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Potential Implications of Accelerated Sea-Level Rise for Turkey

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ABSTRACT

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This study comprises a first-order evaluation of the implications of accelerated sea-level rise and some other aspects of climate change for Turkey's coastal areas. Global sea-level rise during the 20th century has been estimated between 10 and 20 cm and similar changes appear to have occurred along Turkish coasts, although available data is poor. Coastal cities cover less than 5% of the total surface area of Turkey, but they have over 30 million inhabitants and are growing rapidly. The Marmara region around Istanbul has the highest population density of all regions. At the same time, more than 60% of the Turkish Gross National Product (GNP) is produced in the coastal strip from Tekirdag to Kocaeli (along the northern shoreline of the Marmara Sea). Analysis suggests that the effects of a 1-m rise in sea level could be significant and adaptation costs substantial. This preliminary assessment suggests a capital loss of about 6% of current GNP, whereas simple protection/adaptation could cost 10% of current GNP. Continued urbanisation and tourist development will further increase exposure to sea-level rise. Currently, the consequences of sea-level rise and climate change are ignored in coastal management, and although strengthening of coastal management mechanisms is required for a number of reasons, sea-level rise and climate change should be considered an important long-term issue. To assist this, detailed case studies are recommended around Turkey's diverse coast, starting with the strategically important Istanbul area.

ADDITIONAL INDEX WORDS: *Vulnerability, common methodology, Turkish coastlines, Istanbul.*

INTRODUCTION

Turkey is located at the crossroads of two continents, Asia and Europe, with a total land area of 779,452 km^2 (755,688 km^2 in Asia and 23,764 km^2 in Europe). Its coastline is 8,333 km long (EROL, 1991) and is bordered by four different seas: the Mediterranean Sea, the Black Sea, the Aegean Sea, and the Marmara Sea, which is connected to the Black Sea by the Bosphorus Strait and to the Aegean Sea by the Dardanelles Strait (Figure 1).

The estimated population according to the 2005 census is approximately 72.5 million, with a population density of approximately 93 people/km^2. The birth rate has been declining over the last two decades, and the rate of population increase is expected to fall below 1.5% by 2010 (MAKTAV, 2000), with an expected national population of 79 million in 2013 and 88 million in 2025. Figure 2 shows total, urban and rural populations from 1950 to 2000, with estimates for 2025. The urban population is growing rapidly; from 14% of the total population in 1950, to 70% in 2000 and urbanisation, often in coastal locations, is expected to continue.

This increase in urban population is due to intensive migration from eastern and south-eastern Turkey to the large coastal cities such as Istanbul, Izmir, Adana, Antalya, and Alanya. Hence, the population exposed to sea-level rise (SLR) is also increasing. By 2015, Istanbul is forecast to have a population of more than 12 million (DPT, 2006), making it one of the world's major coastal cities (NICHOLLS, 1995). Annual population growth rate for Istanbul between 1990 and 2000 was 29.27 per thousand (29.27‰), which is the largest after Alanya (68.86‰) and Antalya (46.44‰) (DPT, 2006). Table 1 lists the 25 coastal cities and towns that had populations over 100,000 in 2000. Almost half (11) are located in the narrow coastal belt along the Black Sea and these contain about 22% of the total national population. Unfortunately, the lack of vertical resolution on existing topographic maps makes it impossible to accurately estimate the portion of the population that lives within a few metres of sea level.

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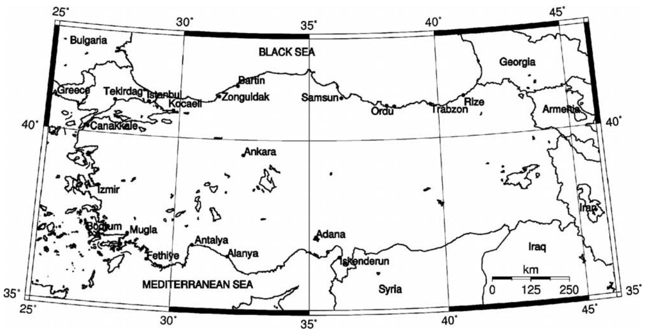

Figure 1. Map of Turkey, including locations of sea-level measurements.

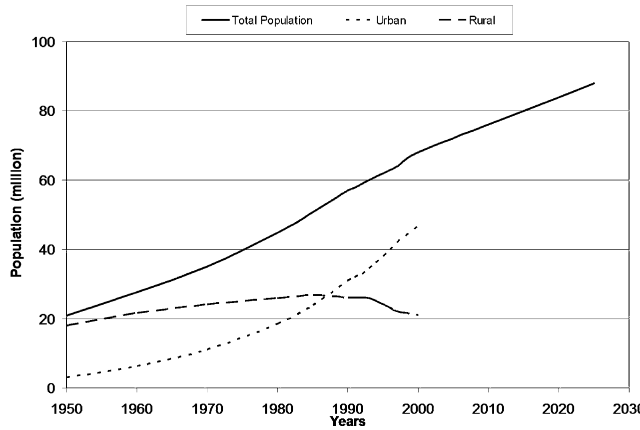

Figure 2. Total, urban, and rural populations of Turkey from 1950 to 2000. Estimated population for 2025 is also included (replotted from Karaca, Antepliogl u, and Karsan, 1995; Karaca, Tayanç, and Toros, 1995).

Approximately 400 major coastal engineering structures can be found on Turkey's coast. These consist of facilities with either a single component such as a pier or a breakwater or those with multiple components such as piers, quay walls, and breakwaters, usually associated with international ports and related infrastructure. The Black Sea coast has 23 ports; the Marmara Sea (inner sea) has 16 ports, and the Aegean and Mediterranean Seas have 12 and nine international ports, respectively. Istanbul has the biggest and largest port in terms of size and trade volume, followed by those at Izmir and Kocaeli. International cargo volume through Turkish ports has increased while domestic cargo volume has decreased. In 1998, cargo-handling volume through the ports reached 155 million tons, including container cargo of 1,347,000 20-foot equivalent units (TFEU).

Fishing has long been an important livelihood for people living on Turkish coastlines and has evolved from a localised occupation to a major industry since the 1970s. Landings dropped from 580,000 tons a year in 1988 to 290,000 tons in 1991 but had recovered to around 550,000 tons in 1995 and 441,690 tons in 2000. The percentage of fishing tonnage in 2000 was Black Sea 76%, Marmara Sea and its straits 15%, Aegean Sea 6% and Mediterranean Sea 3% (DPT, 2006). The future of these fisheries is of immediate concern because of overfishing and pollution, with the effects of climate change being an additional long-term concern.

Tourism has been an important and growing sector since the 1980s, with the coast being the major focus of activity. The number of tourist arrivals has increased from 5.4 to 19.6 million/y between 1990 and 2004 (DPT, 2006): about 21 million tourists visited in 2005, contributing US$15 billion in revenue (14% of total foreign exchange earnings) and making Turkey the 16th most important tourist destination worldwide. The Association for Turkish Tourism Investors have targets of 38 million visitors/y and US$36.4 billion in revenue by the year 2013 (DPT, 2006): Development is concentrated mainly along the coast, extending from the Çanakkale-Balikesir provincial boundary (the Marmara Sea) in the north to the Antalya-Içel provincial boundary (the Mediterranean Sea) in the south. Certified (registered) beds for tourists indicate 27% are found in the Aegean region, 25% in the Mediterranean region, and 21% in the Marmara region (DPT, 2006): Rates of growth in the service sector and urbanisation are above national averages in these areas, partly because of tourism's multiplier effect. As a result, in the coastal municipalities of Balikesir, Izmir, Aydin, Mugla, and Antalya, 32% of the land area has been occupied by vacation homes and 14% of the land area has been set aside as "areas for tourism." This rapid increase threatens natural heritage sites on the coast and the coastal environmental quality, as well as raising socio-economic exposure to SLR.

Table 1. *List of coastal cities and towns with populations over 100,000 according to the 2000 census (city centre population is considered).*

City	Population (thousands)	Annual Growth Rate Between 1990 and 2000 (per thousand)	Elevation (average level, m)	Location
Istanbul	9085	29.27	36	BS, MS
Izmir	2732	24.55	25	AS
Antalya	603	46.44	42	MedS
Içel	537	24.06	3	MedS
Samsun	437	16.88	4	BS
Kocaeli	373	19.26	56	BS, MS
Trabzon	283	26.81	31	BS
Alanya	257	68.86	7	MedS
Iskenderun	159	2.77	3	MedS
Ereğli	159	4.54	2	BS
Bafra	157	2.13	20	BS
Silifke	156	37.28	10	MedS
Fethiye	154	18.92	3	MedS
Ordu	150	3.62	4	BS
Erdemli	142	34.74	5	MedS
Tekirdağ	142	19.05	3	MS
Çarşamba	131	2.01	5	BS
Rize	127	14.83	4	BS
Akçaabat	120	18.04	10	BS
Bandırma	120	15.65	58	MS
Fatsa	120	22.22	5	BS
Milas	112	13.35	45	AS
Giresun	112	8.87	37	BS
Gölcük	107	−3.46	16	MS
Körfez	105	22.00	14	MS
Total	16,421			

BS = Black Sea, MS = Marmara Sea, MedS = Mediterranean Sea.

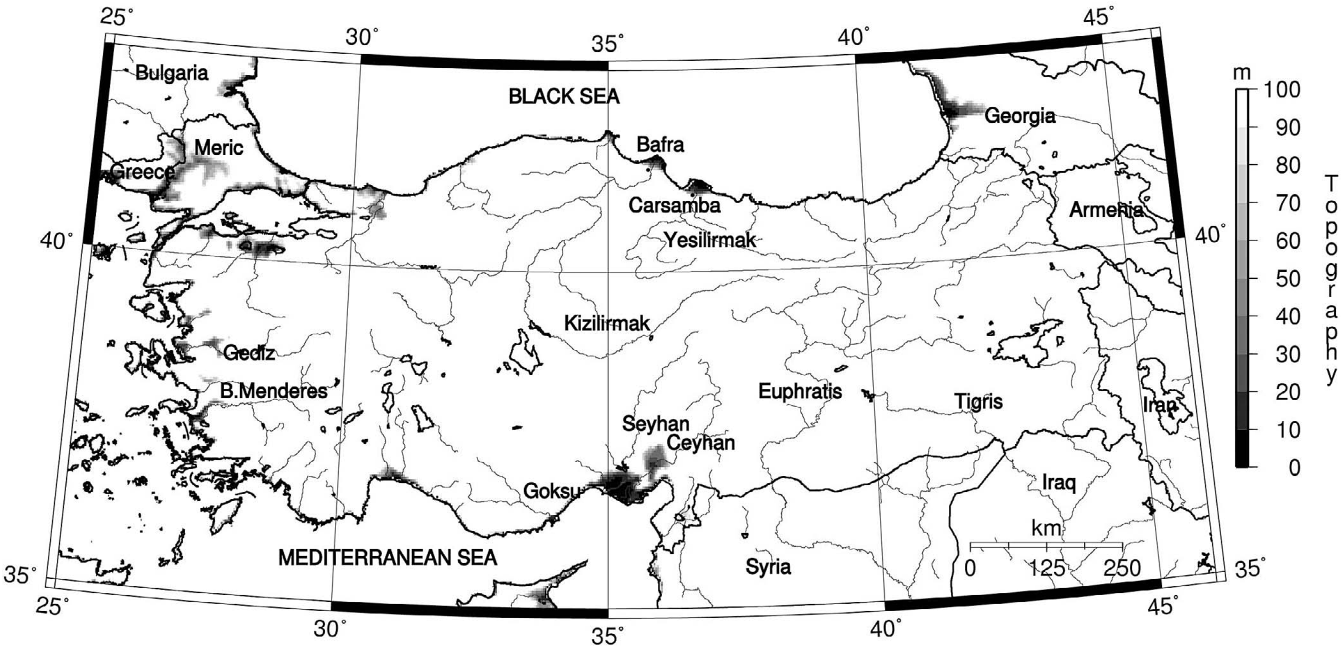

Figure 3. Major rivers and deltaic areas in Turkey (shaded areas are below 100 m).

To date, only two studies consider the possible effects of SLR on Turkey (EROL, 1990, 1991). Both studies were reviews of Turkish coastal characteristics and geomorphology rather than an assessment of the changing coastal environment given SLR or other climate-related changes. These studies are important as the first and only attempts to stress that SLR might have effects on Turkish coastlines, but they only identify the broadest sensitivities rather than any detail concerning possible consequences.

In the following sections, the coastal characteristics and geomorphology of Turkey are discussed. This is followed by a summary of past and possible future climate changes in the region and their effects, with the use of the results of the UKMO/DETR (1999) general circulation model (GCM). The results of this preliminary effects and vulnerability analysis for Turkish coastlines are then presented, followed by a discussion and conclusion.

COASTAL CHARACTERISTICS

The coasts of Turkey are controlled by the geomorphology of the mainland, which comprises the Anatolian Peninsula, especially the North Anatolian and Taurus folded mountain chains, and the belt of faulted central plateau, as well as the submarine relief of the sea basins surrounding the peninsula. Formations associated with fault lines characterise the submarine and coastal relief, particularly in the Aegean and Marmara Seas. According to EROL (1990, 1991), the Turkish coast consists of three main types: (i) erosional rocky and softer cliff coastlines (5752 km or 69%), (ii) accretional sandy coasts (1546 km or 19%), (iii) accretional, partly swampy, deltaic coasts (1035 km or 12%).

Turkey has well-developed coastal dunes, especially along the western Black Sea coast and in the deltas of the Aegean and Mediterranean Seas. These natural barriers to storms provide some defence against the consequences of accelerated sea-level rise (ASLR), at least in the short term. Elsewhere, beach rock has developed along numerous low soil cliffs, notably on the Aegean and Mediterranean coasts and the Black Sea coasts of Istanbul province.

Geologically, Turkey's terrain is structurally complex and tectonically active. Nearly 85% of Turkey is at an elevation of ≥450 m; the median altitude is about 1100 m. In Asiatic Turkey, flat or gently sloping land is rare and largely confined to the deltas of the Kizilirmak River, the coastal plains of Antalya and Adana, the valley floors of the Gediz River, the Büyükmenderes River, and some interior high plains in Anatolia.

Figure 3 shows the areas of Turkey that are <100 m elevation. The following are major deltaic regions (from the Black Sea to the eastern Mediterranean Sea): Yesilirmak (Çarsamba), Kizilirmak (Bafra), Sakarya, Meriç, Gönen, Gediz, Küçük and Büyük Menderes, Aksu, Göksu, and Çukurova (the great plains between the Seyhan and Ceyhan Rivers). These deltaic regions are most threatened by ASLR, especially the agricultural areas on the Çukurova, Bafra, Çarsamba, and Meriç plains.

Sandy beaches are found along 845 km (10%) of the Turkish coast (KAYA, SEKER, and MUSAOGLU, 2001). Although some of these sandy coasts are national parks, one-third are being degraded by rapid tourist development. Tourist accommodation is being extensively constructed, often close to the current shoreline. Recently, there have been increasingly strong objections to tourist development from nongovernmental organizations (NGOs), such as the Association of the Preservation of Natural Life of Turkey, whose aim is to preserve the coastal environment (*e.g.,* for nesting sea turtles, *Carreta carretas,* which use the Turkish Mediterranean coastline beaches during late spring and early summer).

Although the coastal zone contains the most fertile agricultural land of the country, agriculture has generally declined in the face of urbanization, industrialisation, and increasing tourism. Over the last two decades, coastal tourism and yachting have experienced rapid growth, mostly along the Aegean and Mediterranean coastlines (KAYA, SEKER, and MUSAOGLU, 2001). Tourist areas were built first on the narrow beach strip but are now expanding landward on to agricultural areas—trends that are expected to continue. Nonetheless, agriculture in coastal areas will remain an important activity that is vulnerable to SLR.

Coastal wetlands are mostly confined to narrow areas within deltas, such as the Sakarya, Kizilirmak, and Yesilirmak deltas on the Black Sea coast and the Göksu, Seyhan, and Ceyhan deltas on the Mediterranean coast, as well as other low coastal areas on the Aegean Sea (see Figure 3). Lagoons are found mainly behind coastal spits in deltaic areas. The 74 coastal lagoons found in Turkey are distributed as follows: Aegean Sea (40%), Mediterranean Sea (24%), Black Sea (19%) and Marmara Sea (17%) (EMIROGLU *et al.,* 2001). One-third of these lagoons, mainly those on the Aegean Sea, are actively used for fish production. Salt production is also carried out, and the lagoons of Küçükçekmece and Büyükçekmece have been converted to freshwater reservoirs for the city of Istanbul.

Deltas show the largest changes over the last 2000 to 3000 years, with the coastline advancing 40 km seaward in some places (EROL, 1990, 1991). This has had important consequences, including harbour abandonment (AKURGAL, 1970; KAYAN, 1987). In the future, the construction of dams on the upstream rivers is likely to greatly reduce such sedimentation.

Recently, a number of ports have expanded and several larger and smaller fishing harbours and shelters with breakwaters have been built. The numbers of man-made coastline structures are as follows (JICA, 2000): large commercial harbours (60), small harbours (115), shelters with breakwaters (25), abandoned ancient harbours (44), and major coastal protection works (12).

When planning and building this coastal infrastructure, sea level and other environmental conditions are unfortunately assumed to be constant. This is despite current evidence that suggests sea levels around Turkey are already rising. Soft engineering and beach nourishment have not been practiced to date, although it is increasingly being used in many other European countries (DAVISON, NICHOLLS, and LEATHERMAN, 1992; HANSON *et al.,* 2002).

REGIONAL VARIABILITY AND CHANGE

Climate

Turkey's climate results from seasonal alteration of midlatitude frontal depressions and is characterised by polar air masses, subtropical high pressures, and subsiding maritime tropical and continental tropical air masses. Turkey has various climate types in different parts of the country. This diversity is due to two major reasons: (i) Turkey is located in a transition zone that is under the influence of various atmospheric disturbances originating from the northern Sahara and southern Europe and (ii) topographical features are complex and elevation changes rapidly within short distances (KAHYA and KARABORK, 2001; KARABORK, KAHYA, and KARACA, 2005; KARACA, DENIZ, and TAYANÇ, 2000).

A general cooling trend dominated annual and seasonal mean surface air temperature series for much of Turkey until the mid-1990s (KARABORK, KAHYA, and KARACA, 2005; TAYANÇ, KARACA, and YENIGUN, 1997), but a slight warming trend has been observed over the last decade. This is possibly because of the rapid urbanization experienced after 1980s (EZBER *et al.,* 2006). Between the late 1960s and mid-1990s, coastal regions of Turkey, particularly the northern coastal zones, have been generally characterised by cooler than average temperatures, particularly mean summer temperatures (TAYANÇ, KARACA, and YENIGUN, 1997). Annual mean total precipitation in coastal areas for 55 years (between 1950 and 2005) varies from a maximum 2300 mm in Rize (the easternmost Black Sea) to a minimum 594 mm in Icel (also known as Mersin in the eastern Mediterranean Sea). The average temperature for the Black Sea coast over 55 years has been 4–5°C cooler than for the Mediterranean coastal zone.

JEFTIC, KECKES, and PERNETTA (1996) and JEFTIC, MILLIMAN, and SESTINI (1992) contain 11 case studies from the western to eastern Mediterranean basin that assess the effects of climatic change on marine coastal systems. The scope of these case studies was to identify areas most vulnerable to expected climatic change and to suggest policies and measures that could reduce any negative effects of the expected changes. Regional and relevant subregional climate scenarios were prepared by PALUTIKOF *et al.* (1992) on the basis of the combined output of four GCMs—UKMO (United Kingdom Meteorological Office), GFDL (Geophysical Fluid Dynamics Laboratory), GISS (Goddard Institute of Space Sciences), and OSU (Oregon State University)—which were statistically correlated with meteorological records from the Mediterranean basin. Despite the high degree of uncertainty of GCM simulations, the climate scenarios developed by PALUTIKOF *et al.* (1992) predict significant regional and local variations in the future climate of the Mediterranean basin that help the development of site-specific forecasts of future coastal environmental conditions. These climate change scenarios indicate that, in the Mediterranean basin, the temperature change due to the greenhouse effect would be similar to the changes in global mean temperature, with an increase in precipitation during fall and winter periods, but a decrease during the summer in the eastern Mediterranean. However, the coastal regions, particularly in the north, are zones of rapid climate transition, emphasising the need for downscaled scenarios (*cf.* HULME *et al.,* 2002).

According to UKMO/DETR (1999), a new climate model has assessed the effects of climate change on temperature and precipitation conditions, natural vegetation, and water resources for Turkey. HADCM2 (Hadley Centre Climate Model Two) has a climate sensitivity close to the Intergovernmental Panel on Climate Change (IPCC) best estimate value. Run for two CO_2 emissions scenarios, which stabilise concentrations at 750 ppm and 550 ppm, this model did not take into account any increase in other greenhouse gases or aerosols. Changes arising from a business-as-usual emissions scenario, in which CO_2 and other greenhouse gases increase without mitigation were also used for comparison in that report and referred to as the "unmitigated scenario."

Outputs from this model suggest that, by the 2080s, annual average temperatures for Turkey will increase (relative to the 1961–1990 mean) by 3–4°C under the unmitigated emissions scenario, 2–3°C under the 750 ppm stabilisation scenario, and 1–2°C under the 550 ppm stabilisation scenario. Average precipitation will decrease (relative to the 1961–1990 mean) by 1 mm/d under the unmitigated emissions scenario, and 0.5 mm/d under both the 750 and 550 ppm stabilisation scenarios.

Despite the observed cooling trend in the eastern Mediterranean and the coastal regions of Turkey over the last two decades (KAHYA and KARABORK, 2001), climate models provide high confidence that global warming will still increase mean temperatures. This expected increase in temperature and decrease in precipitation will affect surface and groundwater flows and river regimes, the incidence of floods, sediment and nutrients fluxes to the sea, natural ecosystems, and human use of the coastal regions, including fisheries, tourism, and agriculture.

Results of both the UKMO/DETR (1999) model and the studies of PALUTIKOF *et al.* (1992) also indicate that potential evapotranspiration is likely to increase throughout the Mediterranean. Coupled with increases in temperature this would lead to an increase in land degradation and deterioration of water resources and affect, in the long-term, coastal agricultural production as well as aquatic ecosystems. This might also increase the risk of forest fires in the Aegean and Mediterranean coastal areas. An increase in temperature could also lead to a gradual extension of the coastal tourist season, with concomitant environmental problems and economic benefits.

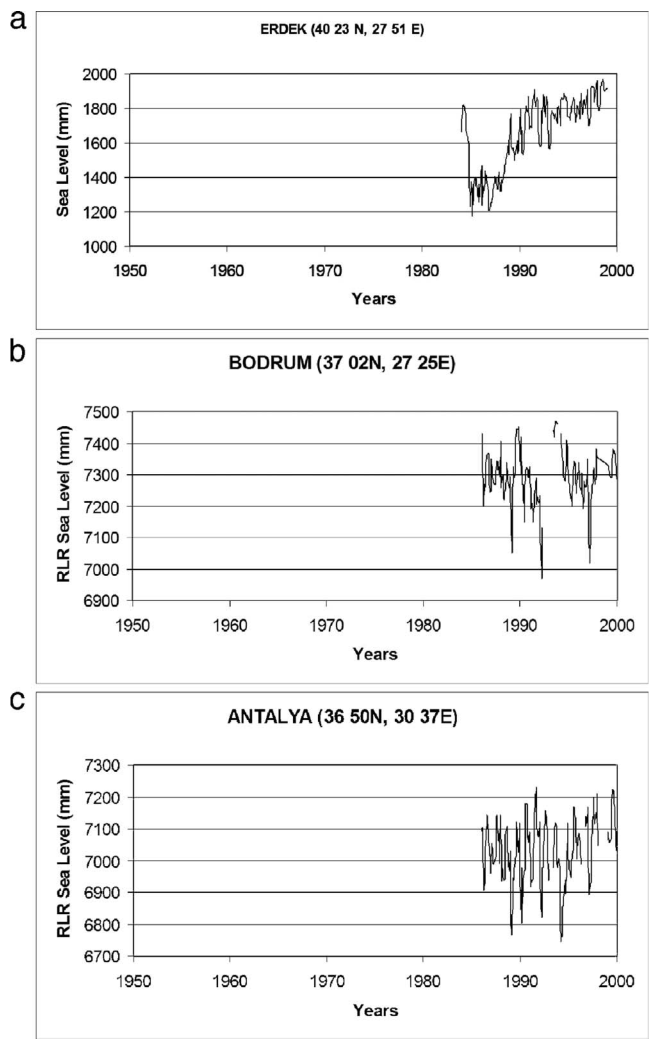

Figure 4. Sea-level variations around Turkey (a) Erdek on the Marmara Sea, (b) Bodrum on the Aegean Sea, and (c) Antalya on the Mediterranean Sea (sea-level data provided by PSMSL [2006]).

Sea Level

The coastlines of Turkey have experienced large fluctuations in sea level throughout geological history. During the last glacial maximum (~25,000 BP) when sea level was lower, the Mediterranean inflow to the Black Sea ceased and the Black Sea became a fully enclosed freshwater lake. The most recent drastic sea-level increase occurred in the early Holocene (~7,500 BP) when the level of the Black Sea was 60 m below present sea level (KARACA, WIRTH, and GHIL, 1999). Subsequent global SLR resulted in the Black Sea being abruptly connected to the Mediterranean Sea through the Bosphorus Strait and rapid submergence around the Black Sea coast (RYAN *et al.,* 1997).

CHURCH *et al.* (2001) estimated that, on the basis of tide gauge measurements, global mean sea levels rose 0.1 to 0.2 m over the 20th century; average rates of SLR were greater during the 20th than the 19th century, but no significant acceleration in the rate of SLR has been detected during the 20th century. However, Mediterranean sea-level records, particularly the north-western Mediterranean and the Adriatic Sea tide gauge data, show a deceleration or even fall in sea level in the latter part of the 20th century. Data is sparse and causal mechanisms are uncertain, but this could result from increases in the density of the Mediterranean deep water and air pressure changes connected to the North Atlantic Oscillation (TSIMPLIS and BAKER, 2000). This suggests that the Mediterranean might not be the best area for monitoring secular trends of sea level. There are no reliable long-term sea-level measurements in the eastern and southern Mediterranean. Figure 4 shows the best sea-level data for Turkey at three representative locations.

The data associated with Figure 4 is rather short (<20 years) and not continuous, so reliable trends cannot be derived (see DOUGLAS, 2001). Therefore, tide gauge data from

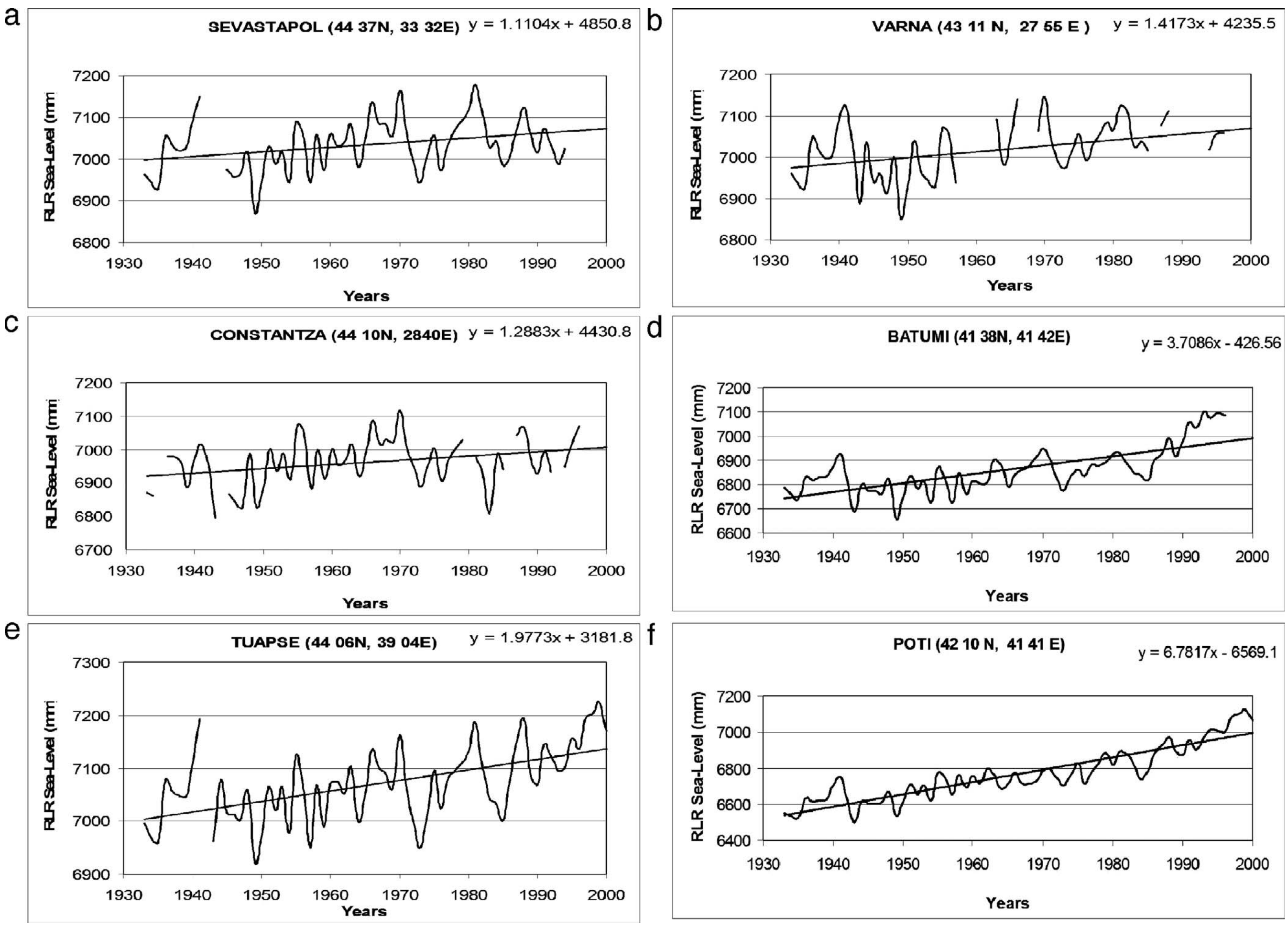

Figure 5. Sea-level data for selected locations around the Black Sea from 1935 to 2000 (a) Sevastapol, (b) Varna, (c) Constantza, (d) Batumi, (e) Tuapse, (f) Poti (sea-level data provided by PSMSL [2006]).

other countries on the Black Sea (Figure 5) were used. The Varna, Constanza, Sevestapol, and Tuapse gauges show a relative SLR of 1 to 2 mm/y, agreeing with reported global mean trends. The Pito and Batumi gauges show a significant relative SLR of 3.7 and 6.8 mm/y, respectively, implying significant subsidence is occurring in Georgia.

SLR for the Turkish Black Sea coast is assumed to be between the western and eastern station values—about 1–3 mm/y. For people living near the Turkish Black Sea coast, this is significant. If this rate of SLR continues, socio-economic life will be affected significantly. For example, the only easy and safe transportation route between the eastern and western ends of the of Turkish Black Sea coast is along roads built near the shoreline. These routes will definitely be affected in the long term by erosion because of SLR and, in the shorter term, by increasing storm and surge damage. Fishing in the eastern Black Sea could also be adversely affected. Rising sea levels and increases in storm surges will also have an effect on agriculture and tourism along the Aegean and Mediterranean shorelines (*e.g.,* cotton production in Çukurova).

EFFECTS AND VULNERABILITY

Implications of SLR on coastal morphology are various, but the main effects are expected to be erosion, flooding, and inundation of coastal lowlands and saltwater intrusion. For high rocky cliff coasts, rising sea level will not cause great changes, but the rate of cliff recession could accelerate, increasing the frequency and extent of landslides. This would be potentially damaging to coastal roads and communications. Along low, eroding soil cliffs, changes might not be immediate, but accelerated wave erosion will gradually increase the rate of inland cliff migration. Because these areas are often already densely populated, including the narrow terrace at the cliff base, serious damage or destruction of coastal establishments would result. However, protecting these areas from waves and inundation will often cause erosion elsewhere.

For deltaic coasts that are advancing seaward today, rising sea level will slow this advance; it might even reverse shoreline change, causing these coasts to retreat. The result of this will be increased flooding across the delta plain, interrupting

Table 2. *Dams in Turkey by purpose (only dams that have a height above the river bed >15 m and storage volume capacity >2 million m³ are considered) (DSI, 2006; Günaydin, 2001).*

	Domestic and Industrial Water Supply	Flood Control	Energy	Irrigation	Total
Black Sea	79	17	13	59	168
Marmara Sea	7	1	1	3	12
Aegean Sea	9	4	2	9	24
Mediterranean Sea	22	23	8	50	103
Inland and closed basins	58	9	30	81	178
Total	174 (36%)	54 (12%)	53 (11%)	199 (41%)	485 (100%)

agricultural activity (particularly on the Kizilirmak, Yesilirmak, Gediz, Seyhan, and Ceyhan plains). Delta plains could also be affected by reduced sediment supplies because of dam construction (*e.g.,* NICHOLLS and HOOZEMANS, 1996; SÁNCHEZ-ARCILLA, JIMÉNEZ, and VALDEMORO, 1998; STANLEY and WARNE, 1998). Table 2 lists dams in Turkey according to their construction purpose and the coast that might be affected by their effects. Only eight out of the 485 dams were built before 1960, and 89% of dams hold sediment, reducing sediment flux to the coast. Although it has not been investigated, the effect of this reduction of sediment supply is expected to have adverse long-term effects, which will exacerbate the effects of SLR.

Periodically, storm surges have been destructive, especially at Izmit-Golcuk Bay in the Marmara Sea and Izmir Bay in the Aegean Sea, Fethiye and Antalya Gulfs, and Mersin and Iskenderun harbours in the Mediterranean and Black Seas. Warming sea surface temperatures can increase storminess and flood frequency in the Black Sea and, therefore, increase coastal erosion. Figure 6 shows the frequency of all (river and coastal) floods, the number of deaths and flooded area between 1955 and 1997 in Turkey. The number of deaths from flood, with the exception of 1995, has declined because of precautions taken, such as the building and rehabilitating of sewage systems and flood defence construction.

The problems of conducting an impact and vulnerability analysis of ASLR for Turkey are no different than those for other developing countries (NICHOLLS and HOOZEMANS, 1996; NICHOLLS and LEATHERMAN, 1995a; NICHOLLS and MIMURA, 1998). Difficulties include (i) the limited or non-availability of relevant data; (ii) the lack of administrative and public awareness: government and people think that coastlines are fixed over time; therefore, no long-term policy for coastal planning and management exits and there is limited interest in the issues of change discussed here; (iii) resource availability and allocation: examining coastal issues does not have a high priority except in the specific context of tourist investment and facilities; (iv) difficulty in developing local and regional scenarios of future climate and other change; and (v) a lack of appropriate analytical methodologies for some impacts.

While there has been no previous national study to analyze

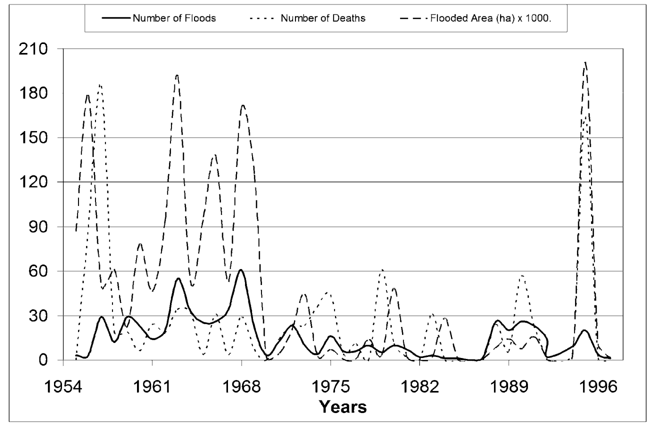

Figure 6. Major riverine and coastal floods in Turkey between 1955 and 1997 (adapted from Bozkurt and Kulga, 1993; DSI, 2006).

the impacts of SLR in Turkey, JEFTIC, KECKES, and PERNETTA (1996), JEFTIC, MILLIMAN, and SESTINI (1992), and NICHOLLS and HOOZEMANS (1996) reviewed the vulnerability to coastal implications of climate change for the Mediterranean basin. They all concluded that the Mediterranean is particularly vulnerable to increased flooding by storm surges as sea levels rise. Whilst there are potential adaptation options, this would place a great economic burden on countries on the south coasts of the Mediterranean (such as Egypt) as they are generally poorer.

To further determine the vulnerability of Turkey to SLR, an adaptation of the IPCC Coastal Zone Management Subgroup (CZMS) common methodology (IPCC CZMS, 1992) method was applied. This, combined with expert judgement, made best use of the limited data that is available. Data used were coastal areas lower than 100 m, determined from topographic data of the U.S. Geological Survey (USGS, 2006), and socio-economic indicators (for 1997) for each coastal province or city derived from the Turkish State Planning Organization (DPT, 2006).

As a first estimate, of the exposed population and related assets that will be affected by SLR, two zones were defined:

Zone 1. The area within 1 km of the shoreline and below 100 m elevation, in which a 1-m rise in sea level would have important direct and indirect effects.

Zone 2. The area within 10 km (but excluding zone 1) of the shoreline and below 100 m elevation, in which a 1-m rise in sea level would generally have a range of indirect effects, in addition to the effects in zone 1 above.

Coastal population estimates for Turkey were calculated from coastal city data found in *Economic and Social Indicators* (DPT, 2006; see Table 1). The population of zone 1 was estimated to be 10% of the total population of each city. The population of zone 2 was approximated by taking 20% of the total urban population of each city. Therefore, the coastal population of each city within 10 km of the shoreline was assumed to be 30% of the total population. This is thought to be a reasonable estimate at a national scale, although for

Table 3. *Preliminary results of effects for Turkey (for 1-m ASLR on the 1997 situation).*

Accelerated Sea-Level Rise Scenario (m)		1 m
Population in zone 1	People (1000s)	2452
	% Total	3.7
Population in zone 2	People (1000s)	560
	% Total	0.8
Capital value in zone 2	Million US$	12,000
	% GNP	5.9
Protection/adaptation costs	Million US$	20,000
	% GNP	9.97

some cities, this estimate is too low—including those on the narrow coastal strip along the Black Sea, where the majority of the population can be considered to live within the risk zones because of the low elevation of these cities. Similarly, cities along deltas such as Adana, Foça, Bandırma, Samsun, Bafra, and Çarsamba are densely populated, with the entire population being threatened by a 1-m SLR. Hence, the population estimates of zones 1 and 2 are reasonable but could be underestimates.

Presently, more than 0.5 million people live in zone 1 (Table 3). All these people will be affected at least indirectly by a 1-m rise in sea level. It is important to note that these exposed populations are growing rapidly, as discussed earlier. Zone 2 is estimated to contain over 2.4 million people and capital values of US$12 billion. Again, economic development is rapid in zone 2, and the capital values in these zones are expected to increase substantially over the next few decades.

To establish a crude estimate of potential adaptation costs to protect these people and capital values, the costs of protecting all the coastal cities with a population of more than 50,000 people was estimated. Assuming a standard sea wall at a unit cost of US$5000/m, with the state planning office of Turkey approximation of the length of coastal frontages in each town/city (totally 240 km or 2.9% of Turkey's coast), the resulting cost is US$20 billion. Note that these costs exclude the cost of beach nourishment at tourist facilities, protecting agricultural areas (including modified water management), cliff protection, and issues such as port and harbour upgrade. These additional adaptation needs would raise the costs presented here substantially. This also raises a range of issues, including the capacity of Turkish coastal management to deal with this range of competing pressures, as well as technical issues such as the availability of sand for nourishment.

On the basis of the results shown in Table 3 and with the use of the IPCC CZMS (1992) classification, Turkish coastlines are characterised as exhibiting low to medium vulnerability. Note that this is based on relative effects; hence, although vulnerability might be relatively low, it could still be significant in socio-economic terms for Turkey—a country between developed and developing country status. The costs of the effects and adaptation are also likely be higher than shown if based on more detailed data and related analysis (*cf.* STERR, 2008).

DISCUSSION

The physical effects of SLR on the Mediterranean lowland coasts can be predicted and modelled quantitatively on the basis of available data and information on morphology, hydrodynamics, sediment budgets, and land subsidence (*e.g.,* JEFTIC, KECKES, and PERNETTA, 1996; *e.g.,* JEFTIC, MILLIMAN, and SESTINI, 1992). A global mean SLR of about 20 cm by 2025 would not have a significant effect in the Mediterranean region, except locally. The negative effects will be felt in low-lying areas, deltas, and coastal cities. Overall, the southern Mediterranean coast is more vulnerable to ASLR than the northern Mediterranean coast (NICHOLLS and HOOZEMANS, 1996).

Despite the limitations and problems of the common methodology (KLEIN and NICHOLLS, 1999), Table 3 reveals a first-order estimate of the vulnerability of Turkey given a 1-m ASLR. Follow-up assessments that use more detailed data will likely give larger numbers for the people affected and at risk, capital value lost, and protection and adaptation costs. Even with the results of this preliminary assessment, the size of the economic loss and response costs are significant in relation to the existing size of the Turkish economy.

Istanbul is the largest coastal city of Turkey: the metropolitan area has a growing population of 9.0 million (in 2000), a total area of 5220 km^2, and a population density of 1740 people/km^2. The length of the coastline of Istanbul is approximately 452 km. About 10% and >90% of the city's population live within 1 and 10 km of the coast, respectively. This leading importance of Istanbul to the Turkish economy can be summarized as follows: largest contribution to Turkey's GDP (21%), the highest tax revenues, the most prosperous banking sector, superior employment opportunities, highest concentration of large workplaces, private investments, technology-intensive sectors, and export and import trading.

One of the key potential effects of ASLR on Istanbul is saltwater intrusion. Two big lagoons (Büyükçekmece and Küçükçekmece) and the Haliç estuary that separates old town from the business district in Istanbul are vulnerable to salinisation. So is the freshwater supply of Istanbul: Terkos Lake, located near the coastline of the Black Sea. "Flagship" cultural and historical sites along the Bosphorus in Istanbul are definitely threatened by the projected rise in sea level, such as the 200-year-old Dolmabahçe Palace and Mosque, the Ortaköy Mosque (see Figure 7), the Beylerbeyi Palace, and the Küçüksu Kiosk.

The vulnerability of Turkey to ASLR appears to be intermediate between northern and southern Mediterranean states: less vulnerable than Egypt and the Nile delta, but more vulnerable than France and Spain. The exposure of Turkey to SLR will continue to grow substantially as Turkey continues to develop and urbanise. The resulting coastal erosion, flooding, and inundation along Turkish shorelines would be coastal problems of national significance, particularly in the middle and eastern Black Sea, the northern Aegean Sea (Saros Bay), and the eastern Mediterranean (Hatay, Iskenderun, Yumurtalik). Tourist and coastal cities are particularly threatened. Many flagship cultural sites would also be damaged or destroyed by ASLR, notably the ancient Greek cities Phaselis and Patara in the southwestern coasts of Turkey. Some could be destroyed by increased wave activity or buried by more active sand dunes (this has recently happened to the ancient city Pompeipolis (Viransehir) on the Mediter-

Figure 7. Historical Ortakoy Mosque in the shoreline of the Bosphorus Strait built in 1894 by the Sultan Abdülhamid II. Source: http://www.ibb.gov.tr/en-US/KenteBakis/GaleriIstanbul/Forograflar/.

ranean coast). Practically, the large number of ruins renders relocation impossible and moreover, would change their character and archaeological context. As a first step, an inventory of threatened sites is required.

NGOs in Turkey have leading roles in the preservation of the coastal environment—like their counterparts in the western world. The leading NGO in the conservation of natural life is the Society for the Protection of Natural Life in Turkey (DHKD in Turkish). It plays a crucial role in developing conservation strategies and establishes international projects to preserve the natural environment. Turkey, being a coastal nation, recognises the increasing number of problems in coastal zones, and actions to address these are being implemented. The Ramsar Wetlands Convention was ratified by Turkey in 1994 with five (out of nine) designated sites being coastal: Gediz Delta, Göksu Delta (Lakes Akgöl and Paradeniz), Kizilirmak Delta, Meriç Delta, Çamalti Salpan, and Homa Weir in Izmir. Most other protection areas declared by the Turkish Government are located in the coastal zones (*e.g.,* Fethiye-Göçek, Gökova, Patara, Kekova, Foça, Datça-Bozburun, and Belek). The Ministry of Environment is planning to establish a Coastal Zone Department for environmental impact assessment (EIA) and the Authority for the Protection of Special Areas (APSA) is declaring new areas as protection areas and developing special environmental programmes.

However, none of the governmental agencies are yet dealing with the issues and problems that will accompany future SLR or, more broadly, long-term coastal management. When asked about the problem, they generally minimise its significance. Even coastal engineers, who would seem more predisposed to incorporate technical information, are still designing coastal infrastructure without any allowance for future changes. In the Turkish law for coastal protection, sea level is treated as an "unchanging" boundary between the land and sea. Even without human-induced warming, such a definition is technically inaccurate as global sea levels slowly rise (DOUGLAS, 2001), including sea levels in the Mediterranean and Black Seas.

CONCLUSIONS

A 1-m rise in sea level assuming no protection response would result in an increase in coastal flooding, storm damage, erosion, and salinisation. Certain settings, including deltaic settings and the developed shorelines along the Black, Marmara, Aegean, and Mediterranean Seas, appear particularly vulnerable to SLR—especially the low-lying deltaic areas of the north, south, and west. In addition, the Marmara region around Istanbul, where most of Turkey's industry and business is located, would experience the consequences of SLR. Although the total area of the region affected compared with the whole of Turkey is small, even a limited rise in sea level over the coming decades could adversely affect the socio-economic well being of the inhabitants of these areas.

Compared with some other countries, such as Bangladesh, Egypt, and the Maldives, Turkey does not appear especially vulnerable to SLR. However, policymakers need to take ASLR into account. So far, there has only been limited assessment of potential effects for Turkey on the basis of future SLR scenarios. Nevertheless, a number of expectations seems reasonable, such as the effects on daily life in big coastal cities, particularly on the Black Sea and Istanbul, and tourism and agriculture along the Aegean and Mediterranean coasts. Fisheries could also be adversely affected.

The best planning approach to climate-induced changes for the coastal regions of Turkey considers both geomorphological and socio-economic factors (NICHOLLS and LEATHERMAN, 1995b). Turkey has a diverse coast with a variety of geomorphology and socio-economic situations. For instance, people in the Black Sea region are highly concentrated in a narrow coastal strip, and their lifestyles depend on fishing and agriculture. Along the coasts of the Aegean and Mediterranean Seas, people deal mainly with agriculture and tourism, with industry around Izmir. Therefore, several more detailed site-specific studies of different coastal regions of Turkey are recommended to further understanding of the climate-induced effects on the coastal environment. These require more detailed data than was available to this study and should follow robust methodologies such as KLEIN and NICHOLLS (1999). Most priority should be given to Istanbul, given its strategic importance to Turkey's population and economy. Collectively, these studies will give a much better understanding and picture of vulnerability of Turkish coastlines against ASLR and assist in preparing for climate change in coastal areas.

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Bu çalismada, hızlı deniz seviyesi yükselmesinin ve kıyılar üzerine iklim değişiminin Türkiye üzerinde olabilecek muhtemel etkileri incelenmiştir. Geçen yüzyılda tahmin edilen deniz seviyesi yükselmesi 10 ila 20cm arasinda bulunmustur. Bu Akdeniz ve Karadeniz için 12cm civarındadır. Türkiye'de kıyı şehirleri toplam alanin 5%'ini kaplamasina karşın 30 milyonun üstünde bir nüfus bu bölgelerde yasamaktadir. Marmara bölgesi, nüfusu en yogun bölgedir. Türkiye GNP'sinin %60 dan fazlasi Tekirdag'dan Kocaeli'ne uzanan kıyı seridinde (Kuzey Marmara kiyilari) meydana getirilmektedir. Istanbul ve Türkiye için Ortak Yöntemi kullandigimizda, 1m hızlandırılmış deniz seviyesi yükselmesi acisindan Türkiye düşük riskli, Istanbul ise; yüksek riskli olarak bulunmuştur. Deniz seviyesinin yükselmesi Türkiye kiyilarinda çok büyük degisikliklere neden olmayacaktir fakat kiyinin hizli degişime sebebiyet verecektir. Bu öncül çalışma, basit bir adaptasyon/korunmanın GNP nin 10% na ve günümüz GNP nin ise 6% sının oranına tekabül ettini ortaya koymuştur. Hızlı şehirleşme ve turizm ile ilgili yatırımlar deniz seviyesi değişiminin etkilerini daha da tetikliyecektir. Maalesef, günümüzde deniz seviyesi değişimleri ve iklim değişiminin sonuçları kıyı yönetimde ihmal edilmektedir ve uzun dönemli planlamalarda düşünülmemektedir. Bu konuyu gündemde tutabilmek için Istanbul gibi stratejik önemi olan bir şehirden başlıyarak Türkiye'nin değişik kıyılarında kapsamlı olarak çalışılması tavsiye edilir.