ECOLOGICAL CHEMISTRY AND ENGINEERING A

Vol. 18, No. 12 2011

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# EFFECT OF CATCHMENT AREA USE ON LEAD AND ZINC ACCUMULATION IN THE BOTTOM DEPOSITS OF LAKES ARDUNG AND BUKWALD

## WPŁYW UŻYTKOWANIA ZLEWNI NA AKUMULACJĘ OŁOWIU I CYNKU W OSADACH DENNYCH NA PRZYKŁADZIE JEZIOR ARDUNG I BUKWAŁD

**Abstract:** The study concerns with the effect of catchment area use on lead and zinc accumulation in the bottom deposits of lakes. It was carried out in two water bodies in the Olsztyn Lakeland. The catchment areas of the investigated lakes are used for various purposes, ranging from forests to agricultural production. Lake Ardung (N 53°45′, E 20°55′) is situated in the eastern part of the Masurian Lakeland, approximately 25 km east of Olsztyn. The lake has an area of 26.2 ha and a maximum depth of 3.6 m. The lake's catchment area of 1539 ha is covered by farmland in 2 %, grassland in 2 %, fallow land overgrown with shrubs in 11.4 % and forests in 84.6 %. Lake Bukwald (N 53°58′, E 20°16′) is located in the vicinity of the village of Bukwald, municipality of Dywity, around 20 km north of Olsztyn. The lake's catchment area of 1156.8 ha comprises arable land in 60 %, forests and afforested areas in 31 % and wasteland in the remaining part.

The studied water bodies were characterized by low concentrations of the analyzed elements. The average lead and zinc levels reached 28.3 mg/kg d.m. and 32.3 mg/kg d.m., respectively in Lake Ardung, and 33.3 mg/kg d.m. and 91.9 mg/kg d.m., respectively in Lake Bukwald. The total zinc and lead accumulation in the bottom deposits of the investigated water bodies, in terms of the surface area of the lakes and their catchments, was significantly higher in Lake Bukwald than in Lake Ardung.

**Keywords:** lakes, bottom deposits, catchment area, trace elements, lead, zinc

Substance runoff from the catchment area into surface waters is determined by various factors, in particular land relief, soil cohesion and fertility, the type of land use, water relations and climate conditions, mostly the volume and distribution of precipita-

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tion [1]. Vast quantities of substances are also supplied by atmospheric precipitation which contributes to the leaching of chemical components from the soil [2, 3].

Bottom deposits are a combination of crystalline and amorphous minerals with a different grain size, a various content of organic matter and mineral or organic colloidal substances [4, 5]. Bottom deposits are formed by the sedimentation of allochtonic material created outside the sedimentation area as well as autochthonic material formed in the place of sedimentation [6]. The bottom deposits of aquatic ecosystems vary immensely from coarse-grained, nearly mineral deposits to fine-grained, mostly organic deposits in the deep strata of lakes. Deposits comprise mineral substances (silica, silicate, aluminosilicate, carbonate) as well as organic substances of various origin (catchment area, littoral and pelagial zones) and various degree of decomposition. Deposits found at deeper strata are generally characterized by greater thickness, fine-grained structure and a higher organic matter content [7].

The trace element content of bottom deposits is conditioned by numerous natural and anthropogenic factors. It is largely determined by the geological structure of the catchment area, its geomorphologic characteristics and climate conditions which are responsible for rock weathering, the mobilization, migration and accumulation of elements in the environment. In undeveloped areas, high concentrations of potentially harmful trace elements in bottom deposits are attributed mainly to different types of human activity in the catchment area, mostly agricultural production [8–10].

## Materials and methods

In the study the effect of catchment area use on lead and zinc accumulation in the bottom deposits of lakes was carried out in two water bodies in the Olsztyn Lakeland. The catchment areas of the investigated lakes are used for various purposes, ranging from forests to agricultural production.

**Lake Ardung** (N 53°45′, E 20°55′) is situated in the eastern part of the Masurian Lakeland, approximately 25 km east of Olsztyn. The lake has an area of 26.2 ha and a maximum depth of 3.6 m. The lake's catchment area of 1539 ha is covered by farmland in 2 %, grassland in 2 %, fallow land overgrown with shrubs in 11.4 % and forests in 84.6 %. Lake Ardung is located in the catchment area of the Lyna River in the watershed of Lyna (tributary of the Pregoła River) and Omulew (tributary of the Narew River in the Vistula Basin) river systems. This area is characterized by a large number of small lakes, ponds and swamps. It is weakly populated, and the predominant types of human activity include farming, forestry and tourism. The parent rock of catchment area soils comprises sandy glaciofluvial deposits that fill the channel surrounded by more cohesive clay formations [11]. The catchment area features mostly podzolic soils in natural pine forests. Depression areas comprise mostly hydrogenic soils developed in the course of several drainage schemes. The lake's present catchment area was formed during land improvement projects carried out in the mid 19$^{th}$ and the early 20$^{th}$ century. As part of those schemes, the lake's water horizon was lowered to expose shallow waters. Today, Lake Ardung is a remnant of a multi-sectional lake with the original area of around 250 ha surrounding the town of Nerwik. The lake was periodically separated to create 224 ha of farmland. The original lake basin which today forms Lake Ardung spanned an area of 62 ha.

**Lake Bukwald** (N 53°58′, E 20°16′) is located in the vicinity of the village of Bukwald, municipality of Dywity, around 20 km north of Olsztyn. Lake Bukwald is a flow through water body fed by four streams in its north-western and the south-western parts. Water is evacuated from the lake via a single watercourse in the village of Bukwald. The lake has an area of 36.2 ha and a maximum depth of 12.4 m. It is supplied from a hilly area marked by significant altitude variations – the difference between the highest and the lowest point in the catchment area is 23.5 m. Lake Bukwald's catchment area of 1156.8 ha comprises arable land in 60 %, forests and afforested areas in 31 % and wasteland in the remaining part. There is a predominance of light to medium-heavy loams in the north, and light and heavy loamy sands turning into light loams and slightly loamy sands in the south. Catchment area soils fall into quality classes IVa and IVb and, locally, IIIa and IIIb.

Surface samples from the bottom deposits of the studied lakes were collected for physical and chemical analyses in June 2008. Sampling sites were distributed along five perpendicular transects, three sites per transect (Fig. 1). The location of sampling sites was chosen based on barimetric charts to produce the most comprehensive overview of the morphological and chemical properties of deposits, subject to the lake-bottom topography, the shape of the lake basin, flow rate, tributaries, etc.

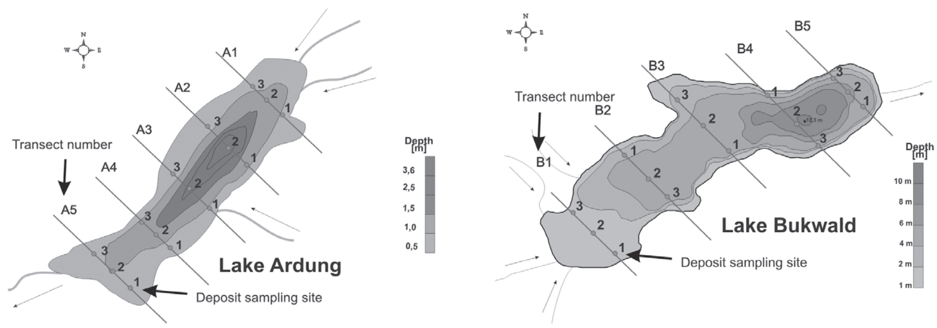


Fig. 1. Location of deposit sampling sites in Lake Ardung and Lake Bukwald

Deposit samples were collected using the Ekman grab (for collecting samples with a surface area larger than 250 $cm^2$). Three samples were collected from each site, and they were averaged into one sample. The deposits and sedimentation water sampled from each site were placed in air-tight glass containers. The physical properties of samples were analyzed by the Troels-Smith method immediately after collection [12].

At the laboratory of the Department of Land Improvement and Environmental Management at the University of Warmia and Mazury in Olsztyn, the following physical and chemical parameters were determined in fresh deposit samples directly after collection:

– solid residue – by the gravimetric method at 105 °C [g/kg d.m.],

– ignition losses – as an indicator of organic substance content, calculated as the difference between solid residue and residue after ignition [g/kg d.m.],

Pb and Zn levels were determined by *atomic absorption spectroscopy* (AAS) in deposit samples at the laboratory of the Department of Technology in Environmental Engineering and Protection at the Bialystok University of Technology.

## Results and discussion

The bottom deposits of the analyzed water bodies were characterized by significant morphological diversity. Deposits from Lake Ardung (Nig. 4) were marked by a much greater degree of darkness than samples from Lake Bukwald (Nig. 2). Structural layering was not determined in samples from both lakes (Strf. 0), and the analyzed deposits were completely homogenous. Owing to continuous contact with water, the surface layers of bottom deposits were strongly hydrated (Sicc. at level 2–3), and they contained highly decomposed plant matter (Humo at level 3–4, H7–H10 on the von Post scale of humification). The investigated deposits had homogenous, greasy structure. Littoral zone samples contained fragments of hydrophyte roots with partially decomposed plant matter and small quantities of mollusk shells, while profundal zone samples were more homogenous (with an absence of plant remains or macrophyte roots). The analyzed deposits had the characteristic features of sapropel formations [12].

Significant differences were observed in the water content of deposit samples. The average dry matter content was 16.3 % in samples from Lake Ardung and 20.9 % in deposits from Lake Bukwald (Table 1). More profound differences in the dry matter content of deposits were found between sampling sites in Lake Ardung. The highest moisture content of 88.7 % was observed in samples from the central part of transect A3, and the lowest moisture content of 65.4 % was reported in transect A1, ie on the side of the inflow to the lake near the river head-streams. In Lake Bukwald, the highest water content of bottom deposits was determined in samples from the central part of transect B2 (86.8 %), and the lowest – on the northern side of transect B4 (66.3 %).

Table 1

Physical and chemical properties of bottom deposits in lakes

| Parameter | Unit | Lake Ardung | Lake Bukwald |
|---|---|---|---|
| | | mean (min – max) | mean (min – max) |
| Dry matter | [%] | 16.3 (11.3–34.6) | 20.9 (13.2–33.7) |
| Organic content | [% d.m.] | 18.9 (14.9–26.0) | 14.0 (8.1–19.9) |
| Pb | [mg/kg d.m.] | 28.3 (20.0–35.0) | 33.3 (24.0–56.0) |
| Zn | [mg/kg d.m.] | 32.3 (19.7–68.8) | 91.1 (45.9–112.9) |

The organic content of deposits is formed by remnants of aquatic organisms that fall to the bottom of the lake, organic suspension, the precipitation and coagulation of organic substances dissolved in water. The organic matter content of deposit surface layers is determined mostly by the productive output of the trophogenic zone, the quantity of allochtonic matter and sedimentation time [13–17].

The average organic matter content of sediment samples from the analyzed lakes was 14.0 % in Lake Bukwald and 18.9 % in Lake Ardung. The reported values are characteristic of post-glacial lakes whose organic matter content ranges from 10 % to 70 % [16, 18]. The results of the study point to variations not only between the water bodies, but also in the spatial distribution of organic matter in the examined lakes. In Lake Ardung, the lowest organic matter concentrations (14.9 %) were noted in deposits from the southern part of the water body on the side of the outflow in transect A5 and in deposits from the side of the inflow to the lake (15.7 %), while the highest organic content at 26 % was reported in the central part of transect A2 (deepest waters). Similar results were noted in Lake Bukwald where the lowest organic matter concentrations were found in samples collected on the side of the outflow (8.1 %) and near the inflow (13.8 %), and the highest organic matter content was determined in deposits from the profundal zone of the lake (19.9 %). Organic matter produced by the precipitation and coagulation of organic substances dissolved in water has a capillary structure, and its specific gravity is similar to the specific gravity of water [12, 14, 15]. The above facilitates the lifting and the transport of substance particles, and it explains the limited organic matter content of samples collected on the side of the outflows and inflows because the deposits accumulating in those areas are depleted by moving water which washes out lighter particles. Runoff and feeder sections of the lake are shallower and more abundant in oxygen which contributes to the mineralization of deposits. The highest organic matter content was noted in the deepest zones of the lake owing to the gravitational force which pushes deposits deeper down the lake basin.

The studied deposits were characterized by an average lead content of 28.3 mg/kg d.m. in Lake Ardung and 33.3 mg/kg d.m. in Lake Bukwald. The geochemical background of lead in the bottom deposits of lakes in north-eastern Poland is 11 mg Pb/kg d.m., and the lead content of unpolluted deposits should not exceed 20 mg/kg d.m. [8]. In Lake Bukwald, the highest Pb levels were noted on the southern side of transect B4 (56.0 mg Pb/kg d.m.), while the lowest lead concentrations were found in deposits on the southern side of transect B1 (24.0 mg Pb/kg d.m.). In the mid-forest Lake Ardung, Pb levels were lower, in the range of 20.0 mg/kg d.m. to 35.0 mg/kg d.m. (Table 1).

The average zinc content of the analyzed deposits was low, ranging from 32.3 mg/kg d.m. in Lake Ardung to 91.1 mg/kg d.m. in Lake Bukwald. The geochemical background of zinc in soils usually does not exceed 50.0 mg/kg dm, while the average values noted in lakes are generally under 100 mg/kg d.m. [19]. The average Zn content of the investigated deposits approximated geochemical background levels. Zinc concentrations in the bottom deposits from Lake Ardung were within the 19.7–68.8 mg/kg d.m. range. The Zn content of samples from Lake Bukwald, whose catchment area is occupied by a housing estate and farmland, was determined at 45.9–112.9 mg/kg d.m. (Table 1). According to the system for classifying the purity of bottom deposits proposed by Bojakowska and Sokolowska [20], the Zn and Pb concentrations noted in this study meet first class purity standards.

Agricultural production in the catchment area of Lake Bukwald, including the use of pesticides, contributes to high Pb values in deposit samples from the lake. Lead concentrations were further increased by the long-term use of tetraethyl lead as an antiknock agent in the fuel powering farming machines as well as atmospheric deposition. According to Nicholson [21], atmospheric deposition is the main source of lead in agricultural areas, and it accounts for as much as 77 % of its total supply.

A comparison of lead and zinc concentrations in deposit samples shows that they were significantly lower in the littoral zones than in the profundal zones of the analyzed lakes. The low Pb and Zn content of bottom deposits in littoral zones could be attributed to bioaccumulation. Deposits in deeper parts of the lake are characterized by high concentrations of organic substances and fine-grained mineral fractions that bind metals [22].

The results of the analysis indicate that the highest concentrations of trace elements in Lake Ardung were found on the side of the outflow and in the profundal zone of the lake, while the lowest Pb and Zn levels were observed on the side of the inflow near the river head-streams. In Lake Bukwald, lower lead and zinc levels were also noted in deposit samples collected on the side of the inflow, while the highest Pb and Zn concentrations were reported in transects on the side of the outflow.

An analysis of total lead and zinc load in the bottom deposits of the examined water bodies points to significantly higher accumulation levels in Lake Bukwald at 1372.6 kg Zn and 502.3 kg Pb. In Lake Ardung, zinc accumulation was 80 % lower (279.5 kg Zn) and Pb accumulation was approximately 50 % lower (247.2 kg Pb) than in Lake Bukwald (Table 2).

Table 2

Accumulation of trace elements in the 0–20 cm layer of bottom deposits in the studied lakes

| Indicator | Lake | | | |
|---|---|---|---|---|
| | Ardung | | Bukwald | |
| | Pb | Zn | Pb | Zn |
| kg/lake | 247.2 | 279.5 | 502.3 | 1 372.6 |
| kg /ha lake | 9.43 | 10.7 | 13.88 | 37.9 |
| kg/ha catchment area | 0.14 | 0.16 | 0.43 | 1.2 |

An analysis of Zn and Pb accumulation in terms of the catchment area unit points to higher deposition in Lake Bukwald at 1.19 kg Zn/ha and 0.43 kg Pg/ha. In the mid-forest Lake Ardung, accumulation values reached 0.16 kg Zn/ha and 0.14 kg Pb/ha. In terms of the surface area of the lakes, the bottom deposits of Lake Bukwald also accumulated more Zn and Pb (13.88 kg Pb/ha, 37.9 kg Zn/ha) than the deposits of Lake Ardung (9.43 kg Pb/ha, 10.7 kg Zn/ha) (Table 2).

A comparison of lead accumulation values in the bottom deposits of the examined lakes indicates that lead concentrations are largely determined by the type of catchment area use. A higher level of trace elements accumulation was noted in the bottom deposits of Lake Bukwald, whose catchment area is used for agricultural production, than in the deposits of the mid-forest Lake Ardung.

## Conclusions

1. Variations in the spatial distribution of lead and zinc were determined in the bottom deposits of the investigated lakes. Higher levels of the analyzed trace elements were noted in deposit samples collected from shallower lake sections on the side of the outflow.

2. The level of Zn and Pb accumulation in the bottom deposits of the examined water bodies was determined mostly by the type of catchment area use and the applied fertilization rates. In the bottom deposits of Lake Bukwald, whose catchment area is used for farming production and human settlement, the total accumulation of the analyzed elements was much higher (1372.6 kg Zn and 502.3 kg Pb) than in the bottom deposits of the mid-forest Lake Ardung (279.5 kg Zn and 247.2 kg Pb).

3. The total lead and zinc accumulation in bottom deposits in terms of the surface area of the lakes was significantly higher in Lake Bukwald (1372.6 kg Zn and 502.3 kg Pb) than in Lake Ardung (279.5 kg Zn and 247.2 kg Pb). The above differences resulted mainly from the type of activity performed in the catchment areas of the investigated water bodies.

### References

[1] Sidoruk M. and Skwierawski A.: *Effect of land use on the calcium, sodium, potassium and magnesium contents in water flowing into the Bukwałd Lake*. Ecol. Chem. Eng. 2006, **13**, 337–343.

[2] Mosiej J.: *Przyrodniczo-techniczne uwarunkowania gospodarowania wodą w dolinie rzeki Ner*. Wyd. SGGW. Rozprawy Naukowe i Monografie. 1999.

[3] Wiśniewski R.J. and Nowicka B.: *Ocena stanu i przyrodnicze uwarunkowania ochrony wód powierzchniowych*. Materiały do monografii przyrodniczej regionu gdańskiego. Gdańsk 2003, 53–65.

[4] Pasternak K.: *Bottom sediments of the polluted dam reservoir AT Otmuchów*. Acta Hydrobiol. 1970, **12**, 377–380.

[5] Nocoń W.: *Zawartość metali ciężkich w osadach dennych rzeki Kłodnicy*. J. Elementol. 2006, **11**(4), 457–466.

[6] Miranda L.E., Hargreaves J.A. and Raborn S.W.: *Predicting and managing risk of unsuitable dissolved oxygen in a eutrophic lake*. Hydrobiologia 2001, **457**, 177–185.

[7] Kajak Z.: *Hydrologia – Limnologia*. Ekosystemy wód śródlądowych. Wyd. PWN, Warszawa 2001.

[8] Bojakowska I. and Gliwicz T.: *Wyniki geochemicznych badań osadów wodnych Polski w latach 2000–2002*. Biblioteka Monitoringu Środowiska, Warszawa 2003.

[9] Cieszewski D., and Malik I.: *Zapis XX-wiecznej historii zanieczyszczenia rzeki Małej Panwi metalami ciężkimi w jej osadach*. Przegl. Geol. 2003, **51**(20), 142–147.

[10] Skorbiłowicz E.: *Ocena jakości środowiska wodnego wybranych rzek powiatu Siemiatycze*. Woda – Środowiska – Obszary Wiejskie 2004, **4**(11), 429–444.

[11] Koc J., Nowicki Z., Glińska K. and Łachacz A.: *Kształtowanie się jakości wód w warunkach malej antropopresji na przykładzie zlewni strugi Ardung (Pojezierze Olsztyńskie)*. Zesz. Nauk. Komitetu „Człowiek i Środowisko” 2000, **25**, 155–166.

[12] Tobolski K.: Przewodnik do oznaczania torfów i osadów jeziornych. PWN, Warszawa 2000.

[13] Mc Coll R.H.S.: *Chemistry of sediments In relation to trophic condition of Wight Rotoura Lakes*. J. Mar. Freshwater Res. 1977, **11**, 371–380.
[14] Januszkiewicz T. and Samulowska B.: *Chemizm współczesnych osadów dennych jeziora Wadąg k. Olsztyna.* Zesz. Nauk. ART Olsztyn 1978, **187**, 31–58.
[15] Rybak J.I.: *Przegląd badań nad osadami*. Ekol. Pol. 1989, **15**, 19–30.
[16] Kentzer A.: Fosfor i jego biologiczne dostępne frakcje w osadach jezior różnej trofii. Wyd. Uniwersytetu M. Kopernika, Toruń 2001, 5–9.
[17] Kowalczewska-Madura K.: *Materia organiczna w osadach dennych jeziora Swarzędzkiego*. Jeziora i sztuczne zbiorniki wodne. Uniwersytet Śląski, Sosnowiec 2004, 125–131.
[18] Siwek H., Włodarczyk M., Brzostowska-Śelechowska D. and Wachowiak M.: *Wpływ wybranych parametrów fizyczno-chemicznych osadu na zawartość nieorganicznych form fosforu w osadach dennych małych zbiorników polimiktycznych.* Acta Agrophys. 2009, **13**, 497–503.
[19] Lis J. and Pasieczna A.: Atlas geochemiczny Polski 1: 2 500 000. Państw. Inst. Geol., Warszawa 1995.
[20] Bojakowska I. and Sokołowska G.: *Geochemiczne klasy czystości osadów wodnych.* Przegl. Geolog. 1998b, **46**, 49–54.
[21] Nicholson F.A., Smith S.R., Alloway B.J., Carlton-Smith C. and Chambers B.J.: *An inventory of heavy metals inputs to agricultural soils in England and Wales*. Sci. Total Environ. 2003, **311**, 205–219.
[22] Szafran K.: *Metale ciężkie w osadach dennych trzech płytkich jezior łęczyńsko-włodawskich*. Acta Agrophys. 2003, **1**, 329–337.

## WPŁYW UŻYTKOWANIA ZLEWNI NA AKUMULACJĘ OŁOWIU I CYNKU W OSADACH DENNYCH NA PRZYKŁADZIE JEZIOR ARDUNG I BUKWAŁD

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**Abstrakt:** Do badań mających na celu określenie wpływu użytkowania zlewni jezior na akumulację ołowiu i cynku w ich osadach dennych wytypowano dwa zbiorniki położone na obszarze Pojezierza Olsztyńskiego. Zlewnie badanych jezior obejmują obszary o zróżnicowanym zagospodarowaniu – od obszarów leśnych po użytki rolne.

Jezioro Ardung (N 53°45′, E 20°55′) położone jest we wschodniej części Pojezierza Mazurskiego ok. 25 km na wschód od Olsztyna. Powierzchnia jeziora wynosi 26,2 ha, natomiast jego maksymalna głębokość 3,6 m. Na obszarze zlewni jeziora o powierzchni 1539 ha grunty orne stanowią 2 %, łąki i pastwiska 2 %, odłogi w znacznym stopniu zakrzewione 11,4 % i 84,6 % lasy. Jezioro Bukwałd (N 53°58′, E 20°16′) położone jest w okolicach wsi Bukwałd w gminie Dywity około 20 km na północ od Olsztyna. Całkowita zlewni jeziora Bukwałd wynosi 1156,8 ha, z czego 60 % stanowią grunty orne, 31 % to lasy i tereny zalesione, pozostałą część stanową nieużytki.

Badane osady charakteryzowały się niskim stężeniem badanych pierwiastków i w jeziorze Ardung średnie stężenie Pb wynosiło 28,3 mg Pb/kg s.m., natomiast Zn – 32,3 mg Zn/kg s.m., zaś w jeziorze Bukwałd było to 33,3 mg Pb/kg s.m. oraz 91,1 mg Zn/kg s.m. Także całkowita akumulacja cynku i ołowiu w osadach badanych zbiorników zarówno w odniesieniu do powierzchni lustra wody, jak i zlewni była zdecydowanie większa w osadach jeziora Bukwałd niż śródleśnego jeziora Ardung.

**Słowa kluczowe:** jeziora, osady denne, zlewnia, pierwiastki śladowe, ołów, cynk