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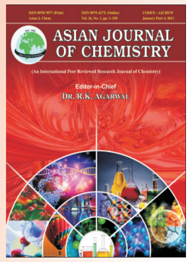

Evaluation of Physico-Chemical Parameters of German-Polish Szczecin Lagoon Water

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This paper presents the evaluation of physico-chemical parameters of German-Polish Szczecin Lagoon water based on the European Union Water Framework Directive.This approach was formulated in the European Union Water Framework Directive (2000/60/EC), which calls for the protection of water, as well as an environment-friendly and comprehensive approach to water assessment. The research was carried out in the years 2008-2012, between April and October. From each of the three measuring stations located in the water Szczecin Lagoon included the study, two separate water samples were taken for chemical analysis. The Odra (German:Oder) estuary is located at the southern Baltic Sea (German-Polish border). It consists of the Szczecin Lagoon and the Pomeranian Bay. The Szczecin Lagoon (687 km^2) can be subdivided into the 'Large Lagoon' (Polish:Wielki Zalew) on the Polish territory and the 'Small Lagoon' (German: Kleines Haff) on the German side. The studied water Szczecin Lagoon had pH values in the neutral range 7.71 to 7.89. According to the classification of the European Union Water Framework Directive, all water were classified as first class. By analyzing the average annual values, one can note that the pH, O_{2diss} and NO_3^- concentration showed a relatively small variation in all the investigated water. The total suspended solids in the Szczecin Lagoon, fell into the II class. The $P_{tot.}$ concentrations in the surface layer of the water Szczecin Lagoon was little differentiated, reaching the levels appropriate for the III quality class. The total phosphorus concentration was 0.43-0.68 mgP dm^{-3}. The concentrations of $PO_4^{3-}{}_{diss}$ in the tested waters varied more significantly-corresponding to water quality classes ranging from IV. The concentrations saturation with O_2 was 41.7-92.8 %. In the case of nitrogen compounds, nitrates and nitrites values for these indicators fell into the I and II class in all the surveyed water Szczecin Lagoon. The indicator which proves high productivity of the water is the biochemical oxygen demand (BOD_5). The level of this indicator in the studied Szczecin Lagoon was at level III. The highest concentration of oxygen in the waters was found in the Szczecin Lagoon (about 8.5 mg O_2 dm^{-3}). In the remaining water oxygen levels were similar (still in I class). National Sanitation Foundation Water Quality Index (NSF WQI) used for rating of water quality in Szczecin Lagoon indicates that the quality of water is slightly polluted (WQI = 53.6). The German-Polish Szczecin Lagoon in the southern Baltic Sea is highly eutrophic coastal water that is affected by algae blooms during summer.

Keywords: Szczecin Lagoon, Water quality index, European Union Water Framework Directive.

INTRODUCTION

Evaluation of the quality of the structure and the functioning of aquatic ecosystems, by comparing the status of the existing undisturbed conditions expected in status (reference), is a requirement for monitoring and evaluation systems of classification by the European Directive 2000/60/EC, known as the European Union Water Framework Directive[1-4]. With this in mind, it is an important issue to properly protect water reservoirs and also take action to counter the adverse effects of human activities on the natural environment, including water bodies[5-7].

The ecological status of surface waters and groundwater is assessed on the basis of the ecological potential of the biological and physico-chemical and hydromorphological indicators[8-12]. The goal of the Water Framework Directive is to achieve good water status in all the Member States of the European Union[12-15].

Monitoring and control of surface water is critical to guaranty high quality water for various applications. Lakes and surface water reservoirs are the planet's most important freshwater resources and provide numerous benefits. They are used for domestic and irrigation purposes and provide ecosystems for aquatic life especially fish, in that way functioning as a source of essential protein and for significant elements of the world's biological diversity. They have important social and economic benefits as a result of tourism and recreation and are culturally and aesthetically important for people throughout the world.

This paper presents the evaluation of physico-chemical parameters of water in the Szczecin Lagoon based on the European Union Water Framework Directive.

EXPERIMENTAL

The Odra (German: Oder) estuary is located at the southern Baltic Sea (German-Polish border). It consists of the Szczecin (Oder-) Lagoon and the Pomeranian Bay. The Szczecin Lagoon (687 km^2) can be subdivided into the 'Large Lagoon' (Polish: Wielki Zalew) on the Polish territory and the "Small Lagoon" (German: Kleines Haff) on the German side. The Lagoon is connected to the Pomeranian Bay *via* three outlets[16].

The entire estuary is dominated by the discharge of the River Odra (Oder) into the Lagoon. With its length of 854 km and basin area of 120,000 km^2, the Odra is one of the most important rivers in the Baltic region. The average annual Odra discharge is 17 km^3 (530 m^3 s 1) and it contributes at least 94 % to the lagoon's water budget[16]. The Szczecin Lagoon is shallow (average depth of 3.8 m), with a maximum depth of 8.5 m. Only in the shipping channel across the lagoon, dredging maintains a depths of 10.5 m.

Szczecin is the capital of Zachodniopomorskie (West Pomeranian) and Voivodeship is located in north-western Poland near the mouth of the Odra river and Szczecin Lagoon, 65 km from the coast of the Baltic sea. It is the country's seventh-largest city. Its population is about 400,000 inhabitants. Szczecin is situated in the very centre of the historic cross-border region of Pomerania.

The research was carried out in the years 2008-2012, between April and October. From each of the three measuring stations located in the water Szczecin Lagoon included the study, two separate water samples were taken for chemical analysis. Upon sampling, the water pH was measured. Water was tested in compliance with the Polish Standards. Collected water samples were stabilized pursuant to the guidelines of the Polish Standards[1,2,14].

Other indicators of water quality were marked within 24 h of sampling.The oxidation of dissolved organic matter was measured with the COD-Mn method, in accordance with Polish Standards[1,2,14]. Dissolved oxygen was marked in accordance with the methodology described by Winkler in Daniszewski's work[1,2].

The degree of water oxygenation was specified by arrays described by Nemerov[17]. The levels of Total Suspended Solids, BOD_5, NH_4^+, NO_2^-, NO_3^-, $PO_4^{3-}{}_{diss}$ and $P_{tot.}$ were marked-in accordance with the methodology described by Daniszewski[1,2,14].

The quality objectives were evaluated according to the criteria recommended for assessing inland surface waters as set out in the European Union Water Framework Directive[8].

RESULTS AND DISCUSSION

The results for the Szczecin Lagoon, along with the classification in accordance with the European Union Water Framework Directive are presented in Table-1.

The pH of the water in the water Szczecin Lagoon is influenced by the physico-chemical and biotic interactions of environmental factors[5,13]. Among others, the degree of acidity directly affects life processes occurring in ecosystems. It is responsible for the correct uptake of nutrients by organisms. High alkalinity is beneficial for assimilation and therefore, the nitrogen and phosphorus compounds found in water are much more accessible than in an acid medium. Apart from high acidity, excessive alkalinity of natural waters (pH < 9) also has a clearly detrimental impact on organisms[11,12,18,19]. pH below 4.8 and above 9.2 are deleterious for aquatic organisms specially for fish. The studied water Szczecin Lagoon had pH values in the neutral range 7.65 to 7.87. According to the classification of the European Union Water Framework Directive, all water were classified as first class.

The aquatic ecosystems of the studied water Szczecin Lagoon experienced loss on ignition and non-corresponding values of COD-Mn according to the estimates, which were based on the measurements of 'loss on drying' and 'residue on ignition' in accordance with the methodology set out by Macioszczyk[20] and on the basis of COD-Mn results, which invariably matched III class water quality. In the water Szczecin

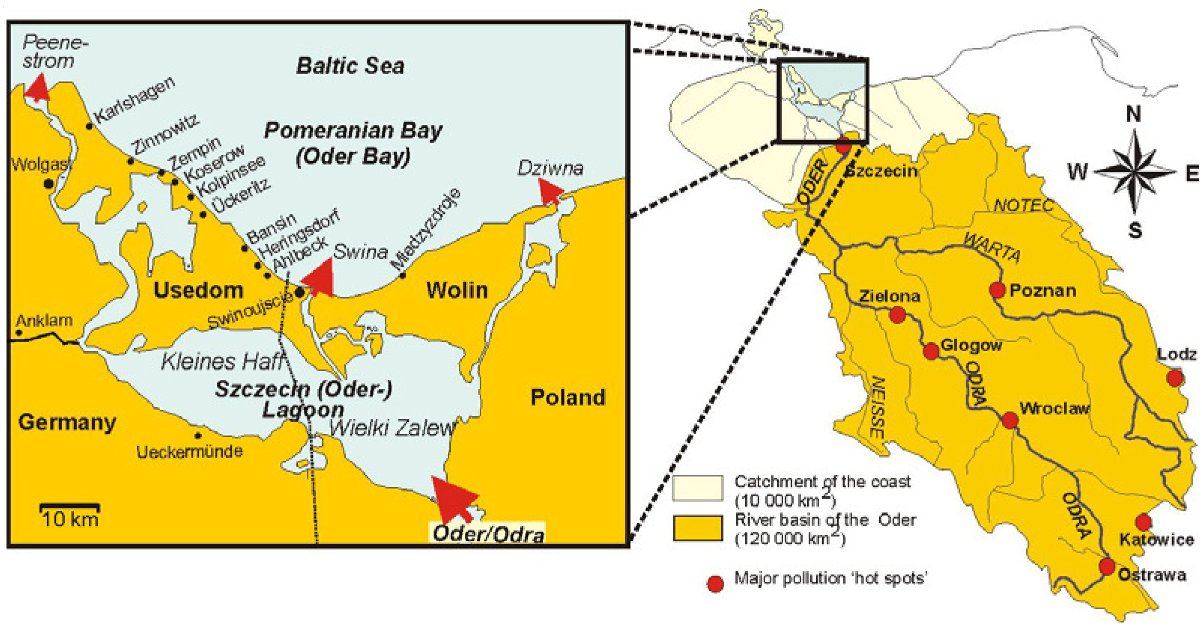

Fig. 1. German-Polish Szczecin Lagoon

Lagoon tested, considerable levels of organic matter, including reducing agents, were maintained throughout the year. The reasons for this state of affairs should also be sought in the Szczecin Lagoon bed sediment, which is rich in organic matter.

The most important elements involved in primary production are phosphorus and nitrogen. The presence of these substances determines the productivity of a water body, as well as its quality. One nutrient significantly affecting the quality of water is phosphorus.

TABLE-1
RESULTS OF THE QUALITY OF SURFACE WATER OF SZCZECIN LAGOON (SPRING, SUMMER AND AUTUMN 2008-2012) ALONG WITH THE CLASSIFICATION VALUES OF INDICATORS ACCORDING TO THE CRITERIA OF THE EUROPEAN UNION WATER FRAMEWORK DIRECTIVE (2000/60/EC)

S. No.	Water quality indices	Units	Spring	Summer	Autumn
			2008 year		
S. No.	Water quality indices	Units	17.04.2008 Spring	24.07.2008 Summer	15.10.2008 Autumn
1	Total suspended solids	mg O_2 dm^{-3}	21.3 (II)	22.9 (II)	20.7 (II)
2	pH	-	7.86 (I)	7.79 (I)	7.81 (I)
3	COD-Mn	mg O_2 dm^{-3}	7.8 (III)	8.4 (III)	8.6 (III)
4	BOD_5	mg O_2 dm^{-3}	4.6 (III)	5.6 (III)	4.5 (III)
5	$O_{2\ diss.}$	mg O_2 dm^{-3}	7.4 (I)	7.3 (I)	7.1 (I)
6	NO_3^-	mg N dm^{-3}	0.26 (I)	0.35 (I)	0.33 (I)
7	NO_2^-	mg N dm^{-3}	0.032 (II)	0.035 (II)	0.030 (II)
8	NH_4^+	mg N dm^{-3}	0.58 (II)	0.74 (II)	0.67 (II)
9	$PO_4^{3-}{}_{diss.}$	mg PO_4 dm^{-3}	0.76 (IV)	0.81 (IV)	0.73 (IV)
10	$P_{tot.}$	mg P dm^{-3}	0.47 (III)	0.59 (III)	0.46 (III)
11	Saturation with O_2	%	54.7 (-)	92.8 (-)	41.7 (-)
12	Residue after ignition	mg dm^{-3}	182 (-)	218 (-)	185 (-)
			2009 year		
S. No.	Water quality indices	Units	15.04.2009 Spring	22.07.2009 Summer	21.10.2009 Autumn
1	Total suspended solids	mg O_2 dm^{-3}	21.4 (II)	21.8 (II)	20.6 (II)
2	pH	-	7.75 (I)	7.89 (I)	7.79 (I)
3	COD-Mn	mg O_2 dm^{-3}	7.6 (III)	8.4 (III)	8.6 (III)
4	BOD_5	mg O_2 dm^{-3}	5.3 (III)	5.7 (III)	5.2 (III)
5	$O_{2\ diss.}$	mg O_2 dm^{-3}	7.1 (I)	7.9 (I)	7.5 (I)
6	NO_3^-	mg N dm^{-3}	0.36 (I)	0.34 (I)	0.36 (I)
7	NO_2^-	mg N dm^{-3}	0.036 (II)	0.038 (II)	0.035 (II)
8	NH_4^+	mg N dm^{-3}	0.67 (II)	0.85 (II)	0.74 (II)
9	$PO_4^{3-}{}_{diss.}$	mg PO_4 dm^{-3}	0.78 (IV)	0.85 (IV)	0.77 (IV)
10	$P_{tot.}$	mg P dm^{-3}	0.53 (III)	0.65 (III)	0.48 (III)
11	Saturation with O_2	%	50.3 (-)	86.5 (-)	45.2 (-)
12	Residue after ignition	mg dm^{-3}	183 (-)	192 (-)	186 (-)
			2010 year		
S. No.	Water quality indices	Units	21.04.2010 Spring	14.07.2010 Summer	20.10.2010 Autumn
1	Total suspended solids	mg O_2 dm^{-3}	19.8 (II)	22.4 (II)	21.6 (II)
2	pH	-	7.78 (I)	7.84 (I)	7.88 (I)
3	COD-Mn	mg O_2 dm^{-3}	7.7 (III)	7.9 (III)	7.4 (III)
4	BOD_5	mg O_2 dm^{-3}	4.6 (III)	5.5 (III)	4.7 (III)
5	$O_{2\ diss.}$	mg O_2 dm^{-3}	7.1 (I)	7.4 (I)	7.2 (I)
6	NO_3^-	mg N dm^{-3}	0.27 (I)	0.39 (I)	0.35 (I)
7	NO_2^-	mg N dm^{-3}	0.032 (II)	0.035 (II)	0.033 (II)
8	NH_4^+	mg N dm^{-3}	0.71 (II)	0.85 (II)	0.73 (II)
9	$PO_4^{3-}{}_{diss.}$	mg PO_4 dm^{-3}	0.76 (IV)	0.82 (IV)	0.77 (IV)
10	$P_{tot.}$	mg P dm^{-3}	0.58 (III)	0.67 (III)	0.56 (III)
11	Saturation with O_2	%	54.7 (-)	81.8 (-)	42.8 (-)
12	Residue after ignition	mg dm^{-3}	183 (-)	201 (-)	185 (-)
			2011 year		
S. No.	Water quality indices	Units	20.04.2011 Spring	20.07.2011 Summer	19.10.2011 Autumn
1	Total suspended solids	mg O_2 dm^{-3}	20.3 (II)	22.7 (II)	21.6 (II)
2	pH	-	7.85 (I)	7.83 (I)	7.79 (I)
3	COD-Mn	mg O_2 dm^{-3}	7.8 (III)	8.4 (III)	7.7 (III)
4	BOD_5	mg O_2 dm^{-3}	4.6 (III)	4.9 (III)	4.7 (III)
5	$O_{2\ diss.}$	mg O_2 dm^{-3}	7.1 (I)	7.6 (I)	7.4 (I)
6	NO_3^-	mg N dm^{-3}	0.42 (I)	0.47 (I)	0.38 (I)
7	NO_2^-	mg N dm^{-3}	0.036 (II)	0.041 (II)	0.038 (II)
8	NH_4^+	mg N dm^{-3}	0.78 (II)	0.83 (II)	0.63 (II)
9	$PO_4^{3-}{}_{diss.}$	mg PO_4 dm^{-3}	0.77 (IV)	0.79 (IV)	0.72 (IV)
10	$P_{tot.}$	mg P dm^{-3}	0.47 (III)	0.55 (III)	0.43 (III)
11	Saturation with O_2	%	68.6 (-)	83.8 (-)	42.9 (-)
12	Residue after ignition	mg dm^{-3}	193 (-)	232 (-)	183 (-)

			2012 year		
S. No.	Water quality indices	Units	18.04.2012 Spring	18.07.2012 Summer	27.09.2012 Autumn
1	Total suspended solids	mg O_2 dm^{-3}	21.7 (II)	22.5 (II)	20.3 (II)
2	pH	-	7.78 (I)	7.84 (I)	7.71 (I)
3	COD-Mn	mg O_2 dm^{-3}	8.2 (III)	8.7 (III)	7.9 (III)
4	BOD_5	mg O_2 dm^{-3}	4.7 (III)	5.6 (III)	4.9 (III)
5	$O_{2\ diss.}$	mg O_2 dm^{-3}	7.9 (I)	8.5 (I)	8.7 (I)
6	NO_3^-	mg N dm^{-3}	0.47 (I)	0.54 (I)	0.49 (I)
7	NO_2^-	mg N dm^{-3}	0.036 (II)	0.038 (II)	0.033 (II)
8	NH_4^+	mg N dm^{-3}	0.75 (II)	0.78 (II)	0.69 (II)
9	$PO_4^{3-}{}_{diss.}$	mg PO_4 dm^{-3}	0.73 (IV)	0.77 (IV)	0.75 (IV)
10	$P_{tot.}$	mg P dm^{-3}	0.61 (III)	0.68 (III)	0.53 (III)
11	Saturation with O_2	%	66.9 (-)	86.8 (-)	47.5 (-)
12	Residue after ignition	mg dm^{-3}	186 (-)	198 (-)	196 (-)

Explanation: I, II, III, IV, (-) - classification of values of examined indicators in accordance with the European Union Water Framework Directive (2000/60/EC) and not classified data – respectively.

It is the primary factor which constrains the development of phytoplankton and thus affects massive algal blooms. It can occur in water bodies in the form of inorganic phosphorus as well as dissolved organic forms.

Nitrogen occurs in the form of gas dissolved in the water, ammonium ions, nitrate and nitrite. In water Szczecin Lagoon, it is the main factor limiting the growth of organisms.

Suspended solids containing much organic matter may cause putrefaction and consequently the stream may be devoid of dissolved oxygen. BOD is the amount of dissolved oxygen needed by aerobic biological organisms in a body of water to break down organic material present in given water sample at certain temperature over a specific time period and considered as an important water quality indicator[9-12]. The total suspended solids in the Szczecin Lagoon, fell into the II class.

The $P_{tot.}$ concentrations in the surface layer of the water Szczecin Lagoon was little differentiated, reaching the levels appropriate for the III quality class according to the classification of the European Union Water Framework Directive. The total phosphorus concentration was 0.43-0.68 mgP dm^{-3}. The highest concentration of total phosphorus was recorded in Szczecin Lagoon-summer 2012 (about 0.68 mgP dm^{-3}). The concentrations of $PO_4^{3-}{}_{diss}$ in the tested water Szczecin Lagoon varied more significantly-corresponding to water quality classes ranging from IV. The highest concentration of $PO_4^{3-}{}_{diss}$ was recorded in Szczecin Lagoon-summer 2009 (about 0.85 mg PO_4 dm^{-3}). An upswing in the concentration of phosphorus compounds in a Szczecin Lagoon may indicate a decreased amount of oxygen in the benthic waters and changes in their redox status leading to releasing phosphorus compounds accumulated in the bed sediment. Increased levels of phosphorus are generally associated with increasing levels of eutrophication.

The concentrations saturation with O_2 was 41.7-92.8 %. The highest concentration of saturation with O_2 was recorded in Szczecin Lagoon-summer 2008. In the case of nitrogen compounds, nitrates and nitrites values for these indicators fell into the I and II class in all the surveyed Szczecin Lagoon in accordance with the classification of the European Union Water Framework Directive.

The indicator which proves high productivity of the Szczecin Lagoon is the biochemical oxygen demand (BOD_5). The level of this indicator in the studied water Szczecin Lagoon was at level III. The highest concentration of biochemical oxygen demand was recorded in Szczecin Lagoon-summer 2009 (about 5.7 mg O_2 dm^{-3}). The highest concentration of oxygen in the waters was found in the Szczecin Lagoon (about 8.5 mg O_2 dm^{-3}). In the remaining water oxygen levels were similar (still in I class).

National Sanitation Foundation Water Quality Index (NSF WQI): National Sanitation Foundation Water Quality Index (NSF WQI) used for rating of water quality in Szczecin Lagoon indicates that the quality of water is slightly polluted (WQI = 53.6). It is almost always endangered or deteriorated. The condition in it usually diverges from normal levels and the water is not able to protect or support plenty aquatic life. Phosphorus, dissolved oxygen, total alkalinity and total solids are the main factors responsible for determination of the lake water quality. These parameters need to be modified to maintain the quality of water for further use.

Conclusion

Assessment of the Szczecin Lagoon by WQI revealed that the lake is slightly polluted and could be placed in average quality class but the trend and hierarchy of the events threatens the lake.

The German-Polish Szczecin Lagoon in the southern Baltic sea is highly eutrophic coastal water that is affected by algae blooms during summer. To reach a good ecological status, as demanded by the EU Water Framework Directive, nutrient reductions in the river basin alone will not result in a sufficiently improved water quality. Several supporting internal measures are possible in theory to combat eutrophication, to remove nutrients and to improve ecosystem quality: (1) dredging or capping of sediment, (2) enlarged reed belts and extended submersed macrophyte areas, and (3) algae farms and finally, enlarged natural mussel beds and mussel cultivation.

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