Long-Term Alterations to the Varna-Beloslav Lake Complex due to Human Activities (Bulgarian Black Sea Coast)

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Abstract

There are several larger lakes at the 412 km long Bulgarian Black Sea coastline, as each distinguishes with a specific hydrological regime and parameters. The deepest and the largest is the Varna Lake, located west from the Bay of Varna at the North Bulgarian coast. The lake is a firth formation at the river valley under a rising sea level during the Holocene, when it was divided from the sea by a large sandy spit. In 1900s with construction of Varna Port a navigational channel between Varna Lake and the sea was built, while in 1920s it was artificially connected to the inland Beloslav Lake by other navigational channel. Since the beginning of the past century the two lakes have been subject of many direct human impacts, such as: digging of three navigational channels; situating a number of ports with different functions; constantly performed dredging activities etc.

The aim of this paper was to trace the long-term changes to the lakes of Varna and Beloslav mostly associated with human activities over a 100-year period. Two types of data were used: historical topographic map from 1910 in scale 1:200 000 and nautical maps in scale 1:10 000 from 1994. The data were processed and analysed with support of GIS and modelling in order to quantify the changes of areas and volumes of the lakes, as well as of the navigational channel between them. The findings from the study clearly reveal significant alterations of the two lakes that have been caused by increased anthropogenic impacts over the whole past century. As a result, the lakes were irreversibly altered in areas, water volumes, hydrological parameters and ecology.

Keywords: water balance; lakes; human impact; 3D GIS model; Bulgaria.

Study area

General physical and geographical background

The Varna-Beloslav Lake complex is located west from the Bay of Varna, at the North Bulgarian Black Sea coast (Fig. 1). It is a geomorphological unit that consists of two natural lakes (the coastal Varna Lake and the inland Beloslav Lake) that have been connected between them with a 5450 m long navigational canal (Canal-2). On the other hand the Varna Lake has been connected to the sea with a 3000 m long navigational canal (Canal-1).

The lakes of Varna and Beloslav are related to the Black Sea catchment basin, with a watershed area of 2611 km^2 and direct inflow to the Black Sea (Fig. 2). A few rivers and smaller streams disgorge into the Varna Lake, among which the largest are rivers of Devnya and Provadiyska that empty near the western shores of Beloslav Lake. From hydrological point of view the watershed of the both lakes belongs to the area with continental climatic influence on the regime of the river water runoff and it is a sub-area with a prevalence of rainfall nourishment. The northern coast of Varna Lake and catchement area of Devnya River are related to the region with prevailing influence of underground nourishment. The module of annual runoff is in the range between 0.5 and 1-2 l/s/km^2, with exception of Devnya River with a module of annual runoff up to 4 l/s/km^2. This increase could be associated with additional inputs from the Devnya karsts springs.

Varna Lake is the deepest and largest by volume along the Bulgarian Black Sea coast and it was divided from the sea by a 2 km-wide sandy spit (Fig. 1; Fig. 3). By its origin, the Varna Lake is a firth formation at the river valley under a rising sea level during the late Holocene, when it was separated from the sea by the constantly growing Asparuhovska sandy spit (Bogkov, 1936; Dachev, 2003). The lake has an elongated shape, as its southern side is high and steep, while the northern one is quite slant. Generally, its bottom is covered with thick (up to 10-30 m) alluvium deposits, which at the deepest parts passed into black hydrogen-sulphide silts. The topography of the lake is characterized by a number of valleys reaching from 30 to 120 m in width (Ivanov et al., 1964).

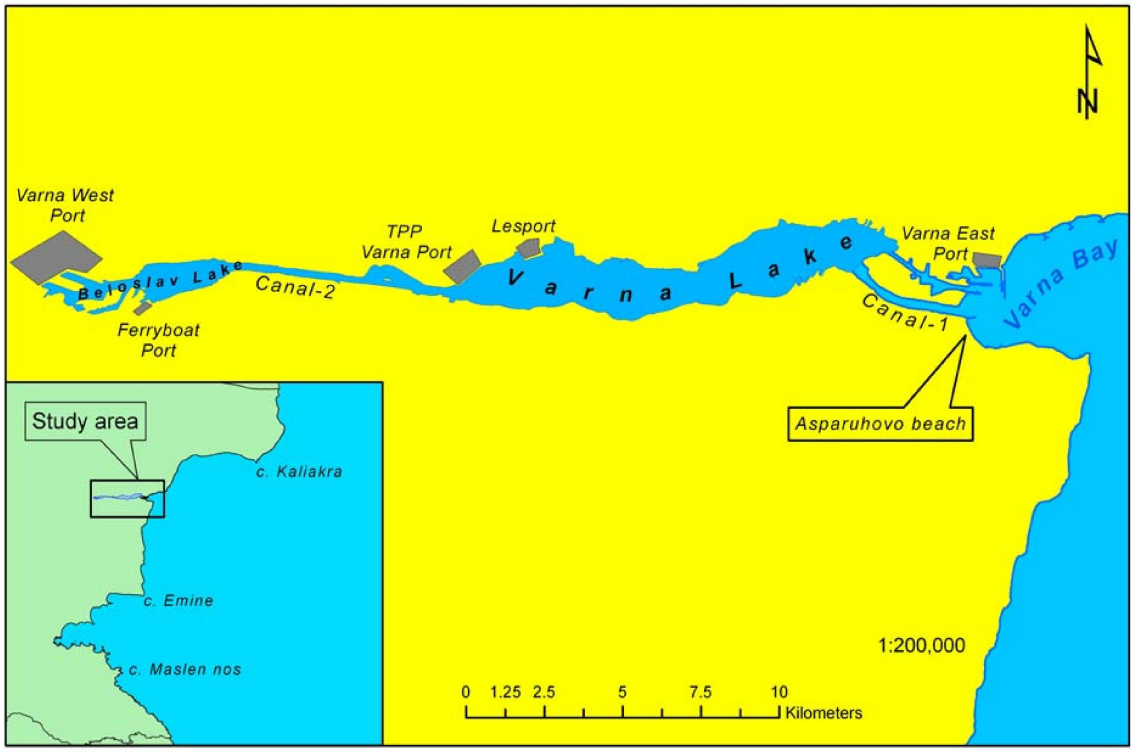

Figure 1. Locator map of study area

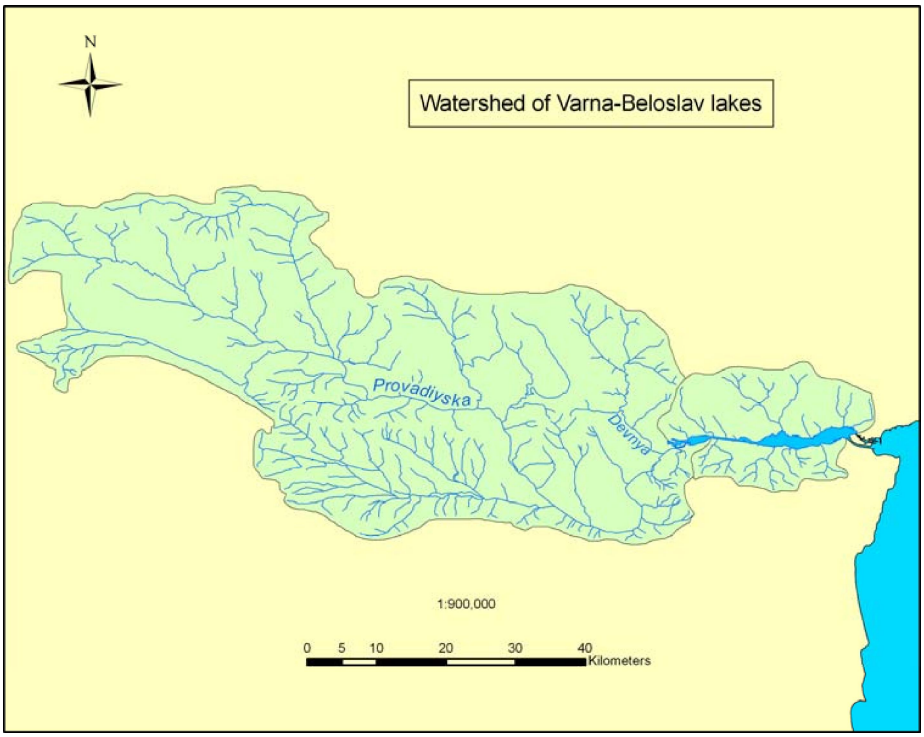

Figure 2. Watershed of the Varna-Beloslav Lake complex

Beloslav Lake is located west from Varna Lake at the same river valley. Initially, both lakes were one whole water basin, but in result of water content decreasing of the rivers, sediments carried out by the floods and due to other factors, the lake had been isolated from the Varna Lake (Ivanov et al., 1964).

The Beloslav Lake was a fresh-water basin until 1923, when the canal with a depth of 3 m between lakes of Varna and Beloslav was dug. After digging of this canal the water level of the lake decreased and large marshy areas were formed in its western part. The western and eastern shores of the Beloslav Lake are low, while along the north and south ones, after small alongshore vegetation, there are high hills built of limestone and silts. The lake's bottom is mainly covered with silt deposits, as in the south-western part, where the rivers disgorge, the fast process of shoaling is observed. The reasons for this process are associated with the inflow from Provadiyska River and after the anthropogenic intervention in the study area (built plants and chemical industrial complex after 1960s) with the input of industrial muddy waters into Devnya River.

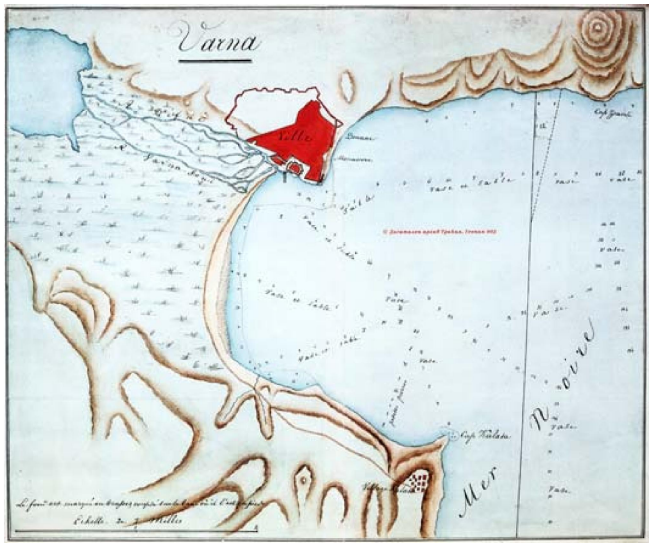

Figure 3. Map of the Varna Bay (1821-1822)
(Provided by "International Commercial and Cultural centre "GEOPAN", 2002)

The Varna-Beloslav Lake complex was a natural fresh-water firth system with a small inflow into the Black Sea until the beginning of the XX century (1906-1909) when the Varna Port East was built and the first navigational canal between Varna Lake and sea was dug with a length 2300 m (Fig. 1; Fig. 4). Since then, a number of human activities have been implemented around the study area over the whole past century: digging of the canal between both lakes in 1923; constructions of a few ports of national significance and industrial complexes along the shores of both lakes since 1970s (Fig. 1): Varna West Port, Thermoelectric Power Plant Port (TPP); Lesport (transport port of national significance used to handle general, bulk and ro-ro car) and Ferryboat complex Port (used to handle ships-ferryboats transporting wagons, ro-ro cargo and passengers); digging of the new navigational canal (Canal-1) providing safety approach for the modern deep-sea ships to the ports; extension of the canal between two lakes (Canal-2); and constantly performed dredging activities in the new navigational canal.
As a consequence, the studied lakes complex and the adjacent sandy spit have been dramatically altered by the increasing human activities, accelerated urbanization and continuously growing population in the coastal zone of Varna Bay.

GIS Modelling – data and methodology

In order to trace the long-term changes to the lakes of Varna and Beloslav over a 100-year period two types of data were used: two historical topographic maps from 1910 in scale 1:200 000 (http://lazarus.elte.hu/hun/digkonyv/topo/3felmeres.htm) and three nautical maps in scale 1:10 000 from 1994, that cover the area of both lakes and two navigational canals (Canal-1 and Canal-2). All maps were scanned, geo-referenced and digitalised into GIS environment.
On the historical maps from 1910 (Fig. 4) are pointed only the coastline configurations of the two lakes and the small river between them, and the old navigational canal, connected Varna Lake with the sea. Hence, these maps were used to identify the shapes/coastline configurations and areas of the both lakes in the beginning of the past century in order to describe the natural state of the study area before increased anthropogenic intervention. On the modern nautical maps from 1994 in scale 1:10 000

(Fig. 5), there are pointed contours with isobaths of the both lakes and navigational canal between them.

Figure 4. Study area before human impacts

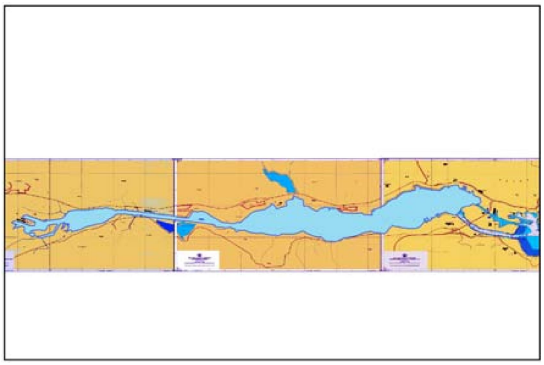

Figure 5. Study area after human impacts

In addition, the 1994 maps remark the depths at hundreds of points around the both lakes and Canal-2. Thus, the drawn contours and the marked depths allow an accomplishment of a precise Triangulated Irregular Network (TIN) model of the Varna-Beloslav Lake complex and navigational canal between them (Fig. 6).

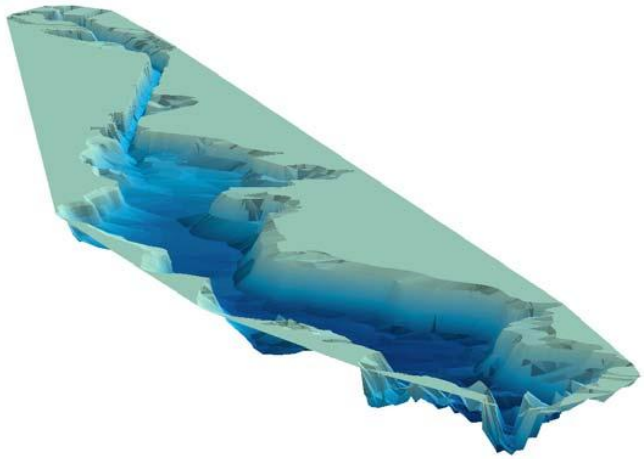

Figure 6. 3D GIS model of Varna-Beloslav Lake and navigational canal

The TIN model was implemented with a help of ArcGIS 3D Analyst, which provides advanced tools for three-dimensional visualization, analysis, and surface generation. This special GIS extension enables to create dynamic 3D models and interactive maps that elevate the visualization and analysis of geographic data (ESRI, 2000-2002). Thus, the generated 3D GIS model then serves for quantifying the areas and volumes of the both lakes and Canal-2.

Results and discussions

Human impacts on the study area and alterations of the lake complex over a 100-year period

Over the past 100-year period significant and irreversible changes of shoreline configurations and hydrological regime of the Varna-Beloslav Lake complex have occurred in result of numerous human activities. The anthropogenic influence on the study area has been remarked since starting of the accelerated process towards urbanisation and industrialisation of the Bay of Varna. Until the beginning of the XX century Varna Lake waters disgorged into the sea through the high-water, but shallow Devnya River (in the past Varna River; Fig. 3). After the construction of Varna East Port this river was drained and during 1906-1909 an old navigational canal was built through the sandy spit separating the lake from the sea. As a result, the lake's water level dropped with approximately 1.40 m and this had led to the sea waters incursion into the Varna Lake, which after that has become brackish. Northerly from the sandy spit (the Asparuhovo beach at present), which separates Varna Lake from

the sea, the enlargement of Varna Port East is located (Fig. 1). In its initial type this first port had been functioning more than half century, but later due to increased goods turnover its extension had been required. That is why the decision for building of Varna West Port in the western part of Beloslav Lake was accepted. In this regard, in 1974-76 a new navigational canal (Canal-1) was put into operation in order to provide the safety approach for the modern deep-sea ships to the Varna West Port (Dachev, 2003). When a new 12 m deep navigational canal crossed by the Asparuhov most began operating, the lake was dredged along the stream. Another navigational Canal-2 to the west lead through the neighbouring Beloslav Lake to the Port of Varna West and to the ferryboat Port. In 1976 TPP (Varna) Port was out into exploitation, which additionally impacted the water-area of the lake complex and thus altering its hydrological regime. Dredging of the Beloslav Lake, enlarging and deepening of the navigational canal between two lakes (Canal-2) and digging of the Canal-1 between Varna Lake and Varna Bay have considerably changed the hydrological regime of the study complex. Therefore, all investigations on water circulations and the exchange between the individual components after 1976 has attained a significant importance since these ones could present the real state of the waters dynamics in the studied area after the anthropogenic influence. It was found that constant intensive water exchange exists between Varna Bay and Varna Lake, as the sea waters incursion westwards have mostly performed through the new Canal-1 and the lake waters to the Varna Bay through the old canal (Veselinov, Mangov, 1980).

After connecting the Varna Lake with two navigational canals to the Black Sea, both lakes of Varna and Beloslav have become brackish i.e. these pure water-fresh basins have turned into salted ones. Gradually, the salinity of the whole Varna-Beloslav Lake system has considerably risen and at present the average salinity has increased up to 17 ‰. For example, the salinity of Varna Lake now varies in large range (13.74–16.82 ‰) and its value depends on meteorological and hydrological conditions during the seasons (Shtereva, Dzhurova 2004). After that, the hydrological and hydrochemical regimes of the inland Beloslav Lake are determined by river inflow and also by water exchange with Varna Lake, which means by the indirect influence of Varna Bay sea waters, flowing through the Canal-2 from the Varna Lake. In this regard, salinity in the surface waters varies in range 8-15 ‰ with minimum in the west part of the lake, where the influence of fresh water from the rivers is more significant (Shtereva, Dzhurova, 2006). A main share of fresh water incoming into the lake is that of the Provadiyska River.

Digging of the new Canal-1 in 1976 was operated through the existing large sandy spit (its remaining part is Asparuhovo beach at present) and thus causing dramatic alterations of the beach area and length. As a consequence, the coastline length of the beach was shortened with 837 m and the beach area was reduced with 56446 m^2 compared with its parameters in 1961 (Fig. 1; Fig. 4), (Stancheva et al., 2007).

Results derived from GIS modelling for contemporary morphometrical parameters of the Varna-Beloslav Lake complex

On the base of performed 3D GIS model and using data from historical (1910) and nautical maps (1994), the morphometrical parameters of both lakes and canal between them were derived and estimated for the two periods of investigation: before and after anthropogenic influence (Table 1).

Table 1 Morphometrical characteristics of the lake complex

Parameters	Beloslav Lake 1910	Varna Lake 1910	Varna Lake 1994	Beloslav Lake 1994	Canal 2 1994	Total Water Area 1994
Length /m/	4050	13500	10360	4300	5450	20110
Width /m/	926	1356	1507	723	311	1015
Area /km^2/	3.750	18.306	15.615	3.108	1.695	20.418
Volume /mln m^3/	no data	no data	168.004	17.164	12.157	197.325

In general, a reduction of the areas of the both lakes compared to these ones in the beginning of the past century was found. Such decrease of the areas could be related with dropping out of the lakes levels after digging of the old navigational canal and connecting Varna Lake with the sea. All these activities have resulted in drying up of the near-shore lakes shoals and thence to reduced area.

Identified long-term changes of the study area due to coastline technogenous occupation

In order to identify long-term modifications of the coastline and features of the study area in result of human activities and coastline armouring (building of ports and protective structures; digging and

extension of the two navigational canals of Canal-1 and Canal-2; construction of ships keys etc.) a segmentation of the coastal area was performed. This mapping presents the ratio between the lengths of natural and armoured coasts along the both lakes, and the length of two canals (Fig. 7). It is obvious from the map that as a replacement of the large marsh areas located along the lakes and between Varna Lake and sandy spit in the near past, at present one of the largest industrial zones of town of Varna is concentrated here. Such significant and irreversible changes have been mainly caused by digging of the two deep-sea navigational canals (Canal-1 and Canal-2) and by resulting decrease of the level of Varna Lake, which caused drying up of the former wet zones.

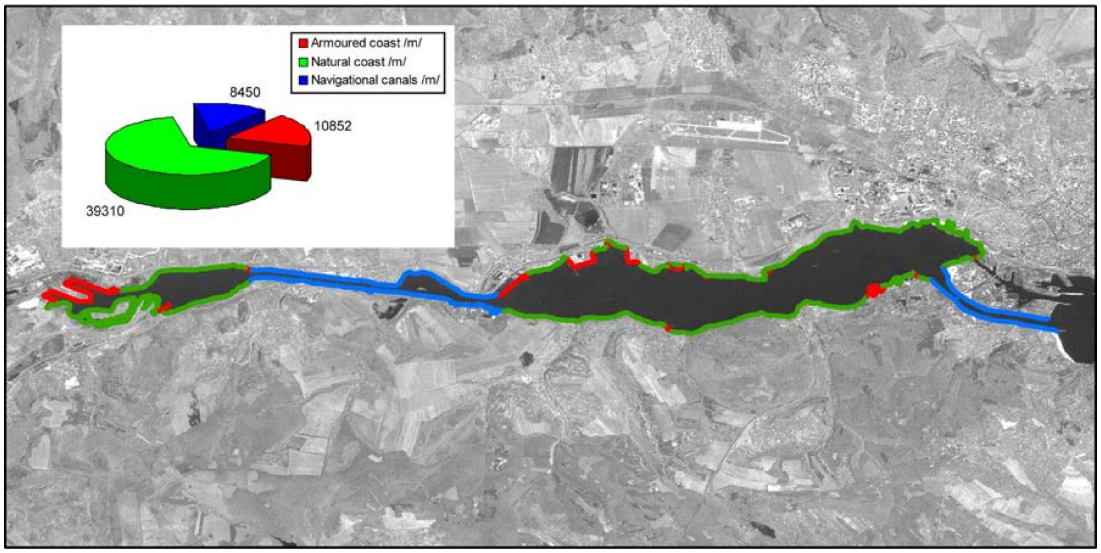

Figure 7. Identified ratio between natural coast and modified coast (by armouring and digging two large navigational canals)

In the beginning of the past century the coast along both lakes was entirely natural, with exception of the old navigational canal connecting Varna Lake with sea. On the contrary, at the end of the XX century navigational canals with total length of 8450 m have been dug and a number of large industrial ports, mentioned above have been built. According to the data of Executive Agency "Port Administration" – Varna, the total length of the ship berths to these ports at the area of both lakes have reached up to 5853 m, as the number of ships berths is 36 (http://www.port.bg/bg/index.html). The safe navigational depth is 12 m approximately, which requests implementation of constant dredging works in both canals: between two lakes and between Varna Lake and sea. Over the last few years the dredged sand has been deposited in the western part of the so-called “Island”, which indeed is a remaining part of the former marsh zones at this area (Fig. 8; Fig. 9).

Figure 8. The “Island” where the dredged sediments are deposited (August 2009 - M. Stancheva)

Figure 9. Dredging works in the Canal-1 (June 2009 – H. Stanchev)

Conclusions

The long-term alterations of the Varna-Beloslav Lake complex were detected for a 100-year period on the base of the results obtained from 3D GIS modelling, mapping and analysis. Irreversible changes and modifications of the lakes features and coastal section around, as well as alterations of the areas and hydrological regime of the whole lake system were identified. In order to evaluate the anthropogenic impacts a coastline segmentation of the study area was performed as the lengths of natural and armoured coasts were identified. This in turn allowed finding the extent of technogenous occupation of the coast: 11107 m or about 24% from the total 46112 m long lakes coastline were armoured. Adding also two navigational canals having a total length of 8500 m, then the length of the technogenous coast has reached up to 42 %.
In relation with required maintenance of the safe shipping depth and following permanent dredging works, the examined Varna-Beloslav Lake system would experience continuative impacts and negative effects. At present, a new project for replacement of the Varna Port East to the northernmost part of the Varna Lake has been operating and this would suppose additional dredging activities leading to new changes of the coastline and bottom features of both lakes. Hence, under the envisaged works it is expected that the investigated area would be exposed even to a more dramatic human-induced disturbance.

References

Bogkov L., 1936: *Notes on the Varna Lake. Press of Bulgarian Geographical Union (Sofia), volume IV. (In Bulgarian).*

Dachev V., 2003: *Genesis and Evolution of Varna Central Beach. Proc. of Institute of Oceanology, Vol. 4. pp. 74-82. (In Bulgarian).*

ESRI, 2000-2002: *Using ArcGIS 3D Analyst: GIS by ESRI. Environmental Systems Research Institute, Redlands: ESRI Press, 261 p.*

Ivanov K., A. Sotirov, A. Rojdestvenski, D. Vodenicharov, 1964: *Coastal lakes. The Lakes in Bulgaria. Proceedings of the Institute of Hydrology and meteorology, vol. XVI, "Nauka i Izkustvo" Press, Sofia, pp. 28-38. (In Bulgarian).*

Shtereva G., B. Dzhurova, 2004*: On the state of Varna Lake. Proceedings of VIth Intern. Conf. "Black Sea'2002", October 2002, Varna, V. 1, 338-341.*

Shtereva G., B. Dzhurova, 2006: *Recent state of Beloslav Lake (Bulgaria). Proceedings of BALWOIS 2006 Conference.*

Stancheva M., J. Marinski, H. Stanchev, 2008*: Evaluation of maritime construction impact on the beaches in Varna bay (Bulgarian Coast). Proc. of 9th International Conference on Marine Sciences and Technologies "Black Sea' 2008", October 23-25, 2008, Varna, 190-195. ISBN 987-954-90156-5-2.*

Veselinov V, G. Gergov, 1980: *First results from the investigation of hydrocomplex bay-lake in the region of Varna town. Hydrology and Meteorology, № 4, pp. 21-26. (In Bulgarian).*

http://lazarus.elte.hu/hun/digkonyv/topo/3felmeres.htm (last accessed on 21.01.2010)

http://www.port.bg/bg/index.html (last accessed on 10.02.2010)