

## SPATIO-TEMPORAL ANALYSIS OF THE COASTLINE OF FALIRO BAY, ATTICA, GREECE

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### ABSTRACT

Coastal zone of Attica has been subject to constant changes generated by human interference during the last decades of the 20<sup>th</sup> century. Faliro Bay is located along the southwestern coast of Attica. Important changes are taking place in the area, due to human development that has irreversibly altered the physical features and has shaped the morphology of the bay. The aim of this paper is to record and monitor the coastline changes in Faliro Bay during a long-term period. In order to detect the changes of the coastline, different methods, such as comparing topographical maps, aerial photographs and satellite imagery of different dates have been used.

**Key words:** *Coastline changes, G.I.S., topographical maps, aerial photographs, satellite imagery, Greece.*

### RESUMEN

La zona costera de Attika ha sufrido cambios continuos en las últimas décadas del siglo 20 provocados por la intervención humana. La bahía de Faliro está localizada a lo largo de la costa sur-oeste de Attika. Significativas modificaciones han tenido lugar en la región, a causa del desarrollo humano que ha cambiado de forma irrevocable las características naturales y ha configurado la morfología de la bahía. El objeto de este trabajo es la presentación y el control de los cambios de la línea costera en la bahía de Faliro en un período de tiempo largo. Para el estudio de los cambios de la línea costera se ha utilizado la comparación de mapas topográficos, de fotografías aéreas y de imágenes de satélite.

**Palabras clave:** *Cambios de la línea costera, G.I.S, mapas topográficos, fotografías aéreas, imágenes de satélite, Grecia.*

### Introducción

The coastal area is the in-between zone of land and sea and its features are formed through the continuous interaction of the Geosphere, the Hydrosphere and the Atmosphere. Apart from the natural impact, it is an area of utmost importance because man has developed multiple activities worldwide. The intense, diverse human activities such as house construction, industry, sewage, tourism, fishing, farm-fishing release trace metals, organic compounds, and fertilizers into the coastal environment (Cracknell, 1999, Doerffer *et al.*, 1999). It is essential to record and monitor the rapid evolution of the coastline to properly manage the coastal environment.

In order to study the coastline changes, various techniques have been used. Some researchers compare topographic maps (Carter *et al.*, 1980, Gunasekera, 1996, Nairn and Cowie, 1997) of different periods, some others compare aerial photographs of different periods, too (Carter *et al.*, 1980, Gunasekera, 1996, Watters and Wiggins, 1999, Skilodimou, 2002). Moreover, satellite imagery has been used to describe coastal changes (Eyles, 1997, Phinn *et al.*, 1998, Mason *et al.*, 2000, Winarso, 2001, Zhu, 2001), and this method has been proved to be a unique tool for environmental research because the mapping of the coastline is accurate and provides with multiple and update information (Yang *et al.*, 1999, Gatsis *et al.*, 2001).

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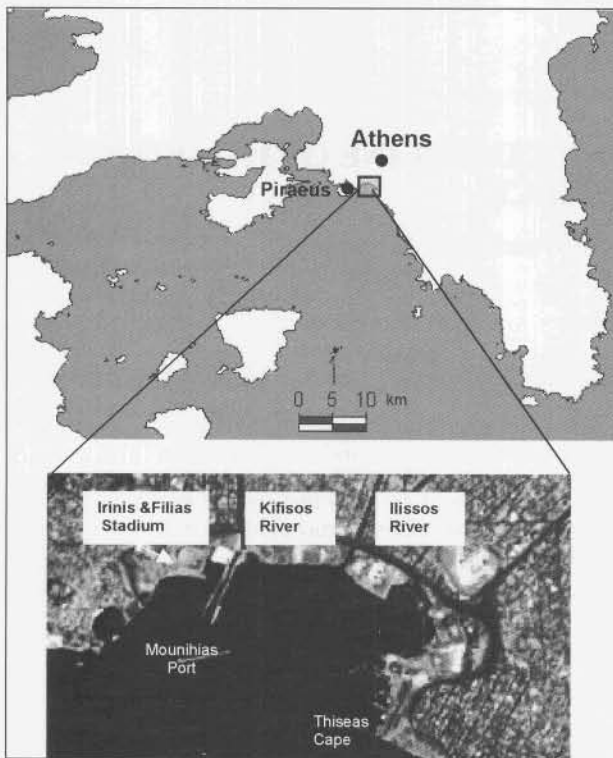


Fig. 1.—The study area.

The coastal zone of Attica has been subject to constant changes due to human interference during the last decades of the 20<sup>th</sup> century. The Faliro Bay is located along the southwestern coastal zone of Attica. Its vicinity to the city of Athens is the cause of being affected by human activities. Human development has irreversibly altered the physical features and has shaped the morphology of Faliro Bay.

The aim of this paper is the spatio-temporal monitoring of the changes occurred in the coastline of Faliro Bay from 1882 to 1999. The authors are identifying the changes of the geomorphologic environment during the time interval of 1882-1991 by comparing topographical maps of different periods. Furthermore, aerial photographs and satellite image (from 1945 to 1999) have been used to measure the coastline changes due to human interference. While being extremely efficient, this methodology is rapid, reliable and economical, in one word, it is a useful tool for the recording and monitoring of the coastline change. Such methodology has been applied for the first time in Greece, and may contribute to the environmental coastal management.

## Description of the study area

The study area is located in the southwestern part of Athens and is extended from Microlimano (Port of Mounihias) up to the Theseas' Cape. It is also a coastal area connecting the city of Athens with the city of Piraeus (fig. 1). The Faliro Bay composes of the estuaries of the Kifisos and Ilissos rivers.

The substrate of area is formed mainly of post-alpine formations. Pliocene sediments are located mainly at the western and eastern part of the bay whereas Quaternary fluvial sediments of Kifisos and Ilissos rivers are met in the middle of the bay (Lepsius, 1893, Haralambakis, 1952, Gaitanakis, 1982).

## Data used

The topographical maps employed were the sheet «ATHEN-PEIRAIEUS», scale 1:25,000, of the Royal German Archaeological Institute, (Allen and Kaupert, 1882), and the sheet «ATHENS-PIREUS», scale 1:50,000 (Geographical Military Service, 1991).

The aerial photographs that have been used were taken from 1945 and onwards because there were no available photographs before that year. Specifically, the aerial photographs dated from 1945 (scale 1:42,000), 1960 (scale 1:30,000), 1972 (scale 1:40,000), and 1987 (scale 1:35,000).

A Landsat 7 TM satellite image has been used and its characteristics are: sensor: thematic mapper ETM+, spectral bands ( $\mu\text{m}$ ): 1:0.45-0.515 2:0.525-0.605 3:0.63-0.690 4:0.75-0.90 5:1.55-1.75 6:10.40-12.5 7:2.09-2.35 8:52-90 (panchromatic), resolution: 30 m/ (60 m for Band 6) (15 m for Band 8), temporal resolution: 16 days, radiometric resolution: 8 BIT PATH/ROW: 184/032, acquisition date: August 1999.

## Techniques and processing

Image processing and GIS techniques have been used to accomplish the research. After scanning the topographical maps, they were electronically compared. The results were only qualitative.

The examined aerial photographs had different scales; therefore, they were adjusted firstly to the EGSA system of projection of the topographic map of Geographical Military Service «ATHENS-PIREUS» (1991), scale 1:50,000, in GeoTiff format. Thus, each aerial photograph is characterized by a georeference adjusting their common points with the ones of the topographical maps. Furthermore, the coastline was digitized in each aerial photograph for all the four different data, and then they were compared. The further processing of the images is accomplished by the TNTmips software.

Lastly, a data fusion georeferenced image has been produced using bands 4, 3, 5 and the panchromatic one, in order to map the coastline on a recent date. Overlaying techniques have been used to identify the changes and measure the land expansion from 1945 to 1999. The employed data and techniques are shown in figure 2.

## Changes from 1882 to 1991 as detected by the comparison of topographic maps

The Faliro Bay is depicted in figure 3; the upper part is the old topographical map whereas the lower

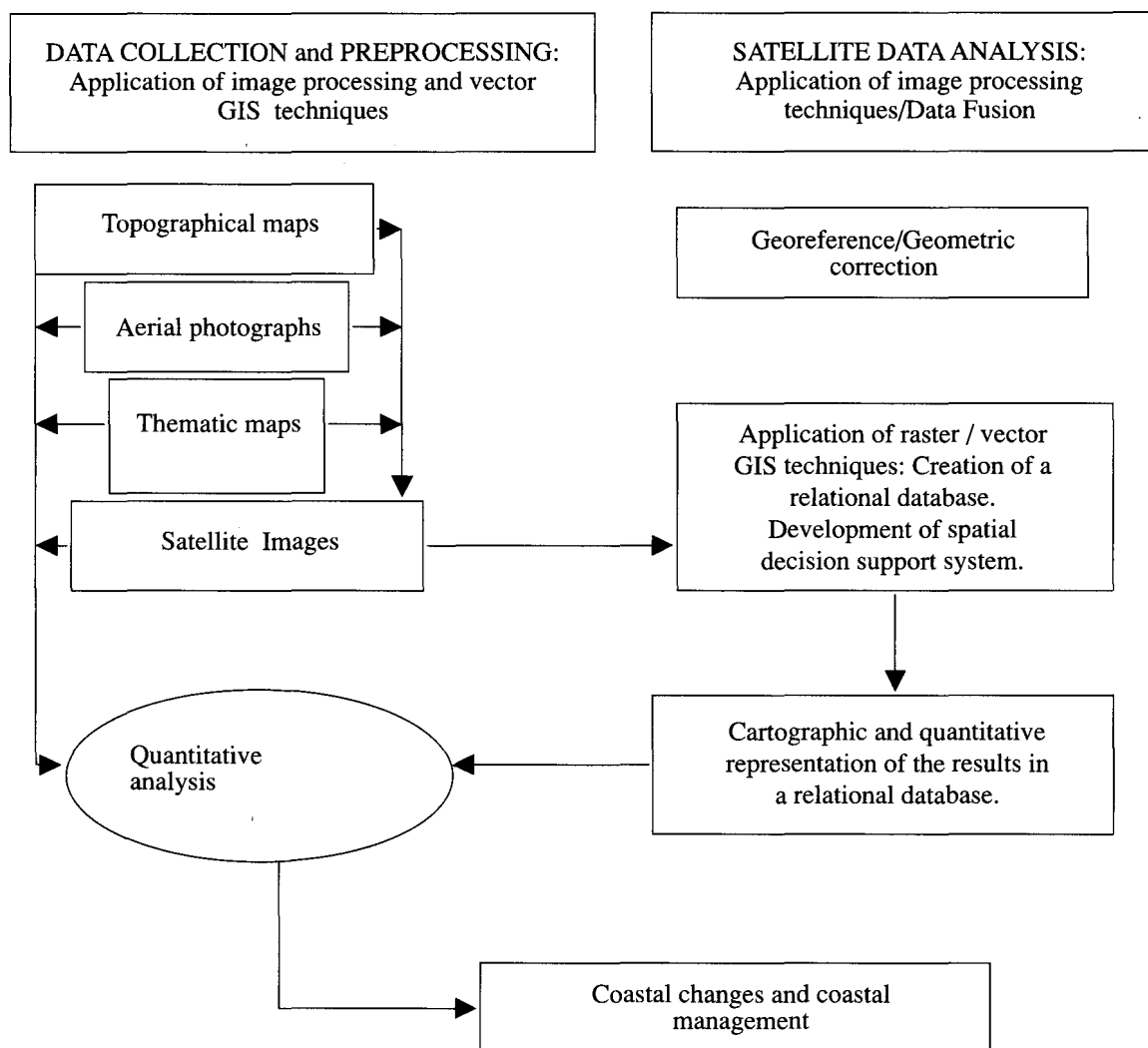


Fig. 2.—Diagram of data and processing techniques used in the study.

part is the recent topographical map. During these 110 years, a lot of significant changes have taken place caused mainly by human interference. The alterations observed in the natural and geomorphologic environment as displayed by the comparison of the topographical maps are:

a. Disappearance of coastal dunes expanding along the shore of Faliro along with elimination of the old lagoon (salz teiche) located in the southeastern part of the region (fig. 3).

b. The construction of technical works and the management of bay led to intensive filling-in. The human interventions resulted to the artificial expansion of the land against the sea and thus the modification of the coastline.

c. Deviation and bank management of the Kifisos and Ilissos rivers.

d. Extensive land use, due to housing construction, construction of roads and technical works such as the Irinis & Filias Stadium and marinas.

**Changes from 1945 to 1999 as recorded from aerial photographs and satellite image**

The changes occurred in the Faliro Bay were recorded by comparing aerial photographs and satellite image and were examined in five periods of time: the first from 1945 to 1960, the second from 1960 to 1972, the third from 1972 to 1987, the

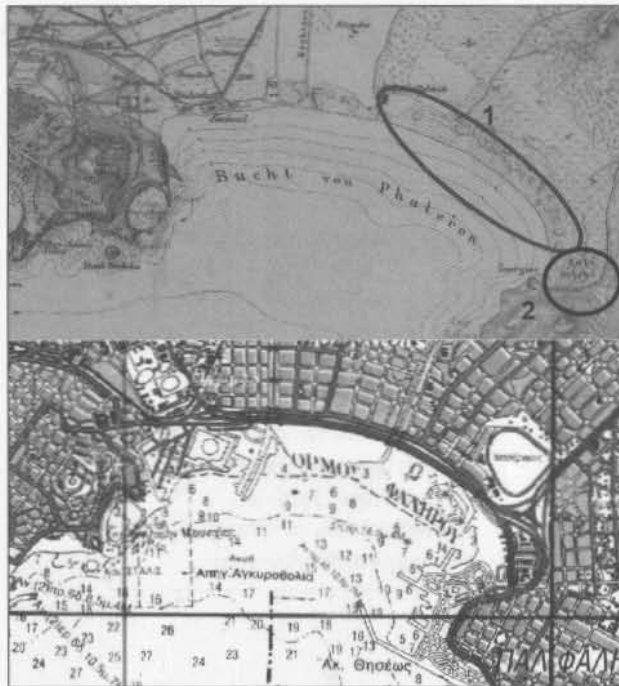


Fig. 3.—The Falirio Bay is shown in two maps of different dates: upper part in 1882 and lower in 1991. The location 1 shows the appearance of coastal dunes. The location 2 shows where the lagoon was situated.

fourth from 1987 to 1999 and a last fifth which covers the years from 1945 to 1999.

#### *Changes of the coastline from 1945 to 1960*

The examination of the 1945 to 1960 aerial photographs reveals that minor changes of the coastline occurred in Falirio Bay during this period. Figure 4 depicts the coastlines of the two different dates. The change in the middle of the coastline stems from the natural deposits of Kifisos and Ilissos rivers. Consequently, the Bay is not yet affected by the construction of public works.

#### *Changes of the coastline from 1960 until 1972*

Between the years 1960 and 1972 human interventions are significant leading to the first hints of alterations in the coastline, as shown in figure 5. The alteration observed at the western part of the Bay is originated from the earth filling in favour of the technical works. The same works take place between the rivers Kifisos and Ilissos aiming at the management of their beds. As for the eastern part of the Bay, it has been banked up to construct new marinas.

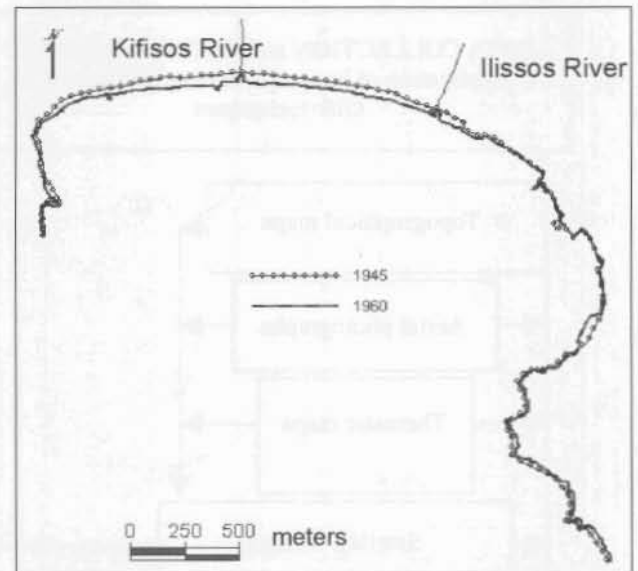


Fig. 4.—Changes on the coastline from 1945 to 1987.

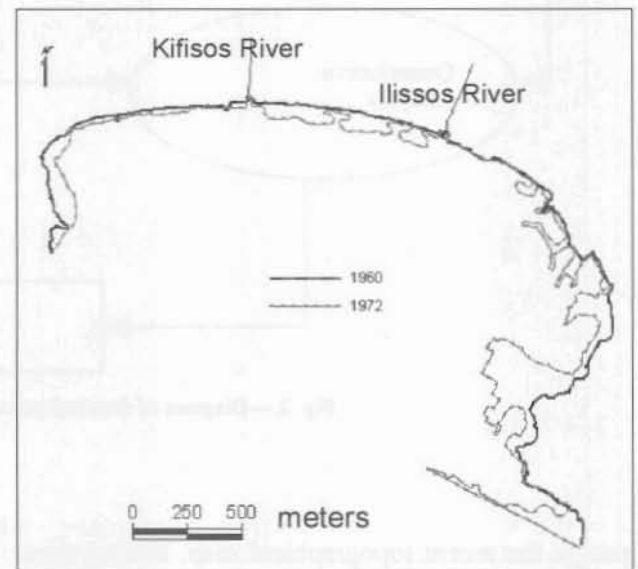


Fig. 5.—Changes on the coastline from 1960 to 1972.

#### *Changes of the coastline from 1972 until 1987*

Changes of the coastline occurred between 1972 and 1987 are depicted in figure 6. The present Irinis – Filias Stadium and secondary marinas were constructed at the western part of the Bay. The bed of Kifisos river has been arranged and, thus, flows into the Bay through an artificial channel. In addition, the government constructed central roads onto the

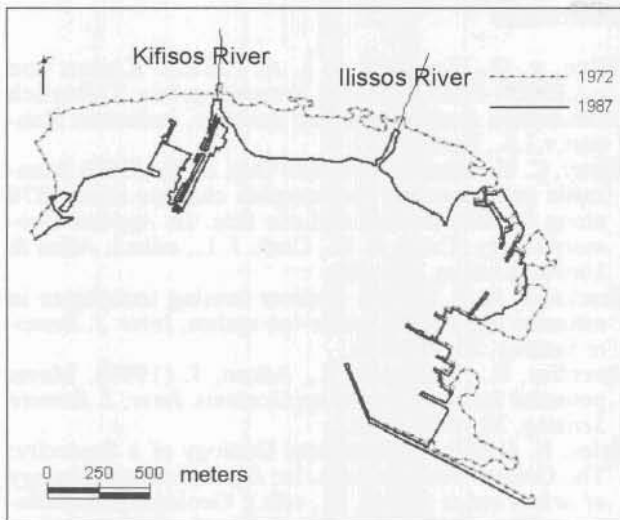


Fig. 6.—Changes on the coastline from 1972 to 1987.

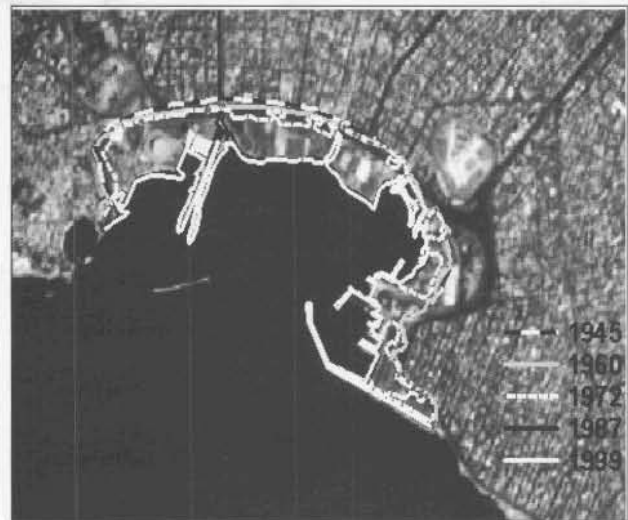


Fig. 8.—The coastlines as mapped on the different dates have been overlaid on the satellite image with acquisition date of 1999.

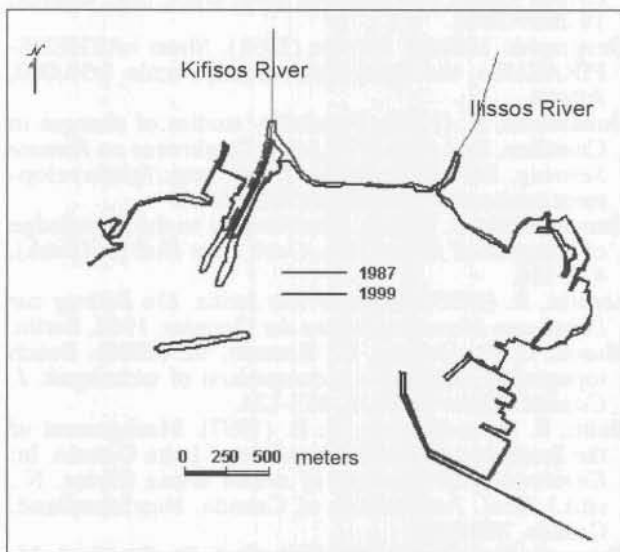


Fig. 7.—Changes of coastline from 1987 to 1999.

earth-filled locations. At the eastern side of the Bay, a modified entrance in the marina is constructed and a second marina is added.

*Changes in the coastline from 1987 to 1999*

Changes in the coastline between the years 1987 and 1999 are shown in figure 7. The coastlines have

resulted by comparing the aerial photograph of year 1987 and the satellite image of 1999. The changes during this time period are detected between Kifisos and Ilisos rivers mouth due the continuous filling in the area. Kifisos discharge through an artificial channel, and, consequently has increased its length; a breakwater has been constructed face to the channel to protect it from the wave activity. An additional change of the coastline has occurred by the expansion of the beach in front of the Stadium Irinis & Filias that have been produced by the construction of another breakwater to protect the beach from sea-erosion. The expansion is, however, the result of a sediment deposit from the sea. Finally, the jetty of the marinas located at the eastern part of the bay, has artificially extended.

*Total changes of the coastline from 1945 until 1999*

The four different coastlines that are respective to the years 1945, 1960, 1987 and 1999 are shown in figure 8. Between the years 1945 and 1999 the coastline of the Faliro Bay has been artificially expanded (fig. 9). Its length is 4,600 meters and its width fluctuates from 25 to 900 meters. All technical works such as the Stadium Irinis & Filias, the crossroads, the marinas are constructed onto locations that were covered by sea in the past years, specifically in 1945. The surface of the earth filled area approaches the 1,238,757 square meters or, according to the quantitative evaluations made using GIS techniques.

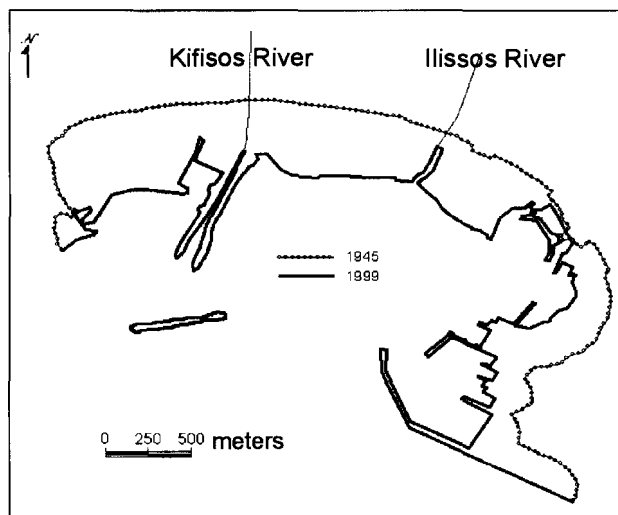


Fig. 9.—Total changes of the coastline from 1945 to 1999.

Nowadays, the uncontrolled filling-in of the study area is on-coming. The changes will be more intensive because of the public works for the Olympic Games of 2004.

## Conclusions

The combination of image processing and GIS techniques is a unique tool to detect the coastline changes over time in relation to economic, social and environmental indicators. Registering and monitoring the coastal changes is an essential knowledge to facilitate proper coastal management.

The employed methodology is rapid, reliable and cost effective and therefore it can be applied to the other coastal areas.

Since 1882, significant changes in the Faliro Bay have taken place in the morphology of the region. Strong human intervention has been interpreted from the comparison of the topographical maps. The effects are:

- The vanishing of the coastal dunes and the lagoons.

- The artificial expansion of the land to the detriment of the sea and, thus, the changes of the coastline

- The final changes of the coastal area, being examined with the help of the aerial photographs and the satellite image, were identified to be of an extent of the order of 4,600 meters length, and 25 to 900 meters width. The surface of the technically filled area approaches the 1.23 square kilometers.

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