climate, sea level rise is a significant threat for the coastal areas. Satellite altimetry data shows clearly the significant sea level rise in the Eastern Mediterranean (Figure 2.13). Relative sea level rise includes also local effects in the coastal areas such as atmospheric pressure, steric effect and local land movement.

Vertical land movement is a prominent local effect for the sea level in the study area. Aksu et al, (1992) reported differential tectonic subsidence in Cilician Basin and İskenderun Bay based on the marine stratigraphic data. However, as the Taurus and Amanos mountains are not depositional environment, it is believed that the subsidence is very small or negligible. The vulnerability for relative sea level is ranked based on the subsidence rates.

The higher subsidence occurs in Cilician Basin, thus the area between Yeşilovacık and Karataş is considered as very high vulnerable (237 km, 40% of the coastline). Another 40% of coastline is marked as moderate vulnerable. These areas, where the Taurus and Avanos mountains are very close to the coastline are subject to low subsidence. The Yumurtalık side of the İskenderun Bay (125 km, 21% of the coastline) is classified as high vulnerable because of the relative subsidence rate (Figure 3.14).

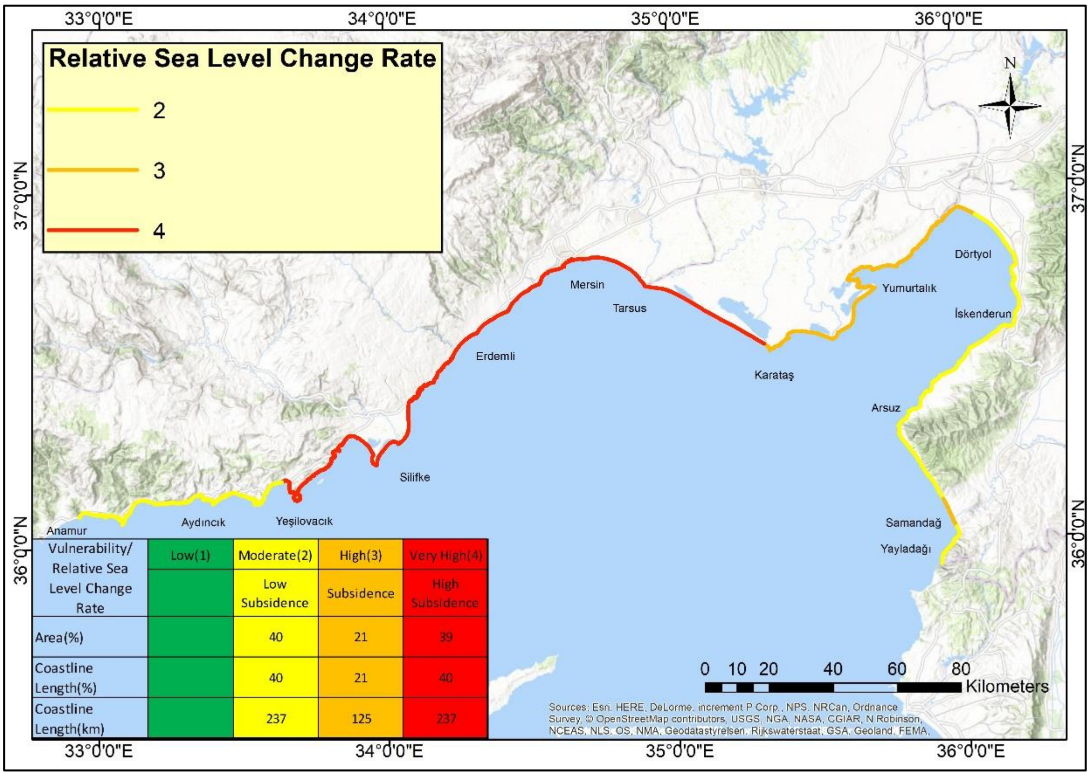


Figure 3.14. Relative sea level change rate map

3.3. Socio-Economic Parameters

Beside the physical characteristics, socio-economic variables are also very important for vulnerability assessment. The existence of socio-economic features such as the infrastructures, the residences, roads increase the coastal vulnerability. The population density is also directly related to the vulnerability of an area. The more the population is dense, the more vulnerable an area is. The protected areas are the safe habitats for many plant and animal species. They increase the vulnerability of the coastal areas against the natural impacts. The vulnerability classification of the socio-economic parameters is given in Table 3.2.

Table 3.2. The vulnerability classification of socio-economic parameters

Parameters/Vulnerability	Low	Moderate	High	Very High
	1	2	3	4
Population (people/0.01 km^2)	0-20	20-100	100-200	200-300
Land use	Water bodies, Unclaimed	Lagoon, Forest	Agriculture, Discontinuous Urban Beach	Continuous Urban, Industrial Units, Ports
Roads	Absent			Present
Protected-area	Absent			Present

3.3.1. Land use

Land use parameter are divided into 4 classes according to their socio-economic importance. Continuous Urban, Industrial units and Ports, which are considered as very high vulnerable, represent about 15% of the study area. They are generally located around Mersin, Erdemli and İskenderun coasts which are using for continuous urban areas. Coasts between İskenderun and Dörtyol and Yumurtalık to Dörtyol are significant for the industrial facilities. For this reason, these coasts are classified as very high vulnerable.

Figure 3.15 shows that agricultural land, discontinuous areas and beaches, which are considered as high vulnerable, make up about 51% (~305 km) of the entire coastline. In Erdemli, Karataş, Yumurtalık, Dörtyol, Arsuz and Samandağ coasts, many discontinues urban areas and beaches, which are commonly used for summer seasons, exist. The region between Mersin and Karataş is generally used as an industrial district. Productive areas between Mersin and Karataş, some parts of Yumurtalık and areas between İskenderun and Arsuz are used for the agricultural activities.

Lagoon and Forests are considered as moderate vulnerable according to land use. The 26% (~156 km) of the coastline are assigned as moderate vulnerable coasts. In most of the coasts in western part of the study area, forests exist. Yayladağı coasts and coast between the Samandağ and Arsuz are classified as forest. Some part of Yumurtalık and Göksu Delta (in Silifke coasts) are considered as lagoons.

There are small areas in the working area that are not included in any usage class. These areas are classified as unclaimed areas. Unclaimed and water bodies are rated as low vulnerable. Göksu delta (Silifke) coasts are the most common low vulnerable areas in the study area. Figure 3.15 demonstrate that low vulnerable areas characterize about 8% (~50 km) of the entire coastline.

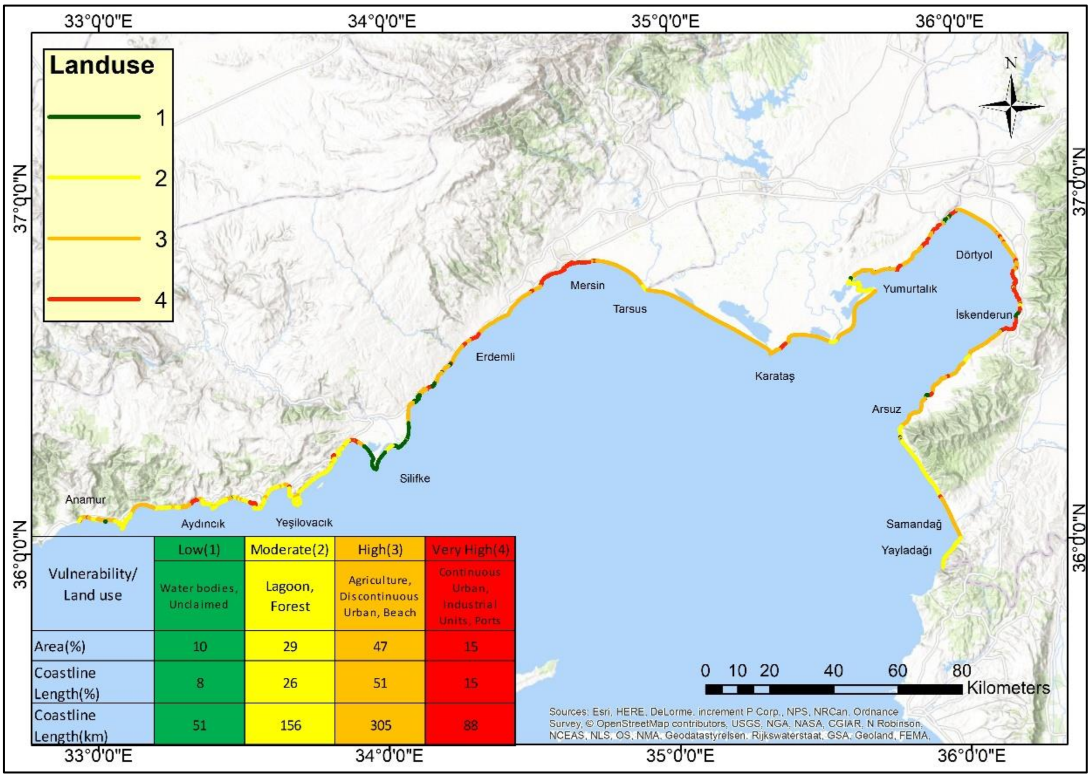


Figure 3.15. Land use classification map of the study area

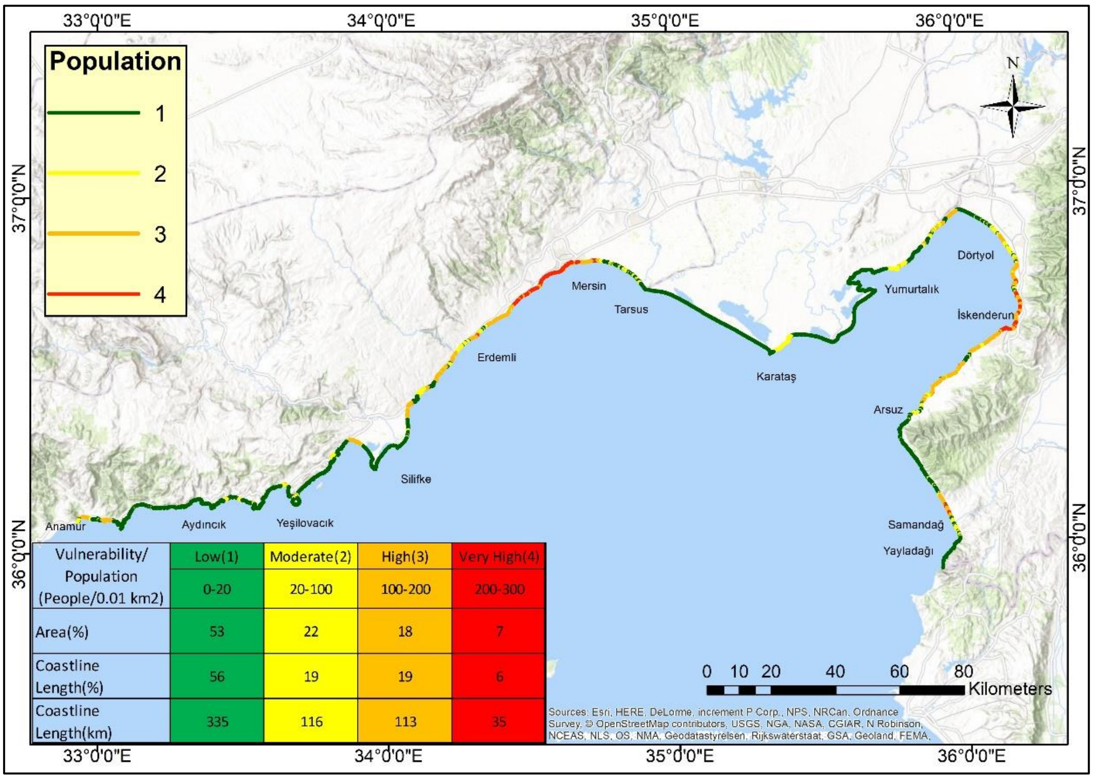
3.3.2. Population

Population parameter divided into 4 classes according to human settlement per 0.01 km^2. High populated areas are evaluated as the most vulnerable.

İskenderun and Mersin coasts are considered as very high vulnerable due to high population density (200-300 people/0.01 km^2). The very high vulnerable coastal areas represent 6% (about 35 km) of the total coastline. Coastal areas with a population density between 100 and 200 people/0.01 km^2 are classified as high vulnerable. Erdemli, Dörtyol and the coasts between İskenderun and Arsuz where there are many discontinuous areas, are classified as high vulnerable. These areas are categorized 19% (113 km) of the entire coastline.

In Karataş and in east side of the Yumurtalık coasts, the vulnerability based on the population density is ranked as low vulnerable (20-100 p/0.01 km^2). Some minor part of the coastline of the study area are evaluated as moderate vulnerable. However, the distribution of the moderate vulnerable coast is scattered (Figure 3.16).

The largest distribution of the population class is low vulnerable coasts. These coasts are commonly represented in Aydıncık, Yeşilovacık, Silifke, Tarsus, Karataş, Yumurtalık, Dörtyol, Yayladağı coasts and coasts between Arsuz and Samandağ. Low vulnerable coasts characterize 56.71% (~354 km) of the study area.



Vulnerability/ Population (People/0.01 km2)	Low(1)	Moderate(2)	High(3)	Very High(4)
	0-20	20-100	100-200	200-300
Area(%)	53	22	18	7
Coastline Length(%)	56	19	19	6
Coastline Length(km)	335	116	113	35

Figure 3.16. Population Classification Map of the study area

3.3.3. Protected Areas

In the study area different types of protected area such as natural parks, wetlands, and wild life conservation areas and national park exist. These protected areas are considered as very high vulnerable. The 37% of the coastline which is equal to about 221 km is covered by protected areas. These protected areas are located in Anamur, Aydıncık, Yeşilovacık, Silifke, Tarsus, Karataş, Yumurtalık and an area between Arsuz and Samandağ.

The remaining 63% of the coastline (about 379 km) does not have protected areas and they considered as low vulnerable (Figure 3.17).

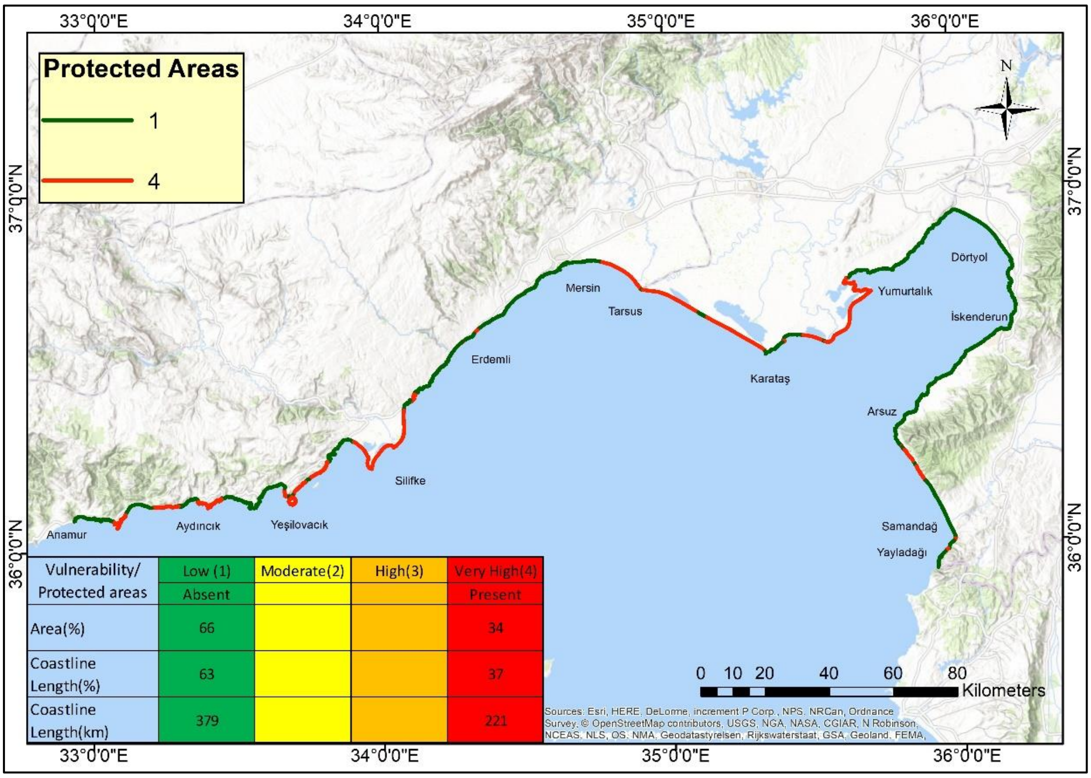


Figure 3.17. Protected Areas Map for the study area

3.3.4. Roads

Road data is classified in 2 group like the protected areas. Coastal areas that intersect roads are more vulnerable than other areas. The 22% (~131 km) of the coastline is considered as very high vulnerable because of presence of the roads in the coastal zone. These kinds of coasts are generally occurred in western parts of the study area especially coasts between the Yeşilovacık and Anamur (Figure 3.18).

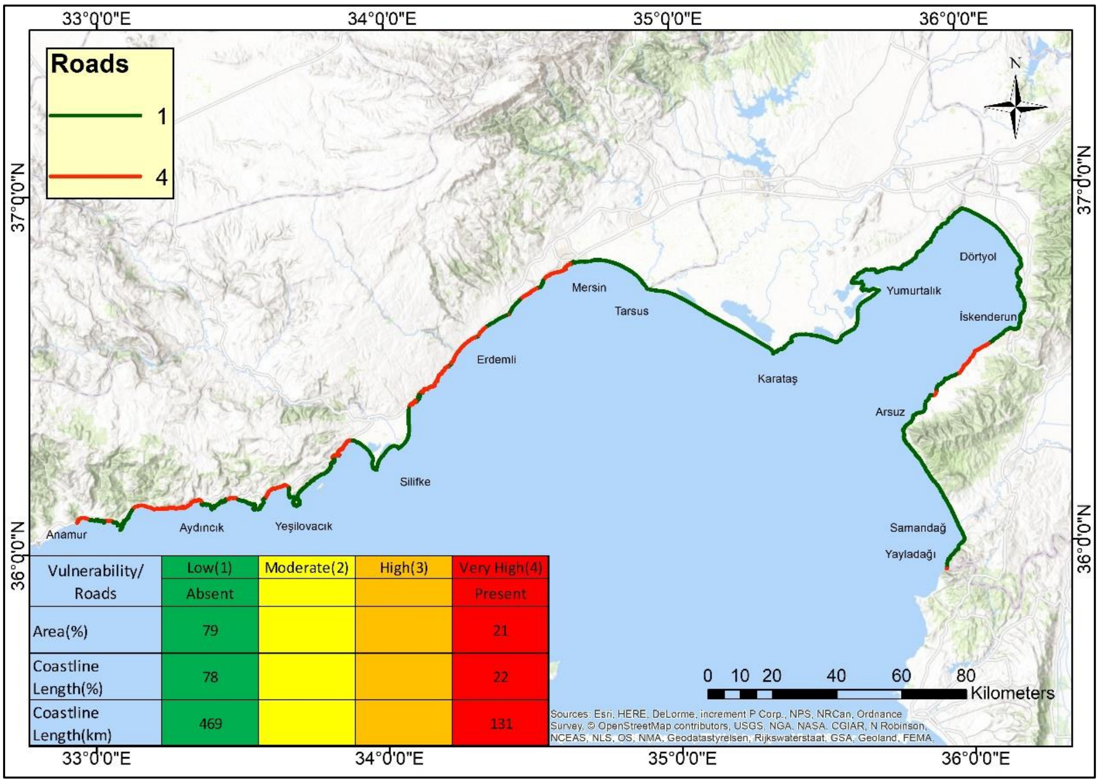


Figure 3.18. Road Classification Map of the Study area

3.4. Coastal Vulnerability Index (CVI) assessments

Five different CVI methods were used for the vulnerability assessment in the study area. All CVI values are divided into 4 vulnerability classes (low, moderate high and very high) with regards to their quantile ranges (0-25%, 25-50%, 50-75% and 75-100%).

3.4.1. Thieler and Hammer Close Method

Calculated CVI values according to Thieler Hammar-Klose method range from 2 to 26.13 (Figure 3.19). Based on the quantile classification, the CVI values above 9.77 are considered as very high vulnerable coastlines. About 149 km, corresponding %25 of the total coastline was assigned to this category. Samandağ coasts, many areas between Tarsus and Yumurtalık, areas between İskenderun and Arsuz are evaluated as very high vulnerable.

Coastal areas with CVI values between 6.46 and 9.76 are classified as high vulnerable. These coastal areas represent about 21% of the entire shoreline. They are primarily located in Silifke, Mersin and east sides of Yumurtalık coasts.

The moderate vulnerability class with the largest distribution in this method covers approximately 28% (~168 km) of the study region. The CVI values for the moderate vulnerability range between 4 and 6.45. The most highlighted moderate vulnerable coasts appear in the areas between Silifke and Erdemli, between Dörtyol and Arsuz.

Especially steeper, with strength landform coasts are classified as low vulnerable (CVI values < 3.99). These areas represent about 150 km of the entire coastline which is equal to 25% of this coastline. In Yeşilovacık, Aydıncık, Yayladağı and some areas around Samandağ are assessed as low vulnerable (Figure 3.19).

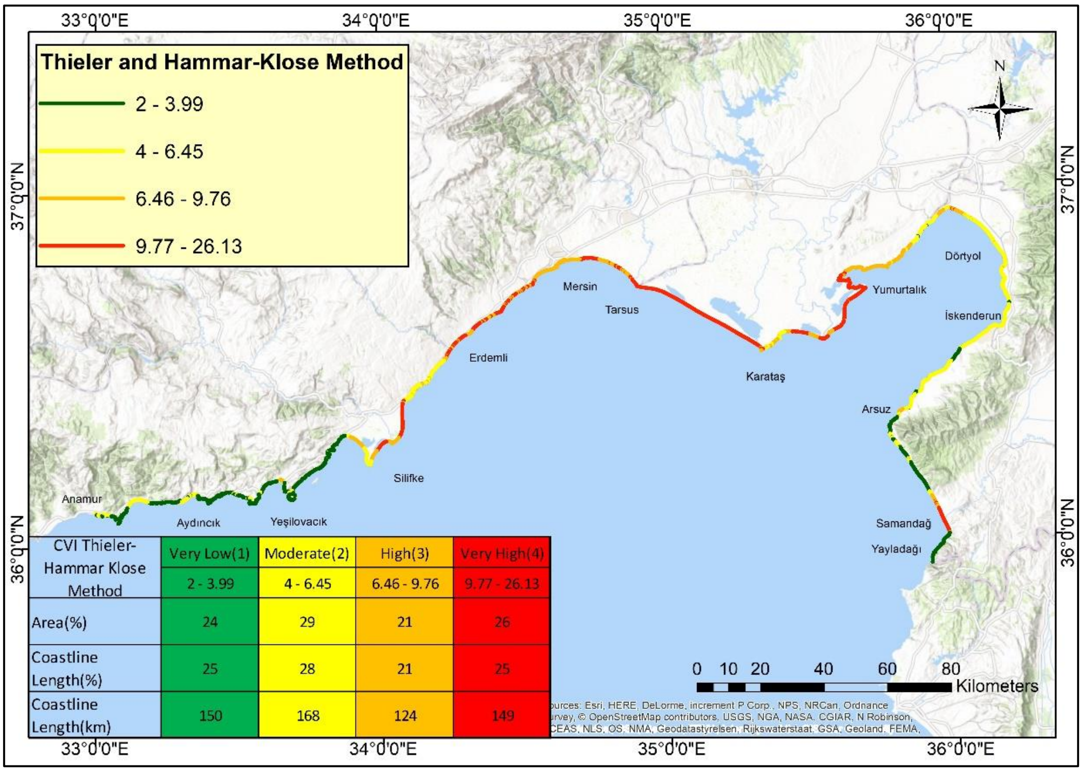


Figure 3.19. CVI map based on Thieler and Hammar-Klose method

3.4.2. CVI_6 method

CVI_6 method uses 7 physical parameters to calculate the vulnerability. According to this method, the CVI values are calculated in the range between 36 and 80 (Figure 3.20).

Very high vulnerable (CVI values > 61.89). coasts represent 25% (~148 km) of the coastline. These coasts are generally exist in Silifke, Tarsus, eastern side of Karataş, Yumurtalık and Samandağ which are generally have low resistence geology and flat geomorphology.

CVI_6 result map demostrate that, Dörtyol, Mersin and Erdemli coasts are classifed as high vulnerable where CVI values range between 53.96 and 61.88. These coasts cover 25%(147 km) of the coastline (Figure 3.20).

Coastal areas with CVI_6 values between the 43.95 and 53.95 are considered as moderate vulnerable. İskenderun coasts and some coasts between Erdemli and Silifke are notable moderate vulnerable coasts in Figure 3.20. Moderate vulnerable coasts contains about 25% (~148 km) of the overall coastline.

Low vulnerable coasts (CVI values <43.94) represent the 19% of the entire coastline. These areas are generally located in western and eastern part of the study area which contains most parts of Aydıncık, Yeşilovacık, Yayladağı and coasts between Arsuz and Samandağ.

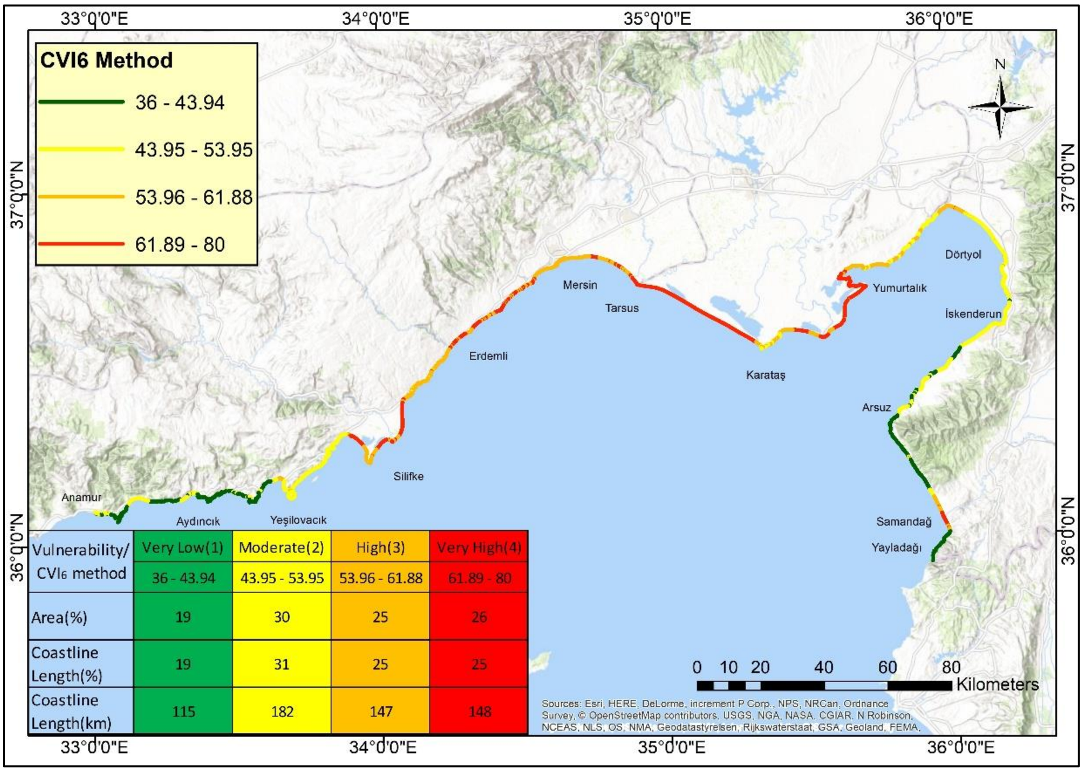


Figure 3.20. CVI map based on CVI_6 method

3.4.3. Relative CVI method

Relative CVI values computed for the study area range between 10 and 27 (Figure 3.21).

The 19% (~111 km) of the entire coastline is classified as very high vulnerable (CVI values>21) according to this method. These coasts are mainly located in Göksu Delta and in between Tarsus and Yumurtalık. The significant protected areas such as national park and wetlands increase the vulnerability in these areas.

Coastal areas with CVI values that range between 15 and 21 are considered as high vulnerable. The largest distribution of the vulnerability (35% = ~205 km of the coastline) is classified as high vulnerable. High vulnerable coasts are generally located in Anamur, Aydıncık, Mersin, Dörtyol and Samandağ coasts.

Erdemli, Yumurtalık and İskenderun coasts are classified as moderate vulnerable areas regarding their Relative CVI values. The interval of the CVI values are between 13 and 15 for this class. Moderate vulnerable coasts represent the 26% (about 156 km) of the overall coastline.

Coastal areas with relative CVI values less than 13 are ranked as low vulnerable. These coasts cover 20% (~119 km) of the entire coastline. Low vulnerable coasts are mainly found in Yeşilovacık, between Erdemli and Silifke, and Yayladağı coasts.

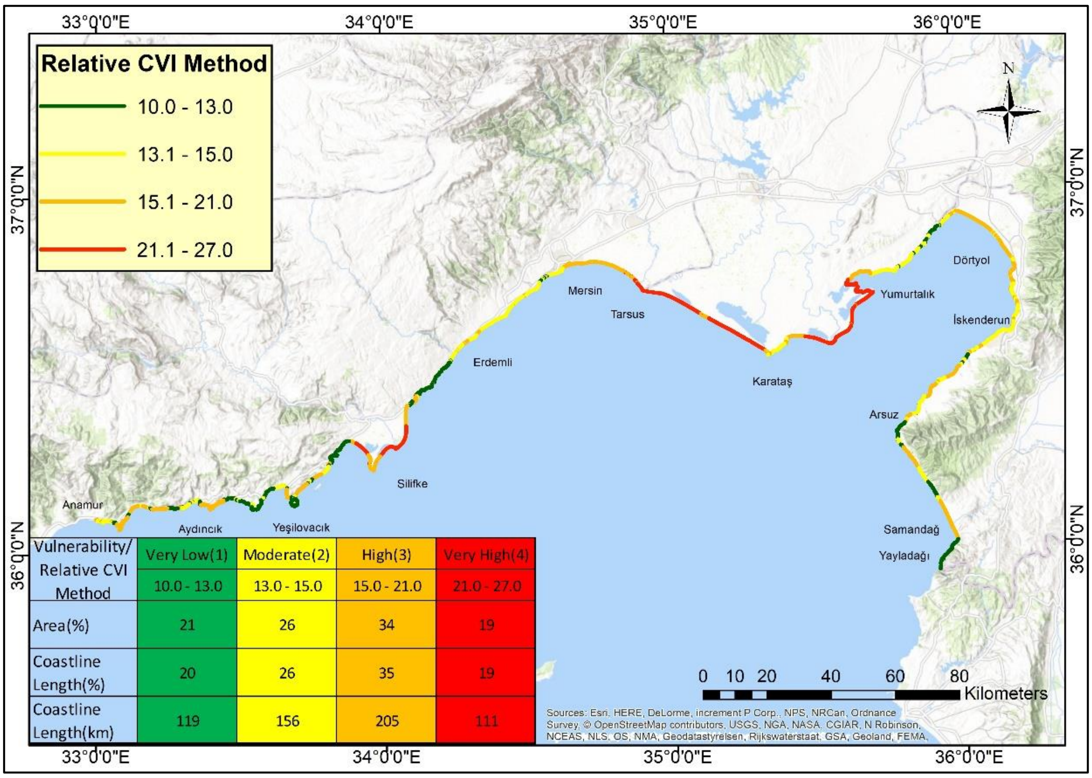


Figure 3.21. CVI map based on Relative CVI method.

3.4.4. Total Vulnerability Index

All physical and socio-economic variables are used in Total Vulnerability Index method with the coefficient values given in Table 2.2. The calculated Total Vulnerability Index range between 0.48 and 1.16 (Figure 3.22).

The coastal areas with CVI values greater than 0.95 are considered as very high vulnerable areas. The very high vulnerable areas represent 25% (equal to 146 km) of the entire coastline. The coast between Mersin and Yumurtalık are classified as very high vulnerable (Figure 3.22).

About 149 km, corresponding to 25% of the total coastline length is classified as high vulnerable with Total CVI values that range between 0.82 and 0.94. The high vulnerable coasts are mainly located in Silifke and between Erdemli and Mersin.

The 28% (about 168 km) of the entire coastline is considered as moderate vulnerable. The distribution of these areas is mainly located in Aydıncık, Karataş, Yumurtalık and Dörtyol coasts.

Coastal areas with CVI values less than 0.73 are considered as low vulnerable areas. These low vulnerable coasts represent about 23% (~127 km) of the total coastline. These areas are mostly concentrated in the Yeşilovacık, Arsuz, Yayladağı and Samandağ coasts.

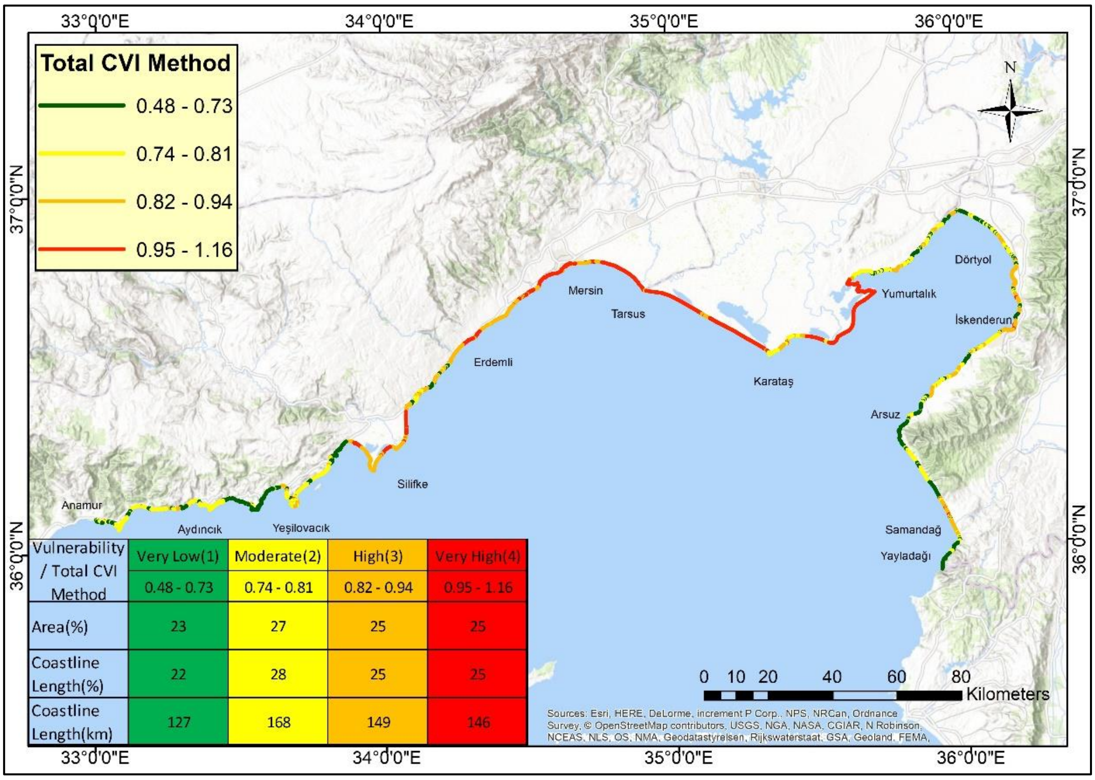


Figure 3.22. CVI map based on Total Vulnerability Index

3.4.5. CVI sub-index

CVI Sub-Index is another method that uses all physical and socio-economic variables like the previous Total Vulnerability Index method. CVI sub-index values are calculated between 6.06 and 81.82 (Figure 3.23).

The coastal areas with CVI values above 53.31 are classified as very high vulnerable. These areas cover 26% (~151 km) of the entire coastline length. About 25% (147 km) of the total coastline is considered as high vulnerable. The range of this class is between 37.56 and 53.3. The very high and high vulnerable coasts are mainly located between Silifke and Yumurtalık. All these coasts have high or very high vulnerable landforms and geologic formations.

The coastal areas with Total CVI values that range between 27.76 and 37.55 are ranked as moderate vulnerable coasts. About 153 km, corresponding to 26% of the entire coastline is assigned to this class. They are largely located in Yeşilovacık, Aydıncık and Yumurtalık coasts.

Coasts with CVI values below 27.75 are considered as low vulnerable according to Sub-Index method. These low vulnerable areas generally appear in Yeşilovacık, Taşucu, Arsuz, Samandağ and Yayladağı. The usage of these coast is forest and also most of them have strength landform and geologic formations.

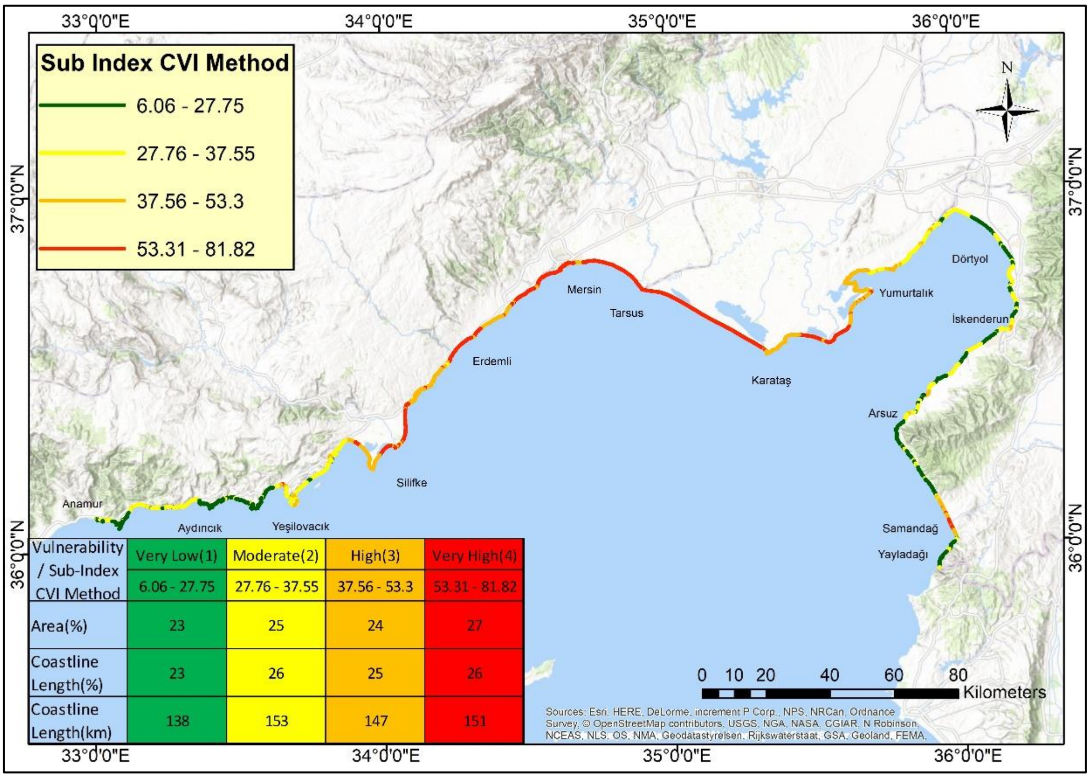


Figure 3.23. CVI map based on CVI Sub-Index Method

CHAPTER 4

DISCUSSION

Coastal Vulnerability Index assessments are used for different places all around world. There are several CVI assessment methods with different types of parameter and different calculation techniques. In this study, the coastal zones of the Mersin and İskenderun bays were assessed regarding the vulnerability with five different CVI methods.

The study area is divided into three parts which have different coastal characteristics to demonstrate the CVI results in appropriate scales. CVI maps were produced for each-parts where the results of all CVI methods can be compared. These regions are called Mersin, Adana and Hatay region which are shown in Figure 4.1

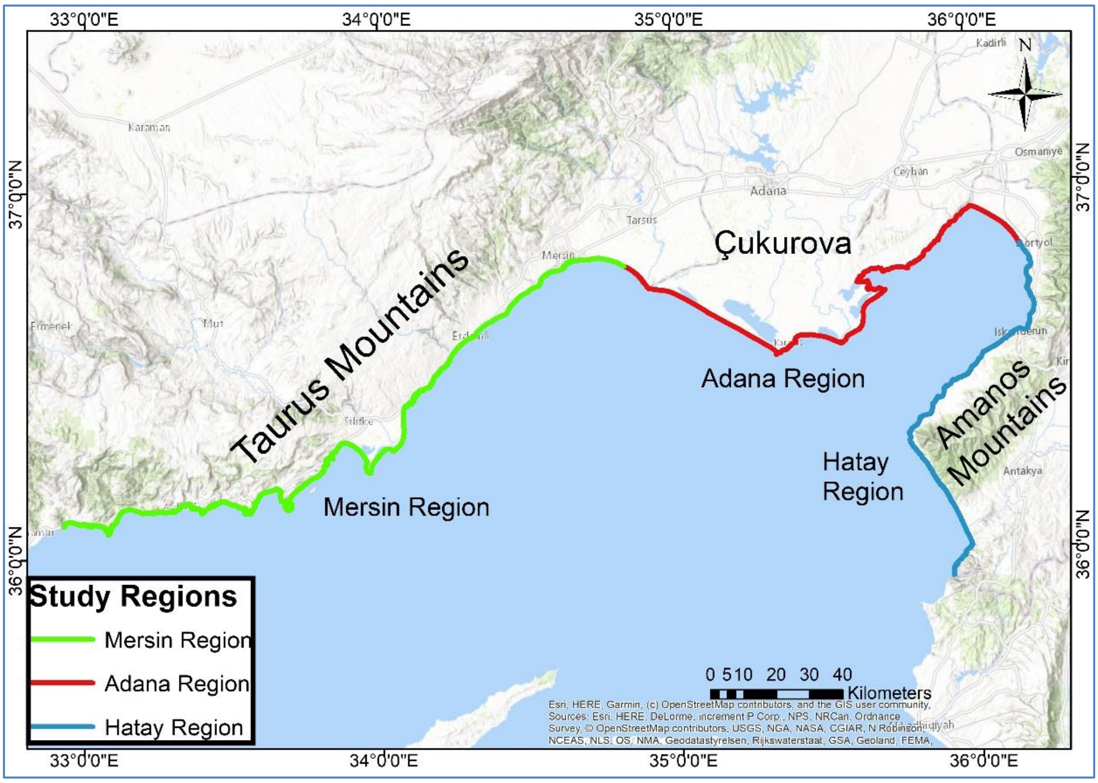


Figure 4.1. Study Regions Map. Study Area divided into 3 regions which are Mersin, Adana and Hatay.

4.1. CVI methods comparison

Thieler and Hammar Klose (THK) and CVI6 methods use only physical parameters such as coastal slope and erosion to calculate the index. CVI6 method uses weighting coefficients to increase the effect of some parameters. Relative CVI method use physical parameters but also it has an additional score for the areas where the vulnerability should be emphasized such as estuaries. The other two methods, Total Vulnerability Index (Total CVI) and CVI Sub-Index, use physical parameters as well as socio-economic parameters to calculate the vulnerability index. Both methods calculate the physical and socio-economic indices separately and then take the average. This allows the contribution of both physical and socio-economic vulnerabilities equally to final index value. Total CVI method has weighting coefficients to grade the importance of the parameters. The method and parameter list are given in Table 4.1.

Table 4.1. Methods and parameters

Method	Physical Parameters	Socio-Economic Parameters
Thieler and Hammar Klose	Coastal Slope Geomorphology Erosion/Accretion Mean Wave High Mean Tidal Range Relative Sea Level	-
CVI6	(4) Coastal Slope (2) Geomorphology (2) Geology (4) Erosion/Accretion (2) Mean Wave High (2) Mean Tidal Range (4) Relative Sea Level	-

Relative CVI	Coastal Slope Geomorphology Geology Erosion/Accretion Mean Wave High Mean Tidal Range Relative Sea Level	Protected Areas
Total Vulnerability Index	(0.5) Coastal Slope (0.4) Geomorphology (0.2) Geology (0.2) Erosion/Accretion (0.3) Mean Wave High (0.3) Mean Tidal Range (0.3) Relative Sea Level	(0.5) Land-use (0.4) Population (0.1) Roads (0.5) Protected Areas
CVI Sub-Index	Coastal Slope Geomorphology Geology Erosion/Accretion Mean Wave High Mean Tidal Range Relative Sea Level	Land-use Population Roads Protected Areas

4.1.1. Mersin Region

Western parts of Mersin region generally have steep, strong landforms. Also, the socio-economic activities are less than other regions. For these reasons, these coasts are classified as low and moderate vulnerable by most of the CVI methods (Figure 4.2). However, the most significant index value difference among CVI methods is in Aydıncık and Yeşilovacık coasts. These coasts are evaluated as high vulnerable according to Relative CVI method unlike the others. In this method, the presence of protected areas is determined to be a critical factor regarding coastal vulnerability. For this reason, an additional score that is added for the coasts within the protected areas increases the vulnerability index.

THK and CVI_6, two methods that use only physical parameters, evaluated Yeşilovacık coasts differently. The main reason of the difference is the weighting coefficients used in CVI_6 method. CVI_6 method used coefficients to increase the vulnerability effect of relative sea level rise rate, coastal slope and shoreline erosion/accretion rate parameters due to their importance. Additionally, CVI_6 method uses the geology parameter that is not available in THK method. The vulnerability due to the geology is classified as moderate for Yeşilovacık (Figure 4.2).

It is generally accepted that the coastal deltas are highly vulnerable to sea-level rise (Özyurt and Ergin (2010). As expected, Göksu Delta (Silifke) is classified as high vulnerable and very high vulnerable mostly by all CVI methods. Although Göksu Delta is a natural protection area, THK method classified some parts of the delta as moderate vulnerable. This is mainly because of the lack of socio-economic parameters and weighted coefficients in this method. This result emphasizes the importance of the use of socio-economic parameters for vulnerability. The physical parameters may not reflect the real vulnerability for sensitive areas.

Mersin and Erdemli are high populated city centers in this region and the population is doubled in the summer seasons. In addition, there are large urban areas, industrial facilities, tourism facilities and agricultural areas along the coast between these two centers. Except the Relative CVI method, the methods calculated the index of the Mersin and Erdemli coasts as very high and high vulnerable (Figure 4.2). The results of the THK and CVI_6 methods that use only physical parameters, are similar. The existence of the socio-economic activities allows the other two methods, Total CVI and CVI Sub-Index, to produce higher vulnerability index values (Figure 4.2). Relative CVI method, on the other hand, calculated the vulnerability at moderate levels due to the lack of protected areas in this part of the study area (Figure 4.2).

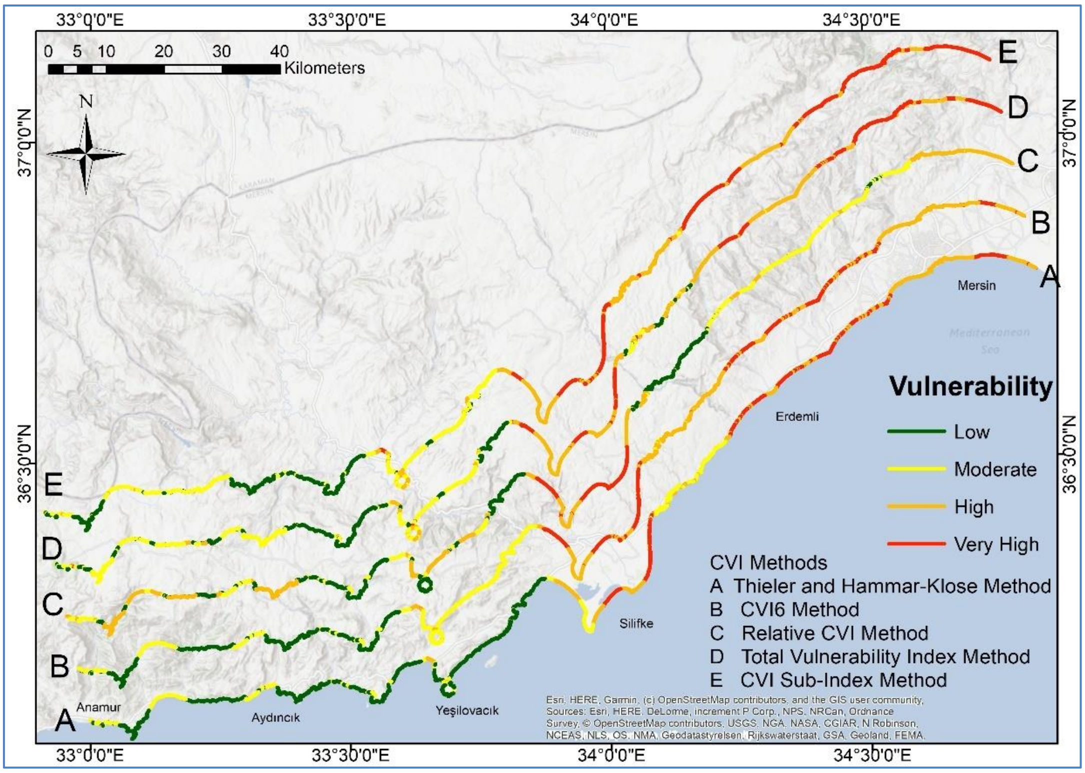


Figure 4.2. CVI methods comparison map of the Mersin region (A: Thieler and Hammar Klose Method, (Thieler and Hammar-Klose, 2000), B: CVI_6 (Gornitz et al., 1997), C: Relative CVI method (Palmer et al., 2011), D: Total Vulnerability Index (Szlafsztein and Sterr, 2007), E: CVI Sub-Index method (Mclaughlin and Cooper, 2010).

4.1.2. Adana Region

The comparison map of the Adana region (Figure 4.3) indicate that there are no serious differences between the CVI methods in the eastern part of this region. All CVI methods consider these areas as high and very high vulnerable. This finding indicate that physically vulnerable coasts are also vulnerable in terms of socio-economically. Therefore, it should be emphasized that the effect of natural events such as inundation and storm surge related to the sea level rise can be felt seriously in this part of the region. The precautions should be taken especially in such areas.

The coastal zone between Yumurtalık and Erzin is categorized as moderate to high vulnerable according to THK and CVI6 methods. On the contrary, same region is classified as low to moderate vulnerable according to other CVI methods (Figure 4.3) indicating that the coasts are less vulnerable in terms of socio-economic parameters. So, the most obvious finding is that socio economic parameters may cause the decrease of vulnerability in some regions which are vulnerable in terms of physical parameters.

Although they use both physical and socio-economic variables for vulnerability assessments, it is also observed a difference between Total CVI and CVI Sub-index methods (Figure 4.3) at the coastal zone between Yumurtalık and Erzin. This difference arises from the weighting coefficient factors in Total CVI method (Table 4.1).

The parameters such as mean wave height, mean tidal range and relative sea level rise rate that are classified as high vulnerable, have lower weighting coefficient factors compared to other variables in Total CVI method.

THK, CVI6 and Relative CVI methods classified the coastal zone between Erzin and Dörtyol as moderate to high vulnerable while other methods categorized this area as low to moderate vulnerable. The coastal slope parameter increases the vulnerability in this part of the region using THK, CVI6 and Relative CVI methods. The low socio-economic activities such as low population and lack of the protected areas decrease the vulnerability while using the Total CVI and CVI Sub-Index methods (Figure 4.3)

It can be seen from Figure 4.3 that according to TH and CVI6 methods, the coasts between Yumurtalık and Dörtyol are evaluated as more vulnerable than other methods. This result suggests that socio-economic parameters such as land use, population and protected area are classified as low vulnerable in these regions.

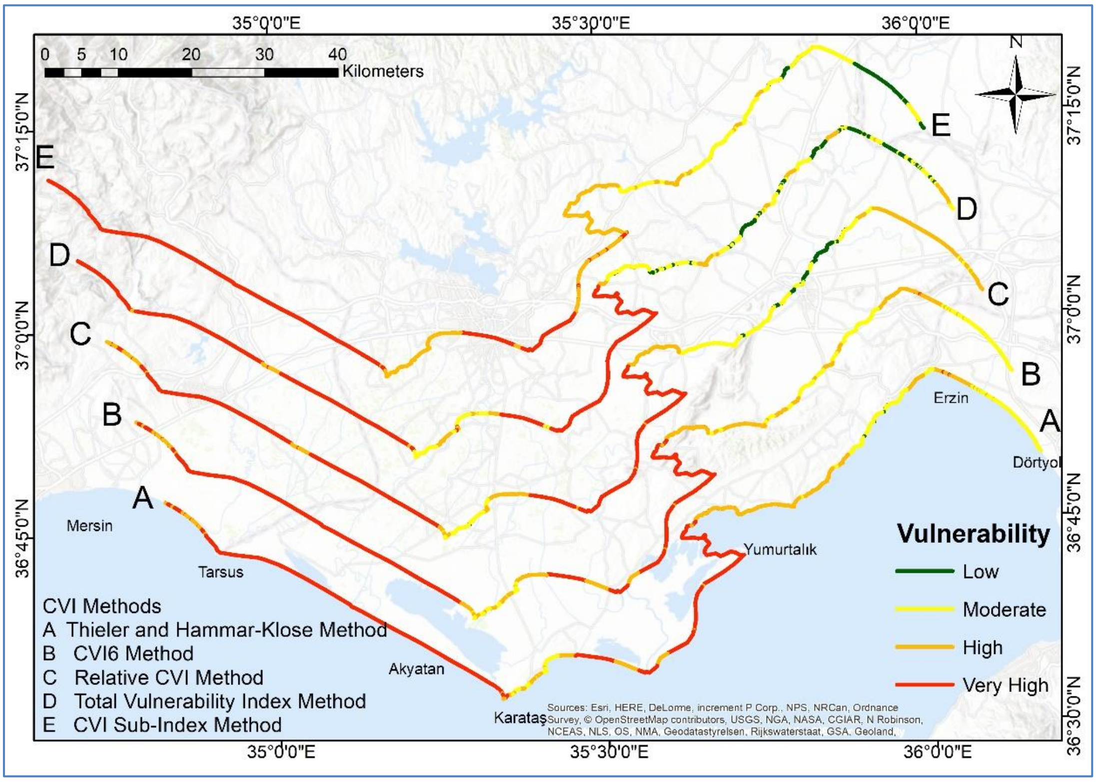


Figure 4.3. CVI methods comparison map of the Adana region (A: Thieler and Hammar Klose Method, (Thieler and Hammar-Klose, 2000), B: CVI_6 (Gornitz et al., 1997), C: Relative CVI method (Palmer et al., 2011), D: Total Vulnerability Index (Szlafsztein and Sterr, 2007), E: CVI Sub-Index method (Mclaughlin and Cooper, 2010).

4.1.3. Hatay Region

Iskenderun is one of the most populated coastal centers in the study area. Many industrial and port facilities that are important in terms of land use are located along the coastal area between Dörtyol and Iskenderun. According to the comparison map (Figure 4.4), all the methods except Total CVI classified this part of the region as moderate vulnerable. This area is classified as high vulnerable by the Total CVI method mainly because of the weighting coefficients. This result indicates that the coefficients should be determined carefully, and by experienced experts. Otherwise the use of the coefficients may produce wrong vulnerability index values.

The coastal areas between Arsuz and Samandağ are classified as low to moderate vulnerable according to most CVI methods (Figure 4.4). This part of the region that is a mountainous area with high slopes at the coast include resilient geological units and the population density is very low. However, there is a wildlife conservation area in this region. The protected area parameter is used as a critical factor in the Relative CVI method that caused the vulnerability to increase.

Samandağ is about 10 km long alluvial plain in the mouth of Asi River. The coastal area of Samandağ is classified as high to very high vulnerable by all the CVI methods (Figure 4.4). Although Samandağ is a touristic place, it is low vulnerable area based on the socio-economic parameters. For this reason, the methods that used only the physical parameters, THK and CVI6, produce high vulnerable CVI index values. As the others use the socio-economic parameters as well, the vulnerability decreases because of the low scores (Figure 4.4).

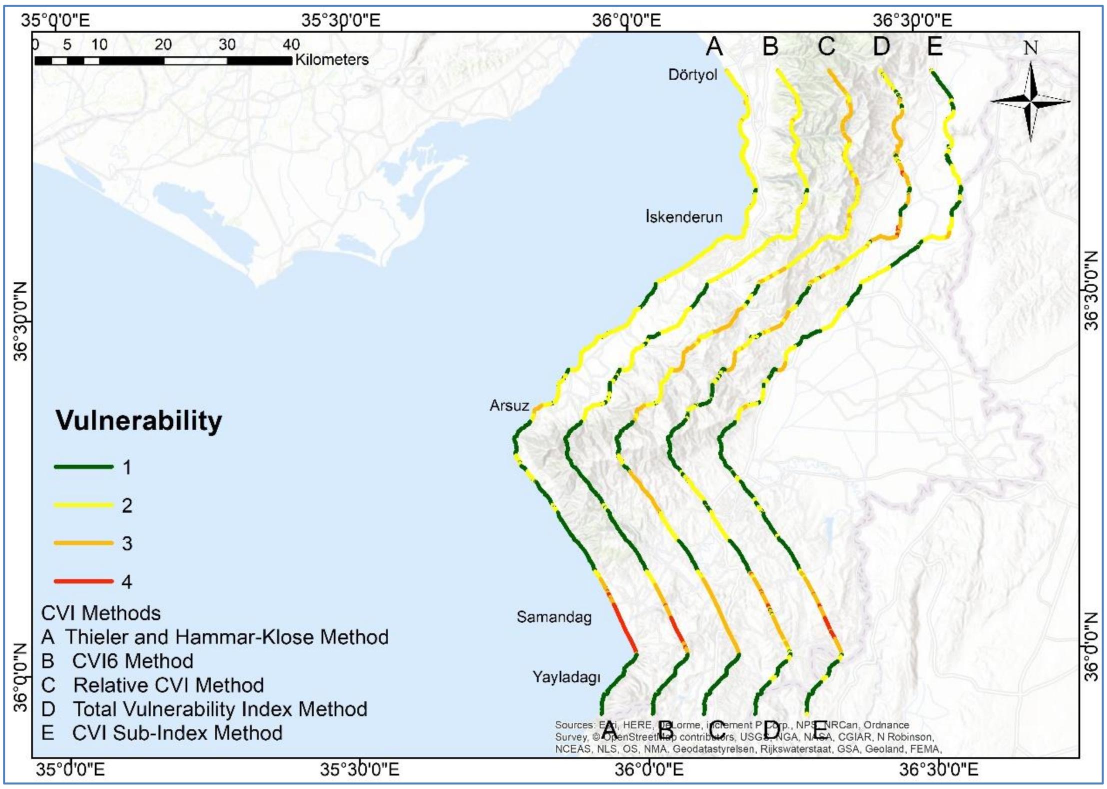


Figure 4.4. CVI methods comparison map of the Hatay region (A: Thieler and Hammar Klose Method, (Thieler and Hammar-Klose, 2000), B: CVI_6 (Gornitz et al., 1997), C: Relative CVI method (Palmer et al., 2011), D: Total Vulnerability Index (Szlafsztein and Sterr, 2007), E: CVI Sub-Index method (Mclaughlin and Cooper, 2010).

4.1.4. General Overview of the CVI Methods

The analysis of the CVI calculation methods in this study indicates that there may not be a single correct CVI method for all the coastal zones in the entire study area. Differences exist between CVI values based on the physical and socio-economic characteristics of the region. Methods such as THK and CVI6 can be applied everywhere because they use only physical parameters. However, the real vulnerability based on the socio-economic activities might be hidden because of the lack of socio-economic parameters with these methods.

Therefore, Total CVI and CVI Sub-Index methods that use socio-economic parameters can produce more reliable vulnerability index values. On the other hand, it is not always easy to find/produce socio-economic data for everywhere.

The socio-economic activities can affect the vulnerability in two ways. One way is that the activities increase the vulnerability because the natural short-term (storms, tides, etc.) and long-term (relative sea level rise) threats can affect not only the coastal areas but also the human and economic life. The other way, the coastal infrastructure built for the socio-economic activities can prevent the effects of natural events, so it decreases the vulnerability. Unfortunately, the coastal infrastructure is not strong enough to handle the natural events in the study area. Therefore, we accept that the socioeconomic parameters increase the vulnerability.

The other important source of the differences of the CVI values among the CVI methods is the weighting coefficients. The developer of the methods such as CVI6 (Gornitz et al., 1997) and Total CVI (Szlafsztein and Sterr, 2007) defined coefficients for some parameters. They believe that some parameters are more critical to vulnerability, thus the score of these parameters must be increased. However, some believed that the coefficient assignment is a subjective judgment (Mclaughlin and Cooper, 2010). One can increase or decrease the vulnerability by manipulating the weighting coefficients. A good example is Duriyapong and Nakhapakorn (2011). They asked 8 experts for the weighting coefficients of the parameters for their CVI assessment, and they got very different coefficients. On the other hand, some claim that weights of the parameters should be defined to more accurate results (Özyurt and Ergin., 2010).

The advantage of the Relative CVI method is that it is sensitive to highlight the critical parameters. The Relative CVI method uses an additional score to emphasize the importance some parameters such as natural or cultural protected areas, which are irreplaceable (Palmer et al., 2011). However, the choice of the critical parameter for a specific area is also subjective.

Some studies modified the THK method formula (the square root of the geometric mean) to add more parameters for vulnerability assessments (Kunte et al. 2014; Pantusa et al., 2018). More physical, even socio-economic parameters are evaluated all together to calculate the vulnerability index. However, evaluating the physical and socio-economic parameters together may reduce the effects of some critical parameters. On the other hand, the Total CVI and CVI Sub-Index methods calculate the vulnerability index of these different types of parameter separately and then take the average. In this way the CVI results are not affected by number of the physical or socio-economic parameters.

CVI Sub-Index method analyses the parameters into 3 sub-indices: coastal forcing, coastal characteristics and socio-economic. Unlike the others methods, CVI Sub-Index divides the physical parameters into two groups: coastal characteristics such as slope, geomorphology, and coastal forcing such as mean wave height, mean tidal range. Sub-indices are normalized by working the results out as a percentage of the maximum and minimum scores sub-indexes have (Mclaughlin and Cooper, 2010). The normalization process prevents sub-indexes with more parameters from getting ahead of others (Mclaughlin and Cooper, 2010).

The scale of the study area and the data availability are the other important factors for the vulnerability assessment. Although the recent developments in Geographic Information Systems (GIS) help to collect coastal data, it is very difficult to find and use high resolution data. In small scale, means in larger area, as the coastal zones may have different vulnerability characteristics, the methods may produce different results. To handle this problem, it is best to apply the vulnerability in big scale, means in small areas. However, as the CVI Sub-Index method analyses the contribution of different types of parameters separately, it can be used for larger area as well.

Different classification methods have been used to divide CVI values into vulnerability classes. For example, Karymbalis et al. (2012) used the natural break classification method to classify coastline segments according to their CVI values. There are many studies in the literature that use natural break method such as this study. However, as mentioned in the data classification methods section of the ArcGIS portal (https://pro.arcgis.com/en/pro-app/latest/help/mapping/layer-properties/data-classification-methods.htm), the natural break method is not a very convenient method for comparing different maps. For this reason, the we use in this study the quantile method, which classifies all classes in equal number of features. This method was used also in Thieler and Hammar-Klose (2000) and Özyurt and Ergin (2010). According to this method, CVI result values are ranked into four classes in terms of vulnerability: low, moderate, high and very high, corresponding to the 0-25th, 25-50th, 50-75th and 75-100th percentiles, respectively.

The distribution of vulnerability classes of cells explains how the cells are distributed around the vulnerability classes more. Considering these distributions, it is seen that the moderate vulnerable class in Thieler and Hammar-Klose method and CVI6 method show more distribution than other classes. The moderate vulnerable classes represent 29% of the study area and 30% of the study area respectively, according to TH and CVI6 methods. The high vulnerable distribution in the Relative CVI method constitutes 34 percent of all cells. In comparison, distributions according to the Total CVI and CVI sub-index methods are generally the same for all classes (Figure 4.5). This result shows that the results of Total CVI and CVI Sub-Index methods using normalization methods are more easily equal number of features.

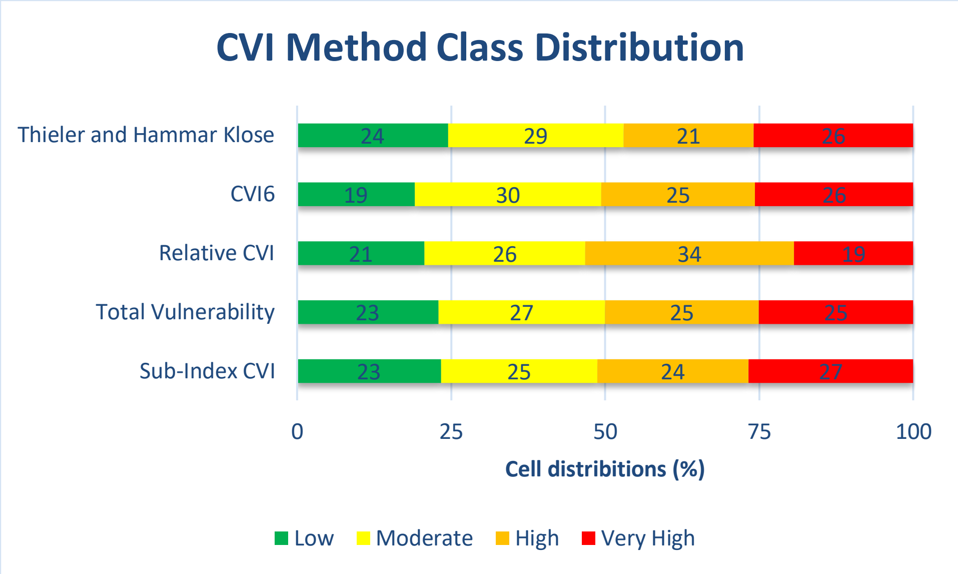


Figure 4.5. CVI Methods Class Distribution

4.2. Coastal Vulnerability assessment of the Cilician Basin

Vulnerability of the study area was evaluated according to 5 different CVI methods. As mentioned before, each CVI method is used more effectively in different areas or different scales. In the study area, some differences between the CVI methods exist.

The importance of socio-economic variables for coastal vulnerability assessments is believed that to be a certain fact. These parameters might increase the vulnerability of physically vulnerable coasts. In addition, communities will be more affected as a result of adverse natural events on the coasts, which are important in terms of socio-economic parameters. For these reasons, CVI Sub-Index method was chosen as an appropriate method for evaluating coastal vulnerability in our study area. In this method, parameters are divided into 3 sub classes (coastal forcing, coastal characteristics and socio-economic). Thus, each kinds of sub-indexes are calculated separately. Then, these indexes normalized for CVI-Sub Index assessment. In this way, the number of parameters within the classes do not dominate the CVI results. Another reason for choosing this method is that it does not use weighted coefficient values that includes subjective judgements.

Figure 4.6 indicates that the western parts of Mersin coasts are generally evaluated as low and moderate vulnerable in terms of all parameters. The eastern parts are considered as more vulnerable than the western parts. This is due to the low slope, weak geologic formations, land uses and high population of the eastern parts. From another point of view the fact that Taurus Mountains are closer to the coasts and coastal areas are steeper in the western parts Mersin. These factors cause the coasts not to be used by people.

Göksu Delta is an alluvial plain formed by the Göksu River. Therefore, it is a vulnerable area in terms of parameters such as slope, geology and geomorphology. The parts where the mouth of the Göksu river flows into the sea and some areas around it are depositional areas. (Figure 4.6). In the research of Özyurt and Ergin (2010), it is mentioned that specific protected areas such as Göksu delta are strictly controlled in terms of land use and settlement. As a result of this, protected area coasts are considered as low vulnerable areas in terms of land use and population parameters. This finding confirms our vulnerability of land use and population parameters. On the other hand, fresh water resources are under threat due to agricultural activities in Göksu Delta (Özyurt and Ergin, 2010). This situation is likely to harm the natural environment and the living creatures living there. Negative events or effects that may occur in these areas are much less likely to be returned or rehabilitated. Therefore, precautions should be taken carefully in areas such as the Goksu delta.

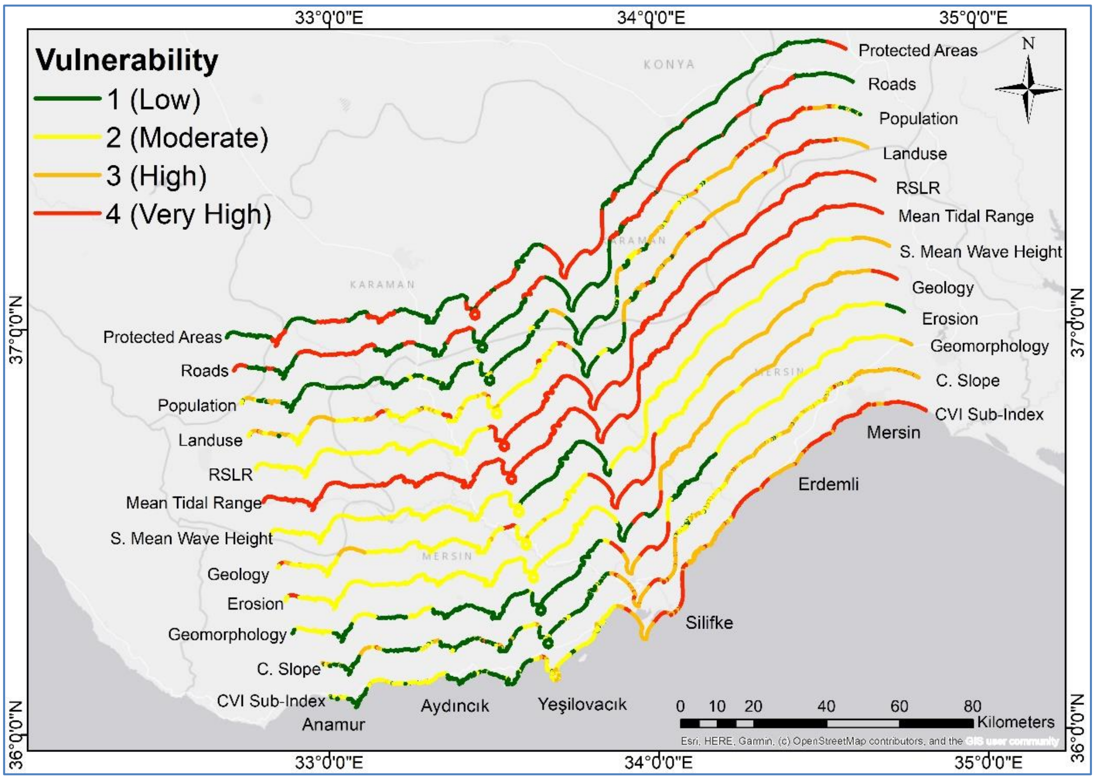


Figure 4.6. The map of vulnerability classification of Mersin region coasts according to the parameters and CVI Sub-Index values. The innermost line corresponds to the CVI Sub-Index and the other lines to the coastal slope, geomorphology, shoreline erosion/accretion, geology, significant mean wave height, mean tidal range, relative sea level rise rate, land use, population, roads and protected area parameters, respectively.

The coastal zone between Mersin and Erdemli is considered as more vulnerable areas than the cities in the western parts according to CVI Sub-index (Figure 4.6). The reason is that these regions are vulnerable according to some parameters such as coastal slope, geology, land use and population parameters. The population on the Mersin coast is the densest in the entire study area. In addition, Mersin port, which is important in terms of international sea transportation, causes this region to be vulnerable in terms of land use. On the shores of Erdemli and Mersin, there are quite a lot of touristic facilities used especially in summer. The population on these coasts increases in summer. As a result of all these factors, it is an expected result that these coasts are evaluated as very high or high vulnerable areas.

The physical parameters used in CVI calculations are classified generally high vulnerable in the Adana region (Figure 4.7). The entire region is evaluated as low vulnerable in terms of road parameter due to the absence of the roads in these coasts.

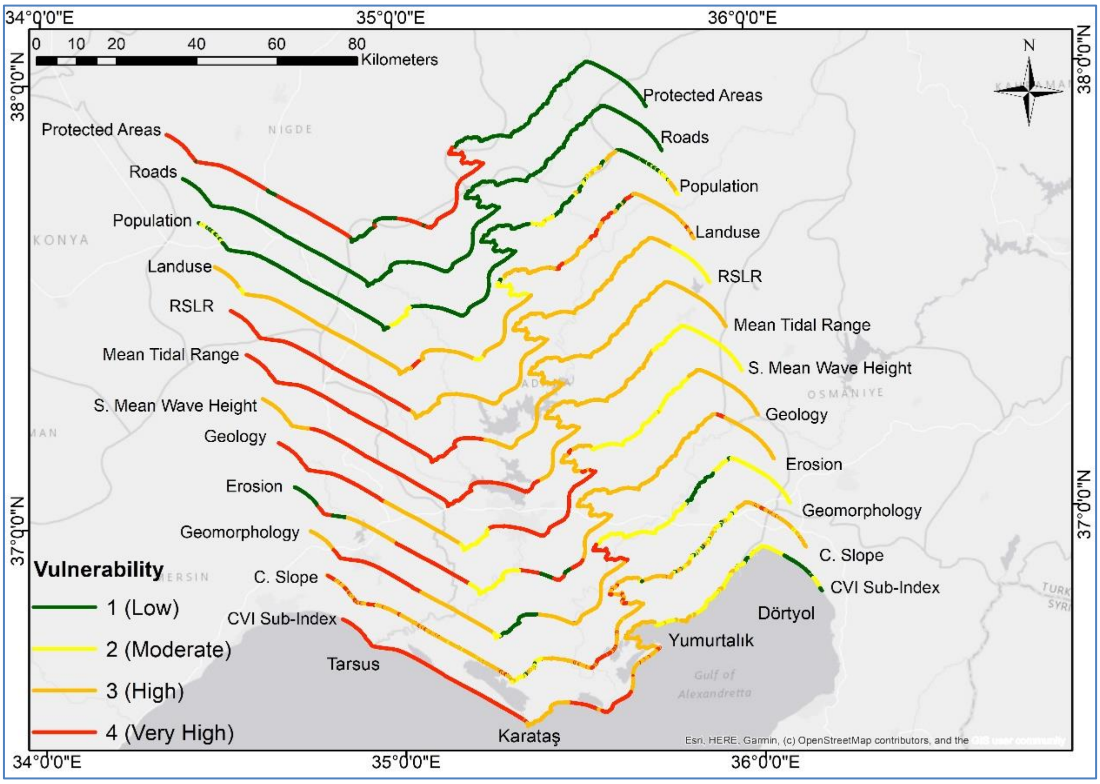


Figure 4.7. The map of vulnerability classification of Adana region coasts according to the parameters and CVI Sub-Index values. The innermost line corresponds to the CVI Sub-Index and the other lines to the coastal slope, geomorphology, shoreline erosion/accretion, geology, significant mean wave height, mean tidal range, relative sea level rise rate, land use, population, roads and protected area parameters, respectively.

The coasts between Tarsus and Yumurtalık are alluvial deltas formed by the Seyhan and Ceyhan rivers. This region has low slope values, weak geologic formations and geomorphologic landforms. There are many wetlands and other natural protected areas along the coastal zones. Despite the low population density, the coastal zone is generally used for agricultural activities due to productivity of land. For these reasons, the coastal area between Tarsus and Yumurtalık are mainly considered as very high vulnerable according to CVI Sub-Index method.

The coasts between Dörtyol and Yumurtalık are mainly classified as low and moderate vulnerable as shown in Figure 4.7. Although these areas are high vulnerable in terms of land use parameter, they are evaluated as low and moderate vulnerable in terms of other socio-economic parameters and some of physical parameters. This result indicates that land use parameter is not enough to dominate the other parameter's vulnerability scores.

İskenderun coasts are generally classified as moderate to low vulnerable according to CVI sub-Index method (Figure 4.8). These coasts are mainly classified as moderate in terms of physical parameters. According to land use and population parameters, they are considered as high and very high vulnerable. However, the absence of the roads and protected areas in the region reduces the vulnerability score of socio-economic sub-index. This finding indicates that coastal areas with high vulnerable in terms of land use and population is not sufficient to evaluate that region as high vulnerable.

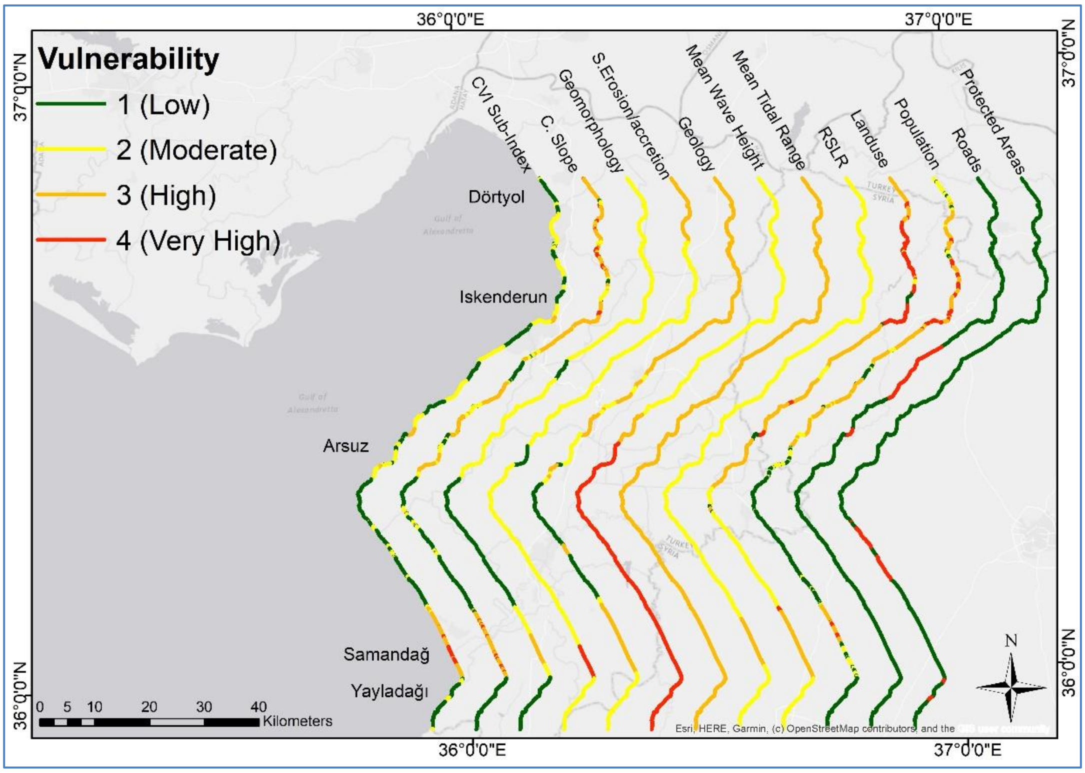


Figure 4.8. The map of vulnerability classification of Hatay region coasts according to the parameters and CVI Sub-Index values. The innermost line corresponds to the CVI Sub-Index parameter and the other lines to the coastal slope, geomorphology, shoreline erosion/accretion, geology, significant mean wave height, mean tidal range, relative sea level rise rate, land use, population, roads and protected area parameters, respectively.

Arsuz coasts are classified as low and moderate vulnerable according to CVI Sub-index method. In fact, the situations on these coasts are approximately the same as Iskenderun coasts. In Arsuz coasts, there is a serious increase in population in the summer season and this region hosts tourist activities. Although these coasts are important in terms of land use and population parameters, other socio-economic parameters and physical parameters reduce the vulnerability scores of the region.

Figure 4.8 indicates that Yayladağı and the coast between Samandağ and Arsuz are generally classified as low vulnerable. Almost all of the physical and socio-economic parameters on these shores are in the low vulnerability class. A wild conservation area, located between Samandag and Arsuz, is a very high vulnerable area in terms of the protected area parameter. However, the fact that only protected area parameter could not affect the CVI Sub-Index result score. Relative CVI method can be more useful than CVI Sub-Index method to emphasize the importance of these kinds of coasts.

Mean tidal range parameter has the same vulnerability value for the Hatay region coasts. In addition, relative sea level rise rate, roads and protected areas parameters show less variability than other parameters in this region. Therefore, it can be expected that these parameters will be less effective for vulnerability assessments in Hatay coasts.

CHAPTER 5

CONCLUSIONS

In this study, the vulnerability of the Mersin and İskenderun bays coasts to natural forces is assessed by Coastal Vulnerability Index (CVI) methods. Physical and socio-economic parameters are used for the CVI calculations.

The vulnerability was computed by five different CVI methods. The CVI Sub-Index method that analyses the parameters into 3 sub-indices (coastal forcing, coastal characteristics and socio-economic) is use the identify the vulnerability of the study area.

According to CVI Sub-Index results, most of the coasts in Mersin Bay have high (147 km) and very high (151 km) vulnerability to natural factors. High and very vulnerable coasts include low slope, weak geological and geomorphological character, coastal plains and deltas where erosion is observed more common. These areas are the most vulnerable to natural forces such as SLR, coastal erosion and inundation. In addition, these coasts contain large protected areas and regions used by people for various social and economic activities. These socio-economic values are the factors that increase the vulnerability of the coasts against natural forces.

Very high and high vulnerable coasts are mainly located between Silifke and Yumurtalık. In addition, Samandağ coastal plain is considered as very high and high vulnerable. On the contrary, rocky coastal areas with high slope values and strong geological formation are classified as low vulnerable. Most of these coasts are located in Aydıncık, Arsuz and Yayladağı regions. Due to their rugged terrain, they cannot be used for human settlements or other socio-economic activities in generally.

In this study, the most suitable CVI Sub-index method was selected for study area by comparing 5 different CVI methods. However, the use of other CVI methods can be more effective in some working areas of different scales. Also, the parameters used here may not differ for other regions. For this reason, a GIS tool has been developed.

This tool is for users to quickly extract the results of 5 CVI methods using their own parameters and class ranges. In addition, it is a tool that can be used by decision makers without having much technical knowledge.

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