AN ASSESSMENT OF THE COASTAL EROSION AT MARATHON EAST ATTICA (GREECE)

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Abstract

The 7 kilometers long coastline of Marathon Gulf (East Attica, Greece), has been chosen for this study, in order to classify its coastal erosion, using the Coastal Vulnerability Index (CVI) through GIS technology, since several incidents of erosion have been identified during the past decades in the area.
The CVI index is used for assessing the vulnerability of a coast to an anticipated future sea-level rise. It relates geological (coastal geomorphology, historical changes of coastline's position, coastal slopes) and oceanographic (wave height, run up and tidal range) variables in a semi-quantitative manner. We combined different kinds of datasets extracted from high resolution panchromatic aerial photographs of several time periods (1960-2010) and traced the contemporary shoreline by high accuracy surveying with Real Time Kinematic (RTK) GPS equipment. The interpretation of all shorelines required geo-statistical analysis in a Geographical Information System, in order to estimate the rate of shoreline change for a period of 53 years.
Retreating rates were calculated for each section reaching the value of 0.6 m/yr. According to the produced CVI values (10.61- 39.52), it is found that 46% of the coast has very high vulnerability, 20% high vulnerability, whilst 29% have low vulnerability. The area named "Plesti" at the southern part of the study area, a large segment at the coast of Nea Makri, the northern part of Agios Panteleimonas beach and the eastern estuary of the Inois river are those with the higher risk. These conclusions are in full agreement with the field observations.

Keywords: coastal vulnerability index, digital shoreline analysis, Real Time Kinematic GPS

Introduction

The coastal area is a highly dynamic environment with many physical processes, such as tidal inundation, sea level rise, land subsidence and erosion or deposition. Those processes play an important role in the shoreline change and coastal landscape development. Shoreline change is considered one of the most dynamic processes in coastal areas (Bagli & Soille, 2003; Mills, et al., 2005). The rate and extent of coastal erosion is expected to intensify as a result of increased sea-level rise, but erosion trends are not easily predicted because of the interplay between various factors, such as the sediment budget and near shore hydrodynamics along with climatic variables (Gornitz, 1991). In addition, dense population being placed near the shoreline leads to more vulnerable areas. It has thus become important to quantify the shoreline change, as an input data for coastal hazard assessment.
The purpose of this study is the assessment of coastal vulnerability of Marathon Gulf. Therefore the Coastal Vulnerability Index (CVI) was applied (Thieler & Hammar-Klose, 1999) and enriched with field data, existing topographic and geo-environmental information and GIS technology. Shoreline erosion or accretion rates were obtained from the interpretation of aerial photographs taken at various periods during the last 53 years. Additional data from the contemporary shoreline were acquired using Real Time Kinematic Global Positioning System (RTK-GPS) equipment, providing accuracy which in most cases can be better than a centimeter. The highest possible spatial resolution of the remote sensing images provides an acceptable and comparable to RTK shoreline trace.
Fieldwork data collection is necessary for the determination of the actual causes of coastal change, which might be related either to natural causes or human intervention or both. Such identification can

be useful for coastal management and find immediate application in many strategies regarding coastal development in both short and long term time scales.

Study area

The coastal zone of the present study is located in North East Attica at the Gulf of Marathon and has a total length of 7.7 km (measured after digitizing the coastline from 1:5,000 topographic diagrams). It lies between Nea Makri and the park of Schinias. The wider area, known as Marathon plain, is surrounded mainly by the mountainous massif of Penteli and is bordered by Mesozoic marbles and schistoliths. It belongs to the Attico-Cycladic geotectonic zone, which untill recently was considered one of the most aseismic and tectonically stable areas of Greece (Poulos et al, 2009). According to recent inquiries there seem to be some tectonic movements in the area. The main river in this area is Inois River, which has formed a deltaic fan with the youngest distributory, named Kainourio, reaching the sea at the easternmost area. The general direction of the drainage network of Inois river, whose sources are found on the northern side of Mount Parnitha (Maroukian, et al., 1993), is NW-SE. The southern part of the coast (Nea Makri) is almost linear with a NNW-SSE direction, whilst the northern part (beach of Agios Panteleimonas) has a SSW-NNE direction, and it is characterized mainly as a low-lying and sandy beach with various coastal geomorphological features (Fig. 1). Old and stabilized coastal dunes usually covered by shrubs and beachrocks are observed along the coast. Some are eroded due to coastal retreat. Also beachrocks, whose extensive parts have been removed or destroyed by human activities, are observed at the study area. Only a small segment at the southern part of the coast is characterized by soft cliffs composed by alluvial deposits. Southwest of the fan was a marshy area, Vrexissa, which was drained some decades ago (Maroukian, et al., 1993). Generally the area is underlain by recent alluvial sediments limited in thickness (Papanikolaou et al., 2008).

The area is characterized by a rapid and without rural planning expansion of urban activities, such as buildings, roads, irrigation network estimated up to 10% the last century (1880 - 2000) according to Xanthakis, et al. (2007), mostly because it is near Athens and attracts many tourists. A significant retreat of the shoreline (100 m) near the Inois river mouth took place during the last 120 years (Maroukian et al, 1993) reaching up to 2 m/yr in the 1950’s and 1960’s. This may have been caused mainly by (1) the drastic reduction of riverine sediment supply due to the Marathon dam, which was built in 1929 (2) the sand extraction from the lower course of the riverbed.

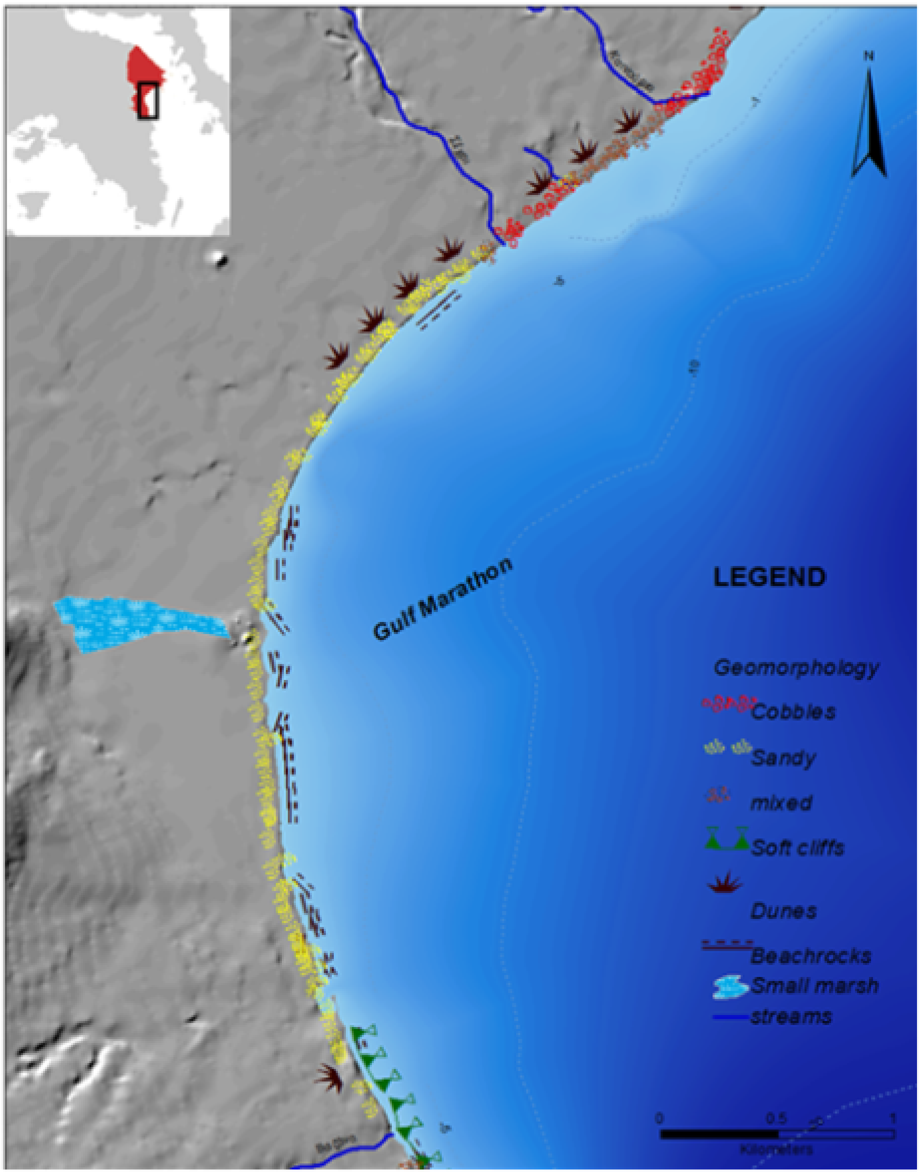

Figure 1. The geomorphological map of the study area - shoreline of Marathon Gulf, East Attica.

Data collection and Methodology

The Coastal Vulnerability Index (CVI) presented here was proposed by Hammar-Klose and Thieler (2001) that modified the initial index proposed by Gornitz et al. (1994). It is calculated as the square root of the product of eight variables, ranked from 1 to 5 according to Table 1, on the basis of its potential contribution to physical changes on the coast and divided by their total number (equation 1):

$$\mathbf{CVI} = \sqrt{\frac{(\mathbf{a}*\mathbf{b}*\mathbf{c}*\mathbf{d}*\mathbf{e}*\boldsymbol{f}*\mathbf{g}*\mathbf{h})}{\mathbf{8}}} \quad (1)$$

where, a: geomorphology, b: coastal slope, c: rate of relative sea-level rise, d: rate of shoreline erosion/ accretion, e: mean tide range, f: mean significant wave height, g: geological formations and h: land use. It was considered appropriate to modify the index adding two more variables, the geology and land use.

Table 1. Ranges for vulnerability ranking fo the eight variables used in equation 1.

CVI	Very low	Low	Moderate	High	Very High
Categories	**1**	**2**	**3**	**4**	**5**
Geomorphology		Soft cliffs	Beachrocks, Dunes	Graveled beaches	Sandy beaches
Shoreline Erosion-Accretion rate (m/yr)		0,03- 0	0 έως -0,25	-0,25 έως -0,35	-0,35 έως -0,6
Coastal Slope (%)	>12,0	12,0-9,0	9,0-6,0	6,0-3,0	<3,0
Relative Sea-level Change (mm/yr)					**15,0**
Mean Wave Height (m)	**0,4-0,5**				
Mean Tide Range (m)					<1,0
Geology			Riverine sediments, debris-flow sediments	Alluvial deposits	Sands
Land use			Crops		Urban activities

Through GIS technology, data management has incorporated the development of a spatial database , for the Marathon Gulf, derived from detailed analogue topographic and geological maps of various scales, satellite images, land use maps and field observations. Data concerning the geomorphology variable were derived from previous detailed (at the scale of 1:5,000) field geomorphological mapping along the study coastline and present field work carried out during the winter of 2012. As a non-numerical variable, it is ranked qualitatively according to the relative resistance of the coastal landforms and rocks to marine erosion.

The shoreline changes mapping of Marathon coastal area has been carried out by using various multi-source spatial data. Firstly, a series of analog panchromatic aerial photographs were collected and combined with topographic survey using RTK-GPS measurements.

Initially we collected the available data and created a quite satisfactory time series of images along the contemporary coastline. We used overlapping air photographs acquired during 1960, 2001 and 2010 and generated an orthophoto mosaic for every year. During this photogrammetric procedure a high resolution (2-meters) Digital Elevation Model was also produced and used for GIS interpretations. All the data were co-registered with a 1-meter spatial resolution ortho-photo mosaic created from the photogrammetric processing of aerial photographs acquired during 1996, whilst the RTK-GPS survey was carried out during the summer of 2013.

Two base stations were established by using static measurements procedure, with a base monument nearby the shoreline, located approximately at the center of the study area. After establishing the two bases, they were used respectively for Real Time Kinematic acquisition of measurements along the shoreline. A tripod with the base GPS antenna was placed at the base station and the rover was carried by walking. The height of the antenna was measured and imported into the solution software (TOPCON Tools v.7) provided by the manufacturer of the equipment. The acquired points were converted to polylines and projected in a Geographic Information System along with the digitized shorelines of the previous years. The rover antenna was setup for acquiring easting and northing coordinates in the Hellenic Geodetic Reference System of 1987 (HGRS/EGSA87), every 50 cm along the shoreline. The accuracy of the present coastline trace was quite high as the specifications of the equipment (TOPCON HiperPro) claim to get measurements with horizontal precision less than 10mm, eventhough the solution software calculated it at 8cm. The vertical precision during the measurements was calculated (by the solution software) less than 20cm, although while measuring coastlines the

elevation is assumed to be constant at 0m and therefore the RTK-GPS vertical precision is not really important.
Additionally the shoreline of 1977 was digitized on scanned and rectified topographic maps acquired from the Hellenic Military Geographical Service (HMGA) and their construction was also based on photogrammetry techniques on previously acquired aerial photographs (scale1:5,000). Therefore a large time window of 53 years is covered by the combination of these datasets, since all of them were geometrically corrected and co-registered at the same projection. The best case scenario was to have computed six different shorelines for the entire area, but there was a gap in the datasets due to lack of information for the shoreline of 2001.
Secondly and in order to make an objective and comparable observation for the entire study area as detailed and accurate as possible and subsequently proceed to the quantification of retro-gradation and pro-gradation at every area, the Digital Shoreline Analysis System (DSAS) version 4.3, was used (Himmelstoss, 2009). This is a software extension to ESRI ArcGIS.10 published by USGS, allowing the user to create several transects perpendicular to the contemporary shoreline at a given distance and measure the position of the historic digitized coastlines. These measurements were used for extracting the rates of change and other multiple useful statistics (Fig. 2).

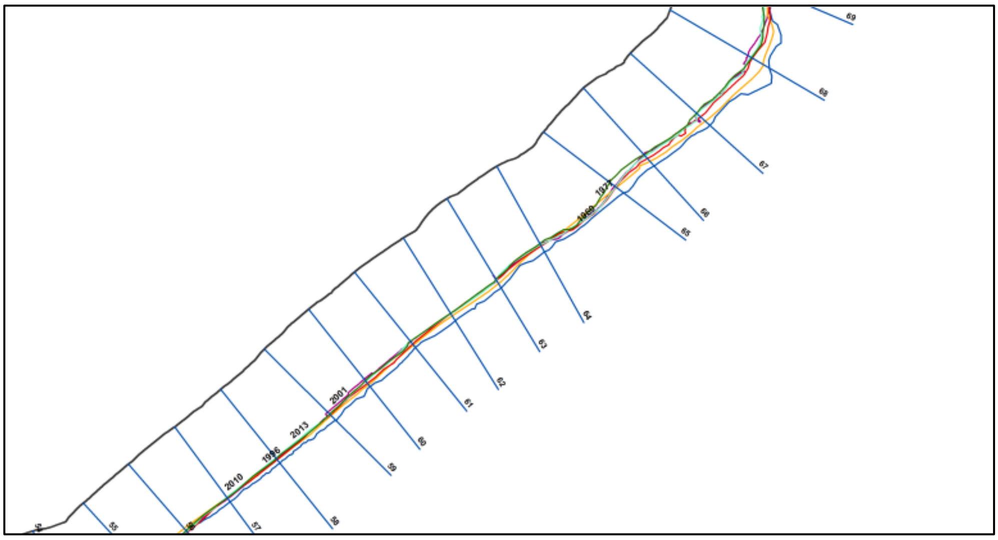

Figure 2. Screenshot of ArcMap project illustrating the transect – shoreline intersection points.

The reported rates are expressed as meters of change along transects per year. The table of statistics is extracted and can be used either by creating graphs or by visualizing them spatially in a GIS environment. We used the statistics only along the coastal segments, where we had six measurements at each section.
The regional slope of the coastal zone was calculated using the Digital Elevation Model (DEM) of the area, created from topographic diagrams at the scale of 1:5,000 with 4 m contour interval obtained from HMGA. Relative sea-level change, for the present study is based on recent considerations (Tsimplis et al., 2009) using modern technologies (satellite measurements).
Mean tidal range is derived from published reports (HNHS, 2005). Mean significant wave height is used as an indicator of the incoming wave energy. The mean annual values of significant wave height have been abstracted from the Wave and Wind Atlas of the Hellenic Seas (Soukisian et al., 2007), which is based on offshore measurements for the period 1997-2007 (POSEIDON project). Geological formations along the shoreline were identified using geological maps of the Institute of Geology and Mineral Exploration of Greece (IGME) at the scale of 1:50,000. Land uses along the coastal zone were defined utilizing the published data of the CORINE land cover 2000 programm and were checked in detail, during the field mapping. Each variable has been ranked from 1 (very low) to 5 (very high) as far as vulnerability concerns, according to the values provided by Thieler and Hammar-Klose (2001).
For each CVI variable a polyline layer was created, while each variable forms a feature class (coverage), which can be displayed graphically (Fig 3). The resulted CVI value was calculated spatially by using equation (1) in a GIS environment.

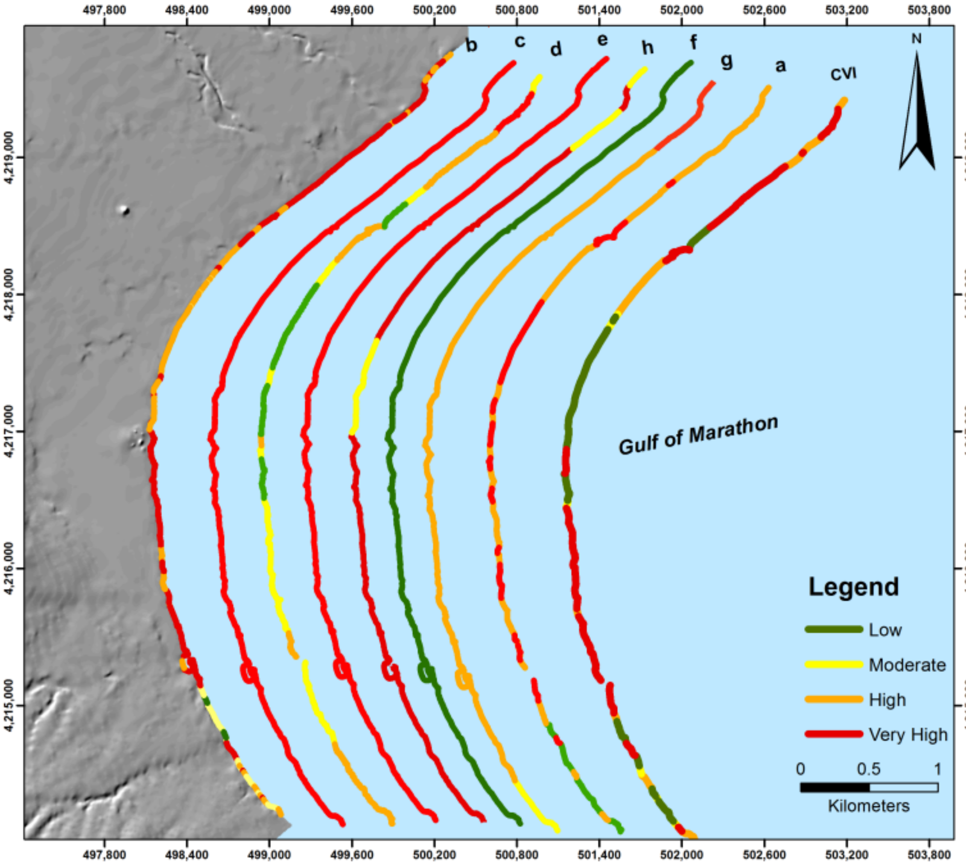

Figure 3. The eight CVI variables and the CVI results for the studied segment of the shoreline. The lines are offset from their real location for viewing reasons.

Results and Discussion

The three main coastal landforms at the study area were sandy to gravelly beaches, beachrocks and sand dunes. Sandy to gravelly beaches ranked with the highest value (5), are the dominant landforms along the Marathon Gulf corresponding to 67.14% of the total coastline (5.8 km), followed by the beachrocks (22.73% of the coastline). The segments where beachrocks or sand dunes coexist with sand or gravel beaches were given the value 4. Finally soft cliffs occupy 10.13% of the shore (about 0. 9 km) and were given the value 2.

Regions with slopes lower than 3% were characterized as of very high vulnerability, while coastal cliffs with slopes higher than 12% were of very low vulnerability (Tab. 1). A large percentage of the coast is of high vulnerability area due to the low lying sandy beaches. Plesti area and the southern coast of Nea Makri are the only regions with soft cliffs (classified at low vulnerability).

Relative sea level change is considered to have the same value along the Marathon coastline. According to previous studies (Tsimplis, 2009) using satellite measurements, it is found for the specific area of the Mediterannean sea for the period 1993- 2000 a rate of 15 mm/yr (high vulnerability, class 5 in Table 1).

Retreating and prograding rates were calculated for each section reaching the values of -0.6 m/yr and 0.03 m/yr respectively (Fig.4). Values between -0.35 and -0.6 m/yr are classified as having very high vulnerability (Tab. 1).

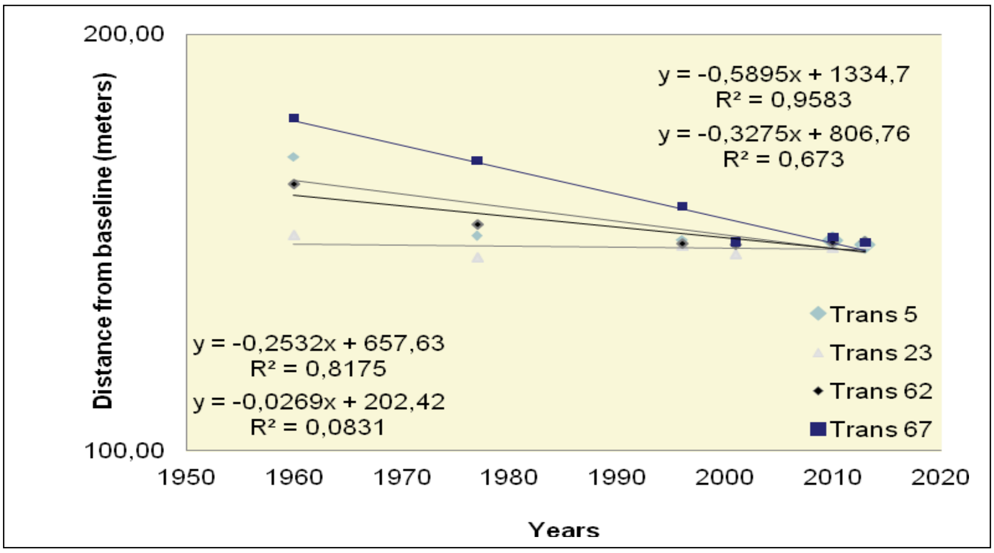

Figure 4. The slope of the equations describing the line is the regression rate.

A large part of the coastline having length of 6 km (76.2%) is characterized by erosion process. Nearly 3 km corresponding to 38.75% of the total coastline, belongs to the category of high and very high vulnerability. Specifically the segment at the south coast of Nea Makri is of high vulnerability (-0.25< d<-0.35 m/yr) and the north part of coast near the estuary of Inois river with very high vulnerability (Fig. 5). This was also obvious at the field coastal mapping (Fig. 6). The rest approximately 1.8 km are classified as having low vulnerability (accretion process) with values between 0.03< d< 0 m/yr.

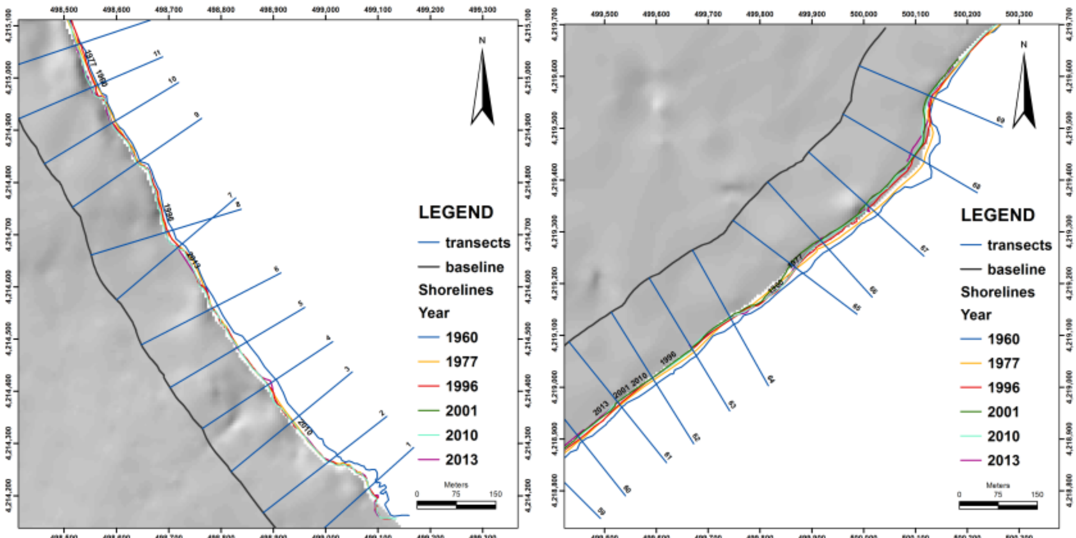

Figure 5. Transects at the areas of Plesti (left) and Inois (right) with highest calculated erosion rates.

Figure 6. Aspects of the area Plesti (left) near Nea Makri and the estuary of Kainourio branch (right) of Inois river with the highest vulnerability.

About 90% of the coast is underlain by alluvials, while only the rest 10% of the coast is underlain by river deposits and coastal formations. The part with sand according the geology map is not of high importance.

Finally two land use categories were identified, crops given the value 3 and constructions and discontinuous urban fabric given the highest value (5).

The calculated CVI values along the coastline of the study area range between 10.61 and 39.52. The geographical distribution of the coastal vulnerability is presented schematically in Figure 4. The classification method was natural breaks with four classes. It is found that 46% of the coast have very high vulnerability, 20% have high vulnerability, whilst 5 % have moderate vulnerability and 29% low vulnerability. Highly vulnerable regions are the area Plesti at south coast of Nea Makri, a large part at the Nea Makri' s beach, the northern part of Agios Panteleimonas beach and the eastern estuary of the Inois river. Most of the tourism activities and facilities as well as settlements are concentrated in the above mentioned coastal segments and according to the field observations, in spite of the presence of some constructions (i.e. sewalls) erosion rate is still active.

Figure. 7. Along the shore at the area of Agios Panteleimonas there is an extend sea wall following the street nearby the sea. Some decades ago at the same area used to be a sandy beach.

Conclusions

In this study the coastline of Marathon Gulf was classified according to coastal erosion, using the Coastal Vulnerability Index (CVI) and new technologies, utilizing GIS technology. CVI values along the shoreline vary between 10.61 and 39.52. The vulnerability of the coast to erosion is spatially non uniform because of variations in some of the incorporated variables. Thus the variables introducing the greatest variability to the CVI values are those of geomorphology, shoreline erosion, regional slope and land use. The other four factors have the same values for the entire shoreline.

According to the criteria of coastal vulnerability, as defined in this study, the sections of coast with the highest CVI ratings include coasts with urban activities and are underlain by alluvial deposits. It is found that 46% of the coast have very high vulnerability, whilst 20% have high vulnerability and 29% have low vulnerability.

Highly vulnerable regions (CVI> 28.19) are the part near Plesti at south coast of Nea Makri, a large part of Nea Makri's coast, the northern segment of Agios Panteleimonas beach and the eastern estuary of the Inois river are those with the higher risk. It is appropriate, in the near future, that this development could be renewed and expanded further with data such as oceanographical parameters, in order to be a useful planning tool for coastal zone managers.

Ackowlegments

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