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RIVER WATER POLLUTION IN AREAS IN SOUTHERN POLAND WITH VARIOUS TYPES OF ANTHROPOPRESSURE

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Summary. The paper presents the results of a study investigating the impacts of various kinds of human activity on the quality of river water in southern Poland. The study concluded that unpolluted river waters were only found in semi-natural mountainous areas. In the mountain foreland the quality of water was compromised by anthropogenic influences, including agriculture, urbanisation and industry. The waters were polluted with organic substances and nutrients, some of the waters with salt and often with trace elements, including heavy metals. As a result the aquatic environment over a large proportion of the study area was characterised by eutrophic conditions and toxicological hazard. Indeed, anthropopressure was found to have a significant degrading effect on the modest Polish water resources.

Key words: water resources, water quality, anthropopressure, river pollution, Poland

INTRODUCTION

Poland has very modest water resources in comparison with other European countries. This assessment is best reflected by the volume of water available to individuals and the economy, a measure determined by dividing the average annual discharge from a country's territory by its population. For Poland the figure stands at approximately 1600 m^3 per person in a very unfavourable comparison to 4500 m^3 for Europe as a whole and 4000 m^3 for the European Union [Hotlos 2008]. The Polish statistic is a result of the country's low average annual precipitation of just 640 mm [Jankowski and Rzętała 2009]. However, precipitation is highly concentrated in the mountains (800–2000 mm) along the country's southern and south-western border that represent just 9% of the country's territory,

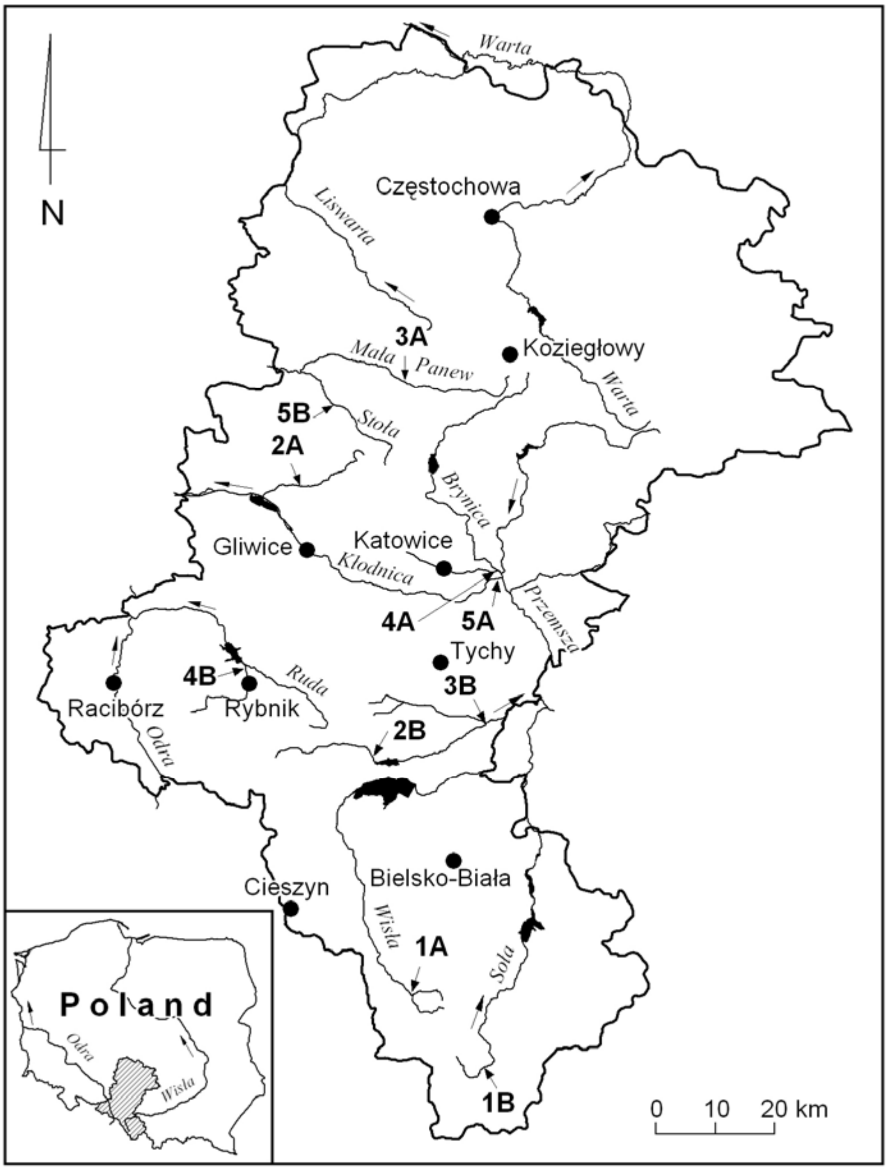

Fig. 1. Study area (Silesian Voivodship, southern Poland) with the data source cross-sections: 1A – River Vistula headwaters, 1B – River Soła headwaters, 2A – River Drama, 2B – River Pszczynka, 3A – River Mała Panew, 3B – River Korzenica, 4A – River Rawa, 4B – River Nacyna, 5A – River Bolina, 5B – River Stoła

but account for approximately 30% of the total water resources [Kostuch 1976]. For this reason it is particularly important to monitor and protect water quality in this part of Poland to ensure that water resources are available in the lowlands without costly treatment.

The paper presents the results of river waters quality in southern Poland. The research objective was to assess the influence of residential and economic activities on the quality of water in an area that has strategic importance for Polish water management. The Silesian Voivodship (region) was selected (Fig. 1) for its large variety of anthropopressure types. The region, with an area of 12.3 thousand square kilometres, includes mountains of semi-natural character in the south, agricultural areas and some of the most industrialised and urbanised areas in Poland. In particular the study focused on investigating water pollution in relation to particular types of anthropopressure.

Reports from various parts of the world demonstrate that anthropopressure is the main contemporary driver of the physico-chemical properties of surface waters [Bukit 1995, Kambole 2003] while the significance of the geochemical background is confined virtually to the headwaters and unpopulated areas alone. At the same time water pollution has been reaching levels that threaten ecosystems and human health [Soldan 2003, Bhavana *et al.* 2009]. Studies on the quality of surface waters typically analyse the occurrence of certain chemicals and regard all forms of anthropopressure as a collective source of pollution [Dassenakis *et al.* 1998, Cheung *et al.* 2003, Huang *et al.* 2010]. There is less research published on the environmental impact of specific types of anthropopressure [Dimitrova *et al.* 1998, Milovanovic 2007, Strauch *et al.* 2009].

MATERIALS

The research was carried out in 2009. At the beginning, the usage of few dozen basins, located in Silesian Voivodship were analysed. Topographic maps (1:10000), aerial photographs as well as satellite images were used for the identification of basins area. Field mapping determining current type of land usage was conducted for the results obtained verification. Cartographic data was subjected to digitalization, including updating contents. Based on the results obtained, generalized basins maps depicting its terrain usage were developed. Four types of surface forming terrain were educed: 1) surface waters, 2) urban and industrial land, 3) forest land, 4) agricultural land and unused green land. Cartographic works and terrain analyses allowed to specify the type of anthropopressure (e.g. agricultural, municipal, industrial) influencing the river waters quality. Ten basins were selected for further investigation – 1A, 1B, 2A, 2B, 3A, 3B, 4A, 4B, 5A, 5B (Fig. 1).

Data on water quality was sourced from the national water monitoring system and specifically from stations located at the confluence of these basins. Physico-chemical properties were analysed on a monthly basis which produced 12 measurement records in 2009. The analysis involved 23 parameters: pH, SEC, hardness, suspended matter, dissolved oxygen, BOD_5, COD_{Mn}, $N\text{-}NH_4$, $N\text{-}NO_3$, N_{tot}, P_{tot}, Ca, Mg, chlorides, sulphates, As, Ba, B, Cr_{tot}, Zn, Al, Cu, volatiles phenols. The laboratory analysis methodology was compatible with Polish and ISO standards.

RESULTS AND DISCUSSION

Basins selected for study were grouped by the prevailing type of anthropopressure influence (Fig. 2):

– 1A, 1B – semi-natural mountain conditions (forests, unmanaged green land, little human activity);

– 2A, 2B – agricultural anthropopressure (agricultural land, small proportion of rural development);

– 3A, 3B – rural municipal anthropopressure (forest and grassland with a rural development);

– 4A, 4B – urban municipal anthropopressure (urban land);

– 5A, 5B – municipal and industrial anthropopressure (urban and industrial land).

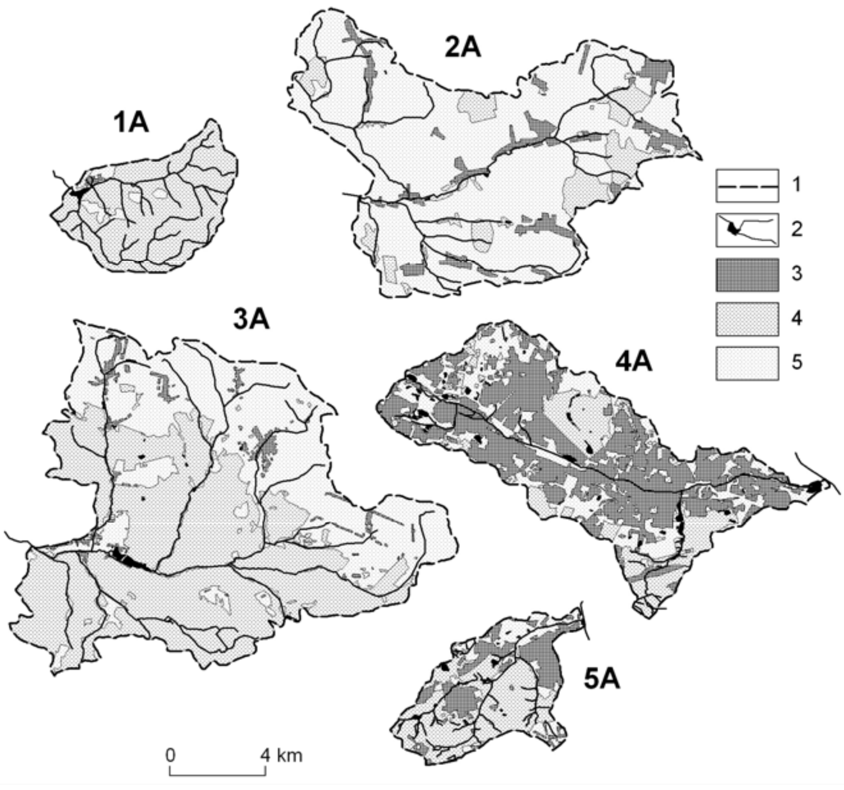

Fig. 2. River basin types broken down by types of anthropopressure: 1A – semi-natural mountain conditions (River Vistula headwaters), 2A – agricultural anthropopressure (River Drama), 3A – rural municipal anthropopressure (River Mała Panew), 4A – urban municipal anthropopressure (River Rawa), 5A – municipal-industrial anthropopressure (River Bolina)

Legend: 1 – basin boundaries, 2 – surface waters, 3 – urban and industrial land, 4 – forest land, 5 – agricultural land and unused green land

It was found that the type of residential and economic activity within the river basin was a clear differentiator of the physico-chemical parameters of the river waters (Tab. 1, Fig. 3).

Waters draining wooded mountainous headwater areas (basins 1A and 1B) were not subject to major anthropogenic influences, as the area was mostly unpopulated and only forest management was involved. These waters were found to be unpolluted with small quantities of organic matter (BOD_5 peaked at 5.4 mg $O_2 \cdot dm^{-3}$) and nutrients (N_{tot} at ca. 1 mg$\cdot$dm^{-3}; P_{tot} at single hundredths of a mg$\cdot$dm^{-3}) while enjoying good oxygen saturation levels (normally above 10 mg $O_2 \cdot dm^{-3}$). Trace elements were mostly at levels typical for natural waters without toxicological hazard [Wilson 1976, Moore and Ramamoorthy 1984, Dojlido 1995]. Only boron concentration (ca. 40 μg$\cdot$dm^{-3}) was higher than the optimum for fish.

In agricultural areas (basins 2A and 2B) running waters contained large quantities of minerals, which was reflected in their conductivity that ranged from 492 to 1779 μS$\cdot$cm^{-1}. Water chemistry stood out with high concentrations of nitrogen compounds (from single milligrams to dozens of milligrams of $N_{tot} \cdot dm^{-3}$). Average annual total nitrogen and nitrates(V) concentrations exceeded Polish thresholds for eutrophic running waters [Ordinance... 2002], i.e. 5.0 mg $N_{tot} \cdot dm^{-3}$ and 2.2 mg N-$NO_3 \cdot dm^{-3}$. In the light of published research, the pollution of water with nutrients and the presence of eutrophic waters must be regarded as virtually inherent in agriculturally managed basins [Sapek 1998]. In the basins studied agricultural activity was the cause of large concentrations of chlorides (36–314 mg$\cdot$dm^{-3}) and the presence of sulphates (69–216 mg$\cdot$dm^{-3}) above the geochemical background levels. Excessive levels of boron and zinc were also detected.

River waters in basins with forest and grassland and rural development (basins 3A and 3B) were characterised by relatively favourable macro-ion composition, but there was evidence of pollution linked with untreated waste discharge (only 28% of the rural population in the Silesian Voivodship were connected to wastewater treatment systems). Considerable quantities of nitrogen and phosphorus compounds were observed in the waters (up to 5.07 mg $N_{tot} \cdot dm^{-3}$ and 0.43 mg $P_{tot} \cdot dm^{-3}$). Among the trace substances analysed there were considerable quantities of barium (up to 130 μg$\cdot$dm^{-3}), boron (up to 110 μg$\cdot$dm^{-3}), zinc (up to 104 μg$\cdot$dm^{-3}) and aluminium (up to 520 μg$\cdot$dm^{-3}). These maximum concentrations may be regarded as threatening to aquatic life and human health.

The impact of dense urban development and economic activity (basins 4A and 4B) on the quality of river water was expressed in both a high concentration of suspended matter (in the order of dozens mg$\cdot$dm^{-3} on average) and dissolved substances (conductivity of thousands μS$\cdot$cm^{-1}). These waters were also often found to be alkaline and because of high concentrations of divalent cations were typically either hard or very hard (at hundreds mg $CaCO_3 \cdot dm^{-3}$). High concentrations of chlorides (176–3540 mg$\cdot$dm^{-3}) and sulphates (137–571 mg$\cdot$dm^{-3}) were also found, as were nutrient concentrations (3.50–22.3 mg $N_{tot} \cdot dm^{-3}$; 0.23–2.15 mg $P_{tot} \cdot dm^{-3}$) and boron, the levels of which (342–819 μg$\cdot$dm^{-3}) posed a threat to aquatic organisms [Dojlido 1995].

Table 1. Average annual values of physico-chemical parameters at selected basin cross-sections (based on data from WIOŚ in Katowice)

Parameter	Unit	Basin cross-sections									
		1A	1B	2A	2B	3A	3B	4A	4B	5A	5B
pH	–	7.27	8.24	7.48	7.28	7.30	6.96	7.52	7.90	7.58	7.06
SEC	$\mu S \cdot cm^{-1}$	76	242	688	1047	376	272	4692	3456	15500	849
Hardness	$mgCaCO_3 \cdot dm^{-3}$	29	96	342	200	176	93	745	410	1672	267
Suspended matter	$mg \cdot dm^{-3}$	5.7	6.4	13.9	12.5	4.1	8.1	47.5	38.4	80.7	37.0
Dissolved oxygen	$mgO_2 \cdot dm^{-3}$	10.9	11.2	9.7	5.7	9.5	7.9	3.9	10.4	1.3	4.0
BOD_5	$mgO_2 \cdot dm^{-3}$	2.4	1.8	2.0	3.9	1.6	3.9	13.7	6.0	50.5	16.9
COD_{Mn}	$mgO_2 \cdot dm^{-3}$	–	–	5.0	7.7	7.6	8.5	19.2	14.3	45.9	25.6
$N\text{-}NH_4$	$mg \cdot dm^{-3}$	0.13	0.09	0.73	2.27	0.29	0.68	11.80	1.89	13.34	11.58
$N\text{-}NO_3$	$mg \cdot dm^{-3}$	0.77	0.68	7.99	3.87	2.36	1.59	1.38	3.26	0.47	1.01
N_{tot}	$mg \cdot dm^{-3}$	1.04	0.98	9.14	7.30	3.07	2.78	15.85	6.85	18.48	18.09
P_{tot}	$mg \cdot dm^{-3}$	0.03	0.04	0.21	0.19	0.05	0.12	1.01	0.65	2.05	1.78
Ca	$mg \cdot dm^{-3}$	–	–	102	55	53	30	163	89	338	89
Mg	$mg \cdot dm^{-3}$	–	–	22	14	11	5	82	46	201	14
Chlorides	$mg \cdot dm^{-3}$	4	12	43	169	18	18	1284	851	5504	99
Sulphates	$mg \cdot dm^{-3}$	13	16	92	126	51	43	440	382	508	114
As	$\mu g \cdot dm^{-3}$	5	5	5	5	5	5	1	1	1	6
Ba	$\mu g \cdot dm^{-3}$	32	59	55	51	108	55	67	48	373	173
B	$\mu g \cdot dm^{-3}$	40	40	63	40	73	40	648	553	1104	1270
Cr_{tot}	$\mu g \cdot dm^{-3}$	2	2	5	2	5	2	2	3	2	5
Zn	$\mu g \cdot dm^{-3}$	11	5	54	20	65	75	38	26	19	217
Al	$\mu g \cdot dm^{-3}$	–	–	128	33	268	151	35	21	67	188
Cu	$\mu g \cdot dm^{-3}$	3	3	3	3	3	6	2	4	2	11
Volatile phenols	$\mu g \cdot dm^{-3}$	0.6	1.0	0.5	0.6	0.5	0.5	3.8	3.4	45.3	0.5

1A – River Vistula headwaters, 1B – River Soła headwaters, 2A – River Drama, 2B – River Pszczynka, 3A – River Mała Panew, 3B – River Korzenica, 4A – River Rawa, 4B – River Nacyna, 5A – River Bolina, 5B – River Stoła

Municipal and industrial anthropopressure (basins 5A and 5B), involving various wastewater streams discharged into rivers and surface runoff from polluted surfaces, resulted in serious levels of water pollution (the maximum conductivity was 26300 $\mu S \cdot cm^{-1}$). Nearly all parameters tested reached values corresponding to deteriorated water quality. High nutrient contents and pollution by toxic substances were accompanied by low oxygen concentrations (periodically as little as tenths mg $O_2 \cdot dm^{-3}$). Very high concentrations of substances involved in the manufacturing and processing activities carried out within the basins were also characteristic of this aquatic environment exposed to municipal and industrial anthropopressure. This was the case for example with zinc (maximum concentration of 350 $\mu g \cdot dm^{-3}$), volatile phenols (maximum concentration of 358 $\mu g \cdot dm^{-3}$) and boron (maximum concentration of 2000 $\mu g \cdot dm^{-3}$). Very high concentrations of chlorides (thousands of $mg \cdot dm^{-3}$) found in the waters were the result of the discharging of water from the drainage of colliery seams into surface waters. Coal mining, an iconic industry in central parts of the Silesian Voivodship, was responsible for introducing 118.5 million m^3 of saline waters with more than 1800 $mg \cdot dm^{-3}$ of chlorides and sulphates combined in 2009. Also the large concentrations of zinc were the result of coal mining and zinc ore processing.

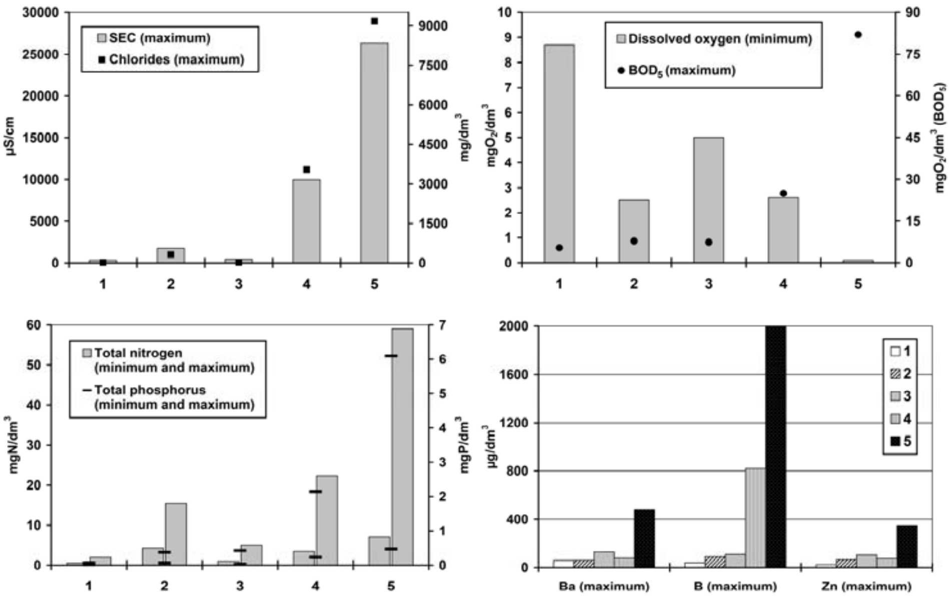

Fig. 3. Extreme values of selected physico-chemical parameters of water under various types of anthropopressure (based on data from WIOŚ in Katowice): 1 – semi-natural mountain conditions, 2 – agricultural anthropopressure, 3 – rural municipal anthropopressure, 4 – urban municipal anthropopressure, 5 – municipal-industrial anthropopressure

It appears from the data that every type of human activity constitutes a threat to the quality of water resources. This is shown in comparisons of the water quality parameters registered in semi-natural mountainous areas with the parameters characteristic of developed foreland areas (Tab. 1, Fig. 3). Discharge of sewage was found to be the most significant factor threatening the quality of the water resources (In 2009, in the Silesian Voivodship discharged 370 million m^3 of sewage, of which 76% was treated but 24% was untreated). The adverse impact of dispersed rural development on water quality was the smallest seen and with good sewage treatment this impact could be virtually eliminated. Agricultural activity, extensive urbanisation and industrialisation caused high water pollution. However, while agriculture was mostly responsible for eutrophication of water [Jaguś and Rzętała 2011], municipal and industrial activity produced a comprehensive degradation of water quality, including trace element pollution, as well as eutrophication [Dimitrova *et al.* 1998, Cheung *et al.* 2003]. Most of the waters studied were characterised by poor quality. In 2009, the National Inspectorate for Environmental Protection found that out of 146 surface water bodies in the voivodship, 116 (78%) suffered from eutrophication and many also suffered from pollution by toxic industrial waste. In that year, the voivodship discharged 219.8 million m^3 of industrial waste into the environment, 20% of which were untreated waste and 54% of which were saline colliery waters mechanically treated to remove suspended coal.

These results and discussion reveal the bad quality of the majority of river waters in the study area, which causes concern in the context of the water resource deficit. This deficit has prompted the erection of numerous retention dams and their reservoirs. Freshwater lake environments often have purification effects on the incoming river waters, but the quality of water in many of the artificial lakes remains equally as bad [Rzętała 2008]. All of this leads to a conclusion that there is an urgent need to protect water resources in southern Poland.

CONCLUSION

The quality of river water was extremely varied within the area of just 12.3 thousand km^2 of the Silesian Voivodship. Unpolluted waters were found in the mountainous southern part of the area. In the remaining part of the region the pollution and its influence on the functioning of ecosystems depended on the specific types of human impact involved. The impacts identified as the most adverse for the quality of water included extensive urbanisation and municipal and industrial development. The key to improving water quality in these circumstances would be to provide adequate wastewater treatment and treatment of stormwater drainage discharge. Agricultural activity would require the application of good farming practices, including respecting the provisions of the European Nitrates Directive (Council Directive 91/676/EEC of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources). The quality of waters of the Silesian Voivodship identified in this study must be seen as an evidence of a failure to effectively protect the region's water resources.

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ZANIECZYSZCZENIE WÓD RZECZNYCH W POŁUDNIOWEJ POLSCE
W WARUNKACH ZRÓŻNICOWANEJ ANTROPOPRESJI

Streszczenie. Badania prowadzono w południowej Polsce, w obrębie województwa śląskiego. Rozpoznano wpływ różnorodnej działalności człowieka na stan jakościowy wód rzecznych. Stwierdzono, że jedynie w obszarach górskich o charakterze półnaturalnym wody nie wykazywały zanieczyszczenia. Na terenach podgórskich ich jakość była pochodną wpływów antropogenicznych – rolnictwa, urbanizacji, przemysłu. Wody były obciążane substancjami organicznymi i biogennymi, nierzadko ulegały silnemu zasoleniu, a w wielu przypadkach zawierały nadmierne ilości substancji śladowych, w tym metali ciężkich. W efekcie środowisko wodne znacznej części obszaru badań cechowała eutrofizacja oraz zagrożenie toksykologiczne. Antropopresja okazała się zatem czynnikiem znacząco degradującym ubogie zasoby wodne Polski.

Słowa kluczowe: zasoby wodne, jakość wód, antropopresja, zanieczyszczenie rzek, Polska