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INDICATIVE GIS-BASED SEGMENTATION OF THE BULGARIAN BLACK SEA COASTLINE FOR RISK ASSESSMENT

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Abstract

An indicative segmentation of the Bulgarian Black Sea coast by geomorphologic and engineering criteria was implemented on the basis of topographic maps in scale 1:25 000 and applying modern GIS approach. A number of 379 various types of segments, both natural and technogenous, were identified along the coast, as 217 were indicated as port and coast-protection structures with total length of 71 km. The results obtained reveal that the cliff types are dominant and embrace almost 61% of the whole Bulgarian shoreline. The sandy beaches comprise at least 30% of the coast and the armouring mostly through hard stabilisation measures constitutes 17% of the coastline. As well as for quantitative assessment of anthropogenic influence along the entire Bulgarian Black Sea coast the coefficient of technogenous impact K was explored. The performed coastline segmentation helps to identify the main geomorphic types (natural landforms and human modifications of the coast) and could be used as a primary basis for risk assessment in the coastal zone.

Key words: coastline, coastal defence, coastal erosion, segmentation, GIS

1. Introduction. Today, with many other coasts throughout the world the Bulgarian Black Sea shoreline is exposed to the combined effects of natural and anthropogenic hazards, as most critical are: storm surge flooding, persistent coastal erosion and increasing human occupation. According to recent investigations [1], the Bulgarian coastline has about 412 km length, stretching between cape Sivriburun on the North and Rezovska River mouth on the South (Fig. 1). It has a general eastward exposure and comprises various erosion rocky cliffs, sandy beaches or low-laying parts of firths and lagoons. Coastal erosion, both natural and human-induced, is only one of the many hazards threatening the coastline. Flooding in low-lying areas due to extreme sea level rise is another potentially severe hazard along the Bulgarian coastline. About 20% (83 km) of the entire coast were indicated as areas vulnerable to inundation by extreme sea level rise and these are mostly firths, lagoons, river mouths and wetlands [2].

Many previous researches have pointed out a constant progress of the erosion process along the Bulgarian coast since 1960s of the past century. After [3], large proportions of the entire coastline or 60% include erosion cliffs, whilst the proportion of sandy beaches constitutes at least 28% of the coast length. Further studies more recently have also identified that 70.8% of the Bulgarian Black Sea coast experiences an intensive erosion activity and this process has become one of the most crucial problems along the coastal zone [4]. Although more than 70 sandy beaches, with total length of 140 km and total area of 5 km^2, are located at the Bulgarian shore [5], coastal erosion is currently a widespread process affecting 58% of the entire coast [6]. Nowadays, erosion is generally more serious problem at Dobrudzha loess coast, between the capes of Sivriburun and Shabla, and along the clayey coast, between the town of Pomorie and cape Lahna (Fig. 1).

In order to find the most relevant solutions to control coastal erosion, it is important to determine thoroughly the exact causes for this process [7]. Several factors of different origin are responsible for the increased rates of erosion and landslides along the Bulgarian coast: 1) environmental factors, such as sea level rise, wave energy, storm surges, geological settings of the coast, changes in sediment supply, etc.; and 2) factors related to human activities, such as rapid coastal urbanisation and development, and armouring the coastline by hard engineering structures (dikes, seawalls and solid groins). Numerous studies carried out at the Bulgarian coast have indicated various erosion rates in coastal units similar in geological structure, which defines the erosion as a multivariable process [8]. The average sea level rise along the Bulgarian Black Sea coast varies from 1.5 to 3 mm/y [9]. Despite such rates are not dramatic for the coast, there would be a case of extreme sea level rise at certain meteorological conditions that could provoke more intense coastline retreat [2].

It is suggested that over the last few decades the major cause for erosion progress has been mostly associated with expanding human impacts in terms of maritime constructions, dredging works and river corrections. As a result, for a

50-year period (1960–2008) the amount of sediment material incoming from cliff erosion, river solid discharge and aeolian drift has decreased from 4 979 700 Mg/y to 1 221 300 Mg/y. This in turn has provoked reduction of sand supply, beach degradation and even stimulating higher erosion rates [6].

Population pressure along the coast is another hazard factor that contributes to coastal zone instability. The Bulgarian Black Sea coast has been highly developed and urbanised in particular over the recent years which has lead to rapidly growing coastal population. For one, during 1934–2001 the number of local residents in 10 km zone from the coast increased with 215% [10]. As most coastal regions, the Bulgarian coast has also experienced over the last decade a real estate boom and increased impact of new developments, such as hotels and residential homes emplaced too close to the shoreline or directly on the sandy dunes. In consequence of these human activities, large parts of the sandy beaches and dunes have been illegally built-up and most recreational resources are presently used uncontrolled thus being at risk of degradation [11].

Nevertheless coastal defence measures applied for more than one century, the erosion and landslide problems along the coast had not been completely solved and there is still a lack of integrated coast-protection management plan. Furthermore, hard stabilisation structures have caused a technogenous occupation (or armouring) of the coastline, which has altered the natural coastal environment. In many cases of such poorly designated solid structures the erosion processes could be exacerbated or even new erosion spots in the down-drift coastal areas could be generated [7, 12].

Therefore a comprehensive evaluation of all potential coastal hazards is needed for complete understanding of the coastline response both to environmental events and anthropogenic impacts [13]. Mapping or indicating the main natural landforms and human modifications of the coastline, i.e. geomorphic coastal types is a key part of identifying those areas most sensitive to various coastal risks. Such coastline typology or segmentation would help to highlight the state of the coastline and to form the primary basis for vulnerability assessment useful in any coastal decision-making [12, 14, 15]. In the context of described environmental hazards and increasing human impacts, the present study focuses on implementing a geomorphic segmentation of the entire Bulgarian Black Sea coast based on quality spatial data and modern Geographic Information System (GIS).

2. Data used and GIS-based methodology. Topographic maps in scale 1:25 000, published in 1994 by the Cadastral Agency were used for the purpose of coastline segmentation. The large and medium scale topographic maps in Bulgaria are made in Geodetic Coordinate System 1970, as the Baltic Geodetic Height System based on Kronstadt zero is adopted as land survey height system [16]. A number of 42 topographic maps in scale 1:25 000 cover the entire Bulgarian Black Sea coastal area (Fig. 2), as they correspond to the zones K-7 and K-5 of the

Coordinate System 1970. Processing of topographic maps includes the following main operations:

• Maps scanning by means of Colortrac SmartLF Cx40 Scanner as 400 dpi resolution JPG files;

• Convert coordinates from the Coordinate System 1970 to geographic coordinates. Since the geodetic network and all topographic maps are in metric Coordinate System 1970, it was necessary to transform all initial data in geographic coordinates ($\boldsymbol{\phi}$ and $\boldsymbol{\lambda}$) in GCS_WGS_1984 (Geographic Coordinate System, World Geodetic System-1984). The estimations were preformed in metric Projected Coordinate System: WGS_1984_UTM (Universal Transverse Mercator)_ZONE_35N. This projected coordinate system employs a projection to transform locations expressed as latitude and longitude values to x; y metric coordinates [17].

• Scanned maps were georeferenced and rectified in GIS environment (GCS_WGS_1984), using the grid of topographic maps. To visualise and analyse spatial data in GIS these data are required to be in accordance with an accepted coordinate system, i.e. to be georeferenced. This process includes assigning a coordinate system that associates the data with a specific location on the earth [17]. Georeferencing defines how the data is situated in map coordinates and is an important step for technique operations with topographic maps and digitalising paper published maps.

• An ArcGIS shape file in ArcCatalog format was generated as vector linear object and then desktop digitalisation of the whole coastline was implemented. Through a vectorisation process (the conversion of raster data (an array of cell values) to vector data (a series of points, lines, and polygons) the coastline segmentation by geomorphologic and engineering criteria was done.

Data processing, mapping of natural landforms/human structures and analysis, as well as assessment of technogenous impact on the coastline were methodologically performed with tools of GIS ArcInfo 9.2. The collected coastal spatial information incorporated into GIS infrastructure allows generation of an initial open-end data base for the entire Bulgarian Black Sea coast. The advantages of applying GIS include the ability to manage large databases, to integrate data from a wide range of sources, as well as to update database by new data sets, which can be further combined with various field surveys or data sources (aerial/high resolution satellite images, DGPS (Differential Global Positioning System), LIDAR (Light Detection and Ranging), etc.). Thus, all main geomorphic types of natural landforms and distribution of various types of port/coast-protection structures along the coast can be easily mapped, visualised and spatially analysed by GIS tools. Since coastal environments, in particular the coastline, are very mobile, there is a need for consistent monitoring over the time. As much as data are accumulated for the study of coastal areas, the capacity to interpret and predict future coastal changes will considerably increase [18].

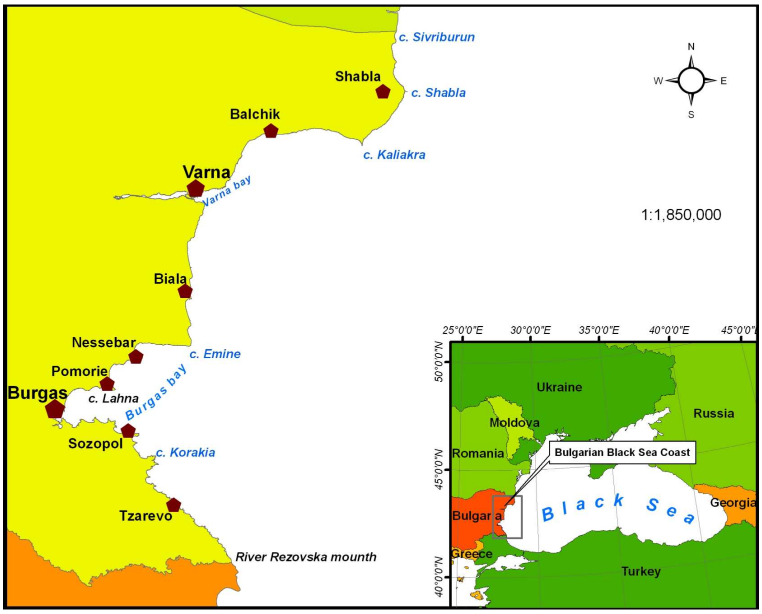

Fig. 1. Locator map of the Bulgarian Black Sea coast

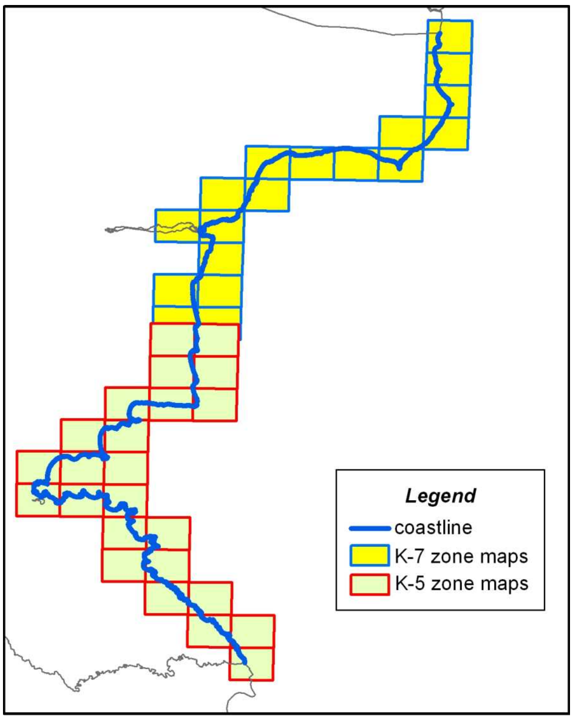

Fig. 2. 1:25 000 scale topographic maps (zones: K-7 and K-5) covered the Bulgarian coast

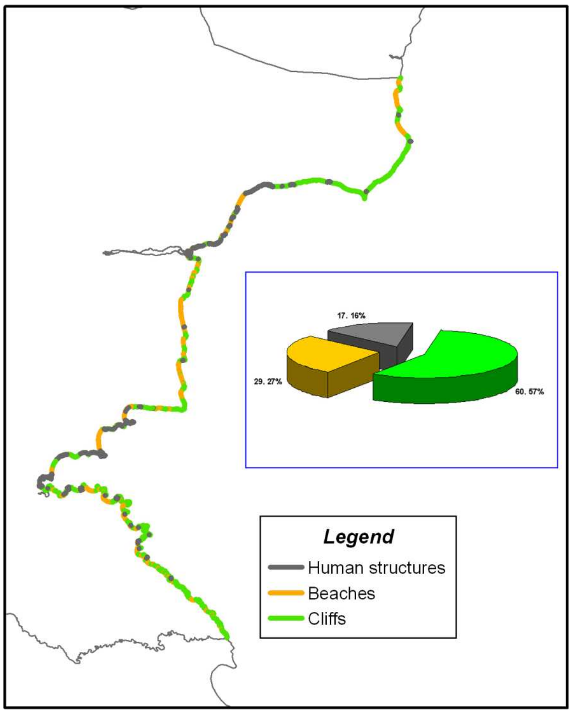

Fig. 3. Map of coastline segmentation

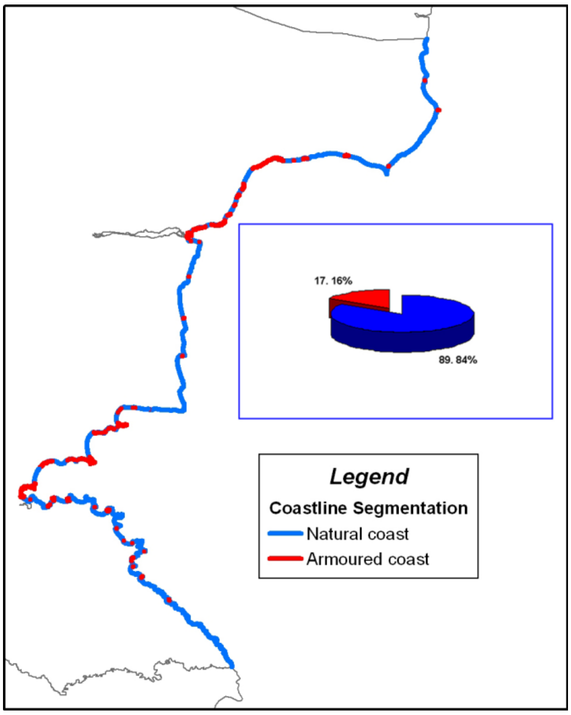

Fig. 4. Natural versus armoured coast

3. Indicative segmentation of the Bulgarian Black Sea coast. Under previous study [19] a detailed field measurement of 31 km long coastal section, between the capes of Ekrene and Galata (North Bulgarian coast), was carried out in May 2007. During the survey the coastline and built maritime structures in north-south direction were measured by means of GPS "Garmin 12" and then mapping and segmentation of this coastal area were prepared.

In the present study, on the basis of data derived from topographic maps and GIS support, coastline mapping and segmentation in scale 1:25 000 were done. A number of 379 various segments, having total length of 439 km, were identified along the entire Bulgarian Black Sea coast. All coastal segments indicated were then combined in two main groups of geomorphic types based on different criteria:

• Natural coastal segments (landforms) were identified by geomorphologic criteria: i) sandy beaches; ii) cliffs (including low overgrown and high erosion types);

• Technogenous coastal segments (various maritime structures both cross- and long-shore) were identified by engineering criteria: i) groins; ii) dikes; iii) seawalls; iv) ports, marinas and navigational channels.

Both natural coastal segments and port/coast-protection structures have a total length of 439 km, which exceeds the length of the Bulgarian coastline (412 km) due to the included cross-shore structures such as groins, ports/marinas, moles and permeable bridges. It is evident from the map of coastline segmentation (Fig. 3) that the cliff types are dominant and embrace almost 61% or 247 km of the whole Bulgarian shoreline. Whilst the sandy beaches comprise at least 30% (121 km) of the coast, there is a clear evidence for an accelerated human intervention in terms of maritime constructions, as the armouring occupies 17 % (71 km) of the coastline (Fig. 4). The port and hard stabilisation structures are not regularly built and distributed along the coast. As a result, there are some parts with largest proportions of armoured coastline: at the northern part of the Bulgarian coast, between cape Ekrene and cape Galata, where 73 various types maritime structures were identified [19] and also at the south part, between the town of Nessebar and cape Foros. These most built-up areas include the largest Bulgarian Black Sea bays of Burgas and Varna, where significant parts of urban/land activities (transport logistics, industries, trades, etc.), coastal infrastructures and tourism development are concentrated.

4. Evaluation of technogenous impact on the Bulgarian Black Sea coast. For quantitative assessment of the impact of maritime structures on the coastline, a so-called coefficient of technogenous impact K was explored. This coefficient represents the ratio between the total length of all maritime hydraulic structures and objects (groins, moles, seawalls, dikes, navigational channels and permeable bridges) and total length of the coastal area studied. K is defined through the following simple equation [20]:

$$K = l/L,$$

where l includes the linear sizes of all structures and objects; and L represents the total length of the coastline. According to this methodology the extent of technogenous impact is considered as minimal at $K = 0.0001-0.1$; averaged when $K = 0.11-0.5$; maximal at $K = 0.51-1.0$ and extreme if $K > 1.0$.

For the whole Bulgarian Black Sea coastline the coefficient is estimated to be: $K = 412000/71174 = 0.17$. After the above mentioned classification [20] this means the extent of technogenous impact could be considered as averaged. However, it should be pointed out that this value derived for the entire Bulgarian coast is not very realistic due to irregular concentration of built maritime structures along the shore. For example, only in the Bay of Varna, between the capes of St. George and Galata, where a large number of port and coast-protection structures have been built, this coefficient is estimated to be: $K = 15676/17780 = 0.88$. Such value determines the extent of technogenous impact at this area as maximal. For the largest Burgas Bay, located between cape Emine on the North and cape Korakia on the South, and having a length of 145 km, the coefficient is: $K = 37387/145000 = 0.26$. This value defines the extent of human impact in the Bay of Burgas as averaged.

5. Conclusions. On the basis of implemented coastline segmentation a number of 379 various geomorphic segments (natural landforms and human structures) were identified along the Bulgarian Black Sea coast. The results show that the cliffs constitute almost 61% of the entire Bulgarian shoreline, sandy beaches comprise at least 30% and the armoured coast occupies 17% of the coastline. To evaluate the extent of human influence at the Bulgarian Black Sea coast the coefficient of technogenous impact was estimated to be $K = 0.17$, which determines the level of engineering occupation as averaged. Although this value for K for the entire coast is acceptable, there are large coastal units with very high extent of technogenous impact: Varna Bay where K reaches to 0.88 and Burgas Bay – $K = 0.26$.

Thus, the coefficient K could serve as an indicator for the extent of human impact and would allow quantifying coastline modifications related to maritime structures (port and coast-protection). The results obtained from the study reveal an increasing human impact on the Bulgarian Black Sea coast particularly expanded over the last few decades. As major cause for currently progressive coastal erosion could be considered the effects of existing large number coastal defence structures. Yet, the hard engineering measures are applied along the coast and thus being one of the dominant modifiers of the coastal processes. As a result, the sporadic natural erosion in the near past has turned into human-caused and has become critical at many coastal units. Coastline protection is still not well planned, and old methods (rubble-mound dikes, seawalls and solid groins) are mostly used instead of modern solutions such as beach nourishment and creating artificial beaches.

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