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Coastal Flood Risk Analysis in Turkey's Black Sea Region †

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Abstract: The risk of coastal flooding is increasing as a result of the combined action of storm surges and sea-level rise in the context of global climate change. The rate of sea-level rise is accelerating year by year, and an increase of more than 60 cm is expected by the end of the century. The Black Sea, even if it is a semi-closed sea, is also affected by this phenomenon, and its effects are visible especially during storms. The August 2021 climate events in Turkey have brought attention to studying floods in the Black Sea coast. Thus, the objective of this paper is to assess the flood risk at the Turkish Black Sea coast. This study uses an efficient methodology to delineate flood-hazard areas using Geographic Information Systems. The result of the research is the development of a flood risk map covering various scenarios of sea-level rise which lead to coastal flooding. The map for the entire Turkish coastal area of the Black Sea Region revealed that the most affected area would be the province of Samsun. The results of this study can be used by policy-makers to implement appropriate risk mitigation strategies in those high flood risk areas.

Keywords: coastal zone; floods; Black Sea; Turkey; global climate change; GIS

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1. Introduction

A large proportion of the world's population lives in coastal areas and more people are expected to live in areas that are vulnerable to the effects of climate change [1–4]. Climate change is a major global problem with significant negative effects for coastal settlements. Risks include sea-level rise, increased frequency and intensity of storms [5]. One of the effects of climate change is sea level rise (SLR). The Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC) projected that global sea level will rise by up to ~60 cm by 2100 [6]. Extreme water levels will also increase as time-average sea-levels rise. In addition, changes in the number, path and strength of atmospheric cyclonic storms may alter the formation and evolution of storm surges [7].

The interaction of climate and non-climate factors increases the sea level and thus increases the probability of an extreme event occurring. Adverse effects resulting from an extreme event may include coastal flooding, coastal erosion, shoreline relocation, saltwater intrusion and groundwater, damage to coastal ecosystems as well as affecting agriculture, tourism, biodiversity and infrastructure [6,8].

Recent studies have predicted that some regions of Europe will be more vulnerable to flooding due to climate change, with catastrophic damage prevalent in coastal areas [9,10]. As in many other parts of the world, floods are some of the most devastating extreme events in Turkey, often resulting in significant losses. In many cases floods have caused deaths, injuries and health deterioration [11].

According to International Federation of Red Cross and Red Crescent Societies (IFRC) following excessive rainfall in the Black Sea Region on 11 August 2021, the flooding has occurred in the Sinop, Bartin and Kastamonu regions. According to information from the Disaster and Emergency Management Presidency (AFAD) of the Ministry of Interior of the Republic of Turkey 68 persons in Kastamonu, 9 persons in Sinop, and 1 person in Bartin have lost their lives as a result of the flash floods [12].

A vulnerability assessment of Turkey coastal areas regarding sea-level rise is needed both as part of coastal management policies for sustainable development and as a guideline for resource allocation for preparation of adaptation for the upcoming problems [13].

The Geographic Information Systems (GIS) has had a significant role in flood hazard assessment and the identification of areas prone to floods and it is a crucial element for any mitigation strategy to the flood risk [14,15].

The proposed methodology attempts to highlight areas affected by rising sea-levels using GIS techniques and open-source data. Informations obtained as a result of this will be accessible and usable in territorial planning by authorities.

2. Materials and Methods

The impact of sea-level rise has been analyzed using ArcGIS geo-processing techniques. A similar methodology has been developed by Malik and Abdalla (2016) [16]. Sea-level scenarios have been developed to assess the vulnerability of coastal areas in Turkey's Black Sea Region (Figure 1).

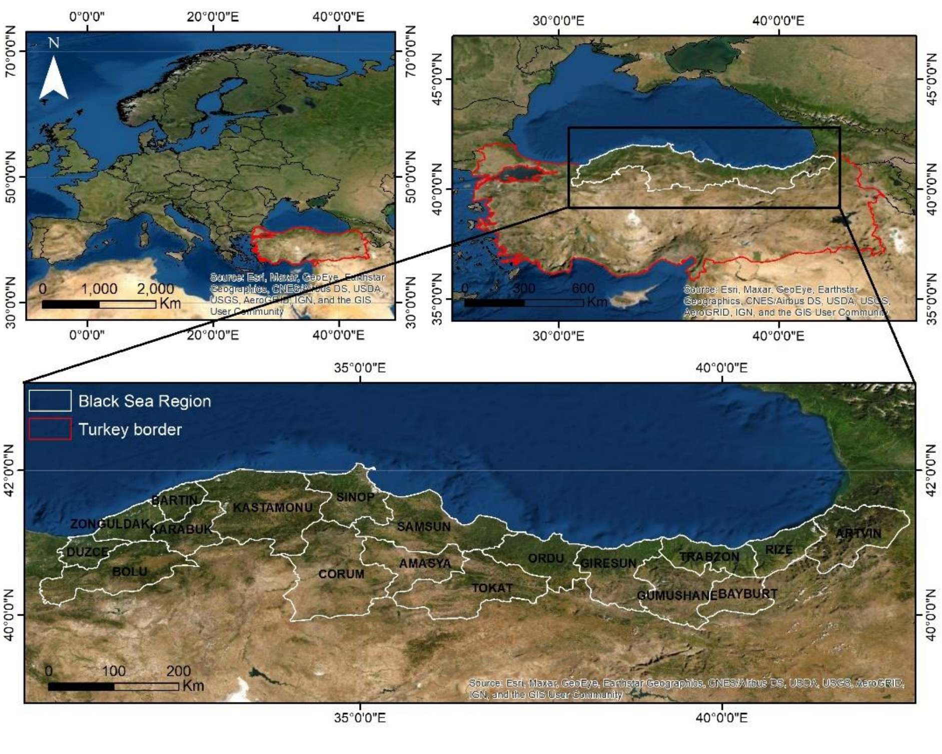


Figure 1. Study area.

The research identifies vulnerable areas with the aim of drawing policy makers' attention to increasing resilience in case of accelerated sea-level rise. This study analyzes the affected areas based on spatial analysis. The spatial analysis has three phases: Digital Elevation Model (DEM) processing, raster calculator and reclassification, raster to polygon and sea level rise scenarios. The methodology is presented in Figure 2.

DEM processing

The DEM used was an European Digital Elevation Model (EU-DEM) at 25 m resolution, version 1.1. The EU-DEM v1.1 upgrade was coordinated by the European Environment Agency (EEA) as part of the EU Copernicus program. This had depths which presented negative values for the respective cells and needed to be removed to keep the integrity in the generated results. To resolve this problem, the ArcGIS fill tool has been used to convert negative values of the raster into meaningful elevations.

Raster calculator and reclassification

Using the Map Algebra Expressions from the raster calculator tool, the cells were extracted in the form of new rasters. This new raster was generated using the elevation values of one to 5 m. The resulting rasters were significant to delineate flood-hazard areas. The generated rasters consisted of cells with two values, 0 and 1: 1 represented the cells that were of interest while 0 represents cells to be removed from the raster. In order to eliminate the cells with values 0 these rasters were reclassified. Using the reclassification tool the 0 value cells was modified as No Data and thus the respective cells had null values. This process was repeated for all five rasters.

Raster to polygon and sea level rise scenarios

Next, the reclassified rasters were converted to a polygon using the raster to polygon tool from Conversion Tools. This conversion was done because vector data is easier to operate than the rasters cells. Following the conversion, shapefiles selected based on location were generated. Choosing the shapefiles depending on their location allowed selecting areas which touched the water boundary. This was done for all five shapefiles.

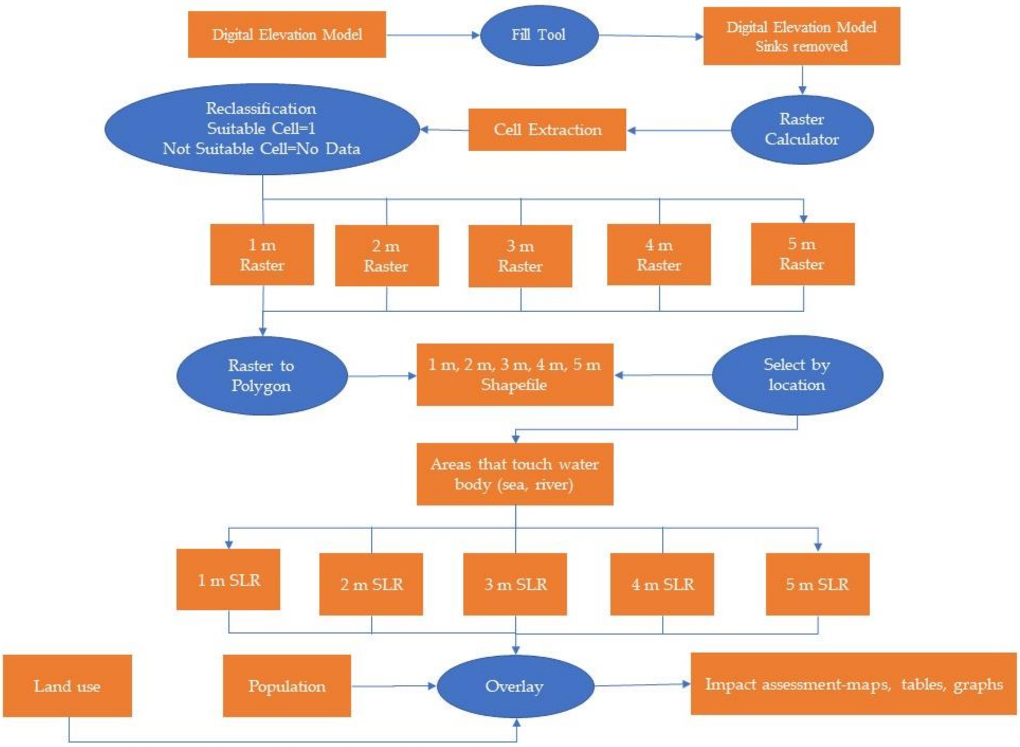


Figure 2. Methodology flowchart.

The 1-m shapefile that touched the water boundary had a sea level rise of 1-m. The 2-m sea level rise scenario was created by selecting the 2-m areas that touched the water body and adding 1-m of sea level rise. The same procedure was applied for the generation of 3, 4 and 5 m sea level rise scenarios.

Once the inundated areas were generated, it was possible to analyze the impact on the study area through spatial analysis. The impact assessment was done by overlaying the inundated layer generated over land-use shapefile and population raster.

The Zonal Statistics as Table from Zonal Tools was used for calculating the population of affected areas. To find out the affected area of land use categories was used Clip Tools from Extract Tools and then Statistics from Attribute Table.

3. Results

Once the inundated model was generated, it was overlaid on to the Black Sea Region area to quantify the area lost due to the sea level rise. It was possible to visually represents the impact of sea level rise from 1 to 5 m. After sea lever rise (SLR) scenarios for the entire region were realized, it was noted that Samsun would be the most affected region (Figure 3). Samsun is a province on the Black Sea coast with a population of 1 348 542 [17]. It is an important agricultural center, with 455 324 ha in the province devoted to agriculture [18].

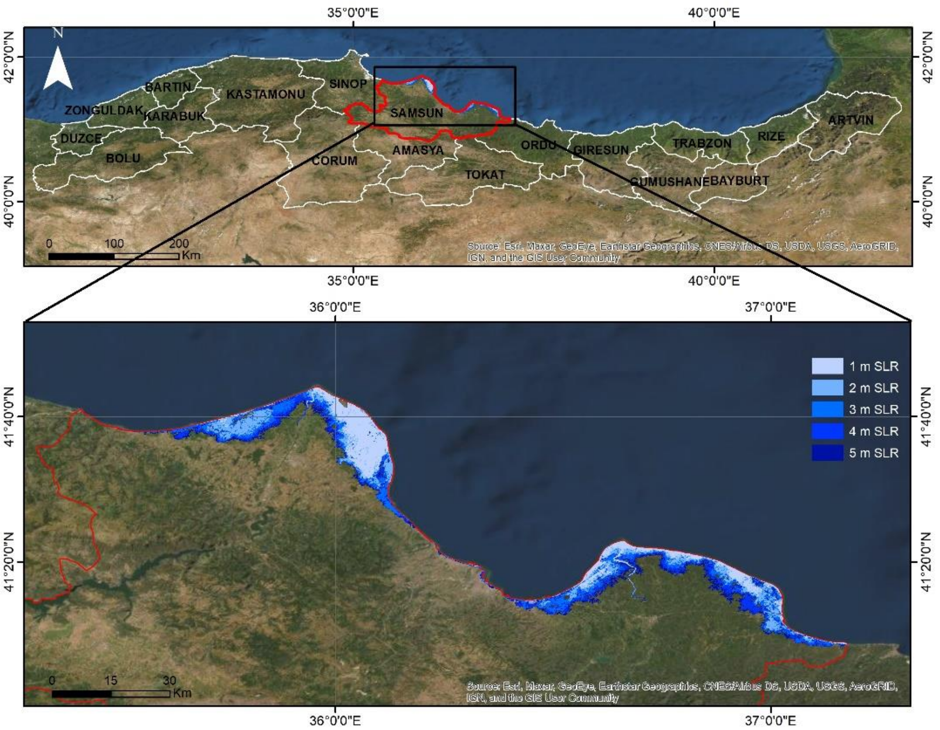


Figure 3. Modeling scenarios on the Samsun province coast.

Modeling scenarios

For significant results, flooded areas have been quantified for the 5 sea-level rise scenarios in Samsun area (Figure 4, Table 1).

At 1 m rise, 175.1 km^2 area which accounts for about 1.7 % of the total area is lost to sea level rise who affected 6 415.5 inhabitants which accounts about 0,5 %.

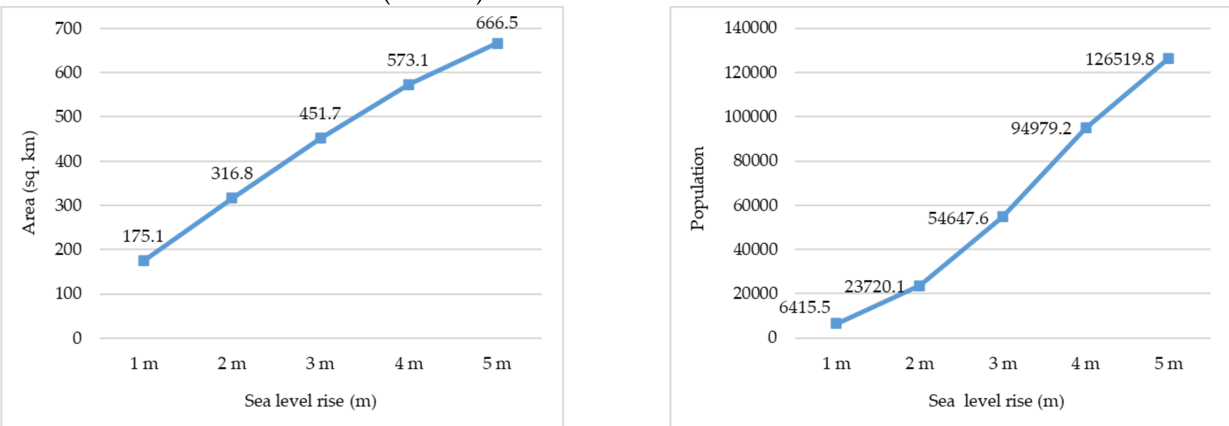
At 2 m rise, 316.8 km^2 area which accounts for about 3.2 % of the total area is lost to sea level rise who affected 23 720.1 inhabitants which accounts about 1.8 %.

At 3 m rise, 451.7 km^2 area which accounts for about 4.6% of the total area is lost to sea level rise who affected 54 647.6 inhabitants which accounts about 4.1 %.

At 4 m rise, 573.1 km² area which accounts for about 5.8% of the total area is lost to sea level rise who affected 94 979.2 inhabitants which accounts about 7.1 %.

At 5 m rise, 666.5 km² area which accounts for about 6.8% of the total area is lost to sea level rise who affected 126 519.8 inhabitants which accounts about 9.4 %.

The most vulnerable land use categories for every scenario are agricultural areas and wetlands (Table 1).



(**a**) (**b**)

Figure 4. Area affected (a) and number of inhabitants affected (b) for the five scenarios of sea level rise.

Table 1. Land use categories affected for the five scenarios of sea level rise.

Land use	1m	2m	3m	4m	5m
Artificial surfaces	1.2 sq km	5.30 sq km	13.8 sq km	23.2 sq km	29.8 sq km
Agricultural areas	52.3 sq km	149.4 sq km	255.4 sq km	355.2 sq km	434.6 sq km
Forest and semi natural areas	17.8 sq km	32.9 sq km	48.2 sq km	57.9 sq km	63.8 sq km
Wetlands	66.4 sq km	89.1 sq km	93.1 sq km	94.4 sq km	94.9 sq km
Water bodies	37.4 sq km	40.1 sq km	41.2 sq km	42.4 sq km	43.4 sq km

Discussions

In Turkey the number of problems were increased in coastal zones and many safety measures are being taken by governmental institutions and agencies [19].

Sea level rise along the Turkish coast is not significant as in some other areas around the world but there will be local vulnerability. Coastal erosion and flooding along Turkish shorelines are problems of national significance. Generally, there is a lack of regional, national and specific data. This data is needed for decisions on adaptive options. There is a great need to identify areas that are at their most vulnerable to the impacts of sea level rise, similar to studies conducted in river basins [20,21]. At this time, sea level rise scenarios are difficult to develop due to defective knowledge of the local and regional factors. All the uncertainties must be considered when explaining impact and response assessments [22].

The modeling presented offers an alternative to identify critical areas, where rising sea levels can have negative effects. The databases used are accessible and can be replicated to other areas. The proposed methodological plus contributes to the completion of these approaches with the spatial design of the phenomenon that can lead to a better understanding of the determinants of a certain level of negative impact of human communities.

4. Conclusions

The main objective of this research was to create potentially inundated coastal areas for Black Sea Region of Turkey. To quantify and to analyze visually the impact of sea level rise on Black Sea Region the Digital Elevation Model (DEM) was used. It was observed that coastal zone of Samsun province will be the most affected area.

In order to analyze the sea level rise impact and assess the damage, a model of inundated areas was created. This model in the form of five different sea level rise scenarios was then overlaid on three GIS layers (total surface, population and land use) to assess the impact.

This study presents a simulation of a different sea levels rise and can be considered by the authorities to implement measures to reduce negative effects.

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