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Integrating GIS and high resolution orthophoto images for the development of a geomorphic shoreline classification and risk assessment—a case study of cliff/bluff erosion along the Bulgarian coast

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Abstract This paper demonstrates the effectiveness of integrating GIS and modern spatial data for the development of a detailed geomorphic classification of the Bulgarian Black Sea coast. This classification is important for the precise measurement of various natural and technogenous (engineered) coastline types and serves as a basis for identification of the areas with high exposure to different coastal hazards. To illustrate potential uses of this simple methodology, a map of the potential coastal erosion/cliff retreat hazard for the Bulgarian coast was produced from this GIS database. Several types of data were used: high resolution orthophoto, topographical maps in 1:5,000 scale and geological maps. Geomorphic classification utilized both geomorphological and engineering criteria. A total of 867 segments were delineated along the coast. Four hundred sixty five were classified as natural landforms (cliffs, beaches, river mouths) with a total length of 362,62 km and 402 were indicated as technogenous segments (port and coast-protection structures, artificial beaches) with a total length of 70 km. Based on the geologic materials present at each segment and cliff height, the cliffed portions of the Bulgarian coast were classified for expected erosion rates, and therefore, hazard vulnerability: low hazard (volcanic type cliff); moderate hazard (limestone type cliff) and high hazard (loess and clayey types cliff). This "predictive model" was then compared to a previously published field study of coastal erosion rates to validate the model. As a result, a new high quality, but qualitative data for Bulgarian coastal bluff/cliff erosion were obtained, incorporated and analyzed in GIS.

Keywords Orthophoto images · GIS · Bulgaria · Coastal erosion · Coastline segmentation

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Introduction

The continuing increase in population of the coastal zone requires adequate and reliable information for the assessment of coastal risks resulting from global climate change, associated impacts of sea level rise, and subsequent coastal erosion. However, attempts to stabilise the coast against erosion and waves may also affect shoreline behaviour. Activities like installing "hard" defence structures, harbour developments or dredging works could have significant impacts, as they alter naturally occurring processes (Griggs 2005; Stancheva and Marinski 2007). A key part of a coastal vulnerability assessment is the identification and mapping of coastal substrates and landforms (i.e., geomorphic types) that have greater or lesser sensitivity to the impacts of climate change and sea level rise, such as accelerated erosion and shoreline recession, increased slumping or rock fall, changing dune mobility, and other hazards (Sharples 2006, 2007). The coastal geomorphic classification scheme utilizes morphology and human modifications of the coast as the primary basis for hazard assessment (Morton and Peterson 2005). Such classification/typology is important for accurate determination of various natural and technogenous landforms (geomorphic coastline types) and serves as a basis for identification of the areas with high exposure to coastal hazards and to quantify the shoreline alterations related to the impact of human structures (Anfuso and Martinez del Pozo 2005; Stancheva 2009).

Currently, the precise detection and measurement of coastline position and length have been improved with the availability of larger spatial databases and analysis technologies including: Light Detection and Ranging (LIDAR), Differential Global Positioning System (DGPS), High Resolution (HR) or Very High Resolution (VHR) satellite images and aerial images/orthophotos, and with the support of Geographic Information System (GIS) (Boak and Turner 2005; Puissant et al. 2008; Goodchild 2009; Gens 2011). There are a number of remote sensing techniques that are commonly used to detect and monitor the coastlines. High resolution satellite images and orthophotographs in conjunction with GIS have been recognized as a powerful and effective tool in presenting coastal features, precise extraction, tracing the coastline, and for accurate assessment of shoreline changes (Chen et al. 2005; Pan 2005; Gens 2011). The era of 1-meter or sub-meter satellite imagery, such as IKONOS, QuickBird, WorldView and GeoEye, present new and exciting opportunities for the geosciences and coastal research community (Liu et al. 2011). Modern remote sensing technologies and analysis in a GIS environment help to provide a comprehensive and systematic approach for detection of dynamic coastal landforms. Changes in coastal features can occur in very short terms/periods, especially with increased human pressure in the coastal zone. Newly acquired modern, high-resolution data, covering large areas of the coastal zone and obtained in a very short period (e.g. month), can help to detect and evaluate sensitive coastline changes and behaviour.

The primary goal of this paper is to demonstrate the effectiveness of integrating GIS and modern high-resolution (HR) spatial data as a method for risks assessment through the construction of a geomorphic classification of the Bulgarian Black Sea coast. As an example, a sensitivity map of the Bulgarian coastline to one hazard, coastal erosion/cliff retreat, was produced from the geomorphic classification, and this predictive map was tested with existing field data.

Study area

Stanchev (2009) used topographical maps in 1:25,000 scale to determine that the Bulgarian coastline is 412 km long. The Bulgarian coast stretches from Cape Sivriburun in the north at the Romainian border south to Rezovo village mouth on the south at the Turkish at the border with Turkey. The coast is comprised of a variety of coastal types: rocky cliffs, sandy beaches, low-lying parts of bays and lagoons. Erosion and cliff retreat, both natural and human-induced, is one of the main hazards affecting the coastline (Stancheva 2010). Flooding in low-lying areas due to storm surges is another risk, as 20 % (83 km) of the coast is at low enough elevation to be at risk to local storm surges. These areas are mostly bays, lagoons, river mouths and wetlands (Palazov et al. 2007).

Previous studies have found that 60 % of Bulgaria's coastline is composed of eroding cliff (Peychev and Stancheva 2009; Stancheva 2009) and that the average rate of retreat is 0.08 m/y. The highest erosion rates of 0.30 m/y were recorded at the loess coast between Capes Sivriburun and Shabla, whereas at the most southern part, at the volcanic rocks, the rate reaches 0.01 m/y at least (Fig. 1). Cliff erosion is largely controlled by the geological settings of the coast, but is also affected by accelerating sea level rise. The average rate of local, relative sea level rise along the Bulgarian Black Sea coast varies from 1.5 to 3 mm/y (Pashova and Jovev 2007). Wave attack during elevated water levels accompanying storm surge can cause intense cliff and beach erosion (Palazov et al. 2007; Stanchev et al. 2009).

Large numbers of defence structures have been built since the 1980s to control erosion and landslide processes along the Bulgarian coast. These mainly include: coastal dikes or rubble-mound embankments, groins and seawalls. Placements of seawalls and dikes on the shoreline, as well as developments of harbour and port infrastructures, have armoured the shoreline and caused impacts similar to those described by Griggs (2005). Based on topographic maps in 1:25 000 scale from 1994, it was found that over 10 % of the entire Bulgarian coast has been armoured (Stancheva 2010). As a result, for a 50-year period (1960–2008) the amount of sediment material, incoming from cliff erosion, river solid discharge and wind-blown material, has decreased from 4,979,700 t/yr to 1,221,300 t/yr. This in turn has provoked reduction of sediment supply, beach erosion and even generated new erosion spots. Therefore, the continuing cliff erosion along the Bulgarian coast is being accelerated at present by expanding human influence in terms of maritime constructions, dredging works and river corrections (Peychev and Stancheva 2009).

Data used and GIS methods

In the present study data from three different sources were used:

i) Topographic maps in 1:5,000 scale from 1983;
ii) High Resolution colour orthophoto images from 2010 and 2011;
iii) Geological maps from 1991/92 in 1:100,000 scale

  i) One hundred seventy three topographic maps in 1:5,000 scale published in 1983 by the Cadastral Agency in Bulgaria cover the entire coastline. The maps have a 1 m contour interval, which allows for a relatively accurate determination of the cliff

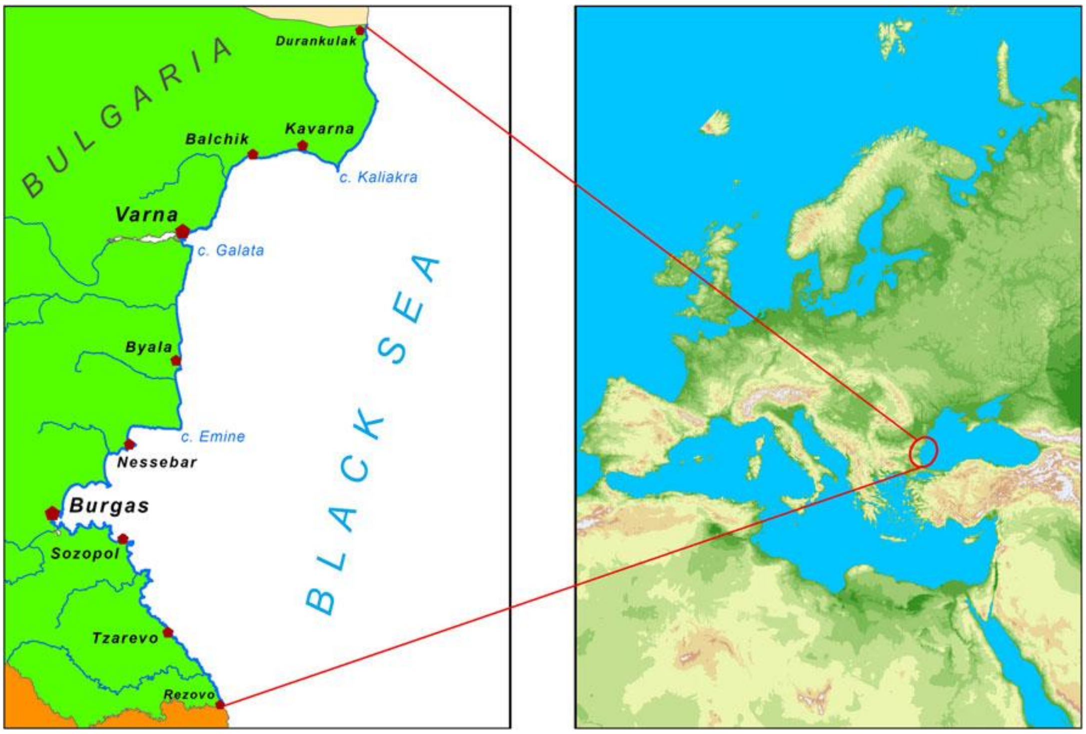

Fig. 1 Locator map of the Bulgarian coast

height. The maps were scanned with a Colortrac SmartLF Cx40 Scanner as 400 dpi resolution JPG files. The scanned colour maps were georeferenced and rectified in GIS environment (GCS_WGS_1984) using the grid of topographic maps with the help of GIS - ArcInfo 9.2. During digitization of orthophoto images for the erosion sections of the coastline, the cliff height is defined by the contour of overlapped topographical map.

ii) Modern colour orthophoto image data were provided by the Ministry of Agriculture and Food (Republic of Bulgaria) under the implementation of a Bulgaria-Romania scientific research project: "Joint GIS-Based Coastal Classification of the Bulgarian-Romanian Black Sea Shoreline for Risks Assessment." Ortho-georeferenced aerial photographs are from 2010 and 2011 with a spatial resolution of 0.4 m. A total of 107 images were used. Fifty six were acquired in 2010 and 51 in 2011, and each image has a size 4/4 km (Fig. 2).

The orthophoto images are registered in Projected Coordinate System: WGS_1984_UTM_ZONE_35N as the data were preliminarily orthorectified. High Resolution (HR - 30 to 5 m) and Very High Resolution (VHR - 4 to 1 m or less) imagery might be exploited to provide spatial information, which can easily be integrated in coastal GIS platforms. In HR orthophoto imagery, the details of sandy beaches, dunes, foot/top of the cliff, shoreline position, human structures etc. become clearly visible and this allows precise mapping. The accuracies of the different techniques are directly related to their spatial resolution. While the vertical accuracy might vary considerably, the horizontal accuracy, which actually determines the location of the shoreline, is typically of the same order of magnitude as the spatial resolution of its source data (Gens 2011). The main benefit of orthorectified photography is improved accuracy, particularly where there is high relief across the area, e.g. cliffed coastlines (Southeast regional coastal monitoring programme).

The entire coast was then divided into segments based on geomorphological and engineering criteria using a hierarchical classification scheme for the Bulgarian coast (Table 1).

Mapping of natural landforms/human structures and analysis was performed with ArcInfo 9.2 tools. The extraction of coastline could be done automatically or by hand digitization in GIS. On a complex shoreline, auto-extraction can generate many errors and leads to time consuming post-processing. Therefore, the Bulgarian coast was hand digitized for shoreline location and segment types according to the preliminary defined hierarchical scheme for

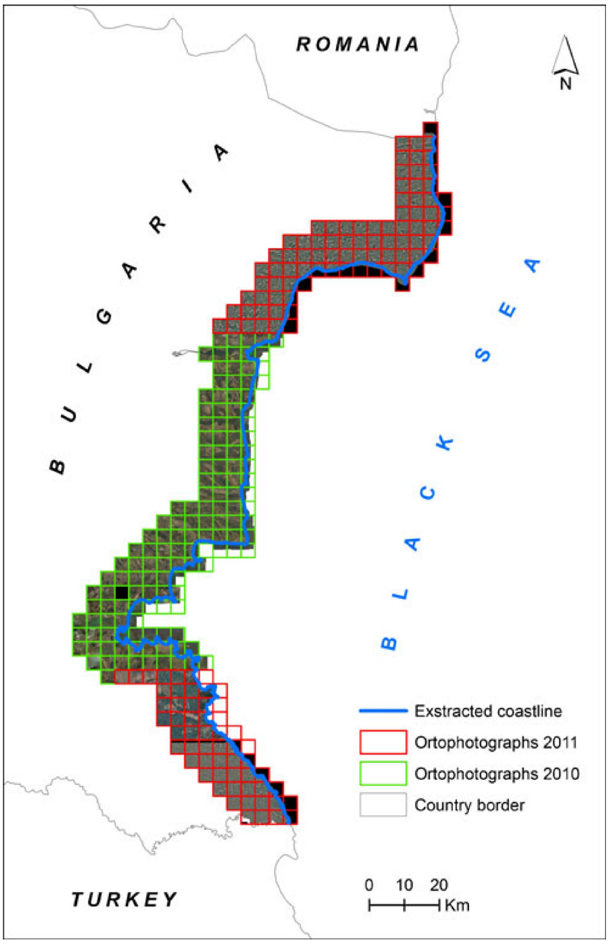

Fig. 2 Orthophoto images covered the Bulgarian coast

coastline segmentation. An ArcGIS shape file in ArcCatalog format was generated as vector linear object and then Desktop handmade digitization of the whole coastline was completed. The coastline segmentation of the Bulgarian coast by geomorphologic and engineering criteria was done through the vectorization process (the conversion of raster data (an array of cell values) to vector data (a series of lines). Simultaneously with the digitization process, the attribute table of each coastal feature/segment was filled in accordance with the respective classification scheme shown in Table 1.

The example of segmentation based on spatial information from orthophoto images is shown on Fig. 3. Maps produced on the base of orthophoto and satellite images with VHR less than 1 m correspond to topographic maps in 1:10,000 scale (Puissant et al. 2008). After digitization of the whole coastline and identifying various types of segments, calculations of their length were performed using GIS Extension XTools Pro 8.x.

Table 1 Hierarchical coastline segmentation scheme

I. Natural coastal landforms
I.1. Estuaries
I.2. Erosion cliff
I.2.1. Loess cliff
I.2.1.1. Low loess type cliff (height up to 10 m)
I.2.1.2. High loess type cliff (height more than 10 m)
I.2.2. Limestone cliff
I.2.2.1. Low limestone type cliff (height up to 10 m)
I.2.2.2. High limestone type cliff (height more than 10 m)
I.2.3. Volcanic rock cliff
I.2.3.1. Low volcanic rock type cliff (height up to 10 m)
I.2.3.2. High volcanic rock type cliff (height more than 10 m)
I.2.4. Clayey cliff
I.2.4.1. Low clayey type cliff (height up to 10 m)
I.2.4.2. High clayey type cliff (height more than 10 m)
I.3 Sandy beaches
I.3.1. Sandy beaches in front of cliff
I.3.1.1. Narrow sandy strips (with average width up to 15 m)
I.3.1.2. Wide sandy beaches (with average width more than 15 m)
I.3.2. Sandy beaches followed by foredunes and dune fields landward
I.3.2.1. Narrow sandy strips (with average width up to 15 m)
I.3.2.2. Wide sandy beaches (with average width more than 15 m)
I.3.3. Sandy beaches limited landward by coastal estuaries/lagoons
I.3.3.1. Narrow sandy strips (with average width up to 15 m)
I.3.3.2. Wide sandy beaches (with average width more than 15 m)
I.3.4. Pocket sandy beaches (formed between erosion promontories)
I.3.4.1. Narrow sandy strips (with average width up to 15 m)
I.3.4.2. Wide sandy beaches (with average width more than 15 m)
I.3.5. Urbanized sandy beaches limited landward by roads/ infrastructure
I.3.5.1. Narrow sandy strips (with average width up to 15 m)
I.3.5.2. Wide sandy beaches (with average width more than 15 m)
II. Technogenous coastal landforms
II.1. Port/harbour structures
II.1.1. Harbour breakwaters
II.1.1.1. Shore-connected
II.1.1.2. Detached
II.1.2. Jetties/marinas
II.1.3. Port moles
II.1.4. Quay walls
II.1.5. Navigational channels
II.2. Coastal-protection structures
II.2.1. Sea/coastal dikes
II.2.2. Rip-rap/embankment
II.2.3. Groins

II.2.3.1. I-shaped groins
II.2.3.2. Y-shaped groins
II.2.3.3. T-shaped groins
II.2.3.4. Γ-shaped groins
II.2.4. Seawalls
II.2.5. Detached breakwaters
II.3. Artificial beaches
II.3.1. Artificial beach with retaining wall
II.3.2. Artificial beach without retaining wall

iii) Geological maps are from 1991/92 in 1:100,000 scale. Seven map sheets that cover the whole Bulgarian coast were used to determine the geological composition and structure of the cliff types.

For easier follow on, all activities of the methodology described are presented in a flow chart (Fig. 4).

Similar attempts to coastline classification and segmentation have been done prior by different initiatives and studies. Recognition in the early 1990s of variability in physical, ecological and human characteristics of coasts has focused efforts towards classifying coastline at a world-wide scale under the LOICZ Project (Land-Ocean Interactions in the Coastal Zone, until 2015) of the International Geosphere-Biosphere Programme and the International Human Dimensions Programme on Global Environmental Change. The important task of that project is to establish a global coastal zone "typology" based upon available descriptive and dynamic scientific information. Thus typology, the 'study or systematic classification of types that have characteristics or traits in common', has become a commonly used term and technique in coastal zone studies over the past two decades (Buddemeier et al. 2008). As regional project of LOICZ, the 5th Framework DINAS-COAST project (Dynamic and Interactive Assessment of National, Regional and Global Vulnerability of Coastal Zones to Climate Change and Sea-Level Rise) developed a GIS database covering the world's coastline, as 12 148 segments were identified (Vafeidis et al. 2008). In DINAS-COAST data base model all data are expressed as attributes of seven geographic feature types, namely, linear coastline segments of variable length, subnational administrative units, countries, major selected rivers, major selected tidal basins or

Fig. 3 Map of coastline segmentation

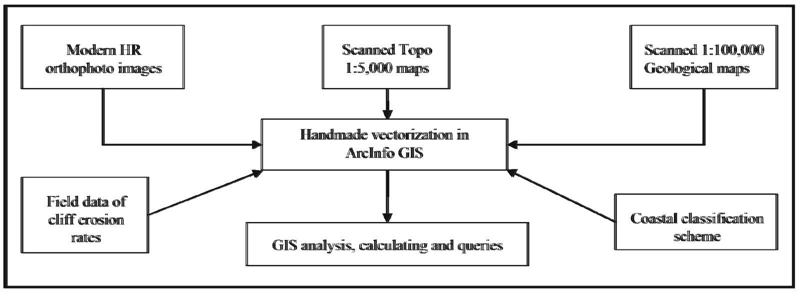

Fig. 4 Flow chart summarising the methodology used

estuaries, world heritage sites, and relevant climate and sea-level scenarios.

EUROSION project, commissioned by the General Directorate Environment of the European Commission (2001–2004) generated a database in digital GIS format, with several layers of information (coastline, elevation, boundaries, geology, coastal defence works etc.) in scale 1:100 000 (EUROSION Project 2004a). The baseline shoreline is being improved locally as part of the process to produce the layer geomorphology and geology. Improvements are based upon large scale maps (in general 1:50,000).

Investigations at regional and local scale have been carried out for subdivision of European coastlines by morphogenetic criteria or segmen- tation of littoral zone by natural landforms/human structures in cells of different dimensions and characteristics (Anfuso and Martinez del Pozo 2005).

The United States Geological Survey (USGS) National Assessment of Coastal Change Project has generated a broad classification that can be applied to most coastal regions in the USA and a Coastal Classification Atlas, including the basic information for risk assessment has been created (Morton and Peterson 2005). An indicative map of geomorphic vulnerability to coastal hazards has been prepared for the entire 6,500 km of the Tasmanian coast. It was produced from a GIS line map with attributes providing a uniform coded descriptive classification of coastal landform types at 1:25,000 scale (Sharples 2007).

There are numerous methods for coastal classifications, determining rates of shoreline erosion and mapping coastal vulnerability to erosion. Most of these methods involve direct field measurement or detailed assessments from a time-series of aerial photographs. For shorelines where there has not been long-term monitoring, it is still desirable to have an understanding of the likelihood for future erosion. The methodology described in this paper is particularly useful for examining shoreline erosion vulnerability along coasts where there is little, previous historical data of cliff erosion rates. By combining newly available orthophoto imagery with geological data, one can produce a good map for future cliff erosion vulnerability. These data have been spot-verified with a small number of field measurements and the methodology can be easily applied in other locations.

Results and discussions

Geomorphic classification and segmentation of the Bulgarian coast

The first GIS-based classification/segmentation of the Bulgarian coast was produced using topographical maps in 1:25,000 scale published in 1994 (Stancheva 2009). Three hundred seventy nine various segments, with a total length of 439 km, were identified along the entire coast and were grouped as natural (landforms) and technogenous (port and coast-protection structures). However, due to the intensive developments of the coast and numerous newly built structures over the period 1994–2012, the data from older topographic maps is out of date and requires updating.

The length of the digitized coastline taken from modern HR orthophotos of Bulgaria is 432.35 km. Port and coast-protection constructions were mapped as line segments, not polygons, and their sea-facing perimeter was also mapped as a linear feature. A total of 867 segments were delineated along the Bulgarian coast including both natural and technogenous landforms. Four hundred sixty five segments were classified as natural landform (cliffs, beaches, river mouths, etc.) with a total length of 362.62 km. Four hundred two were classified as technogenous shorelines (port and coast-protection structures, and artificial beaches) with a total length of 69,89 km. All coastal segments were also combined into two main groups of geomorphic types based on geomorphological and engineering criteria set up in the classification hierarchical scheme (Table 1):

- Natural coastal segments (landforms) were identified by geomorphologic criteria: i) 17 river mouths, 243 segments of sandy beaches; ii) 205 cliff segments (including low overgrown and high erosion types);
- Technogenous coastal segments (various maritime structures both cross- and long-shore and artificial beaches) were identified by engineering criteria: i) 178 different types of groins; ii) 31 dikes; iii) 26 seawalls; iv) 73 embankments/rip-raps; v) 62 ports, marinas/quay walls and navigational channels; vi) 14 segments, representing artificial beaches.

Both natural and technogenous coastal segments have a total length of 498,33 km, which exceeds the length of the entire coastline (432,35 km) due to the included cross-shore structures such as groins, ports/marinas, moles and permeable bridges. Cliff type is the most common shore type along the Bulgarian coast comprising 49.3 % or 213 km of the whole shoreline. Sandy beaches comprise at least 34.5 % (149 km) of the coast and the armoured/engineered coast occupies 16.2 % (70 km). Port and coast-protection structures with "hard" stabilization (seawalls, groins, etc.) are not regularly spaced along the coast. Construction of these structures mostly depends on requirements for defending the shoreline and infrastructure at sections most hazard-prone to flooding and erosion. There are some areas with heavily armoured coastline: at the northern part of the Bulgarian coast, between the town of Balchik and Cape Galata, where 111 types of maritime structures were identified with a length 46 km; and between Nessebar town and Sozopol town, where 186 structures are found. These most technogenously occupied areas also include the largest Bulgarian Black Sea bays, Burgas and Varna, where significant parts of urban/land activities (transport logistics, industries, trades, etc.), coastal infrastructures and tourism developments are concentrated.

Predictive map of cliff erosion vulnerability

Coastal erosion and related flood and landslide phenomena normally generate very high economic, social and environmental costs. In order to prevent and avoid these costs, it is necessary to have very good and detailed information about the real impacts in the past and present. All coastal EU Member States have problems with coastal erosion. Over 20 % of the evaluated European coastline is affected (EUROSION Project 2004a; DEDUCE consortium 2007). These problems could increase because of the effects of climate change.

Currently, coastal erosion is a widespread process along the Bulgarian Black Sea coastline (Peychev and Stancheva 2009). In order to find the most relevant solutions to control coastal erosion or cliff retreat, it is important to determine the reasons for this process (Stancheva and Marinski 2007). Several different factors are responsible for the increased rates of cliff erosion and landslides along the Bulgarian coast: 1) environmental factors, such as sea level rise, and more frequent storm surges, geological settings of the coast, shortage in sediment supply etc.; and 2) factors related to human activities, like coastal urbanisation, expanded developments, and armouring the coastline by hard engineering structures (dikes, seawalls and solid groins). Peychev and Stancheva (2009) found that coastal erosion over the last few decades has been mainly activated by accelerated anthropogenic impact on the Bulgarian coast in terms of maritime constructions, dredging works and river engineering. Field measurements of coastal erosion rates have been carried out by the Institute of Oceanology, Bulgarian Academy of Sciences since the 1980s using a consistent methodology (Parlichev 1986; Peychev and Stancheva 2009).

HR orthophotos, along with solid geological data, can be used within a GIS database to produce maps of coastal vulnerability with good accuracy. Such maps reflect the state of the coast at the time of image acquisition. Acquiring older photography can allow the production of time-series maps, maps of the current state of the coast, leading to predictions of future shoreline trends. The vulnerability map provides an effective initial tool to guide coastal planners in the absence of more detailed assessments for large coastal regions (Sharples 2006), which can be further easily upgraded with more data for wave erosion, flooding and socio-economic data. This information will help to guide development planning in coastal areas that might potentially be subject to erosion, storm surge flooding and other coastal hazards both at the present time, and increasingly in the future in response to projected sea level rise.

Map of exposure of European regions (NUTS2 level) to coastal erosion was produced under EUROSION project, as impact indicators included: population living within the radius of influence of coastal erosion, urbanized and industrial areas within the radius of influence of coastal erosion, growth of coastal urbanized areas between 1975 and 1990, and areas of high ecological values within the radius of influence of coastal erosion. Indicators of sensitivity and impact indicators have been aggregated to define the score of "risk of coastal erosion". Coastal regions have been classified into four different categories: 1) Very high exposure; 2) High exposure; 3) Moderate exposure and 4) Low exposure (EUROSION Project 2004b).

In this case, the geospatial data have been used to construct a map of the Bulgarian coastline showing vulnerability to one hazard, coastal erosion/cliff retreat (Fig. 5).

Based on this map for coastal erosion, the Bulgarian coast was classified by geological structure and cliff height as being:

i) low hazard: coastal sections made up of volcanic type cliff, built by potassium-alkaline trachytes, latites, psammitic and psephitic tuffs, pyroclastic flisch, volcanites, andesite-basalts, basalts crop out along the southernmost coast between Capes Foros and Rezovo (Fig. 5);

ii) moderate hazard: coastal sections made up of limestone type cliff, where the coast is built by limestones, clays, clayey marls, sands and sandstones. This includes the coast between Capes Shabla and Foros in the middle part of the Bulgarian coastline (Fig. 5);

iii) high hazard: coastal sections of loess and clayey type cliff, where the erosion coast is built by loess sediments underlain by Upper Sarmatian limestones (between Capes Sivriburun and Shabla) and by clays, sandy clays and aleurolites outcropped at the area of Burgas Bay (Fig. 1 and 5).

The total length of cliff coast is 213 km, with the loess type cliff comprising 1.0 % and clayey type cliff 2.5 % of the eroding coast. Limestone type cliff is dominant and spreads along 107 km or 50.4 % of the coastline, and volcanic type cliff occupies 98 km or 46.1 % of the coast. The classification of cliff vulnerability is supported by field measurements of cliff erosion rates. According to Peychev and Stancheva (2009), the average rate of erosion of loess sediments is quite

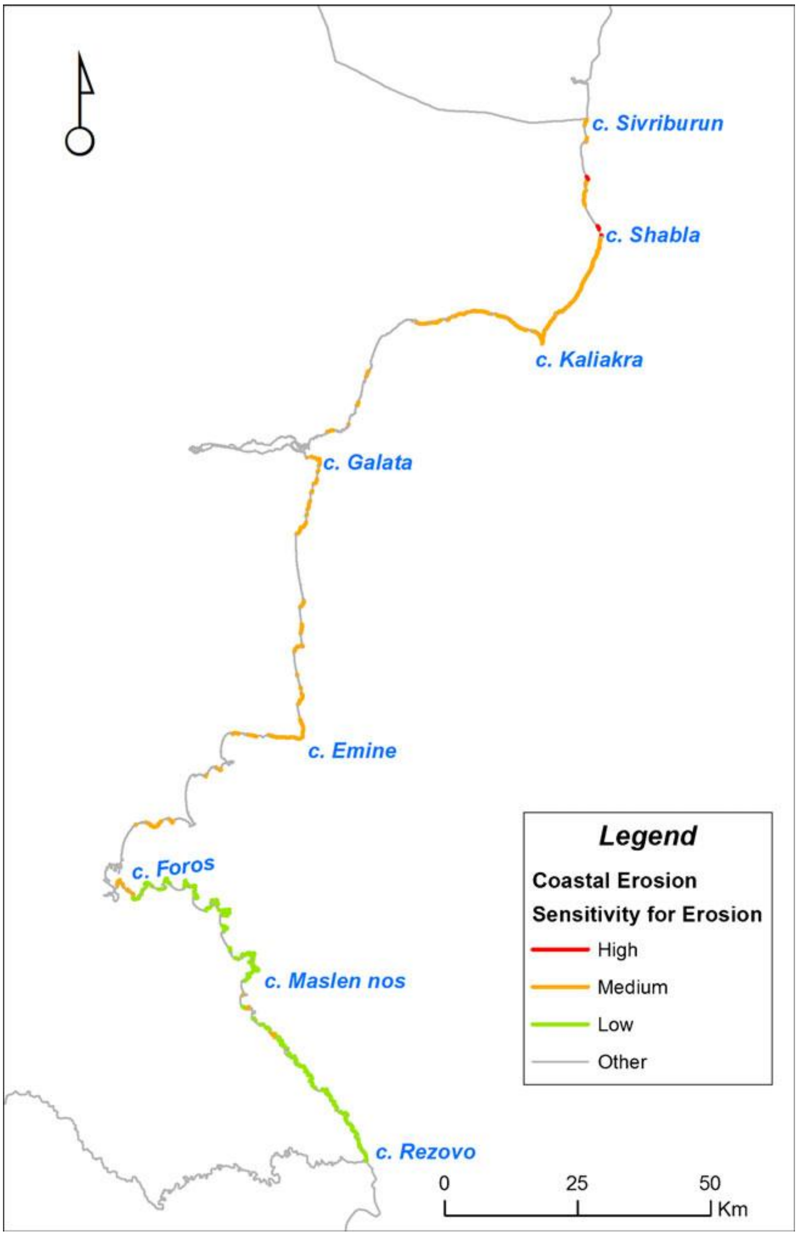

Fig. 5 Sensitivity map for coastal erosion

high: 0.30 m/y. At certain sites (e.g. north from Cape Shabla), the erosion rate reaches 1.2–1.6 m/y. It is quite high as well in coastal sections built by clays and sandy clays. The average rate of erosion ranges from 0.19 to 0.29 m/y. The average rate of erosion in limestone type cliff varies between 0.05 and 0.30 m/y. Volcanic type cliff is resistant to erosion and respectively the average rate of erosion is low: 0.01 m/y.

Comparing with results of EUROSION project for exposure of European regions to coastal erosion, for the coastline of Bulgaria for NUTS2 regions of Varna and Burgas this exposure is defined as moderate due to larger scale 1:100,000 of shoreline segmentation. However, data for coastal erosion rates of the project and present study are compatible and show similar figures. For example, at cliff segment of cape of Shabla, the results from EUROSION project reported a cliff retreat at rates of 0.30 m/y to 2.0 m/y which corresponds to the results of erosion rates from field measurements according to Peychev and Stancheva (2009) used for producing coastal erosion map in this paper.

As the erosion rate and vulnerability of the coastline is constantly changing due to natural and anthropogenic factors, the erosion sensitivity map supported by HR digital orthophotos and GIS methods is very useful in identifying cliff locations along the Bulgarian coast that may be most susceptible to erosion. These areas should be closely monitored.

Conclusions

The efficient and sustainable management of dynamic shorelines and coastal zones requires the availability of modern high resolution geospatial data and tools for data collection, processing, storage and analysis.

Over the recent decade, the Geographic Information System, in combination with Remote Sensing (satellite and orthophoto images with submeter resolution) has been proven as reliable and powerful technologies for studying coastal processes. Incorporation of modern high resolution spatial data into GIS allows for accurate and detailed detection of coastal features and shoreline changes through image digitization and analysis. With the help of GIS and modern spatial data, and based on an assumed hierarchical coastline segmentation scheme for the Bulgarian coast, all main geomorphic types of natural landforms and distribution of various types of port/coast-protection structures were precisely delineated and classified, digitized as vector objects and analyzed afterwards.

A modern, detailed segmentation of the Bulgarian coast has been created to provide the basis for identifying and assessing those areas most vulnerable to coastal risks. As an example, a sensitivity map of the Bulgarian coastline to one hazard, erosion/cliff retreat, was produced using geological and topographical maps to determine lithological composition and cliff height of each erosion segment. In this way, integrating various types of spatial data sources in a homogenous GIS environment provides a possibility for more precise assessment of sensitivity for coastal cliff erosion. The collected coastal spatial information incorporated into a GIS database will allow updating the database in the future with historical or modern data sets, which can be further combined with various field surveys or data sources.

This study used orthophotographs and geologic maps to classify the Bulgarian Black Sea coast into segments based on geomorphic type. These data were then used to develop a predictive model for cliff erosion vulnerability based primarily on the structure and geologic make up of the cliff/bluff sections of shore. The predicted erosion susceptibility was verified for a representative number of segments using field data collected previously (Peychev and Stancheva 2009). Therefore, we assume that map of cliff vulnerability to erosion is valid for all segments identified.

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