IGGE
International Journal of Geography and Geography Education
Research Article/Araştırma Makalesi

To Cite This Article: Kazı H., & Karabulut M. (2023). Monitoring the shoreline changes of the Göksu Delta (Türkiye) using geographical information technologıes and predictions for the near future. International Journal of Geography and Geography Education (IGGE), 50, 329-352.
http://dx.doi.org/10.32003/igge.1304403

MONITORING THE SHORELINE CHANGES OF THE GÖKSU DELTA (TÜRKİYE) USING GEOGRAPHİCAL INFORMATION TECHNOLOGIES AND PREDICTIONS FOR THE NEAR FUTURE

Coğrafi Bilgi Teknolojileri Kullanılarak Göksu Deltası'nın Kıyı Değişiminin İzlenmesi ve Yakın Geleceğe Dair Öngörüler

Hüsna KAZI*, Murat KARABULUT

Abstract

Coasts have a rich complex structure that hosts different ecosystems, habitats and species. Because of this properties, the coastline is exposed to changes from time to time. Remote sensing and Geographic Information Systems (GIS) play an important role in examining and managing the increasing pressure on the coasts in long periods of time and in creating future models. The aim of the study is to determine the coastal changes experienced on the shores of the Göksu Delta between 1985 and 2020. As a result of the analyses, it was seen that the areas with the highest erosion in the Göksu Delta over a 35-year period are Altınkum, the mouth of the Göksu River and the end parts of İncekum. It has been determined that the accumulation is concentrated on the east and west coasts of Incekum (İnceburun) cape. As a result of statistical calculations using DSAS, the possible position of the coastline in 2030 and 2040 has been determined.
Anahtar Kelimeler: Göksu Delta, Shoreline, Remote Sensing, GIS, DSAS

Öz

Kıyılar, farklı ekosistemlere, habitatlara ve türlere ev sahipliği yapan zengin kompleks bir yapıya sahiptir. Bu özelliği nedeniyle kıyı şeridi, zaman zaman değişimlere maruz kalmaktadır. Uzaktan algılama ve Coğrafi Bilgi Sistemleri (CBS), uzun dönemlerde kıyılar üzerinde artan baskının incelenip yönetilmesinde ve ileriye dönük modellerin oluşturulmasında önemli rol oynamaktadır. Çalışmanın amacı Göksu Deltası kıyılarında 1985-2020 yılları arasında yaşanan değişimleri belirlemektir. Yapılan analizler neticesinde 35 yıllık zaman zarfında Göksu Deltası'nda aşınmanın en fazla olduğu alanların, Altınkum, Göksu Nehri'nin ağızkesimi ve İncekum'un uç kısımları olduğu görülmektedir. Birikmenin ise İncekum burnunun doğu ve batı kıyılarında yoğunlaştığı tespit edilmiştir. DSAS kullanılarak yapılan istatiksel hesaplamalar sonucunda 2030 ve 2040 yıllarında kıyı çizgisinin muhtemel pozisyonu belirlenmiştir.
Keywords: Göksu Deltası, Kıyı Çizgisi, Uzaktan Algılama, CBS, DSAS

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Geliş Tarihi/Recieved: 28.05.2023 **Kabul Tarihi /Accepted:** 30.06.2023 **Ç. Yayınlanma Tarihi/Online Published:** 29.09.2023

INTRODUCTION

Coastal areas are at the forefront of morphological units where marine and terrestrial environments are in constant interaction with each other (Uzun, 2014). For this reason, the coastline is defined as a dynamic ecosystem that is affected by changes in both environments (Bheeroo vd.2016). The rapidly changing coastline in the last few years has become an important environmental problem affecting coastal areas worldwide (Kermani et al., 2016). Almost everywhere in the world, the coastline is exposed to erosion and accretion due to hydrodynamic and geomorphological factors or anthropogenic activities (Sytnik et al., 2018). Waves, coastal currents, tides, and estuarine/sea level changes are among the hydrodynamic factors affecting the coastlines (Deepika et al., 2014). In recent years, it has been emphasized that sea level rises due to climate change, thus increasing the imbalances in the coastline, and these areas do not remain stable (Masselink&Russell, 2013; Toimil et al., 2017). According to the fifth evaluation report published by the IPCC (International Panel on Climate Change), it is stated that since the middle of the 19th century, there have been serious increases in sea levels compared to the previous two periods (Jayanthi et al., 2018).

Anthropogenic mobility over coastal areas can cause a faster change in contrast to natural activities. Factors such as the rapid increase in population and built up structures in coastal areas and the filling of coastal areas pose a threat to the coastline. Dams built on rivers cause changes in both the surrounding river regime and the coastline. In their study conducted in 2017 to determine the coastline changes in the Nile Delta, Darwish et al., emphasized that the coast was rapidly eroded after the Aswan Dam was built (Darwish et al., 2017). Coastal change studies show that more than 80% of the world's coasts experience erosion at rates ranging from 1.0 cm to 30 m per year (Nassar et al., 2019).

The continuous change of the coastline as a result of erosion and sedimentation complicates the management of coastal areas (White & El Asmar, 1999). In the planning of these sites, researchers have made manual calculations and measurements for many years. However, these methods are time-consuming and cause human-induced problems. Short or long-term monitoring of the coastline and determining the parameters affecting the coastline require a systematic approach. For this reason, various software and techniques used also facilitate the necessary planning for the protection of coastal areas (Tağıl & Cürebal, 2015; Özpolat & Demir, 2014; Sheik, 2011). For example, GIS software and remote sensing technologies provide great advantages for various coastal studies such as examining the change in the coastline, determining the hazards that may occur in the field, determining the amount of erosion-deposition and sediment, and creating future prediction models (Maiti & Bhattacharya, 2009). Models that facilitate land-water separation or show the water level produced by GIS software are frequently used for coastal studies (Ghorai et al., 2016). DSAS (Digital Shoreline Analysis System) is one of the add-ons that generates these models. Working integrated with ArcGIS, DSAS is preferred for the determination, monitoring, and mapping of past and future coastal position (Siyal et al., 2022). There are many studies on the subject examining the past and current status of the coastline (Berlanga-Robles & Ruiz-Luna, 2002; Sahin et al., 2022; Van & Binh, 2008, Kuleli, 2010), whereas there are studies that predict the future position appears to be insufficient. Determining the future location of the coastline provides the managers with alternative methods for planning, while making the decisions faster and more applicable.

Göksu Delta, chosen as the study area, is located in the Adana part of the Mediterranean region. The delta is surrounded Taşucu from the west, Mediterranean Sea from the south, Susanoğlu from the east, and Silifke from the north-northwest (Karabulut, 2015; Karabulut & Küçükönder, 2018; Figure 1). The average width of the delta is 155 km^2 (138 km^2 land, 17 km^2 water). The Göksu Delta, which has a coastal length of approximately 35 km, is one of the important delta plains of Turkey (Karakoç, 2011). The materials carried by the Göksu River were effective in its formation (Kılar, 2018).

Göksu Delta, which is a nesting area for many living things, draws attention among the deltas in the Mediterranean in terms of ecological and biological diversity (Karabulut & Kızılelma, 2017; Karakoç and Karabulut 2010). Paradeniz Lagoon, located to the west of the Göksu River, is an important area rich in fauna and flora. The lagoons formed by the material carried by the waves are suitable for being affected by the changes to be experienced on the coasts. In order not to destrory this diversity, the delta has been protected by many national and international laws of nature (Karabulut et al., 2012). The climate, topography, and water resources that are suitable for agricultural activities have made the Göksu Delta one of the most important agricultural centers of Turkey. In the delta, which draws attention with its economic and ecological values, it is extremely important to protect and sustain diversity, to examine the changes that have occurred or may occur, and to investigate the causes.

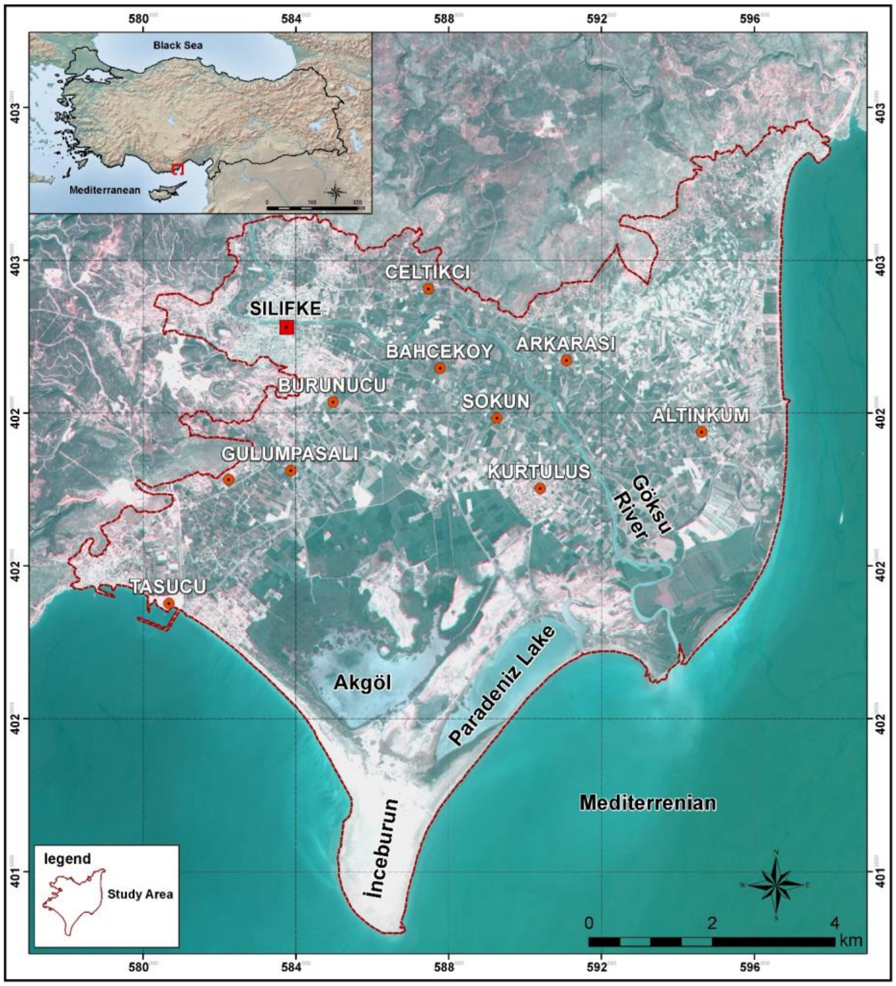

Figure 1. Study area location map

The aim of this study is to determine the coastal line changes in the Göksu Delta during the 35-year period between 1985 and 2020. It is aimed to revealing the periods and characters of the changes that occurred, identifying the most affected areas, and to create predictions for the future state of the coast by taking into account the analyses made.

MATERIAL AND METHOD

In this study, three stages were followed in order to determine the change in the coastline. (a) Satellite images of the study area between 1985 and 2020 were downloaded and edited. (b) shoreline was determined using various methods, and error rates were estimated. (c) erosion and accumulation movements on the coastline were evaluated spatially and temporally (Figure 2).

Numbers Satellite images Dates Resolution (m) Improvement

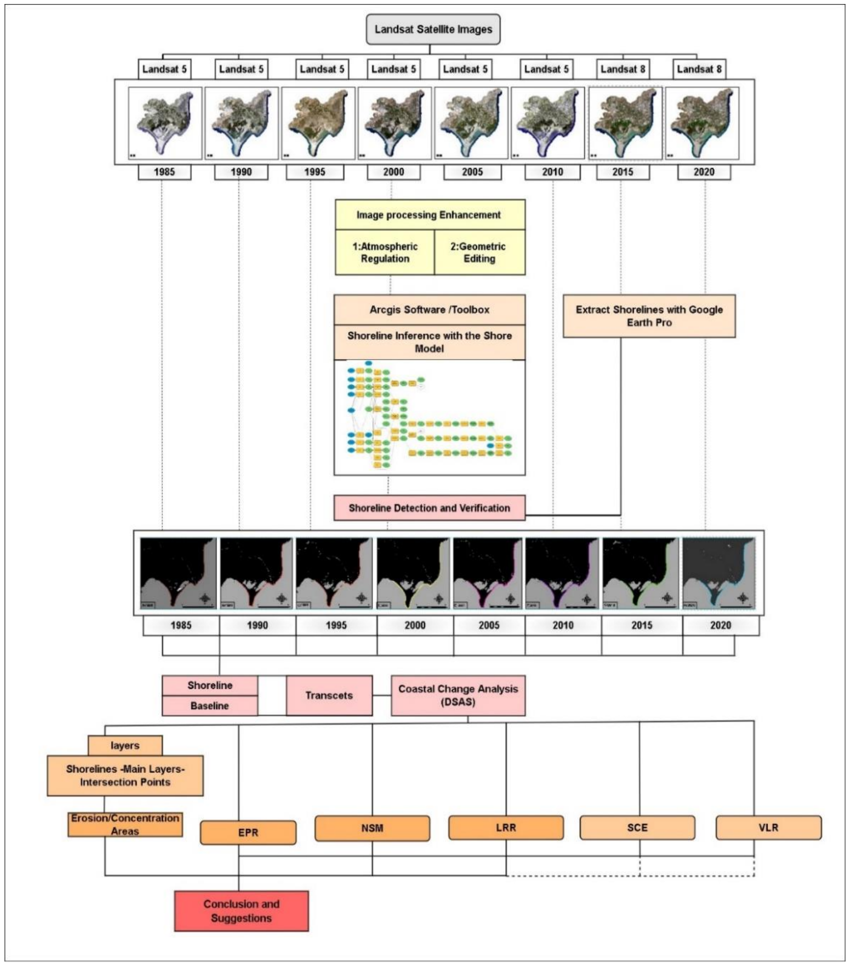

Figure 2. Work flow diagram Figure

Data Sources

In order to determine the change in Göksu Delta, 8 Landsat satellite images (TM and OLI) of different years (1985, 1990, 1995, 2000, 2005, 2010, 2015, 2020) obtained from the USGS were used (Table 1). The temporal and spatial resolutions of the satellites were taken into account in order to determine the coastline and detect the change.

Table 1. Satellite images used in the study and their features

Numbers	Satellite images	Dates	Resolution (m)	Improvement
1	TM	08/22/1985	30x30	15x15
2	TM	08/20/1990	30x30	15x15
3	TM	10/05/1995	30x30	15x15
4	TM	15/08/2000	30x30	15x15
5	TM	21/07/2005	30x30	15x15
6	TM	27/08/2010	30x30	15x15
7	OLI TIRS	09/10/2015	30x30	15x15
8	OLI TIRS	09/07/2020	30x30	15x15

Pre-Processes and Determination of the Shoreline

Satellite images undergo a series of preprocessing before being subjected to analysis. Thus, some errors in satellite images are eliminated and the image is made ready for analysis. The image processing and enhancement techniques used in this study are band fusion, radiometric editing, geometric editing, and resolution enhancement. After the preliminary processes, the shoreline was determined. More than one method was applied at this stage. A model covering Landsat Tools, Tessa Tools, NDWI, MDWI, Wetness and classification methods was created and applied separately for each year. According to the years and the characteristics of the image, the most appropriate method was preferred. Coastlines in 1985-2000 were determined by the Reclasiffy and Iso Calculator methods. MNDVI and NDVI were used to extract the coastline in the 2000-2010 period. It was observed that Landsat and Tessa Tools gave more accurate results in determining the shoreline in 2015. The shoreline for the year 2020 is derived from a 5 m resolution satellite image from Google Earth Pro (Figure 3).

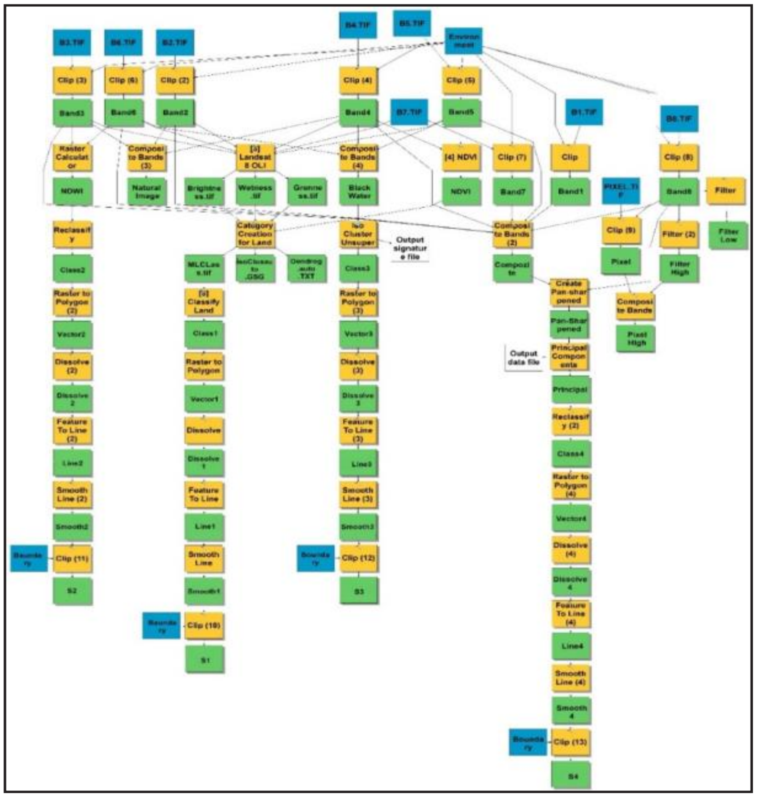

Figure 3. Model created for shoreline detection

Calculation of Erosion and Deposition Rates

Various statistical methods are used to determine the short or long term changes in the coastline, erosion and accumulation areas (Lazuardi et al., 2022). One of these methods is DSAS, which is an ArcGIS add-on. The working logic of the DSAS plugin is based on the statistical calculation of the change and speed of the shorelines in vector format over a specified time (Thieler & Danforth, 1994; Fotsi et al. 2019). The analyses made with the DSAS tool in the study are Net Shoreline Movement (NSM), End Point Rate (EPR), Linear Regression Rate (LRR).

Net Shoreline Movement (NSM)

The NSM statistic calculates the distance between the oldest and the newest shoreline for each transet (Equation 1). Therefore, the units are in meters (Himmelstoss et al. 2018). In order to use the NSM statistics, coastlines belonging to two different periods are required. The following formula is applied to calculate the NSM statistics:

$NSM = \mathbf{Po - Pn}$ **(1)**

Here, Pn and Po denote the new shoreline position and the old shoreline position, respectively.

End Point Rate (EPR)

EPR is a method used to estimate the annual rate of change of coastline. It is calculated by dividing the distance between the oldest coast and the newest coastline by the elapsed time (Isha et al., 2020; Equation 2). In other words, dividing the NSM result by the elapsed time gives the EPR result. The biggest advantage of the EPR calculation is its ease of calculation. Only a minimum of two years of shoreline data is needed to calculate the EPR statistic (Quang et al., 2021). However, this advantage can turn into a disadvantage in some cases because the fact that the account belongs to only two years can affect the final result in long-term studies (Prieto et al., 2018). Positive values obtained as a result of the process indicate that there is agglomeration on the shore, while negative values indicate erosion.

$EPR = \mathbf{L_1 - L_2 / t_1 - t_2}$ **(2)**

Here, L1-L2 is the distance separating two different shorelines; t1 and t2 represent the dates of the two shorelines.

Linear Regression Rate (LRR)

LRR statistics are produced by dividing all coastlines intersecting along the profile line by time (Pratomo & Pramudya, 2021; To & Thao, 2008; Oyedotun, 2014; Thieler et al., 2009). The biggest advantage of the LRR method is that it minimizes the possible errors by using all shoreline data. One of the problems encountered in the LRR calculation is the inequality between the old and new shoreline data. In a study where long-term changes are calculated, the distribution of old and new data should be similar. The LRR statistic is a useful and reliable method for predicting future coastline positions (Natesan et al., 2015).

FINDINGS

In this section, the erosion and accumulation movements in the coastline and the spatial and temporal changes of these movements will be evaluated. In this direction, time series were analyzed by dividing them into 3 periods. The first period covers 1985-2000, the second period 2000-2010, the third period 2010-2020. As a result of the analyses made, the effect of the erosion-deposition cycle on the coastal morphology over a 35-year period was determined. Using the results obtained from the analyses, the estimated position of the coasts of the Göksu Delta in 2030 and 2040 was calculated.

Changes in the 1985-2000 Period

The results represented that erosion is dominant in the Göksu Delta in the 1985-2000 period. According to the EPR statistics, there is a loss of land between – 13 m and – 6 m per year in areas where erosion is intense. The regression from the coastline reached its maximum in the 1995-2000 period. The Altinkumu and Incekum (İnceburun) coasts are the areas where erosion is experienced the most throughout the period. The main reason for the severe erosion on the Altınkum coast is anthropogenic intervention. Changing the bed of the Göksu river in the 1940s reduced the amount of sediment reaching the Altınkum area. Thus, erosion has accelerated in these areas. It was determined that there was an accumulation of 10-25 m per year during the 1985-2000 period. Especially in the period between 1985 and 1990, the agglomeration reached its peak level (20-47 m/y). The accumulation areas on the shores of Göksu Delta are; river mouth and the eastern and western shores of Incekum cape (Figure 4).

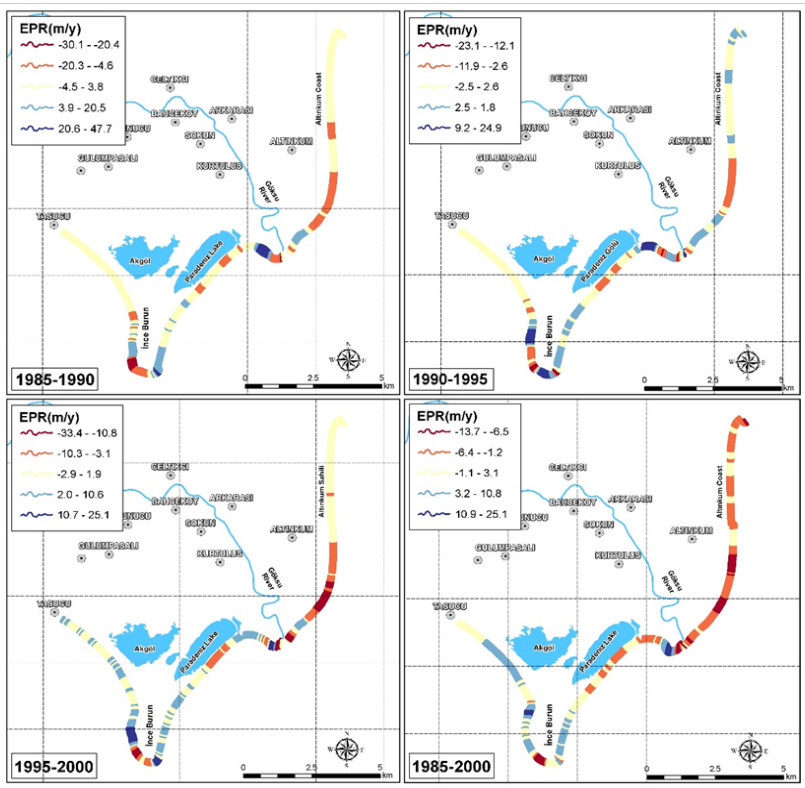

Figure 4. Coastline change in 1985-2000 period according to EPR statistics

In the 1985-1990 period, it was determined that the tip of the İncekum cape locality was heavily eroded. It is observed that the accumulation is in the areas close to the mouth of the Göksu River. Contrary to the general view, in the period covering the years 1990-1995, dense accumulation was recorded in İncekum. It has been determined that the areas where the regression is experienced in the coastal line are Altınkum and İncekum. In the 1995-2000 period, it is seen that severe erosion existed at many points. Altinkum, River mouth, Incekum are among these areas. Average land loss was calculated as – 33 to – 10 m/y (Figure 5).

Figure 5. EPR graph for the 1985-2000 period

According to the Figure 6 showing the NSM statistics, it is seen that high erosion occurred in the study area between 1985 and 2000. In the areas where erosion is intense (Altınkum and İncekum cape localities), it has been determined that the sea progress is between – 181 and – 45 m. The high accumulation rate throughout the period was calculated as 82-263 m. The mouth of the Göksu River, the eastern and western shores of Incekum Cape and Taşucu are the areas where the accumulation takes place.

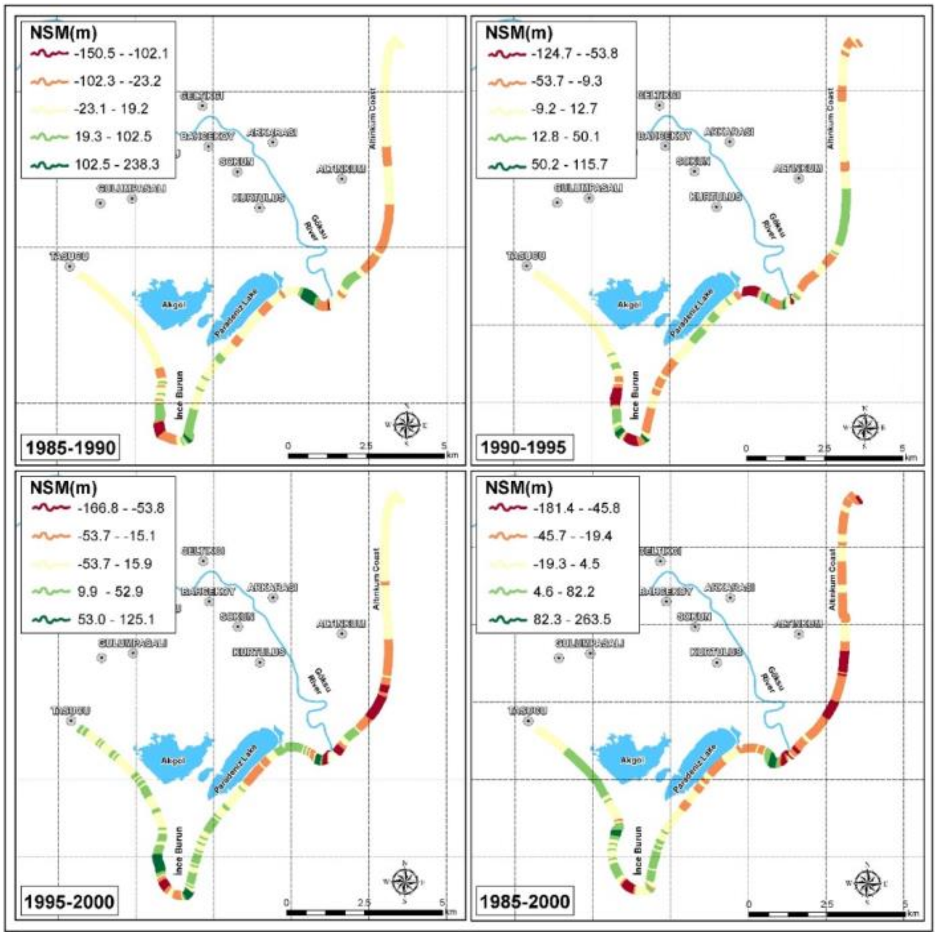

Figure 6. Coastline change in 1985-2000 period according to NSM statistics

The results represented that the coastal line progression reached the highest level (102-238 m) in the period between 1985 and 1990. It has been determined that there is intense accumulation in the mouth of the river, whereas the İncekum locality has been eroded. In the period of 1990-1995, it is seen that the regression in the coastline was intense. Severe erosion has been recorded at the tip of Incekum and its western shore, around the Paradeniz Lagoon. The area that attracts attention in this period is Altınkum locality. It is possible to talk about the existence of accumulation, unlike other periods (12-50 m). Between 1995 and 2000, there was a situation against the coast in Altınkum, the river mouth and partially in İncekum Cape. These areas were exposed to erosion at a rate of – 168 to – 53 m. In the 1995-2000 period, the areas where the coastline advanced were the western shores of Incekum Cape and partly at the tip and around the river mouth (Figure 7).

Figure 7. NSM graph for the 1985-2000 period

Changes in the 2000-2010 Period

According to the results that the delta coasts regressed in the 10-year period including the 2000-2010 period. When the result of the EPR statistics is evaluated, it has been determined that there is a decrease of 50 to 11 m per year in the İncekum locality. It is observed that the coastline progresses (8-23 m/y) on the western shore of Incekum cape. Although erosion has occurred from time to time in the mouth of the Göksu river, long-term accumulations have occurred (Figure 8). The changes in the coastline were minimal in the area between Taşucu and İncekum.

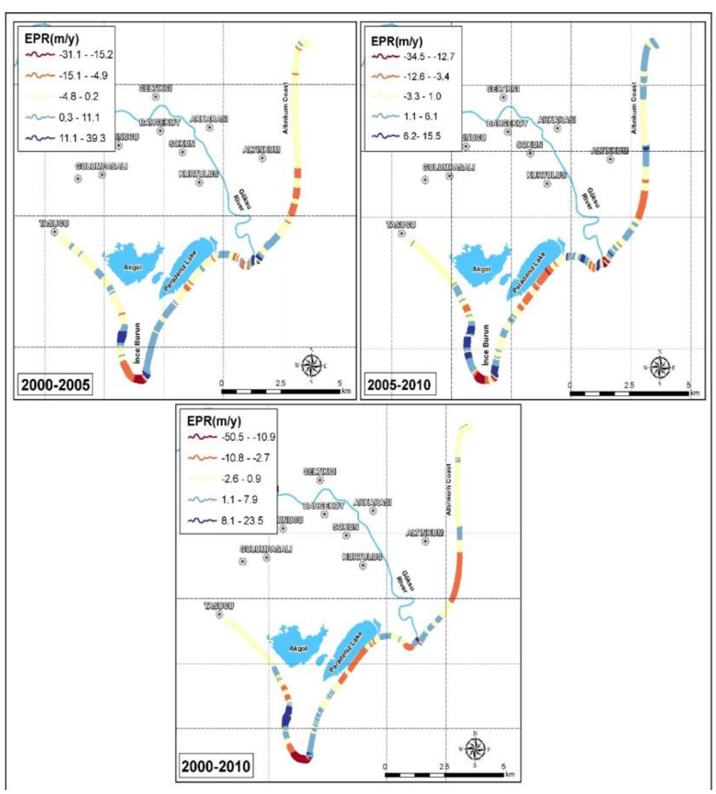

Figure 8. Coastline change in 2000-2010 period according to EPR statistics

It is found that the accumulation was more effective during the 2000-2005 period. On the eastern shores of the Incekum headland, an average of 0.3 meters to 11 meters of accumulation has been recorded per year. It was determined that severe erosion took place only at the tip of Incekum. Between 2005 and 2010, the western shores of Incekum cape were exposed to high concentrations (6-15 m/y). Accumulation was observed in Altınkum locality only during the period of 2005-2010. Erosion of – 34 to – 12 meters per year has been detected in the southern end of Incekum and the estuarine regions (Figure 9).

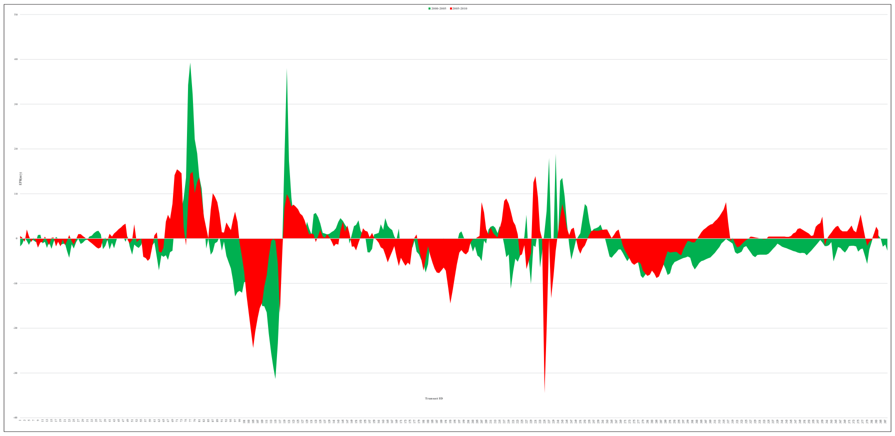

Figure 9. EPR graph for the 2000-2010 period

As a result of the NSM statistics for the 2000-2010 period, it is seen that there is severe erosion (-257 – -106 m) at the south end of Incekum Cape and high accumulation (79-235 m) on the west coasts. Although accumulations are seen from time to time in Taşucu locality, it has been determined that they maintains their position to a large extent (Figure 10).

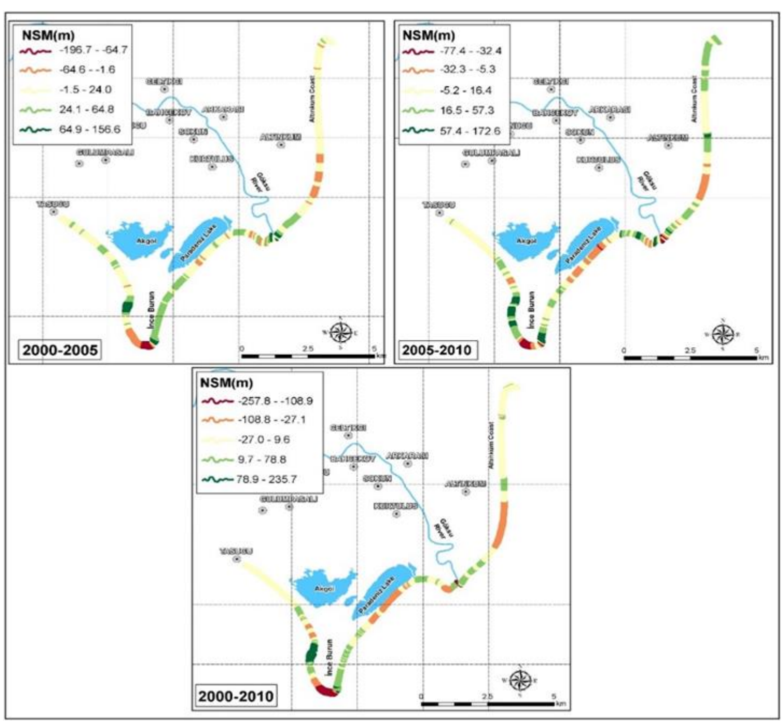

Figure 10. Coastline change in the 2000-2010 period according to NSM statistics

The areas where the coastline advanced in the period covering the years 2000-2005 are the east and west coasts of Incekum and the region where the Göksu River reaches the sea. An average of 55-196 meters of accumulation was recorded in these fields. The areas where erosion was detected on the coast during this time period are south of İncekum and Altınkum. When the period of 2005-2010 is examined, it is observed that severe accumulation increased on the west coast of Incekum. In addition, the eastern border of the delta and the coastal promenade of the Paradeniz Lagoon are seen so clearly for the first time (Figure 11).

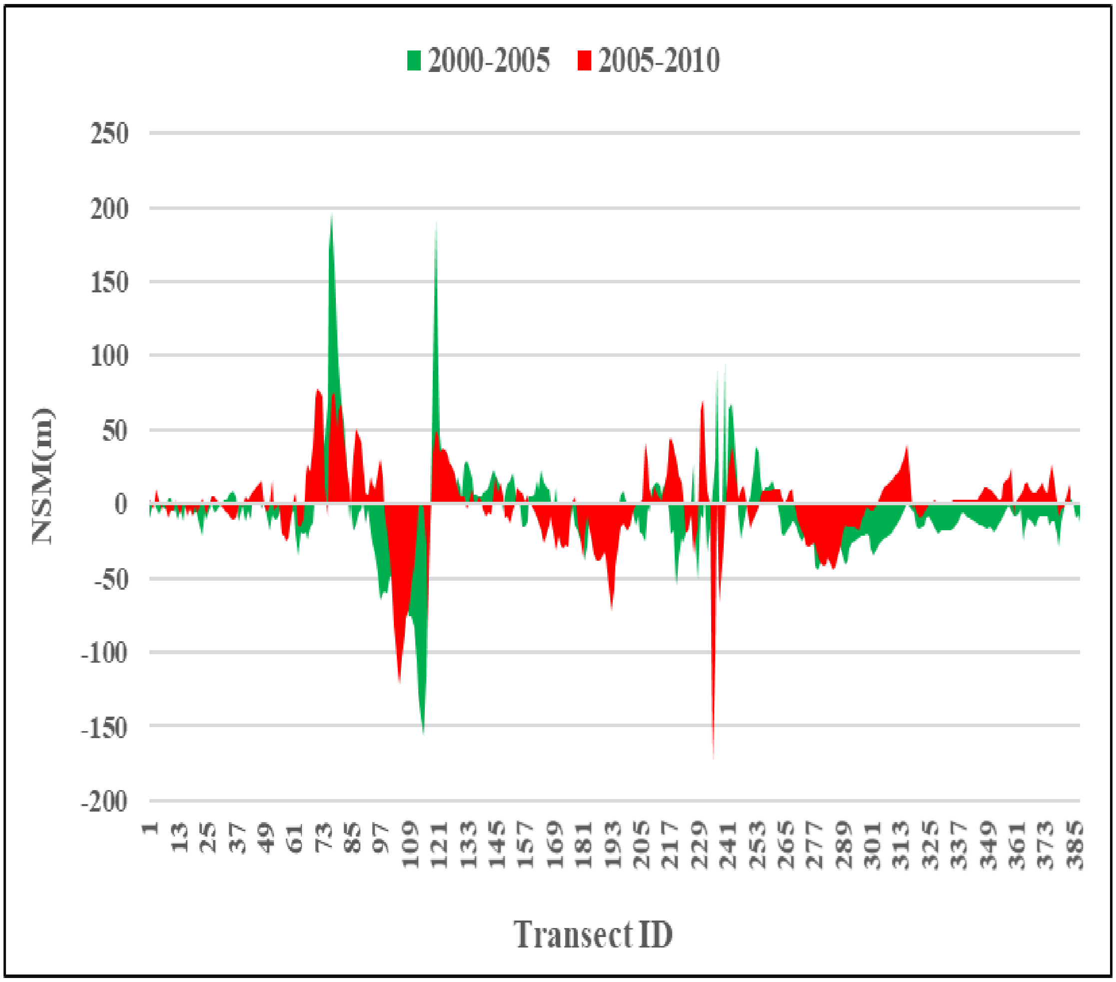

Figure 11. 2000-2010 period NSM graph

Changes in the 2010-2020 Period

In the 2010-2020 period, wear was recorded in almost every area. It is observed that there is erosion on all of Altınkum coasts. The southern tip of Incekum Cape, the coastal promenade and partially Taşucu coasts are other areas where erosion occurs. It is observed that the coast regresses at rates ranging from – 0.5 to – 14 meters per year. It is indicated that the erosion that started after 2015 increased its effect until 2020. In this period, the only area with intense accumulation is the mouth of the Göksu River and its surroundings (Figure 12).

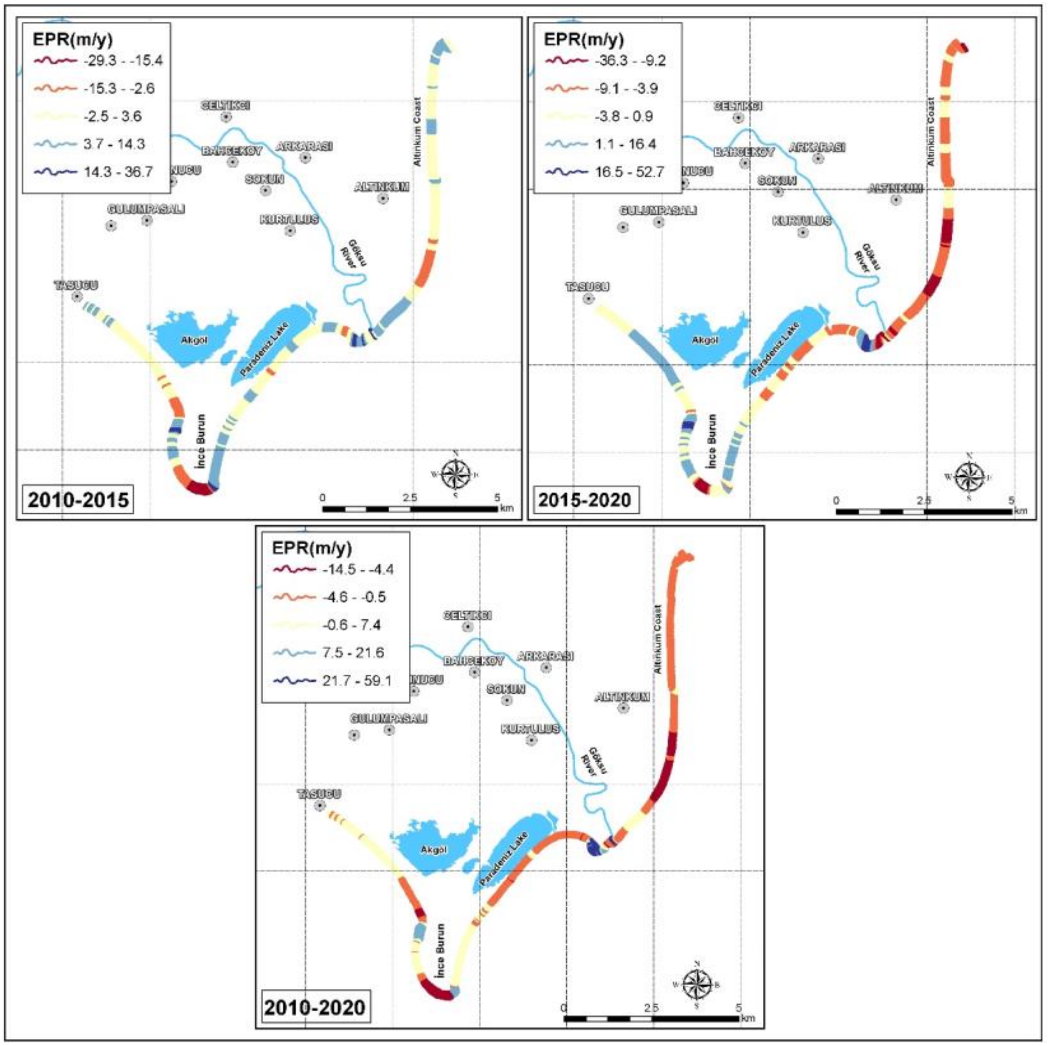

Figure 12. Coastline change in the 2010-2020 period according to EPR statistics

Contrary to the general view, it has been determined that the areas where accumulation is experienced are more in the process covering the years 2010-2015. It was clearly shown that the coast progresses in the eastern and western shores of Incekum cape and partially in Altınkum locality. Incekum cape is located at the point where coastal currents coming from both the west (Taşucu Bay) and east (consisting of sediments from Göksu River) meet. For this reason, the eastern and western shores of Incekum cape are areas where accumulation is high. The accumulation in these areas varies between 3 meters and 36 meters on average per year. The areas where severe coastal recessions were recorded in this process are the river mouth and the south of Incekum cape. Erosion reached its maximum level in the period of 2015-2020. Altınkum location, coastal promenade and south of İncekum cape are the areas most affected by erosion. In these areas, the coast has regressed from – 4 meters to – 36 meters per year. The regions where the coastline advances are the river mouth, Taşucu and İncekum localities (Figure 13).

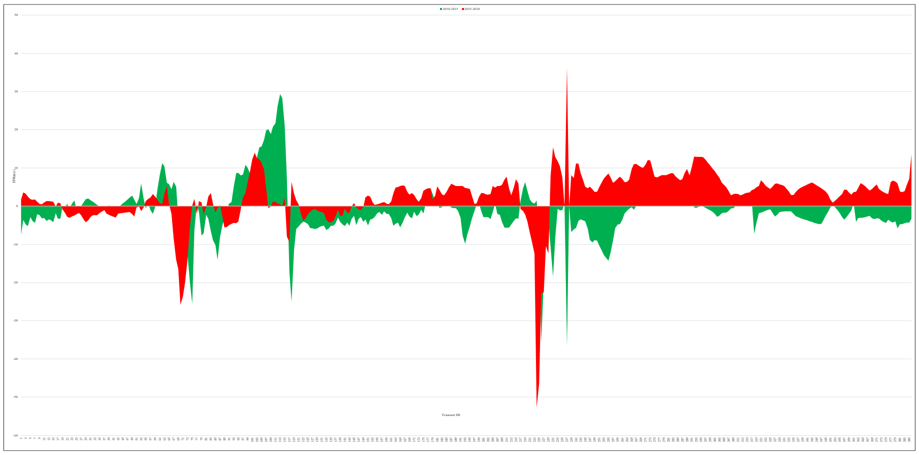

Figure 13. EPR graph for the period 2010-2020

When the NSM statistics prepared for the 2010-2020 period in Figure 14 are evaluated, it is seen that the accumulation is dominant in the estuarine region of the eastern and western shores of Incekum cape (19-590 m). It has been determined that the coastline has receded in the south of Altınkum locality and İncekum locality. In areas where erosion is severe, the regression is determined to be between – 15 and – 145 m on average (Figure 14).

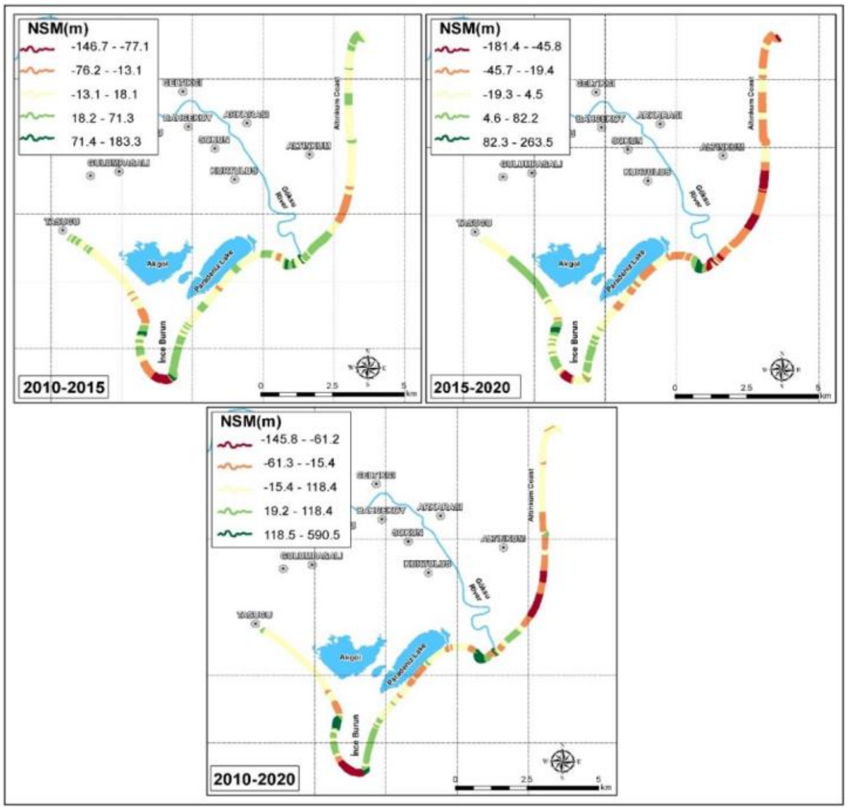

Figure 14. Coastline change in the 2010-2020 period according to NSM statistics

When the changes that took place between 2010 and 2015 are examined, it is seen that the progress in the coastline continues. Incekum, Altinkum and partly Taşucu regions are areas where accumulation is clearly seen. While erosion was effective in the estuarine region in the previous period (2000-2010), the material transported from the Göksu River rapidly advanced along the shoreline after this period. The rate of accumulation varies between 18 and 183 meters. In this period, it can be seen that heavy accumulation took place only to the south of Incekum (-77 /-146 m). In the 2015-2020 period, a regression is observed against the delta. The most affected areas in this period are the Paradeniz Lagoon coastal promenade and Altınkum location. Erosion has occurred in almost all of the Altinkum coastlines. The regression rate in these fields varies between – 19 and – 181 meters. At Taşucu and İncekum localities, progress has been made on the shoreline (4-263 m). An average of 82-263 m progression was detected in the areas where accumulation is severe (Figure 15).

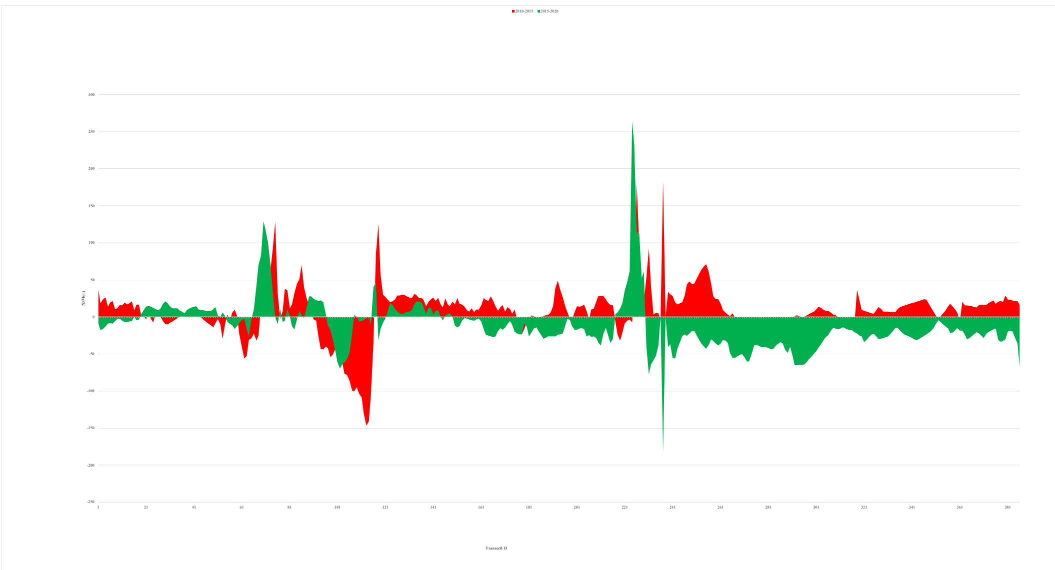

Figure 15. NSM graph for the period 2010-2020

LRR Statistic Result

LRR is a statistical approach that calculates the rate of change in the shoreline. In order to better convey the outputs obtained as a result of the LRR process, the Göksu Delta was examined by dividing it into 3 zones. Zone 1 covers the area from Taşucu location to the mouth of Göksu River; Zone 2 represents the mouth of the Göksu River and Altınkumu locality; and finally Zone 3 represents Altınkum location and the eastern border of the delta.

Changes in Zone 1

When the changes in the region forming zone 1 are examined, it has been determined that the shoreline in the F1 sector (south of İncekum cape) has regressed. The intensity of the regression was calculated at 12 m/y. As in other analyses, regressions were recorded in the coastal promenade of the Paradeniz Lagoon (Sectors A1 and B1) as a result of the LRR. An average of – 5 meters of erosion occurs here per year.

The east and west coasts of Incekum headland (Sectors E1 and G1) are the areas where dune accumulation is intense. The shoreline advances an average of 5 to 11 meters per year. It is seen that the change in the İ1 sector (between Taşucu and İncekum) is minimal (Figure 16).

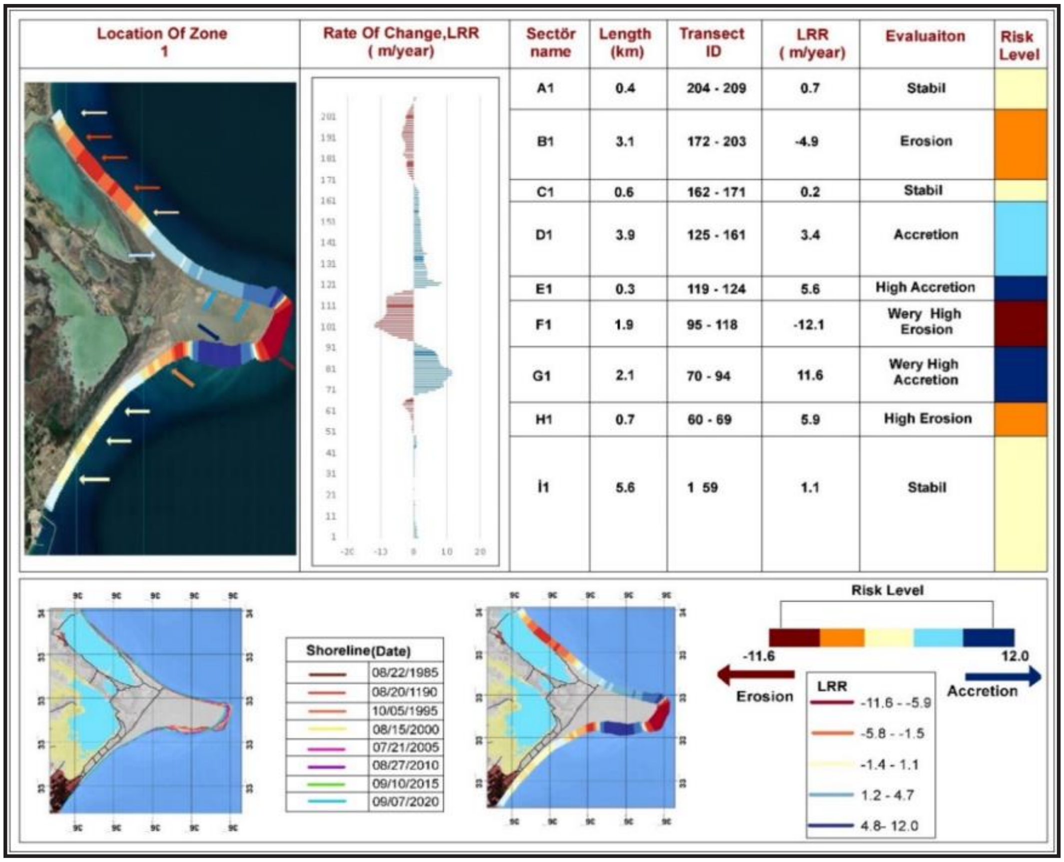

Figure 16. Zone 1 LRR statistical results

The results obtained from the LRR statistics were compared with the EPR and NSM statistics. As a result of this evaluation, the R2 value was calculated as 0.98 (Figure 17). It has been determined that all three statistical outputs produce close results. The areas where wear and deposition are at their maximum show a great deal of similarity.

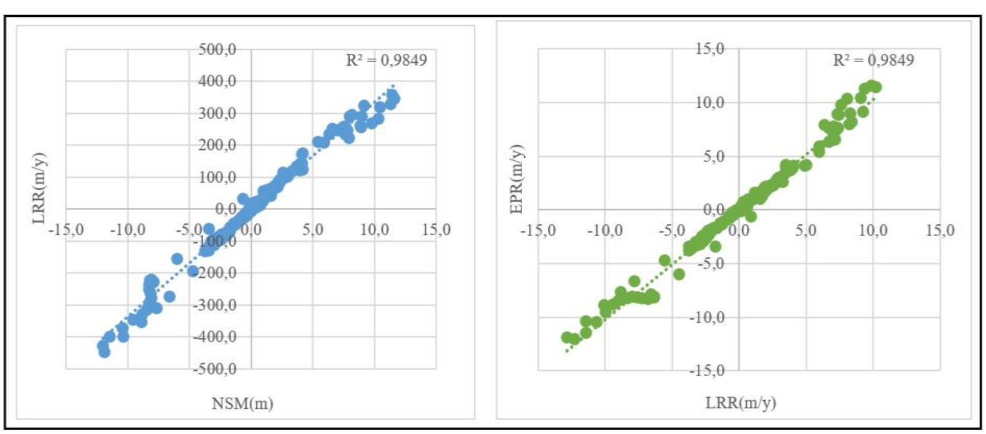

Figure 17. Comparison of coastline ratios obtained by different statistical methods for zone 1

Changes in Zone 2

When the LRR statistics of the area between the mouth of the Göksu River and Altınkumu are evaluated; It is seen that the coastline is advancing in almost every area. In these areas, sand dune accumulation occurs at an average rate of 1-6 meters per year. The area where the accumulation peaks is sector C2 (6 m/y). In zone 2, the only area where the shoreline regresses is the estuary (sector B2). Here, the rate of decline is between – 1 and – 6 meters per year on average (Figure 18).

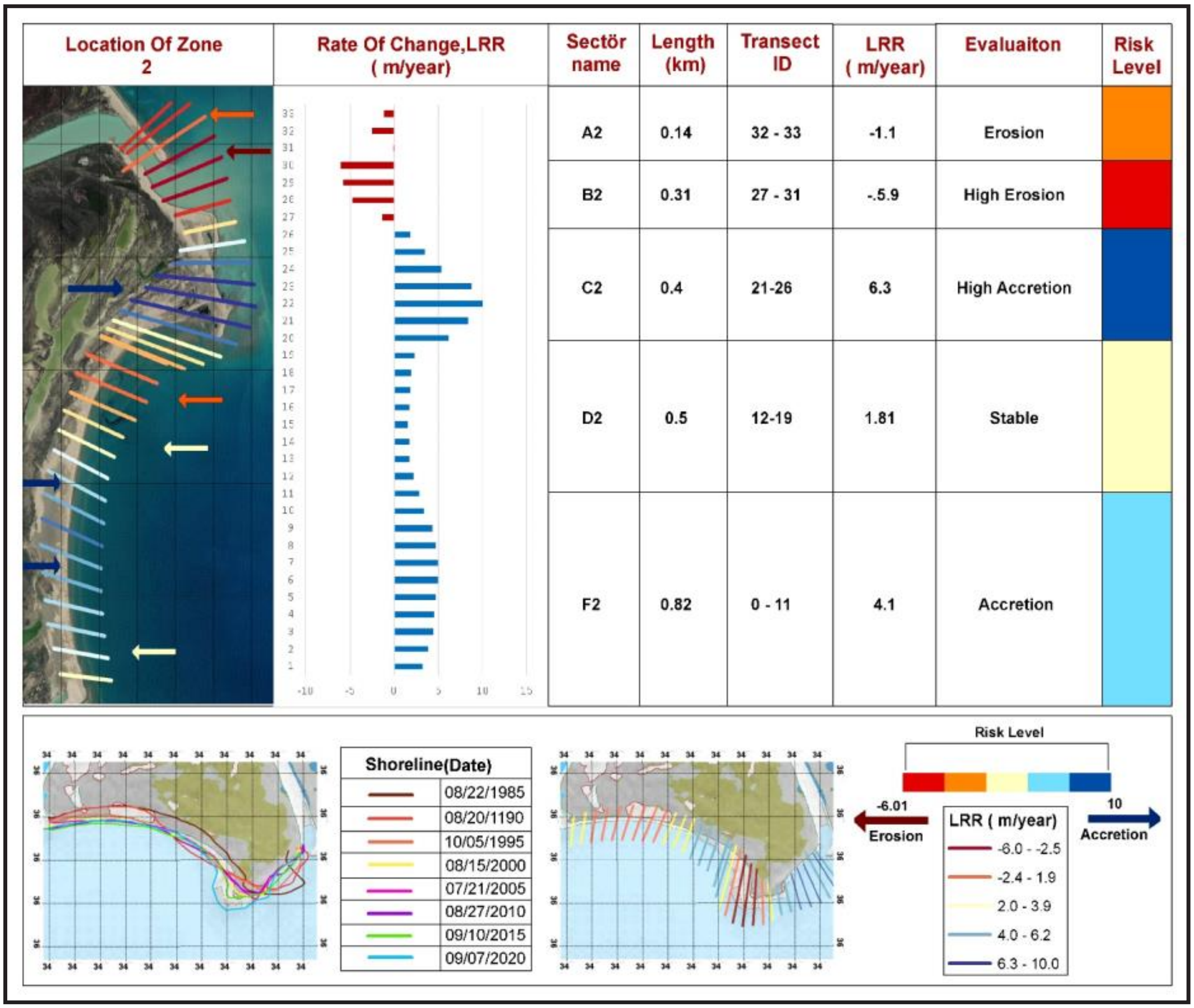

Figure 18. Zone 2 LRR statistical results

The R2 value obtained by comparing LRR with EPR was found to be 0.84, NSM. It was determined that the areas of high wear and accumulation in the areas representing zone 2 were compatible in all three statistics (Figure 19). Uncertainties at the Göksu river mouth affect the agreement between the statistics.

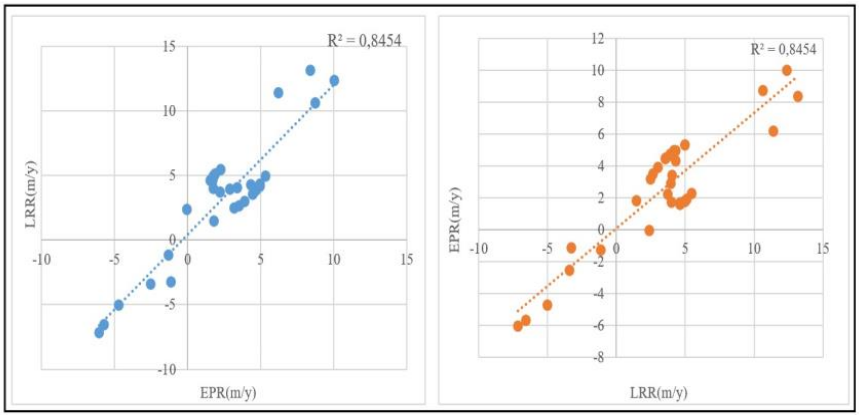

Figure 19. Comparison of coastline ratios obtained by different statistical methods for zone 2

Changes in Zone 3

According to Figure 20, which shows the LRR statistic calculated for zone 3, it is seen that there is high erosion in the 35-year period. The severely eroded area covers the F3, G3 and H3 sectors. Especially in the G3 sector, very high wear has been recorded. Here, the rate of change is calculated as – 5 m/y, in the F3 – H3 sectors, as – 3 and – 2 m/y, respectively. In the D3 sector, where an average of – 1 meter of decline is experienced per year, low erosion has been detected. Accumulation areas in zone 3 are sectors A3, C3, E3 and I3. The İ3 sector is the only area in Zone 3 where there is high agglomeration and an average of 3 m of sand is accumulated annually. The accumulation rate in other sectors varies between 0.11 m/y and 1 m/y (Figure 20).

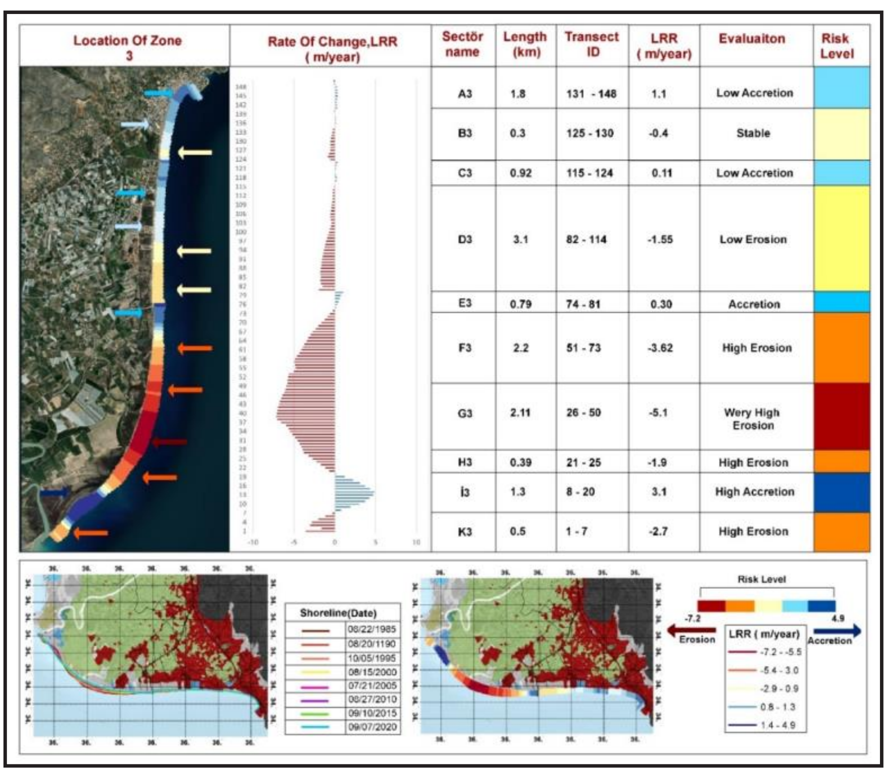

Figure 20. Zone 3 LRR statistical results

The results of the LRR statistics and the outputs obtained from the EPR and NSM calculations were compared. The obtained R2 value is 0.99 with EPR and 0.98 with NSM (Figure 21). It is seen that the statistical results produce very close results. Erosion and accumulation areas were almost the same in all three statistics.

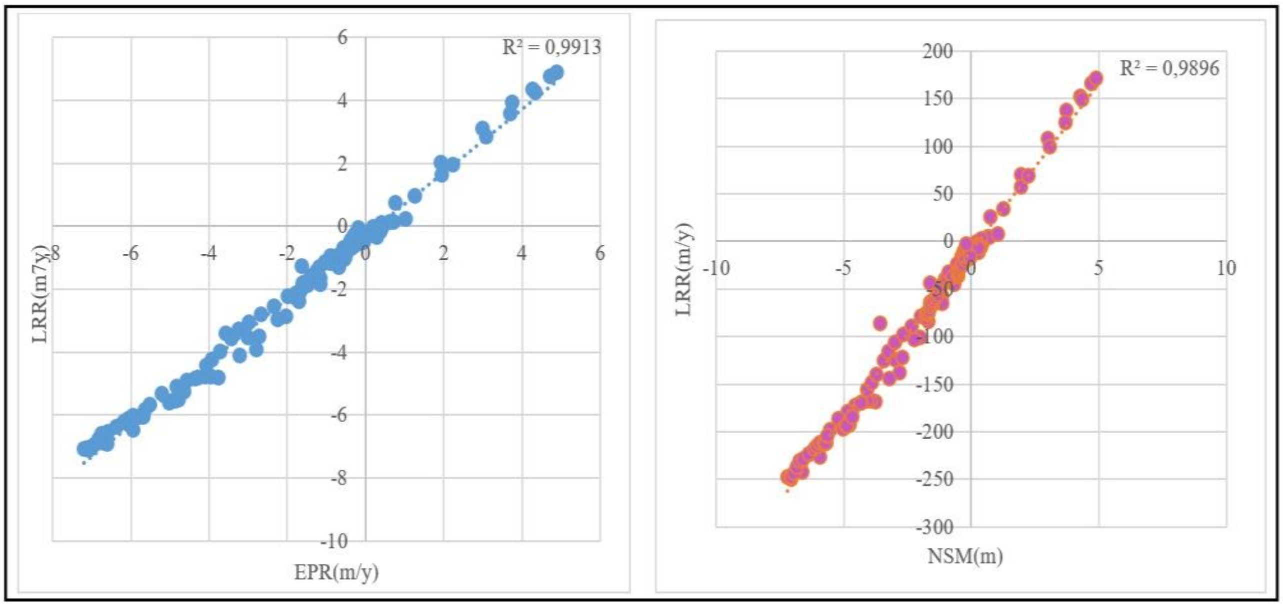

Figure 21. Comparison of coastline ratios obtained by different statistical methods for zone 2.

Estimated State of the Coastline in 2030 and 2040

Probability calculations were made with the DSAS add-on in order to determine the coastal position of the Göksu Delta in 2030 and 2040. Based on the statistical results, possible erosion or accumulation areas of the coastline in the next 20 years have been determined. With the data obtained from the results of this study, a prediction model was created and the change that could occur in ten-year periods was calculated.

Shoreline Forecasts for 2030

As a result of the calculations, it is seen that the strip from Taşucu to İncekum can remain stable in 2030. Similar to other periods on the western shores of Incekum, it is estimated that the accumulation may be dominant and thus the shoreline will progress. The tip of Incekum, the southeast shores of Lake Paradeniz and the mouth of the Göksu River are predicted to regress on the coast due to erosion. Although partial erosions are observed along Altınkumu location, it has been determined that it will maintain its current position to a large extent (Figure 22).

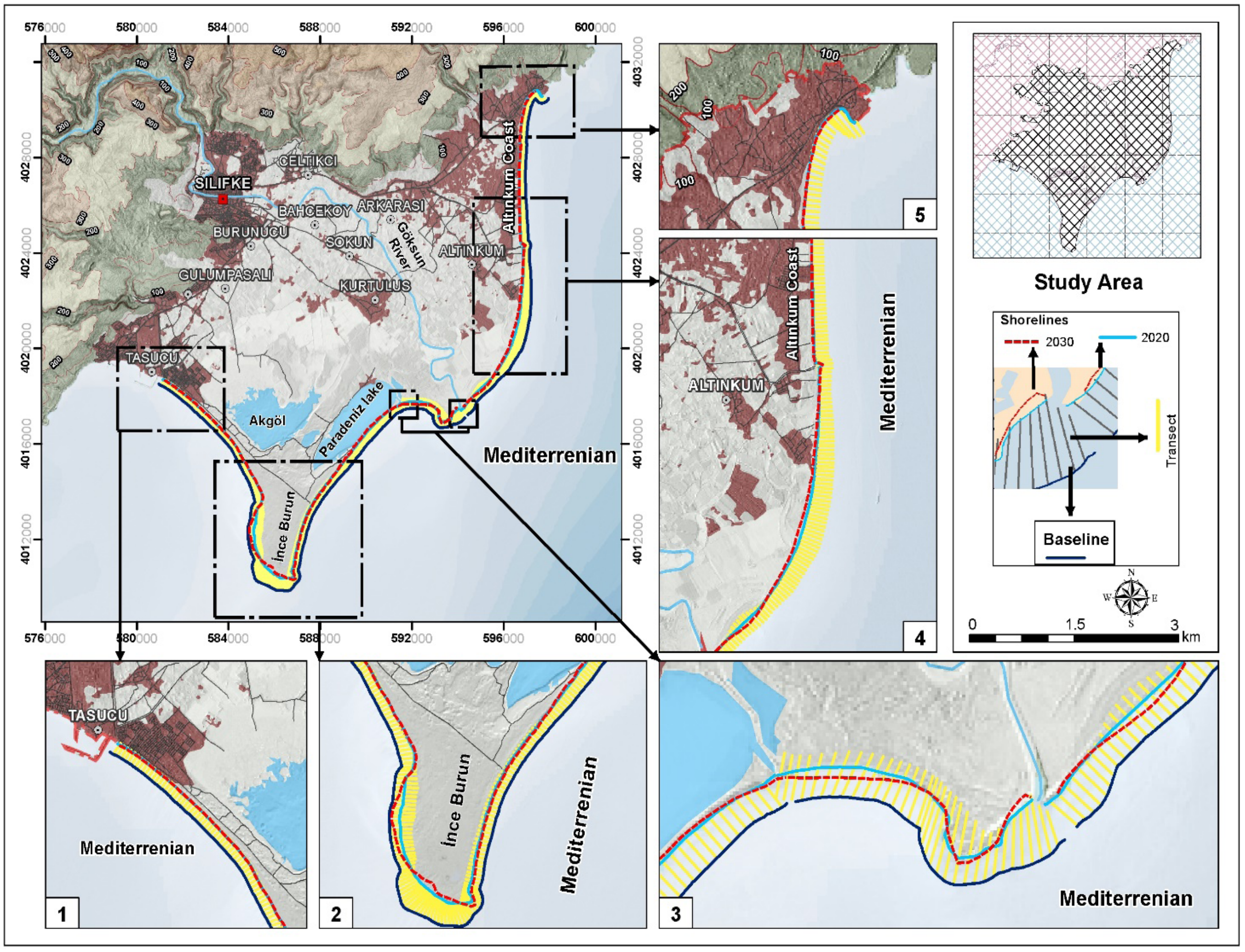

Figure 22. Estimated position of the coastline in 2030

Shoreline Forecasts for 2040

As a result of the analyses made to determine the location of the coastline in 2040, it is estimated that the area between Taşucu location and İncekum will be in a similar position to both the year 2030 and the current coastline. It is predicted that the western shores of Incekum will be exposed to high concentrations, while the headland may be eroded. The area where Göksu River is in contact with the sea has been calculated as having possible erosion. It is observed that erosion can be at a high level, especially in the coastline between Paradeniz Lake and Göksu River. It has been determined that there may be a regression of the shoreline at the location between the Göksu River and Altınkum (Figure 23).

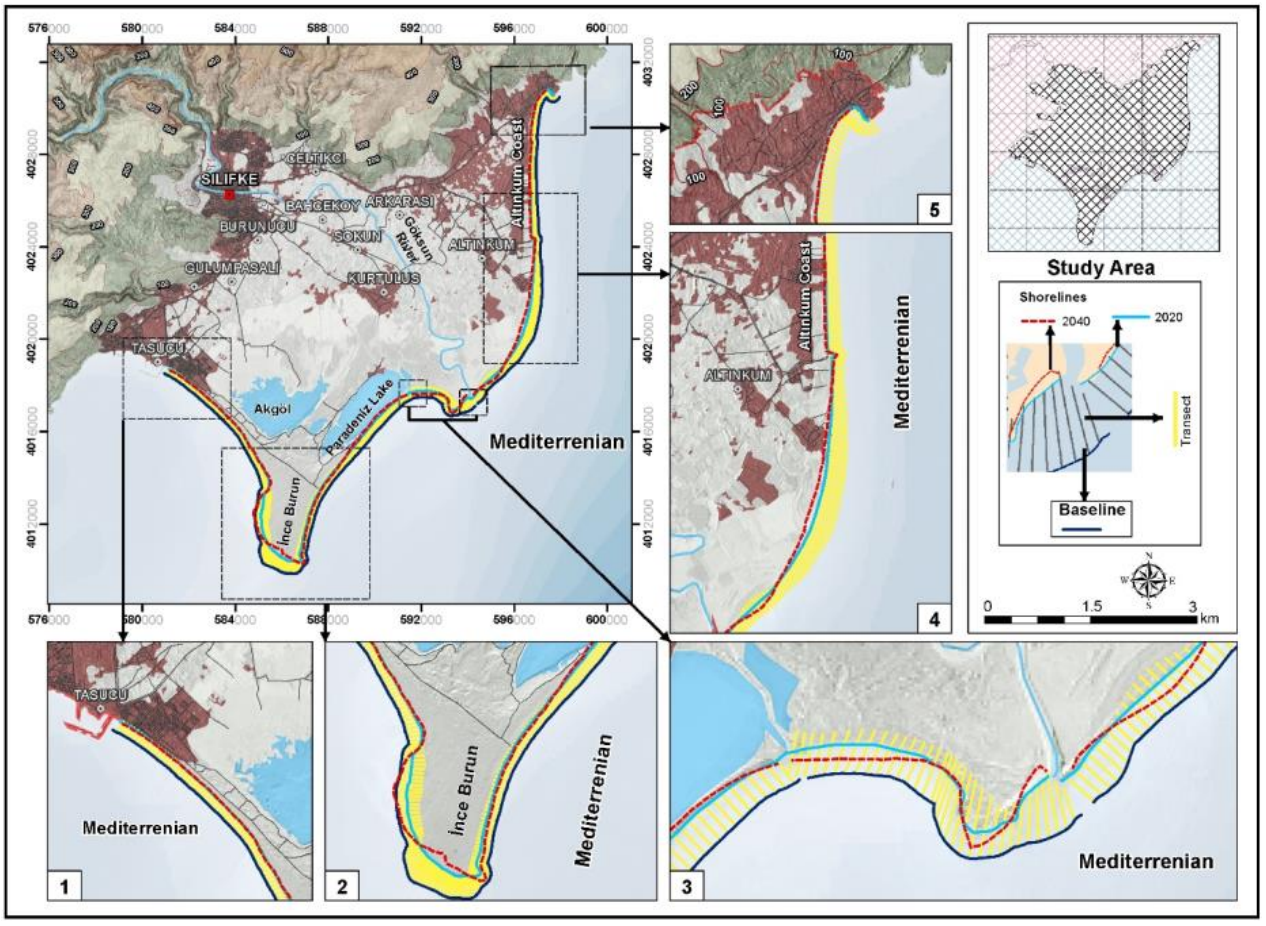

Figure 23. Estimated position of the coastline in 2040

CONCLUSION AND DISCUSSION

Coasts are areas with unique geographical and morphological characters. The pressure of various factors on the coast changes the coastal features dramatically. Especially after the 20th century, the coasts have become the economic base of the countries (Song et al., 2021). This situation has brought about the unplanned use of the coasts as a result of anthropogenic activity. Some coastal countries have had a direct impact on the coastline by moving the coastline towards the sea in order to increase production. However, sea level rises experienced in later periods caused economic, ecological and social consequences (Liu & Jezek, 2004). For this reason, the effective and sustainable use of the coast and the protection of ecological values necessitate geographical planning. Satellite systems and the development of various analyses; It produces reliable results in monitoring the changes in the coastline and creating future forecasts. The use of satellites with high temporal and spatial resolution provides great advantages in the planning phase.

In the analyses made to determine the coastline change of Göksu Delta; Incekum, Altinkum, the part of the Goksu River in contact with the sea and its surroundings seem to have had a dynamic character over a 35-year period. According to the EPR statistics, it was determined that the erosion areas during the 1985-2000 period were the coastal cordon of Altınkum, İncekum and Paradeniz Lagoon (-1 and – 13 m/y). It is observed that erosion peaked in the 1995-2000 period. The east and west coasts of the Incekum cape and Taşucu locations are dune accumulation areas. The accumulation rate here is between 3 meters and 25 meters per year on average. Severe accumulations were experienced between 1985-1990. In this period, NSM statistics produced similar results. It has been determined that the erosion areas are Incekum cape and Altinkum, and the deposition takes place on the east and west coasts of Incekum cape and Taşucu.

As a result of the EPR statistics in the 2000-2010 period, it is seen that the coastline regressed between – 2 and – 50 meters per year on average. Areas where the regression is clearly felt are Incekum Promontory and Altinkum. Erosion has intensified during the period of 2005-2010. It is seen that the change is in favor of the delta in the 2000-2005 period. Especially in the western shores of Incekum cape, accumulation has occurred throughout the period. During the 2000-2010 period, an average of 1-23 meters of sand dunes were added to the shores of the Göksu Delta per year. It is seen that the NSM calculations prepared for the 2000-2010 period are largely similar to the EPR. Erosion is seen to be dominant in the coastal promenade of Paradeniz Lagoon, in the south of Altınkum and İncekum cape. It was determined that the accumulation intensified on the west coast of Incekum.

According to the results of EPR and NSM in the 2010-2020 period, it was determined that erosion progressed in almost every area. According to the EPR statistics, erosion is dominant in Incekum, Altinkum and Paradeniz coastal lines during this period. The average amount of erosion varies between – 0.5 and – 14 m/y. Intense accumulation is observed only in the mouth of the Göksu River and around it (21-59 m/y). According to the NSM result, the erosion areas are İncekum and Altınkum. Contrary to the EPR statistics, the coastal promenade of the Paradeniz Lagoon has remained largely stable, although partial erosion has occurred. Göksu River mouth was determined as the accumulation area similar to the result of EPR. Unlike the EPR calculation, the east and west coasts of Incekum cape are also areas where dune accumulation occurs. As a result of both statistics, wear accelerated after 2015. As a result of LRR calculations, it was determined that both erosion and accumulation are intense in Zone 1. Similar to other calculations; On the east and west coasts, it was determined that there was accumulation. It is observed that accumulation is dominant along zone 2, and erosion only occurs at the mouth of the Göksu River (Sectors A2 and B2). Zone 3 (Altınkum location), unlike Zone 2, has been subject to continuous erosion. Accumulation was detected in only 4 sectors (A3, C3, E3, H3).

As a result of the estimation analysis for the years 2030 and 2040, it has been determined that the areas sensitive to erosion and agglomeration are similar to the previous years. In 2030, it is predicted that the İncekum location will be able to advance the border of the western coasts. It is stated that the area between İncekum and Göksu River will be under the influence of erosion. In 2040, similar to 2030, the west coast of Incekum is the area where the accumulation can be maximum. It has been calculated that the regression of the shoreline may occur at the tip of Incekum. It has been estimated that the area between Taşucu and İncekum may be similar to its current location. As a result of the analysis, it is seen that the areas most open to change are İncekum, Altınkum and partially Göksu River and its surroundings. Between Taşucu-İncekum and between Altınkumu and the eastern border of the delta, the shorelines remained mostly stable, although the area changed from time to time (Figure 15).

When the previous studies on the change of the Göksu Delta coastline are examined, it is seen that the erosion and accumulation areas are largely similar. Kilar and Çiçek (2018) indicate that the areas where the shoreline regresses are Incekum and Altinkum; In the areas where the coastline advances; They pointed out that it is the mouth of the Göksu River and the coastal promenade of the Paradeniz Lagoon. Karakoç and Karabulut (2010) emphasized that there was a continuous accumulation on the eastern and western shores of Incekum cape and the mouth of the Göksu River during the period covering the years 1972-2009, while erosion occurred at the ends of İncekum cape, Paradeniz Lake coastal cordon and Altınkum region. Gürbüz, in his study in 1997, discussed that erosion is high on the eastern shores of the Göksu Delta and this situation is related to the changing of the bed of the Göksu River. He stated that the coastline of the Göksu Delta changes more and more each year and emphasized that the dams built in the region and the areas opened to agriculture will affect the change. Our analyses in addition to the results of these studies show that there is not only accumulation but also erosion at the mouth of the Göksu River. The difference in the mouth of the Göksu River with similar studies indicates that the area tends to change every year.

As a result of the findings obtained, 4 regions sensitive to change were determined. These areas are Göksu River mouth, İncekum cape, Paradeniz Lagoon coastal promenade and Altınkum locations. Keçer and Duman (2007), in their study examining the artificial effects on the Göksu Delta, draw attention to the fact that the change of the bed of the Göksu River in the 1950s disrupted the natural balance of the delta. In another study by Keçer in 2001, it was reported that erosion increased in Altınkum locality and even reached the level of disaster. The outputs of this study show that the erosion experienced in Altınkum and its surroundings has reached a more serious level in recent years. The increase in construction on the coasts of Altınkum and the widespread use of sand from the delta accelerates the changes that may occur. The Ermenek Dam (2009) built on the Göksu River is expected to have a negative impact on the river's regime. On the other hand, Ermenek Dam reduces the amount of sediment carried by the river and this stops the progress of the coastline. Perhaps the most important factor leading to changes in the shoreline is wave erosion. The physical structure of the Altinkum shores is in a position to be affected by wave erosion. Human activities on the river (such as river mouth changes) pave the way for wave erosion.

The protection of the natural system should be the primary goal in the planning of coastal areas. The areas to be opened for agriculture or settlement should be determined in a way that does not spoil the character of the delta, and the activities there should be controlled. Long-term monitoring of coastal areas guides the method of these areas. Scientific research should be taken into consideration while researching solutions for the problems in the delta. Forecast models covering the next few decades provide great advantages for managers. The use of these models in planning can help protect the delta ecology.

ACKNOWLEDGEMENTS

The first author of this study is a YÖK 100/2000 (Remote Sensing and Geographic Information Systems (including RF, IR and Acoustic Sensors, Advanced Data/Image Processing)) priority field scholar. Thanks YÖK.

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