Assessment of Physicochemical Properties and Water Quality of the Lom River (NW Bulgaria)

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Abstract This study presents results of physicochemical monitoring and water quality assessment of a small lowland river, located in an agricultural region. The analysis is conducted in compliance with the Bulgarian river water quality standard. It is based on output data from three water sampling points, which include information about 14 parameters, measured from 2012 until 2016. An assessment of the pollution status was carried using CCME Water Quality Index and Oregon Water Quality Index (OWQI). The overall water quality index was calculated as 58.78 which fell under the "marginal" water class (index value ranges from 0 to 100). Results showed worsening of the physicochemical properties as moving downstream the river sections. Downstream is observed a slight deterioration in the values and concentrations of some physicochemical parameters (BOD_5, $N\text{-}NO_3$, Total Nitrogen, and Total Phosphorous) due to the effects of urban sewerage, urban wastewater and agricultural wastes. Based on the used indexes, the water quality is categorized as "Good" to "Poor". CCME WQI indicates the water in the upstream can maintain healthy river ecosystems but in the downstream the quality is frequently endangered. OWQI index showed the water in the upstream river section is suitable for daily living activities, but in the downstream quality is in the "Poor" category and it needs "Special treatment".

Keywords Water quality · Pollution · CCME WQI · OWQI · Lom river

Introduction

Water quality is affected by a wide range of natural and anthropogenic factors, whose share is variable in a spatial and temporal aspect (UNEP/WHO 1996; Ostrowski et al. 2005; Kanownik et al. 2013). The river water pollution is directly connected with agriculture and industrial activities (Carpenter et al. 1998), precipitations and inadequately treated household sewage (Igbinosa and Okoh 2009). Water Framework

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Directive (WFD) seeks to achieve good ecological status of surface waters across the European Union by 2027. Despite some improvements recent years, the majority of Europe's water bodies still fail to meet the European Union's minimum target for "good status" according to the EEA report "European waters—assessment of status and pressures 2018". The report identifies that the one of the main threats which hinders progress in meeting the EU targets is nitrate pollution from agricultural activities into water bodies. To get a true reflection of what happens within the catchment of a river basin, either through point or nonpoint sources of pollution, studies of spatial and temporal changes in water quality are very important (Raburu and Okeyo-Owuor 1999). Regular water quality monitoring of the water resources are absolutely necessary to assess the quality of water for ecosystem health and hygiene, industrial use, agricultural use, and domestic use. However, when a large number of samples analyzed and parameters are monitored, it becomes too difficult to evaluate and present the water quality as a single unit (Chapman 1992). Traditional approaches to assessing water quality are based on a comparison of experimentally determined parameter values with existing guidelines. This does not readily give an overall view of the spatial and temporal trends in the overall water quality in a watershed (Debels et al. 2005). Water Quality Index (WQI) is considered as the most effective method of measuring water quality. This is an effective method that allows to compare the quality of various water samples based on a single numerical value, and not only the parameters values of each sample. It helps to gather whole scenarios of water quality parameters into useful information that is easily comprehensible, and thus can be used by the state agencies as well as the general public (Uddin et al. 2017).

This work presents results of physicochemical monitoring and water quality assessment of the Lom River—a small lowland river, situated in the Danube Plain. The Lom River is one of the few relatively unpolluted by industry rivers in the Danube Plain. However, in recent decades due to unsustainable human activities the river basin has suffered serious deterioration in downstream water quality. The primary cause of water quality problems are the discharge of domestic and agriculture wastes, and the excessive use of pesticides and fertilizers. In the present study to evaluate the overall water quality status in the river, the Canadian Council of Ministers of the Environment Water Quality Index 1.0 (CCME WQI) was used, following the Bulgarian river water quality standard (Regulation 12/2002, 4/2012). CCME WQI is a well-accepted and universally applicable computer model for evaluating the water quality (Canadian Council of Ministers of the Environment). In Bulgaria, it was recently used to evaluate the water quality status of several river basins (Varbanov and Gartsiyanova 2017; Gartsiyanova 2017). Besides the applications of CCME WQI in Canada, this index also has been adopted in several other countries: Albania (Damo and Icka 2013), Spain (Terrado et al. 2010), Chile (Espejo et al. 2012), India (Sharma and Kansal 2011; Venkatramanan et al. 2016), Bangladesh (Reza and Singh 2010), and Iran (Mohebbi et al. 2013; Jafarabadi et al. 2016). In addition, to assess the water suitability for specific human uses, the Oregon Water Quality Index (OWQI) was applied, which is used also for a trend analysis in water quality status in the United States (Cude 2001; Walsh and Wheeler 2012).

Study Area

The catchment of the Lom River is situated in the western part of the Danube drainage basin in Bulgaria. It covers an area of 1139.8 km^2 (Hristova 2012) (Fig. 1). The catchment area of the Lom River covers part of the north slopes of the Western Stara Planina (Chiprovska and Svetinikolka planina), the hill Vederenik of Western Fore-Balkans and part of the Western Danube Plain. The Lom River flows in length of 92.5 km. It springs from the Balkan Mountains and flows into the Danube River within the Danube Plain. Mean annual flow for 1960÷2017 period varies from 0.68 m^3/s (at Gorni Lom) to 6.07 m^3/s (at Vasilovtsi). The coefficients of variation, Cv, vary between 0.25 at Gorni Lom, to 0.38 at Vasilovtsi. The seasonal discharge regime is characterized by a high flow phase during the spring months (April–May) and a low flow period in the summer–autumn hydrological season (August–September). The climate conditions in the catchment are moderate continental. The annual average air temperatures range from 4.2 °C (in the Chuprene Reserve area) to 11.8 °C (cf. Lom). The annual amount of precipitation increases from 500–550 mm, on the Danube coast, to 800–1200 mm, in the Chiprovska Stara Planina, with a maximum in the months of May–June and minimum in the months of February–March (Climate Reference Book …, 1990). In the mountainous area, the river basin is covered with dense pine, spruce, beech and oak forests and in the plain due to the deforestation events, the natural vegetation is reduced and replaced with a cultural one.

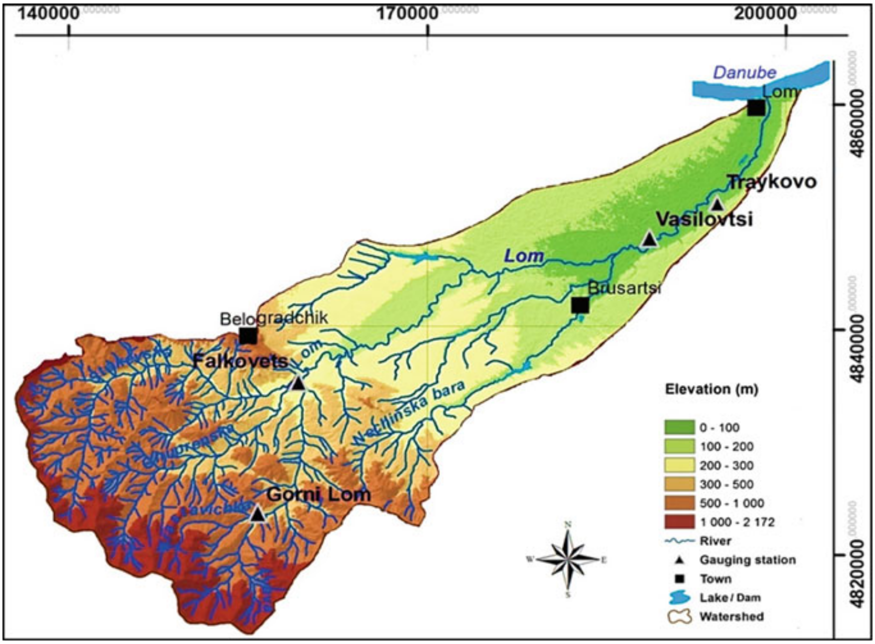

Fig. 1 Relief, hydrographic and hydrometric structure in the Lom River basin (Hristova et al. 2017)

The predominant land use type in the Lom River basin is agricultural, covering an area of 579.1 km^2 (50.8%). The high-altitude zone of the Lom River is characterized by livestock grazing activities and forest coverage (dominating from broad-leaved forests). The main source of water pollution is from soil runoff sediments, fecal material, and household wastewater from small urban settlements. The lower area is a flat landscape cultivation zone with extensive agricultural production (cereal and technical crops: wheat, barley, corn, sunflower, and perennial vineyards), as well as cattle-grazing activities. In addition, urban expansion and industrial developments are also important. The river basin concentrates 42 settlements, including three cities, with a total population of 47.000, which corresponds to population density of 41 people per km^2. Water contamination arises from the agricultural, domestic and industrial activities.

Output Information and Research Methods

The objects of analysis are the values and concentrations of physicochemical indices for the Lom River's water, investigated during the 2012–2016 period. Output data is provided by the Danube Basin Directorate for three water sampling points, situated in the upper stream and downstream river sections. The water quality status is conducted in compliance with the Bulgarian river water quality standard (Regulation 12/2002, 4/2012). Total of 14 water parameters are analyzed: Dissolved Oxygen, Oxygen saturation, pH-value, conductivity EC, Ammonium-Nitrogen ($N\text{-}NH_4$), Nitrate nitrogen ($N\text{-}NO_3$), Nitrite nitrogen ($N\text{-}NO_2$), Total Nitrogen, Total Phosphorous, Orthophosphate ($P\text{-}PO_4$), Biochemical Oxygen Demand (BOD_5), Suspended Solids, Chloride, Sulfates. Descriptive statistics are presented, i.e., minimum and maximum and arithmetic mean, calculated for each individual parameter. An assessment of the water quality is carried using two selected indexes: Canadian Council of Ministers of the Environment (CCME) and Oregon Water Quality Index (OWQI). Current study sought to test the listed indexes due to their simplicity, but robust nature of reporting water quality issues (Cude 2001; CCME 2001; UNEP 2007). CCME WQI is an overall rating, which relies of three factors: (1) the numbers of variables whose objectives are not met (scope); (2) the frequency with which the objectives are not met; (3) the amount by which the objectives are not met (amplitude) (El-Jabi et al. 2014). These factors are calculated as a ratio between the "failed tests" to total number of conducted test, only the third (amplitude) factor requires some additional steps (Saffran 2001; Uddin et al. 2017). The CCME WQI rating is computed by the formula

$$\text{CCME WQI} = 100 - \frac{\sqrt{F_1^2 F_2^2 F_3^2}}{1.732}$$

where the numerators are the factors: scope F_1^2, frequency F_2^2, amplitude F_3^2, the constant 1.732 is a normalization factor used to render the CCME as a value from 0 to 100.

CCME values are converted into rankings by using the categorization scheme presented in Table 1.

CCME WQI is based on "desirable stats". In this paper, they are fixed for each individual sampling point. The calculations are conducted in compliance with the reference values for excellent quality status, recommended for the surface water body types R2 and R8 (Regulation 4/2012) (Table 2). This approach is useful for describes of water as a biotope of the aquatic flora and fauna, wildlife habitats, etc., also for evaluating of water suitability for human uses, i.e., it applies for an integral assessment (CCME 2001; El-Jabi et al. 2014).

OWQI is a water quality rating, combining data for eight parameters or sub-indices (DO%, BOD_5, T °*C*, pH, Total P, N-NH_3, Susp. Solids and Bacteria coliform *E. Coli*). Each one of parameters has a different weight in the final estimate (Appendix A: Cude 2001). Six of the listed sub-indices are used here (those whose data are available). For this purpose, the numbers of parameters in the original formula was corrected. The OWQI assessment is computed as follows:

$$\text{OWQI} = \sqrt{\frac{n}{\sum_{i=1}^{n} \frac{1}{SI_i^2}}}$$

where n—total numbers of sub-indices (parameters); SI_i—sub-index *i*.

This formula allows the most impaired variable to import the greatest influence on the water quality index and acknowledges that different water quality variables will pose differing significance to overall water quality at different times and locations.

Table 1 CCME WQI and OWQI ratings and values (CCME 2001; Cude 2001)

WQI	Value rating of water quality
Canadian council of ministers of the environment water quality index (CCME WQI)	
95–100	Excellent water quality
80–94	Good water quality
60–79	Fair water quality
45–59	Marginal water quality
0–44	Poor water quality
Oregon water quality index (OWQI)	
90–100	Excellent water quality
85–89	Good water quality
80–84	Fair water quality
60–79	Poor water quality
0–59	Very poor water quality

Table 2 Variables and objectives (Reg. 4/2012)

Variables	Objectives for excellent status	
	R2 type Mountain rivers (*Krastavichka river/Lom river—Gorni Lom*)	R8 type Lowland rivers (*Lom River—before the town of Lom*)
DO_2, mg/l	10.5÷8.00	9.00÷7.00
DO_2 Sat., %	>90	>80
pH	6.5÷8.5	6.5÷8.5
EC, μS/cm	700	700
N-NH_4, mg/l	<0.04	<0.10
N-NO_3, mg/l	<0,1	<0.7
N-NO_2, mg/l	<0.03	<0.03
Total N, mg/l	<0.2	<0,5
Total P, mg/l	<0.012	<0.15
P-PO_4, mg/l	<0.01	<0,07
BOD_5, mg/l	<1	<2
Cl, mg/l	>200	>200
SO_4, mg/l	>250	>250

(Cude 2001). OWQI values also cover a ranking system, where a result of 100 is the best achievement and a value of 0 is the worst result (Table 1).

OWQI is a possible tool for assessing of trends (annual, seasonal) in water quality status because of its final assessment represents an average value of the water quality ratings, calculated for each individual measurement during the study term (Cude, 2001). Trend ratings are not applied here, because the observation period is relatively short, but the values obtained give an informative result about the water suitability for human uses. This is the strength of the index—it is targeted at a specific type of water use, such as drinking, fishing or irrigation.

Results

Among the 14 investigated quality parameters, 8 meet the requirements for excellent water quality state in each measurement sampling point: Dissolved Oxygen, Oxygen saturation, pH-value, conductivity (EC), Suspended Solids, Nitrite nitrogen, Chloride, Sulfates (Tables 2 and 3). In good ecological status, general physicochemical quality elements should not reach levels outside the range established to ensure ecosystem functioning (Table 2). According to Bulgarian river water quality standard, water quality in the upper stream river sections (at the Krastavichka River and Lom River—Gorni Lom) is in better condition than the downstream river

Table 3 Values of physicochemical indices and water quality status of the Lom River (2012–2016)

Parameters	Water sampling station								
	Krastavichka River			Lom River—Gorni Lom			Lom River—before Lom		
	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
pH	6.89	8.28	7.72	7.24	8.46	7.83	7.36	8.83	8.09
EC, μS/cm	87.10	272.00	168.10	75.00	202.00	127.00	216.00	525.00	359.00
DO_2 Sat., %	78.90	124.50	90.81	71.30	118.00	89.58	55.10	119.30	82.04
DO_2, mg/l	7.70	12.30	9.90	7.10	12.10	9.68	6.40	12.90	10.30
N-NH_4, mg/l	0.02	0.07	0.03	0.02	0.09	0.04	0.03	0.21	0.08
N-NO_3, mg/l	0.04	1.66	0.42	0.04	1.91	0.53	0.37	3.70	1.29
N-NO_2, mg/l	0.002	0.011	0.005	0.003	0.036	0.007	0.006	0.079	0.018
Total N, mg/l	0.29	2.00	1.04	0.44	4.10	1.64	0.72	3.00	1.81
PO_4-P, mg/l	0.007	0.045	0.021	0.005	0.04	0.016	0.006	0.1	0.03
Total P, mg/l	0.01	0.03	0.02	0.01	0.03	0.02	0.02	0.20	0.06
BOD_5, mg/l	0.90	3.00	1.79	0.70	3.30	1.70	1.30	4.40	2.53
Cl, mg/l	1.05	9.80	4.04	0.66	13.30	4.78	4.20	17.50	9.61
SO_4, mg/l	4.40	22.10	11.47	5.20	26.50	14.11	18.80	51.40	30.19
Und. Sub. mg/l	12.00	41.00	21.73	16.00	42.00	23.95	24.00	95.00	36.12

section (Lom River—before the town of Lom). Downstream is observed a deterioration in the values of some physicochemical water quality parameters (BOD_5, N-NO_3,$NH_4^+ - N$ and Total Phosphorous) (Table 3). Concentrations of ammonium, BOD and nitrate in water are used as indicators of organic matter pollution and the impacts of sewage release into rivers (WHO 2006; Bilotta & Brazier, 2008). BOD_5 indicates high concentration of organic pollution and high concentration of biodegradable organic material in water. Ammonium occurs at high concentration in sewage, when present in stream water, ammonium utilizes the available oxygen for oxidation process to nitrate. All settlements in the area do not have wastewater treatment plants, i.e., the waste water is discharged into the Lom River. Further, nutrient loads from agricultural areas are prevailing in downstream areas. As a consequence, a chemical analysis of the Lom River quality data indicates that water pollution increased downstream, as shown by the statistically significant differences in ammonium, BOD_5, nitrate and Total Phosphorous between upstream and downstream sampling points (Table 3). The increasing of the nitrate values during the summer season confirms the statement for water pollution by agricultural activities. Upstream is observed and increased concentrations of nitrogen. Farming practices like uses of nitrogen-rich fertilizers and organic manure from pastoral livestock are the major sources of excess nitrogen in the upstream part of Lom river.

The applied water quality indices generally show a decrease of water quality from upstream to downstream. In this study, the primary focus was on fourteen (14) water quality parameters. The total numbers of individual tests are 794. The number of parameters not meeting Reg. 4/2012 objectives are six (Ammonium-Nitrogen, Nitrate nitrogen, Total Nitrogen, Total Phosphorous, Orthophosphate, Biochemical Oxygen Demand (BOD_5) and the number of tests not meeting objectives are 189. The quality ratings at the Krastavichka River are "Fair"(CCME WQI is 65) or the water can maintain a healthy ecosystems (Table 4). At the sampling points of the Lom River (Gorni Lom and before town of Lom), exceedances of nutrients resulted in an overall quality rating of "Marginal" (CCME WQI varies from 53.14 to 58.10) (Table 5).

OWQI rating in the sampling points at the Krastavichka River and Lom River at Gorni Lom is "Good" and "Fair" (OWQI rating is 86 and 84, respectively). These assessments mean the water is suitable for fishing and irrigation purposes and it is acceptable for drinking after an initially treated. The water sampling point at the Lom River—before town of Lom, achieves an overall score of "Poor"(OWQI is 73), which means the river waters are seriously polluted (Table 6).

Table 4 The calculated values of CCME WQI in Lom River

Stations	Number of failed variables	Number of failed tests	Value
Lom River—before town of Lom	3	56	58.10
Lom River—Gorni Lom	6	86	53.15
Krastavichka River	6	47	65.10

Table 5 CCME ratings, values and descriptions, as stated in CCME (2005b)

Rating	CCME values	Interpretive description
Excellent	95–100	Water quality is protected with a virtual absence of threat or impairment; conditions very close to natural or pristine level
Good	80–94	Water quality is protected with only a minor degree of threat or impairment; conditions rarely depart from natural or desirable levels
Fair	60–79	Water quality is usually protected but occasionally threatened or impaired; conditions sometimes depart from natural or desirable levels
Marginal	45–59	Water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels
Poor	0–44	Water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels

Table 6 OWQI ratings, values and descriptions, as stated in Cude—OWQI (2001)

Rating	OWQI values	Interpretive description
Excellent	90–100	Water quality is unaffected. Water is suitable for drinking, fishing, irrigation and industrial purposes. A construction of treatment plants is not required
Good	85–89	Water quality is almost unaffected. Water is suitable for fishing, irrigation and industry. Water use for drinking requires a construction of treatment plant
Fair	80–84	Water quality is affected. Water is acceptable for irrigation and industry and unacceptable for drinking. A construction of treatment plants is advisable
Poor	60–79	Water quality is impaired. Water is acceptable for industrial purposes. Water uses for irrigation and vital activities obliges a construction of treatment plant
Very poor	0–59	Water quality is seriously impaired. Water is inappropriate for human uses and industrial purposes. A construction of treatment plants is compulsory

Correlation analysis is a preliminary descriptive technique to estimate the degree of association among the variables involved (Ahmed et al. 2012). CCME WQI is positively corelated with Conductivity and Dissolve Oxygen parameters, besides all others parameters negatively impacted the WQI. The results showed that water quality index decreases with increase in parameter concentration and vice versa for parameter Dissolve Oxygen (Table 7).

Table 7 Correlation between CCME WQI and water quality parameters

Parameter	pH	EC, μS/cm	DO_2, mg/l	$N\text{-}NH_4$ mg/l	$N\text{-}NO_2$ mg/l	$N\text{-}NO_3$ mg/l	Tot. N, mg/l	PO_4–P mg/l	Tot. P, mg/l	BOD_5 mg/l	WQI
pH	1										
EC, μS/cm	0.159	1									
DO_2, mg/l	0.026	0.295	1								
$N\text{-}NH_4$, mg/l	0.039	0.001	−0.057	1							
$N\text{-}NO_2$, mg/l	0.041	0.150	0.160	0.311	1						
$N\text{-}NO_3$, mg/l	0.027	0.191	−0.081	0.313	0.009	1					
Total N, mg/l	−0.025	0.255	−0.062	0.273	−0.006	0.915	1				
PO_4–P, mg/l	0,009	0.048	0.187	0.165	0.535	−0.104	−0.051	1			
Total P, mg/l	0.123	0.006	0.094	−0.007	0.151	0.362	0.280	0.436	1		
BOD_5, mg/l	0.027	0.393	0.203	−0.053	0.396	−0.086	−0.064	0.275	−0.018	1	
WQI	−0.084	0.139	0.305	−0.463	−0.230	−0.344	−0.297	−0.312	−0.285	−0.095	1

Conclusion

The results show that CCME WQI and QWQI is an effective and sensitive tool for evaluating the state of the river water quality depending on the objectives to be met. Based on CCME WQIs model, the water quality in the Lom River is categorized as marginal to fair. The Canadian Water Index indicated that the water quality is frequently endangered, conditions very often deviate from natural levels. The quality of surface water in the upstream of the Lom River is in fair condition. The main source of water pollution upstream is mountain livestock farming, which results in the increased concentration of nitrogen. Downstream the water quality gradually deteriorates, due to wastes from living and agricultural practices. BOD_5, N-NO_3, Total Nitrogen, and Total Phosphorus are the most important parameters that determinate the rating of water quality, not meeting the standards (objective) of good water quality status. In order to achieve a good quality status of the Lom River's water, it is necessary to implement an adequate wastewater management through the construction of modern and efficient waste water treatment plants and to reduce the diffuse water pollution from agriculture.

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