GEO-ECOLOGICAL ASSESSMENT OF TUZLA LAKE (CONSTANȚA COUNTY, ROMANIA)

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Abstract. Tuzla Lake emerged in the 70's as an extension of Techirghiol Lake. The forming of the lake occurred due to human factors (intensive irrigations) and was favoured by natural factors (years of intense pluvial regime). The periodical increase of the Tuzla Lake level produced flooding in the area; the most recent ones (September 2005) significantly affected the buildings and the land around Tuzla Town. In order to evaluate the geo-ecological state of Tuzla Lake, including the impact from the last flooding events on the morphology of the lacustrine basin, the following investigations were performed: bathymetry measurements, sedimentological evaluations, and determination of the physico-chemical, chemical and microbiological parameters of the water. These investigations were performed during 2005 and 2006, and they consisted of the periodical sampling of the water and sediments as well as of bathymetry measurements *sensu stricto* before and after the 2005 flooding events. The central area of Tuzla Lake has a positive morphological element directed N-S, which divides the basin of the lake in two distinct areas: a western area, maximum 2m deep, and an eastern area, over 1.5m deep. Following the September 2005 floods, a decrease in the depth of the lake by 60-70cm in the southern part of the lake and by 30cm in the northern part occurred. Probably, one of the effects of the flood was the partial clogging of the lake. The lithology of the samples analyzed (mud, silt) indicates that the Tuzla Lake sediments are specific to a lacustrine environment. The aquatic environment is eutrophic (high level of nutrients and reduced oxygen level), an environment suggested by the blackish colour and the oily consistency which is specific to the sapropelic muds. The laboratory analysis results indicate low values for dissolved oxygen, and values significantly above the standards for PO_4^{2}, SO_4^{2-}, as well as high salinity values (30-40 ‰). Therefore, it was concluded that the water in Tuzla Lake is polluted. This observation, along with the fact that there was an excess of lake vegetation that favoured an increase in anophelic habitats, indicates the fact that Tuzla Lake presents a hazard for the human health of the communities in the area.

Key words: grain-size, hydrochemistry, bathymetry, geo-ecology, Tuzla Lake

INTRODUCTION

Up until 1970, the land occupied by Tuzla Lake was a lot smaller than today. Starting with the introduction of irrigation systems, the freshwater input into Techirghiol Lake from irrigation channels as well as underground infiltrations and a heavy rain regime in some particular years increased the water level of Techirghiol Lake. A golf formed right next to it, which moved toward Tuzla Valley close to Tuzla Town, forming in the end the actual Tuzla Lake (Fig. 1). This lake extends to a surface of 49 hectares today, and it represents a permanent ecological and environmental risk.

The engineering works for the protection of Techirghiol Lake and for the prevention of a reduction in the salinity of the lake (well known for its therapeutic properties) began in the 70's. During the 1972-1973 period, as a result of the water level increase caused by the input of freshwater, a series of boreholes were drilled in the Biruința Area, and two pumping stations were installed for the capture of underground water. A dam was built in 1983, which was meant to limit the freshwater input into Lake Techirghiol from large flow-rate springs.

The engineering protection works continued in 1983 with the design and implementation of pumping stations, which capture and transport the freshwater through a pipe towards Tatlageac Lake (23 August) and further into the sea.

Also, two smaller dams were built on the Izvoarelor Valley and Gospodăriei Valley. In 1989, in order to isolate the saline Techirghiol Lake from the buffer lake, a large dam was built, which transported the freshwater through the main pipe by gravity into Belona Lake located on the seashore.

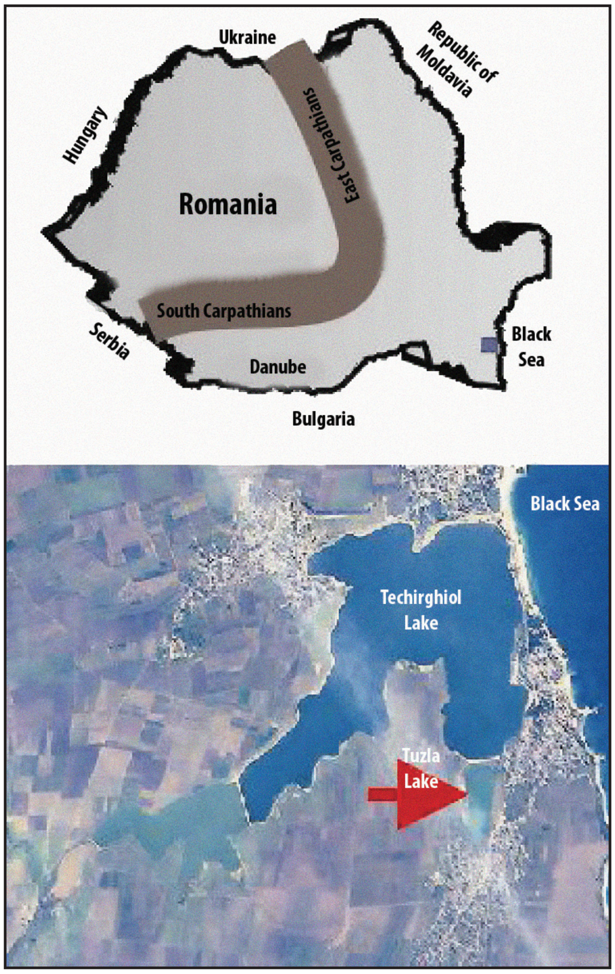

Fig. 1 Site Location (www.googlearth.com)

These engineering works failed to improve the situation of the Tuzla Lake. As a consequence of the high water level in the lake, several floods occured in Tuzla Town. These floods affected the buildings in the area and the land around them. Following the September 2005 floods, the situation in Tuzla deteriorated with 11 houses destroyed, 61 houses badly affected and another 203 houses and 85 establishments that were flooded.

Aside from the engineering problems, in time, significant ecological problems emerged. As a result of the excess vegetation in the lake, which favoured the increase in anopheline populations, the quality of the aquatic environment was reduced to becoming a real hazard for the health of the people. Last but not least, the transformation of Tuzla Lake in a recreational and fishing (the lake contains fish) site is an additional hazard as long as it does not meet the minimum health standards.

METHODOLOGY

In order to get data on the geo-ecological state of Tuzla Lake, regular water and sediment samples were collected. Also, bathymetry measurements were performed in 2005 and 2006. The second set of bathymetry measurements was performed to identify the possible changes in the morphology of the basin resulted from the flooding events in autumn 2005, and to observe whether or not these events influenced the water regime in the lake or the lake shores.

Bathymetry measurements

The high accuracy bathymetry measurements were performed in two stages: at the end of May 2005 and at the end of June 2006. The entire surface of Tuzla Lake was covered by a network of bathymetry profiles directed east-west and equidistant at 40m, which were intersected by numerous control profiles directed north-south. The total length of the bathymetry profiles measured in 2005 and 2006 was over 48km.

In order to perform the water depth measurements, a modern bathymetry system was used. This was the single beam Ceeducer model with an operating frequency of 200 kHz and a precision of ± 0.01 m. The automated data acquisition system included a DGPS receptor model Ashtech and a portable computer, which was used for data acquisition and for a rigorous real time control of the navigation including the uniform coverage of the investigated area with bathymetry profiles. To perform the measurements, the equipment was installed on a small engine boat.

The processing and interpretation of the entire data collected was performed on the OASIS montage™ programme. The projection system used to display the results was UTM on elipsoide WGS-84.

Sedimentological and hydro-chemical sampling

In order to define the grain-size and geo-ecological characteristics of the Tuzla Lake sediments, water and sediment samples were collected from different sectors of the lake basin. The samples were collected with a Van Ven boden-greiffer of 22-20cm opening. The identification of human influences was considered in the selection of the sampling points. The impacts from the solid waste landfill of Eforie Nord, Eforie Sud and Tuzla were identified by collecting several samples from the northern edge of the lake (Samples: TU 06-01, TU 06-02 and TU 06-03). The TU 06-04 sample was collected to identify the influence of a household and the Constanta-Mangalia railway located on the shore. The TU 06-06 sample is representative for the obvious euthrophication of the lake. The TU 06-05 sample is representative for the southern edge of the lake that is impacted by the water drainage from the former Tuzla Valley. The TU 06-07 sample, collected from Techirghiol Lake, constitutes the confirmation sample for the parameters measured.

For the grain-size analysis, the grab samples were collected from the first 10 cm of sediment. These samples were considered representative of the sediment interval to be studied. For heavy metal determinations in sediments, one sample was collected from the water/sediment interface. This level was considered most affected by contamination due to human activities. The sediment samples collected were analyzed in the GeoEcoMar laboratories.

The water samples were collected from the same locations with the sediment sampling points. Moreover, the following parameters were determined *in situ* (using the WTW Multiline P4 Field Kit) at these locations: total oxygen content of water (mg/l), oxygen content or saturation percentage (%), electrical conductivity (CND-mS/cm), total dissolved solids (TDS g/l), suspended solids (SS-mg/l), pH and temperature. The chemical field determinations consisted of the quantification of the ionic groups (mg/l) NO_3, NO_2, PO_4 and SO_4 using the portable spectrophotometer *Hach DR/2000*.

Aside from the sampling for physico-chemical parameters and the nutrient concentration of water, water sampling was performed for bacteria determination. These samples were collected according to the existing standards. The micro-biological determinations were performed according to STAS 3001/1991 in the specialized laboratories of ECOIND.

RESULTS

Bathymetry

From the entire area of circa 0.43 km^2 of Tuzla Lake, the bathymetry measurements spanned an area of approximately 0.35 km^2, which corresponds to the central sector uncovered by vegetation and sufficiently deep for the engine boat access. The results of the bathymetry measurements performed in 2005 and 2006 are presented in Fig. 2. The isobaths displayed on the maps represent real depths for the water read at 1.05m level of the hydrometric gauge located on the southern end of the lake. The level curves for the land were from the 1:25 000 topographic map performed by DTM and are aligned to the national reference altitude system – the Baltic Sea.

The bathymetry map based on the 2005 data reveals the fact that most part of the Tuzla Lake is characterized by depths larger than 1.5m. The deepest parts of the lake are circa 2m and are in the north-western sector of the lake. In the central area, a positive morphological element was identified, which was directed north-south and which corresponded to a higher area on the bottom of the lake that divides the lacustrine basin in two.

In the middle area of the lake, from the center (Fig. 3) towards the west, many positive morphological elements directed east-west were also identified. These further divide the western sector of the basin into smaller sectors. Even though the amplitude of these local elements is relatively moderate (0.2-0.6m), they constitute the base of some islands or peninsulas covered by reed. Their continuity is remarkable, which indicates the fact that their origin comes from past anthropogenic works.

The high detail bathymetry measurements performed in 2006 allowed for the evidencing of the same morphological elements mapped in the previous year. The main observation from the second measuring event is the general reduction in depth (0.05m to 0.3m) of Tuzla Lake due to the significant volume of sediments discharged in the lacustrine basin by the September 2005 flood. This is shown in Fig. 4. The maximum sediment thickness (0.25-0.3m) is in the southern sector of the lake, which is the area connected to Tuzla Valley that gradually decreases towards the north to values of 0.05-0.1m.

Sedimentology

The macroscopical description of the sediment samples collected from Tuzla Lake is summarized in Table 1. The sample location data (GPS coordinates, water depth, distance from shores) and the lithological characteristics of the sediments are shown.

Grain-size analysis

The grain size analysis of sediments was performed by the dry screening method for the sandy fraction, and by the pipeting method for the clayey and silty fractions. For the dry screening, we used a set of 17 screens of various sizes between 0.063m and 2.0mm, and the pipeting was performed for the 0.063mm and 0.001mm grain size interval. The results are presented in Tables 2, 3 and 4.

With the exception of one sample (TU 06-04), which consisted of sand with gravel elements, the sediments of Tuzla Lake consist of grey-blackish clayey-silty mud. These present a film or a grey-yellowish, oxidated, mud stratum of 2-3mm on the surface. The sediments from most locations have a silty composition of 47.3% to 63.96% and/or a clay composition of 25.59-51.81%. The sand content is secondary to these. The sand percentage in samples increases towards the southern end of the lake. The exception comes from the TU 06-04, next to silt and clay (5.75%) and lithic fragments (limestone, green silts, etc.) corresponding to the gravel grain-size (43.87%) and the sandy fraction (50.38%). The lithic fragments are sloped and of different origin. If we exclude the lithic fragments (probably brought into the area for hydro-engineering and railway consolidation works), the TU 06-04 sample consists mainly of silt and clay and belongs to the same texture category as the other samples.

In Shepard's triangle diagram (1954), the sediments belong to the clayey silt type.

The texture parameters that give significant information on the environmental condition are the standard deviation and the asymmetry coefficient. The standard deviation σ_1 (Folk & Ward, 1957) is an indicator of the sorting and has values between 1.9 and 3.6 corresponding to a low degree of sorting. This indicates that the sediments come from many sources such as shore erosion, wind transport, or come from deposition from wastewater and/or other anthropogenic sources.

Table 1 Sample location and description

Sample	Water depth (m)	Distance from shores (m)		GPS Coordinates	sediment description		
		Left	Right		Level	Interval	Lithological characterization
TU06-01	1.74		150	44º 01' 12.17 N 28º 38' 10.30 E	A	0-15 cm	Semi-compact, greenish on top, black mud Slightly gelatinous, Techirghiol type mud
TU06-02	1.73	100		44º 01' 09.23 N 28º 38' 21.60 E	A	0-16 cm	Blackish silty mud, slightly greyish on top. Cylindrical elements that are extremely thin, probably of vegetal or animal origin appear on top. No gelatinous aspect.
TU06-03	1.80		50	44º 01' 07.50 N 28º 38' 10.14 E	A	0-15 cm	Blackish silty mud, slightly greyish on top, semi-compact, slightly sandy at the base (<10%). Cylindrical elements that are extremely thin, probably of vegetal or animal origin appear. Gelatinous aspect and an odour specific to the Techirghiol mud.
TU06-04		30		44º 00' 41.48 N 28º 38' 19.98 E	A	0-8 cm	Fine gravel with angular elements in a matrix (< 20%) of thick dark greyish silt. Obs.: location altered by animal dejection and by wastewater.
TU06-05		5		44º 00' 37.29 N 28º 38' 14.78 E	A B	0-1 cm 1-10 cm	Fine gravel to the top of the sample, in a silty greyish yellow matrix (<10%). Shell fragments from marine bivalves.
TU06-06	1.46		80	44º 00' 44.19 N 28º 38' 11.15 E	A B	0-0.1 cm 0.1-12 cm	Silty mud, blackish on top (milimetric film); Silty mud, greenish-grey, semi-compact, slightly gelatinous. Live worms.
Techirghiol Lake							
TU06-07	1.80	150			A B C	0-0.2 cm 0.2-10 cm 10-16 cm	Sandy silt, yellowish green with green algae Silty mud, black with (red) worms and bioturbations. Coarse to silty sand: whitish grey. The sand is made of shell fragments. Obs.: clearly bedded sample.

Table 2 Fraction percentages by Wentworth Grain-size Scale

Sample	Gravel %		Sand %					Silt %				Clay %		
	fine	very fine	very thick	thick	medium	fine	very fine	thick	medium	fine	very fine	thick	medium	Fine
Tuzla lake														
TU 01	0.00	0.00	0.00	0.02	0.17	0.23	0.43	4.52	9.70	17.79	15.34	15.95	9.07	26.79
TU 02	0.00	0.00	0.00	0.02	0.09	0.21	0.29	1.92	17.42	16.60	13.81	17.65	10.88	21.10
TU 03	0.00	0.00	0.02	0.12	0.38	0.85	1.64	3.42	25.57	16.25	14.18	12.62	7.73	17.23
TU 04	17.88	25.99	22.08	16.58	9.64	1.70	0.38	1.03	0.74	0.60	0.45	0.37	0.26	2.30
TU 05	5.65	4.34	2.36	1.72	2.00	5.11	5.23	14.59	16.45	11.52	5.44	9.41	5.41	10.77
TU 06	0.00	0.00	0.00	0.01	0.06	0.30	0.99	21.14	17.60	13.34	11.87	13.37	8.72	12.58
Techirghiol Lake														
TU 07	0.00	0.33	0.24	0.51	3.80	8.22	8.51	22.38	17.45	10.74	5.24	5.25	2.37	14.97

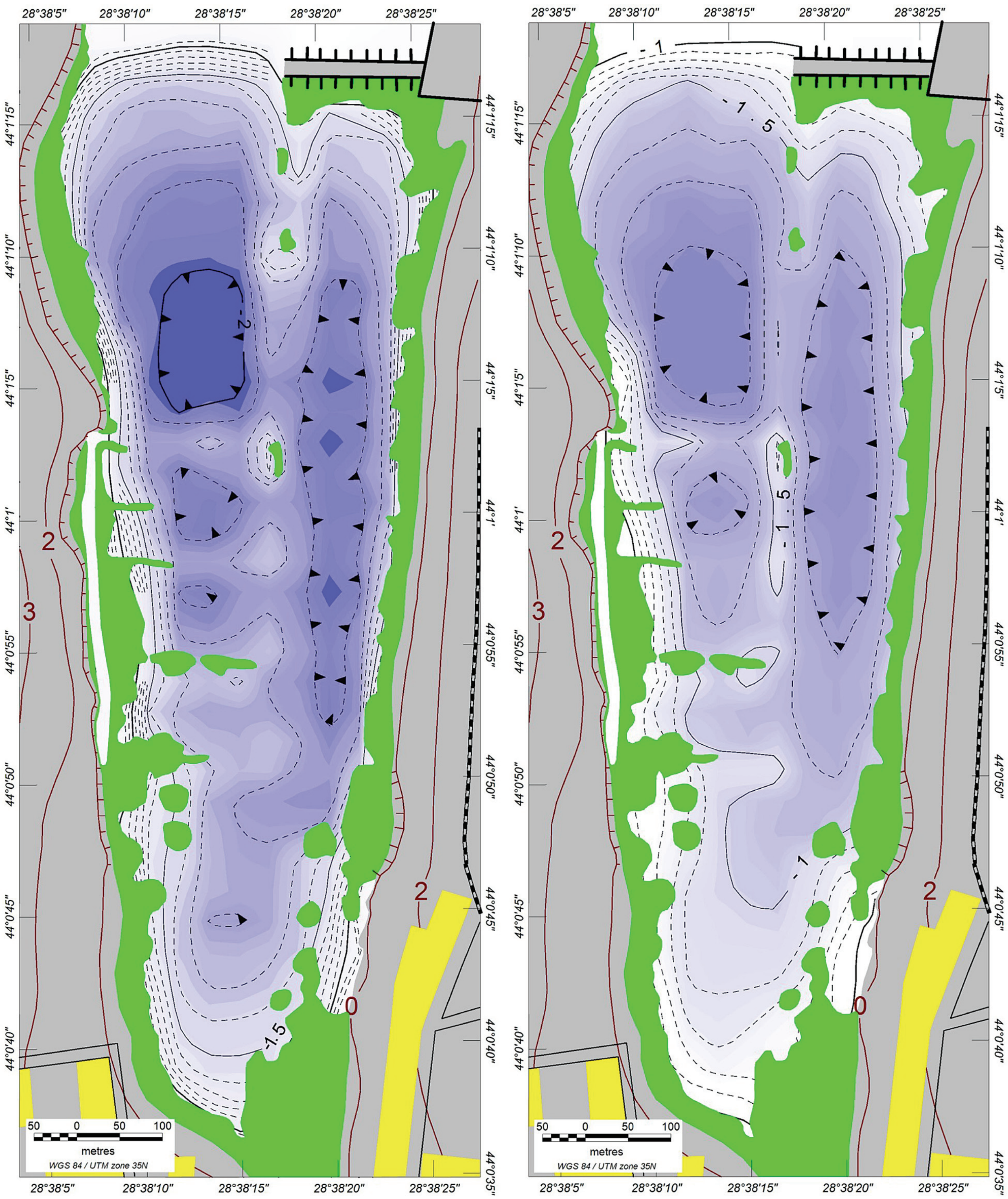

Fig. 2 Bathymetry maps of Tuzla Lake from the May 2005 (high left) and June 2006 (high right) data

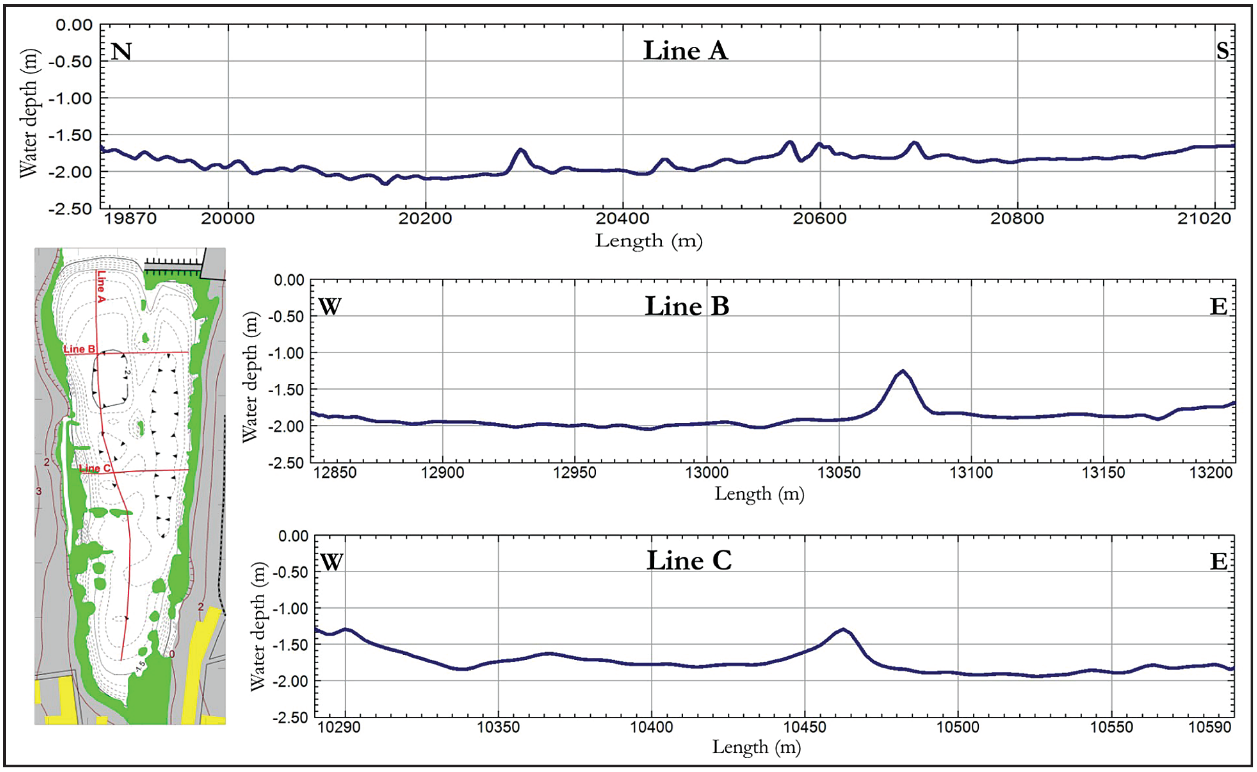

Fig. 3 Bathymetric profiles evidencing the presence and amplitude of local anthropogenic ridges on the bottom of the Tuzla Lake

Table 2 Fraction percentages by Wentworth Grain-size Scale

Sample	Gravel %		Sand %					Silt %				Clay %		
	fine	very fine	very thick	thick	medium	fine	very fine	thick	medium	fine	very fine	thick	medium	Fine
Tuzla Lake														
TU 01	0.00	0.00	0.00	0.02	0.17	0.23	0.43	4.52	9.70	17.79	15.34	15.95	9.07	26.79
TU 02	0.00	0.00	0.00	0.02	0.09	0.21	0.29	1.92	17.42	16.60	13.81	17.65	10.88	21.10
TU 03	0.00	0.00	0.02	0.12	0.38	0.85	1.64	3.42	25.57	16.25	14.18	12.62	7.73	17.23
TU 04	17.88	25.99	22.08	16.58	9.64	1.70	0.38	1.03	0.74	0.60	0.45	0.37	0.26	2.30
TU 05	5.65	4.34	2.36	1.72	2.00	5.11	5.23	14.59	16.45	11.52	5.44	9.41	5.41	10.77
TU 06	0.00	0.00	0.00	0.01	0.06	0.30	0.99	21.14	17.60	13.34	11.87	13.37	8.72	12.58
Techirghiol Lake														
TU 07	0.00	0.33	0.24	0.51	3.80	8.22	8.51	22.38	17.45	10.74	5.24	5.25	2.37	14.97

Table 3 Grain-size classification of texture parameters

Sample	Grain-size composition				Grain fraction	Texture parameters				
	Gravel %	Sand %	Silt %	Clays %		Median (Φ)	Average (Φ)	Std. Dev. Σ (Sorting)	Asymmetry	Kg
Tuzla Lake										
TU 01	0.00	0.84	47.35	51.81	Silty clay	8.11	8.19	1.98	-0.02	0.69
TU 02	0.00	0.61	49.76	49.63	Clayey silt	7.97	8.00	1.97	0.00	0.69
TU 03	0.00	3.00	59.42	37.58	Clayey silt	7.12	7.52	2.10	0.21	0.77
TU 04	43.87	50.38	2.82	2.93	Sand + gravel	-0.73	-0.58	2.00	0.27	1.45
TU 05	9.99	16.42	48.00	25.59	Clayey silt	5.55	5.52	3.68	-0.11	1.21
TU 06	0.00	1.37	63.96	34.68	Clayey silt	6.74	7.01	2.20	0.18	0.74
Techirghiol Lake										
TU 07	0.33	21.28	55.81	22.59	Sand	5.34	6.10	2.85	0.30	1.05

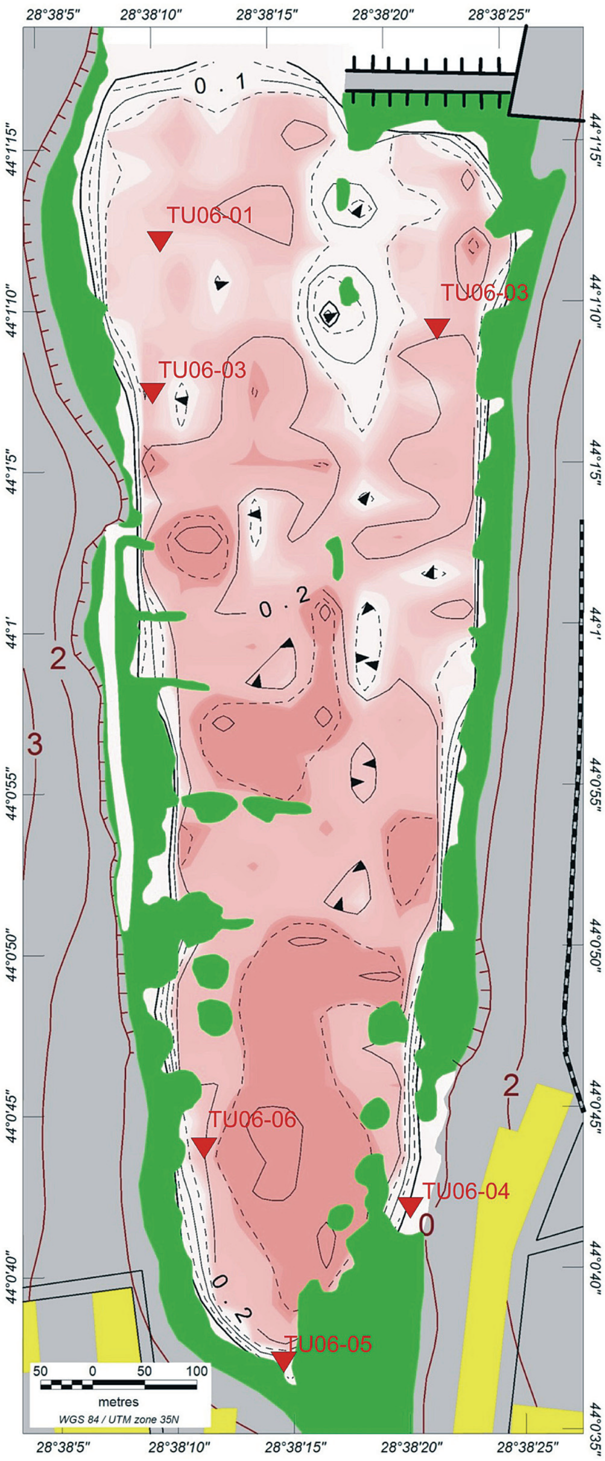

Fig. 4 Sediment thickness map for the sediments discharged by the flood of September 2006. Sampling locations

Table 4 Grain-size parameters

Sample	Asymmetry	Kurtosis	Folk-Ward Sorting
Tuzla Lake			
TU 06 01	Symmetry	Platicurtic	Poor
TU 06 02	Symmetry	Platicurtic	Poor
TU 06 03	Asymmetry +	Platicurtic	Very poor
TU 06 04	Asymmetry +	Leptocurtic	Poor
TU 06 05	Asymmetry -	Leptocurtic	Very poor
TU 06 06	Asymmetry+	Platicurtic	Very poor
Techirghiol Lake			
TU 06 07	Asymmetry +++	Mesocurtic	Very poor

Physico-chemical, chemical and microbiological parameters

The analysis of water samples collected at a constant depth of 0.5m revealed the physico-chemical parameters (Table 5), nutrient content values (Table 6) and microbiological composition (Table 7).

DISCUSSION AND CONCLUSIONS

The bathymetry maps performed based on the measurement data collected during May 2005 and June 2006 reveal in detail the morphology of the Tuzla Lake basin as it was before and after the major flood of September 2005. The isobaths represented in the two maps indicate the real depth of the water at the 1.05 water level read at the reference hydrometric gauge of the lake.

The high precision bathymetry measurements revealed the presence on the bottom of the lake of several underwater positive elements on the north-south and east-west directions, with amplitudes ranging between 0.2m and 0.6m and an obvious anthropogenic origin. These divide the lacustrine basin in several low depression areas.

The presence of the clogging phenomena was identified on the entire surface of Tuzla Lake. The main factor responsible for this natural process is the sediment input into the lake from floods on the Tuzla Valley. Therefore, only the sediments transported by the flood of 2006 determined a general reduction of the lake depth by 0.05-0.1m in the northern sector and 0.25-0.30m in the southern sector.

The Tuzla Lake sediments consist of clayey-silty muds that are grey to blackish, sporadically greyish-green, soft, oily similar to the sapropelic mud, and with hydrogen sulfide odour. These characteristics indicate a reducing environment.

From the lithological description of the sediment samples and the grain-size analysis, the conclusion is that the sediments are specific to an eutrophic lacustrine environment (large concentration of nutrients and reduced oxygen con-

Table 5 Physico-chemical parameters of water

Sample	Water depth (m)	O_2 (mg/l)	O_2 (%)	T (C^0)	CND (mS/cm)	pH	SAL ($^0/_{00}$)
TU-06-01	1.74	10.61	134.2	26.8	7.02	9.05	39
TU-06-02	1.73	10.75	134.8	27.0	7.12	9.05	39
TU-06-03	1.80	9.38	117.8	26.8	7.04	9.00	39
TU-06-04	0.79	16.88	208	28.1	7.15	9.14	40
TU-06-05	1.25	17.7	219	27.9	7.23	9.12	40
TU-06-06	1.46	14.35	183.9	27.9	7.17	9.11	40
Techirghiol Lake							
TU-06-07	1.80	8.98	111.2	26.3	83.4	8.52	592

Table 6 Nutrient content

Sample	Water depth (m)	NO_2 (mg/l)	NO_3 (mg/l)	SO_4 (mg/l)	PO_4 (mg/l)
TU-06-01	1.74	2.666	2.079	112	2.75
TU-06-02	1.73	2.710	2.079	105	0.64
TU-06-03	1.80	2.816	2.277	110.1	1.05
TU-06-04	0.79	2.701	2.079	108.6	3.00
TU-06-05	1.25	2.886	2.475	107.5	0.46
TU-06-06	1.46	3.031	2.673	109.1	4.23
Techirghiol Lake					
TU-06-07	1.80	1.271	0.99	57.5	0.27

Table 7 Microbiology analysis results

Sample	Water depth (m)	Probable number of coli bacteria (total coli)*	Probable number of thermo-tolerant coli bacteria (faecal coli)	Probable number of faecal streptococci
TU-06-01	1.74	109×10^2	49×10^2	348
TU-06-02	1.73	13×10^3	33×10^3	2
TU-06-03	1.80	24×10^3	24×10^3	348
TU-06-04	0.79	33×10^2	490	109
TU-06-05	1.25	460	110	None
Techirghiol Lake				
TU-06-07	1.80	33	11	None

** Measurement unit: total number of coli/100 mc^3; number of faecal coli/100 mc ^{3}; number of faecal streptococci/100 mc ^{3}, analysis report by ECOIND Bucharest 2006* tent). That environment is suggested by the blackish colour and the oily and gelatinous aspect of the sapropelic muds that indicate an alteration of the vegetal material and/or benthic fauna leading to the formation of a humus-gel (Jipa & Vlad, 1998). Aside from the degradation of the organisms, the gelatinous aspect may be due to presence of detergents or other pollutants in the water.

From a physico-chemical point of view, the water in Tuzla Lake obeys the quality standards for O_2 with a minimum concentration of 9.38mg/l (sample TU 06-03) and a maximum concentration of 17.7 mg/l (sample TU 06-05), a minimum saturation value for O_2 of 117% (sample TU 06-03) and maximum O_2 of 219% (sample TU 06-05), a minimum temperature of 26.8^{0}C (sample TU 06-03) and a maximum of 27.9^{0}C (sample TU 06-05), minimum values for conductivity of 7.02 mS/cm (sample TU 06-01) and maximum of 7.23 mS/cm (sample TU 06-05), a minimum pH of 9.00 (sample TU 06-03) and a maximum of 9.14 (sample TU 06-04), and a salinity of 39-40 ‰.

The previously presented data corroborated with the pH data indicate that the Tuzla Lake water is excessively polluted. This fact is confirmed by the data on the content of PO^-_4, all of which indicate a significant level of pollution.

According to the bacteria indicators, Tuzla Lake is classified as Category II in terms of the probable number of coli and the probable number of thermo-tolerant coli (faecal coli). The national standards for water quality are shown in Table 8 for comparison (Environmental Protection – Normative Acts, 2004). These normative acts are in line with the EC Norms (The European Parliament and Council Directive 2000/60/EC from October 23, 2000 for the establishment of a framework for the Community policy on water).

In conclusion, the sample analysis results indicate the following:

- the quantity of O_2 (mg/l) and O_2 (%) shows lower values than the standards;
- the concentration of PO_4^{2-} is higher than the standard values in the samples TU 06-01, TU 06-04 and TU 06-06 and lower than the standard values in samples TU 06-02, TU 06-03 and TU 06-05 ;
- the concentration of nitrates, nitrites and sulphates are generally within the standard limits ;
- the relatively high salinity of the water in Tuzla Lake (30-40 ‰) was identified in all samples collected;
- very high pollutant levels were identified in samples TU 06-06 si TU 06-01, which were collected from the north and south of the lake. Also, there is a solid waste landfill serving several towns on the western shore of the lake;
- the values identified in the samples are characteristic for significant pollution of the water.

Table 8 Lake water quality (underlined values are from samples collected from Tuzla Lake)

Substance	Unit	Very good quality	Good quality	Medium quality	Poor quality	Very poor quality
		Normal	Suspected pollution	Polluted water	Significant pollution	Excessive pollution
pH		6.5-8.5			5.5-8.5; 8.5-9.5	< 5.5 > 9.5
O_2	mg/l	>7	7-5	5-3	< 3	
O_2	%	> 90	70-90	50-70	< 50	
NO_2^-	mg/l	< 0.1	0.1-0.3	0.3-1	2-1	> 2
NO_3^-	mg/l	< 5	5-25	25-50	50-80	> 80
PO_4^{2-}	mg/l	< 0.2	0.2-0.5	0.-1	2-1	> 2
SO_4^{2-}	mg/l	< 150	150-250	250-400	> 400	

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