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STUDYING THE COASTLINE LENGTH THROUGH GIS TECHNIQUES APPROACH. A CASE OF THE BULGARIAN BLACK SEA COAST

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Abstract

Number of researches to define the exact length of the Bulgarian Black Sea coast has been undertaken to date under various types of surveys. However, estimating the coastline length with high accuracy has turned not very simple scientific task. Different values of length for the Bulgarian coastline ranging between 354.0 km and 456.8 km have been determined in coastal investigations. Furthermore, a small number of studies on measuring the coastline length was associated with data sources used for estimations (e.g. maps or satellite images) and scale or resolution of spatial data. This paper aims to focus the attention on the still existing question: How long exactly is the Bulgarian Black Sea coastline? For this purpose a modern GIS techniques approach based on statistical analysis and visualisation for more precise coastline measurements was applied. The present study also deals with the issue how different types of spatial data sources may produce different results for the coastline length.

Key words: coastline, geostatistics, GIS, map scale, segments, spatial data

1. Introduction. Due to the complexity and dynamic nature of the coasts, measuring the coastline position and length with high accuracy has historically been difficult for coastal researchers [1]. The coasts are continuously changing in respond to wind/wave processes, sea level variations and sediment movement. Various human activities could often cause much more significant alterations of the near-shore currents, sand transport and shoreline position [2]. By contrast to the instantaneous shoreline, which is the position of the land-water interface at one instant in time [3], the coastline represents the boundary line between land and water, a continuous and often indented line by numerous small or larger bays and prominent points. Therefore, the coastline refers to the outer, more stable and more general shape of the shore [4].

Quantifying accurate coastline length is of fundamental importance for many coastal zone management or planning applications such as coastal classification/land cover use, coastal erosion and environmental monitoring. Land planners and coastal developers are interested in up-to-date coastline information for managing human activities (coastal infrastructures and recreational resorts) for inventorying natural resources and delineating the most hazard-prone coastal areas [3, 5, 6]. However, determining coastline length with high accuracy has turned not very simple scientific task, as it was first found by [7] in his paper "How Long is the Coast of Britain?". A cited study examines the property that the measured length of a stretch of coastline depends on the scale of measurement – the smaller the increment of measurement, the longer the measured length becomes.

Coastline length depends on many factors involved, among which the most important is the geological structure of the coast since this defines coastal indentation index (e.g. smooth, average and highly indented coasts). Crystalline rocks such as granite tend to erode irregularly and very slowly, producing a highly irregular coastline, while sedimentary rocks tend to erode more regularly and rapidly producing relatively straight coasts [8]. Another important aspect is the scale of geographical spatial data, since with a map the spatial data contain geographic information limited to the scale of the database. For one, a 1 : 100 000 scale map does not include as much details as 1 : 50 000 scale map, because it represents an area that is four times smaller. The reduction of details on the maps is known as map generalisation [5]. Some other factors are also responsible for precise estimation of the coastline length: type and resolution of spatial data; map projection; map generalisation; measuring units, horizontal and vertical datums for the geographic coordinates.

The present paper aims to approach the means, methods and measurements of the Bulgarian Black Sea coastline length with support of modern techniques such as Geographic Information System (GIS). The results obtained also show that spatial data collected from different sources (nautical and topographical maps or satellite images), in different scales (1:25 000 to 1:500 000) or differ-

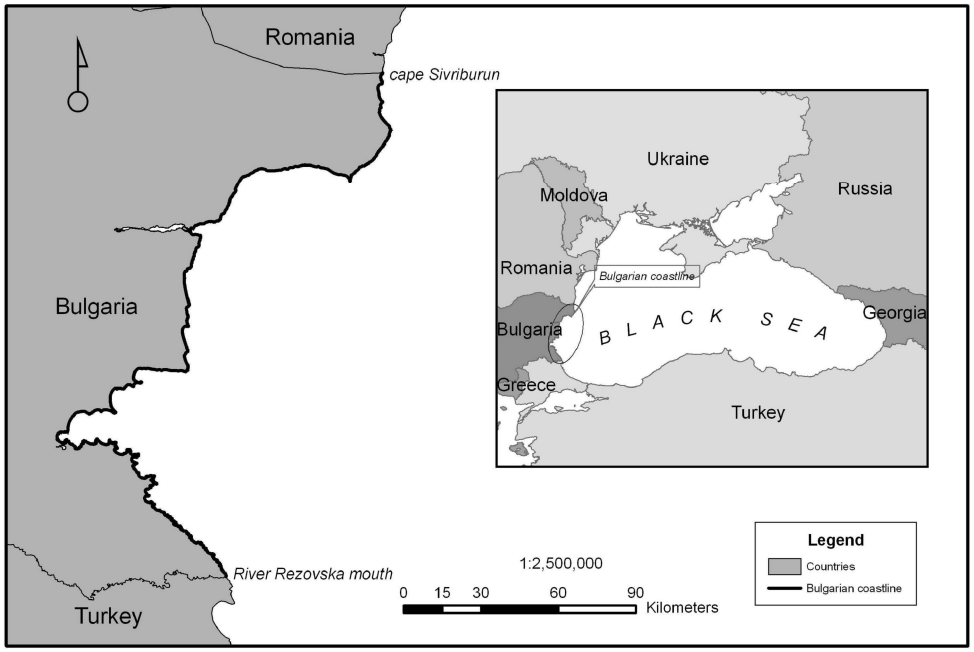

Fig. 1. Bulgarian Black Sea coast

ent resolution (14.5 m, 28.5 m and 57.0 m) may produce different values of the coastline length.

2. Measured lengths of the Bulgarian Black Sea coastline. The Bulgarian Black Sea coast is located in the western part of the Black Sea, between cape Sivriburun on the north to the Romanian border and Rezovska River mouth on the south to the Turkish border (Fig. 1). The length of the Bulgarian coastline has been measured and studied by many authors (Table 1), as various length's values ranging from 354.0 km to 456.8 km have been estimated. Five of all shown references and Web sources have determined that the Bulgarian coastline length is 378.0 km, which in fact is the most cited length by coastal scientists. In other known sources the defined values for the Bulgarian coastline length are different: 354.0 km, 371.0 km, 398.0 km and 456.8 km. It should be also mention that only in two of these reference sources the type of spatial data and maps scale used for measuring the coastline length were cited.

3. Data and methods. The methods for coastline investigations have continuously been sophisticated: availability of first aerial photographs in the beginning of the past century has provided a possibility for precise and complete records of coastline configuration. Another often used traditional method for coastal studies is the tachometry ground survey which is, however, a time- and cost-consuming method. The accurate measurements and detection of the coastline position and

Table 1

Previously measured lengths of the Bulgarian Black Sea coastline

Source	Publishing source	Year of publication	Coastline length (km)	Cited spatial data source
Geography of Bulgaria, Volume 1, Physical Geography	Sofia – Publ. House of BAS	1966	378.0	Topographic maps in scale 1 : 100 000
Black Sea	Publ. House "Georgi Bakalov" – Varna	1978	371.0	No cited
Geomorphology of the Bulgarian Black Sea coast and shelf (Popov V., K. Mishev)	Sofia, Publ. House of BAS	1974	378.0	No cited
Geographical Dictionary of Bulgaria	Publ. House "Science and Technics", Sofia	1980	378.0	No cited
Encyclopaedic Dictionary of Oceanology	Publ. House "Galaktika", Varna	1992	378.0	No cited
Morphodynamical and lithodynamical coastal processes in coastal zone (Peychev V.)	Publ. House "Slavena"	2004	378.0	No cited
http://www.bulgariabeach resorts.com/coastline.html	Internet website	2008	398.0	No cited
http://earthtrends.wri.org/	World Resources Institute	2008	456.8	World Vector Shoreline Database at 1 : 250 000
http://bg.wikipedia.org/wiki	Internet website	2008	354.0	No cited

length have been recently improved with the availability of larger spatial coastal databases and analysis technologies such as: digital photogrammetry, Light Detection and Ranging (LIDAR), Differential Global Positioning System (DGPS), High Resolution (HR) or Very High Resolution (VHR) satellite images and GIS [3, 6]. Application of GIS to shoreline investigation allows integration of traditional and modern data in such a way that they can be presented in geographically correct space and coastline changes occurred in various time scales can be precisely evaluated. Thus, GIS provide a valuable technology for data storing, access, integration, modelling, analysis, mapping, display and dissemination [9].

In the present study the length of the Bulgarian Black Sea coastline was estimated on the basis of spatial information obtained from various types of data sources:

• Nautical maps in scale 1:100 000, 1:200 000 and 1:500 000; published by Hydrographic Office of Bulgarian Navy.

• Topographical maps in scale 1:25 000, 1:100 000 and 1:200 000; published by the Cadastral Agency.

• Orthorectified satellite Landsat 7 Enhanced Thematic Mapper Plus (ETM+) images from 1999 and 2000. Two LandSat 7 scenes cover the Bulgarian part of the Black Sea. Each scene has different resolution: 14.5 m (panchromatic), 28.5 m (multispectral mode – 6 bands) and 57.0 m (thermal infrared).

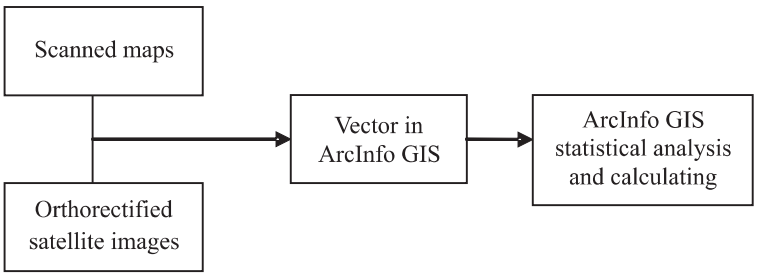

Fig. 2. Data processing

Processing of different data sources includes a few main steps as presented in Fig. 2. Nautical and topographical maps were scanned with resolution 400 dpi and were georeferenced in ArcInfo 9.2 GIS environment using the coordinates from the maps grid. Before gathering the information for coastline mapping in GIS the satellite images should be processed in order to remove distortions from the image and this process is called orthorectification [9]. Therefore, for analyses in GIS the used satellite images were preliminary orthorectified. Then, for each data source nine linear objects (polylines) were created in ArcCatalog as shapefiles (in ArcGIS format) that contain spatial and attribute data. Digitalisation of the coastline from maps and satellite images was hand-made in reference system GCS (Geographic Coordinate System) and datum WGS_1984 (World Geodetic System). Each digitalised coastline consisted of individual lines (segments), as these lines have two points called vertices. The segment's length between two points was calculated as this length determines the dimension of individual segments. The sum of the lengths of all single segments aggregates the total coastline length. All calculations of coastline length for different sources were automatically performed using XTools Pro GIS extension (Fig. 2) and the results were added in the attribute Table.

4. Results and discussions. On the basis of processed spatial coastal data (maps and satellite images) different values for the Bulgarian coastline length were determined. The results obtained are shown in Table 2: number of segments, mean length of individual segments, total coastline length and Standard

Table 2

Calculated values and SD for the coastline length from different data sources

Coastline Source	Scale/ Resolution	Years	Number of Segments	Mean Segments Length (m)	Estimated Coastline Length (km)	SD of Segments Length (m)
Topographical map	1 : 25 000	1995	10 590	38.9	411.8	34.6
Topographical map	1 : 100 000	1991	4 959	78.1	387.4	44.2
Topographical map	1 : 200 000	1991	3 267	115.8	378.4	58.3
Nautical map	1 : 100 000	1991	3 151	122.9	387.2	59.2
Nautical map	1 : 200 000	1990	1 249	291.6	364.2	164.4
Nautical map	1 : 500 000	1981	1 113	317.1	352.9	136.4
Satellite (LandSat 7) Image	14.25	1999/2000	5 122	80.8	413.9	55.1
Satellite (LandSat 7) Image	28.5	1999/2000	3 208	122.5	392.9	69.5
Satellite (LandSat 7) Image	57.0	1999/2000	2 158	178.1	384.4	106.9

Deviation (SD) of coastal segments estimated. The largest number of coastline segments (10 590) was derived from 1 : 25 000 scale topographical maps. This segment's number is almost twice higher than the number of coastline segments extracted from the satellite image with resolution 14.25 m or segments defined on 1 : 100 000 scale topographical maps. The smallest number of segments (1 113) was produced through digitalisation of 1 : 500 000 scale nautical map. Consequently, the mean segment's length ranges from 38.9 m for the coastline extracted from 1 : 25 000 scale topographical map and 317.1 m for the coastline, digitalised from 1 : 500 000 scale nautical map. Therefore, the degree of geographic data resolution is an important factor for spatial or statistical analysis and estimations in GIS environment. It is obvious from the results obtained from different data sources that the larger the map scale or the smaller the pixel's size for satellite images is the longer and more detailed becomes the total coastline length.

4. Conclusions. On the basis of GIS analysis performed and results obtained for the length of the Bulgarian Black Sea coastline the following conclusions could be remarked:

• The length of the Bulgarian coastline (without adjacent islands) estimated from different types of data sources ranges between 364.2 km and 413.9 km.

• The larger scales of the maps are used the more detailed coastline features are presented and the longer the coastline length becomes.

• The higher resolution satellite images are used the more detailed coastline can be extracted.

• The most cited value of 378.0 km of the Bulgarian coastline length was probably defined from the topographical map in scale 1:200 000.

How long is exactly the Bulgarian Black Sea coastline? The recommended answer is that it mainly depends on the scale/resolution of spatial data sources used for coastline measurements and method by which the coastline length was determined. With lack of this information, the coastline length measurements would be incorrect which leads to wrong concluding results. At this point the value of 412.0 km for coastline length, extracted from 1:25 000 scale topographical maps and consisted of 10 590 coastline segments could be considered as most reliable result for the length of the Bulgarian Black Sea coast. It is expected, however, more precise and larger value for coastline length to be obtained in case 1:5 000 scale topographical map or VHR satellite images (e.g. 0.6–4.00 m) are used.

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