Lost Coasts

Istanbul and Izmir

Sea Level Rise And Its Potential Impacts
for Istanbul and Izmir Provinces



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SEA LEVEL RISE AND ITS POTENTIAL IMPACTS FOR ISTANBUL AND IZMIR PROVINCES

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[version 1.1]

Executive Summary

1. In the context of this project, the effects of changes in sea level that may occur due to climate change have been analyzed for Istanbul and Izmir Provinces. Factors such as earthquakes, tectonism, tsunami, and ground liquefaction that may cause seawater intrusion are out of the scope of the project.
2. This study is based mostly on the *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate (SROC).* The worst of the scenarios (RCP 8.5) was taken as a basis in revealing the effect of the change in sea level due to climate change. Estimates based on the IPCC's RCP 8.5 scenario are expected to rise globally by about 0.5 cm in the middle of the century and by about 1.0 m by the end of the century. The impact of global sea level change on inland seas is expected to differ from the global one due to local dynamic conditions.
3. İstanbul and İzmir, although are major coastal 'megacities' of the country, they differ substantially in many key aspects:
    a. they have different 'geometries' as a result of their tectonic setting and history;
    b. they are surrounded with coastal seas of different character as to the marine and atmospheric climatologies; these differences lead to different vulnerabilities to static sea level rise and storm surge events.
4. Similarly spatial patterns of economic activities and land use also differ in both cases, leading to different exposures to future sea level rise and changing storm surge climatologies;
5. Studies were conducted (unfortunately) based on different information resources. For İstanbul, coastal topography was based on a LiDAR survey with horizontal 30 cm resolution; in the case of İzmir, we had to be content with 2014 SRTM topography data with roughly 20 m x 30 m horizontal resolution.
6. Both settlements have areas that are likely to be affected by changes in sea level. These areas can be grouped as cultural heritage, natural area, urban/residential, commercial and industrial. The relative weights of these use categories change with each coastal district.
7. A study was conducted to determine the financial losses that will occur due to the rise in sea level. Real estate sales values were estimated in sample areas selected from risky areas.
8. The distinction natural vs. built was important is accessing vulnerability to sea level rise. Shorelines of both provinces have been visited and evaluated based on this distinction as well as on other parameters related to the usage and structure

9. For both settlements, the dynamic nature of continuous public works and real estate development involving the coastal band renders any long-range projection attempts extremely uncertain.

Global Context

Global sea level is a state variable for the Earth System and has been changing throughout the history of our planet. The global mean sea level is determined by the volume of liquid water in the world's oceans; the volume of liquid water is in turned controlled by its temperature (and to a lesser extent, by its salinity) and, most importantly, by the volume of ice stored on land (ice sheets, valley glaciers and snowfields). Therefore, any repartitioning of water between its liquid and solid forms, mostly due to changes in temperatures and precipitation regimes, will change the global sea level. On the other hand, the evolution of the sea surface level in relation to adjacent land, i.e. the local sea level, will depend on many dynamic factors besides the global levels. Tectonically induced vertical motions of the land mass and erosional processes will change the sea-land geometry at long (from thousands to millions of years) time scales. At shorter time scales, tidal motions and ocean-atmosphere interactions (such as storm surges) will set the daily (even hourly) picture.

Since the beginning of intensive use of fossil fuels, our planet has been experiencing the rapid climate change superimposed on longer time scale fluctuations. Changes observed during the last two centuries can be 'explained' to a large extent by a multitude of Earth System Models. The same models do provide us with projections, *i.e.* what to expect for the remaining part of this century and beyond. Of course, the catch is that the projections are based on **greenhouse gas emission scenarios**; therefore, we have to live with a range of uncertainties. As an essential climate state variable, these models generate explanations and projections for the **global sea levels**.

The task of 'distilling' the current state and the progress of climate science is undertaken by the *Intergovernmental Panel on Climate Change* (IPCC). This group of experts generate, every six to seven years, comprehensive reports covering all aspects of climate change. This study is based mostly on the *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate (SROC)* (IPCC, 2019) although we refer also to 5th (AR5) and 6th (AR6) Assessment Reports.

This study uses on the Global Mean Sea Level (GMSL) projections documented in SROCC. We selected three RCP's and three time horizons as it is depicted in *Table 1* and generated (rounded) numerical GMSL estimates from supplemental data provided by SROCC.
(https://www.ipcc.ch/report/ar6/sr/srocc/download/SROCC_Ch04-SM_DataFiles.zip)

Table 1: ***GMSL estimates from SROCC 2019*** *[Global sea level change in meters]*

	2040 (2031-2050)	**2055** (2046-2065)	**2090** (2081-2100)
RCP 2.6	**0.17** [0.12 - 0.22]	**0.24** [0.17 - 0.31]	**0.39** [0.26 - 0.53]
RCP 4.5	**0.17** [0.12 - 0.22]	**0.26** [0.18 - 0.33]	**0.48** [0.34 - 0.64]
RCP 8.5	**0.20** [0.14 - 0.25]	**0.31** [0.23 - 0.40]	**0.70** [0.51 - 0.91]

Range of values at central year of the period **median** with [5% - 95%] bounds.

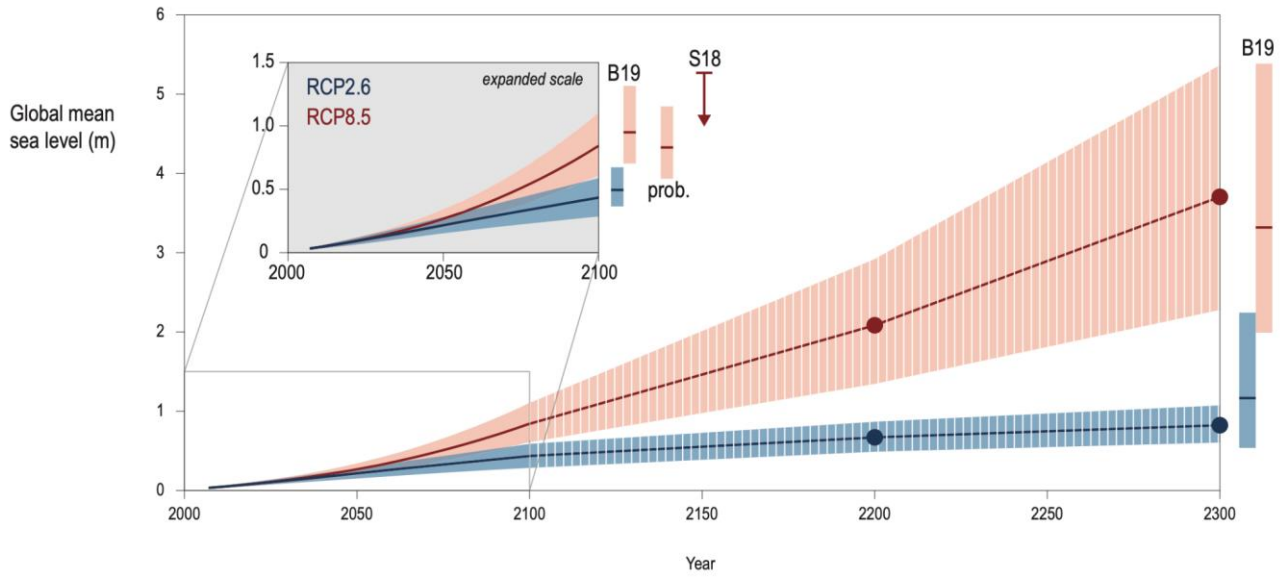


Figure 1. Global SLR from SROCC (2019) report.

From Global Mean Sea Level to Local Mean Sea Level

"Sea level rise is not globally uniform and varies regionally. Thermal expansion, ocean dynamics and land ice loss contributions will generate regional departures of about ±30% around the GMSL rise. Differences from the global mean can be greater than ±30% in areas of rapid vertical land movements, including those caused by local anthropogenic factors such as groundwater extraction (high confidence)." (SROCC, 2019, p. 324)

For studying the impacts of local sea level changes, Istanbul, which is the largest socioeconomic settlement of Turkey (and one of the world's largest cities), has been chosen as an example (Figure 2). It is stated that Istanbul may be significantly affected by the change in sea level (Istanbul BB, 2021: 52). Areas that will be affected by sea level are mostly places that have lost their natural coastline feature. In order to monitor the effects of the change in sea level on natural coasts, İzmir, which is ranked 3rd in Turkey's socioeconomic development ranking (Acar, Kazancık, Meydan & Işık, 2019: 35), has been chosen as the second sample area.

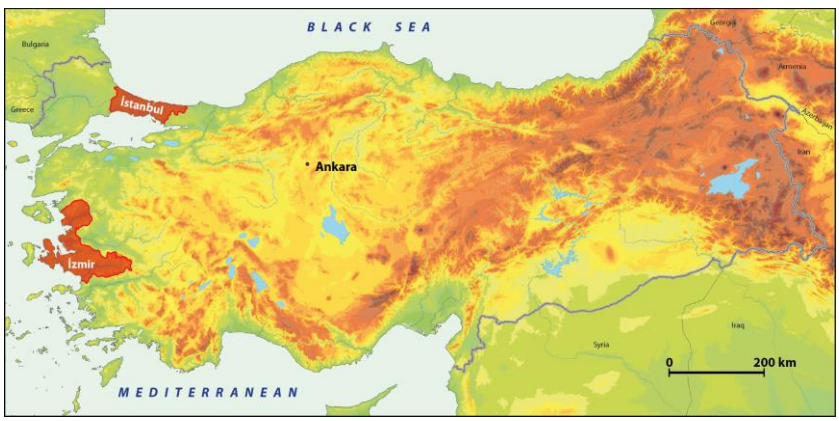


Figure 2. Location map.

We have to take into account all the issues mentioned in the above quote from SROCC report when exploring the future of sea level for İstanbul and İzmir Provinces.

- Turkey is a tectonically active land, at the junction of many plate tectonic boundaries. There is a wealth of GPS based horizontal motion data, but when it comes to evaluate the magnitude of vertical motions at decadal/century timescales, the picture is very uncertain to say the least. Therefore, in this study mainly concerned with 10-100 year timescales, we will not pronounce on the contribution of tectonic vertical motions at coastal areas.
- Although storm surges, *i.e.* short time scale extreme sea level (ESL) changes are very important in assessing coastal flooding risks, producing reliable climatologies (such as return periods, magnitudes, etc.) for the future is quite complex. It requires thorough analysis of heterogeneous mareograph data and atmosphere-ocean modeling at fine scales.
- Tidal amplitudes are relatively small for both coasts: < 0.2 m for İzmir, and < 0.15 m for İstanbul.
- As a first approximation, we are using the Regional Sea Level (RSL) estimates from SROCC report.
    - For İzmir, these values are representative of the 'open Aegean Sea' SLR, so it should be acceptable to use them directly;
    - İstanbul is a more complex situation: bordering the Black Sea and the Sea of Marmara, and divided by a two-layered flow of the Bosphorus, requires special attention. Based on a recent Sannino *et al.* (2022) study using a full ocean model, one can see that there is no substantial difference between İstanbul and the Aegean Sea. (see Sannino et al., Figure 20). Therefore, we use (at least tentatively) the same values for İstanbul too.

Table 2: ***Local sea level rise estimate for İzmir (and for İstanbul) (i.e. the base scenario)***

	2040 (2031-2050)	**2055** (2046-2065)	**2090** (2081-2100)	**2100**
RCP 2.6	**0.15**	**0.21**	**0.31**	**0.34**
RCP 4.5	**0.15**	**0.22**	**0.40**	**0.45**
RCP 8.5	**0.17**	**0.28** [0.20 - **0.37**]	**0.60**	**0.73** [0.54 - **1.03**]

Values are medians of regional sea level rise projections with respect to the mean sea level rise in the period 1986-2005

Impact Assessment: Data Requirements

Obviously, the most important input for any sea level rise study are the **high spatial resolution** and **high vertical accuracy** DEM data. Data availability for Istanbul and İzmir is not the same.

- For İstanbul, we have access to data from a LIDAR survey of the whole province. These data have a horizontal resolution of 30 cm and we were able to set levels at 50 cm intervals.
- For İzmir, we use tentatively (while inquiring to access better data) 2014 SRTM 1 arc-second DEM, corresponding roughly to a 20 x 30 m resolution.

Based on these elevation data and additional georeferenced information we obtained from İstanbul Metropolitan Municipality (and with some assistance from Google Earth), we compiled a list of Points of Interest (POI) (Table 3). These locations are likely to be under eminent risk due SLR.

Table 3: ***Example Areas (According to Cultural Heritage, Natural Area, Urban Area, Commercial Area) in Istanbul.***

Area	Cultural heritage	Natural Area	Urban	Commercial	Industry
Silivri Harbor			x	x	
Büyükçekmece		x	x		
Küçükçekmece		x	x		
Haliç (Golden Horn)	x	x	x	x	
Beşiktaş	x		x	x	
Terkos Lake & Ağaçlı		x			
Pendik			x	x	x
Kadıköy			x	x	
Üsküdar			x	x	
Küçüksu	x		x		
Riva		x	x		

We compiled a similar list for the Izmir Province (Table4).

Table 4: ***Example areas (according to cultural heritage, natural area, urban, industry/commercial) in İzmir***

Area	Cultural heritage	Natural Area	Urban	Commercial	Industry
Selçuk	x	x			
Karşıyaka			x		
Konak	x			x	
Gediz Delta		x			
Aliağa (Nemrut Bay)					x
Çandarlı		x	x		
Dikili		x	x		

The study consists of data acquisition and literature review, field observations and evaluation of findings. In the first stage, using remote sensing data, areas that can be affected are determined based on different scenarios related to the change in sea level. Remote sensing data are data prepared/prepared by Istanbul Metropolitan Municipality and Izmir Metropolitan Municipality. The digital elevation model data of Istanbul and Izmir were evaluated with ArcGIS 10.6, and preliminary information was checked with Google Earth Pro satellite images before the field study. The second phase consisted of field observations made in the provinces of Istanbul and Izmir. Field observations were made in areas thought to be risky and in areas with low risk potential.

Knowing the current sea level is important in revealing the change in sea level. For Istanbul, tide gauge on the Bosphorus and the one at Şile (Black Sea coast) can be used. Menteş tide gauge data can be used for İzmir. Due to gaps in observation times and the need for comparison with GPS, data prevented us from using them directly. In one of the previous studies, the evaluation of sea level and geodetic measurements covering the years 1984-2002 for the Izmir coast was discussed. No statistically significant vertical movement was detected at the Menteş tide gauge and GPS points, and an increase at a rate of 6.8 ∓ 0.9 mm/year was estimated (Yetkin, 2014: 747-748).

Therefore, based on this study, an increase of 59-77 cm can be expected at the end of the century for the Izmir Bay. Since the desired information from the tide gauge data could not be reached, the data of the coastline obtained by remote sensing methods were used instead.

Today, storm surges provide important clues in terms of alluding to impacts in the future. However, there are no direct records of storm surge, neither for Istanbul nor for Izmir. The information consists mostly of anecdotes. In the event of flooding due to storm surge, there are records of the interventions made by the fire brigade.

Studies show that besides the superstructure, the infrastructure is also affected by the change in sea level. For this purpose, expert opinion was sought regarding the distribution of treatment plants in both provinces and possible problems that might occur. It is stated that changes in sea level may cause physical damage to the wastewater network, as well as have different effects ranging from loss of efficiency and increase in operating costs (Appendix 1, Appendix 2, and Appendix 3).

Within the scope of this study, a study was conducted to determine the financial losses that will occur due to the rise in sea level. Real estate sales values were estimated in sample areas selected from risky areas. For this purpose, real estate offices were interviewed and the advertisements on the real estate websites on the internet were evaluated. However, for an economic process, the formation of prices and their stability could not be guaranteed, it was not possible to control the reliability of the data. In addition to the variability in the market conditions, the location of the real estate, the construction features and the year of construction also affect the prices. Another problem in this regard is the determination of the real estate that will be affected by the sea level and the level of impact. For comparison, the unit price per square meter was calculated and expressed in Euros (Table 5). The purpose here is to give a rough estimate. It will only be possible to determine a more realistic financial loss that will occur through studies that are more detailed.

Table 5. Square meter price of real estate in selected areas (Euro)

	Minimum	Maximum
Goldenhorn (Eyüp)	500	1400
Goldenhorn (Sütlüce)	50	1200
Büyükçekmece	950	1650
Silivri	500	1850
Göksu	4350	9700
Üsküdar	1200	1400
Kadıköy (Rıhtım)	1400	4900
Kadıköy (Kurbağalıdere)	1450	4700
Pendik	600	9700

The unit square meter price of the selected areas has been determined in order to give an idea, taking into account the average prices. Some areas contain non-tradable cultural heritage items. Some of the risky areas have been gained by filling the coast in recent years and are used recreationally. It was not possible within the scope of this study to determine the land value of areas that may be inundated as a result of sea level rise due to climate change.

Studies along İstanbul and İzmir shores

In the field studies carried out in the provinces of Istanbul and Izmir, the areas that will be affected by the change in sea level; natural coasts, partially protected areas and artificial coasts were evaluated by grouping them.

Istanbul and Izmir provinces are located in areas shaped by different geological factors and processes in terms of formation and development. This has led to the formation of different geometry in both provinces. In contrast to Istanbul, which was shaped by the torsion of an old erosional plain, İzmir has a structure that stretches perpendicular to the sea, fragmented by faults, and consists of collapsed and rising blocks. This situation has led to the formation of different units in terms of geomorphology and the different development of the river network.

İstanbul

The water section line passing through the south of the Asian part in Istanbul province is closer to the north in the European part (Figure 3). Today, a significant part of the rivers that are draining into the Sea of Marmara have been rehabilitated and taken into a channel or remained under the settlements. Due to the fact that the rivers discharging waters into the Black Sea region are partially affected by the change in sea level, sea water will enter inland and the characteristics of the groundwater will change. Sea level changes will be greatest along the coast. It should be expected that this effect would continue in a certain area from the mouth of the rivers to the source.

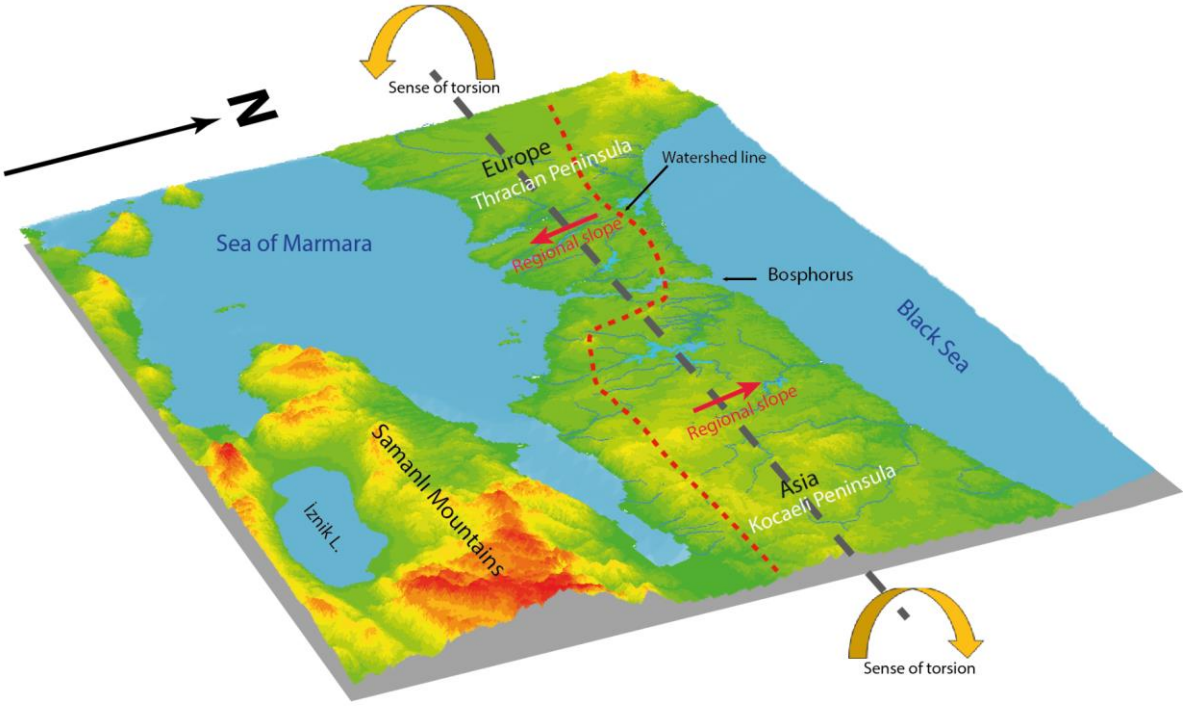


Figure 3. A digital elevation model of İstanbul and its surroundings (It was redrawn from Şengör & Kındap, 2019: 251).

A 2-day field study was carried out in İstanbul, and possible risky areas were examined on site. For details, check Appendix 1.

Areas with an elevation of less than 1 m in Istanbul cover approximately 28.1 km^2, and areas between 1-2 m cover an area of 92.8 km^2. The size of this value is more clearly understood when it is considered that Fatih district is 28.3 km^2 and Maltepe district is 94 km^2. It is seen that the lower courses of the streams as well as the coasts will be affected by the rise in sea level (Figure 4).

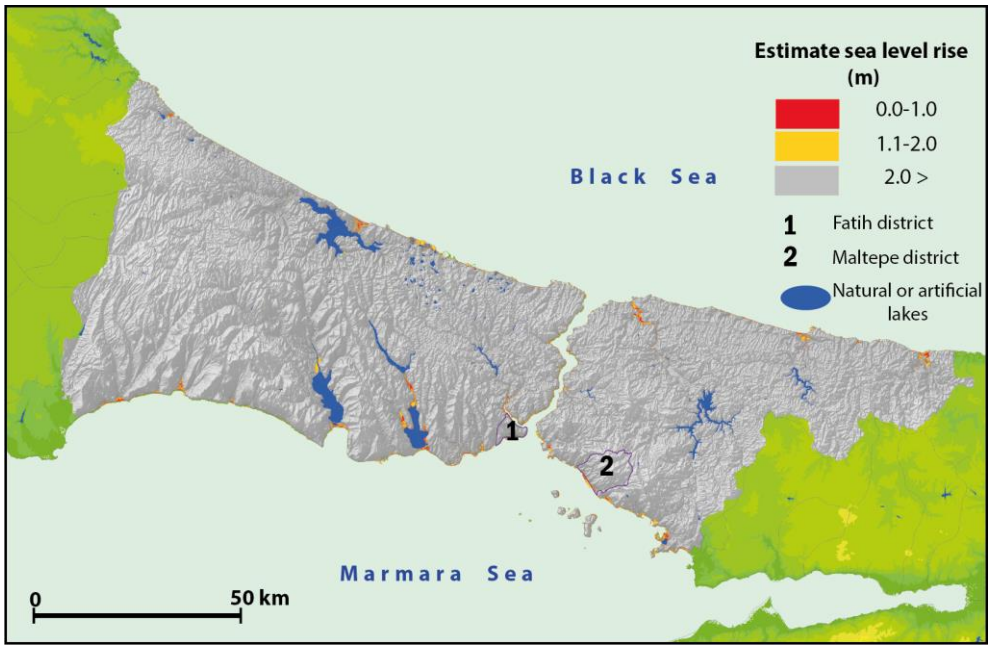


Figure 4. Areas that are thought to be affected by sea level rise

Golden Horn, Anadoluhisarı, the Göksu valley and Kurbağalıdere are places where the change in sea level will be clearly observed (Figure 5). The Golden Horn was formed by the occupation of an old valley by the sea in the Quaternary. Until recently, both sides of the Golden Horn had intense settlement and industrial use. Today, industrial facilities have been removed and recreation areas have been created along the coast. Some of the old industrial facilities have been converted into fair and meeting venues. The Golden Horn shipyard, which has lost its former importance, is still used for minor repairs. As in the whole Bosphorus, it is expected that the seaside mansions, palaces and facilities in Anadoluhisarı will be affected by the change in sea level in general. It should be noted that the effect of the storm surge experienced in certain periods today would become permanent with the rise in sea level in this area. It is thought that future storm surges and seawater will be much more effective on coastal structures. In addition, the rise in sea level and the occupation of a part of the bed of the seawater in streams such as Göksu and Küçüksu are also in question. The same effect will be experienced in the Kurbağalıdere valley located in the south of Kadıköy. Due to the suitability of the topography, it can be expected that more seawater will enter the interior parts of Kurbağalıdere compared to the Küçüksu environment, where the limited impact will be experienced. In this area, where old agricultural areas are located, problems may arise due to the height of the groundwater due to the construction of houses today.

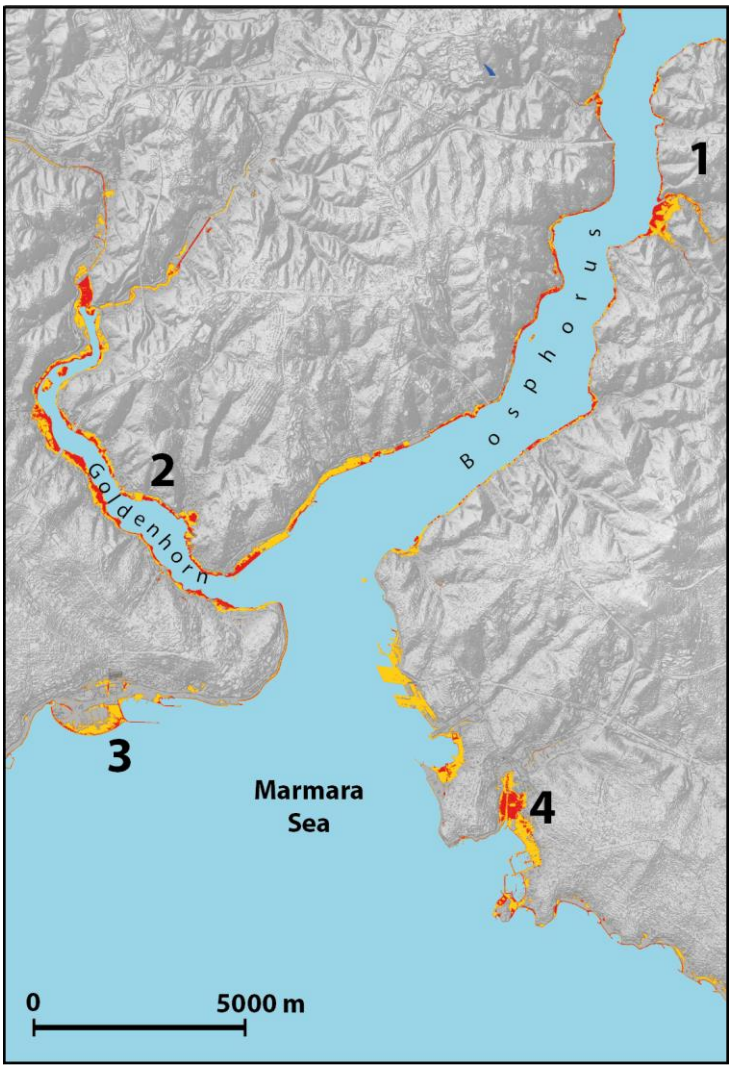


Figure 5. Areas expected to be affected by the rise in sea level around the Bosphorus (1-Küçüksu, 2-Goldenhorn, 3-Yenikapı, 4-Kurbağalıdere)

Along the northern coast of Istanbul, there are areas that are likely to be affected by sea level changes. The coal extraction activities that continued behind this coast until the recent period and then the filling of some areas along the coast caused the natural coast to lose its feature. Terkos Lake, which is located behind the coast and is one of the lakes where Istanbul's water needs are met, is a coastal barrier lake. It is known that the sand dunes that separate the lake from the sea are narrowed and salty water inflows occur from time to time. Various studies have been carried out to strengthen the sand dunes separating the lake from the sea. A change should be expected due to sea level rise.

Apart from these areas, Prince Islands, located in the Sea of Marmara to the south of Istanbul, constitute one of the areas that can be partially affected by a change in sea level. This group of islands consists of inhabited Kınalı, Burgaz, Heybeli, Büyükada and Sedef island, as well as a number of uninhabited islands and rocks. Its total area is 19.9 square kilometers (Figure 6). According to the calculations, approximately 2.7% of the islands have an elevation between 0-1 m and 4.4% have an elevation between 1-2 m. Especially the pier and the coastal area where the settlement is located are expected to be affected by the change in sea level.

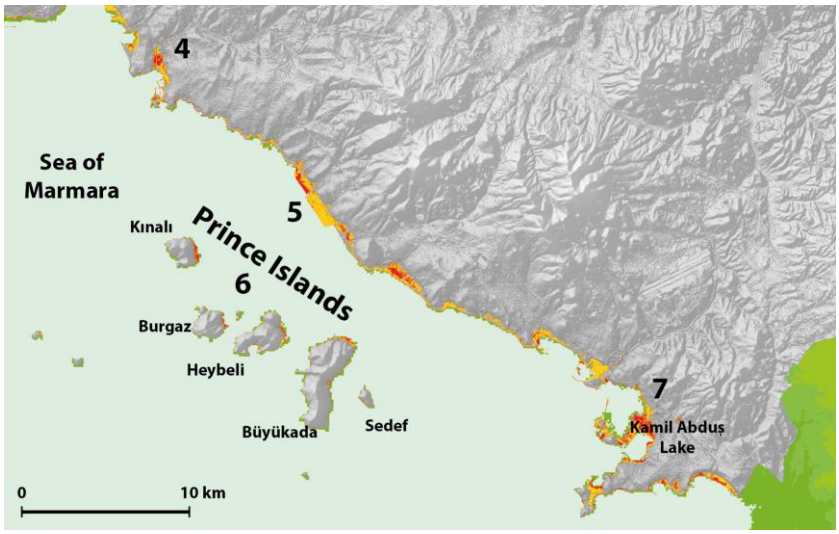


Figure 6. Areas expected to be affected by the rise in sea level around the Prens Islands (4-Kurbağalıdere, 5-Maltepe, 6-Prince Island, 7- Tuzla)

According to 2020 data, approximately 15.5 million people live in Istanbul. Most of the population resides in the districts adjacent to the Marmara Sea. Since the 1980s in Istanbul, the central business area has started to gain a multi-centered appearance towards the periphery. Despite the inadequacy of housing and employment conditions in the historical center, the attraction created by the new centers caused some of the population to move towards the interior. However, the districts that will be affected by the change in sea level still have a relatively large population (the population living in the districts on the coast of the Marmara Sea is about 6.2 million).

For Istanbul, especially the mansions, palaces, religious facilities and structures located on the shores of the Bosphorus are areas that will be significantly affected by sea level. Nowadays, it is seen that various arrangements such as reinforced glass barriers have been made to prevent seawaters from damaging the structures due to storm surge. However, these are not expected to be sufficient in the long run. More measures that are permanent should be taken to protect these structures.

The fact that the natural drainage on the coasts of Istanbul is largely below the settlement has made it necessary to build certain facilities for the removal of surface waters and wastewaters. Some of these waters collected by the canal systems are discharged into the Sea of Marmara by deep discharge after being processed by the pre-treatment, advanced treatment and advanced biological treatment facilities on the coast. Especially in areas close to the sea, these systems are expected to be affected by the rise in sea level.

İzmir

İzmir province was chosen as the second sample area. In the study, field observations came to the fore because there was not enough resolution altitude data about İzmir. The main reason for choosing the province of İzmir is the existence of natural areas and agricultural areas outside the settlements that will be affected by the rise in sea level. While the rise in sea level will cause problems in the built-up areas in Izmir Bay, it will require taking various measures in agricultural areas and other natural areas. The rise in sea level in these areas causes some areas along the coast to be submerged, and the inclusion of salt water in groundwater is an important problem in terms of agricultural production.

The topographical features of İzmir province are determined by the mountains extending perpendicular to the sea and the rivers located between these mountains (Figure 7). The fragmentation of the mountains in question by faults has led to the emergence of a compartmentalized structure. The collapsed areas, which also form important alluvial fields, are also among the areas that will be primarily affected by the change in sea level.

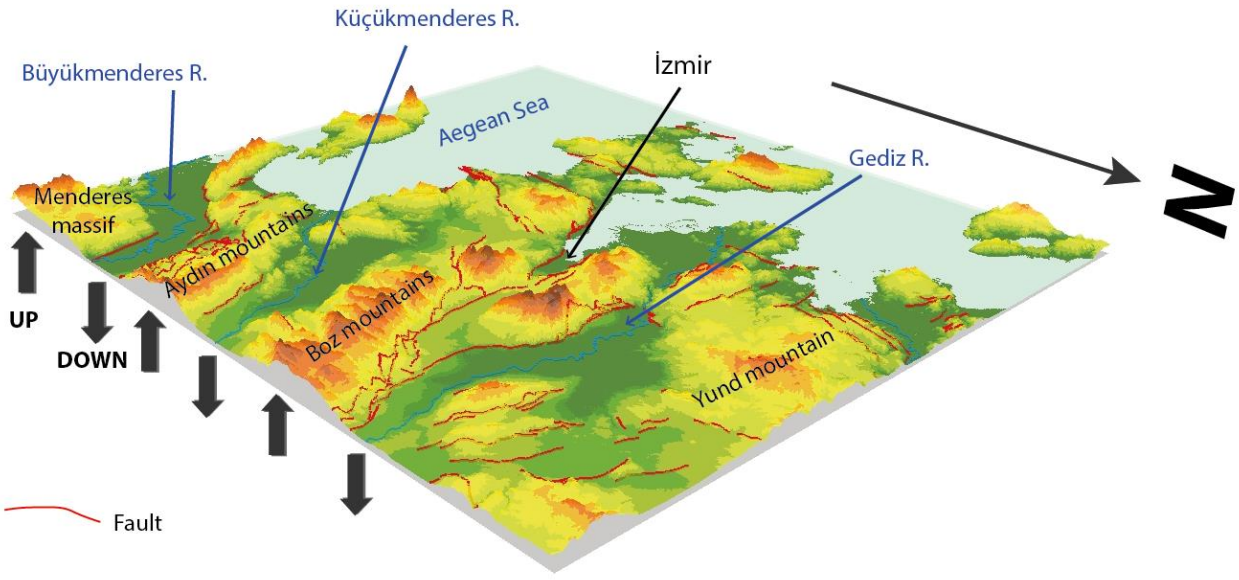


Figure 7. A digital elevation model of İzmir and its surroundings.

It is seen that natural coasts such as Çandarlı bay and Gediz delta in the İzmir Province are partially used for agricultural production. In addition, salt production is carried out as in the Gediz delta (Figure 8). Although these areas vary in size, there are also breeding areas for birds. İzmir will be affected by the rise in sea level, but some of these effects can be reduced by natural processes and some by human interventions.

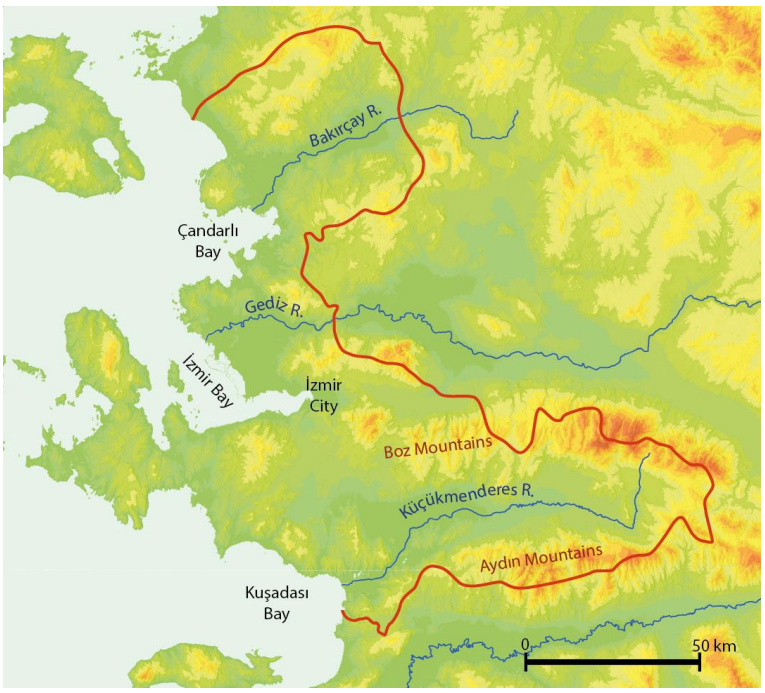


Figure 8. Location map for İzmir province

A 3-day field study was carried out in İzmir, and possible risky areas were examined on site (Figure 9 and Figure 10). For details, check Appendix 2.



Figure 9. Location of field observations in İzmir Province (1-Çandarlı Bay (Bakırçay delta and Aliağa surrounding), 2-Alaçatı, 3-Sığacık, 4-Kuşadası Bay, 5-İzmir Bay).



Figure 10. Locations of field observation around İzmir Bay (a- Çamaltı Saltworks, b-Bird Sanctuary, c-Çiğli WWTP, d-Mavişehir, e-Karşıyaka, f-Çakal Dalyanı and İzmir Urban Forest, g- Güzelbahçe).

In İzmir province, the place where the change in sea level will be most effective is İzmir Bay. Izmir Bay, in a narrow area, is the scene of the movement of the water body. The storm surge, which becomes evident in Istanbul, especially in southwesterly weather, takes place in the Izmir Bay in a way that affects the entire bay. Today, storm surges are effective both in Karşıyaka in the north and in Alsancak in the south. In storm surges, there may be a 60-70 cm change in sea level from place to place. With the storm surge, the seawater intrudes into the land for about 100 m today.



Konak and its surroundings, located on the southern coast of Izmir Bay, are one of the places most heavily affected by storm surges in the bay. Despite the protective arrangements made for open public spaces, there are no structures along the Kordon to prevent seawater from flooding the land on stormy days. Similarly, on storm surge days, seawater can flood the coast of the Konak Square. During the field studies, it was observed that the storm surge can be effective in the northern parts of the Izmir Bay, especially around

the Yunuslar train station and along the Kordon in the south, and the waters could reach the buildings. Especially in Kordon, the dock needs to be transformed into a shape that will break and reflect the waves.

Wastewater disposal is an issue to incorporate into sea level rise studies. For example, the treatment of İzmir's wastewater is carried out at Çiğli Wastewater Treatment Plant (WWTP). Wastewater is collected in certain centers with an infrastructure surrounding the Izmir Bay and conveyed to Çiğli. Seawater intrusion into some of these collection centers is a major problem. The fact that certain amounts of salt remain in the wastewater after treatment in Çiğli is the most important obstacle to the use of this water in agricultural irrigation. The water coming out of the treatment is not therefore used in the irrigation of the Menemen plain, and it is discharged into the Izmir Bay in case of need. If no precautions are taken, it seems inevitable that more seawater will be mixed into the wastewater system, especially due to sea level rise. In the meetings held with Çiğli WWTP staff, it was understood that instead of collecting the wastewater of the whole of İzmir Bay to the facility, the amount coming from small facilities will be reduced, and Çiğli WWTP will be renewed with new technologies.

In a study on Karşıyaka, it is pointed out that there are strategic areas along the coastline in terms of both morphological and spatial functions (Ercanlı & Savaşır, 2022: 282). On the coastline, there is a coastal wall rising to 0.5 meters in certain places. This coastline continues from Karşıyaka to the west of Mavişehir. Despite existing arrangements, some new measures need to be taken after the change in sea level.

Some conclusions

As a general conclusion from this study, It is clear that the change in sea level will cause some disturbance in the provinces of Istanbul and Izmir, but it will not be as drastic as the expected effect in some cities of Europe or in the islands of the Pacific. Palaces such as Dolmabahçe Palace, Beylerbeyi Palace, and Küçüksu Pavilion on the Bosphorus in Istanbul, and religious buildings on the coast (Şemsipaşa Mosque in Üsküdar, mosque, church and synagogue in Ortaköy) will be affected by the rise in sea level. It is clear that this effect will not occur just on the outer surfaces, but also on the characteristics and level of the groundwater.

Both Istanbul Metropolitan Municipality and Izmir Metropolitan Municipality have various studies and publications on climate change (İstanbul BB, 2021; İzmir BB, 2020). At the management level, there is some awareness of sea level change and its effects. Scientific studies have been carried out for several decades. Informing citizens is important in terms of raising awareness about climate change and sea level rise.

Istanbul and Izmir, chosen as the sample areas to determine the possible effects of the change in sea level, have different formation mechanisms in terms of geology. This is also reflected in their geomorphological features. Consequently, there are different land uses too.

It is expected that the southern coasts of Istanbul, where urban settlement continues almost uninterrupted, will be more affected by the change in sea level. However, the natural morphology of Istanbul’s Marmara shores has been modified due to fillings made at different periods. The northern shores of Istanbul are high shores, although there are bays in places. These areas will not be affected by the possible change in sea level.

İzmir, on the other hand, has a topography where the coast is fragmented by various faults and the relatively elevated and/or lowered blocks extending perpendicular to the coast. It forms wide plains in the sections where there are streams settled on low blocks. Although high blocks lose their elevation towards the coast, they form high coasts. The coastline was modified by intervening on the low coasts (around the

gulf) where the urban center of Izmir is located. Some of the low coasts adjacent to the residential area are largely shaped by natural processes. These areas are designated as protected areas such as a bird sanctuary and Çamaltı saltpan.

Storm surges are an important aspect of sea-coastal settlement interactions by themselves, but at the same time, they serve as a surrogate for the study of the future impacts of sea level rise. Due to the geometry of the Sea of Marmara and Izmir Bay, Istanbul is less affected by storm surges than the Izmir Bay. There is no natural coastal feature on the southern coasts of Istanbul, where the low coasts are located. On the other hand, storm surges in İzmir are more potent both in the gulf and in other natural coasts. Coastal structures that were partially built in Izmir Bay in order to prevent the seawaters from flooding the land will need to be revisited over time.

This study is a preliminary study to draw attention to the importance of the subject, to determine the method and tools to be applied, and to discover the first findings. It is clear that other regions of the country should be examined, as well as the detail level should be improved with narrower field studies. In this regard, Çukurova coast (Adana Province) comes to mind first for serious impacts of the rise in sea level. However, the Kızılırmak, and Yeşilırmak Deltas on the Black Sea coast, Büyükmenderes and the Meriç (which will require international cooperation) Deltas on the Aegean, are among the places where great changes might have to occur in land use. Turkey is very rich in cultural heritage on or near the coast, and special care should be given in planning the appropriate conservation strategies under the global threat of climate system changes.

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Appendix 1: İstanbul Sites

A. Natural coasts

1. Riva



One of the places that is an example of low coasts on the Black Sea coast is the place where the Riva Stream reaches the sea. It is seen that certain parts of the said area have been interfered with.



There is a 150 m wide beach along the east bank of the stream. The beach is cleaned and leveled before the beach season to free the sand from foreign debris and to give it a smooth appearance.



The mouth of the Riva River was widened towards the sea with a 1.5 m high embankment. This prevents the mouth of the stream from being blocked by the material carried by it and/or by the waves. The height of the scale in the photo is about 1 meter.



Another area where sea rise will be effective in Riva is the riverbed. Due to the rise in sea level, it is inevitable that salt water will intrude inland along the stream. Some areas around the stream will be inundated. However, this will not cover large areas. On the other hand, it is clear that the introduction of salt water inland and mixing with freshwater will cause deterioration of groundwater quality. Due the absence of agricultural activities in the area in question, this will not cause any serious salinization problem for the soils.



B. Partially protected areas

1. River valleys

Many rivers within the settlements in Istanbul were either covered or turned into a closed channel, or the riverbed was rehabilitated. With these arrangements, it is possible to use certain parts of the riverbeds.

Küçüksu meadow and its surroundings



Küçüksu meadow and its surroundings constitute a plain made up of alluvial materials brought by streams. Küçüksu Pavilion, one of the many, designed as recreational buildings for the sultans, was first built here as a wooden structure for Mahmut I in the 18th century. The building, which underwent various repairs and renovations, was demolished in the 19th century and rebuilt as masonry. The area known as Küçüksu meadow today has been arranged as a garden. The height of the area where Küçüksu Pavilion is located is around 2-3 m above the sea level. Göksu is located in the north of the area and Küçüksu is in the south. Cleaning and deepening works has been carried out at the mouth of the stream. Approximately 550 m of seawater penetrate upstream into Küçüksu and this intrusion is 1300 m for Göksu. The Küçüksu coast, which reaches the sea by dividing the garden of the Küçüksu Pavilion, has been partially preserved in its natural state. The parts of both streams, outside the areas arranged in the valleys, is generally within the general settlement area.





Through our field study, it was determined that the coast is 60 cm high just south of Anadolu Hisarı, and that in the section where the stream is arranged, equipment is in place to allow small boats to dock on both coasts. The part of the Küçüksu Pavilion, which reaches the sea through the garden of Küçüksu, does not allow such an intervention. The part of both streams outside the areas arranged in the valleys is generally within settled areas.

The change in sea level is expected to be effective on the coast and especially in the Göksu valley. Some of the possible effects can be eliminated with the engineering services to be performed. It is possible that the effect in some areas will be greater. They will be affected by the change in sea level and the places where the impact will be limited are very close to each other. The height of the bridge, which is close to the point where Göksu joins the Bosphorus, is at a level that will not be affected by a possible sea level change. On the other hand, the low elevation along both banks of the river will be affected by the changes in sea level, especially the residences and workplaces along the riverbanks. It is expected that the technical interventions to be made to the berthing areas of the boats can eliminate the effect, while the buildings used as residences or workplaces will be damaged.





Similarly, Küçüksu Pavilion, which has a narrow garden between the building and the sea, is among the places that can be affected. The Küçüksu Pavilion was built on a leveled area of approximately 60-70 cm above the water level. Today, there is a wall about 50 cm high along the shore to prevent flooding during storm surges. In case of sea level rise, these measures taken to prevent seawater from entering inland areas will need to be further strengthened. It is predicted that the ground floor of Küçüksu Pavilion, which was built as a two and a half floor structure, will be affected by the change in sea level.



Kurbağalıdere valley (Kadıköy)



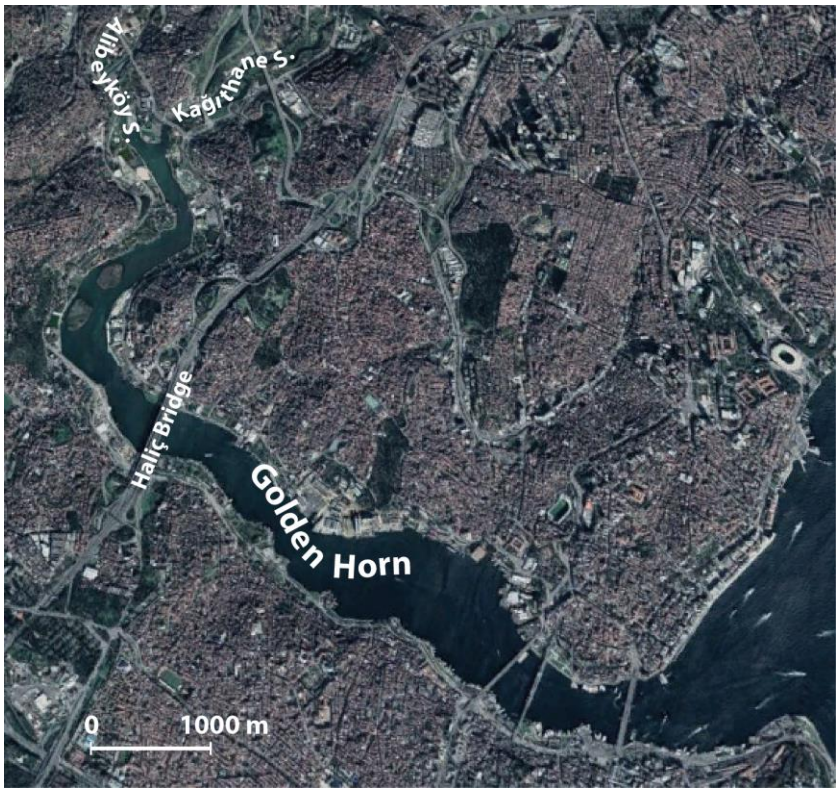
Kurbağalıdere is one of the streams that reach the Sea of Marmara from Kalamış bay and have survived until today. As a result of the cleaning and deepening works carried out in the bed of the stream, sea water can now enter inland for approximately 1200 meters. The first 500 meters of this is arranged for the docking of small boats.



About 6 kilometers from the source of the stream, which causes floods from time to time, has been confined into a channel. Today, Kurbağalıdere passes through heavily built up areas and is not used for any purpose. Depending on the rise in sea level, it is possible for sea water to penetrate up to 1 km. Changes in water quality are not expected to cause any problems.



2. The Golden Horn



One of the places where changes in sea level can be considered to be effective is the Golden Horn. Alibeyköy Stream and Kağıthane Stream, which take their sources from the high areas in the north of the Çatalca peninsula and merge in Silahtarağa, form two main streams that join the Golden Horn. The low slope in the lower channel caused it to draw bends. Due to the change in sea level during the Quaternary, the bed of the stream was inundated by the sea (Yalçınlar, 1977: 26-27). Alibeyköy dam is located on the upper course of Alibeyköy Stream. As a result, its flow is under control. Kağıthane stream, where floods were experienced in rainy periods until recently, was taken into a channel after the rehabilitation works. The distance from the junction of the two rivers to the Bosphorus is approximately 7.5 km.



In the Golden Horn, where the effects of storm surge are not seen or are limited, the effects of sea level rise are also limited and can be easily alleviated.

3. Tuzla Shipyard and Kamil Abduş (Fish) Lake



There are many islands parallel to the southern coast of Kocaeli peninsula. Some of these islands close to the shore are connected to the mainland by a tombolo and/or a shore arrow. Shallow marshes and small lakes complement this topography. This is particularly evident in old wetlands. Tuzla shores are examples of areas where the coastal topography has been changed by human intervention. Until the 1970s, there was a lake (Kamil Abduş Lake), an island connected to the land by a tombolo (Sakız island) and an island (Ekrembey island) on the Tuzla coast. At this time, the island of Sakız and Ekrembey were connected and expanded, and the sea was deepened in order to establish shipyards. By changing the direction of the stream feeding Kamil Abduş Lake, the area covered by the lake, its water level and salinity have changed, and the species it contains has decreased. Since the 1980s, the naturalness of the topography has disappeared with the arrival of industrial facilities (Doğaner, 2000: 8-12). They first tried to dry up the lake, but later on it was decided protected it as a wetland, and artificial shapes were created in the lake in order to create a bird habitat. Today, the lake has a size of about 72 hectares.







C. Artificial coasts

1. Residences on the Bosphorus

While a few villages and altar sites were mentioned on the Bosphorus in the 2nd century, there were small fishing villages and villages where viticulture and/or horticulture activities were carried out in the Byzantine period, while from the 17th century onwards from Beşiktaş to the north of the Bosphorus there were mansions, summer seaside palaces and mansions began to be built. The buildings in question are also an indicator of the social status of the time. The mansions on the European side of the Bosphorus were mostly built adjacent, while the Asian ones were built within the gardens (Artan, 1994: 281-283).

In the 18th and 19th centuries, the mansion is located on the coast, and the functions of transportation, trade, etc. are provided by sea. Most of the time the road connection is a narrow path. In the lower part of these multi-storey buildings, partially below sea level, there is a boathouse, like today's garages. Most of the mansions have flat areas above sea level in the fore part. At the garden level, there are units such as kitchen, pantry, etc. The high ground floor contains spaces where daily life is maintained and guests are received. The upper floor is mostly reserved for bedrooms. Although they were built as residences, today the functions of some mansions have turned into commercial functions such as hotels, restaurants and entertainment centers.

A rise of approximately 1 meter in sea level is not expected to affect these mansions. It is observed that the platform in question gets wet during periods of storm surge, though after a sea level rise, storm surges can negatively affect these buildings.

2. Piers

In Istanbul, which is also called sometimes as "the city with a sea in the middle", settlements are connected to each other by sea, both between two continents and along the Bosphorus.
Sea transportation, which used to be the basis of transportation in the Bosphorus in the past, lost its former importance with developments in highways and bridges.
Piers are man-made facilities directly on the shore. The places where the piers are located are generally located in a small bay in accordance with the settlements that are old villages. Measures such as the construction of breakwaters have been taken in those that are open to wind and currents.
Depending on the technological developments, there have been changes in the sea transportation vehicles. An important part of the piers in the Bosphorus were built in the first half of the 20th century. The decks of the ships of the time were close to sea level, so the piers were built low. Especially since the last quarter of the 20th century, ships with higher decks have been built and the piers have been renewed. It is possible that sea level changes will require some renewals at the piers.
The natural coast is not very high above sea level, both at the piers and around it. The structuring of the coast sometimes is such that waters originating from the land may not easily flow to the sea. In addition, it is seen that the sea rises during the storm surge and the waves are effective around the coast. Infrastructure and superstructure are renewed in certain periods in order to use these areas without any problems. As an example, Üsküdar and Kadıköy piers can be mentioned.

Üsküdar



Üsküdar pier and its surroundings are examples of places where problems are experienced especially in the drainage of land-based waters. Today, Üsküdar Square is located at the junction of several different streams in the past. Today, these streams do not have surface flow. On the other hand, the

main routes on the highway pass through the valleys of the aforementioned rivers. The most obvious problem in the square, where there were also ferry services between Üsküdar and Kabataş for a while, is related to drainage. The low elevation and slope make it difficult to drain surface waters. There are also metro entrances in Üsküdar square today. Inflows are not expected to be affected by possible sea level rise or storm surge. On the other hand, especially on days when there is a southwestern storm, the waters in the Marmara Sea tend to pile up to the north. Although this does not cause flooding, it causes the water level to rise significantly. It is thought that the rise in sea level due to climate change and storm surges that will occur in southwestern weather will require so.



Expansion works were carried out on the coast of Üsküdar square. The newly created walking area is about 1.7m above sea level on a calm day. While it is possible to wet the surface with water spray on a stormy day, seawater is expected to penetrate during storm surge.

The Şemsipaşa Mosque, built by Mimar Sinan in 1580, is located on the seaside. There is a narrow walking path between the wall of the mosque and the sea. A special drainage system has been built to drain the seawater that enters the garden of the mosque on stormy days. The elevation of the coast was partially abandoned, as it was determined that the mosque was damaged during the works carried out to widen and elevate the walking path on the coast. On the other hand, a walking path has been prepared that gradually decreases in elevation up to about half of the sea-facing façade of the mosque.



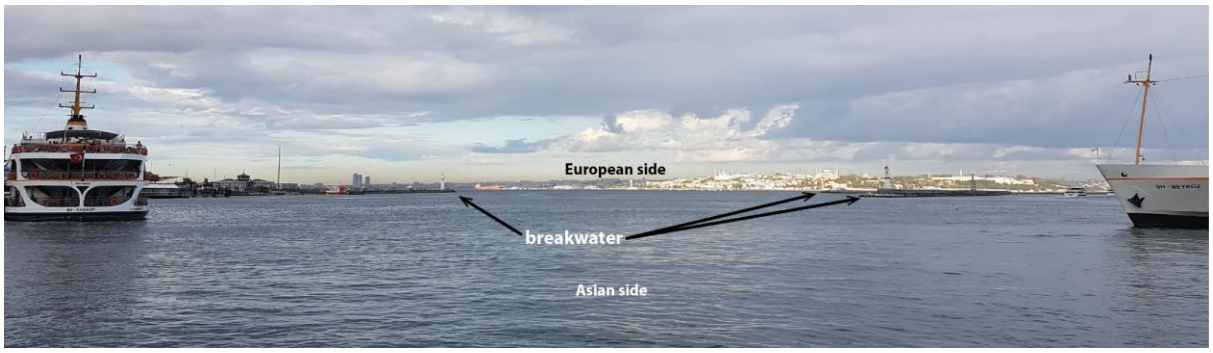
Due to the rise in sea level, the garden is likely to be flooded. This will be particularly evident during storm surges.

Kadıköy



Kadıköy pier is located in a bay. In order to protect the sheep, which is naturally open to the effects of the Marmara Sea, breakwaters were built at different times. For this reason, the effects of storm

surge are not seen in the bay. On the other hand, the water level in the bay rises during periods when southerly winds, especially southwestern winds, are dominant





The subway entrance in the pier square is not affected by the storm surge in today's conditions. On the other hand, it will be necessary to take precautions for storm surges that will occur after sea level rise.

3. Fill areas

The development of settlement in Istanbul has changed significantly in the last century. Villages in the Bosphorus, where fishing and vegetable and fruit production are generally made, are not found on the shores of the Marmara Sea, except for a few places. Earthquakes that took place in certain periods were also effective in this. Villages 1-2 km inland from the coast (such as Göztepe, Erenköy, Bostancı on the Asian side, and Bakırköy, Yeşilköy on the European side) were mostly located in large gardens. Over time, houses that were used as summer houses at first and then permanent residences began to be built in these villages. It is known that there are some mansions near the coast.

The construction of the coastal road has been started on the European side since the 1950s and on the Asian side since the second half of the 1970s. The coastal road on the Asian side has gained its

present appearance since the 1980s. While the coastal road was being built, it was preferred to open the road by demolishing the existing structures on the European side, while a green belt was created on the areas produced by filling the sea on the Asian side, and a new highway was built in the interior. Since the 2000s, new recreation areas have been created on the coastlines of both continents (such as Yenikapı, Bakırköy on the European side, and Maltepe and Kartal coasts on the Asian side) and old beaches have been preserved from time to time.
The shores of the said filling areas have been arranged in such a way as to minimize the effects of sea level. On the other hand, during storm surges, it is seen that seawater reaches inland from time to time and seaweeds, etc., are washed ashore. Earthquakes and tsunamis that will affect the coastline are outside the scope of this report. Under normal conditions, the change in sea level is not expected to be effective in new fill areas. However, it can be thought that storm surges accompanying the rise in sea level may cause seawater to enter inland; therefore, some measures may be required on the coast.
Filling areas in the Asian continent are located between Fenerbahçe-Maltepe and Kartal-Pendik. In the east of Pendik up to Tuzla, there are marinas and shipyards on the coast. Filling areas on the European side have a more fragmented appearance. Yenikapı, Yedikule and Zeytinburnu are the main filling areas. Some of the marinas and piers along the coast are located on the areas reclaimed from the sea.

FenerbahÇe-Maltepe coastline

A significant portion of the coastline has been gradually built on more than one elevation. There is a wall about 50 cm high to prevent seawater from entering. The second level is approximately 50 cm and the third level is approximately 2 m. Walking path, bicycle path, green area and gymnastic equipment are located on this level. Especially on days when there is a southwestern storm, seawater is effective in the 1st and 2nd stages. Depending on the rise in sea level, it should be expected that some adjustments would be made on these coasts.



A large area was created with the filling carried out in Maltepe. There are recreation areas and sports facilities in the said area.



Between Kumkapı and Yenikapı

A recreation area was obtained by filling the area to the west of Yenikapı pier. In the said area, there are Architect Kadir Topbaş Performance and Art Center, areas where outdoor activities are held and green areas.



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Appendix 2: İzmir Sites

A. **Natural coasts**

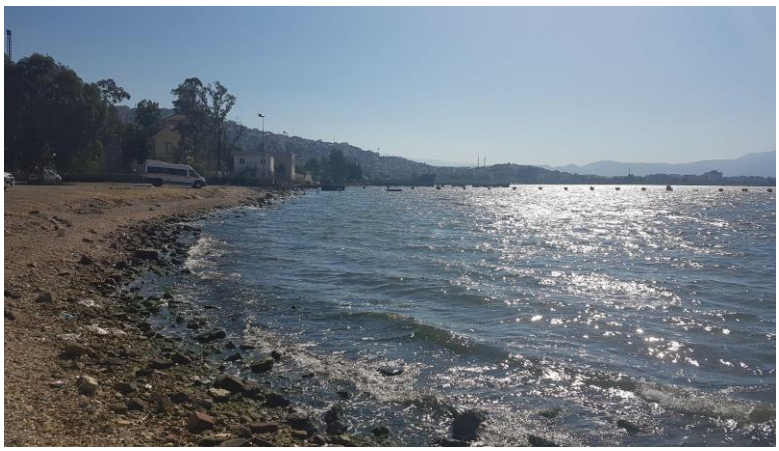
1. Construction and human interventions

North of Izmir Bay, east of Alaybey Shipyard, south of Turan train station



Problem: Storm surge preventing/delaying flood and overflow waters from reaching the sea

The area formed by rivers such as Bostanlı Stream, Dallık Stream and Yamanlar Stream and their branches in the north of İzmir Bay is named Karşıyaka delta (Koçman, et al., 1996). It is known that the rivers forming the delta could not reach the sea especially during the storm surge. This situation has become even more evident with human interventions such as highway, railway and housing construction, especially on the Karşıyaka delta. In this area, where arid-semi-arid climatic conditions prevail, the existing streams dry up in summer and flow especially in winter. The torrential character of the precipitation causes the beds of the rivers to fill up in certain periods. Especially during periods of storm surge due to winds blowing from the south, the waters brought by the rivers cannot reach the sea, causing floods by raising the water level. While the floods caused by heavy rains because loss of life and property behind the coast, it also causes problems in the Karşıyaka delta due to flooding. Incorrect land use in the delta prevents the water from draining. The highway running parallel to the coast and the construction on the coast next to the railway are among the factors that prevent drainage. Other than a stone residence dating from the 19th century (1879) on the shore, other structures are more recent.



The northern shores of Doğanbey bay: Cumhuriyet and Gümüldür

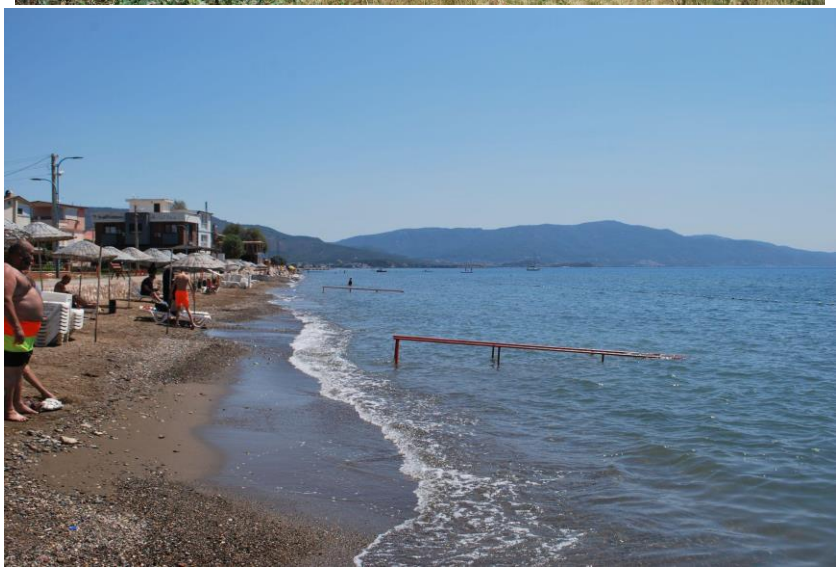


Problem: Storm surge preventing/delaying flood and overflow waters from reaching the sea

Doğanbey Bay, located in the north of Kuşadası Bay, is widely used for recreational purposes. Administratively, it is within the borders of two different districts. Cumhuriyet neighborhood of Seferihisar district is located at the western end of the bay. To the east of this settlement are the Gümüldür and Özdere settlements of the Menderes district. There are areas with an elevation exceeding 500 meters in places behind the coast. The rivers, which take their sources from the high areas, reach the sea by passing the areas that have been reshaped by human activities behind the coast. In order to prevent the floods from time to time, the beds of the rivers were deepened and taken into the canal. Seawater is introduced towards the interior along the created channel. During periods of storm surge, it is seen that the streams cannot discharge their waters. The water that cannot be discharged damages the interior structures. It is thought that this threat will increase further due to the rise in sea level. The accumulation of sand and gravel brought by the waves at the mouth of the stream is also an important problem. To solve this problem, the accumulated material is removed and stored on the shore.

Cumhuriyet neighborhood





Gümüldür





2. Impact on recreation and tourism areas on the coasts

There are tourism areas that can be affected by the rise in sea level at different levels. This effect will occur partly due to the narrowing of the beach areas, the loss of the characteristics of structures such as piers on the shore. Various examples of fields in this regard are given below.

Problem: Change in the coastline and area losses in coastal dunes due to changes in sea level

Beaches on the shores of Güzelbahçe



Unstructured coasts, which are used as daily recreation areas, are among the places that are expected to be affected by the change in sea level. However, it is estimated that the negative impact of the process on the natural structure will be limited. Facilities such as fishermen shelters and moles in this area will need to be strengthened over time.





Yumru Bay and its surroundings in the south of Alaçatı



Yumru Bay, which is located in the south of Alaçatı settlement, has preserved its naturalness until recent years, and the area, which was discovered by surf enthusiasts in the 1990s, has turned into an important tourism center in the following years. The area around the bay, where accommodation facilities were built, was later filled with residences. The fact that the bay is relatively shallow and dominates the wind in a certain direction makes the bay more attractive for surfers. While there are partially natural beaches on the western shores of the bay, there are marinas and mansion-style residences to the north of the beaches. A bank was built so that the water coming from the Karşıyaka creek would not destroy the dwellings on the shores of the bay and the waterway would not become shallow. The fact that the depth is only 1-1.5 m in the area to the south of the marina is another important factor in its preference for surfing. The rise in sea level is expected to lead to an increase in depth and a change in the coastline. It does not seem possible to eliminate the consequences of the change in sea level. This situation will cause a loss in its attractiveness, especially for sports tourism.







Sığacık bay



Sığacık Bay forms an area where more than one stream reaches the sea. The rise in sea level will have a high impact on its tourism potential. The height of the boat mooring places around the castle is about 1 m above sea level. It is among the places that will be primarily affected by the possible rise. Similarly, the marina is among the places to be affected.





Akarca Beach and its surroundings



The area defined as Akarca beach is a natural beach and a tourism area with secondary residences behind the beach. Located approximately 500 m off the coast, the island is connected to the coast by a partially submerged tombolo. Sea level rise can cause the tombolo to be completely submerged. It is not expected that the residences with gardens located along the coast will be directly flooded with seawater. However, seawater will most likely invade the gardens of houses that run parallel to the shore. During storm surge days, this effect will be more pronounced. It is expected that the short distance to the sea will lead to a change in the groundwater level and cause the groundwater to become salty.







There are also small natural coves around the area in question, as in the northeast of Tepecik. The fact that the area is not built is an important advantage.

Özdere

Just behind the coast, which has a narrow natural beach, there are residences that are partially used for tourism. As a consequence of rise sea level rise, the buildings will not be inundated directly by the sea. However, due to its proximity to the sea, the foundations of the houses will be affected by seawater and problems such as salinization due to the change in the ground water level might be experienced.





3. Protection of natural areas



Problem: Preventing natural areas from sustaining their existence due to human interventions

The Gediz delta in İzmir is an area where the competition of natural and human elements is prominent. In particular, interventions made to benefit from natural areas are important. Today, the effects of human activities such as the construction, industrial development, wastewater treatment plants, salt production and road construction realized on the coast and just behind it are at a high level. The level reached by the water during the events that take place in the form of storm surge today are also indicative of the possible height of the sea level in the future. Examples of today's natural coasts that may be affected by sea rise are given below.

Bird Sanctuary

Gediz Delta Bird Sanctuary, which is one of the important bird breeding areas in Turkey, is located in the Gediz delta to the north of İzmir Gulf. The area in question extends as a wide belt where the entire delta meets the sea. More than 250 bird species were observed in the field (Akarsu, Onmuş and Sevil, 2006: 186). The elevation of this area, which is formed by the accumulation of alluvial material carried by the waters from the Gediz River, is below 1-2 meters in places. The continuation of alluvial material transport by the stream in response to the rise in sea level will ensure that the area is not affected. However, due to the interventions to the flow regime of the Gediz River, the incoming alluvial material is decreasing. The decrease in the amount of water carried by the river will also cause the delta to not renew itself in the future. In this case, the rise in sea level will mean the inundation of the land by the sea and the change of the hydrological structure. This suggests that it will have a significant negative impact on the future existence of the Bird Sanctuary.



Wetland and high-rise residences rising behind it (There is a highway between the buildings and the wetland).

Çiğli wastewater treatment plant





Source: https://www.izsu.gov.tr/tr/TesisDetay/1/80/1

The facility, which is one of the largest wastewater treatment plants in Turkey, was established to collect and treat the wastewater of the residential area surrounding the Izmir Bay. Wastes are directed to the facility through the Customs, Bayraklı, Karşıyaka and Çiğli pumping stations. The facility is established on an

area of 30 hectares. Its average capacity is 604,800 m^3/day. The treated water coming out of the treatment plant is discharged to the sea through an 8 m wide, 2 m deep and 2.5 km long reinforced concrete open channel (Web 1).



In the interviews, it was stated that seawater was mixed with the system in some areas and therefore there was also seawater in the wastewater, and the wastewater could not be used for irrigation purposes because salty water came out as a result of the treatment. The plant is located in an area close to the seaside. It can be expected that structures such as the ponding pool in the facility will be statically affected by the possible sea rise. However, it is on the agenda to gradually overhaul the facility in the relatively near future. Modernization studies are planned for both the collection and treatment of wastewater. At the moment the treated wastewater cannot used as irrigation water due to its salinity. It is planned to carry out gradual modernization works for the desalination of wastewater. On the other hand, due to the rise in sea level, it is expected that the water will intrude inland and cause groundwater salinization.

Çamaltı Saltworks

An important area that is expected to be affected by the change in sea level in the Gediz Delta is the Çamaltı saltpan. Salt production is carried out in pools separated from each other by low walls. Any change in sea level has important consequences for salt production. For plants that produce salt from seawater, the fall in sea level requires the transport of seawater over long distances. Evaporation of seawater is the general condition for production. In direct proportion to the rise in sea level, the embankments must also be raised. Pools where seawater is kept for evaporation must be at a certain depth. Rising sea level requires raising the levees (walls) separating the pools. Today, the reinforcement and elevation of the walls between the pools and the filling and leveling operations to be performed on the ground in order to provide a certain water depth constitute the first stages of production. The fact that these applications are also mandatory in the current salt production shows that it can be easily adapted to the change in sea level, regardless of the cost.





4. Change to be experienced in natural backshore areas

Küçük Menderes Delta



The Küçük Menderes River, located in the southernmost part of İzmir, meanders, follows the tectonic groove it is in, and reaches the Aegean Sea. Today, most of the Küçük Menderes River has been channeled. One of the main features of the Küçük Menderes River is that it brings abundant alluvial material. The coastline has advanced in historical periods due to the filling of the tectonic depression area in which the stream is located with alluvium. The port of Ephesus was filled with alluvium brought by Küçük Menderes and Manas Stream in the 4th century, and the filling could not be stopped despite various interventions. Today, Ephesus is approximately 6 km inland from the coast. The high groundwater level is an important feature that restricts agricultural activities in this plain. It includes threats such as possible rise in sea level, effect on groundwater level, and change in water quality.





In recent years, projects have been developed to make the harbor of the ancient city of Ephesus, which has moved away from the coast due to alluvium brought by the Küçük Menderes River, usable again. In the first phase of the project, it was planned to build a marina on the coast and infrastructure works were completed. Possible sea-level rise will require harmonizing this investment.



B. Structured coasts

1. Areas with storm surge on stormy days

Karşıyaka Yunuslar Train Station surroundings



Problem: Seawater intrusion due to storm surge.

Karşıyaka is among the places most affected by the storm surge. Particularly, the seawaters, which are piled up by the winds blowing from the south, on the Karşıyaka coast, enter into the interior by 100 m in places. Especially at the intersection of Yunuslar train station and Girne Street, it is seen that even in today's conditions, it has crossed the filling area, railway and highway and reached the buildings. In order to prevent the damage caused by sea swells, a concave wall of about 1 m high is built along the coast today, trying to prevent the waves from reaching the land.



Mavişehir



Problem: Opening of alluvial fill areas to settlement, storm surge in areas with high groundwater level and inability of surface flow to reach the sea

As the alluvial material brought by Gediz made the bay shallow and prevented the entrance of commercial ships, the stream was diverted to an old bed further north with the works carried out in 1886. Mavişehir was established in a swampy area that forms part of the old Gediz bed. While the high ground water level causes damage to the buildings, as a result of the storm surge, the gardens and ground floors of the buildings near the shore are in danger of flooding. Peynircioğlu Stream, which passes through Mavişehir, not only carries a terrestrial flood risk, but also damages its surroundings due to the inability to drain the waters. In order to prevent such damages, the stream has been rehabilitated and its surroundings have been turned into a recreation area. In swells, the water can reach the buildings behind the shore. This situation necessitated the construction of a 1-1.5 m high dam in a belt along the coast. In addition, a separate channel was built along the coast in order to drain the water coming from the land. The water accumulated in the channel is discharged to the sea by pumping. In cases where the evacuation is insufficient or an excessive amount of water comes in, the houses behind the coast are flooded again.







Çakalburnu Dalyan and İnciraltı Urban Forest



Problem: Coastal recreation areas being affected by rising seawater levels

Inciralti urban forest was formed on the embankment made on the eastern edge of the Çakalburnu Dalyanı on the southern shores of the Izmir Bay. The front of the dalyan is partially covered by the shore arrow. The filling material was obtained by using this place as a rubble dumping area for a while. The elevation of this area above sea level is not much. With the arrangement made, it seems possible to organize the İnciraltı urban forest, which has recreational functions, in accordance with the changes in sea level. The old dalyan, to the west of the filling area, has turned into a lake that is partially connected to the sea. This lake is also home to numerous bird species. 121 bird species have been counted from Çakalburnu Dalyanı (Web 2) Due to the insufficient connection of the wetland with the sea, water circulation cannot be ensured and algae is observed in places. The elevation of the shore arrow separating the wetland from the sea is not high and has a high potential for being affected by possible sea rise. With the arrangements to be made on the coast in time, the negative effects can be eliminated.





2. Inadequate coastal structures that cannot withstand sea level rise requiring renovation

Aliağa and Nemrut Bay



Problem: Structured shorelines affected currently by storm surge

Aliağa port and Nemrut bay in the south are located in the south of Çandarlı Bay. It is expected that the facilities belonging to the shipbreaking industry in Nemrut Bay will adapt over time to the change in sea level. The fixed and surface piers of the Aliağa refinery are located on the western shore of Aliağa Bay in the north. South and west of the bay, where the coast of Aliağa settlement is located, the coast is relatively elevated and walking areas along the coast have been created. However, since the reinforcement on the shore is not concave, the waves crashing rise and fall on the walking platform. It is possible for the water to cover the walking platform, especially during sea swells. The Güzelhisar delta is developing in the north of the bay. There are recreational facilities of various establishments in this area where old swamps and shallow lakes are located. This shows that as a result of sea level rise, certain areas will be affected by the change. However, this effect can be reduced/removed by human interventions to the coastline.



C. Areas that will be exposed to changes in sea level but not expected to be affected

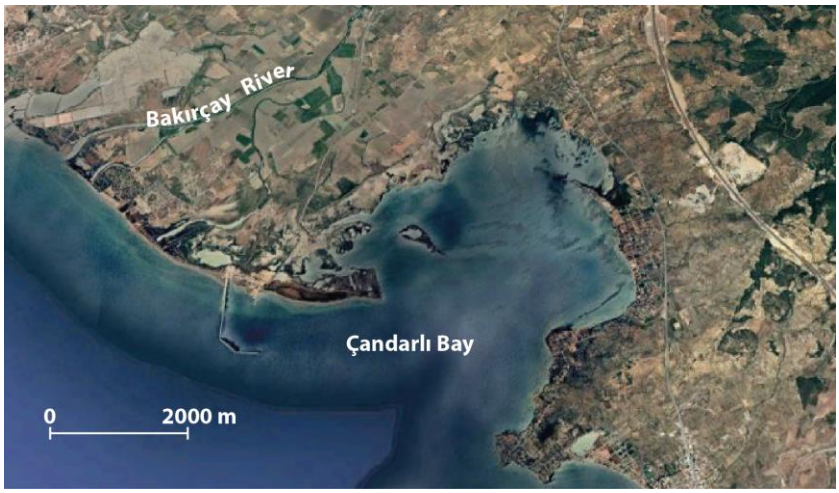
1. Yenişakran



On the Yenişakran coast, one of the areas in the south of the Çandarlı Bay, where the natural coastal feature is not disturbed, there is a narrow coastal band and residences behind it. However, steep rise of the coast will reduce the impact of possible sea level changes. The residences behind the coast can be expected

to be affected by this sea level change. However, the effect of change can be eliminated with measures that do not involve high costs.

2. Çandarlı Bay



Lakes and salt marshes are formed especially in the north of the bay where Bakırçay flows. The lakes formed here and the sand islets formed due to the low depth create separate habitats for birds and other organisms; they may be interrupted due to interventions to the water regime and construction. Çandarlı Bay has a formation that continues to be shaped by different faults. It can be expected that the compartmentalized structure will cause a movement in the form of higher elevation in the high areas on the sides of the bay and a lowering in the depression area in which Bakırçay is also located. The lowering in the valley means that Bakırçay carries more alluvial material to the sea, which forms the permanent pedestal level, and the development of the coast continues. However, the rise in sea level that will occur due to climate change is not expected to meet the lowering that will occur as a result of tectonic processes.





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(Web 1) https://www.izsu.gov.tr/tr/TesisDetay/1/80/1, accessed 16.10.2022
(Web 2) https://archive.md/20190817193120/https://yesilgazete.org/blog/2019/05/20/kuslar-cakalburnu-dalyanini-terk-ediyor/ accessed 16.10.2022

Wastewater systems and sea level change

By Murad Özbaşaran

General

Wastewater treatment systems provide very critical service to communities in urban areas. Improvement in public health, reduction in environmental pollution and relatively in mortality and disease are the positive effects of wastewater treatment systems. Despite these improvements, urban wastewater systems, like any engineered system, can malfunction or fail when stressed beyond their predicted design and functional condition. Failure or malfunction can result from internal factors relating to poor condition of equipments and/or operational mistakes, which can be recovered quickly by repair and maintenance or some technical advice. However, apart from those common problems, a very serious, extraordinary and new thread for wastewater systems is in front of the door: sea level increasement derived by climate change!

Climate change became the first and essential thread for wastewater treatment plants, as well as sewage and pumping systems. This report aim to highlight the various problems associated with climate change - especially sea level increasement – that will affect wastewater treatment (WWT) systems of two big cities of Turkey, Istanbul and Izmir.

Problem Description

It is estimated that sea level increasement will have several effects on wastewater treatment systems. Physical destructions and treatment process problems are the essential risks for the systems. It is calculated that the sea level will increase 1.5 m in the near future which will bring the following problems;

- Pipes float due to increased groundwater level will cause cracking and corrosion,
- Groundwater ingress will lead to loss of functionality and capacity,
- Erosion /inundation will cause damage to infrastructures,
- Floatation, corrosion, inundation, flooding will cause a reduction in the service zone of the pump station,
- Flooding and infrastructure damage, raised groundwater table will prevent sludge, management and dewatering facilities,
- Increased pumping heads for outfalls will be a potential problem for discharge,
- Soakage and weak performance because of waterlogged by soil,
- Floatation of below ground chambers, soil structure,
- Organic and inorganic matter brought by seawater shall block the sewage system,
- The overflow will turn the design calculation upside-down,
- The discharge pipelines hydraulics will be changed and shall bring some discharge problems,
- The infiltration of seawater through sewage system, will change the chemical and biological stability of the wastewater characterization,
- An over salinity can block the biological growth of the microorganisms and relatively the treatment efficiency.

The focus of this report is Istanbul and Izmir which have several WWTPs that will be at risk. The below figure (Figure 1) and table (Table 1) show the location and the risk availability of the City of Istanbul.

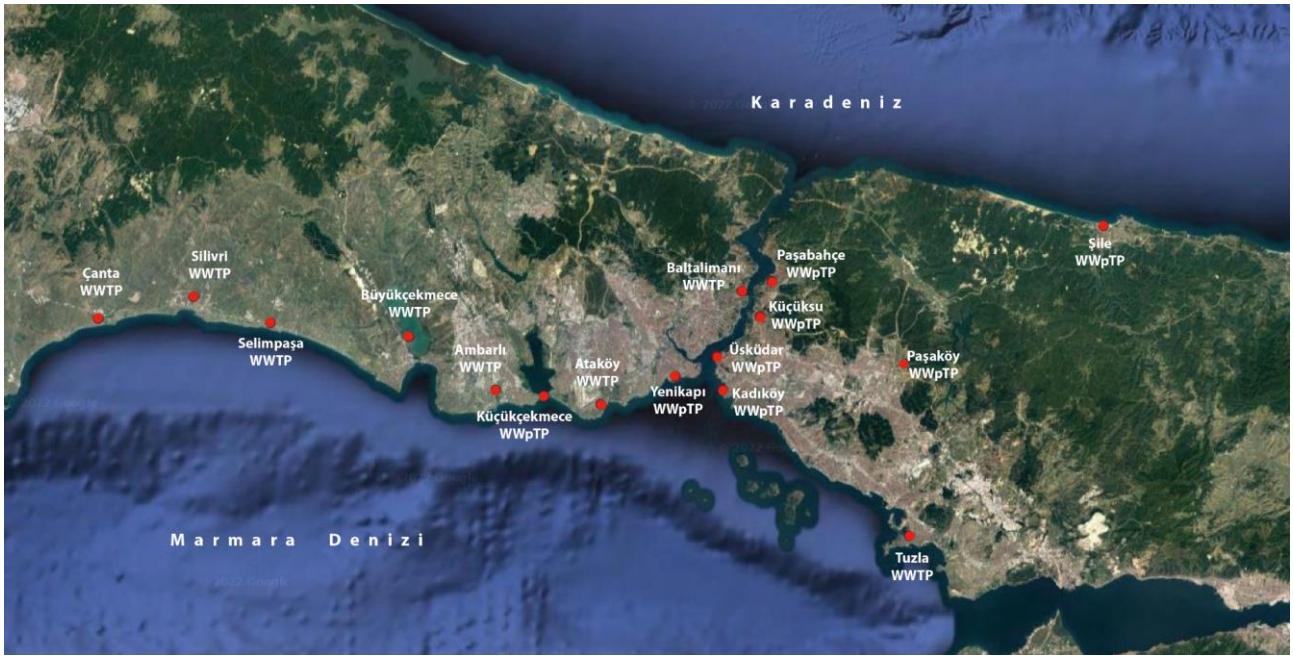


Figure 1. Location of Wastewater Treatment Plants (WWTP) or Wastewater Pretreatment Plants (WWpTP) of Istanbul

The WWTP's have been examined and evaluated regarding to the risks mentioned above.

Table 1. Wastewater Treatment Plants of Istanbul (≥ 5,000 m^3/day)

Name of WWTP (Europe Side)	Treatment Process	Risky	Capacity (m3/day)
Ataköy İleri Biyolojik Arıtma Tesisi	Biological	Yes	600,000
Ambarlı İleri Biyolojik Atık Su Arıtma Tesisi	"	No	400,000
Büyükçekmece İleri Biyolojik Atık Su Arıtma Tesisi	"	Yes	132,500
Selimpaşa İleri Biyolojik Atık Su Arıtma Tesisi	"	Yes	70,000
Çanta İleri Biyolojik Atık Su Arıtma Tesisi	"	Yes	52,000
Silivri İleri Biyolojik Atık Su Arıtma Tesisi	"	Yes	36,500
Yenikapı Atık Su Ön Arıtma Tesisi	Pretreatment	Yes	864,000
Baltalimanı Atık Su Ön Arıtma Tesisi	"	No	625,000
Küçükçekmece Atık Su Ön Arıtma Tesisi	"	Yes	354,000
Name of WWTP (Asia Side)	Treatment Process	Risky	Capacity (m3/day)
Tuzla İleri Biyolojik Atık Su Arıtma Tesisi	Biological	Yes	250,000
Paşaköy İleri Biyolojik Atık Su Arıtma Tesisi	"	No	200,000
Küçüksu Atık Su Ön Arıtma Tesisi	Pretreatment	Yes	640,000
Şile Kumbaba Atık Su Ön Arıtma Tesisi	"	Yes	46,000
Kadıköy Atık Su Ön Arıtma Tesisi	"	Yes	833,000
Üsküdar Atık Su Ön Arıtma Tesisi	"	Yes	77,760
Paşabahçe Atık Su Ön Arıtma Tesisi	"	No	575,000

The below figure (Figure 2) and table (Table 2) show the location and the risk availability of City of Izmir.

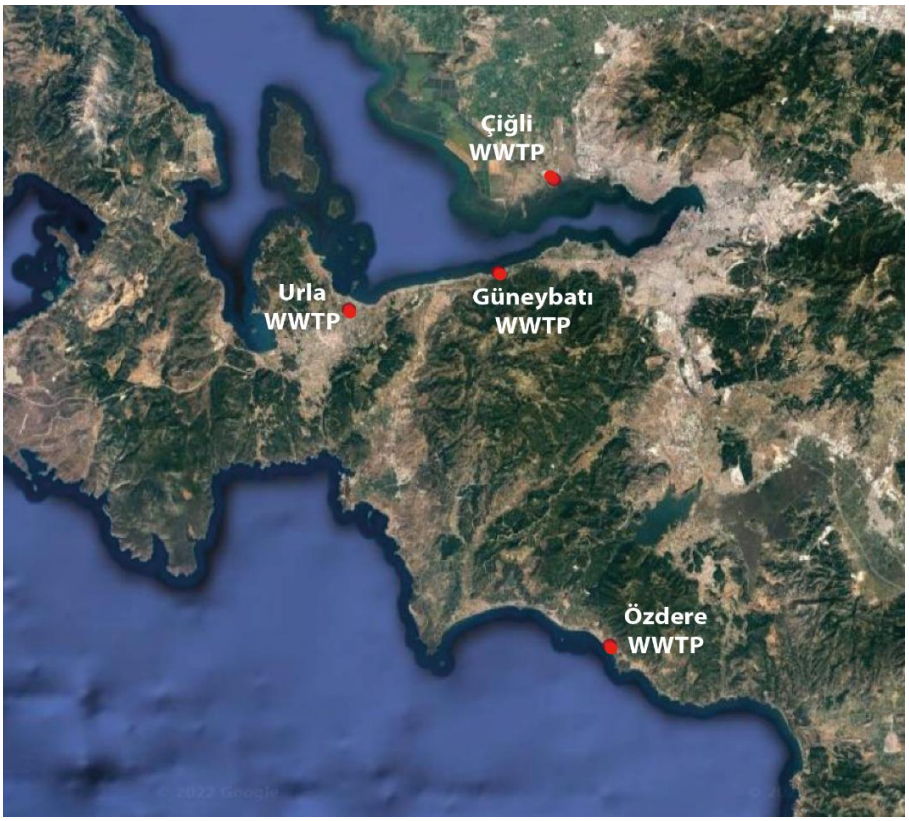


Figure 2. Location of WWTP of Izmir

The WWTP's have been examined and evaluated regarding to the risks mentioned above.

Table 2. Wastewater Treatment Plants of Izmir (≥ 5000 m^3/day)

Name of WWTP	Treatment Process	Risky	Capacity (m3/day)
Çiğli AAT	Biological treatment	Yes	604,800
Doğanbey A.A.T	"	No	25,000
Özdere A.A.T.	"	Yes	25,000
Çeşme A.A.T.	"	No	21,900
Aliağa AAT	"	No	21,600
Güneybatı A.A.T.	"	Yes	21,600
Urla A.A.T.	"	Yes	21,600
Havza A.A.T.	"	No	21,600
Torbalı A.A.T.	"	No	21,600
Ödemiş A.A.T.	"	No	15,765
Çandarlı A.A.T.	"	No	15,204
Bergama A.A.T.	"	No	14,304
Kemalpaşa AAT	"	No	12,960
Seferihisar A.A.T.	"	No	10,800
Selçuk D.A.A.T.	Wetland treatment	No	10,200
Yenifoça A.A.T.	Biological treatment	No	10,000
Foça A.A.T.	"	No	9,763
Tire A.A.T	"	No	6,976
Ayrancılar A.A.T.	"	No	6,912
Bayındır A.A.T.	"	No	6,912

Conclusion

As a result of climate change, sea-level rise, will bring several hazards and damages that will prevent critical services of the municipalities.

Climate change adaptation is increasingly being recognized as important for managing the performance and location of wastewater systems, which means that understanding the science and local knowledge is key for adaptation strategies (Kettle, et al., 2014).

Impact assessments are a necessary step in the process of planning for addressing climate impacts (Danilenko et al., 2010). However, it has been recognized that a coordinated and comprehensive study of the impacts of climate change on wastewater, relevant to local climate and geographic constraints has to be done immediately. This study highlighted this need and topics to be evaluated to define the steps for the comprehensive studies and works.

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