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INFLUENCE OF ANTHROPOGENIC CONTAMINATION ON QUALITY OF SURFACE AND UNDERGROUND WATERS IN DRAINAGE BASIN OF LAKE KRASNE

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Summary. The study was aimed at the assessment of the effect of anthropogenic contamination on the quality of underground and surface waters in the drainage basin of Lake Krasne, situated within the area of the Łęczna-Włodawa Lakeland. The study was conducted in May, June and August 2013. Seven sampling points were selected for the study – three were dug wells and the remaining four points were situated in the lake, close to potential sources of anthropogenic contamination. In the water from the wells only in individual cases an elevated level of chemical contamination was found, exceeding the norms defined for drinking water. Both in water samples from the lake and from the wells the presence of large numbers o meso- and psychrophilic bacteria was noted, as well as of *coliform* and faecal *coliform* bacteria, which indicates a high level of contamination of the waters under study with household sewage. Higher intensity of that phenomenon was observed in the summer months. The quality of underground waters in the drainage basin of Lake Krasne and in the lake itself is largely a result of human activity and of deficiencies in the development of sanitary infrastructure. The achievement of good status of waters in the drainage basin under analysis requires decisive actions, and especially the regulation of water-sewage management and rationalisation in the area of the recreational use of the values of the lake and its neighbourhood.

Key words: lake, Krasne, surface waters, underground waters, water purity, anthropogenic contamination

INTRODUCTION

The status of purity of waters of a given water body is affected by numerous factors, but the amount of inflowing contaminants is related most frequently with the type of drainage basin adjacent to a given lake [Kuczyńska-Kippen *et al*. 2004]. The pressure caused by human activity, i.e. the so-called anthropopressure, constitutes the greatest threat to the status of quality of surface waters. Its continuous effect causes gradual deterioration of the status of waters and their degradation. The most important pressures on the water environment include the following: significant water consumption for living and economic purposes, disposal of insufficiently purified wastewaters to surface waters or to the ground, area runoff from agriculture, burdened with biogenic compounds, improper performance of cultivation treatments, lack of infrastructure for the disposal of precipitation and thaw waters, especially from urban areas, intensive utilisation of recreational functions and excessive tourist traffic [PIEP in Lublin, 2013]. Analyses of the Province Inspectorate of Environmental Protection (PIEP) indicate that 75% of surface and underground waters in the Lublin Province are threatened with not attaining the good status by the year 2015 [PIEP in Lublin, 2013].

The objective of the study was the estimation of the effect of anthropogenic contaminants on the quality of underground and surface waters in the drainage basin of Lake Krasne. An attempt was made to determine the main causes of contamination of waters in the drainage basin of the lake, and to recommend actions aimed at improvement of the current status.

MATERIAL AND METHODS

The study was conducted in the drainage basin of Lake Krasne, included in the lake complex of the Łęczna-Włodawa Lakeland. It is situated in the village Krasne, commune Uścimów, in the Lublin Province. The lake occupies an area of 75.9 ha, has a length of 1228 m and width of 856 m, while its water capacity is 8,106.5 thousand m^3. Lake Krasne is a deep reservoir of karst origin. The bottom of the lake has two sinkholes – the west one (depth of 23 m) and the east one (depth of 33.3 m). The average depth of the lake is 10.7 m, and the length of the shoreline is 3514 m [PIEP in Lublin, 2013]. The Report on the Status of the Environment of the Lublin Province in 2012 defines the abiotic type of Lake Krasne as 7a, and its Schindler index as < 2 [PIEP in Lublin, 2013].

The drainage basin of Lake Krasne occupies an area of 265.27 ha. The primary land use types in the basin include arable lands – 96.41 ha (36.34% of the area), grasslands and pastures – 36.64 ha (13.81%), other water reservoirs – 23.16 ha (8.73%), and forests – 19.79 ha (7.46%). Lake Krasne, thanks to its attractive situation and easy access to the water, is intensively used for recreational purposes. The tourism-related buildings and structures account for 0.5% of the area and show a constant growing tendency.

The study on the quality of surface and underground waters in the drainage basin of Lake Krasne was made in May, June and August, 2013. Seven sampling points were selected for the study – three of them were dug wells (water from two of the wells – No. 1 and 3, is used for household needs), and the remaining four points were situated within the lake, close to potential sources of anthropogenic contamination. Points No. 4 and 7 are situated in the vicinity of the beaches of two large recreational centres, another one (No. 5) close to an asphalt road directly neighbouring the lake, and the last one – in the immediate vicinity of a forest (Fig. 1).

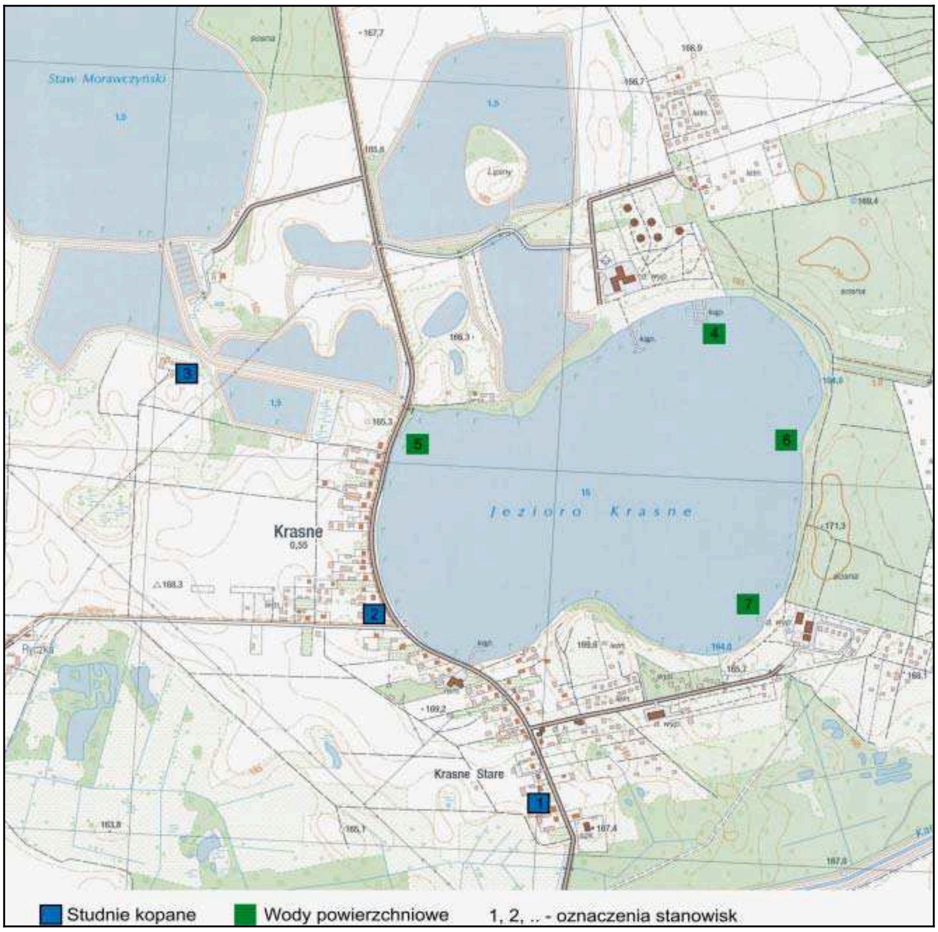

Fig. 1. Location of water sampling points in the drainage basin of Lake Krasne

The physicochemical analyses of the waters were made at the Analytical Laboratory of Water and Wastewaters, Faculty of Environmental Engineering and Geodesy, University of Life Sciences in Lublin. The microbiological parameters were assayed at the Laboratory of Ecological Food of Plant Origin, Faculty of Food Sciences, Human Nutrition and Biotechnology, ULS in Lublin. The following parameters were assayed in the samples of waters from the lake: temperature, pH, dissolved oxygen, electrolytic conductivity, total suspended solids, BOD_5, COD_{Cr}, concentration of total nitrogen, ammonia, nitrates, nitrites, total phosphorus and phosphates, chlorides, sulphates, iron and manganese. The measurements taken in the well waters included pH, electrolytic conductivity, and the concentration of ammonia, nitrates, nitrites, chlorides, sulphates, iron and manganese. The physicochemical analyses were conducted in accordance with the methods commonly applied [Hermanowicz *et al*. 1999]. In addition, in the water samples assays were made of the numbers of *coliforms* in 100 cm^3 and faecal *coliforms* in 100 cm^3, as well as of the numbers of mesophilic and psychrophilic bacteria, according to the Polish standards [PN-75/C-04615/05; PN-75/C-04615/07; PN-ISO 6222/99].

The results of the physicochemical analyses of the lake waters were compared to the threshold values of water quality indices defined in the Regulation of the Minister of the Environment of 9th November, 2011, on the method of classification of the status of uniform parts of surface waters and of environmental standards of quality for priority substances [Regulation of the Minister of the Environment 2011], while the results of microbiological assays were referenced to the standards given in the Regulation of the Minister of Health of 8th April, 2011, on the supervision of water quality at bathing resorts and places used for bathing [Regulation of the Minister of Health 2011]. The quality of the well waters was compared to the requirements defined in the Regulation of the Minister of Health of 29th March, 2007, on the quality of water for human consumption [Regulation of the Minister of Health 2007] and in the Regulation of the Minister of Health of 20th April, 2010, revising the regulation on the quality of water for human consumption [Regulation of the Minister of Health 2010].

RESULTS AND DISCUSSION

The quality of the well waters, due to their use for household purposes, was referenced to the requirements defined in the Regulation of the Minister of Health for water meant for human consumption [Regulation of the Minister of Health 2010]. It was found that the analysed waters meet the above requirements in terms of the content of ammonia, chlorides and sulphates. In individual cases exceeded levels of nitrates, nitrites, iron and manganese relative to the norms were noted (Tab. 1). Analysis of water from the wells, in the context of requirements laid down for underground waters, indicated their medium quality. Only in the case of the concentration of nitrates and nitrites there were individual instances of values characteristic for waters of unsatisfactory quality (class IV), while most of the chemical parameters met the requirements defined for satisfactory water, and even for water of very good quality [Regulation of the Minister of the Environment 2008]. Therefore it is hard to draw the conclusion on any negative effect of human activity on the quality of those waters.

Somewhat different conclusions follow from the microbiological analysis. *Coliform* bacteria were found in numbers from 2.3 × 10 to 2.4 × 10^5 MPN·100 cm^{-3}, while faecal *coliforms* – from 6 to 7 × 10^4 MPN·100 cm^{-3}, whereas the Regulation of the Minister of Health [2010] permits only individual cells of *coliforms* in drinking water. Contamination with faecal *coliforms* was lower, but considerable numbers of those bacteria were found in nearly 80% of the cases (Tab. 1). In the case of three samples (No. 1 – in June and August and No. 3 in August) the ratio of faecal *coliforms* to all bacteria from the *coli* group was higher than 0.7, which indicates water contamination with human faeces [Korzeniewska and Niewolak 1999]. This type of contamination usually causes an increase in the concentration of the ammonium form of nitrogen which was not observed in the cases studied. With the simultaneous high level of nitrates it can be concluded that from the moment of contamination to the time of sampling enough time elapsed for oxidation to the ammonium form to have taken place.

The total number of psychrophilic bacteria in the well waters varied from 2.01 × 10^3 to 7.56 × 10^5 cfu·cm^{-3}, while the number of mesophilic bacteria from 8.18 × 10^2 to 7.46 × 0^5 cfu·cm^{-3} (Tab. 1). In each series of tests the permissible number of meso- and psychrophilic bacteria, defined in the Regulation of the Minister of Health [2010] at the level of 50 and 100 cfu·cm^{-3}, respectively, was notably exceeded. In addition, an increase in the microbiological contamination of the water was observed in the summer period in relation to the samples collected in May.

The main chemical indices taken into consideration in the assessment of purity of lake waters are biogenic elements, i.e. nitrogen and phosphorus. Considering the type of surface waters such as Lake Krasne, above-normative concentration of total phosphorus were found at all the sampling points, that could have a significant effect of the development of eutrophication, as identified in the lake waters in the course of monitoring studies [PIEP in Lublin, 2013]. The highest levels of total phosphorus were noted in spring at points No. 6 and 7, where they exceeded even the value of 2 mg·dm^{-3} (Tab. 2). Total nitrogen concentration oscillated at a level defined as permissible for the type of surface waters as that represented by lake Krasne.

Among other indices analysed, and not included in the evaluation of waters, notable are the rather high values of COD, at a low BOD_5. In most cases, the ratio of BOD_5 : COD was lower than 1 : 10, which may indicate intensive processes of self-purification, including the mineralisation of compounds susceptible to biochemical degradation. The effect of that is an increase in the level of refractants and stable compounds, not susceptible to further biodegradation. Adopting the criteria

Table 1. Quality of water from wells (sampling points) in drainage basin of Lake Krasne

Parameters	Sampling points								
	1			2			3		
	V	VI	VIII	V	VI	VIII	V	VI	VIII
pH	6.43	6.56	6.41	6.8	7.42	6.71	6.65	6.56	6.52
Conductivity, $\mu S \cdot cm^{-1}$	532	532	530	482	424	561	1004	445	358
Ammonium, mg $NH_4 \cdot dm^{-3}$	0.06	0.04	0.07	0.11	0.04	0.12	0.13	0.08	0.09
Nitrates, mg $NO_3 \cdot dm^{-3}$	16.62	22.56	17.9	26.43	12.83	38.7	46.9	38.36	73.5
Nitrites, mg $NO_2 \cdot dm^{-3}$	0.18	0.06	0.31	0.11	0.57	0.31	0.15	0.2	0.16
Chloride, mg Cl dm^{-3}	44	61.6	57.6	7.5	11.7	5.2	46.5	14.8	13.9
Sulphates, mg $SO_4 \cdot dm^{-3}$	165	169	82	112	67	82	209	138	84
Iron, mg Fe $\cdot dm^{-3}$	0.06	0.11	0.05	0.09	0.16	0.06	0.39	0.19	0.27
Manganese, mg Mn $\cdot dm^{-3}$	< 0.01	< 0.01	0.1	< 0.01	< 0.01	< 0.01	0.062	< 0.01	< 0.01
Total coliforms, MPN·100 cm^{-3}	1.3×10^3	2.3×10	7×10^4	2.1×10^2	2.4×10^4	2.4×10^5	6.2×10	7×10^3	7×10^4
Faecal coliforms, MPN·100 cm^{-3}	6	2.3×10	7×10^4	6.2×10	1.3×10^3	6.2×10^2	< 5	2.4×10^2	7×10^4
Psychrophilc bacteria, cfu $\cdot cm^{-3}$	5×10^4	2.01×10^3	1.42×10^4	2.25×10^4	1.12×10^5	5.05×10^5	4.36×10^3	6.06×10^5	7.56×10^5
Mesophilic bacteria, cfu $\cdot cm^{-3}$	2.89×10^4	8.18×10^2	1.08×10^4	2.25×10^4	5.85×10^4	1.42×10^5	2.8×10^3	7.46×10^5	3.65×10^5

Table 2. Quality of water in Lake Krasne

Parameters	Sampling points											
	4			5			6			7		
	V	VI	VIII	V	VI	VIII	V	VI	VIII	V	VI	VIII
Temperature. °C	21.4	20	22.5	21.2	19.9	22.4	21.3	19.7	22.5	21.3	19.8	22.5
pH	8.34	8.34	7.51	8.61	8.17	7.93	7.19	8.04	7.6	8.08	8.14	7.76
Dissolved oxygen, $mgO_2 \cdot dm^{-3}$	8.18	10.04	8.74	10.29	10.11	8.93	7.98	8.89	8.86	8.68	9.15	8.8
Conductivity, $\mu S \cdot cm^{-1}$	289	263	253	279	261	251	296	266	254	307	265	265
Total suspended solids, $mg \cdot dm^{-3}$	13.4	4.4	24.2	1.8	1.7	12.9	7.4	3.6	3.6	0.94	4.3	2.1
BOD_5, $mg\ O_2 \cdot dm^{-3}$	3.99	2.57	2.5	1.87	2.43	1.61	1.97	2.25	0.87	2.96	2.54	1.52
COD_{Cr}, $mg\ O_2 \cdot dm^{-3}$	25	34	24	22	34	24	31	38	27	23	39	11
Ammonium, $mg\ NH_4 \cdot dm^{-3}$	0.07	0.05	0.06	0.06	0.03	0.07	0.1	0.04	0.09	0.11	0.04	0.07
Nitrates, $mg\ NO_3 \cdot dm^{-3}$	0.4	0.3	0.46	0.4	0.35	0.5	0.3	0.18	0.42	0.38	0.24	0.36
Nitrites, $mg\ NO_2 \cdot dm^{-3}$	0.04	0.03	0.07	0.04	0.03	0.03	0.06	0.06	0.06	0.03	0.05	0.05
Total nitrogen, $mg\ N \cdot dm^{-3}$	0.8	1.2	0.4	1	1.1	0.5	0.9	1.6	0.5	0.9	0.9	0.8
Phosphates, $mg\ PO_4 \cdot dm^{-3}$	0.06	< 0.01	< 0.01	0.493	< 0.01	0.021	1.371	< 0.01	< 0.01	8.532	0.049	< 0.01
Total phosphorus, $mg\ P \cdot dm^{-3}$	1.5	0.06	0.29	0.22	0.03	0.06	2.13	0.05	0.01	2.8	0.07	0.04
Chlorides, $mg\ Cl \cdot dm^{-3}$	12.1	13.5	15	2.1	13.8	16.4	14	12.6	9.2	14.2	13.9	14.5
Sulphates, $mg\ SO_4 \cdot dm^{-3}$	23	19	13	67	21	25	23	22	28	30	21	37
Potassium, $mg\ K \cdot dm^{-3}$	3.68	5.12	6.44	6.1	4.88	4.69	4.13	5.5	3.79	6.63	4.79	2.66
Iron, $mg\ Fe \cdot dm^{-3}$	0.04	0.24	0.03	0.04	0.07	0.04	0.09	0.08	0.1	0.05	0.07	0.05
Manganese, $mgMn \cdot dm^{-3}$	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Total coliforms, $MPN{\cdot}100\ cm^{-3}$	2.4×10^2	2.4×10^5	7×10^4	7×10^2	2.4×10^4	2.4×10^5	2.1×10^2	7×10^5	1.3×10^5	2.3×10	2.4×10^5	7×10^5
Faecal coliforms, $MPN{\cdot}100\ cm^{-3}$	6.2×10	2.4×10^5	6.2×10^3	6	2.4×10^4	2.4×10^5	5	7×10^5	1.3×10^5	< 5	2.4×10^5	7×10^5
Psychrophilic bacteria, $cfu \cdot cm^{-3}$	1.09×10^3	2.61×10^4	8.55×10^3	3.91×10^3	8.18×10^3	2.45×10^4	1.18×10^3	4.02×10^4	1.78×10^4	4×10^2	9.82×10^4	1.19×10^3
Mesophilic bacteria, $cfu \cdot cm^{-3}$	7×10^2	2.6×10^4	5.46×10^3	2.6×10^2	8.55×10^3	2.52×10^4	4×10^2	1.19×10^4	1.2×10^4	4×10^2	2.67×10^4	1.89×10^3

defined for COD in the Regulation of the Minister of the Environment of 2004, the waters analysed can be classified in quality classes III or IV. Te processes of degradation should cause an increase in the concentration of inorganic forms, but that was observed only in the case of phosphates, and only in the spring series of tests. The causes of that phenomenon can be sought also in the exchange of components between the lake water and the deposits of bottom sediments. In the summer a notable decrease was noted in the content of phosphates at all the sampling points. This may be a symptom of intensification of the processes of primary production that involve an increase of the demand for nutrients dissolved in the water. That can also be indicated by increase of pH of the water, and of the concentration of total nitrogen, and of its organic form in particular. On the other hand, the microbiological analysis indicates a different origin of those compounds.

The results of analysis of the number of faecal *coliform* bacteria indicate that only the samples collected in May were characterised by perfect quality in terms of the presence of those bacteria. In the following months none of the samples displayed even the satisfactory quality. The ratio of faecal *coliforms* to all bacteria from the *coli* group in the samples of water from the lake was lower than 0.7 in the samples collected in May, while later samples had the ratio equal to 1, which indicates contamination of the lake waters with household sewage. The total number of psychrophilic bacteria in the lake waters was from 4×10^2 to 9.82×10^4 cfu·cm^{-3}. In the case of mesophilic bacteria, their numbers varied from 4×10^2 to 2.67×10^4 cfu·cm^{-3} (Tab. 2). The ratio of the total number of psychrophilic bacteria to the total number of mesophilic bacteria was higher than 10 : 1 which permits approximate classification of pure waters [Berleć *et al.* 2009]. Based on that index, only sample No. 5 from May (ratio of 15:1) can be classified as clean water, while the remaining samples were distinctly contaminated as their ratio values were from 0.81 : 1 to 3.67 : 1.

CONCLUSIONS

1. In the well waters, only in individual cases an elevated level of chemical contaminants was found, exceeding the norms defined for drinking water. The factor disqualifying the quality of those waters was the numbers of meso- and psychrophilic bacteria, as well as *coliform* and faecal *coliform* bacteria.

2. The concentration of chemical contaminants in the waters of Lake Krasne was at a medium level. Above-normative concentrations were noted in spring in the case of phosphates, probably as a result of processes of mineralisation of organic matter accumulated in the bottom sediments during the previous year.

3. Starting in June, in the lake waters the presence of large numbers of meso- and psychrophilic bacteria was noted, as well as of *coliform* and faecal *coliform bacteria*, which indicates contamination of the waters analysed with household sewage and may be related with intensification of tourist traffic around the lake.

4. In the waters of Lake Krasne there take place cyclic biochemical transformations, characteristic for the processes of eutrophication, including mineralisation of organic compounds, which is indicated by low ratio of BOD_5 to COD and elevated levels of phosphates in spring and by uptake of nutrients, which in turn is indicated by a drop in the level of phosphates in the summer period.

5. Influx of matter from outside, mainly with household sewage, is the primary cause of the variation of water quality indices in Lake Krasne. The result of that is disturbed ionic balance in the reservoir that may have an effect on the quality of the waters for many years.

6. The achievement of good status of waters in the drainage basin under analysis requires decisive actions, and especially the regulation of water-sewage management and rationalisation in the area of the recreational use of the values of the lake and its neighbourhood.

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WPŁYW ZANIECZYSZCZEŃ ANTROPOGENICZNYCH NA JAKOŚĆ WÓD POWIERZCHNIOWYCH I PODZIEMNYCH W ZLEWNI JEZIORA KRASNE

Streszczenie. W pracy dokonano oceny wpływu zanieczyszczeń antropogenicznych na jakość wód podziemnych i powierzchniowych w zlewni jeziora Krasne, które zlokalizowane jest na terenie Pojezierza Łęczyńsko-Włodawskiego. Badania wykonywano w maju, czerwcu oraz sierpniu 2013 roku. Do badań wytypowano siedem punktów pomiarowych – stanowiły je trzy studnie kopane oraz cztery punkty zlokalizowane w obrębie jeziora przy potencjalnych źródłach zanieczyszczeń antropogenicznych. W wodach ze studni tylko w pojedynczych przypadkach stwierdzono podwyższony poziom zanieczyszczeń chemicznych, przekraczający normy określone dla wód do picia. Zarówno w wodach z jeziora, jak i w wodach ze studni wykazano obecność dużej liczby bakterii mezo- i psychrofilnych, a także bakterii z grupy *coli* i *coli* typu kałowego, co wskazuje na wysoki stopień skażenia badanych wód ściekami bytowymi. Większe nasilenie zjawiska stwierdzono w miesiącach letnich. Jakość wód podziemnych w zlewni jeziora Krasne i w samym jeziorze jest w dużej mierze wynikiem działalności bytowo-gospodarczej człowieka i braków w zakresie rozwoju infrastruktury sanitarnej. Osiągnięcie dobrego stanu wód w analizowanej zlewni wymaga podjęcia zdecydowanych działań, szczególnie uregulowania gospodarki wodno-ściekowej oraz racjonalizacji w zakresie rekreacyjnego wykorzystania walorów jeziora i jego otoczenia.

Słowa kluczowe: jezioro Krasne, wody powierzchniowe, wody podziemne, czystość wód, zanieczyszczenia antropogeniczne