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Land use and land cover classes affected by the possible sea level rise in Mersin city center (Türkiye)

Onur Güven*[1], Ümit Yıldırım[2], Cüneyt Güler[3], Mehmet Ali Kurt[4]

[1]Bayburt University, Central Research Laboratory, Bayburt, Türkiye
[2]Bayburt University, Faculty of Applied Sciences, Department of Emergency Aid and Disaster Management, Bayburt, Türkiye
[3]Mersin University, Engineering Faculty, Department of Geological Engineering, Mersin, Türkiye
[4]Mersin University, Engineering Faculty, Department of Environmental Engineering, Mersin, Türkiye

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Abstract

In this study, a sea level rise (SLR) investigation was carried out in an area representing the Mersin city center located in the south of Türkiye. The study area covers an area of *ca*. 385 km^2. Future projections provided by the Intergovernmental Panel on Climate Change (IPCC) were used for the SLR assessment. These projections are for the years 2100, 2200, 2300, 2400, and 2500 and the SLR for these periods are 0.83 m, 2.03 m, 3.59 m, 5.17 m, and 6.63 m, respectively. It is aimed to determine the areas affected by the SLR that will occur according to these projections. In this context, land use and land cover (LULC) data were obtained from the CORINE 2018 dataset. The data obtained were adapted within the boundaries of the study area and processesed using various GIS analyses. The results have shown that all LULC classes are greatly affected by the SLR, but in varying degrees. Land losses as a result of SLR are as follows: 0.4% at 0.83 m SLR, 9.8% at 2.03 m SLR, 16.7% at 3.59 m SLR, 21.6% at 5.17 m SLR, and 25% at 6.63 m SLR.

1. Introduction

Coastal regions are areas of critical importance in terms of the possible effects of climate change. Sea level rise (SLR) is one of the most important consequences of climate change affecting people living in coastal regions (Antonioli et al., 2020). It is inevitable that Türkiye, which is surrounded by the sea on three sides and has a coastline of 8,333 km (Demirkesen et al., 2008), will be affected by SLR. Türkiye's coasts are home to approximately 30 million people and produce more than half (~60%) of the country's gross production (Üstün, 2019). Sea water levels are rising due to two different parameters defined as the increasing water volume of the seas and their cumulative expansion (EPA, 2016).

The seawater level has increased by 98 mm from 1993 to the present (NASA, 2023) at a rate of 3.2 mm/yr over the last decades (Antonioli et al., 2020). The Mediterranean is one of the most vulnerable regions of the world to climate change, with 86% of the region's World Heritage sites at risk of water inundation and erosion (Reimann et al., 2018). According to data based on tide measurements, the SLR in the Mediterranean basin is 1.8 mm/yr (Antonioli et al., 2020).

City of Mersin borders the Taurus Mountains to the north, the Mediterranean Sea to the south, Antalya province to the west, and Adana province to the east. Mersin is a port city on the Mediterranean coast in southern Türkiye. Mersin is the city that has the longest coastline in Türkiye, with a length of *ca*. 321 km. The population of Mersin is 1,916,432 as of the end of 2022, and it is one of the most populous cities in Türkiye. In Mersin, the urban population continues to increase yearly. Mersin covers an area of 15,485 km^2, of which 53% consists of forests, 21% is agricultural lands, 22% is non-agricultural lands, and 4% is meadows and pastures (MTSO, 2023). Mersin's agricultural product diversity is high due to its suitable climatic conditions, flat areas with fertile soils brought by rivers, and its location on the coast (Kafalı Yılmaz, 2008). In addition, Mersin, which ranks first in Türkiye with a container business volume of 2.1 million TEU, has an essential economic infrastructure in maritime trade (MIP, 2021).

Many studies were conducted on the SLR in Türkiye, but studies on micro-scale areas are limited (Demirkesen et al., 2008; Geymen & Dirican, 2016; Kuleli et al., 2009; Kurt & Li, 2020; Simav et al., 2015; 2016; Üstün, 2019; Zengin, 2023). In this study, Mersin city center was chosen as the study area, which resides within the

***Corresponding Author**
*(onurguven@bayburt.edu.tr) ORCID 0000-0001-5608-7633
(umityildirim@bayburt.edu.tr) ORCID 0000-0002-7631-7245
(cguler@mersin.edu.tr) ORCID 0000-0001-8821-6532
(malikurt@mersin.edu.tr) ORCID 0000-0001-7255-2056

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borders of three districts. In the present study, LULC types affected by SLR was evaluated using GIS technology and currently available climate projections.

2. Method

2.1. Study area

The study area (covering 385.4 km^2) constitutes the center of Mersin city, located on the Mediterranean coast in the south of Türkiye (Figure 1). While the study area is a narrow coastal plain in the west, it expands like a fan towards the east. Müftü Stream and Deliçay River are the important rivers of the study area. The climate in the study area is typically Mediterranean, characterized by hot and dry summers and relatively mild and rainy winters. The average annual rainfall is 613.2 mm, and the average annual temperature is 19.3 °C in the study area (MGM, 2023).

The population density of the Mersin city center is increasing every year due to constant migration. It is estimated that approximately 695,000 people live in this area. Transportation is provided by highways (O-51 and D400), railway (Adana-Mersin), and seaway. On the other hand, there is a marina and seaport (MIP) where international trade takes place. The internationally active and one of the largest industrial establishments in the region, the soda/chromium industry, is located on the east coast of the study area.

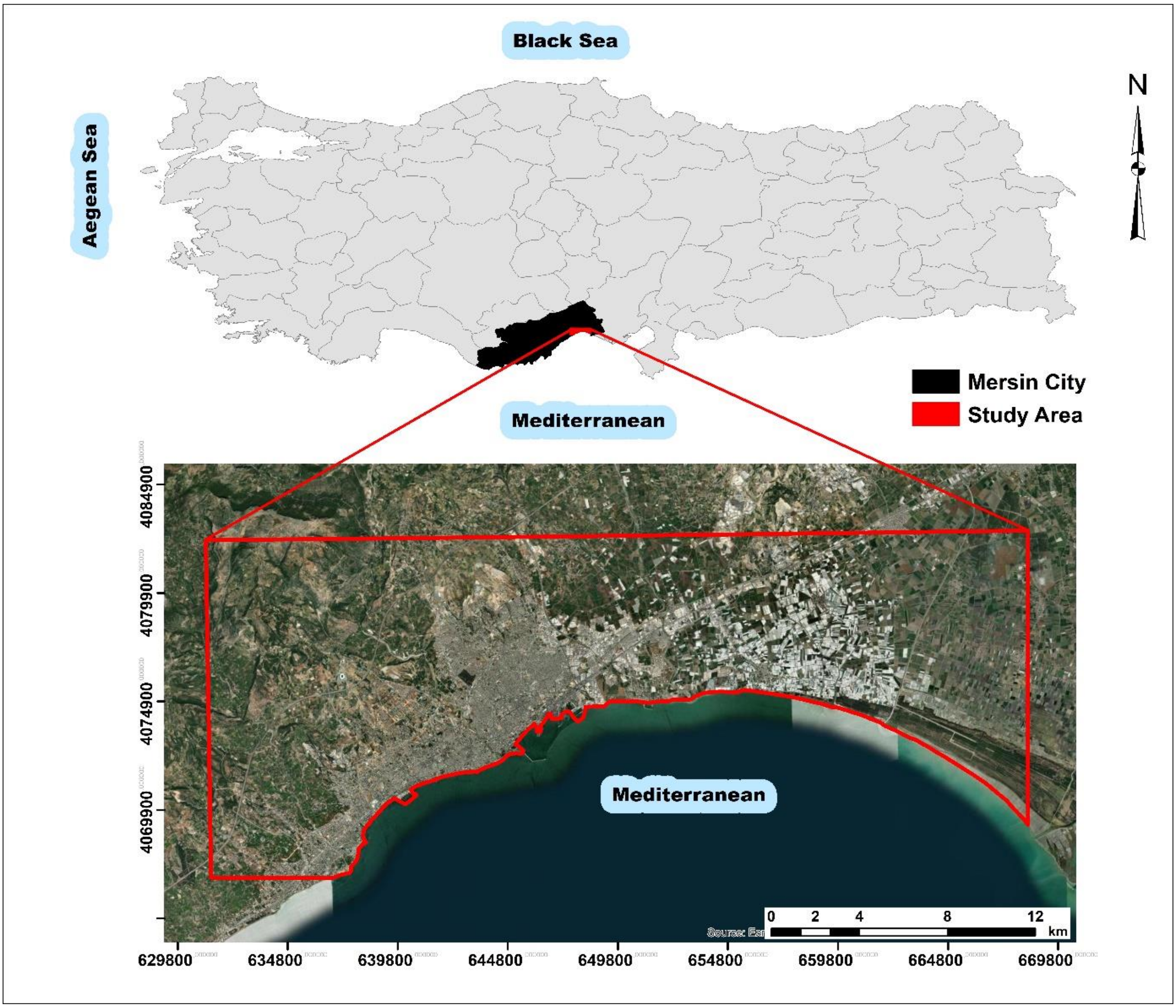

Figure 1. Map of the study area representing Mersin city center

The slope is an important parameter controlling many coastal regions' SLR effects over time (Al-Jeneid et al., 2008). The study area has a slope between 0°-65°. (Figure 2). Low-slope areas from west to east cover large areas. The slope of these areas is less than 10°.

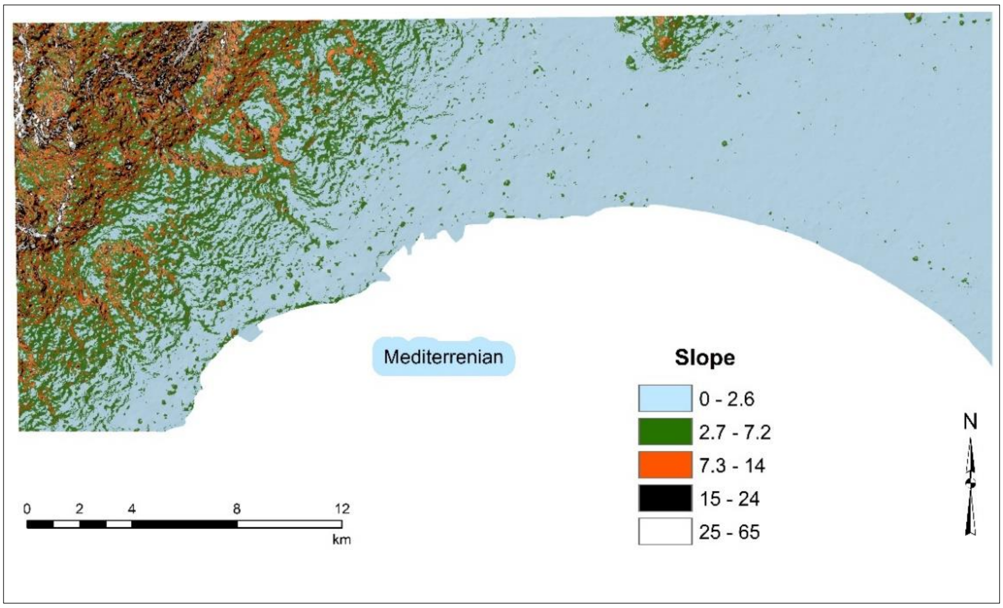

Figure 2. Slope map of the study area

2.2. Sea level rise

A digital elevation model (DEM) was used to determine the future areas of seawater inundation. Contour lines were taken as a basis when creating the DEM. DEM with a resolution of 10×10 m was obtained by digitizing 1:25,000-scale topographic maps (Figure 3) using ArcGIS 10.4 software (ESRI, 2016). All data used in this study were georeferenced using the WGS 1984 UTM Zone 36N coordinate system. The topographic elevations in the study area ranges from 0 m to 901 m. The distance of highland areas to the sea decreases towards the west.

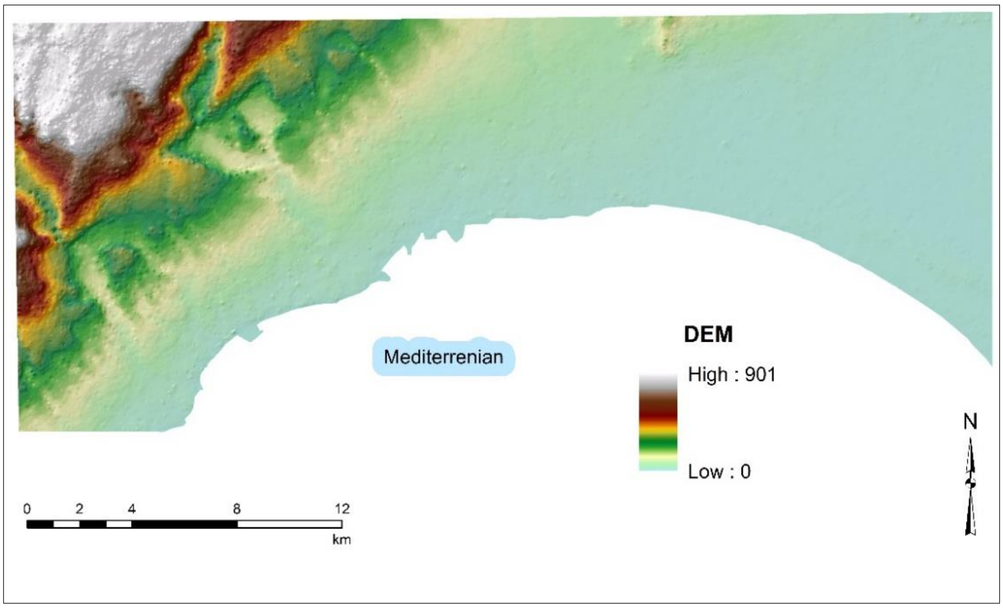

Figure 3. Digital elevation model (DEM) of the study area

The scenarios in the Intergovernmental Panel on Climate Change (IPCC) report (IPCC, 2014) revealed the risk situation due to SLR in the study area. The report includes SLR scenarios for the years 2100, 2200, 2300, 2400, and 2500. SLR scenarios are divided into three categories based on low, medium, and high CO_2 concentrations (IPCC, 2014). In this study, the SLR scenario applied according to high CO_2 concentration is taken as a reference, and SLR values are presented by the years in Table 1.

Table 1. IPCC 5th Assessment Report on SLR scenarios

Scenario (Year)	2100	2200	2300	2400	2500
SLR (m)	0.83	2.03	3.59	5.17	6.63

2.3. Land use and land cover

This study aims to determine the LULC classes affected by the SLR for Mersin city center. LULC data in grid format obtained from the CORINE dataset (EEA, 2018) was used to create the LULC layer for the study area. CORINE is a LULC dataset using satellite imagery and a computer-aided visual interpretation technique (Kaya & Demir, 2022).

LULC parameters (Figure 4) adapted to the study area are classified into 13 individual classes (Table 2).

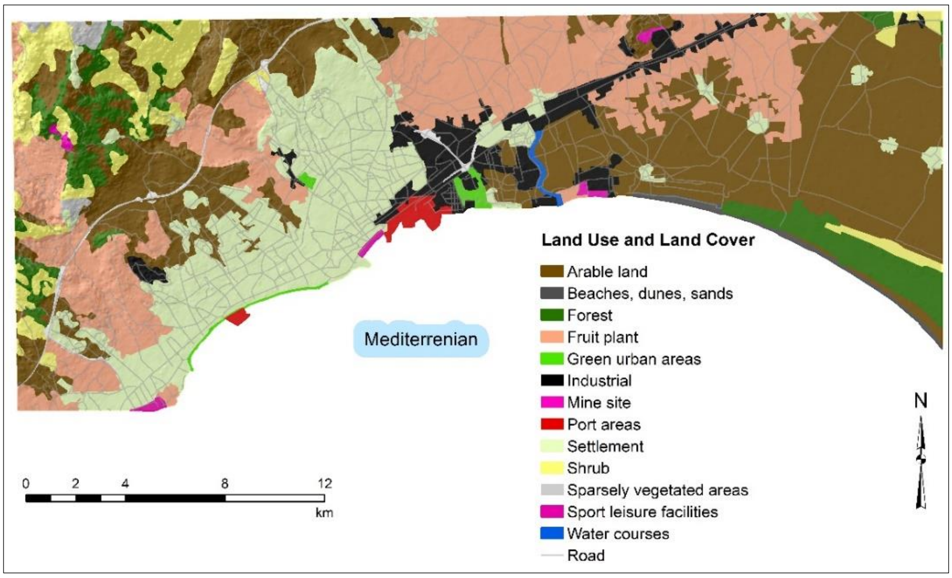

Figure 4. Map showing the LULC classes of the study area

Table 2. LULC types of the study area

LULC	Area (km²)	LULC	Area (km²)
Arable land	145.0	Sparsely vegetated areas	2.1
Fruit plants	89.0	Green urban areas	2.1
Settlement	72.9	Beaches, dunes, sands	2.1
Forest	23.2	Mine site	1.1
Industrial	22.6	Sport-leisure facilities	0.6
Shrub	21.6	Water courses	0.6
Port areas	2.5	**Total**	**385.4**

2.4. Data processing

The methodology followed to determine the inundation areas depending on the SLR and create spatial results is shown in the flow chart (Figure 5).

The Fill tool was used to remove sinks that may occur in the DEM data. Several calculations made use of this newly created DEM. Using Map Algebra in the raster calculator, sea level and SLR values given in Table 1 were calculated, respectively. The inundation areas were then determined by subtracting each SLR value from sea level, one at a time.

Where sea level inundation is anticipated, the sea level rise rasters have 1s; in other places, they have 0s or null values. As a result, the LULC where seawater inundation would occur was determined by multiplying this raster by the LULC raster. Finally, numerical results were obtained by calculating the number of pixels containing each land use value in square kilometers (km²).

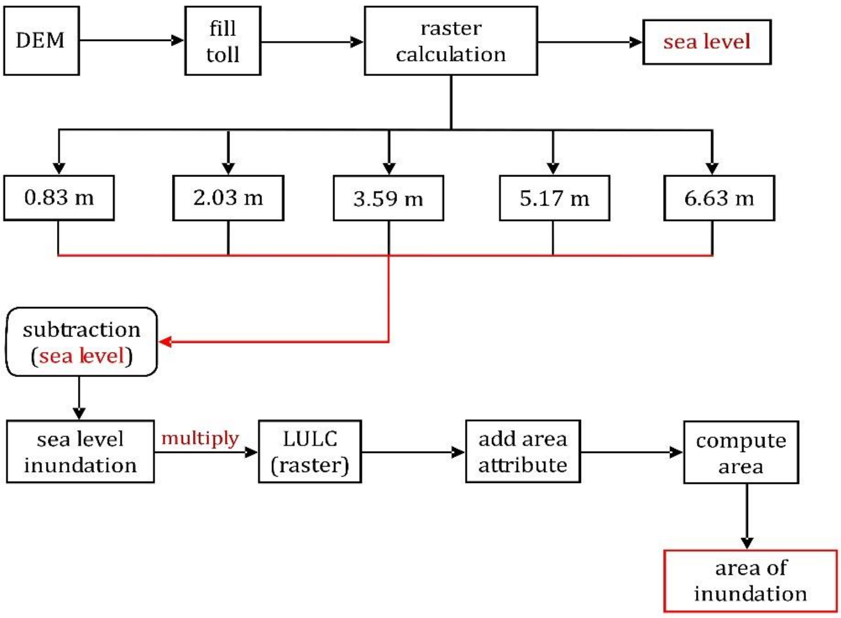

Figure 5. The flow chart depicting the methodology used in this study

3. Results

In this study, five different SLR scenarios (0.83 m, 2.03 m, 3.59 m, 5.17 m, and 6.63 m) were considered for the Mersin city center. The areas most affected by these scenarios are located at the east of the study area (Figure 6). This area is a coastal plain formed by alluvial deposits brought by the Deliçay and Tarsus rivers. This area's slope, characterized by a delta environment, varies between 0°-10°. In addition, the city's important agricultural areas are located in the most sensitive area with respect to SLR.

LULC types affected by the combination of SLR and LULC were determined spatially (Table 3 and Figure 12). Except for sparsely vegetated areas, all LULC classes were affected by different SLR scenarios. The most affected classes were arable land and forest. A section of the Adana-Mersin highway (D400) is inundated when sea level rise by 6.63 m. LULC losses in SLR scenarios for 2100, 2200, 2300, and 2500 are 0.4%, 9.8%, 16.7%, 21.6%, and 25.0%, respectively.

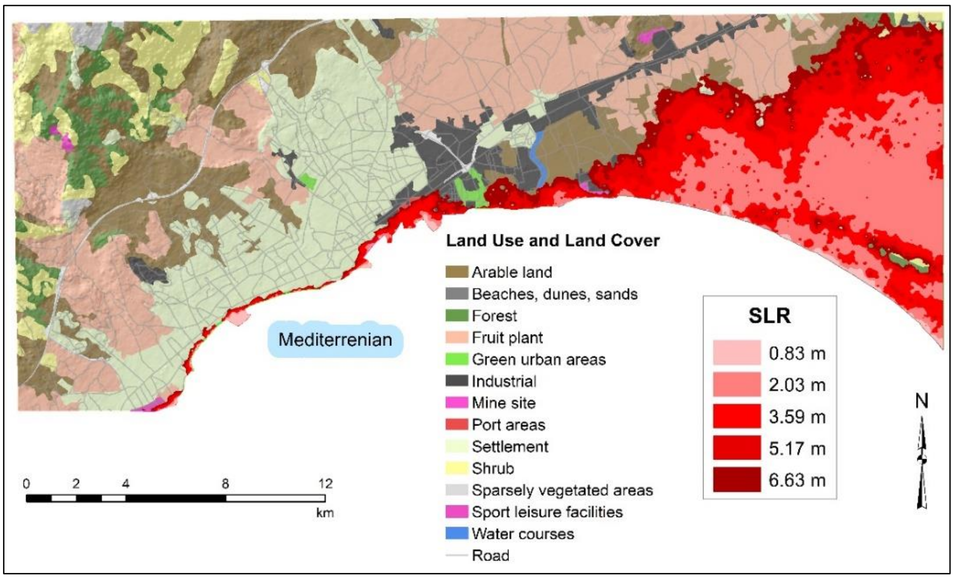

Figure 6. Sea level rise (SLR) map of the study area for the five IPCC scenarios

At 0.83 m SLR, the affected area is minimal (Figure 7). The most affected LULC type was beaches, dunes, and sands, followed by the port area. The loss of this area is 33%. Roads will not be affected by the sea water inundation. Approximately, 0.4% of the total area was inundated by the sea in 2100.

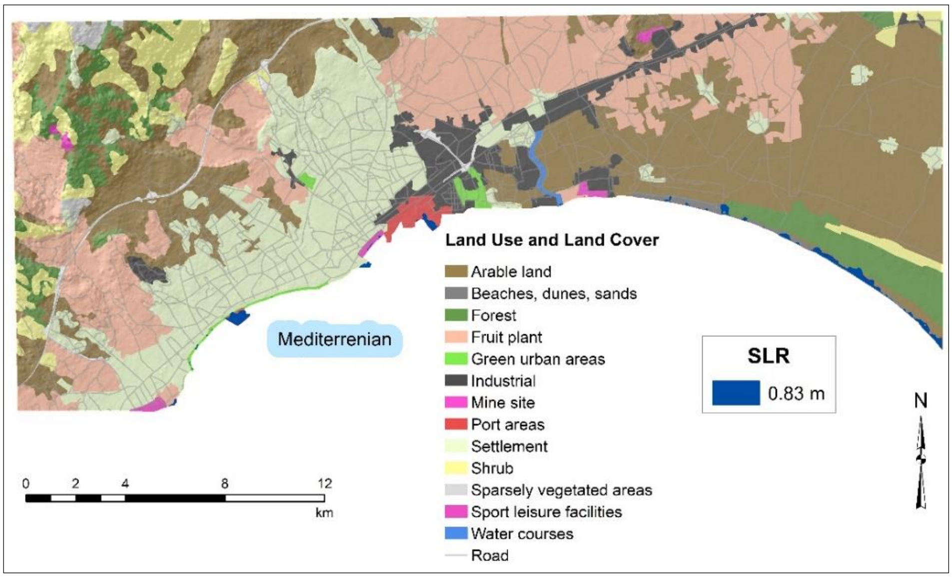

Figure 7. Sea level rise (SLR) map of 0.83 m SLR (year 2100)

However, by the year 2200, 9.8% of the total area will be inundated by the sea (Figure 8). LULC-type named arable lands are most affected (30.8 km^2) by 2.03 m SLR. According to the results, 76% of the beaches, dunes, and sands will be inundated by the year 2200. Forests have the most land loss after arable land. Some roads east of the study area will be affected by 2.03 m SLR. Industrial, shrub, and mine site LULC classes also will be affected by the SLR.

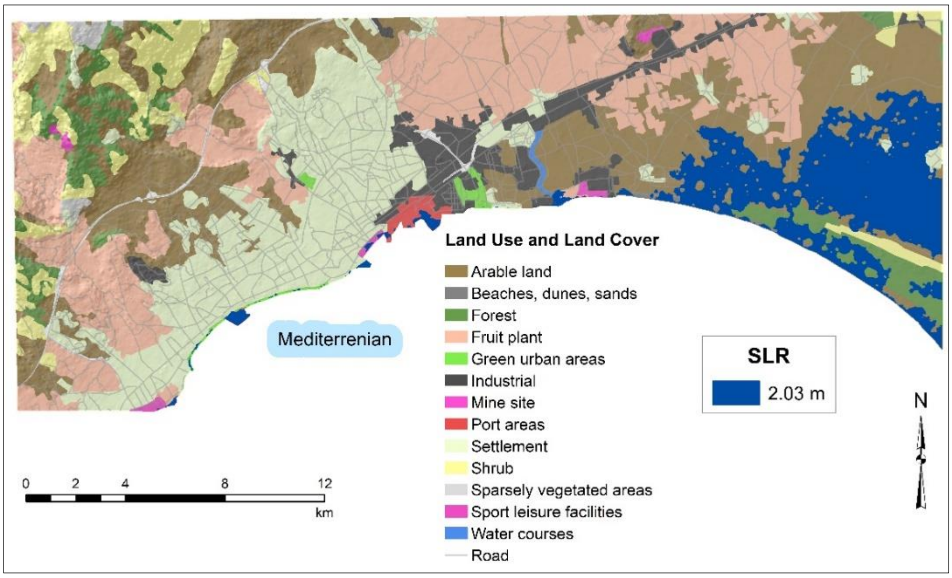

Figure 8. Sea level rise (SLR) map of 2.03 m SLR (year 2200)

A 3.59 m rise in sea level will led to the loss of one-third of arable land. 16.7% of the total area will be inundated by the sea (Figure 9). Significant economic losses will likely occur in the port area, more than half of which is inundated. Most of the forests in the coastal zone were affected by the 3.59 m SLR. With this rise, part of the coastal roads will be affected by the SLR.

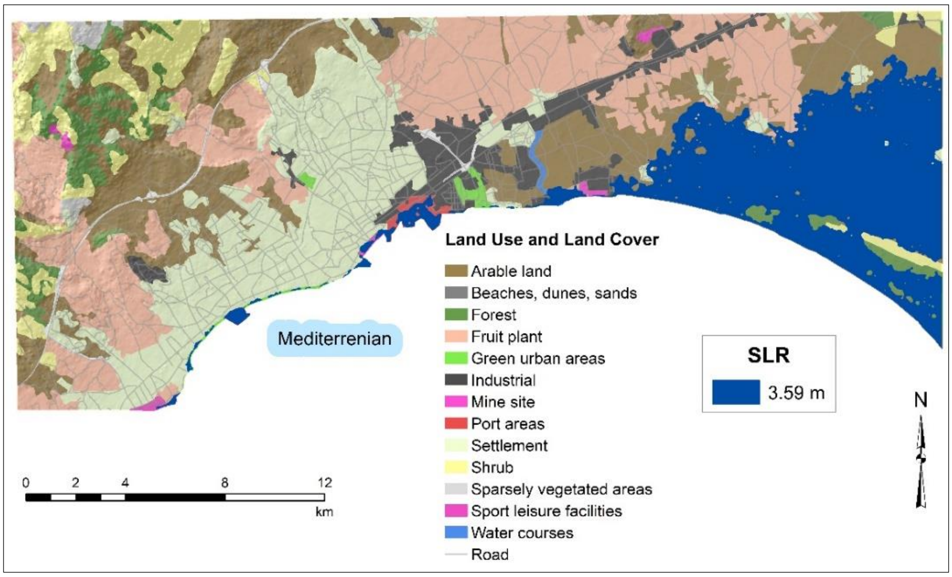

Figure 9. Sea level rise (SLR) map of 3.59 m SLR (year 2300)

At 5.17 m SLR, beaches, dunes, and sands will be completely inundated. Half of the sports-leisure facilities were also inundated. According to this scenario, 21.6% of the total area will be inundated by the year 2400 (Figure 10). Depending on the elevation and slope, there is a considerable land loss in the east of the study area. In this area, most of the forests, along with arable land, will be occupied by the seawater.

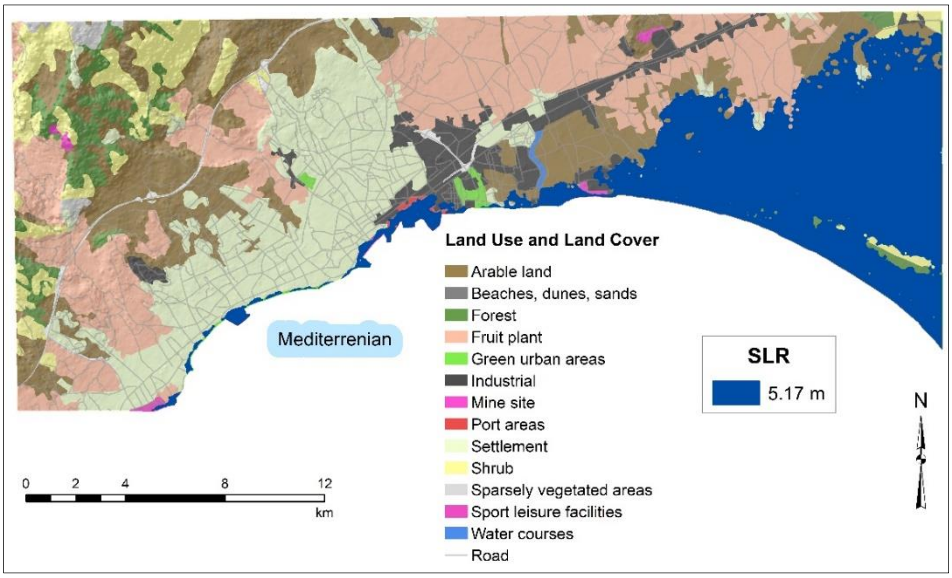

Figure 10. Sea level rise (SLR) map of 5.17 m SLR (year 2400)

IPCC's year 2500 scenario of 6.63 m SLR has the most significant impact. According to this scenario, 21.6% of the total area will be inundated by the sea (Figure 11). Nearly, 92% of the port area is affected by the SLR. The loss of arable land is 68.1 km^2. The forest area in the coastal region is about to disappear. At the same time, most of the agricultural areas east of the study area, namely the Tarsus Plain, will be inundated. As a result of this rise, a part of the intercity highway, as well as the coastal road will also be inundated.

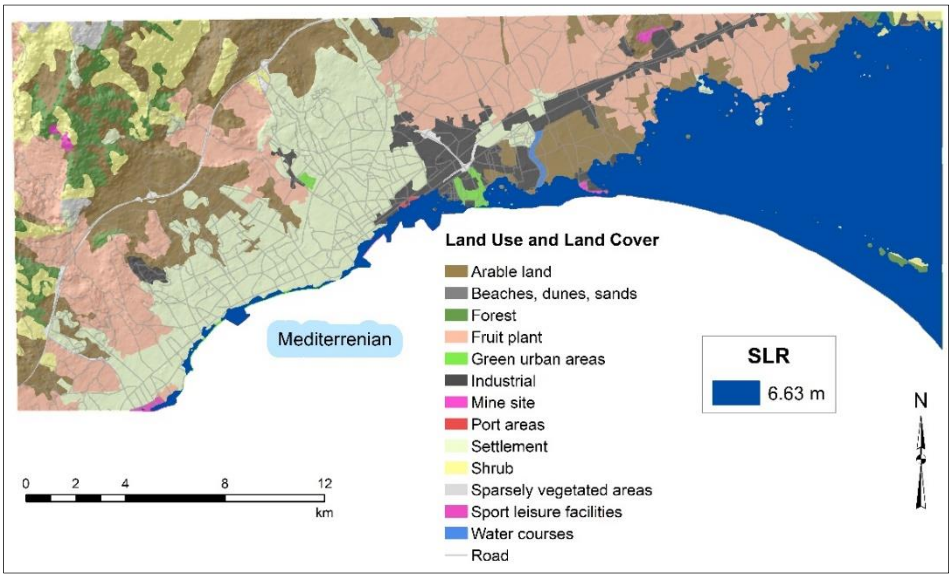

Figure 11. Sea level rise (SLR) map of 6.63 m SLR (year 2500)

Table 3. LULC classes affected according to different SLR scenarios

	SLR Scenarios				
	0.83 m (2100)	2.03 m (2200)	3.59 m (2300)	5.17 m (2400)	6.63 m (2500)
LULC	LULC Loss (km^2)				
Arable land	0.3	30.8	49.2	61.3	68.1
Fruit plants	0.03	0.2	1.2	2.8	4.6
Settlement	0.07	0.3	1.1	2.4	3.6
Forest	0.09	3.8	7.8	9.4	10.2
Industrial	-	0.1	0.3	1.1	2.2
Shrub	-	0.02	0.2	1.0	1.7
Port areas	0.5	0.7	1.6	2.0	2.3
Sparsely vegetated areas	-	-	-	-	-
Green urban areas	0.03	0.1	0.4	0.5	0.7
Beaches, dunes, sands	0.7	1.6	2.0	2.1	2.1
Mine site	-	0.005	0.1	0.1	0.2
Sport-leisure facilities	0.02	0.1	0.2	0.3	0.4
Watercourses	0.01	0.1	0.1	0.1	0.2

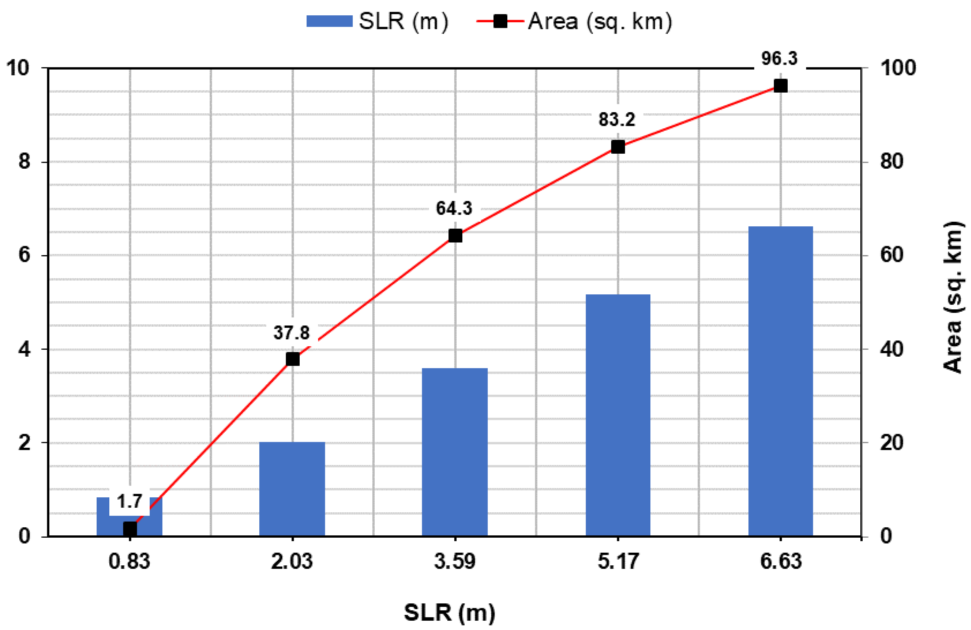

Figure 12. Total area (km^2) lost to sea level rise

4. Discussion

The Mersin city center, home to various LULC classes, was selected for the evaluation of the SLR effect. In addition, this city plays an important role in international trade.

Many studies conducted in Türkiye are large-scale studies covering all coastal provinces. According to Demirkesen et al. (2008), which identifies coastal areas being vulnerable to rising sea levels, some areas of Mersin are at high risk. Similar results were also obtained in the study of Kuleli et al. (2009). The eastern region of our study area (Adana provincial border) is one of the most vulnerable regions of Türkiye to SLR. The studies conducted by the other researchers also support this study.

This study can be considered as a micro-scale when considered on a country basis. Studying smaller areas is essential in terms of climate change and water management. In this study, only global scenarios presented by IPCC are considered.

The delta regions of the study area are in great danger due to rising sea levels. Economic activities here will be interrupted in the future due to SLR. These results reveal the fact that in the future SLR will have important socio-economic and ecological effects. In addition to socio-economic and ecological impacts, the impact of rising sea levels on historical and archaeological sites is significant. The results of this situation can be found in a study conducted by Zengin (2023). Soli Pompeipolis Ancient Port in Mersin is at very high risk for SLR.

Micro-scale studies can raise awareness for policymakers and local governments. The outputs of such studies can be used as a base for studies such as sustainable water management, coasts, and catchments. With SLR, not only land loss but also population migration is inevitable. Therefore, branches of science such as climate change, economics, sociology, and ecology should be considered together to find a solution to this important global problem.

5. Conclusion

To evaluate the SLR effect, the study area within the borders of Mersin city center, covering three districts was selected. 10×10 m resolution DEM data served as the basis for the SLR investigation. Contour lines were used to produce the DEM. CORINE 2018 LULC dataset was adapted to the study area to evaluate LULC types affected by SLR. A total of 13 LULC classes were defined in the study area. These LULC classes were combined with the SLR, and the affected areas were calculated.

According to data collected, arable land was the most impacted LULC class (at 6.63 m SLR). It was followed by forests, fruit plants, settlements, port areas, industrial, beaches-dunes-sands, shrubs, green urban areas, sports-leisure facilities, mine sites, water courses LULC types. Land losses as a result of SLR are as follows: 0.4% at 0.83 m SLR, 9.8% at 2.03 m SLR, 16.7% at 3.59 m SLR, 21.6% at 5.17 m SLR, and 25% at 6.63 m SLR.

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Author Contributions

Onur Güven*:* Writing draft, methodology, software. **Ümit Yıldırım**: Visualization, data curation, writing draft. **Cüneyt Güler**: Writing, investigation, reviewing. **Mehmet Ali Kurt:** Investigation, writing, reviewing.

Statement of Conflicts of Interest

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

Research and publication ethics were complied with in the study.

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