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National assessment of sea level rise using topographic and census data for Turkish coastal zone

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Abstract Turkish coastal zone elevation to sea level rise was illustrated by using digital elevation model and Geographical information systems methods. It was intended to determine several parameters such as population, settlements, land use, wetlands, contribution to national agricultural production and taxes at risk by using high resolution SRTM topographic, orthorectified Landsat Thematic Mapper Mosaics and census data with GIS methods within 0–10 m elevation of national level. All parameters were examined for coastal cities, coastal districts, settlements and villages' status. As a result of the analysis of data set, it was found that approximately 7,319 km^2 of land area lies below 10 m contour line in Turkey, and is hence highly vulnerable to sea-level rise. 28 coastal cities, 191 districts and 181 villages or towns are located below 10 m contour line in study area. In the short term, for the struggle of negative impact of sea level rise, the findings suggest that the Ministry of Environment should declare new areas as protection areas and develop special environmental programs for national level.

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Introduction

International Panel on Climate Change reports that climate change will have many negative effects, including increased intensity of storms, floods and droughts, rising sea levels, and loss of biodiversity. Sea level rise (SLR) causes extraordinary threat to countries with high density of population and economic activity in coastal areas. Until now, SLR researches estimated a 0–1 m rise during the 21st century (Church et al. 2001; IPCC Third Assessment 2001).

Model projections of the IPCC SRES scenarios give a global mean sea-level rise of 0.09 to 0.88 m by 2100, with sea level rising at rates approximately two to four times faster than those of the present day (EEA 2004; Meehl et al. 2007). Sea level rise until this moment has also been significantly faster than the level predicted in the 2007 IPCC reports. In Europe, regional effects may result in sea-level rise being up to 50% higher than these global estimates (Woodworth et al. 2005). The impact of the North Atlantic Oscillation on winter sea levels provides an additional uncertainty of 0.1 to 0.2 m to these estimates (Hulme et al. 2002; Tsimplis et al. 2004).

The rate of sea level rise for the last 20 years was 25% faster than in any other 20-year period, the main reasons are supposed to be ocean thermal expansion and melting from non-polar glaciers. There had been a close relationship between temperature and sea level rise throughout the 20th century, as sea levels rose at a rate of about 2 mm per year per degree Fahrenheit. Applying this relationship to future warming scenarios implies that sea level will rise between 50 and 140 cm by 2100. This estimate is much higher than the IPCC Third Assessment Report estimates of 21 to 70 cm by 2100 and the fourth Assessment Report estimates of 18 to 59 cm by 2100. The bottom line is that if the current relationship between warming and sea level rise continues, the IPCC estimates would be unrealistic, and sea level rise of more than 1 m by 2100 is a real possibility.

Several studies have showed the estimates of the potential impacts for some developed countries (Baarse et al. 1994; Bijlsma et al. 1996; Ng and Mendelshon 2005; Zeidler 1997); developing countries (Adam 1995; Dennis et al. 1995; French et al. 1995; Han et al. 1995; Warrick et al. 1996); or specific areas of the world (Yim 1995). Only few studies such as: Nicholls and Mimura (1998), and Nicholls and Tol (2006), have estimated the impacts of SLR on a great extent of regional or world scale. These studies research the impact of such extreme climate scenarios as a 5 m SLR. However, while indicators of impacts mostly include land loss, population affected, capital loss value and wetlands loss, different studies used different indicators or regions, making it difficult to compare the relative magnitude of impacts across countries or regions.

Although a national evaluation hasn't been conducted related to SLR in Turkey, several local research was carried out on coastal flood risk analysis and quantitative coastal inundation vulnerability of Turkey to SLR until the year of 2205 (Demirkesen et al. 2007, 2008).

In this research, several parameters such as population, settlements, land use, wetlands, contribution of national agricultural production and taxes at risk were determined by using GIS methods with high resolution SRTM topographic, orthorectified Landsat Thematic Mapper Mosaics and census within 0–10 m elevation of national level. All parameters were examined under the range of coastal city, coastal district, settlements and villages status.

The coastal environment of Turkey

Turkish coastal environment was researched part by part from different points of view. The most important information source about Turkish coasts is the proceedings of Turkish Coasts Conference, conducted by Turkish National Committee on Coastal Management, bi-annually since 1997 and published with the title "Turkish Coasts: The National Conference on the Coastal and Marine Areas of Turkey". The six volumes published up till now are widely used and serve as the basic source of information for coastal and marine environments of Turkey. The most recent research document, Coastal Area Management in Turkey, was prepared by the author Prof. Erdal Ozhan who is the Chairman of MEDCOAST (PAP/RAC 2005) and was published by the Priority Actions Program, Regional Activity Centre of the Mediterranean Action Plan. According to this research document, the Turkish coastal environment was briefly described as follow;

The total length of the Turkish coastline including the islands is 8,333 km, of which 1,067 km are island shores. The distributions of this total according to the four seas are the Black Sea: 1,701 km (20.4%), the Sea of Marmara: 1,441 km (17.3%), the Aegean Sea: 3,484 km (41.8%), and the Mediterranean: 1,707 km (20.5%) (Gunay 1987). These four coastal regions show distinct geographical features. Mountain ranges run parallel to the coast along the Black Sea coast, especially in the eastern part, limiting the size of the coastal area to extreme minimums on one hand and bringing a marked influence on the climatology the region on the other. The western Mediterranean coast has geological features similar to the eastern Black Sea coast, e.g. high mountain ranges running in close proximity to the shoreline. However, the climatology of this coast, which is basically Mediterranean, is far different. Along the eastern Black Sea and the western Mediterranean coast, the width of the coastal area is very narrow (in the order of a few hundred meters), thus rendering the area unsuitable for many coastal uses including urbanization. Along the Aegean coast, the mountains run perpendicular to the coast, thus allowing the rivers like Buyuk Menderes to form fertile alluvial plains and productive deltas. Due to the perpendicular orientation of the mountains, the Turkish Aegean shoreline is highly indented, housing numerous bays and coves that have been inhabited by humans since historic times. This makes the Aegean coast extremely important with respect to the presence of invaluable cultural sites and resources, and thus a prime area for tourism and recreation, and other coastal uses that are also supported by numerous coastal features and natural attractions.

Other alluvial plains are located along the western Black Sea coast (like those of Kizilirmak and Yesilirmak) and the middle to eastern Mediterranean coast (like the plains of Goksu, Seyhan, Ceyhan and Asi). The coastal area along these alluvial and deltaic shores widens significantly from a handful of kilometers to a few tens of kilometers, presenting agricultural land of the highest productivity.

The coastal area around the Sea of Marmara is generally suitable for human development. The terrain is not as rugged as the eastern Black Sea and the western Mediterranean coast. The proximity to the City of Istanbul and to Europe has contributed to the potential development value of the Marmara coast, which is relatively more developed and densely populated.

Turkey is divided to seven "geographic regions" and four of these are named after the sea that they border. The Black Sea (Karadeniz) Region is often referred to in two parts: the eastern and the western Black Sea regions. These "geographic regions" are very large areas. At a lower level, are the provinces that are basically political (administrative) units. The provinces of Turkey that have a coastline along at least one of the four seas are. The four coastal geographic regions and their coastal provinces are:

1. The Black Sea Region: Artvin, Rize, Trabzon, Giresun, Ordu, Samsun, Sinop, Kastamonu, Bartın, Zonguldak, Duzce and Sakarya;
2. The Marmara Region: Istanbul, Kirklareli, Tekirdag, Edirne, Canakkale, Balikesir, Bursa, Yalova, and Kocaeli;
3. The Aegean Region: Izmir, Aydin and Mugla;
4. The Mediterranean Region: Antalya, Icel, Adana and Hatay.

The boundaries of the provinces have been drawn based on administrative features. The coastal provinces in all cases occupy both coastal and inland land areas. A further administrative division exists within provinces (districts—"ilce" in Turkish) (Fig. 1).

Turkey is one of the riches countries in terms of wetlands in Europe. The wetlands cover an area of 1,851,000 ha in Turkey including the artificial lakes. Some 58 out of a total of 250 wetlands of Turkey are labeled as "internationally important", and 18 of these are acknowledged as "Class A" wetlands. Seventy-six wetlands having a total area of 1,240,000 ha are indented as important bird sanctuaries (Ministry of Environment 2002). Out of nine wetlands (having a total area of 159,300 ha) that are included in the Ramsar List, four are located in the coastal zone (Goksu Delta, Gediz Delta, Akyatan Lagoon, and Kizilirmak Delta) (Ministry of Environment 2001).

Turkey has 72 lagoons of various sizes, distributed along her long coastline. The Aegean coast is the richest in terms of the number of lagoons, total lagoon area (about 20,000 ha) and fish production (about 562 tons per year). Two lagoons—Bafa and Koycegiz—account for 60% of the total area. The lagoons along Turkey's Black Sea and Mediterranean coast are found mainly as parts of the deltaic systems. Lagoons of the Kizilirmak Delta in the western Black Sea coast and those of the Goksu, Seyhan and Ceyhan Deltas in the eastern Mediterranean coast are among the important pristine nature preservation areas (Deniz 2002).

The length of the Turkish coastline with sand dunes is about 845 km. Until recently, coastal dunes were significantly damaged by road construction, plantations, sand extraction, secondary houses and tourism projects (SPO 2001).

Agriculture in the coastal regions is most important over the alluvial deposits of the major rivers such as Yesilirmak and Kizilirmak (Black Sea), Gediz, Buyuk Menderes and

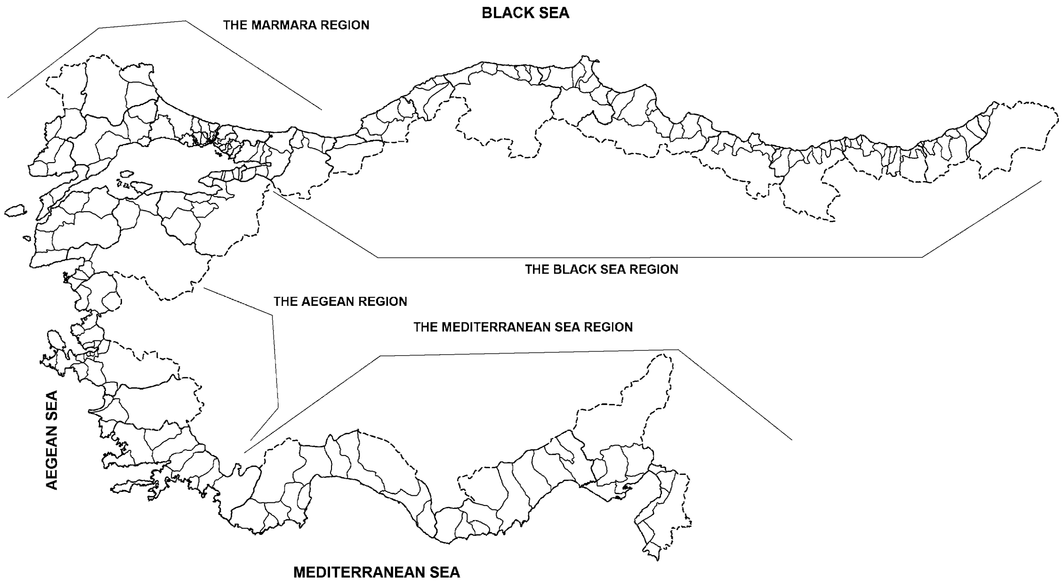


Fig. 1 Turkish coastal regions, cities and districts map

Dalaman (Aegean), Goksu, Seyhan and Ceyhan (Mediterranean). The products are usually varieties with high market values, including cotton, tobacco, tea, citrus and other fruits, olives and grapes. Since the 1989s, the agricultural sector has been consistently loosing to tourism development and services invariably in the tourism centers along the Aegean and the Mediterranean, and to industry and urbanization around the Sea of Marmara.

Sea level monitoring/measurement

Sea level monitoring and measurement activities are realized by General Command of Mapping in Turkey. Yildiz et al. (2003) reported these activities as follow;

Turkish National Sea Level Monitoring System (TUSELS) at present has Ankara data center and tide gauge stations namely Antalya-II and Erdemli at Mediterranean coasts, Bodrum-II and Mentes at Aegean Sea coasts, Erdek at Sea of Marmara coast, Amasra, Trabzon-II and Igneada at Black Sea coasts and the works for the enlargement of TUSELS still function. Under the frame of TUSELS, sea level measurements and ancillary meteorological parameters are collected digitally with high accuracy. At the data center, the activities of transferring, quality control and analysis of tide gauge data are done. The calculation of the hourly sea level values for the other years is based on the tidal constituents obtained taking into consideration the tidal prediction. Then, hourly sea level values of 18 years (1985–2002) for Antalya-II, Bodrum-II and Mentes tide gauges and of 19 years (1984–2002) for Erdek tide gauge are quality controlled by comparing them with the predicted values by removing datum shifts and time errors as much as possible. A 119-point low-pass filter is applied to the hourly sea level values in the computation of daily values and the daily values are used to obtain monthly values with a simple average. Harmonic analysis is applied to the monthly sea level values of four tide gauges and mean sea levels (MSL) and relative changes of MSLs are calculated. This procedure yields relative MSL changes at Antalya-II, Bodrum-II, Mentes and Erdek as 8.7 ± 0.8 mm/yr, 3.3 ± 1.1 mm/yr, 6.8 ± 0.9 mm/yr and 9.6 ± 0.9 mm/yr respectively. While the relative mean sea level change at Bodrum-II is found to be in good agreement with the global sea level rise estimates, it is found to be much higher than the global sea level rise estimates at Antalya-II, Mentes and Erdek tide gauges.

Data and method

A rise in sea level would cause erosion and inundation, and also move the zones at risk of flooding upward and landward (Nicholls et al. 1999). According to Behnen (2000), areas below 10 m level are most vulnerable to sea level rise. Lower slopes experience a greater increase in flood risk due to sea level rise than steeper slopes (Nicholls et al. 1999).

Extensive assessments of sea level rise need exact maps of the whole coastal zone, but map scales and accuracy change nation by nation. Given that the typical error in SRTM altitudes is of the order of 3 m in most coastal areas (Rodriguez et al. 2005), there may be better local data for our region of interest while the Shuttle Radar Topography Mission (SRTM) dataset at 90 m resolution is the best publicly available topographic datasets for near-global use.

The SRTM digital elevation data, produced by NASA originally, is a major breakthrough in digital mapping of the world, and provides a major advance in the accessibility of high quality elevation data for large portions of the tropics and other areas of the developing world. The SRTM 90 m DEM's have a resolution of 90 m at the equator, and are provided in mosaiced 5 deg $\times$ 5 deg tiles for easy use.

Landsat data was provided through NASA's Earth Science Enterprise Scientific Data purchase Program Produced, under NASA contract, by Earth Satellite Corporation. Data set title is GeoCover Orthorectified Landsat Thematic Mapper Mosaics published by NASA Stennis Space Center. These data are available with no copyright restriction and can be obtained from the Land Processes Distributed Active Archive Center at EROS Data Center.

As can be seen in Table 1 vector, raster and tabular data were used. As census data, city and district population was obtained from National Statistical Institute (NSI 2007) census. Village and other smaller settlement's population was obtained from local government web portal of Turkey which was developed by the Local Government Research and Training Centre of The Public Administration Institute for Turkey and the Middle East and financially supported by the Turkish State Planning Organization (YerelNET 2007). Population increment rate, population density, income from national budget for each person, income tax rate and agricultural production rate were obtained from Dincer and Ozaslan (2004 Grading to Districts by according to Socio-economical development).

Vector data In order to create GIS database point and region vector data were used. The point vector data was settlements, and cities and the region vector data was districts and boundary. Vector data were extracted from 1:500,000 scale cartographic maps by manual digitizing methods.

Software Global Mapper software was used to process raster data like scanned maps and SRTM data. On the other hand MapInfo software was used to establish vector and attribute database in GIS.

The GIS model was used in this assessment by using spatial coastal data combined with common sea level rise projections. In general definition GIS consists of computer hardware, software, data,

Table 1 Data source and type

Data name	Data type	Scale / resolution	Producer
SRTM-DEM	Raster	– / 90 m	NASA (2007)
Settlements	Vector-point	1:500,000 /–	
District boundary	Vector-region	1:500,000 / –	
City boundary	Vector-region	1:500,000 / –	
Coast line	Vector-line	1:500,000 / mixture of 14.25 m	Digitized from satellite data
Satellite data	Raster	– / mixture of 14.25 m	NASA, LANDSAT TM-ETM+, 1990–2000
Census	Attribute-table	– / –	NSI (2007) and YerelNET (2007)

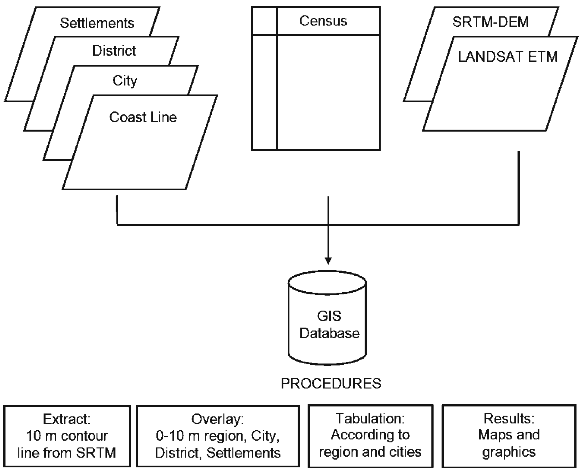


Fig. 2 GIS data model and procedures

methods, and personnel that functions as an automatic system for the capture, storage, update, retrieval, manipulation, analysis, management, and display of all forms of geographically referenced information. GIS data model and procedures were given in Fig. 2.

A first-order estimate of potential losses of land to SLR was arrived at by integrating digital elevation data with the above sea-level rise scenarios using a geographical information system (GIS). In the first step average tidal range values were estimated for all coastal administrative units. Then, based on these values and using the elevation dataset, land area loss as a function of sea-level rise was calculated for each administrative unit. In this step, low-lying inland areas and water bodies were masked out. First-order estimates of population exposure to SLR were calculated by combining the above data. These datasets were then used to calculate resident coastal population counts for the areas lost based on 2007 census data.

Results and discussion

Turkish coastal zone elevation to sea level rise was illustrated by using Digital Elevation and GIS models. Table 2 shows general results of national assessment. As a result of the analysis data set, approximately 7,319 km of land area lies below 10 m contour line in Turkey, and is hence highly vulnerable to sea-level rise. 28 coastal cities, 191 districts and 181 villages or towns are located in the area below 10 m contour line. Thus, approximately 10% of national land lies within 0–10 m contour line. These districts have significant values for agricultural production, population, taxes and income. For example, over 25 million people live in these areas and nearly 27.5% of national agricultural production and 12.5% income tax obtained from these coastal areas.

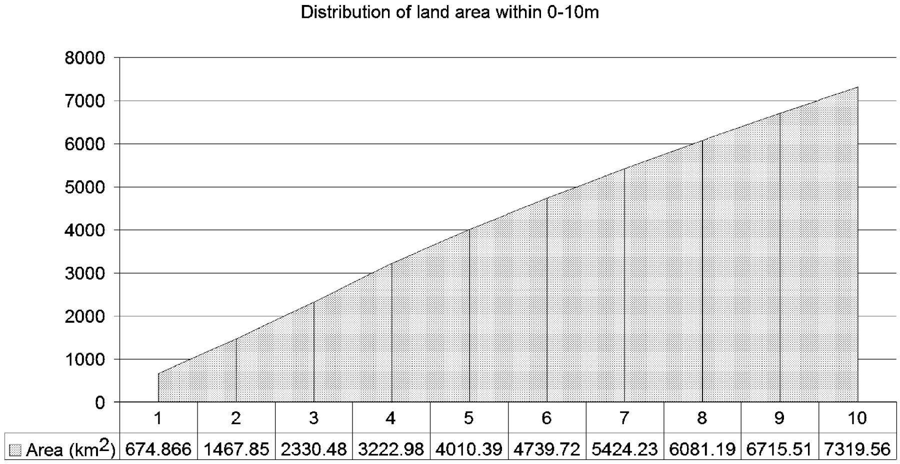
In order to estimate the total extent of the regions at risk by SLR, various data on national land distribution with respect to the elevation above sea level were compiled. Figure 3 shows us potential coastal land loss from inundation only, in the event of an increase in global mean sea level of 10 m, excluding protection and erosion.

Figure 4 illustrates the spatial distribution of these land areas below the 10 m line, the land

Table 2 General results of national assessment

Coastal district level	Average	Sum
City		28
District (ilce)		191
Settlements (village or town)		181
Population (person)	130,909.4	25,003,696
Population increment rate (‰)	13.87	
Population density (person/km^2)	172.74	
Income from national budget (TL)	184,012.65	29,626,036
Income tax rate (%)	0.0776679	12.5045
Agricultural production rate (%)	0.1713780	27.5918
Area within 0–10m (km^2)		7,319.561
Settlements within 0–10 m		181
Population within 0–10 m		1,679,036

Fig. 3 Distribution of land area within 0–10 m



distribution rises as a linear function of the elevation above the mean high water line. There are large areas within 10-m elevation of present high water, partly reflecting the extensive areas of natural and intertidal habitats around Turkish shores.

Turkey has a long coastal zone, the characteristics of which change region by region. Hence, potential land loses and other risks due to the sea level rise were examined according to the regions.

Regional vulnerability calculated using nine parameters, was given Table 3. As can be seen in Table 3, although Marmara Region is the most vulnerable area in terms of population at risk, Mediterranean Region is the most vulnerable area for potential land losses.

Global sea level rise for the last century has been estimated between 10 and 20 cm for the Mediterranean and Black Sea regions, the sea level rise is around 12 cm in the last century (MoEF 2007). Although coastal settlements below 10 m contour line cover nearly 10% of total land coverage of Turkey, over 25 million people live in coastal area.

Sea level rise along the Turkish coast is not likely to be as significant as in some other areas around the world but there will be local vulnerability due to topography and subsidence; Regional sea-level rise is not that well understood and there is a lack of consistency between simulated patterns of change. In many cases, regional efforts will be more efficient in terms of developing and

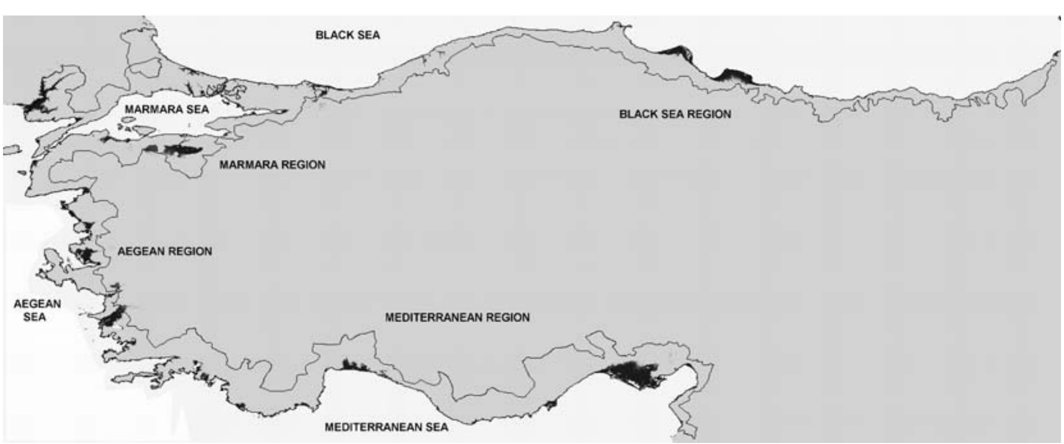


Fig. 4 Coastal areas below 10 m elevation above the present mean sea level

Table 3 Regional vulnerability

Region	1	2	3	4	5	6	7	8	9
Mediterranean	4	27	5,634,047	60	427,815	2,669.9	3,384,824	2.69284	10.83841
Aegean	3	31	3,634,161	38	208,226	1,833.3	4,588,819	1.55674	3.93627
Marmara	9	69	12,049,152	32	841,789	1,698.5	15,152,501	5.68526	5.91736
Black sea	12	63	3,686,336	51	201,206	1,140.9	6,499,892	2.56969	6.8998

1 City, 2 districts, 3 populations, 4 settlements (within 0–10 m), 5 populations (within 0–10 m), 6 areas (within 0–10 m), 7 income from national budget (TL), 8 income tax rate (%), 9 agricultural production rates (%)

assessing adaptation options, a regional perspective would provide a useful link between research and policy at the national and global scales.

Coastal erosion, flooding and inundation along Turkish shorelines are problems of national significance, particularly in the Aegean and Mediterranean regions and also within two important agricultural deltaic plains in middle parts of Black Sea region. Touristic coastal cities are particularly under threat which will cause destruction of many cultural sites by sea level rise like ancient cities in Mediterranean and Aegean regions. Deltaic coasts are expected to undergo a shoreline change due the rising sea level that will result in increased flooding across the delta plain causing interruption of agricultural activity.

Turkey, being a coastal country, recognized the increasing number of problems in coastal zones and many safety measures are being taken by several governmental institutions and agencies (MoEF 2007). For example, most of the areas located in the Aegean and Mediterranean coasts are declared as protection zones by the Turkish government. In a short term, for the struggle of negative impact of sea level rise, The Ministry of Environment should declare new areas as protection zones and develop special national level environmental programs.

There are some uncertainties in national and regional climate change scenarios, as these mainly consist of simple downscaling of global scenarios, based on model-driven scenarios with limited variables. Frequently, sea level rise is used as the unique indicator of climate change. Also, the number of exposure or sensitivity variables is entirely limited. Therefore the assessment results of global studies can not be used in spatial planning and for decision-making on a regional scale. There is also considerable uncertainty regarding sea level rise and its impacts, for this reason the selection of adaptation options are very difficult. Especially, there is a lack of regional, national and site specific data that is needed to make decisions on adaptive options. There is a great need to identify those areas that are most vulnerable to the impacts of sea level rise. The identification should focus on densely populated low lying areas and deltas. The need for common database arrangements to promote exchange of information and international databases accessible to all nations has also been identified. At this time, sea level rise scenarios are difficult to develop due to our defective knowledge of the local and regional factors. All the uncertainties must be considered when explaining impact and response assessments.

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