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Toxicity of water in anthropogenic reservoirs in post-mining areas assessed on the basis of biotests

Introduction

Water direction is often chosen for the reclamation of opencast mines and areas where there are subsidence basins due to underground exploitation. The quality of water in anthropogenic reservoirs in post-mining areas depends on the type of water the reservoir is supplied with (forming water, precipitation water, surface stream water) and on lithological conditions. The way the reservoir is used and its size are also important. Allowing various forms of recreation on a small reservoir creates a risk of deterioration of water quality.

The waters of many reservoirs are subject to monitoring tests conducted by the Provincial Inspectorates for Environmental Protection (GIOŚ 2020). If a bathing area has been created in the reservoir, the water is controlled by the State Sanitary Inspectorate (Ordinance MH 2019). Physicochemical monitoring of water allows for the precise determination of the

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chemical composition of water and the identification of pollutants present in it, but it also has certain limitations and disadvantages.

Biological monitoring is an important supplement to physicochemical methods of assessing the state of the environment. Biological monitoring methods can be used independently of physicochemical methods, constituting a preliminary stage of assessing the state of the environment. The presence or absence of particular species, and especially populations or groups of organisms living in a given aquatic ecosystem, is a precise and reliable indicator of the state of these waters (Rand and Petrocelli 1985; Rawson 1991). *In situ* assessment of living organisms is laborious but much cheaper than physicochemical monitoring. Biological methods cannot determine the exact concentration of a given pollutant, but this is the only way to assess the actual impact of a pollutant or a mixture of pollutants on living organisms in given conditions. The reaction of organisms may change depending on the substances present in the environment and the living conditions such as water oxygenation, temperature, water pH, etc. Substances co-occurring in the environment may mutually reinforce their toxic effects or reduce them, giving an effect greater or lesser than the sum of the toxic effects of individual substances. In addition, in optimal living conditions, living organisms will better tolerate the toxic effect of pollutants, but, for example, a decrease in water oxygenation or a drop in temperature may reveal the toxic effect of pollutants contained in the water (Traczewska 2011).

In addition to *in situ* methods, a number of laboratory biotests have been developed. They allow for the assessment of the toxicity of individual substances or their mixtures, as well as the assessment of the toxicity of environmental samples. Assuming that environmental conditions (including pollution) affect all organisms in the ecosystem evenly, biological monitoring does not have to take into account all species. However, it can limit observations to a few selected ones. Both in situ and laboratory tests use organisms with a narrow range of tolerance to pollution (stenotype organisms). Microorganisms, plants (most often algae, but also duckweed), and animals (invertebrates and fish) are used to assess the quality of water and sewage. Depending on the toxicity of the substance, we distinguish acute toxicity (there is a visible and profound health effect of the substance's impact on the organisms after a short time of exposure) and chronic toxicity (the occurrence of the effect requires a long time of exposure, sometimes it can only occur in the next generation). Biotests aimed at detecting acute toxicity usually last for a short time (e.g., the acute toxicity test on *Daphnia magna* lasts for 48 h), and the observed effect is most often the mortality of individuals. Chronic toxicity tests last longer, and the observed effects include for example, reduced biomass growth, decreased reproductive rate, immobilization, or the ability to regenerate (Piontek 1998; Pawul 2003; Traczewska 2011).

Among the microorganisms most frequently used to assess the acute toxicity of water and sediments, the bacteria Vibrio fischeri should be mentioned. During the test, their ability to bioluminescence is assessed (Bond and Martin 2005; Traczewska 2011, Johnson 2013; Baran et al. 2019; Domínguez et al. 2023). Among the algae, green algae (e.g., *Selenastrum capricornutum*, *Scenedesmus subspicatus*, *Chlorella vulgaris*) and diatoms (e.g., *Skeletonema* *costatum*, *Navicula seminulum*, *Phaedactylum tricornutum*) are most frequently used to test water quality. For them, the measured effect of toxicity is growth inhibition (Wren and McCarroll 1990; Traczewska 2011). Among the vascular plants, duckweed is most frequently used to test water pollution, for which inhibition of biomass growth is measured (Mkandawire et al. 2013: Traczewska 2011). Among invertebrates, bloodworms, amphipods, mayflies, daphnia are used to test the acute toxicity of water and bottom sediments, and the tested effect is mortality. Chronic toxicity tests can also be performed on invertebrates, examining, for example, immobilization, reproduction, and food intake rate (Barata et al. 2008; Traczewska 2011; Chen et al. 2015; Rasti et al. 2020). Fish are also used to test water toxicity, e.g., fathead minnow, zebrafish, and rainbow trout. Mortality is observed as an effect of acute toxicity, and embryonic-larval growth and survival as an effect of chronic toxicity. They can also be used to assess the toxicity of bottom sediments (Lamer et al. 2009; Traczewska 2011). The organisms listed above constitute only a small part of those used in biological monitoring. Standardized test procedures have been developed for many organisms (Traczewska 2011).

The paper presents the results of water toxicity tests for three anthropogenic reservoirs of different sizes, created in different ways and with different methods of use. Two of them are related to sulfur extraction, one was created in an open pit, and the other in subsidence areas after borehole exploitation. The third reservoir was created in a quarry after aggregate exploitation. All forms of recreation are allowed in two of the reservoirs, and fishing is allowed only in one. It has been shown that biological tests can be used to check the quality (toxicity) of water in the reservoirs, and it has been confirmed that the genesis of the reservoir and its use affect the quality of water.

1. Characteristics of the research area

The anthropogenic reservoirs discussed are located in southern Poland. They are the Bagry reservoir (in the Małopolska province), Tarnobrzeg Lake, and one of the reservoirs located between Tarnobrzeg and Grębów (in the Podkarpackie province). Each of the studied reservoirs was created in post-mining areas.

The Bagry Reservoir is one of the largest water reservoirs located in Kraków. The water surface area is 31.4 ha. The average depth of the reservoir is 6 m, and the maximum is 11 m. Aggregate extraction in this area began in the 19th century. Since extraction went below the level of underground waters, it was necessary to drain the deposit. When the pumps were turned off in 1945, the water filled the pit. The demand for aggregates after the war resulted in the reactivation of extraction in the western part of Bagry and a significant extension of the reservoir. The end of extraction is estimated for 1972. At the turn of the 1970s and 1980s, the coastline was slightly changed. After 1986, changes were made to adapt part of the reservoir to the needs of sports and recreation (Pietrzyk-Sokulska 2010; Gawałkiewicz 2017a, 2017b).

The Bagry reservoir is a non-draining reservoir supplied by rainwater, meltwater, and underground water. It is a natural enclave of nature in the center of a large city. It is characterized by significant biodiversity. The irregular banks of the reservoir are overgrown with aquatic plants, providing an excellent living and breeding environment for water birds. Meadows with tufts of bushes or single trees create the immediate surroundings of the reservoir.

From the very beginning of its existence, the reservoir attracted local residents, becoming a place of recreation. Currently, the reservoir is stocked with fish. Various forms of recreation are allowed there (fishing, swimming, kayaking and other water sports) (Pietrzyk-Sokulska 2010; Gawałkiewicz 2017a, 2017b).

Tarnobrzeg Lake (formerly Machów Reservoir) is located in the southern part of the city of Tarnobrzeg. It is a reservoir created by flooding the pit of the former opencast Machów Sulfur Mine with water from the Vistula River flowing nearby. It is the second largest, after Lake Solina, anthropogenic water reservoir in the Podkarpacie region. Its surface area is approximately 500 ha, its shape resembles a circle, the average depth is 22 m, and the maximum depth reaches 42 m (Gołda et al. 2005; Burchard et al. 2007; Mitura 2015; Sermet and Górecki 2020).

The Machów Sulphur Mine operated in the years 1964–1994. After the end of extraction, there remained a pit with an area exceeding 560 ha and reaching a depth of 80–110 m. The cessation of exploitation did not immediately entail stopping the drainage of the pit. The need to maintain the level of underground water below the bottom of the pit resulted from the fact that the deposit waters, which would otherwise fill the pit, contain high concentrations of sulfates and hydrogen sulfide. The liquidation and reclamation works in the following years also required the drainage of the pit (Gołda et al. 2005; Burchard et al. 2007; Mitura 2015; Sermet and Górecki 2020).

The area subject to reclamation work had an area of approx. 1,200 ha. Reclamation was carried out in the water direction (pit) and forest-meadow direction (surroundings of the pit). The creation of the reservoir was possible thanks to the previous thorough sealing of the bottom and the cutting off of the highly mineralized deposit waters. During the reclamation works, the slopes were profiled and reinforced, and the interior of the excavation was first filled with about 3.5 million tons of post-refining waste. Then, a 25 m thick insulating layer made of clay was applied on top of it. Before exploitation, these clays constituted a layer of overburden, which was removed and stored on an external dump. In 2005, the reservoir was prepared in this way and began to be filled with water from the nearby Vistula. For this purpose, two channels were built: one to supply water to the reservoir from the river and one to drain water. Thanks to this, partial water exchange in the reservoir is ongoing. The water reservoir is characterized by exceptional water transparency, which reaches a dozen or so meters. From the south and east, the banks of the reservoir have been forested and bushed (Gołda et al. 2005; Burchard et al. 2007; Mitura 2015; Sermet and Górecki 2020).

Convenient transport connections, good water quality and existing infrastructure make Tarnobrzeg Lake popular as a place of recreation. It is a well-prepared and developed area for tourism. There is a bathing area, a beach about 2 km long, a marina and water equipment rentals.

In the Tarnobrzeg area, sulfur was also extracted using the borehole method in the Jeziórko Sulfur Mine from 1967 to 2001. Currently, there are water reservoirs in the area of the former Mine, which were formed mainly in subsidence basins (one of these reservoirs is the research area of tis article). The land subsidence was caused by underground smelting of sulfur. The depressions ranged from a few dozen centimeters to 6 m. There were also changes in existing hydrological systems. There were contaminations of soils and grounds with sulfur as a result of the eruptions (Gołda 2000; Gołda et al. 2005; Czajkowski et al. 2014).

The first reclamation works on the devastated areas started in 1986. However, the reclamation of these areas on a larger scale started in 1993. The areas with the most significant land depressions due to subsidence were reclaimed in the water direction. Twenty-two water reservoirs were created, varying in size (0.2–30.7 ha). Their total area is approx. 188 ha. Since the land was contaminated with sulfur, they were covered with a layer of post-flotation lime. Contamination was also isolated. In the remaining area, neutralization and isolation of contaminated land were also carried out, and recultivation was carried out in the forest and meadow direction (Gołda 2000; Gołda et al. 2005; Czajkowski et al. 2014).

Water reclamation was supposed to ensure habitat diversity and increase the biodiversity of ecosystems. The created reservoirs also serve recreational (fishing grounds) and landscape functions. Bathing is prohibited in all reservoirs. Currently, the entire area is protected under the Natura 2000 initiative, where it has been classified as an area called Puszcza Sandomierska PLB180005.

Table 1 summarizes the characteristics of the water reservoirs discussed.

Table 1. Characteristic features of the studied water reservoirs

Tabela 1. Charakterystyka badanych zbiorników wodnych

	Bagry Reservoir	Tarnobrzeg Lake	Reservoir on the area of the former Jeziórko Sulfur Mine
Exploited raw material	clay, gravel and sand	sulfur	sulfur
Year of end of mining	1972	1992	2001
Approximate max. depth of water reservoir	11 m	42 m	6 m*
Approximate average depth of water reservoir	6 m	22 m	no data available
Water surface area	31.4 ha	500 ha	approx. 188 ha**
Possibility of bathing	yes	yes	no

* Maximum depth of subsidence.

** Approximate total water surface area of all formed water reservoirs.

2. Methodology of research

One sampling point was selected for each of the discussed water reservoirs. In the case of Tarnobrzeg Lake and the Bagry Reservoir, these were points a few meters from the shore near the beach. In the case of the reservoir in the area of the former Jeziórko Sulfur Mine, it was a point behind the reed vegetation belt. One water sample was taken from each point at the beginning of the summer recreational season. At the same time, one sample of bottom sediment was also taken from Tarnobrzeg Lake and one from the Bagry Reservoir. Bottom sediment was not collected from the reservoir in the area of the former Jeziórko Sulfur Mine due to the difficult access to the reservoir.

The toxicity analysis of waters collected from the discussed reservoirs included a phytotoxicity test in relation to *Lepidium sativum*. For this purpose, a series of dilutions of the tested waters were prepared, respectively: 100%, 50%, and 25%. The test was carried out on Petri dishes. For each dilution, three replicates (3 dishes) were prepared. 10 ml of the solution was poured into each dish. Three dishes were also prepared as control objects with distilled water. Ten seeds of *Lepidium sativum* were introduced into each dish. The dishes were covered and incubated in the dark for 72 hours at 25°C. After this time, germination and early growth of the test plants (root length) were assessed (Traczewska 2011; Tongur and Yıldız 2021; Śliwka et al. 2022).

The impact of tested waters on the germination of test plants was defined as the percentage of inhibition and calculated according to the formula (Baran et al. 2019):

$$IG = (A - B)/A \cdot 100\% \tag{1}$$

↳ IG – inhibition of germination,
A – the number of germinated seeds in control object,
B – the number of germinated seeds in experimental object.

Root growth inhibition (IR) was calculated in the same way, substituting A with the average root length in the control object and B with the average root length in the in experimental object.

The toxicity of water towards the invertebrates *Daphnia magna* was also tested. A chronic toxicity test was conducted, consisting of assessing the reproduction of daphnia. Similarly to the test of *Lepidium sativum*, three replicates were also prepared for each tested sample. In this case, however, the test was conducted only on undiluted water. The test was conducted in 100 ml containers, each of which was filled with 90 ml of the tested water. Three control samples were also prepared with water used for breeding daphnia. Ten daphnia were introduced into each container. The containers were set aside for 21 days. During the test, daphnia were fed with food yeast. After this time, the number of daphnia in the samples was measured (Traczewska 2011).

The analysis of the toxic properties of the bottom sediments included testing the phytotoxicity of them towards *Lepidium sativum*, *Sorghum saccharatum*, and *Sinapis alb*a. For this purpose, the Phytotoxkit test for the solid phase was performed. The test is in accordance with ISO 18763. Test objects were prepared on Phytotoxkit test plates using collected bottom sediment samples and reference soil (control objects). For each sediment and control soil, three repetitions for each plant were performed, with ten seeds in each repetition. The test plants were incubated in an incubator at 25°C in the dark. After three days of incubation, germination inhibition and early growth (length of roots) of test plants were assessed (Baran and Tarnawski 2013; Tigret 2024). The percentage of germination inhibition and root growth inhibition was calculated similarly to the test for *Lepidium sativum* on Petri dishes.

The results of the test towards *Lepidium sativum* in the liquid phase and the Phytotoxkit test were statistically evaluated to check whether the obtained differences in root lengths were significant. Since the means were compared in several populations, for this purpose, a one-way ANOVA analysis and Tukey's post hoc test were performed at a significance level of 0.05. These analyses were performed in Statistica, version 13.

3. Results and discussion

A toxicity test of *Lepidium sativum* was performed for the tested waters. It was checked whether the waters collected from the tested reservoirs had an inhibitory effect on seed germination. The highest germination inhibition values, at all tested concentrations, were observed for water taken from the reservoir on the premises of the former Jeziórko Sulfur Mine (JEZ); however, for none of the tested samples did germination inhibition exceed 20% (Figure 1). This indicates the lack of toxic effect of water taken from the discussed reservoirs on the germination of *Lepidium sativum* seeds.

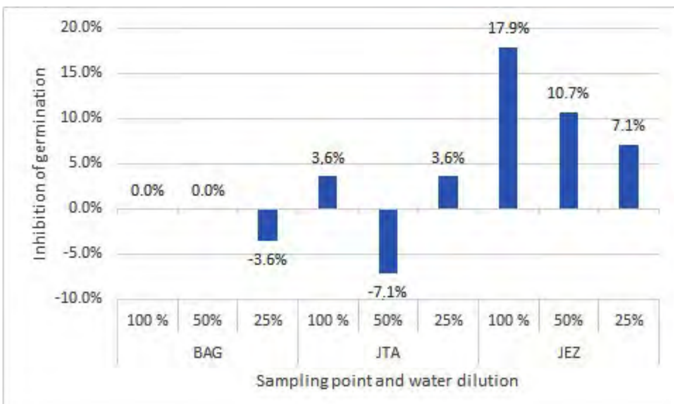

Fig. 1. Inhibition of *Lepidium sativum* germination in the waters taken from the tested reservoirs

Rys. 1. Hamowanie kiełkowania *Lepidium sativum* w wodach pobranych z badanych zbiorników

The influence of the tested waters on root growth was also checked. Comparing the lengths (average values) of plant roots in the control sample and other tested samples, it can be seen that the longest plant roots occurred in the control sample. However, when comparing the analyzed reservoirs, for each of the prepared dilutions, the longest roots were observed in water samples from Tarnobrzeg Lake (JTA). The second in order was the Bagry reservoir (BAG), while the shortest roots were measured in water samples collected in the reservoir in the area of the former Jeziórko Sulfur Mine (JEZ) (Figure 2).

To check whether the observed differences were statistically significant, analysis of variance (ANOVA) and Tukey posthoc tests were performed.

It was found that in the case of *Lepidium sativum* root growth for all analyzed water reservoirs, there are significant differences in its length compared to the control sample (Figure 3), which indicates the toxicity of these waters towards *Lepidium sativum*. There are no significant differences in root lengths for samples with different concentrations from the same reservoir. There are also no significant differences in root lengths between plants germinating in the waters taken from different reservoirs (undiluted samples).

The toxic effects of the waters collected from the reservoirs (irrespective of sample dilution) are also confirmed by the assessment of the percentage of root growth inhibition (Figure 4).

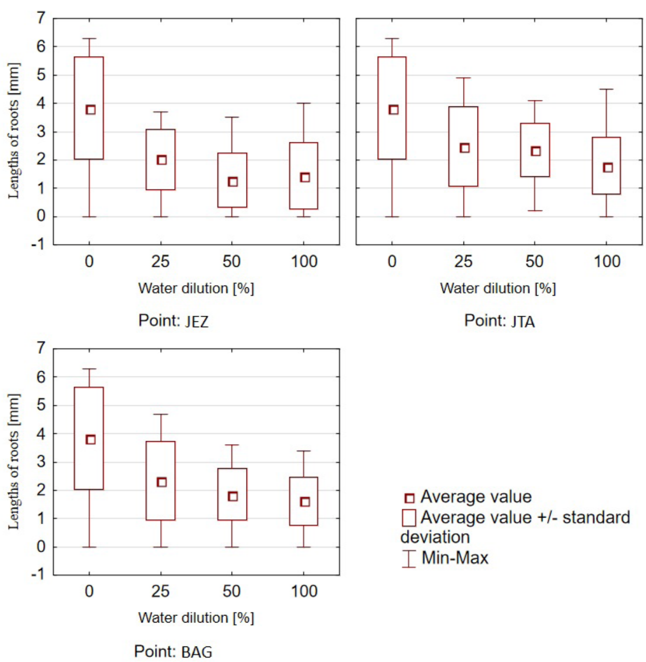

Fig. 2. Lengths of *Lepidium sativum* roots in tested samples

Rys. 2. Długości korzeni *Lepidium sativum* w badanych próbkach

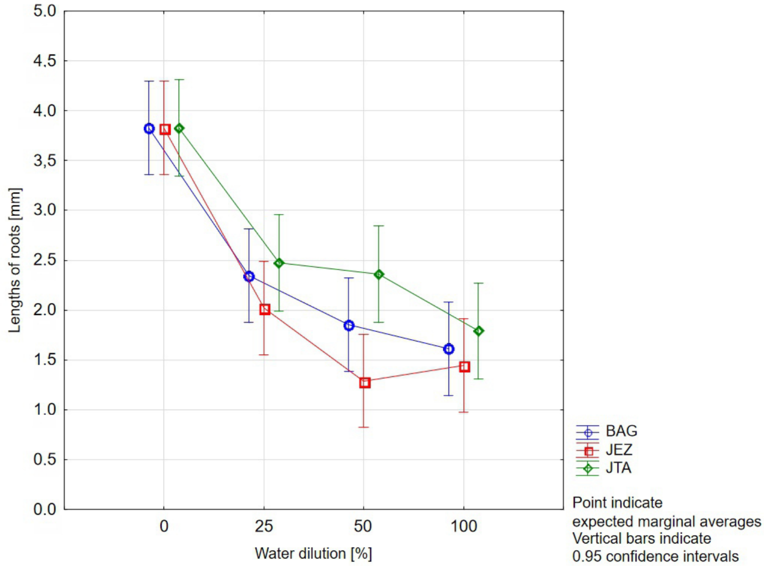

Fig. 3. Expected marginal averages of lengths of *Lepidium sativum* roots in all tested samples the graph illustrates the ANOVA analysis)

Rys. 3. Oczekiwane średnie brzegowe długości korzeni *Lepidium sativum* we wszystkich badanych próbkach (wykres ilustruje analizę ANOVA)

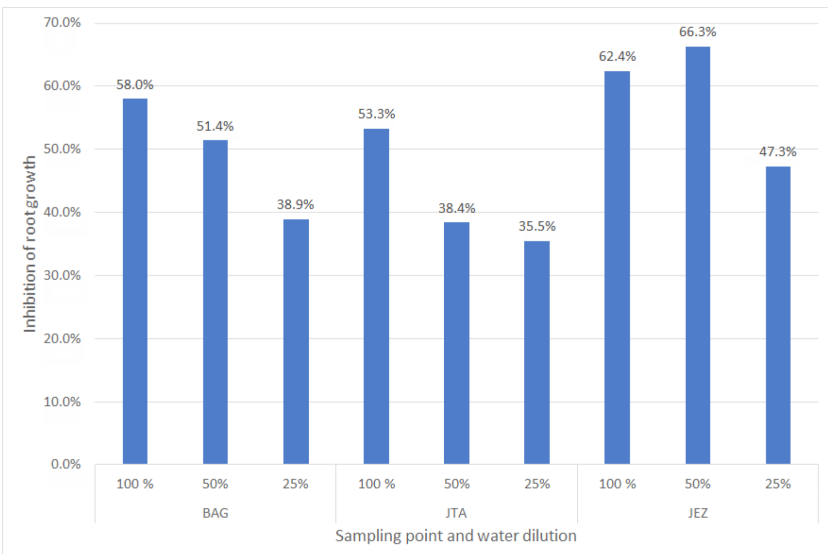

Fig. 4. Inhibition of *Lepidium sativum* root growth in the waters taken from the tested reservoirs

Rys. 4. Hamowanie wzrostu korzeni *Lepidium sativum* w wodach pobranych z badanych zbiorników

According to the literature (Baran et al. 2019), the percentage of the toxic effect (PE) is less than 20%, which indicates a lack of significant toxic effect (the sample is non-toxic). When the percentage toxic effect is between 20% and 50% (20% ≤ PE < 50%), the sample is considered to be of low toxicity. Samples whose percentage toxic effect is greater than or equal to 50% are considered to be toxic. According to this classification, all tested undiluted water samples are toxic to the growth of *Lepidium sativum* roots. However, for water taken from Tarnobrzeg Lake (JTA), PE is 53.3%, which is only slightly above the limit above which the sample is considered to be toxic. It should be noted that after dilution to 50%, this water becomes low-toxic. Water from other reservoirs becomes low-toxic only at a dilution of 25%. It should be noted, however, that for water taken from the reservoir in the area of the former Jeziórko Sulfur Mine (JEZ) in such a dilution, PE is slightly below the limit value (it is 47.3%).

For waters collected from the three studied reservoirs, as a supplement, a toxicity test on the invertebrates *Daphnia magna* was also performed, assessing their reproduction. After 21 days of observation, it was found that the number of individuals in the waters collected from the reservoirs was higher than in the control sample (Figure 5). In the tested samples, the final number of individuals was close to the initial number.

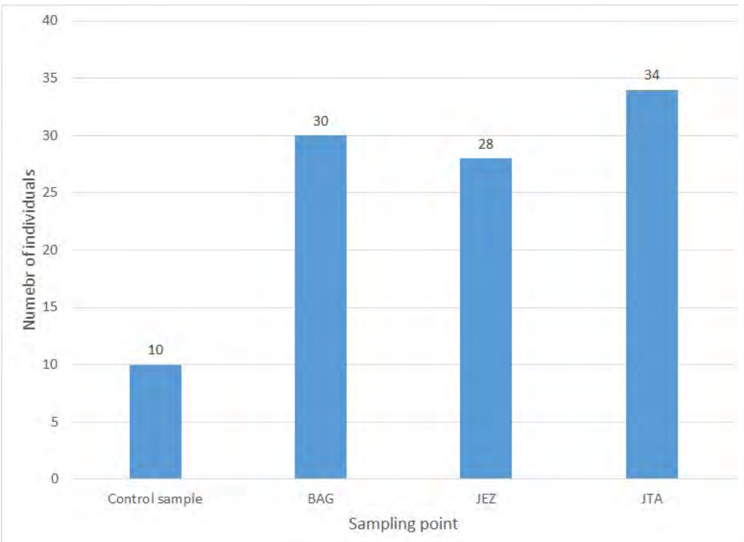

Fig. 5. Number of *Daphnia magna* individuals in tested and control samples after 21 days of observation

Rys. 5. Liczba osobników *Daphnia magna* w próbkach badanych i kontrolnych po 21 dniach obserwacji

The low number of daphnia in all samples could be due to the underfeeding of the tested organisms. The approximately three times higher number of daphnia in the tested waters than in the control sample indicates the lack of substances toxic to these organisms in the tested waters. In addition, one can suspect the presence of an organic substance (additional food) that the daphnia fed on in the water samples taken from the reservoirs.

The Phytotoxkit test was performed on bottom sediments collected in the Bagry Reservoir and Tarnobrzeg Lake. The study did not include bottom sediments from the reservoir in the area of the former Jeziórko Sulfur Mine due to the impossibility of collecting them. The inhibition of plant germination (*Sorghum saccharatum, Lepidium sativum, Sinapis alba*) was determined for each of the sediments (Figure 6). All obtained values of germination inhibition were lower than 20%, and no toxic effect was found for any of the bottom sediments.

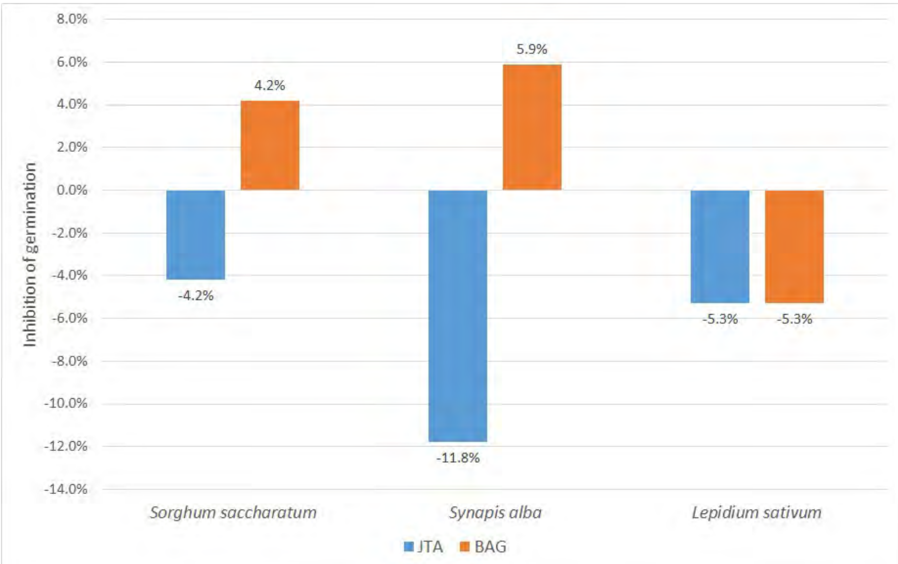

Fig. 6. Inhibition of germination in the bottom sediments taken from the tested reservoirs

Rys. 6. Hamowanie kiełkowania w osadach dennych pobranych z badanych zbiorników

Comparing the average root lengths for the control soil and bottom sediments from water reservoirs, it can be seen that in the samples from the Bagry reservoir (BAG), the lengths of *Sorghum saccharatum* and *Sinapis alba* roots were shorter than in the control sample, while the roots of *Lepidium sativum* were longer than in the control sample. In the case of bottom sediments from Tarnobrzeg Lake (JTA), the average root length was slightly shorter than in the control sample, and the roots of the remaining plants germinating on these sediments were longer than in the control sample (Figure 7).

To check whether these differences were statistically significant, ANOVA analysis of variance and Tukey post-hoc tests were performed.

The results of the analysis indicate no significant differences between the lengths of *Sorghum saccharatum* roots for all three tested samples (JTA, BAG, and control soil).

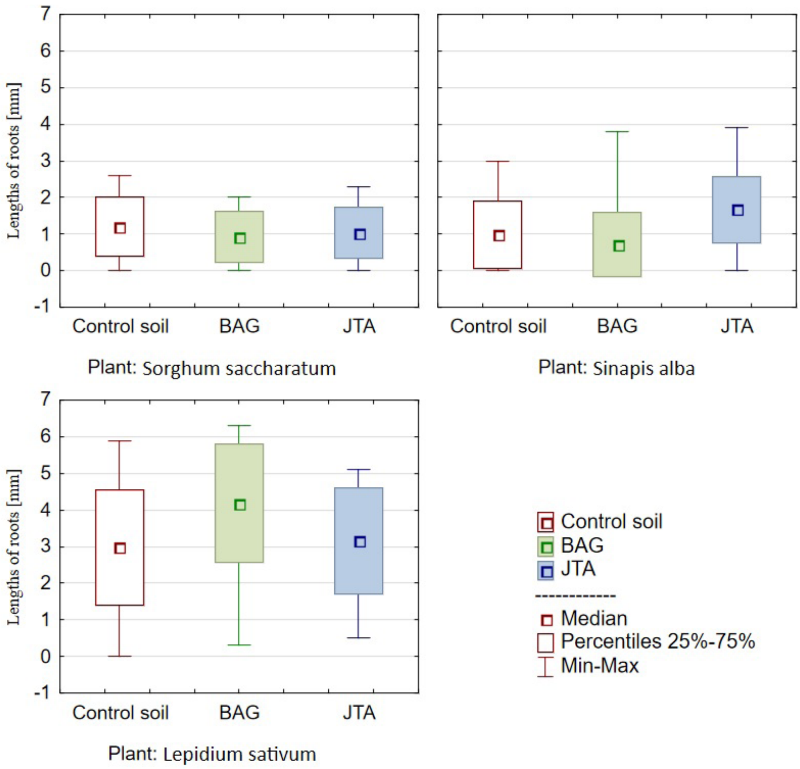

Fig. 7. Lengths of roots (*Sorghum saccharatum*, *Lepidium sativum*, *Sinapis alba*) in tested samples

Rys. 7. Długości korzeni (*Sorghum saccharatum*, *Lepidium sativum*, *Sinapis alba*) w badanych próbkach

The roots of *Sinapis alba* germinating on the bottom sediments from Tarnobrzeg Lake (JTA) were significantly different (longer) compared to the control sample and sediments from the Bagry reservoir (BAG). For *Sinapis alba*, no significant differences were found in the lengths of roots between the control sample and the bottom sediments from the Bagry reservoir (BAG). For *Lepidium sativum*, significant differences were noted between the lengths of roots of plants growing on the bottom sediments from the Bagry reservoir (BAG) (the roots were longer) and the control sample. There were no significant differences between the other groups (Figure 8).

When analyzing the percentage of root growth inhibition (Figure 9), the sediments from Tarnobrzeg Lake (JTA) should be classified as non-toxic (PE < 20%). A strong stimulating effect for *Sinapis alba* is noticeable here. The sediments from the Bagry reservoir (BAG) show low toxicity towards *Sorghum saccharatum* and *Sinapis alba* and a stimulating effect towards *Lepidium sativum*.

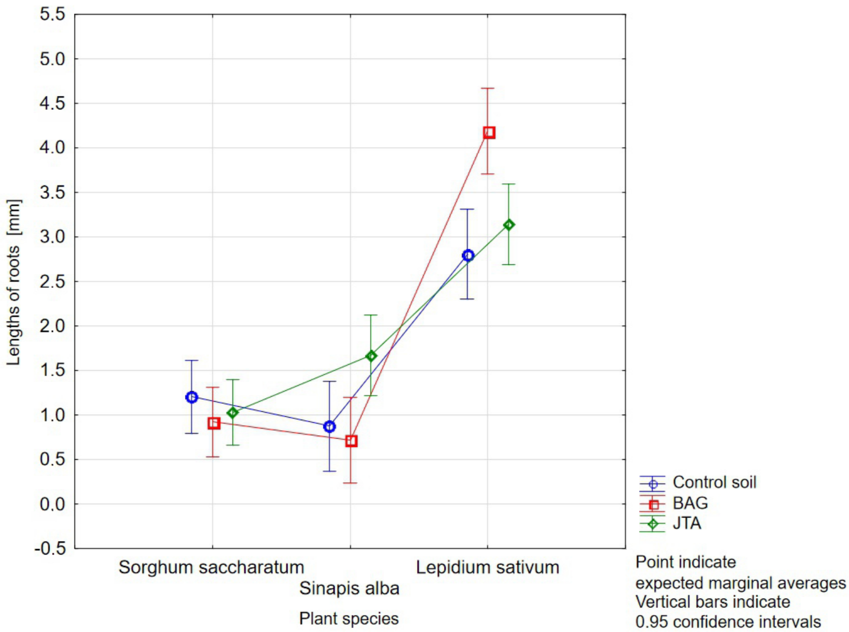

Fig. 8. Expected marginal averages of lengths of roots (*Sorghum saccharatum, Lepidium sativum, Sinapis alba*) in all tested samples (the graph illustrates the ANOVA analysis)

Rys. 8. Oczekiwane średnie brzegowe długości korzeni (*Sorghum saccharatum*, *Lepidium sativum*, *Sinapis alba*) we wszystkich badanych próbkach (wykres ilustruje analizę ANOVA)

Conclusions

The results of the conducted analyses of the toxicity of waters collected from three different water reservoirs indicate their different toxicity. The best is the water collected from Tarnobrzeg Lake (JTA). It does not show toxicity in relation to the germination of *Lepidium sativum*. However, undiluted, it is toxic in relation to the growth of *Lepidium sativum* roots. Analysis of the results of the daphnia reproduction test indicates that these waters are beneficial for these invertebrates. Tested water is non-toxic but may contain organic substances. Analysis of sediments taken from this reservoir showed no toxic effects on the germination and growth of the test plants. However, a stimulating effect was observed on the growth of *Sinapis alba* roots.

Water collected from the Bagry reservoir (BAG) also did not show toxic properties in relation to the germination of *Lepidium sativum*. Toxicity was observed in relation to the growth of *Lepidium sativum* roots in undiluted water and after dilution to 50%. Similarly to Tarnobrzeg Lake (JTA), the analysis of the results of the daphnia reproduction test indicates

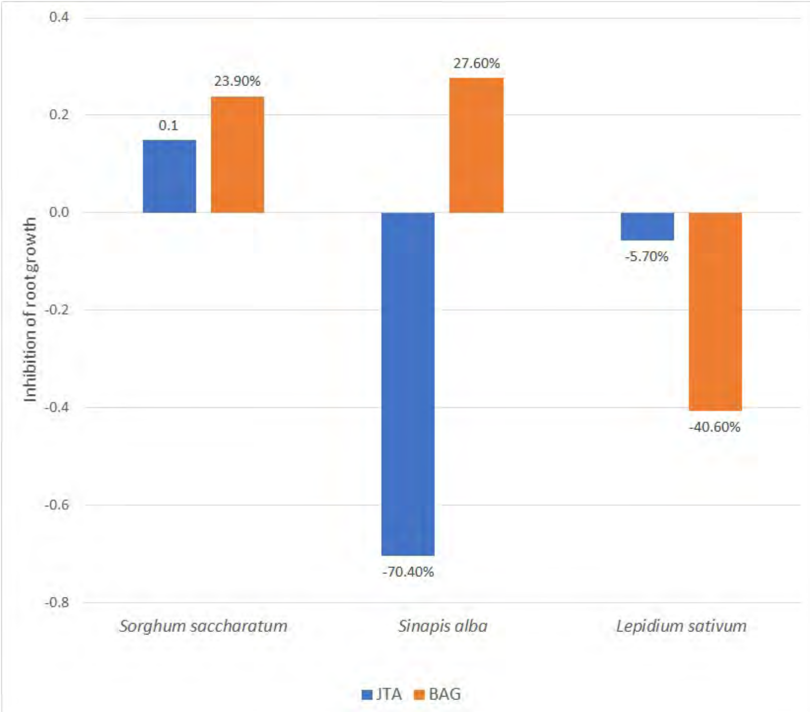

Fig. 9. Inhibition of root growth in the bottom sediments taken from the tested reservoirs

Rys. 9. Hamowanie wzrostu korzeni w osadach dennych pobranych z badanych zbiorników

that this water is beneficial for these invertebrates. The tested water is non-toxic but may contain organic substances. Analyses of sediments taken from this reservoir showed no toxic effects in relation to the germination of test seeds and weak toxicity in relation to the growth of *Sorghum saccharatum* and *Sinapis alba*. However, a stimulating effect was observed in relation to the growth of *Lepidium sativum* roots.

The highest toxicity was recorded in water taken from a reservoir in the area of the former Jeziórko Sulfur Mine (JEZ). Similarly to the two previous reservoirs, this water does not show toxicity in relation to the germination of *Lepidium sativum*. It is toxic to the growth of roots of *Lepidium sativum* in undiluted water and after dilution to 50%. Similarly to the case of Tarnobrzeg Lake (JTA) and the Bagry reservoir (BAG), the analysis of the results of the daphnia reproduction test indicates that this water is beneficial for these invertebrates and that organic substances may occur in it. No bottom sediment tests were performed for this reservoir.

Differences in water quality in reservoirs may result from their origin, size, and method of use. On the Bagry Reservoir (BAG) and on Tarnobrzeg Lake (JTA), various forms of recreation are permitted, which can always pose a threat to water quality. Tarnobrzeg Lake

(JTA) is a much larger and deeper reservoir than the Bagry Reservoir (BAG), and this may be the reason for the better water quality. Thanks to the reclamation and sealing of the bottom in Tarnobrzeg Lake (JTA), the type of raw material extracted does not affect the water quality when compared to these two reservoirs. In the reservoir on the site of the former Jeziórko Sulfur Mine (JEZ), fishing is permitted only, so it would seem that the water there would have the lowest toxicity, but it is not. This reservoir is much smaller and shallower than Tarnobrzeg Lake (JTA) and smaller than the Bagry Reservoir (BAG). However, it seems that the reason for the more significant water toxicity in this case is not its size but insufficient isolation of sulfur-contaminated soils. The insulating layer in these areas was much thinner than in the case of Tarnobrzeg Lake (JTA).

The Authors have no conflict of interest to declare.

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TOXICITY OF WATER IN ANTHROPOGENIC RESERVOIRS IN POST-MINING AREAS ASSESSED ON THE BASIS OF BIOTESTS

Keywords

biassay, toxicity tests, anthropogenic reservoirs, water quality, bottom sediments

Abstract

A common direction of reclamation of open pits and land subsidence in post-mining areas is the water direction. The quality of water in reservoirs created in this way depends on a number of factors, e.g., the method of reclamation, current use, and the size of the reservoir. The paper presents the results of water toxicity tests for three anthropogenic reservoirs of different sizes, created in different ways and with different methods of use. Two of them are related to sulfur extraction; one was created in an open pit (Tarnobrzeg Lake), and the other in subsidence areas after borehole exploitation (reservoir on the area of the former Jeziórko Sulfur Mine). The third reservoir was created in a quarry after aggregate exploitation (Bagry Reservoir in Cracow). All forms of recreation are allowed in two of the reservoirs, and fishing is allowed only in one. The scope of the presented research results concerns the germination and early growth test against *Lepidium sativum* and the reproduction test against *Daphnia magna*. The results of toxicity tests of bottom sediments collected from Tarnobrzeg Lake and the Bagry reservoir were also presented (germination and early growth tests against *Sorghum saccharatum*, *Sinapis alba*, and *Lepidium sativum*). Based on the bioassays, it was found that the water in Tarnobrzeg Lake is of the best quality, while the water in the reservoir in the area of the former Jeziórko Sulfur Mine is of the poorest quality. The good quality of water in Tarnobrzeg Lake is undoubtedly due to its size. Bottom sediments from Tarnobrzeg Lake showed no toxicity towards plants, and bottom sediments from the Bagry reservoir showed low toxicity towards two plant species.

TOKSYCZNOŚĆ WÓD W ZBIORNIKACH ANTROPOGENICZNYCH NA TERENACH POGÓRNICZYCH OCENIONA NA PODSTAWIE BIOTESTÓW

Słowa kluczowe

biotesty, zbiorniki antropogeniczne, testy toksyczności, jakość wody, osady denne

Streszczenie

Częstym kierunkiem rekultywacji wyrobisk i zagłębień na terenach pogórniczych jest kierunek wodny. Jakość wody w tak powstałych zbiornikach zależy od szeregu czynników, np. sposobu przeprowadzonej rekultywacji, obecnego użytkowania oraz wielkości zbiornika. W pracy przedstawiono wyniki badań toksyczności wód dla trzech zbiorników antropogenicznych o różnej wielkości, powstałych w różny sposób oraz z różnym sposobem użytkowania. Dwa z nich wiążą się z wydobyciem siarki, jeden powstał w odkrywce (Jezioro Tarnobrzeskie), a drugi na terenach osiadań po eksploatacji otworowej (zbiornik na terenie dawnej Kopalni Siarki Jeziórko). Trzeci ze zbiorników powstał w wyrobisku po eksploatacji kruszyw (zalew Bagry w Krakowie). Na dwóch zbiornikach dozwolone są wszelkie formy rekreacji, na jednym tylko wędkowanie. Zakres prezentowanych wyników badań dotyczy testu kiełkowania i wczesnego wzrostu względem *Lepidium sativum* oraz testu rozrodczości *Daphnia magna*. Zaprezentowano także wyniki badań toksyczności osadów dennych pobranych z Jeziora Tarnobrzeskiego i zalewu Bagry (test kiełkowania i wczesnego wzrostu względem *Sorghum saccharatum*, *Sinapis alba* i *Lepidium sativum*). Na podstawie przeprowadzonych biotestów stwierdzono, że w Jeziorze Tarnobrzeskim woda ma najlepszą jakość, najsłabszą zaś w zbiorniku na terenie dawnej Kopalni Siarki Jeziórko. Do dobrej jakości wody w Jeziorze Tarnobrzeskim przyczynia się niewątpliwie jego wielkość. Osady denne z Jeziora Tarnobrzeskiego nie wykazywały toksyczności względem roślin, osady z zalewu Bagry wykazywały niską toksyczność w stosunku do dwóch gatunków roślin.