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Time and Space Variability of Water Quality in the Inner-city River in Lublin from the Aspect of Existing Natural and Land Use Conditions

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1. Introduction

The quality of water in a river catchment basin depends on many factors. The method of land management and use plays a decisive role. This is connected with the presence of sources of pollutants, volumes and quality of emissions to the environment as well as the use and efficacy of anti-pollution systems (Hat et al. 2004, Mallin et al. 2009). The protection of water resources must be preceded by detailed, multiple-aspect analysis of the status of respective components of the natural environment and phenomena occurring in the environment-society-economy system. In addition, the current capacity of the ecosystem in terms of anthropogenic impact and its self-purification and water renewal ability must be taken into account (Khan & Ansari 2005, Poskrobko 2007). At present, direct influx of polluted rainwater into inner-city sections of river beds has been a growing problem. Rainwater captures all pollutants it finds on its way – both in the air and on sealed surfaces (among others roofs, roads, parking lots, depots, markets) (Beck & Birch 2012, Jennings & Jarnagin 2002). Limited infiltration and retention result in extremely high run-offs of poor quality (area pollution), which in turn can induce hydrobiological stress in water courses (impact of harmful physical, chemical and biological stimuli) (Geiger & Dreiseitl 1999). These phenomena are random and they have not been satisfactorily examined yet. On the other hand, comprehensive protection of surface water quality is deemed a key factor in catchment management, in particular in territories subject to considerable changes in land use (Carroll et al. 2013).

This paper aims at evaluating the variability of water quality in the Czerniejówka River flowing through the southern and central parts of Lublin city (south-eastern Poland). The analysed river is a right-bank tributary of the Bystrzyca River which, in turn, disembogues into the Wieprz River. The studies were carried out in 2009-2016. They took into account natural factors (such as, for example, weather, rain run-offs, water regime in the valley) and anthropogenic ones (e.g. land development, drainage system, sources of pollution) that could determine high variability of the quality of water in water courses. The sampling points (SP) were situated in sections with various use of adjacent land (agricultural land – 1, high-density building development – 2). The paper also attempts to evaluate the options for protecting the quality of river water resources. The collected results should provide valuable material for experts in environmental protection, water management and spatial planning.

2. Material and methods

2.1. Study area

Lublin is located in south-eastern Poland near the northern edge of the Lublin Upland. It is the largest city on the east bank of the Vistula, covering an area of 147 km^2. Its population is approximately 340 thousand (US 2017). Many industrial plants representing various areas of industry operate within the Lublin conurbation. Road infrastructure and housing as well as commercial and service building development have been growing fast. Unfortunately, many old housing estates and industrial grounds require revitalisation and modernisation. Among other things, the water and sewage and waste management must be put in order.

The Czerniejówka River under observation is a right-bank tributary of the Bystrzyca – Lublin's main river (Fig. 1). The Czerniejówka catchment basin extends over about 170 km^2 and in physiographic terms it is located in the northern part of the Giełczew Elevation. The mean altitude of the basin is 225.5 m a.s.l. with the mouth on the 169 m a.s.l. ordinate. Dusty and sandy-dusty surface formations of good permeability are found here. The Czerniejówka flows in a well-developed valley with a flat bottom and strongly inclined slopes. The valley is filled with Quaternary sandy sediments. It contains numerous springs of little capacity. The water flow in the river in the cold season (autumn-winter) exceeds that in the warm season (spring-summer). The largest amounts of water appear in springtime as a result of intense short-term surface run-offs (thaws). An abundant and even underground water supply determines even daily river flows. The water resources in the basin of the Czerniejówka River are intensely utilised for covering the municipal water supply needs of Lublin (underground water intakes) (Michalczyk et al. 2011).

Outside the city limits the structure of land use in the basin of the Czerniejówka River is dominated by agricultural land with a definite predominance of arable land. The lower part of the catchment, within which the SPs are located, remains under a strong influence of the city. A strong differentiation in land development is clearly visible here, with a predominance of single-family residential buildings. Multi-family buildings are often old unkempt tenement houses. The river basin has about 30 separate sewerage systems disposing rainwater directly into the river bed. All rainwater outlets are located above SP 2 (mouth section of the river). The vast majority of them are situated between points 1 and 2 (inner-city section of the river) (ADAPTCITY 2019). The wide bottom of the valley, in the neighbourhood of SP 1, is covered by arable land with a considerable share of allotment (community) gardens. It spreads on both sides along 0.7 km towards the mouth of the river. Another section of the valley, 1.2 km long, is dominated to a larger extent by single-family houses, and numerous wasteland areas (unbuilt land) were destined for building development. It is also a location of single industrial buildings (among others, the largest brewery in the Lublin Region), warehouses and office buildings. The final part of the valley with SP 2 is densely built-up up till the river bed. This is a location of new multi-family houses, industrial, office, commercial premises, warehouses and utility buildings. The analysed section of the river is crossed by five bridges, including one railway bridge (Geoportal Miejski 2019). The distance between SPs is 2.3 km (Fig. 1). SP 1 is situated 20 m above the bridge at Mickiewicz Street, and SP 2 – 60 m above the bridge at Fabryczna Street. The river bed near the SPs is 4.5 m wide.

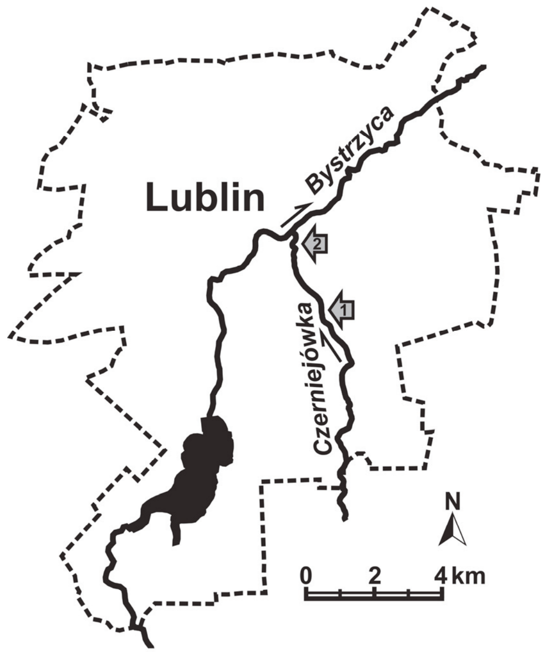

Fig. 1. Location of the Czerniejówka River and SPs 1 and 2

2.2. Climatic conditions

The climatic conditions in the study area were evaluated based on own observations and information available in statistical reports (Table 1). In 2009-2016 the annual precipitation sums were differentiated and they normally exceeded the multiannual average. Precipitation was particularly abundant in 2014. The difference was close to 200 mm in comparison to an average year (1971-2010). In addition, the highest monthly precipitation sum (240 mm in May) was recorded in that year. It accounted for 30% of the annual precipitation. Years 2011 and 2012 were exceptionally dry – precipitation sums amounted to about 500 mm. In November 2011 the precipitation level stopped at only 1 mm. Both in the multiannual period (1971-2010) and in the study period (2009-2016), the lowest monthly supply was observed in February (30 mm), and the highest, respectively, in July (82 mm) and May (102 mm).

Table 1. The lowest and the highest annual precipitation sums and average air temperature in the study period compared with average climatic conditions in a multiannual period (CSO 2009, 2011, 2013, 2014)

	Period	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	I-XII
Precipitation (mm)	2012	43	19	27	31	34	68	58	45	38	87	24	28	502
	2014	67	15	43	54	240	77	76	90	29	24	23	54	792
	1971-2010	32	30	37	39	63	69	82	69	63	43	38	33	598
Temperature (°C)	2010	-8.6	-2.6	2.6	8.8	13.8	17.3	20.8	19.4	11.8	5.2	6.0	-5.0	7.5
	2015	0.6	0.4	4.7	7.9	12.4	16.7	19.3	21.8	14.6	6.8	4.7	3.3	9.4
	1971-2010	-3.1	-2.0	2.0	8.0	13.5	16.1	18.5	17.7	13.0	7.8	3.0	-1.6	7.7

Except in the year 2010, average air temperatures in the study period were considerably above the multiannual average. The difference between average annual temperatures in 2009-2016 and 1971-2010 was 0.7°C. Particularly low average monthly temperatures were noted in January, February and December 2010 (Table 1). As a consequence, the surface water table was frozen and it was necessary to take samples from underneath the ice. The highest average annual temperature (9.4°C) was noted in 2015. Both in the multiannual period and in the study period the warmest month was July. According to Kaszewski (2008), the average annual number of days with snowfall in the study area is 48, while snow cover in the Lublin Region is maintained for about 60 to 80 days.

2.3. Analyses of water quality and flow measurements

The physical and chemical properties of waters were analysed on a seasonal basis (at 32 measurement dates). At both SP samples were taken using ladles at 20-minute intervals. Water temperature was measured upon sampling. At the Water and Wastewater Laboratory of the University of Life Sciences in Lublin the following values were determined: electrolytic conductivity (by conductometry), pH (by potentiometry), total suspended solids (by drying and weighing), dissolved oxygen (O_2), BOD_5 (by dilution), COD (by dichromate method), ammonium ions (NH_4^+), nitrates (NO_3^-), nitrites (NO_2^-), phosphates (PO_4^-), sulphates (SO_4^-), iron (Fe^+), potassium (K^+), and chlorides (Cl^-) (photometric determination). The above-mentioned chemical components were measured using photometers: MPM 2010 (WTW) and LF 205 (Slandi). The physical properties of water were determined using a multi-parameter meter, Multi 340i (WTW). In the evaluation of the quality of river water the extreme and mean values of the analysed indicators were determined for every SP. Statistical variability of the results was based on the standard deviation and the coefficient of variation. The non-parametric Wilcoxon test was used for comparing water quality indicators for both SPs and both half-year seasons (autumn-winter and spring-summer) (significance level $\alpha = 0.05$).

In 2013-2016 water levels and flow intensity were also measured at SP 2. In 2013 measurements were carried out once a month and in the remaining years at water sampling dates. The flow volume was determined by an indirect sectional method after determining the cross-section area of the water course (direct levelling) and measurement of the flow speed (floating element).

3. Results and discussion

The results of studies carried out in 2009-2016 point to a moderate differentiation in water quality in the Czerniejówka River. The coefficient of variation exceeding 50% refers to most indicators. This parameter reaches a considerable value for suspended solids, BOD_5, NO_3^- (at SP 2 – 73.8-96.1%) and PO_4^- (at SP 1 – 77.2%). The highest variability of concentrations approximating 300% is characteristic of NH_4^+ (SP 2). Relatively low variability was recorded for pH, O_2, SO_4^- and Fe^+ (3.2-41.9%). A comparative analysis for both SPs showed similar trends in variability for most parameters. However, the average values of the evaluated indicators often differed in the midstream and downstream. The median values for a definite majority of indicators are similar or identical to their mean values (table 2). It can be determined by the high number of analysed samples (32 values for each indicator at the specific SP).

The variables deteriorating the quality of run-off were NO_2^-, PO_4^- and Fe^+. Mean concentrations of those pollutants were, 0.12, 0.52 and 0.35 mg·dm^{-3}, respectively. The levels of PO_4^-, reaching up to 1.90 mg·dm^{-3}, were particularly alarming. In 2009 and 2012 the average annual concentrations of that component exceeded 0.70 mg·dm^{-3} at both SPs (maximum: 1.20 mg·dm^{-3} at SP 1 in 2009).

Nitrogen and phosphorus are dangerous nutrients contributing to eutrophication of water ecosystems (Khan & Ansari 2005). In turn, iron is deemed a factor reducing the development of cyanobacteria when other nutrients are freely available (Chi et al. 2016). In the analysed river the levels of some pollutants increased after rainfall and surface run-offs. Liu et al. (2012) demonstrated a positive correlation between rainfall and the concentrations of biogenic components in the receiving bodies of water (washing out and transport during run-offs).

The degrees of pollution in the Czerniejówka River at SPs 1 and 2 were compared using a non-parametric Wilcoxon test (level of significance $\alpha = 0.05$). Statistically significant differences in distribution of the analysed characteristics were found for conductivity, O_2, NH_4^+, NO_3^-, SO_4^-, Fe^+ and Cl^- (Table 2). At the mouth of the river (SP 2) water was more polluted than in the midstream (SP 1). Differences between the mean values of the above-mentioned variables ranged from 6.1 (O_2) to 120.4% (NH_4^+). Although the mean concentration of PO_4^- at SP 1 was 13.2% higher than at SP 2, the statistical analysis did not show a different distribution of values for that indicator.

The deterioration in water quality down the river is evidence of an increased number of pollution sources in a highly urbanised part of the city. Some authors demonstrated a relationship between the quality of surface run-off and the use of the catchment basin (Goonetilleke et al. 2005, Peng et al. 2016). Field observations and analysis of maps available at https://www.geoportal.gov.pl and https://geoportal.lublin.eu, confirmed that many very unkempt and contaminated areas existed in the region of the analysed section of the river. This refers, among other things, to old buildings, a road network or some unused grounds. In addition, illegal waste dump sites were discovered. Discharging untreated rainwater directly into the Czerniejówka River is a big problem. The rainwater is discharged by surface run-offs and through open flumes and underground channels (Fig. 2).

Table 2. Characteristic values of basic quality indicators of river water at SPs 1 and 2 in 2009-2016 ("+" statistically significant differences at the level of $\alpha = 0.05$, "-"no statistically significant differences at the level of $\alpha = 0.05$)

Variables	Point	Minimum	Maxmum	Average	Standard deviation	Variation coefficient	Significant difference
Temperature (°C)	1	2.0	20.0	10.5	5.8	55.3	-
	2	2.5	20.0	10.5	5.6	53.5	
Conductivity ($\mu S \cdot cm^{-1}$)	1	491	787	567	67.0	11.8	+
	2	421	2460	645	336.4	52.1	
pH	1	7.0	8.2	7.7	0.3	3.8	-
	2	7.0	7.9	7.6	0.2	3.2	
Suspension ($mg \cdot dm^{-3}$)	1	2	85	19	17.6	92.1	-
	2	2	97	19	18.6	96.1	
O_2 ($mg \cdot dm^{-3}$)	1	5.3	12.4	9.9	1.7	17.4	+
	2	5.3	12.8	9.3	1.8	18.8	
BOD_5 ($mg \cdot dm^{-3}$)	1	0.2	7.0	2.6	1.5	55.3	-
	2	0.4	11.4	2.9	2.2	75.3	
COD_{Cr} ($mg \cdot dm^{-3}$)	1	2	29	12	6.0	51.6	-
	2	3	37	13	8.3	64.9	
NH_4^+ ($mg \cdot dm^{-3}$)	1	0.05	0.47	0.17	0.1	59.5	+
	2	0.06	6.30	0.38	1.1	282.1	
NO_3^- ($mg \cdot dm^{-3}$)	1	0.52	19.30	8.27	5.7	69.0	+
	2	0.79	31.00	10.98	8.1	73.8	
NO_2^- ($mg \cdot dm^{-3}$)	1	0.03	0.33	0.12	0.06	52.0	-
	2	0.04	0.31	0.13	0.07	56.6	
PO_4^- ($mg \cdot dm^{-3}$)	1	0.13	1.90	0.56	0.4	77.2	-
	2	0.01	1.30	0.48	0.3	58.1	
SO_4^- ($mg \cdot dm^{-3}$)	1	32	126	66	22.2	33.9	+
	2	37	144	88	24.1	27.5	
Fe^+ ($mg \cdot dm^{-3}$)	1	0.12	0.84	0.34	0.1	41.9	+
	2	0.14	0.79	0.37	0.1	40.7	
K^+ ($mg \cdot dm^{-3}$)	1	1.9	26.0	8.0	5.3	66.8	-
	2	2.1	28.0	7.9	4.9	62.9	
Cl^- ($mg \cdot dm^{-3}$)	1	10.1	43.4	17.1	6.8	39.7	+
	2	11.3	78.3	22.7	12.5	55.0	

Fig. 2. Discharges of polluted rainwater into the Czerniejówka River: a) street gutter and open flume near SP 1, b) outlet of an underground channel near SP 2

Pollutants in rainwater can be very hazardous to natural receiving bodies. Their volume and quality depends on many different factors, e.g. land development method, type of tight surfaces, traffic intensity, degree of air pollution and weather conditions (Petrucci et al. 2014, Zubala 2018). During surface water supply the levels of many pollution indicators in the Czerniejówka River increased. This refers, among other indicators, to conductivity, suspended solids, COD and certain nutrients. During the study period the mean conductivity (mineralisation ratio) at SPs 1 and 2 amounted to 567 and 645 $\mu S \cdot cm^{-1}$, respectively (Table 2). Only at one measurement date was the level of 800 $\mu S \cdot cm^{-1}$ exceeded (2460 $\mu S \cdot cm^{-1}$ in March 2013). Gajkowska-Stefańska et al. (2007) describe that conductivity of natural water ranges from 50 to 1000 $\mu S \cdot cm^{-1}$, and that of wastewater can considerably exceed 1000 $\mu S \cdot cm^{-1}$. The content of suspended solids in the analysed water was not high; on average, it amounted to 19 $mg \cdot dm^{-3}$. Similar to conductivity, the maximum concentrations were recorded in March 2013 (85 and 97 $mg \cdot dm^{-3}$). At that time, turbid melt-waters were discharged (Fig. 2b). It must be emphasized that water was sampled at stabilised flow with a reduced amount of eroded material in agricultural areas. In years characterised by high annual precipitation totals (e.g. 2014) the average level of suspended solids was lower than 10 $mg \cdot dm^{-3}$ (as a result of catchment flushing). The saturation of river water with oxygen was high (on average 9.3-9.9 $mg \cdot dm^{-3}$). This phenomenon is very positive in the context of self-purification processes (mineralisation of organic pollutants) (Juang et al. 2008). Despite good aerobic conditions, BOD_5 and COD at some dates reached hazardous values. This particularly refers to SP 2 where the maximum levels were recorded: 11.4 (BOD_5) and 37.0 $mg \cdot dm^{-3}$ (COD) (Table 2). Among biogenic pollutants the most hazardous for the Czerniejówka River were NO_2^- and PO_4^-. Considering the mean concentrations of pollutants at SP 2 (0.13 and 0.48 mg·dm^{-3}) and average flow intensity at the mouth of the river (0.34 m^3·s^{-1}), the annual discharge of NO_2^- and PO_4^- from the catchment basin could reach 1.39 and 5.15 Mg respectively. In 2013-2016 the extreme flow rates in the measurement section were 0.17 and 0.95 m^3·s^{-1}, whereas water levels ranged from 0.12 to 0.35 m (on average 0.20 m). The group of pollutants with relatively high concentrations also includes Fe^+. The maximum values approximated 0.80 mg·dm^{-3}. The release of this component is fostered by strong humidity at the bottom of certain sections of the valley (Michalczyk et al. 2011). In waterlogging conditions, it is likely that Fe^+ is activated as a result of reduction (gleying processes) (Kabata-Pendias & Pendias 1993).

The study also took into account the characteristics of river water quality in the cold half-year (autumn-winter) and in the warm half-year (spring-summer). Each season was characterised by different weather conditions (Table 1) that could have an influence on the differentiation in the quality of waters in the Czerniejówka River. In the cold season (half-year) 60% of the analysed indicators were more varied than in the warm season (half-year). In particular, this referred to temperature, conductivity, NH_4^+ and Cl^-. In the warm season the coefficient of variation was considerably higher for K^+ only. At the level of confidence of 0.95 ($\alpha = 0.05$), the Wilcoxon test showed statistically significant differences in temperatures, conductivity, O_2, PO_4^- and Cl^- between half-year periods. In addition, a different distribution of NO_3^- concentrations was found in the statistical test for $\alpha = 0.10$ (Table 3).

The difference between mean temperatures of water in both half-year periods amounted to as much as 190%. The value of that parameter depended primarily on changes in atmospheric air temperatures. Temperature is an important physical indicator. As it grows, the solubility of solids increases while that of gases, e.g. O_2, decreases (Chełmicki 2002). The average content of oxygen in water in the cold season was about 1 mg·dm^{-3} higher than in the warm season. In the cold season of the year, higher electrolytic conductivity was also observed. Its average value was 658 μS·cm^{-1} (maximum 2460 μS·cm^{-1}). This phenomenon is linked, among other things, to melt-water run-offs carrying high loads of pollutants. Maintained snow cover fosters gradual accumulation of subsequent quantities of pollutants, including anti-slip chemicals (Ociepa et al. 2015). This can be confirmed by increased content of Cl^- in water samples in winter. The mean concentration of Cl^- in the cold season was 22.6% higher than in the warm season. Levels of Cl^- grew down the river, which is most likely due to an increasing share of roads in the river basin area and uncontrolled run-offs from road surface. Discharge of precipitation waters containing high levels of chlorides can disturb the functioning of freshwater ecosystems (Rivett et al. 2016).

Table 3. Characteristic values of basic quality indicators of river water in the cold (1) and warm half-year (2) ("+" statistically significant differences at the level of α = 0.05, "-"no statistically significant differences at the level of α = 0.05)

Variables	Half-year	Minimum	Maxmum	Average	Standard deviation	Variation coefficient	Significant difference
Temperature (°C)	1 2	2.0 12.0	10.0 20.0	5.4 15.6	2.4 2.3	44.6 14.7	+
Conductivity ($\mu S \cdot cm^{-1}$)	1 2	491 421	2460 644	658 554	336.6 42.7	51.1 7.7	+
pH	1 2	7.0 7.1	8.2 8.0	7.6 7.7	0.3 0.2	4.0 3.0	-
Suspension ($mg \cdot dm^{-3}$)	1 2	2 2	97 65	20 18	21.2 14.4	105.1 78.3	-
O_2 ($mg \cdot dm^{-3}$)	1 2	5.3 5.7	12.8 10.8	10.1 9.2	2.1 1.3	20.3 13.7	+
BOD_5 ($mg \cdot dm^{-3}$)	1 2	0.4 0.2	11.4 8.1	3.0 2.5	1.9 1.7	64.7 69.0	-
COD_{Cr} ($mg \cdot dm^{-3}$)	1 2	2 3	37 36	11 13	6.7 7.8	58.7 59.0	-
NH_4^+ ($mg \cdot dm^{-3}$)	1 2	0.07 0.05	6.30 0.41	0.38 0.18	1.1 0.1	286.0 58.7	-
NO_3^- ($mg \cdot dm^{-3}$)	1 2	0.52 1.00	31.00 26.81	8.63 10.62	7.0 7.1	81.4 67.0	- (+ α=0.10)
NO_2^- ($mg \cdot dm^{-3}$)	1 2	0.03 0.05	0.29 0.33	0.12 0.13	0.07 0.07	56.4 53.3	-
PO_4^- ($mg \cdot dm^{-3}$)	1 2	0.01 0.18	1.50 1.90	0.43 0.60	0.3 0.4	65.1 68.3	+
SO_4^- ($mg \cdot dm^{-3}$)	1 2	33 32	125 144	77 77	24.9 26.6	32.5 34.7	-
Fe^+ ($mg \cdot dm^{-3}$)	1 2	0.14 0.12	0.79 0.84	0.36 0.35	0.1 0.2	36.8 45.9	-
K^+ ($mg \cdot dm^{-3}$)	1 2	2.9 1.9	14.2 28.0	7.2 8.6	2.7 6.7	37.4 77.7	-
Cl^- ($mg \cdot dm^{-3}$)	1 2	10.1 10.1	78.3 33.9	22.4 17.3	13.2 5.4	59.0 31.2	+

Despite variations in mean concentrations of nutrients (e.g. NH_4^+ – 52.7%), the statistical test revealed a different distribution of values for PO_4^- and NO_3^- only. The concentrations of both components were higher in the warm season, which contrasts to data presented by some authors. They demonstrated that the content of nutrients in the water environment decreases during vegetation, which is linked to the intense intake of the components by growing plants (Birgand et al. 2007, Jarvie et al. 1998). Increased levels of phosphorus and nitrogen in the waters of the Czerniejówka can be a result of increased supply of these elements in spring and summer; it is considerably higher than the autotrophs require.

Out of 31 systems of rainwater networks connected to the catchment basin of the Czerniejówka River, only 10 have separators installed (ADAPTCITY 2019). In other cases, rainwater is discharged into the river with no treatment at all. Unfortunately, it may be suspected that this is sometimes the case with other wastewater as well (illegal discharge into street inlets). These problems should be solved by providing all rainwater sewerage networks with settling tanks and separators and designing and implementing an efficient inspection and monitoring system. Another good solution is also increasing the retention of rainwater within the catchment, e.g. by creating special reservoirs and permeable surfaces (Zubala & Patro 2015). Illegal waste dump sites must be eliminated and adequate cleanness of the drained areas, including roads, car parks and premises, must be ensured. In addition, it is necessary to run information campaigns encouraging users of arable land in the valley of the river to use good agricultural practice and reduce uncontrolled outflow of fertilizers and other pollutants (DEFRA 2009). The quality of river water can also be protected by supporting self-purification processes. On sections with a deep-cut river bed, weirs providing artificial aeration of water and retaining suspended solids can be built (Imhoff & Imhoff 1996).

4. Summary

The studies showed that the quality of water in the inner city Czerniejówka River was moderately variable. Values of the analysed indicators were relatively highly differentiated for NH_4^+, suspended solids, PO_4^-, BOD_5 and NO_3^-. In turn, low variability was recorded for pH, O_2, SO_4^- and Fe^+. The indicators that considerably deteriorated the quality of water in the river were NO_2^-, PO_4^- and Fe^+ (risk of eutrophication). The annual loads of NO_2^- and PO_4^- discharged from the catchment basin were 1.39 and 5.15 Mg, respectively. Lower quality of water was observed at the strongly urbanised mouth of the river, which may testify to a growing number of pollution sources down the river. The presence of considerably neglected and polluted areas existing within the study area (old buildings, road network, and wasteland) poses a big problem. Illegal waste dump sites were even found there. Discharging untreated rainwater directly into the

river bed is a significant risk (increased values for conductivity, suspended solids, COD and some nutrients). In the study period the examined parameters were also observed to vary during a season. In the cold season 60% of the indicators (mainly temperature, conductivity, NH_4^+ and Cl^-) were characterised by higher differentiation in values than in the warm season. Statistically significant differences were found for temperature, conductivity, O_2, PO_4^-, NO_3^- and Cl^-. In the winter months the values of conductivity and Cl^- levels increased, which is connected with an influx of snowmelt into the river. The concentrations of PO_4^- and NO_3^- were higher in the warm season. This phenomenon is due to the supply of nutrients considerably exceeding the requirement of autotrophs. Due to the variation of seasonal factors, they must be taken into account in developing the water resources management strategy for a catchment. The risk for river water quality must be reduced by undertaking comprehensive measures. These include detection and elimination of all pollution sources within the catchment basin (e.g. pretreatment of rainwater, elimination of illegal waste dump sites and good agricultural practice) and reducing the migration of existing pollutants (e.g. creating precipitation water retention and infiltration sites, forming plant buffer zones in the valley and building weirs in the river).

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Abstract

The paper evaluates the variability of water quality in Lublin's inner-city river taking into account natural and anthropogenic factors that are likely to determine its pollution level. The study period was 2009-2016. The sampling points (SP) were situated in places with different degrees of investment in and use of adjacent grounds. The physical and chemical properties of waters were analysed on a seasonal basis. The values determined for the samples included temperature, conductivity, pH, suspended solids, O_2, BOD_5, COD, NH_4^+, NO_3^-, NO_2^-, PO_4^-, SO_4^-, Fe^+, K^+ and Cl^-. Chemical composition was determined by means of a photometric method. The statistical Wilcoxon test was used for comparing water quality indicators for both SP s and in the cold and warm season. In 2013-2016 water levels and flow intensity (indirect, sectional method) were also measured at the mouth of the river. Most of the analysed indicators were characterised by the coefficient of variation exceeding 50%. The values were relatively highly differentiated for NH_4^+, suspended solids, PO_4^-, BOD_5 and NO_3^- (73.8-282.1%). On the other hand, low variability was observed for pH, O_2, SO_4^- and Fe^+ (3.2-41.9%). The indicators that considerably deteriorated the quality of water in the river were NO_2^-, PO_4^- and Fe^+ (risk of eutrophication). Considering the mean concentrations of pollutants and flow intensity (0.34 $m^3 \cdot s^{-1}$), the annual discharge of NO_2^- and PO_4^- from the catchment could reach 1.39 and 5.15 Mg respectively. Worse water quality was recorded at the mouth of the river where the adjacent grounds were highly urbanised. This phenomenon can testify to a growing number of pollution sources down the river. Detailed observations confirmed that many considerably neglected and polluted areas existed within the examined section of the river valley (old buildings, road network, wasteland, illegal dump sites). Discharging untreated rainwater directly into the river bed is a huge problem (increased values for conductivity, suspended solids, COD and some nutrients). In the cold season 60% of the analysed indicators (mainly temperature, conductivity, NH_4^+ and Cl^-) were more varied than in the warm season. Statistically significant differences were found for temperature, conductivity, O_2, PO_4^-, NO_3^- and Cl^-. In the winter months the values of conductivity and Cl^- levels increased, which is connected with an influx of strongly polluted snowmelt into the river. The concentrations of PO_4^- and NO_3^- were higher in the warm season. It is likely that the supply of nutrients at that time was higher than required by the autotrophs. Due to a considerable variation of seasonal factors, they must be taken into account in developing the water resources management strategy for a catchment basin. Only a comprehensive approach to the problem of river water quality protection can generate positive effects. The necessary measures include detecting and eliminating all sources of pollution and reducing migration of the existing pollutants.

Keywords:
river water, pollutants, urbanised area, environmental protection

Czasowa i przestrzenna zmienność jakości wody w rzece śródmiejskiej Lublina w aspekcie istniejących warunków naturalnych i użytkowania terenu

Streszczenie

W pracy dokonano oceny zmienności jakości wód śródmiejskiej rzeki Lublina z uwzględnieniem czynników naturalnych i antropogenicznych, mogących decydować o jej zanieczyszczeniu. Badania prowadzono w latach 2009-2016. Punkty kontrolno-pomiarowe usytuowano w miejscach o odmiennym stopniu zainwestowania i użytkowania terenu przyległego. Analizy właściwości fizyczno-chemicznych wód prowadzono sezonowo. W próbkach oznaczano temperaturę, przewodność, pH, zawiesinę, O_2, BZT_5, ChZT, NH_4^+, NO_3^-, NO_2^-, PO_4^-, SO_4^-, Fe^+, K^+ i Cl^-. Składniki chemiczne były określane metodą fotometryczną. Test statystyczny Wilcoxon wykorzystano do porównania wskaźników jakości wody w obydwu punktach pomiarowych oraz w półroczu chłodnym i ciepłym. W latach 2013-2016 w odcinku ujściowym rzeki wykonywano również pomiary stanów wody i natężenia przepływu (metoda pośrednia odcinkowa). Większość analizowanych wskaźników cechował współczynnik zmienności przekraczający 50%. Stosunkowo duże zróżnicowanie wartości dotyczyło NH_4^+, zawiesiny, PO_4^-, BZT_5 i NO_3^- (73,8-282,1%). Natomiast niską zmienność obserwowano w przypadku pH, O_2, SO_4^- i Fe^+ (3,2-41,9%). Wskaźnikami, które w znacznym stopniu obniżały jakość wody rzecznej były NO_2^-, PO_4^- i Fe^+ (zagrożenie eutrofizacją). Uwzględniając średnie stężenia zanieczyszczeń oraz natężenie przepływu (0,34 $m^3 \cdot s^{-1}$), roczne ładunki NO_2^- i PO_4^- odprowadzane ze zlewni mogły osiągnąć kolejno 1,39 oraz 5,15 Mg. Gorszą jakość wody odnotowano w ujściowym odcinku rzeki, z silnie zurbanizowanym terenem przyległym. Zjawisko to może świadczyć o rosnącej ilości źródeł zanieczyszczeń wraz z jej biegiem. Szczegółowe obserwacje potwierdziły istnienie wielu obszarów mocno zaniedbanych i zanieczyszczonych w rejonie badanego fragmentu doliny (stara zabudowa, sieć drogowa, nieużytki, nielegalne składowiska odpadów). Duży problem stanowi odprowadzanie nieoczyszczonych wód deszczowych bezpośrednio do koryta rzeki

(wzrost wartości przewodności, zawiesiny, ChZT i niektórych biogenów). W półroczu chłodnym 60% analizowanych wskaźników cechowała większa zmienność niż w półroczu ciepłym (głównie temperatura, przewodność, NH_4^+ i Cl^-). Ważne statystycznie różnice stwierdzono w przypadku temperatur, przewodności, O_2, PO_4^-, NO_3^- i Cl^-. W miesiącach zimowych rosła wartość przewodności i Cl^-, co wiąże się z dopływem silnie zanieczyszczonych wód roztopowych do rzeki. PO_4^- i NO_3^- miały wyższe stężenia w półroczu ciepłym. Dostawa składników odżywczych w tym okresie prawdopodobnie przewyższała zapotrzebowanie autotrofów. Znaczna zmienność czynników sezonowych wskazuje na konieczność ich uwzględniania w opracowywaniu strategii zarządzania zasobami wodnymi zlewni. Jedynie kompleksowe podejście do problemu ochrony jakości wód rzecznych może przynieść pozytywne efekty. Wśród niezbędnych działań należy wymienić wykrycie i eliminację wszystkich źródeł zanieczyszczeń oraz ograniczanie migracji zanieczyszczeń już powstałych.

Słowa kluczowe:
woda rzeczna, zanieczyszczenia, teren zurbanizowany, ochrona środowiska