# Coastal Risk Analysis of the Black Sea under the Sea Level Rise

**Nevin Betul AVSAR, Senol Hakan KUTOGLU, Bihter EROL and Shuanggen JIN, Turkey**

**Keywords**: Black Sea, Sea Level Rise, Coastal Zone Management, Risk Management

## SUMMARY

This study focuses on the Black Sea coast vulnerability. For this purpose, present-day sea level changes in the Black Sea are estimated from satellite altimetry data. The result shows accelerated rise in sea level of 3.19 ± 0.81 mm/year for the period of 1993–2014. Although the geographical distribution of Black sea level variation rate is mostly uniform, it is detected bigger than the mean in the southeastern part. Coastal areas below 20 m elevation along the Black Sea shore are also determined from the topography and bathymetry data. When these areas are arrayed according to their size; Russia, Ukraine, Romania, Georgia, Turkey, and Bulgaria, respectively are at risk. In the Black Sea coast, the most important threats are confirmed as coastal erosion and saltwater intrusion.

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## 1. INTRODUCTION

Scientific researches reveal that global mean sea level rise will accelerate during the 21st century in response to ocean thermal expansion and glaciers/ice sheet melting. The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR5) projected based on the scenarios that global sea level may rise between 26 to 82 cm over the next 100 years (Church et al. 2013). It means that the sea level rise should consider a serious threat especially for the unprotected coastal zones. Since, it causes physical impacts such as permanent/temporal inundations (including floods), coastal erosion, destructive storms, and saltwater intrusion.

The rise in global mean sea level has been estimated as 3.27 mm/year from satellite altimetry observations over January 1993-September 2014 by the French Archiving, Validation and Interpretation of the Satellite Oceanographic Data (AVISO) (Url-1). However, the variations in sea level differ from the global to regional mainly due to non-uniform ocean warming and salinity variations (see Figure 1). Moreover, Glacial Isostatic Adjustment (GIA), tectonic movements, changes in ocean circulations, regional hydrology, etc. contribute the spatial patterns in sea level trend (Cazenave and Le Cozannet 2013; Nicholls and Cazenave 2010).

Coastal zones have changed progressively along the history with urbanization, populations, economies, etc. Thus, it is essential to monitor sea level changes and its impacts on coastal communications. The possible consequences of sea level rise should be analyzed in terms of land, population, agricultural lands, urban extent, wetlands, and Gross Domestic Products (GDP). With sea level rise, the inundation of coastal areas would be expected creating problems for infrastructure, transportation, agriculture, and water resources. The coastal zones also encounter many problems like coastal erosion leading to land loss.

According to the scenarios in the final report of the ClimateCost project of European Community, many people (~ 438000) may need to move away from coastal zones because of flooding by the 2050s (Brown et al. 2011). It is stated in the report that in the European, although some coastal areas are already well protected against rising sea levels (e.g. the low-lying sections of the North Sea coast), other coastal zones such as those of Bulgaria and Romania have far less projection.

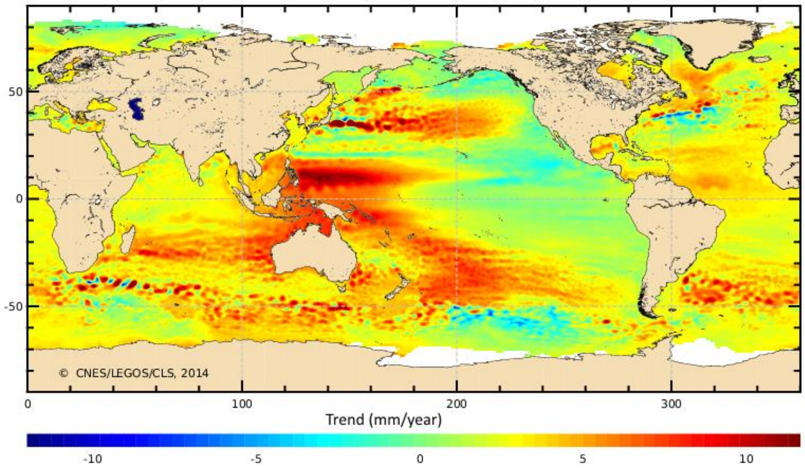


**Figure 1.** Regional mean sea level trends from January 1993 to June 2014 (Url-1).

Turkey's coastlines, bordered by four different seas (the Mediterranean Sea, the Black Sea, the Aegean Sea, and the Marmara Sea), contain large populations (almost one-third of the total population) and significant socio-economic activities. A comprehensive analysis of potential implications of sea level rise for Turkish coasts was performed taking into account their coastal characteristics by Karaca and Nicholls (2008). They treated Turkish coastal areas as two zones which are within 1 km and 10 km of the shoreline, respectively and below 100 m elevation for the analysis. With reference to this, they assessed the vulnerability of Turkey to accelerated sea level rise as intermediate, namely less vulnerable than Egypt and the Nile delta, but more vulnerable than France and Spain. They also mentioned the attitudes of Turkish authorities to sea level rise. Many other national and local scale studies in Turkey have also revealed that some coastal areas, particularly the low-lying deltaic plains, are highly vulnerable to the future sea level rise (Alpar 2009; Demirkesen et al. 2008; Kuleli et al. 2009; Simav 2012). Turkey's Black Sea coast contains three important deltas (Kizilirmak, Yesilirmak, and Sakarya) and lagoons of Kizilirmak Delta. According to the investigations, coastal erosion and ground/surface water salinization associated with sea level rise have already affected these coastal areas significantly.

The Black Sea is a nearly closed sea having limited interaction with the Atlantic Ocean through the Turkish Straits and the Strait of Gibraltar (Figure 2). Black Sea's physical and chemical structure is taken form with its hydrological balance. Vigo et al. (2005) pointed out that the Black Sea level has been largely controlled by an interannual or interdecadal steric effect. Additionally, Yildiz et al. (2011) stated that Black Sea has relatively strong temporal mass variations in relation to the wide drainage area of its covering a large part of Europe and Asia. The past measurements of both tide-gauges and satellite altimetry have revealed that the mean sea level of the Black Sea has risen rapidly (Cazenave et al. 2002; Kubryakov and Stanichyni 2013; Vigo et al. 2005). So, monitoring of Black Sea level changes is important in terms of coastal risk assessment and coastal management planning, etc.

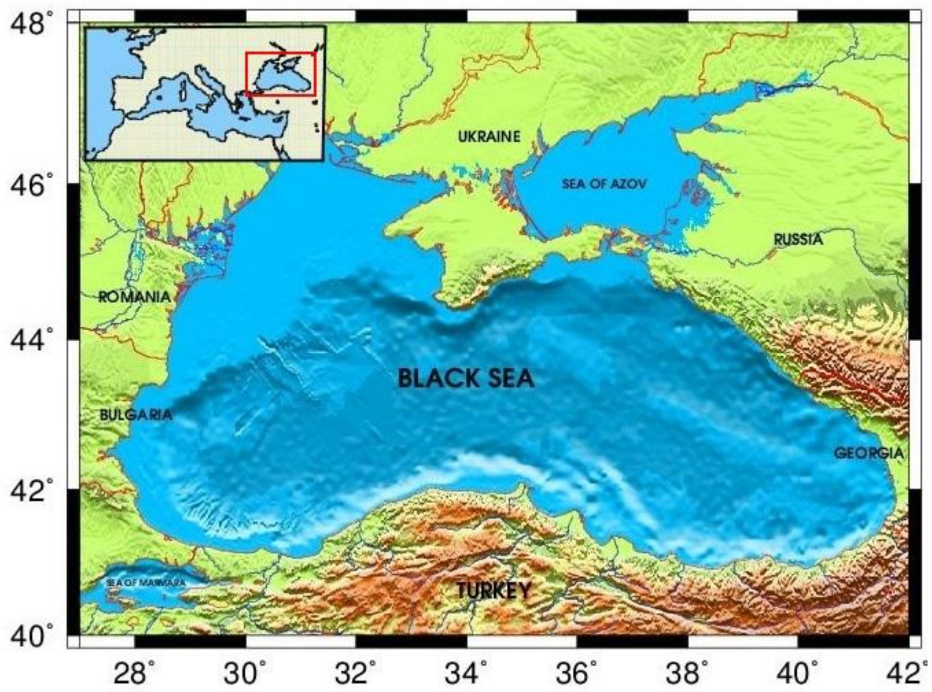


**Figure 2.** Location of the Black Sea.

The purpose of this study is to assess the possible consequences of sea level rise in the Black Sea coast considering its current vulnerability. For this aim, we have investigated the Black Sea level variations using satellite altimetry data and tide-gauge data. Additionally, the low-lying areas are detected from topographic and bathymetric data. We have mentioned the impacts of sea level rise in the light of the studies on the Turkey's Black Sea coasts.

## 2. IMPLICATIONS OF SEA LEVEL RISE ALONG BLACK SEA COAST

There are evident that the Black Sea had been a fully enclosed freshwater lake during the last glacial maximum (~21000 BP) and for some time after. The latest drastic sea level rise occurred in the early Holocene (~7500 BP) when the level of the Black Sea was 60 m below present sea level (Karaca et al. 1999). Subsequent global sea level rise resulted in the Black Sea being abruptly connected to the Mediterranean Sea through the Dardanelles and the Bosphorus Straits and rapid submergence around the Black Sea coast (Karaca and Nicholls 2008). Hence, the coastlines of Black sea have experienced large changes in sea level throughout geological history.

Mountain ranges run parallel to the coast along the Turkey's Black Sea coast (Figure 2). So, inhabitants in the Black Sea region are highly concentrated in a narrow coastal strip. Karaca and Nicholls (2008) pointed out that warming sea surface temperatures can increase storminess and flood frequency by affecting the precipitation patterns in the Black Sea. They also claimed that even if sea level rise rate is 1–3 mm/year, it would affect socio-economic life in the Turkish Black Sea coast. For example, the transportation route between the eastern and western ends of the Turkish Black Sea coast is along roads built near the shoreline. This route will definitely be damaged in the long term by coastal erosion and, in the shorter term, by increasing storm and surge effects.

Terkos Lake and Kizilirmak Delta along the Black Sea were reported as the coastal areas at high risk for inundation by Demirkesen et al. (2008). Terkos Dam Lake is an important freshwater supply for Istanbul. Kizilirmak and Yesilirmak Deltas (or Bafra and Carsamba Plains, respectively), located on the central Black Sea coasts, are two of the largest wetlands of Turkey. The ecological system of the Kizilirmak delta is extremely rich in terms of biological variety, as well. These deltas provide highly productive agricultural lands. However, at present coastal erosion is a major challenge for these alluvial areas. Coastal retreat along the eastern side of the Kizilirmak Delta was reported as 2.5–5.0 m/year by Alpar (2009). Furthermore, the movement of saline water into fresh water sources in these areas threatens the activities such as agriculture and fishing. Permanent submersion of lagoons and low-lying coastal areas, and gradual transformation of the lagoons into bays is other likely impacts in the Kizilirmak Delta.

Assuming no significant land movements (subsidence/uplift), no acceleration in the rate of sea level rise, and no inter-annual to decadal changes in the seasonal parameters, Simav (2012) projected sea level rise by 2100 using the satellite altimetry data. The prediction was also extended including the predictions of extreme wave heights and meteorological in same period to estimate an inundation level. According to this, the maximum level of inundation expected to occur by 2100 was calculated as 7.5 m in Kizilirmak and stated that %9 of the coastal area in Kizilirmak would be at risk of inundation. Moreover, the mean annual rate of shoreline recession at Kizilirmak Delta was determined as 6 cm/year over September 1992 – February 2012.

Karasu which is a touristic region on the Turkey’s Black Sea coast has been experienced drastic coastal erosion reached the threatening dimensions for the settlement. According to the temporal analyses of Landsat satellite images, the maximum erosion on the coastline was detected as ~100 m between 1987 and 2013 (Gormus et al. 2014). Figure 3 shows locations of the Karasu region and the deltas. The common vulnerability of these areas (Karasu and the deltas) to accelerated sea level rise is to sediment-starved as a result of dam or port constructions.

Kuleli et al. (2009) developed an index to determine implications of sea level rise in Turkish coastal cities using the parameters such as population, settlements, land use, wetlands, contribution to national agricultural production, and taxes. The results indicated that the highest risk, most vulnerable areas in the Turkey’s Black Sea coast occur at Samsun and Istanbul cities.

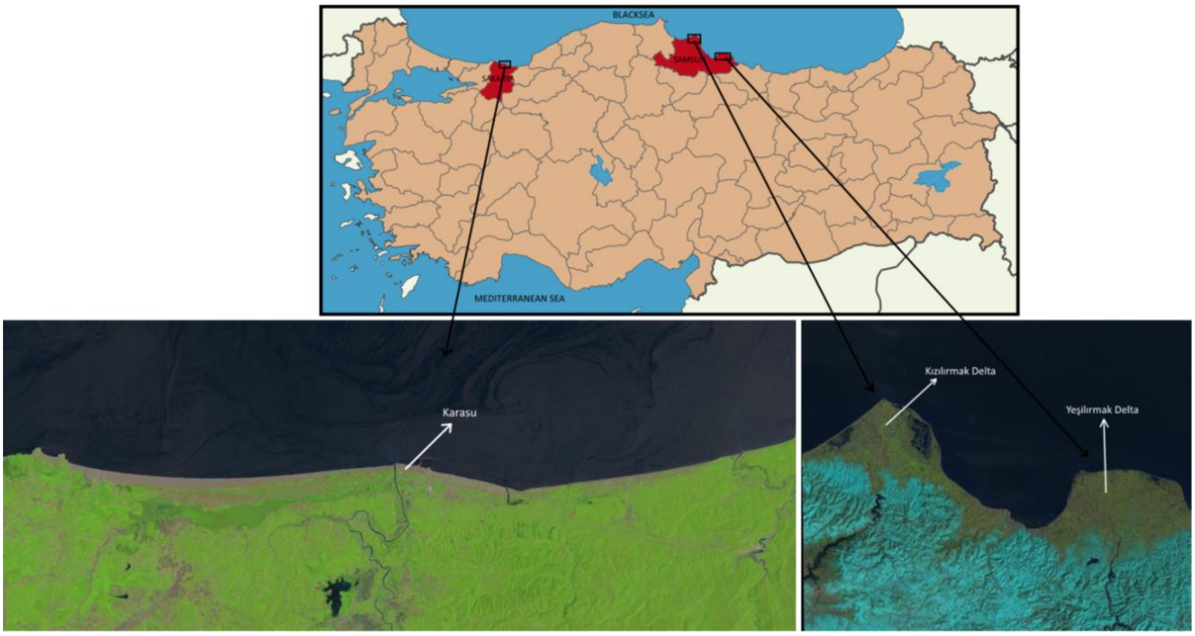


**Figure 3.** Locations of the Kizilirmak and Yesilirmak Deltas, and Karasu from the Landsat 8 images.

The Introducing Climate Change in the Environmental Strategy of the Protection for the Black Sea (CLIMBIZ) project also reported that an important part of the most critical coastal erosion areas in the Europe is in the Black Sea coastline (%13 erosion loss) (Hills et al. 2013). It was stated that the erosion is the most significant problem for most countries around the Black Sea, especially for the Bulgarian and Romanian coasts. According to the project report, increased storminess and erosion might also damage oil and gas infrastructure on the Russian, Ukrainian, and Georgian coasts. The consequences of sea level rise might be caused migration to the coastal hinterland and inshore waters.

### 2.1 Linear trend in Black Sea mean sea level

In the study, present-day sea level changes in the Black Sea are investigated using satellite altimetry data. For this purpose, all satellite merged maps of sea level anomalies data at 0.125° x 0.125° grids was provided by AVISO (Url-2). This data set covers ~22 years from January 1993 to May 2014. The reference period to generate sea level anomalies is based on 20 years of data (1993–2012). Necessary geophysical and atmospheric corrections have been applied to the data set; ionospheric delay, dry and wet tropospheric corrections, solid Earth and ocean tides corrections, inverse barometer effect, instrumental corrections, sea state bias, etc. For further details see SSALTO/DUACS (2014).

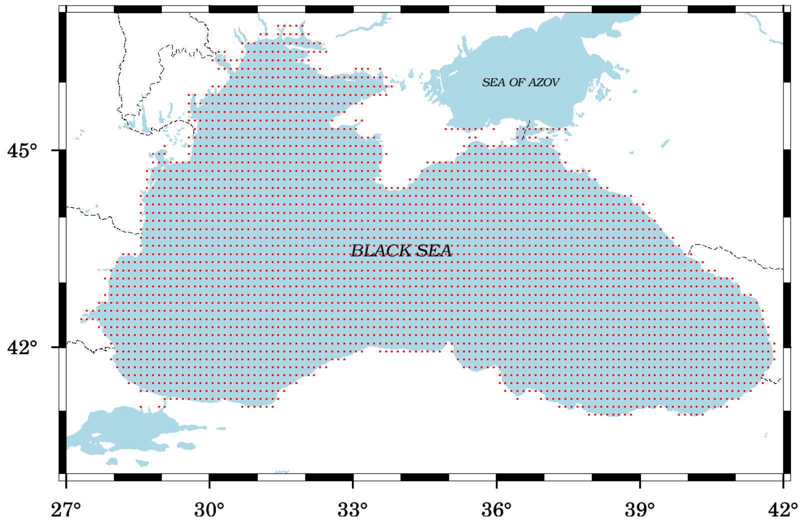


**Figure 4.** Altimetry grid points.

The study area contains 3249 altimetry grid points (Figure 4). For evaluation, the monthly satellite altimetry data set was obtained from the daily data at these grid points. Then, the trends were calculated using the method of least squares. The mean rate of sea level rise has been detected as 3.19 ± 0.81 mm/year over the Black Sea. The result is in agreement with the reported global mean trend; the Black Sea mean sea level has risen over 1993–2014. Figure 5 demonstrate sea level variations during this period. Figure 5 supports that between the early 1990s and 1998, sea level rise in the Black Sea has been observed with an accelerated value. Cazenave et al. (2002) have reported this rate as 27 ± 2.5 mm /year.

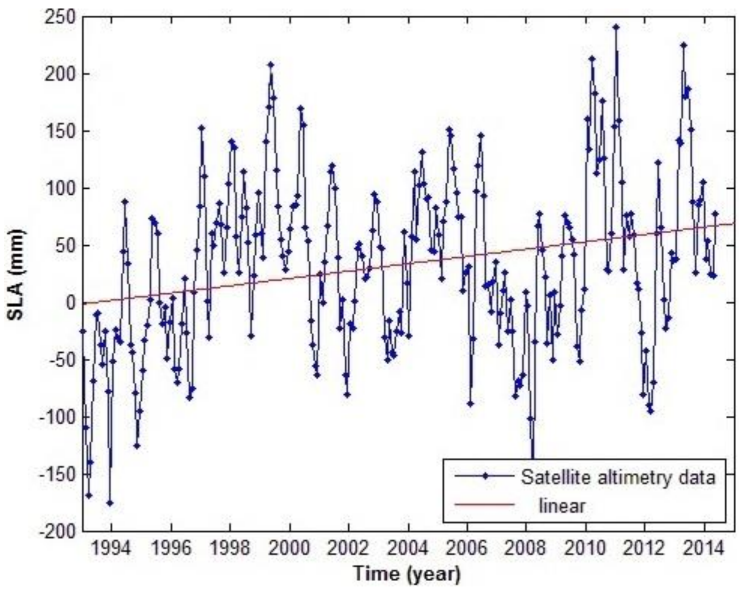


**Figure 5.** Black Sea level variations from satellite altimetry data.

**Table 1.** The trends of sea level variations at tide-gauge stations.

| Tide-gauge station | Country | Time-span | Trend (mm/year) |
|---|---|---|---|
| Igneada | Turkey | 2002–2009 | -6.33 ± 3.97 |
| Amasra | Turkey | 2001–2009 | -0.62 ± 2.01 |
| Trabzon-II | Turkey | 2002–2009 | -6.60 ± 3.96 |
| Batumi | Georgia | 1982–2013 | 1.97 ± 0.08 |
| Poti | Georgia | 1974–2013 | 6.65 ± 0.07 |
| Tuapse | Russia | 1917–2011 | 2.41 ± 0.11 |

Our result pertains to post-1993. Such value of the trend is evidently associated with the sea level variability features at the 22-year temporal scale. However, the satellite altimetry's utility has been sometime limited by the fact that the coasts undergo a complex dynamics (Vignudelli et al. 2006). Even though this challenge is overcome via coastal altimetry, the satellite altimetry is a more global technique. In this manner, tide-gauge measurements can reflect the variations particular to coast better. For example, in Kubryakov and Stanichyni (2013), it was pointed out that the trend determined 8–9.5 mm/year in the coastal areas of the Black Sea exceeds it in the open sea by 1.5–2 times (4.5–6 mm/year) for the period of 1992–2005. They claimed this difference has been resulted in the cyclonic Rim Current intensification. Moreover, the relative sea level rise rate is expected to be higher in coastal zones affected by subsidence.

There are no long-term sea-level measurements along the Turkey's Black Sea coasts (< 20 years). However, we have selected the data of the some tide-gauge stations from Permanent Service for Mean Sea Level (PSMSL) (Url-3). We have also detected the trends at these stations (Table 1).

Unfortunately, the tide-gauge data are not up to date and there are no data for each country in the Black Sea coast. So, these values are not significant at the present. However, at the Poti tide-gauge station it is distinguished that there is a relative sea level rise implying significant subsidence is occurring in Georgia's Black Sea coast. The trends determined at the Batumi and Tuapse tide-gauge stations can be regard as coherent with the global mean trend. The trends from the tide-gauges stations in the Turkey's coast show a sea level drop in the period of 2002–2009. These results should be analyzed using more detailed data (including GNSS data) to further understand reasons of the sea level changes.

### 2.2 Black Sea bathymetry

Bathymetric maps are important as they provide valuable information about the impacts of sea level rise such as ongoing and potential beach erosion, and land sinking (Url-4). In this concept, we have also mapped the bathymetry of the Black Sea using the data at 30" x 30" grids presented by GEneral Bathymetric Chart of the Ocean (GEBCO) (Url-6) (Figure 6).

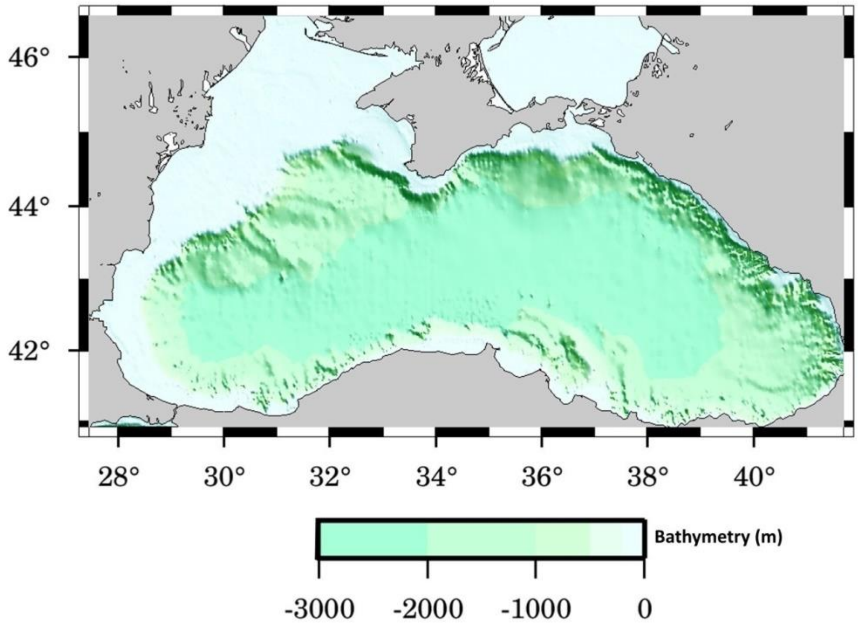


**Figure 6.** Black Sea bathymetry.

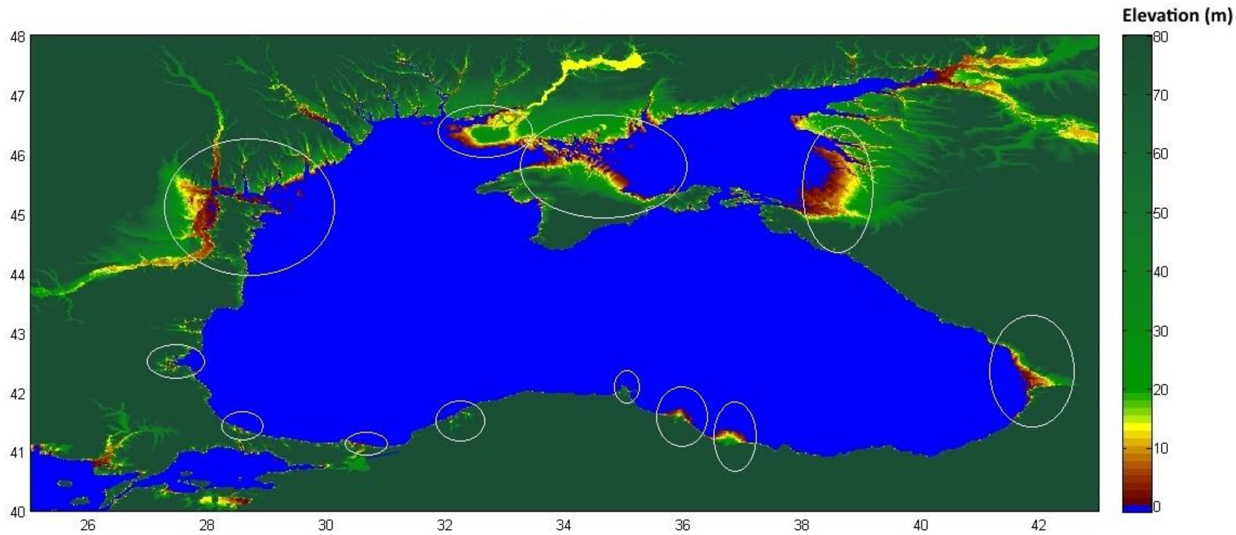


**Figure 7.** Coastal areas below 20 m elevation along the Black Sea shore.

The shelf occupies a large area in the north-western part of the Black Sea, where the shelf is over 200 km wide with as depth ranging from 0 to 100 m, and even reaching 160 m in some places. In other parts of the sea it has a depth of less than 100 m and a width of 2.2 to 15 km. Near the Anatolian and Caucasian coasts the shelf is only a narrow intermittent strip. For further details see Url-5.

Furthermore, Figure 7 focuses on the spatial distribution of land area below the 20 m line. These areas are highly vulnerable to sea level rise. According to the figure, in all the countries along the Black Sea coast, there are many hazardous areas. In order to estimate vulnerable of these areas to sea level rise, general characteristic of the regions should examined in terms of soil type, land use, population, income, etc.

When the geographical distribution of sea level trends is investigated, the maximum rate (~5 mm/year) is observed in the part which is between of 38º–40º northern latitudes and 41º–42º eastern longitudes of the Black Sea. Although there are no low-lying areas in this part, it should be considered.

## 3. CONCLUSIONS

It is very likely that in the 21st century, sea level change will have a strong regional pattern, with some regions experiencing significant deviations from the global mean change. Therefore, local, regional and national patterns of potential consequences of sea level rise should be assessed. The coastal vulnerabilities should be identified. It should be considered the implications of sea level rise for population location, economic, infrastructure, and construction planning. This issue should be regarded as higher priority in coastal management. The governments and local authorities should design long-term policy for coastal planning. The necessary precautions for reducing effects of sea level rise should be implemented for all coastal areas. In this concept, the risk management also is important in such a planning.

The recent and possible consequences show that there are serious impacts of sea level rise in Turkey’s Black Sea coast, for especially Kizilirmak Delta, in terms of coastal erosion and the social-economic values. In this concept, the physical effects of sea level rise on the Black Sea coast should be modelled quantitatively on the basis of available data as to morphology, hydrodynamics, sediment budgets, and land subsidence as suggested by Karaca and Nicholls (2008). Accordingly, the optimal coastal planning should be provided taking into account socio-economic factors as well.

Consequently, the Black Sea has a coastal zone that shows various characteristics region to region. Hence, potential land losses and other risks due to the sea level rise should be treated according to region. In order to predict regional/local sea-level rise accurately, it should be developed reliable methods by understanding coastal sea level forcing mechanisms in the Black Sea.

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