DETERMINATION OF THE BLACK SEA AREA AND COASTLINE LENGTH USING GIS METHODS AND LANDSAT 7 SATELLITE IMAGES

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Abstract. Quantifying accurate coastline length is important for management applications, such as coastal classification/land cover use, erosion and environmental monitoring. However, due to the dynamic nature of the coastline, measuring its length with high accuracy has turned out to be a difficult research task. By far, different values of the Black Sea coastline length have been determined and these values range between 4020 km and 4500 km. Potential reasons for this could be mostly associated with various data sources and different methods applied. In this context, the study presents recent results for the Black Sea coastline length, which have been obtained during generation of the geo-data base at the IO-BAS. For this purpose, a number of 24 satellite images (Landsat 7) were used. Data processing and analysis were methodologically supported by GIS techniques for precise measurement of the coastline length. In addition, new results for the Black Sea total area were also obtained.

Key words: coastal GIS, geo-statistics, map scale, segments, spatial data sources

1. INTRODUCTION

The accurate length of the coastline and water area are one of the most important geographic characteristics for each ocean/sea. Coastline delineation is a prerequisite for the geographic description of the physical form of a continent. Quantifying accurate length of the coastline is essential for many coastal zone management and 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, for inventorying natural resources and delineating the most hazard-prone areas (Liu & Jezek, 2004; Boak & Tarner, 2005; Puissant *et al.*, 2008). However, a precise determination of the coastline length has turned out to be a not very simple scientific task, as it was first found by Mandelbrot, (1967) in his paper "How Long is the Coast of Britain?". The author has introduced the concept of fractal dimension (D) to the coastal community (Tanner *et al.*, 2006). Mandelbrot's study examines the property that the meas-

ured length of a stretch of coastline depends on the scale of measurement, as the smaller the increment of measurement, the longer the measured length becomes.

The coastline length depends on many important factors. The major factor is the geological structure of the coast, since this defines indentation index (e.g. smooth, average and highly indented coasts). Crystalline rocks, such as granite, tend to erode at random and very slowly, producing a highly irregular coastline, while sedimentary rocks tend to erode more regularly and rapidly, producing relatively straight coasts (Pilkey & Thieler, 1992). 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 a 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 (Kostiuk, 2000). Some other factors are also important for the precise estimation of the coastline length: type and resolution of

spatial data; map projection; map generalisation; measuring units; horizontal and vertical data for the geographic coordinates.

Nowadays, the accurate detection and measurements of coastline position and length have been improved with the availability of larger spatial coastal databases and analysis technologies such as: Light Detection and Ranging (LIDAR), Differential Global Positioning System (DGPS), aerial images and High Resolution (HR) or Very High Resolution (VHR) satellite images and with the support of Geographic Information System (GIS) (Boak & Tarner, 2005; Puissant et al., 2008).

The present study describes recent results obtained for the Black Sea area and coastline length, based on the modern data collected during generation of the geo-data base at the Institute of Oceanology - Bulgarian Academy of Sciences (IO-BAS). For this purpose, a number of 34 Landsat 7 satellite images were used.

2. MATERIALS AND METHODS

Study area

The Black Sea is the largest semi-closed sea bordered by Europe to the North, West and East and by Asia to the South. It is connected by the strait of Kerch to the shallow Azov Sea and with the Marmara Sea (the Mediterranean Sea, respectively) by the strait of Bosphorus (Fig. 1). The Black Sea lies between six countries: Bulgaria, Romania, Ukraine, Russia, Georgia and Turkey.

Fig. 1 Location map of the study area

It is well-known that, during the Quaternary, the Black Sea level had altered many times, in accordance with drastic climatic changes (glaciations and inter-glaciations). The Bosphorus strait, with its sill placed at about -34 m, had determined a specific regional behaviour of the Black Sea: when the water level was lower the sill depth, as the connection with the Mediterranean Sea, was interrupted and the Black

Sea water level varied under the local hydrological and climatic conditions (Panin, 1999; Panin, 2009). These Quaternary changes of the Black Sea water level had also significantly influenced the alterations and evolution of its coastline and area, respectively.

State of the art

The coastline length and area of the Black Sea have been measured and studied by many regional and outside authors (Ross et al., 1974; Nankinov, 1996; Panin, 1999, Loghin, 2000; Panin, 2007, Panin, 2009). By far, different values of the Black Sea coastline length and area have been determined. Those for the coastline length range between 4020 km and over 4400 km. Values obtained of the Black Sea area also vary in large diapason: between 413 500 km^2 and 436 000 km^2. Furthermore, in most cases, there is no information pointing the type of spatial data, map scales or methods have been used for measuring the coastline length and area. Hence, potential reasons for such different values of the Black Sea area and coastline length could be mostly associated with different types of data sources, maps scale or images resolution, as well as due to different methodologies applied.
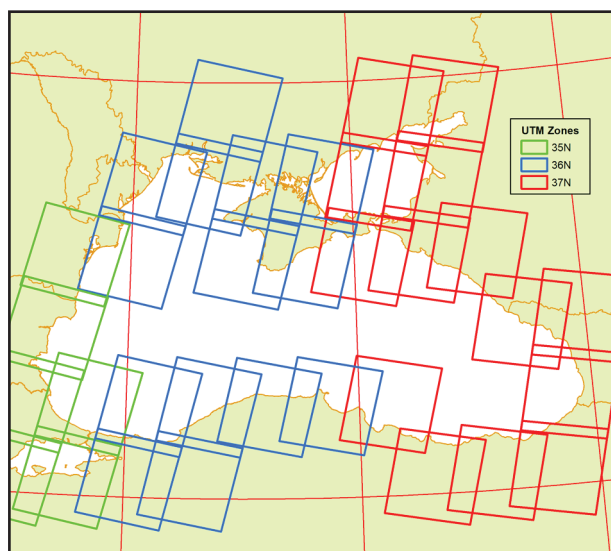
The subject has been investigated over the prior study devoted to measuring the Bulgarian Black Sea coastline length (Stanchev, 2009). Using different data sources, such as topographical and nautical maps, in scales between 1:25 000 and 1:500 000; and Landsat 7 satellite images with various spatial resolutions (14.25 m, 28.5 m and 57.0 m), different values of coastline length were derived. The length of the Bulgarian coastline (without adjacent islands), estimated from these different sources ranges between 364.2 km and 413.9 km. It was found that the larger scales of the map are used, the more detailed features of the coastline will be presented and the longer coastline length becomes respectively. In case we use the higher resolution satellite images the more detailed coastline will be extracted as well.

Data used and methodology

The accurate detection and measurements of the coastline position and length have been recently supported by modern technologies and data, such as GIS, HR or VHR satellite images. For the purpose of the present study, orthorectified satellite Landsat 7 Enhanced Thematic Mapper Plus (ETM+) images were used (http://www.glcf.umd.edu/data/landsat/). The pixel size is 14.25-meter panchromatic, Band 8. The approximate scene size is 170 km north-south by 183 km east-west. Ground control points (GCPs) are fixed as the images have been registered to the Universal Transverse Mercator (UTM) map projection and coordinate system, and the World Geodetic System 1984 (WGS84) datum. Positional accuracy on the final image product has a Root Mean Square (RMS) error of better than 50 meters. The RMS error measures the errors between the GCPs and the transformed locations of the image source control points.

Table 1 Landsat 7 satellite scenes processed

Scenes	Path	Row	Year	Month	Day
1	180	029	2000	7	2
2	181	031	2000	7	25
3	181	030	1999	7	23
4	181	029	2000	6	7
5	180	031	2000	7	2
6	180	028	2000	8	19
7	172	030	2000	9	12
8	172	031	2000	7	10
9	172	032	2000	7	10
10	174	029	2000	8	9
11	175	029	2001	7	2
12	176	029	1999	9	22
13	177	029	2000	5	10
14	178	028	2000	8	21
15	174	032	2000	6	22
16	173	032	2000	7	17
17	173	030	2001	9	6
18	176	029	2000	8	21
19	179	028	2002	5	14
20	175	031	1999	8	14
21	176	031	1999	8	21
22	177	031	2000	7	13
23	179	031	2001	6	12
24	178	031	2000	8	21

Fig. 2 Landsat 7 satellite images nomenclature by UTM Zones

The Black Sea coastline was derived from satellite image mosaic compiled of a number of 24 LandSat 7 scenes covering the entire Black Sea area (Table 1). Four scenes have been registered in Zone 35N, ten in Zone 36N and the other ten – in Zone 37N (Fig. 2). The date of satellite images acquisition is between June 1999 and May 2002.

All data processing and analysis were performed in ArcInfo GIS environment. The extraction of coastline could be done automatically or by hand-made digitalization in GIS. However, the post processing of automatically extracted coastline is typically more time-consuming due to the errors of derived coastline. Therefore, it was suggested that the hand-made digitalization would be more accurate for detecting the coastline location.

Preliminary collected coastal data consist of more than 150 000 vertices (segments), including the Black Sea shore, the Azov Sea and the Marmara Sea shores. These also include lagoons, firths, sand spits, river estuaries, islands, as well as the offshore port and coast-protection structures. Therefore, to measure only the length of the Black Sea coastline, the segments of the Azov and the Marmara Seas were eliminated, as well as all units, such as lagoons, islands, sand spits, etc. After elimination, the number of remaining vertices for the Black Sea coast accounted for almost 40 000 segments (Table 2).

Table 2 Results for the Black Sea coastline length

Country	Number of segments	Mean Segments length (m)	Coastal Length (km)
Bulgaria	5,122	81	414
Georgia	1,387	236	322
Romania	2,129	120	256
Russia	2,668	159	421
Turkey	14,765	116	1700
Ukraine	13,787	128	1756
Total	**39,858**	**122**	**4869**

All individual segments were, then, merged into one single linear object – the coastline. This object was, then, converted to polygon feature using the XTools Pro Extension, Version 5.3.0. This polygon feature allows calculating the Black Sea coastline length and area.

The applied method for coastline extraction from HR Landsat 7 satellite images has many advantages as compared to the traditional surveys: i) the images have a wide territorial range, so that the whole Black Sea is covered; ii) we use only one data source, thus removing potential errors from combining different data with different spatial and time scales; and iii) all scenes were acquired free of charge and in a short time interval (over a 3-years period).

In contrast to other coastal sites in meso/macrotidal climate, the coastline extraction from satellite images is more

accurate for the Black Sea coast. This owes to the fact that the Black Sea is almost tideless (about 15 cm) and, therefore, the remote sensing methods are applicable for the precise extraction and detection of the coastline. Typically, the shoreline is taken as the water line, especially, in microtidal environments (Pajak & Leatherman, 2002), or as the seaward vegetation limit, dune foot, or cliff top, in mesotidal environments (Crowell *et al.*, 1991; Martinez del Pozo & Anfuso, 2008). For example, at sites with large tides, the accuracy of the coastline locating from satellite images significantly depends on the initial information, not only of the date, but even of the exact hour of images production. This then impose the need of data correction to eliminate the remaining errors of inaccurate coastline location.

3. RESULTS AND DISSCUSSION

After processing 24 Landsat images, we received the results for the length of the Black Sea coastline (Table 2). The Bulgarian and Romanian coasts are entirely located into the UTM 35N Zone, the Russian and Georgian coasts – into UTM 37N, while the coasts of Turkey and Ukraine are located in the three UTM Zones with main parts in 36N Zone.

The coastline length was separately calculated by each of the UTM Zones for more precise measurements. Based on the sum of these three results, we derived the total length of the Black Sea coastline: 4869 km. This value is larger with almost 500 km than the prior estimated length of 4400 km. The average length of each coastal segment that constitutes the whole Black Sea coastline is 122 m (Table 2). The differences between previous and present length values are most probably due to the measurement scales and spatial resolution of various data sources used. The larger is the map scale, or the higher is the spatial resolution, the more details of the coastline would be measured. This, finally, results in a longer coastline, which confirmed again Mandelbrot's concept of fractal dimension.

The ArcInfo vector polygon feature of the Black Sea area was derived through feature conversion of the coastline vector polyline feature using XTools Pro Extension, Version 5.3.0. To obtain the reliable Black Sea area, this vector polygon was also divided on three parts by the UTM Zones: UTM 35N, UTM 36N and UTM 37N Zones. The area values estimated for each zone are presented in Fig. 3. Then, the final result of 421638 km^2 for the Black Sea area was derived through the sum of three separate UTM Zones.
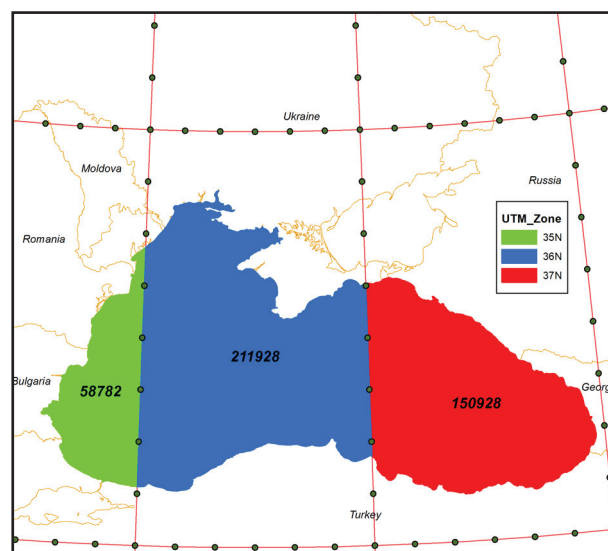

Fig. 3 Calculated area of the Black Sea by three UTM Zones

4. CONCLUSIONS

The study presented new results for the area and coastline length of the Black Sea, based on the Landsat 7 satellite images and GIS technology. The estimated Black Sea coastline length is 4869 km and its area is 421638 km^2. The results obtained could be considered as comparable with results from 1: 50 000 scale topographical maps.

In accordance with Mandelbrot's concept of fractal dimension, it was found that the coastline length, mainly depends on the map scale/spatial resolution of data sources used for measurements and methods by which the coastline length was determined. If we miss this initial basic information, the estimations of the coastline length would be incorrect and unreliable. This, in turn, could lead to the wrong concluding results. It is expected, however, to obtain a more precise and larger value for the whole Black Sea coastline length, in case VHR satellite images (e.g. 0.6-4.00 m) are used.

5. ACKNOWLEDGMENTS

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