

THE EFFECT OF COOLING WATER DISCHARGE FROM THE POWER STATION ON THE QUALITY OF THE SKAWINKA RIVER WATER

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Abstract: The effect of cooling water discharge from Skawina coal-fired power station on the quality of the Skawinka river water was presented in the paper. Hydrochemical research of both river and cooling water was conducted in 2012. Water for analyses was sampled from the river in 3 measurement points: 50 m above, 100 and 1000 m below cooling water discharge from the power plant. On the same dates cooling water samples were collected from the discharge channel. Selected physicochemical indices assessed in them comprised: the temperature, total suspended solids, dissolved oxygen, degree of oxygen saturation, electrolytic conductivity, total dissolved substances, pH, SO_4^{2-} , Cl^- , Ca^{2+} , Mg^{2+} , Na^+ , K^+ , PO_4^{3-} , N-NH_4^+ , N-NO_2^- , N-NO_3^- , Fe and Mn. The analyses revealed that cooling water discharge from the power station caused an increase in electrolytic conductivity and concentrations of dissolved substances and chlorides in the Skawinka water to the level exceeding border values for waters of purity class II. It affected a worsening of chemical state of the river from very good to good. Moreover, cooling water discharge raised water temperature and decreased dissolved oxygen content in the Skawinka river water, therefore worsening the cyprinid fish habitat condition. Statistical analysis showed that the discharge statistically significantly increased concentrations of all analysed salinity indices and nitrite nitrogen in the Skawinka water. However, it did not result from cooling water pollution by power generating technology applied by the power station, but was the effect of cooling the power station appliances with polluted water taken from the Vistula River, which after use is drained to the Skawinka.

Keywords: cooling waters, power station, quality water, Skawinka River

1. INTRODUCTION

Power stations are among the major causes of the global environment pollution (Kaldellis & Kapsali, 2014; Rubio et al., 2014; Policht-Latawiec et al., 2015). Fossil (conventional) fuels have always been, still are and will be crucial for the energy balance both in Poland (Patrycy, 2011; Policht-Latawiec & Kapica, 2013) and in the world (Sanders et al., 2014). In order to reduce the amount of pollutants supplied to the environment by power industries, unconventional sources of energy are gaining increasingly greater importance in electricity generation (Johst & Rothstein, 2014). However, in Poland hard and brown coal still remain the most important extracted energy carriers. Their share in 2013 was 79%, whereas the renewable energy sources constituted only 14% (Energy, 2014; Grudziński & Stala-Szlugaj, 2015). Development of

electrical power engineering, beside climatic changes, causes pollution of soil, surface and ground water (Dragićević et al., 2010; Liu et al., 2011). It negatively affects peoples' health and proper development of plant and animal organisms (Van Vliet et al., 2012). Operation of power plants diminishes water resources of a region in result of irretrievable losses and intensified water pollution due to disposal of sewage generated in production of electricity. Exploitation of fuel burning installations generates various kinds of sewage, including water from cooling circuits, from flue gas desulphurization, sewage from furnace waste removal, from water treatment station, from washing of boilers and other parts of the installation (Michalak, 2014). Sewage discharge may lead to worsening the chemical state (Kanownik & Rajda, 2011; Kanownik et al., 2013; Policht-Latawiec et al., 2013; Tsuzuki, 2015) and change of the trophic state

(Karadavut et al., 2011; Choi et al., 2012; Neverova-Dziopak & Cierlikowska, 2014; Policht-Latawiec et al., 2014; Kanownik & Policht-Latawiec, 2015; Zbierska et al., 2015) of the receiving water.

Growing energy demand, ageing of the installations and obligation concerning the environment protection through diminishing the negative environmental impact, as stated in the EU climatic and energy packet cause, that power stations wanting to produce electricity must adjust their pollutant emissions to the permissible values as required by the legal acts, of which the latest is the Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions – IED (Directive, 2000/60/EC; Directive, 2010/75/EU; Wiklent & Kistowski, 2013; McDermott & Nilsen, 2014; Tang et al., 2013). Therefore, the power plants care about the improvement of coal quality, introduce new burning technologies (Byers et al. 2014; Danner et al., 2012; Tian et al., 2015), control and reduce pollutant emission (Langaker et al., 2011).

2. MATERIAL AND METHODS

The aim of presented research was the assessment of the effect of cooling water discharge from Skawina S.A. coal-fired power station on the physicochemical state of the Skawinka river water in area of the Skawina district, in the south-western part of the Malopolskie voivodship. The power plant supplies electricity and thermal energy to the Skawina inhabitants and largely to the inhabitants of Krakow. The main fuel used by the power station is hard coal and biomass, constituting about 10%. The installed capacity of electric power is 490 MWe, the maximum thermal power in central heating water and technical steam is 588 and 72 MWt.

The power plant was constructed in 1957–1961. From the beginning, the power plant has been operating on the open water circuit, extracting water from the Vistula river from the surface intake located on the Łaczański Channel in Borek Szlachecki town, in the amount not exceeding $20.5\text{m}^3\cdot\text{s}^{-1}$, including the necessary lockage of $4.3\text{m}^3\cdot\text{s}^{-1}$ for cooling the basic appliances and auxiliary devices, and from the Skawinka river from a surface intake - to supplement water losses from water-steam boiler and heating circuit. Prior to the inflow into the central pump station, water flows through grills and strainers. There are six pumps, working simultaneously, installed in the power plant with the flow rate $Q = 16000\text{m}^3\cdot\text{h}^{-1} = 4.5\text{m}^3\cdot\text{s}^{-1}$ and water pumping height $H = 11\text{ m H}_2\text{O}$. Cooling water is pumped through the pumps by collectors (\emptyset

2400/2200/1800 mm), from which it is distributed to the individual turbine condensers and other receivers. Discharge water from condensers heated by the hydro power plant with a capacity of 1.6 MW is drained into the Skawinka River. In order to protect the Skawinka river water against harmful effect of the pollutants in the post-production water, a number of local devices for sewage treatment are functioning, including oil separators and grit chamber before cooling water and rainwater discharge, coalescing oil separators, sewage treatment plant by the heavy oil plant and settling tank with filter on the coal square.

Hydrochemical research on the Skawinka River was conducted in 2012. The river is 33.479 km long, with mean bottom slope 10‰. The Skawinka springs are located on the Babica Mt. slopes in the Makowski Beskid Mts. on the altitude of about 560 m a.s.l. The Skawinka flows into the Vistula River on the altitude of 209 m a.s.l. In the Beskidy Mts. the Skawinka course is only 3 km long, further the river flows in the Beskid Foothills area, whereas at its final section, below Skawina town it enters the area of alluvial Vistula river valley (Konracki, 2013). The river flows in a bed with the bottom composed of sandstones and shales from the cretaceous and paleogene age, and in the lower course of miocene clay deposits. According to surface water typology, the Skawinka is a lowland, sandy-loam river. The Skawinka River catchment area of 352.40 km^2 is situated in the Malopolskie voivodship (Fig. 1). Water resources in the basin Skawinka is mainly surface water, as in the whole Polish Carpathians. Flow characteristic of the river above the discharge of water from the power plant Skawina were the maximum – $346\text{m}^3\cdot\text{s}^{-1}$, the average – $3.06\text{m}^3\cdot\text{s}^{-1}$ and low – $0.46\text{m}^3\cdot\text{s}^{-1}$.

Water for the analyses was collected from the Skawinka River on 8 dates in 3 measurement-control points: point 1 at 3+115 km, situated 50 m above cooling water discharge from the power plant, point 2 at 2+965 m and point 3 at km 2+065 m were located respectively 100 and 1000 m below the water discharge (Fig. 1). Additionally cooling water was sampled from the discharge channel (point D) of the Skawina power plant.

The assessments of water quality indices were conducted using reference methods (Regulation, 2011). The assessments conducted in the field comprised: water pH by means of CP-104 ph meter, electrolytic conductivity at 20°C (EC) using CC-102 conductometer, water temperature, dissolved oxygen concentration (DO) and oxygen saturation degree (OSD) by means of CO-411 oxygen meter.

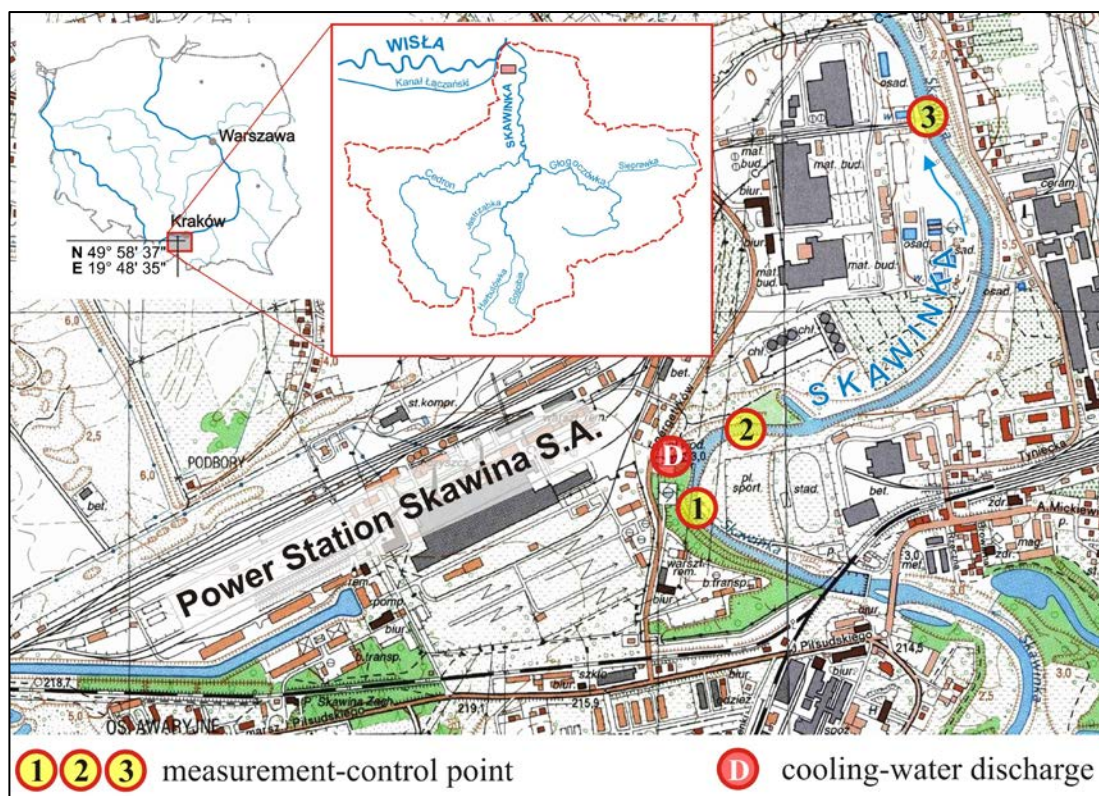


Figure 1. Location of measurement and control points on the investigated section of the Skawinka River

In the laboratory total suspended solids (TSS) were determined by means of oven-dry method, total dissolved solids (TDS) by evaporation; sulphates (SO_4^{2-}) by precipitation method, concentrations of Ca^{2+} , Mg^{2+} , Na^+ , K^+ , Mn and Fe ions using atomic absorption spectrometry (ASA) on Unicam SOLAAR 969 spectrometer. Concentration of ammonium nitrogen (N-NH_4^+), nitrite nitrogen (N-NO_2^-) and nitrate nitrogen (N-NO_3^-), phosphates (PO_4^{3-}) and chlorides (Cl^-) were assessed using flow injection analysis on FIAstar 5000 apparatus. The concentration of NO_2^- ions was computed from the nitrate nitrogen form assessed in the laboratory.

Elaboration of the results comprised determining the minimum, maximum and mean values, as well as, arithmetic mean, median and standard deviation for the indices in the measurement control points. The values of pollution indices in the cooling water from the power plant discharged into the Skawinka river were compared with the highest values permissible for the sewage supplied to water or to the soil and for the substances particularly harmful to the environment, as stated by the Regulation of the Minister of the Environment (Regulation, 2009). The river water quality was determined in compliance with the Regulation of the Minister of the Environment of 22 October 2014 (Regulation, 2014), checking whether the water met the requirements for the inland waters which are the habitat for fish in

natural conditions, in compliance with the Regulation of the Minister of the Environment dated 4 October 2002 (Regulation, 2002). Statistical implications about the significance of differences of the indices values between the measurement control points were conducted using non-parametric Kruskal-Wallis test. Subsequently, the Mann-Whitney U test on the level of $\alpha = 0.05$ was conducted for the pairs of points for the indices differing significantly between the measurement control points. Non-parametric tests were selected due to a lack of normal distribution for a majority of the analysed indices, according to the results of Shapiro-Wilk test and a lack of variance equality determined by the Fisher-Snedecor test. Moreover, the cluster analysis was conducted for the measurement control points and physicochemical indices within the individual points, aimed at grouping the objects (points or indices) so that the objects within each of the identified group were similar to each other, but possibly the least similar to the objects of the other groups, according to the rule of internal similarity and external dissimilarity. If there are clusters of objects similar to each other, the structure may be presented as separate branches on a hierarchical tree (tree diagram). Estimation of the distance between groups was conducted using Ward's method, which bases on the analysis of variance and aims at minimizing any two cluster sum of squares (Stanisz, 2007).

3. RESULTS

During the period of investigations cooling water revealed the average temperature of 16.6°C (Table 1). The maximum value was 23.5°C and was lower than the permissible value (35°C) according to the regulations on the conditions which must be fulfilled at the sewage discharge to water or soil (Regulation, 2009). Values of total suspended solids were on a low level, from 1 to 6 mg·dm⁻³, and their mean value was 4.8mg·dm⁻³. Oxygen conditions in the discharged water were proper: minimal concentration of dissolved oxygen - 5.9mg·dm⁻³ and the oxygen saturation level - 72%. Considering the salinity indices, maximum values of chlorides and sodium (1172 and 954 mg·dm⁻³) exceeded the permissible values (1000 and 800 mg·dm⁻³) stated for sewage drained into the water. Mean values of all analysed and included in the Regulation of the Minister of the Environment (Regulation, 2009) indices of cooling water pollution were lower than permissible values. The pH of water drained from the power station was within the 7.3 – 7.9 pH range, whereas the values of biogenic indices and metals (Fe and Mn) were several times lower than the permissible values.

During the period of research, water temperature in the Skawinka River was within the range from 3.0 to 24.2°C. Discharge of cooling

water caused a 1.5°C increase in the mean water temperature in the Skawinka (Table 2). Mean values of total suspended solids were on a low level: 3.3; 5.0 and 3.9 mg·dm⁻³, respectively in points 1, 2 and 3. Mean values of the indices characterizing water physical condition along the investigated river section did not exceed limit values for class I (Regulation, 2014). Over the whole period of the investigations, the Skawinka river water revealed very good oxygen conditions – average oxygen saturation degree reached 108, 100 and 99%, respectively in the investigated 1, 2 and 3 control points and did not exceed 148%, whereas the average dissolved oxygen concentration in these points exceeded 7mg·dm⁻³. Below the water discharge forms the power plant (in points 2 and 3), electrolytic conductivity was on a high level, exceeding the limit value of 1500 μS·cm⁻¹ for class II, on average respectively: 2519 and 2408 mg·dm⁻³. Total dissolved solids concentration also exceeded the limit value for class II and was on average 1791mg·dm⁻³ in point 2 and 1758mg·dm⁻³ in point 3 (Table 2). Both these and maximum values 3820 and 3944 mg·dm⁻³ evidence a considerable water pollution below the cooling water discharge. For chlorides, mean values in both point 2 and 3 (781 and 769 mg·dm⁻³) were over twice higher than the value permissible for class II - 300mg·dm⁻³ (Regulation, 2014).

Table 1. Statistical parameters describing pollution indices values in cooling waters from Skawina power station discharged to the Skawinka River and permissible values stated in Ministry Regulation

Index	Range	Average	Standard deviation	Permissible values stated in Ministry Regulation (2009)
Temperature (°C)	5.5 – 23.5	16.6	6.0	35
Total suspended solids (mg·dm ⁻³)	1 – 6	4.8	4.8	35
Dissolved oxygen (mgO ₂ ·dm ⁻³)	5.9 – 15.4	9.3	2.9	-
Oxygen saturation degree (%)	72 – 131	96	18	-
Electrolytic conductivity (μS·cm ⁻¹)	1238 – 5200	2418	1290	-
Total dissolved solids (mg·dm ⁻³)	1052 – 3704	1793	902	-
SO ₄ ²⁻ (mg·dm ⁻³)	96 – 260	142	58	500
Cl ⁻ (mg·dm ⁻³)	278 – 1172	702	293	1000
Ca ²⁺ (mg·dm ⁻³)	58 – 110	77	16	-
Mg ²⁺ (mg·dm ⁻³)	24 – 78	43	19	-
Na ⁺ (mg·dm ⁻³)	114 – 954	443	263	800
K ⁺ (mg·dm ⁻³)	5 – 22	13	6	80
Cl ⁻ + SO ₄ ²⁻ (mg·dm ⁻³)	378 – 1362	845	340	1500
Reaction (pH)	7.3 – 7.9	7.6	0.2	6.5 – 9.0
PO ₄ ³⁻ (mg·dm ⁻³)	0.07 – 0.23	0.14	0.06	-
N-NH ₄ ⁺ (mg·dm ⁻³)	0.00 – 0.54	0.21	0.22	10
N-NO ₂ ⁻ (mg·dm ⁻³)	0.06 – 0.16	0.11	0.04	1
N-NO ₃ ⁻ (mg·dm ⁻³)	1.6 – 3.3	2.1	0.6	30
Fe (mg·dm ⁻³)	0.11 – 0.66	0.37	0.20	10
Mn (mg·dm ⁻³)	0.00 – 0.31	0.15	0.09	-

Table 2. Range and mean values of physicochemical elements and water quality class in the Skawinka River

Index	Range			Average			Limit values for class (Regulation, 2014)	
	Measurement-control point						I	II
	1	2	3	1	2	3		
Temperature (°C)	3.0 – 21.1	3.2 – 24.1	3.2 – 24.2	14.8	16.3	16.3	≤ 22	≤ 24
Total suspended solids (mg·dm ⁻³)	0 – 9	1 – 15	0 – 14	3.3	5.0	3.9	≤ 25	≤ 50
Dissolved oxygen (mgO ₂ ·dm ⁻³)	7.2 – 17.5	5.7 – 15.3	5.2 – 14.2	10.8	9.6	9.3	≥ 7	≥ 5
Oxygen saturation degree (%)	85 – 148	70 – 137	75 – 128	108	100	99	-	
Electrolytic conductivity (μS·cm ⁻¹)	256 – 566	1449 – 5220	804 – 5260	418	2519*	2408*	≤ 1000	≤ 1500
Total dissolved solids (mg·dm ⁻³)	192 – 396	968 – 3820	568 – 3944	301	1791*	1758*	≤ 500	≤ 800
SO ₄ ²⁻ (mg·dm ⁻³)	42 – 86	53 – 261	70 – 257	56	136	136	≤ 150	≤ 250
Cl ⁻ (mg·dm ⁻³)	23 – 85	393 – 1101	224 – 1268	51	781*	769*	≤ 200	≤ 300
Ca ²⁺ (mg·dm ⁻³)	31 – 59	59 – 110	47 – 111	48	77	74	≤ 100	≤ 200
Mg ²⁺ (mg·dm ⁻³)	6.3 – 10	24 – 86	22 – 78	8.9	43	40	≤ 50	≤ 100
Na ⁺ (mg·dm ⁻³)	10 – 78	227 – 1038	106 – 1020	31	496	445	-	
K ⁺ (mg·dm ⁻³)	3.2 – 6.5	4 – 23	4 – 24	4.8	14	13	-	
Reaction (pH)	7.4 – 8.0	7.4 – 7.8	7.5 – 7.8	7.7	7.6	7.6	6 – 8.5	6 – 9
PO ₄ ³⁻ (mg·dm ⁻³)	0.08 – 0.28	0.08 – 0.26	0.00 – 0.20	0.15	0.14	0.13	≤ 0.2	≤ 0.31
N-NH ₄ ⁺ (mg·dm ⁻³)	0.00 – 0.83	0.00 – 0.55	0.00 – 0.55	0.21	0.16	0.19	≤ 0.78	≤ 1.56
N-NO ₂ ⁻ (mg·dm ⁻³)	0.02 – 0.09	0.06 – 0.17	0.06 – 0.16	0.05	0.10	0.11	-	
N-NO ₃ ⁻ (mg·dm ⁻³)	0.8 – 2.9	1.4 – 3.0	1.0 – 3.1	1.5	2.1	2.0	≤ 2.2	≤ 5
Fe (mg·dm ⁻³)	0.01 – 1.72	0.14 – 1.63	0.08 – 1.44	0.73	0.52	0.49	-	
Mn (mg·dm ⁻³)	0.00 – 0.34	0.07 – 0.31	0.01 – 0.85	0.13	0.18	0.21	-	

* does not meet the requirements of quality class II (it is below the good state)

The other analysed salinity indices were much higher below the cooling water discharge, still their values were within water quality class I. Higher values of the indices characterising salinity of the Skawinka river water below the discharge were caused by cooling of the power plant devices with water taken from the Vistula river. According to the report on the state of the environment in the Malopolskie voivodship developed by the Voivodship Inspectorate for the Environmental Protection in Krakow, during the investigated period, water in the Vistula River above Skawina town was below good state due to high electrolytic conductivity and high concentration of dissolved solids and chlorides. Concentrations of sulphates, calcium and magnesium did not exceed the limit value for quality class I (Report, 2013).

The highest sulphate (SO₄²⁻) concentration was 216mg·dm⁻³, magnesium – 86mg·dm⁻³, sodium – 1038mg·dm⁻³ in point 2 and 111 mg·dm⁻³, calcium and potassium – 24 mg·dm⁻³ in point 3. The reaction of the Skawinka river water was slightly alkaline. Along the whole investigated length of the watercourse, incidental high biogen concentrations were registered, yet their mean values did not exceed the limit values for class I (Table 1). The highest total iron concentrations (1.72mg·dm⁻³) were noted in point 1. Average value of this element was the highest in point 1 – 0.73 mg·dm⁻³ and the lowest in point 3 – 0.49 mg·dm⁻³. Manganese concentration fluctuated

from 0.00 to 0.85 mg·dm⁻³, whereas mean value of the concentration along the whole investigated length of the watercourse did not exceed 0.21 mg·dm⁻³ (Table 2).

The water was unsuitable for natural habitat of the salmonid and cyprinid fish along the whole analysed stretch of the Skawinka River, due to high concentrations of nitrites. In each water sample nitrite concentration was higher than 0.03 mg·dm⁻³ (Table 3). Moreover, in point 1 the analysed water does not provide conditions favourable for fish because of high concentrations of nitrate nitrogen. Additionally, below the cooling water discharge, neither the temperature nor water saturation with oxygen in the Skawinka River meets the requirements of the cyprinid fish habitat (Regulation, 2002).

Statistical analysis conducted by means of non-parametric Kruskal-Wallis test for the measurement control points situated on the Skawinka River revealed, that the values of water quality indices differed statistically significantly between these points for the group of indices characterising salinity and nitrite nitrogen concentration. For these indices the test probability is lower than 0.01 (Table 4). Analysis of the differences of water parameters for the pairs of points on the Skawinka, conducted using U Mann-Whitney's test revealed, that significant differences occurred between point 1 and 2 and 3 (Table 5).

Table 3. Assessment of water usability as a natural habitat for fish

Index	Frequency of index values (% of samples) in normative range for a given fish category						Values required for inland waters as environment for fish (Regulation, 2002)		
	salmonids			cyprynids					
	Measurement-control point						salmonids	cyprynids	
	1	2	3	1	2	3			
Temperature (°C)	100	75*			100			21.5 ¹	28.0 ¹
Total suspended solids (mg·dm ⁻³)	3.3 ³	5.0 ³	3.9 ³	3.3 ³	5.0 ³	3.9 ³	average annual value ≤ 25		
Reaction (pH)	100			100			6-9 ²		
Dissolved oxygen (mgO ₂ ·dm ⁻³)	88	50	38*	88	75	63	50% ≥ 9	50% ≥ 8	
	100			100			100% ≥ 7	100% ≥ 5	
N-NH ₄ ⁺ (mg·dm ⁻³)	88*	100		88*	100		≤ 0.78 ²		
NO ₂ ⁻ (mg·dm ⁻³)	0*			0*			≤ 0.01 ²	≤ 0.03 ²	

¹ for 98% of samples, ² for 95% of samples, ³ average value, *requirements not fulfilled

Table 4. Comparison of water quality indices values between the measurements points using non-parametric Kruskal-Wallis test

Index	Median				Results of Kruskal-Wallis test			
	Measurement-control point				Test value		Probability test	
	1	D	2	3	1, 2, 3	D, 2, 3	1, 2, 3	D, 2, 3
Temperature (°C)	15.6	17.2	16.9	17.0	0.85	0.03	0.65	0.99
Total suspended solids (mg·dm ⁻³)	2.0	3.5	4.0	3.0	0.80	0.71	0.67	0.70
Dissolved oxygen (mgO ₂ ·dm ⁻³)	9.6	8.6	8.8	8.7	1.40	0.13	0.50	0.94
Oxygen saturation degree (%)	106	93	96	95	1.44	0.36	0.49	0.83
Electrolytic conductivity (μS·cm ⁻¹)	433	1969	2139	2132	15.4	0.11	<0.01	0.94
Total dissolved solids (mg·dm ⁻³)	308	1466	1506	1446	15.4	0.25	<0.01	0.88
SO ₄ ²⁻ (mg·dm ⁻³)	55	117	118	111	12.7	0.001	<0.01	0.99
Cl ⁻ (mg·dm ⁻³)	50	700	825	780	15.4	0.40	<0.01	0.82
Ca ²⁺ (mg·dm ⁻³)	50	71	73	72	12.7	0.49	<0.01	0.98
Mg ²⁺ (mg·dm ⁻³)	9.3	40	41	36	15.5	0.42	<0.01	0.81
Na ⁺ (mg·dm ⁻³)	23	475	437	412	15.4	0.13	<0.01	0.94
K ⁺ (mg·dm ⁻³)	4.9	11.5	15	11	10.3	0.26	<0.01	0.88
Reaction (pH)	7.6	7.6	7.7	7.5	0.26	1.03	0.88	0.60
PO ₄ ³⁻ (mg·dm ⁻³)	0.13	0.12	0.12	0.12	0.03	0.001	0.98	0.99
N-NH ₄ ⁺ (mg·dm ⁻³)	0.06	0.18	0.07	0.16	0.27	0.24	0.87	0.88
N-NO ₂ ⁻ (mg·dm ⁻³)	0.05	0.10	0.10	0.09	10.9	0.28	<0.01	0.87
N-NO ₃ ⁻ (mg·dm ⁻³)	1.3	1.9	1.9	1.9	5.14	0.11	0.08	0.95
Fe (mg·dm ⁻³)	0.56	0.44	0.39	0.39	1.56	0.17	0.46	0.92
Mn (mg·dm ⁻³)	0.11	0.15	0.16	0.11	1.21	0.34	0.54	0.84

The statistical value in bold that the differences are statistically important on the level α = 0.05

Table 5. Significance of differences of water indices values between individual measurements points on the Skawinka – non-parametric U Mann-Whitney test

Point	EC			TDS			SO ₄ ²⁻			Cl ⁻		
	1	2	3	1	2	3	1	2	3	1	2	3
1	∞	<0.001	<0.001	∞	<0.001	<0.001	∞	0.005	0.001	∞	<0.001	<0.001
2	1706	∞	0.79	1198	∞	0.67	63	∞	0.92	775	∞	0.92
3	1699	-7	∞	1138	-60	∞	56	-7	∞	730	-45	∞
Point	Ca ²⁺			Mg ²⁺			Na ⁺			K ⁺		
	1	2	3	1	2	3	1	2	3	1	2	3
1	∞	<0.001	0.005	∞	<0.001	<0.001	∞	<0.001	<0.001	∞	0.006	0.006
2	23	∞	0.83	31.7	∞	0.60	414	∞	0.75	10.1	∞	0.71
3	22	-1	∞	26.7	-5	∞	437	-4	∞	6.1	-4	∞
Point	N-NO ₂ ⁻											
	1	2	3									
1	∞	0.005	0.004									
2	0.05	∞	0.92									
3	0.04	-0.01	∞									

Difference between medians

∞	∞	∞
∞	∞	∞
∞	∞	∞

Probability test (p)

EC – Electrolytic conductivity; TDS – Total dissolved solids. The statistical value in bold that the differences are statistically important on the level α = 0.05

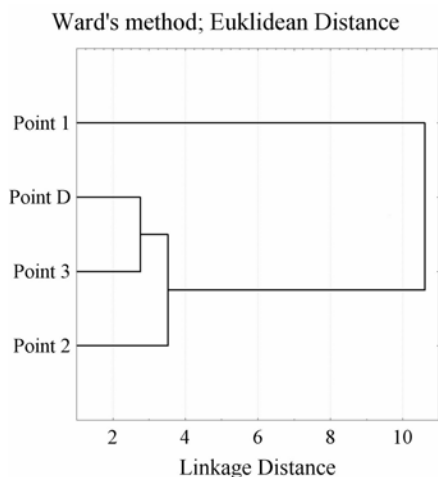


Figure 2. Cluster analysis (dendrogram) similarity of physical and chemical indicators of water measurement and control

However, no statistically significant differences in physicochemical indices values were

registered between the cooling water and water in the Skawinka River below the discharge. The fact was also confirmed by the cluster analysis conducted for standardized values of physicochemical indices, on the basis of which it was stated that the cooling water and water in the Skawinka below the discharge form one group, whereas water in the Skawinka above the discharge forms a separate cluster (Fig. 2).

Cluster analysis of water indices values in each measurement control point allowed to identify three groups of water quality indices for each point. However, the clusters differ depending on the analysed point. The structure of pollution indices clusters in the Skawinka River below the discharge (points 2 and 3) is identical as in cooling water (point D) – the first groups comprises EC and TDS, the second Na^+ and Cl^- , whereas the other indices form the third group.

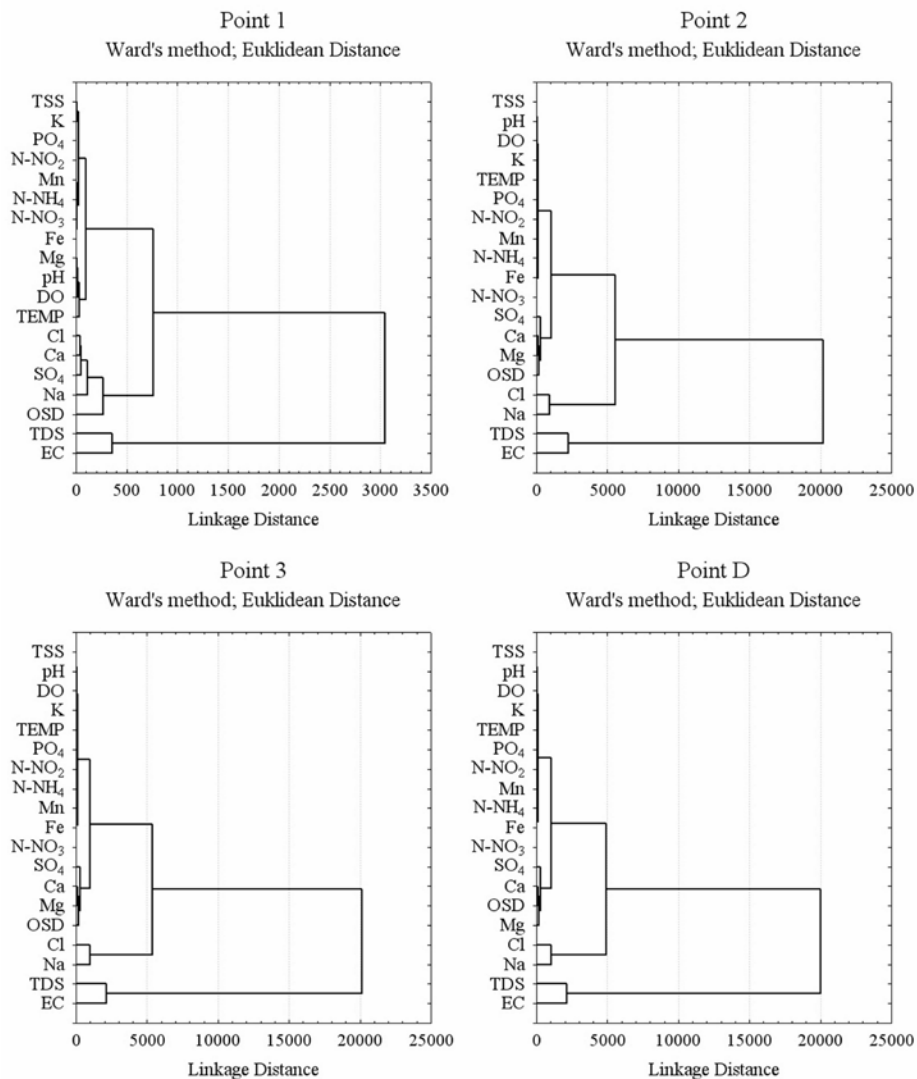


Figure 3. Dendrogram (Ward's method) of the analysed of physical and chemical indicators of water measurement and control

It is different above the discharge (point 1), where EC and TDS were in one group, Cl⁻, Ca²⁺, SO₄²⁻, Na⁺ and OSD, whereas the other indices form the third group (Fig. 3).

4. CONCLUSIONS

The analysed pollution indices of cooling water from the power plant met the requirements posed for the industrial sewage discharged to surface water according to the decree of the Minister of the Environment of 2009.

Physicochemical state of the Skawinka River water below the water discharge from the power plant does not meet the requirements of quality class II (it is below the good state) due to high electrolytic conductivity and high concentration of total dissolved solids and chlorides.

Along the whole investigated section of the Skawinka River, water does not meet the requirements for inland waters providing a habitat for fish under natural conditions, due to high nitrite concentration. Therefore, cooling water discharge is a threat to the cyprinid fish life due to raised temperature and lowered content of oxygen dissolved in the Skawinka water.

On the basis of the statistical analysis it was found that cooling water discharge caused a worsening of the quality and a change of the structure of water pollution indices in the Skawinka. A statistically significant impact on the quality of the Skawinka River water was stated for all analysed indices of salinity and nitrite nitrogen.

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