LONG-TERM COASTAL CHANGES OF VARNA BAY CAUSED BY ANTHROPOGENIC INFLUENCE

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Abstract. This research aims to explore coastline alterations and changes to the beaches of Varna Bay, North Bulgarian Black Sea coast, between 1908 and 2007. A large number of different types of port and coast-protection structures have been constructed along the coast of the study area, over a 100-year period. As a result of human activities *i.e.* building of harbour, navigational channels, coastal dike and solid groin system, the coastline of study area and adjacent beaches have been significantly modified. Various sources of shoreline position data were used to detect long-term coastal changes: the historical map of Varna Bay at a scale of 1:10 000, from 1908; and the modern satellite image from 2007. Data processing and analysis were performed in GIS environment, as both map and satellite image were preliminary geo-referenced. An indicative segmentation by landform units (beaches/cliffs) and technogenous units (port/coast-protection structures) of both historical and current coastlines was produced to identify changes caused by anthropogenic influence. On the basis of coastline segmentation, an assessment of technogenous impact on the study area, both in 1908 and 2007, was done to quantify the increased extent of human intervention. The results clearly indicate that the long-term coastline/beach changes could be mainly considered as human-induced. Furthermore, at many sites the coast was irreversibly modified.

Key words: coastal erosion, coastal defence structures, coastal GIS, shoreline modifications, sand beaches, ICZM

INTRODUCTION

The coasts are constantly changing due to interference of both natural and anthropogenic processes, as these alterations could be of long and short duration. The long-term changes occur over periods such as decades or centuries, while the short-term refer to movements occurring from over a season to a few years (Boak & Turner, 2005; Morton *et al.*, 2004; Morton & Miller, 2005). Large sections of Europe's coast are currently dominated by humans as geomorphic agents. Under a rising sea level and growing population along the coasts, the behaviour and future coastline evolution will become even more impacted by human actions (Cooper, 2009). Attempts to stabilise the coast against erosion and waves can also greatly influence shoreline behaviour. Frequently, activities such as installing "hard" defence structures, harbour developments or dredging works could provoke significant coastal modifications, as they react with naturally occurring processes (Griggs, 2005; Stancheva & Marinski, 2007). Traditional forms of coastal defence, still commonly applied, consist of structures designed to resist natural processes, such as wave action and sediment movement. These are generally known as „hard engineering" options and include: vertical seawalls; coastal dikes (or embankments); revetments; groins; rock armouring or ripraps, etc. (Lees & Duncan, 1997).

Studies on long-term coastal changes would be helpful in any ICZM (Integrated Coastal Zone Management) strategy, since identifying major shoreline trends is a key component of planning and management. Data from historical coastal maps have mostly been used to detect and reconstruct the old coastlines for comparison with modern data. However, there are potential errors associated with such historical maps, including errors in scale; datum changes; distortions from shrinkage, stretching and folds; different surveying standards; projection errors; and partial revision. On the other hand, their advantage is being able to provide a historical record that is not available from any other data sources (Boak & Turner, 2005).

In this regard, the present study intends to explore human-induced coastline modifications and changes to the beaches of Varna Bay, North Bulgarian Black Sea coast over a 100-year period (1908-2007). For this purpose, two primary objectives were pursued: first, the historical shoreline detection of Varna Bay and assessment of technogenous impact; and, second, tracing general changes of the coastline and existing beaches. The paper compiles available coastal data in different time scales: the 1:10 000 scale historical map from 1908, the satellite image from 2007, and data from GPS survey in 2007.

Due to the lack of datum and projection information on the historical map from 1908, the investigations in this study were not intended to precise measurements of shoreline dynamic, in terms of erosion/accretion processes. Instead, we used it as the only one available data source to identify the long-term coastline modifications in the bay of Varna, as well as to detect human-induced beach changes. The application of Geographic Information System (GIS) has the advantage of integrating historical and modern data in one geographically correct space and to trace accurately the long-term coastal changes. Using geomorphologic and engineering approaches, a GIS-based indicative segmentation by landform types and technogenous types was implemented for both historical and modern coastlines. On the basis of coastline segmentation, an assessment of technogenous impact on the study area, in 1908 and 2007, was done to quantify the increased human intervention.

General presentation of the study area

The bay of Varna is situated in the northern part of the 412 km long Bulgarian Black Sea coast, between cape Sv. Georgi, on the north, and cape Galata on the south (Fig. 1). The adjacent coastline is 17780 m long and ESE generally oriented. Since, on the historical map, the coast of Varna Bay is presented between the capes of Sahanlak and Galata (a section with a length of 15808 m), we assumed the study area between these two capes in order to compare the available historical and modern shorelines.

Main wind waves approaching the coastline are from NE, E and SE directions. On the base of direct wind wave observations and taking into account the major factors, such as coastline orientation, it was found that the bay of Varna is among the areas with the lowest wave heights at the Bulgarian coast. The average values of significant wave height ($H_{1/3}$), which means the average height of one-third of the measured waves, do not exceed 0.22 m (Grozdev, 2006).

The study coast mainly consists of sandstones, marls and clays, and the average rate of cliff erosion is 0.20 m/y (Peychev, 2004). Two wave energy fluxes with opposite directions determine the long-shore sediment transport along the coast of Varna Bay (Fig. 1): the first one, named Evksinogradski, starting at cape Sv. Georgi with SW direction, and the second one, named Asparuhovski, beginning at cape Galata with W direction (Dachev & Cherneva, 1979). This way, the two capes of Sv. Georgi and Galata are the zones where the fluxes diverge, while the western part of Varna Bay (the Asparuhovo beach) is the zone of their convergence. This is the most probable reason for the discharge of two sediment fluxes at the far end of the bay. Over the Holocene, this process had favoured the formation of a large sand spit, named Asparuhovska, separating the Varna Lake from the sea (Dachev, 2003).

Several sand beaches are located in the bay of Varna (Fig. 1): i) the natural Evksinograd beach; ii) the artificial Varna-groins beach, created between the fields of solid groins; iii) the Varna-central beach, formed in the re-entrant angle between the 1 km long harbour mole and the coastline; and the natural Asparuhovo beach, which is a remaining part of the former sand spit. The beaches are composed of terrigenous sand and are middle in grain size (0.32 mm), with a prevailing quartz component and low carbonate content, between 5-15 % (Dachev *et al.*, 2005).

Fig. 1 Location map of study area

A large number of maritime hydraulic constructions (port and coast-protection) have been installed over a 100-year period of investigation in the Varna Bay. Furthermore, the defence activities have been increasing in particular over the last few decades. Human intervention in terms of building harbour and coast-protection structures started by the beginning of the past century. In 1906, a 1 km long mole of Varna harbour and old navigational channel were constructed in the south-western part of the bay. At that time, the smaller port mole, in the northernmost part at cape Sahanlak, was also built (Fig. 1). The created re-entrant angle on the windward side of the harbour mole had acted as a "trap" for the Evksinogradski long-shore sediment flux. As a consequence, a new beach strip named Varna-central was formed, but the sand supply to the further south-westerly Asparuhovo beach has been interrupted ever so. In 1976, a new navigational channel was dug to serve the deeper-draft generations of vessels on their way to the ports of loading, located in the lake of Varna (Fig. 1). In addition, significant alterations of water conditions and bottom morphology in this area have been observed, due to the effects of two navigational channels (Dachev, 2003).

During the 1980s, numerous coast-protection structures were installed in the bay of Varna and their effects resulted in disturbance of the natural geomorphologic processes. North of the Varna-central beach, first a 3 km long coastal dike was constructed (Fig. 1) and later, a system of impermeable concrete groins was built: 101, 102, 102B groins, and the ones in the area of Evksinograd beach.

Other types of technogenous impact on the coast of Varna Bay are the regular dredging activities performed in the new navigational channel. In 1986, a channel dredging was done and the material was deposited on the area of the Asparuhovo beach. Later, at the end of the 1980s, a certain amount of this sand was taken from Asparuhovo beach in order to fill the compartments between the groins 101 and 102, situated at the present Varna-groins beach (Fig. 1).

2. MATHERIALS AND METHODS

Different sources of shoreline position data were used to detect the 100-year (1908-2007) coastline/beach changes of the Varna Bay: historical data, derived from the old map at scale 1:10 000; and modern data, extracted from the satellite image (May 2007), freely available from Google Earth (http://earth.google.com/) and the data from the GPS field survey in 2007.

Detection of the long-term coastline and beach changes was methodologically supported with tools of GIS. This allows for combining historical datasets and modern high-quality data and will allow for the complex survey of the coastline changes over time scales. In this way, the application of GIS will promote integration of traditional and modern data, so that they will be presented in a geographically correct space and changes occurred in various time scales can be accurately evaluated (Longley *et al.*, 2006).

The position of the historical shoreline from 1908 was derived through methods of map scanning, geo-referencing and digitalising, as the shoreline position was accepted as waterline. Large scale topographical maps (1:5 000), printed in 1983, were used to determine geographical coordinates of the Ground Control Points (GCPs) required for map geo-referencing. Therefore, a set of GCPs, such as clearly visible objects, both on the 1908 historical map and the 1983 topographical maps were selected (Fig. 2).

The satellite image (May 2007) of the Varna Bay was obtained from the Google Earth version (http://www.digitalglobe.com/): QuickBird`s satellite images with a resolution of less than 1 m. The image scene was geo-referenced in GIS environment, using the same GCPs determined on the base of topographical maps in scale 1:5 000 (Fig. 3). Further, the extraction of the shoreline positions from the historical map and the satellite image requires digitalising in GIS format (Fig. 2 and 3). All estimations and analysis were implement-

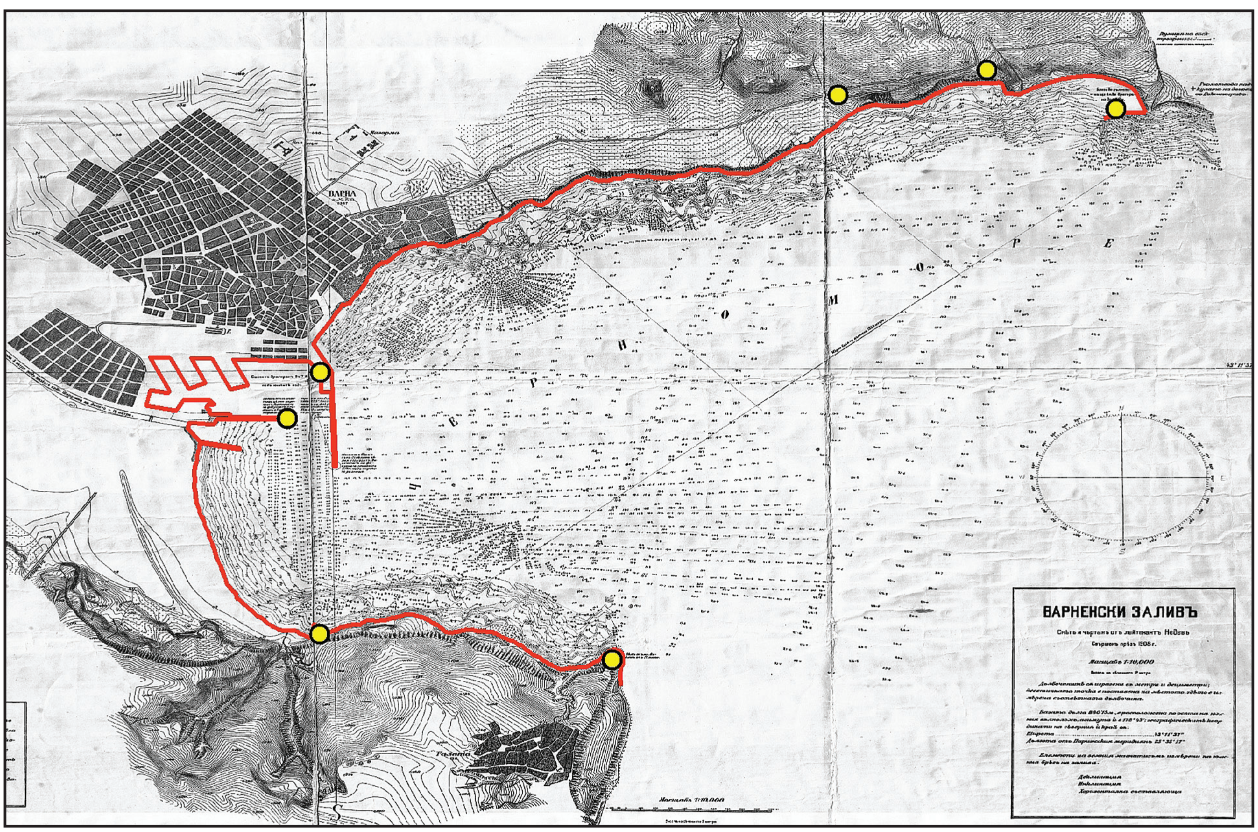

Fig. 2 Historical map in scale 1:10 000 (1908)

ed in metric Projected Coordinate System: WGS_1984_UTM ZONE_35N.

The average shoreline position for the Black Sea is accepted at elevation –0.3 m in the Baltic Vertical Reference System (Dachev *et al.*, 2005; Stancheva & Stanchev, 2006). Despite of high qualities of the old map and the good results from its geo-referencing, there is a lack of data on map datum, projection and grid. Namely these disadvantages did not allow application of the map to precise measurements of the shoreline position and subsequently comparison with a modern shoreline in terms of assessing the erosion/accretion processes. However, this historical map could be considered as reliable data source and could be useful in identifying long-term coastline and beach changes. For the purposes of coastal segmentation and to highlight the current state of the study area, a detailed field survey was carried out in May 2007. The coastline and all the maritime structures (port and coast-protection) were measured with the Global Positioning System (GPS) "Garmin 12" approaching accuracy of 5-7 m. These data were then incorporated into GIS and were used as additional information to satellite image data for a more detailed segmentation of the coastline in 2007.

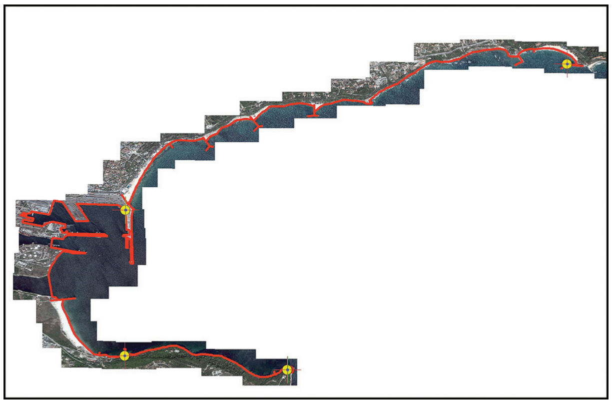

Fig. 3 Satellite image scene (2007)

Based on data available from the historical map, the GPS field survey and the satellite image, an indicative segmentation (or typology) of both historical (1908) and modern (2007) coastline was performed. The first step of segmentation was to obtain qualitative information on the coastline through an analysis of the historical map and the satellite image. ArcGIS shape files in ArcCatalog format were then generated as vector linear objects. Desktop digitalisation of both coastlines was implemented using geomorphologic and engineering approaches. Different coastal segments (landforms and technogenous objects) were defined and mapped in GIS environment. Thus, all the main types of landforms and the distribution of various port/coast-protection structures along the coast can be easily inventoried, visualised and spatially analysed by GIS tools.

For the quantitative assessment of the human impact on the studied coastal area, the so called coefficient of technogenous impact K was used. It represents the ratio between the total length (l) of all maritime structures (groins, moles, seawalls, dikes, channels and permeable bridges) and the entire length (L) of the study coastal section:

K=l/L, (Aybulatov & Artyukhin, 1993). According to this methodology the extent of technogenous impact could be classified as minimal at K=0.0001-0.1; average, when K=0.11-0.5; maximal at K=0.51-1.0 and extreme, when K>1.0. All port and coast-protective structures were mapped as line segments, not like polygons and their waterward perimeter was also mapped as linear features. In this way, the obtained coefficient K can be used as an indicator for the extent of human influence providing quantitative evaluation of technogenous impact on the coast.

3. RESULTS AND DISSCUSSION

3.1. Coastline segmentation and assessment of technogenous impact

Mapping or indicating the main landform types (beaches/dunes and cliffs) and human modifications of the coastline (port and coast-protection structures) is a key part of identifying those areas most sensitive to various coastal risks. Such indicative typology or segmentation would help to highlight the state of the coastline and to form the primary base for vulnerability assessment useful in any coastal decision-making (Anfuso & Martinez del Pozo, 2005; Sharples, 2006).

Various types of segments identified along the coastline of Varna Bay were combined in two major groups:

1. landform coastal segments, presented by natural or artificial sand beaches and erosion cliffs;
2. technogenous coastal segments, presented by port/coast-protection structures and navigational channels.

It is obvious from the maps of coastline segmentation (Fig. 4 and 5) that at the beginning of the past century, the coastal area of Varna Bay was low urbanized and mostly characterised by natural landforms: small sand strips at some sites, the large Asparuhovo beach in the deepest part of the bay, and erosion cliff sections. There were only few maritime structures: Varna harbour mole built in 1906, old navigational channel and smaller port mole at cape Sahanlak in the northernmost part of the bay (Fig. 4).

By contrast, the present situation in the bay of Varna is completely different (Fig. 5): an increase of sand beaches to a number of 10 has been recorded for a 100-year period, as their total length is 5762 m in 2007. On the other hand, the length of erosion sections decreased from 8380 m in 1908 to 2899 m in 2007, mostly due to coastal armouring through the construction of a 2900 m long defence dike. Extensive building of coast-protection structures, in particular, dikes and solid impermeable groins has been noted over the last few decades. As a result, during the GPS field survey in 2007, a number of 27 technogenous segments, with a total length of 12655 m, were identified along the coast of Varna Bay (Fig. 6).

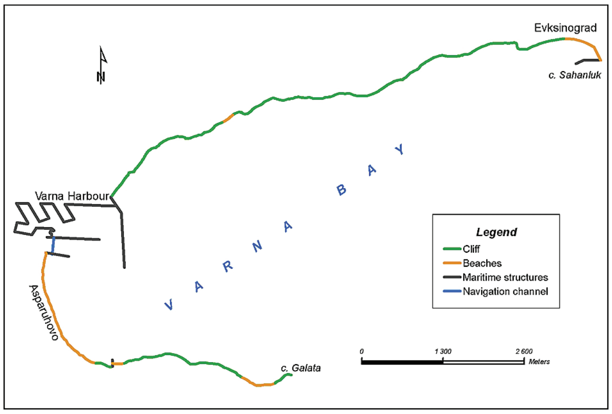

Fig. 4 Coastal segmentation (1908)

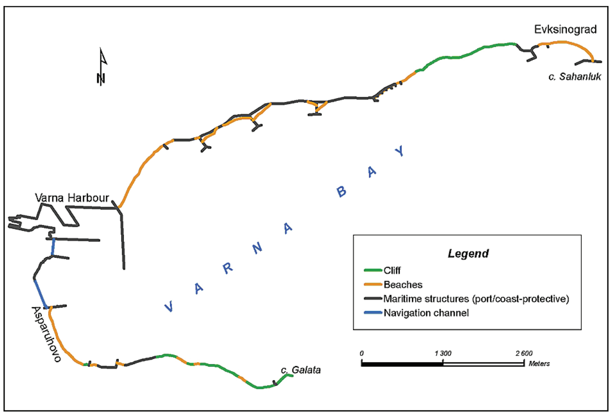

Fig. 5 Coastal segmentation (2007)

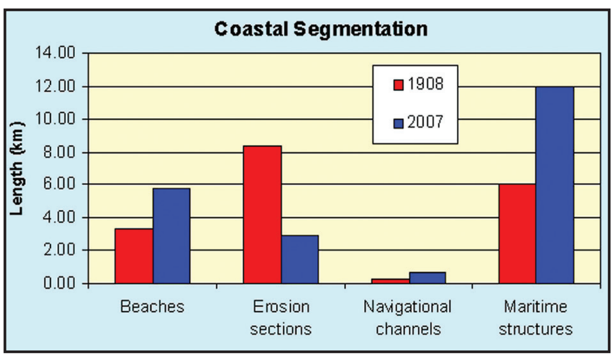

Fig. 6 Landforms vs. port/coast-protection structures

In order to quantify to what extent the technogenous impact has increased for one century, the coefficient K was determined, both for historical and modern coastlines. In 1908, the coastal area between capes of Sahanlak and Galata had a length of 15632 m, as the length of landform type segments was 11718 m long, while the maritime structures comprised 6322 m of the entire coastline. Consequently, the coefficient K was estimated to 0.40, which defines the extent of technogenous impact as average.

Quite the contrary, the length of the studied coastline was 15808 m in 2007, as the landform segments were 7062 m long, but technogenous segments have significantly increased and reached a number of 27 with total length of 12655 m. The coefficient K was estimated to be 0.80 for the coastline in 2007, which means the extent of technogenous impact could be classified as maximal.

3.2. Long-term changes to the beaches of Varna Bay

The beaches in the bay of Varna were analysed in north-south direction, as follows: Evksinograd, Varna-groins, Varna-central, and Asparuhovo (Fig. 1).

The natural Evksinograd beach is located in the northernmost part of the study area. It is bordered by the port mole in the east and by one protective structure (spur) in the south-west, built in the 1980s (Fig. 1). The beach origin is related to sediment supply from the adjacent erosion-landslide cliff and small galley, but its further growth was a result of sand accretion in the re-entrant angle of mole. In fact, this process had retained the beach preservation for one century. The compared historical (1908) and modern (2007) shorelines are shown in Fig. 7. It should be pointed out that Evksinograd beach has not only been enlarged for one century, but the shoreline has also significantly moved seaward and the current rear beach line has now covered the old 1908 shoreline position. Due to the wave diffraction and sand accretion in the re-entrant mole angle, constant dredging activities in the port-shadow area are required for its efficient exploitation. Furthermore, since the 1980s, these works have been performed at shorter intervals. The dredged sand is usually distributed along the beach strip in order to nourish its central and west parts. Indeed, the beach is now enclosed between the 120 m long port mole in the east and the 50 m long spur in the west, thus minimising the occurrence of natural dynamic processes. Therefore, the current modifications of the Evksinograd beach should be mostly associated with such periodical dredging activities.

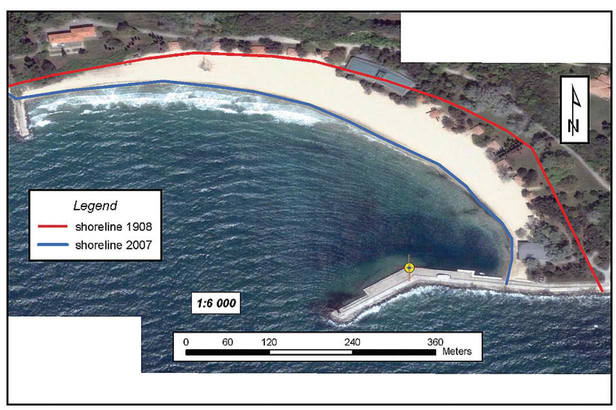

Fig. 7 Long-term coastline evolution (1908-2007). Evksinograd beach

The so called Varna-groins beach is situated in the northern part of the bay, and it was artificially created (Fig. 1). The dominant retreating cliff, as well as the lack of large beaches at this section enforced the implementation of large number of coast-protection activities. During the 1980s, first, a 3 km long coastal dike as road connection was built, as the shoreline was moved seaward with about 40 m, thus creating a new land territory. A few years later, a project for the serial construction of impermeable concrete groins in the south-north direction was run, and methods of beach filling and transverse sand bypassing were successfully applied (Dachev, 2003; Dachev & Leyontev, 2005). As a result of these activities a few sand beaches, generally named Varna-groins, were formed between groins compartments. Thus, the coastline in this section was irreversibly modified, being now the rear line of this artificial beach (Fig. 8). After the construction of the dike, the active cliff retreat was stopped, but sediment supply incoming landward was impeded, which has disturbed the long-term natural nourishment of the beaches. It has to be stressed also that the beach strips between groin fields were formed only as a result of applied sand filling and bypassing. In fact, hard structures with mutually exclusive functions (port and coast-protecting) were built, through which the protected water-areas for vessel`s wharf were created. Thus, instead of the classic type groins, a system of jetties with T-, Г- and Y-shapes were designed along the study area (Stancheva & Marinski, 2007). In addition, with building of these groins, 100-120 m in length, the Evksinogradski long-shore sediment flux has been interrupted. This in turn has disturbed the sand delivery to the further south Varna-central beach.

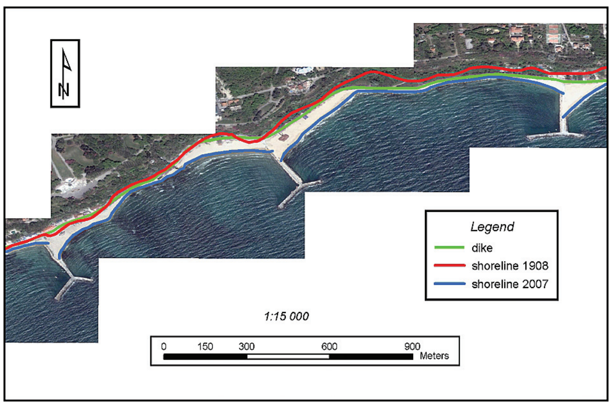

Fig. 8 Long-term coastline evolution (1908-2007). Varna-groins beach

The Varna-central beach is located between the Varna-groins beach and the 1 km-long harbour mole, built in 1906 (Fig. 1). The beach was formed as a result of sand accretion in the re-entrant angle between structure and coastline (Dachev, 2003). It is obvious from the historic map (Fig. 2), that in the beginning of XX century the coast in this section was an erosive cliff without any beach strip in front. Due to interruption of Evksinogradski long-shore sediment flux by the large mole, the formed beach has steadily grown and remained stable for more than seven decades until construction of the groins system north of it (Dachev, 2003).

On the other hand, since building of the harbour mole, the sediment supply to the further south Asparuhovo beach had been considerably diminished. Comparison between the historical shoreline from 1908 and the modern shoreline from 2007 is presented in Fig. 9. After the construction of solid groins, the Evksinogradski sediment flux, which had mainly nourished the beach for half a century, was interrupted. In addition, the accelerated urbanization of the bay of Varna over the last two decades (*e. g.* the construction of buildings directly on the beach) has also caused a progressive reduction of its area. The beach is currently enclosed between the system of impermeable solid groins and the harbour mole, as the sand could just migrate between structures under various wave conditions. As a result, a part of the beach has been severely decreased at its northern end and now it is at risks of disappearing.

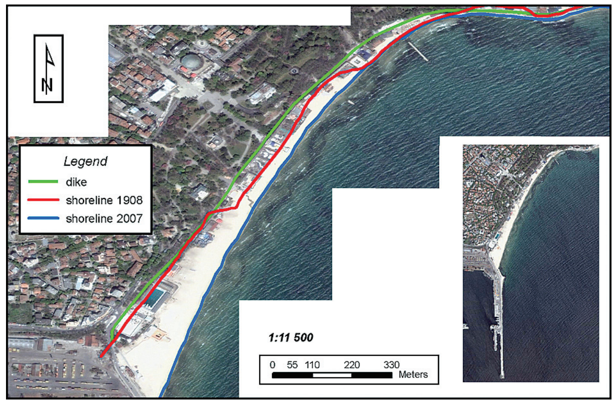

Fig. 9 Long-term coastline evolution (1908-2007). Varna-central beach

The natural Asparuhovo beach is located in the south-western part of the Varna Bay and thus, it is the most sheltered beach against wave action (Fig. 1). In the north, the beach is bordered by the protective structure (spur) of the deep-water navigational channel. In the east, it ends at the erosion coast, where Middle Miocene limestones, sandy marls, limy clays and sandstones are outcropped. Before human interventions, the beach was constantly growing due to discharge of the two long-shore sediment fluxes at this far end of the study area.

Since the beginning of the past century, the shoreline changes of Asparuhovo beach have been mainly caused by the maritime hydraulic constructions in the bay of Varna. Many negative impacts on the beach provoked by human activities have been observed for the entire 100-year period. The Varna harbour mole has interrupted the major sediment supply from N to the beach, thus causing a sand deficit also to the underwater coastal slope. Dredging of the deep-water navigational channel had particularly adverse effect on the beach: its length was reduced by 800 m (Fig. 10). Moreover, two navigational channels have "trapped" long-shore sand transport and thus disturbed the natural regime of beach nourishment. Generally, regular dredging works remove the sediment material as they are similar to sand mining (Magoon & Treadwell, 2009). This way, the beach has constantly been impacted by the reduction of sediment input. The geographical location of Asparuhovo beach at the far end of the bay, however, favours its preservation and dominant sand accretion, but indeed along the reduced beach strip (Stancheva *et al.*, 2008; Stancheva *et al.*, 2009).

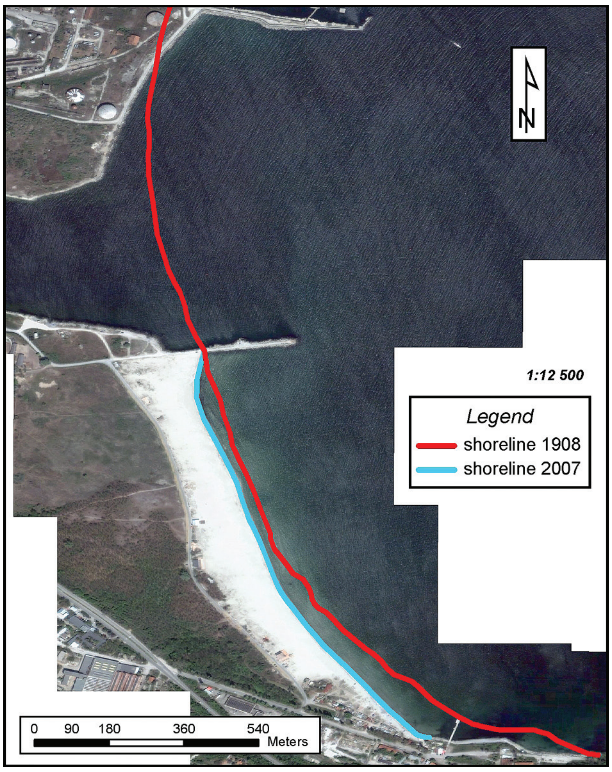

Fig. 10 Long-term coastline evolution (1908-2007). Asparuhovo beach

4. CONCLUSIONS

On the basis of this historical detection of shoreline/ beach changes in the bay of Varna, some concluding remarks from the study could be outlined. As a result of human activities *i.e.* building of harbour, navigational channels, dike and solid groins system, the coastline of Varna Bay has been irreversibly modified for a 100-year period (1908-2007).

The identified long-term coastal changes and beach alterations are mainly related to the impacts of port and defence structures on the coast. Two of the existing beaches (Varna-central and Varna-groins) were formed as a result of human activities: sand accretion in the re-entrant angle of harbour mole and artificial beach created between groins compartments.

On the contrary, the construction of large groins system has disturbed sediment supply to the neighbouring beaches of Varna-central and Asparuhovo, triggering severe erosion at certain parts. The length and area of natural Asparuhovo beach were reduced by digging of the deep-water navigational channel and the beach is currently impacted by constant dredging activities. Hence, the consequences for studied coastal area could be considered as negative: the built maritime structures have caused cross- and alongshore sediment deficit, which consequently disturbs natural nourishment of the adjacent sand beaches.

5. ACKNOWLEDGMENTS

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