DE GRUYTER OPEN

DOI: 10.1515/eces-2015-0007 ECOL CHEM ENG S. 2015;22(1):107-123

Martyna A. RZĘTAŁA[1], Andrzej JAGUŚ[2], Robert MACHOWSKI[1] and Mariusz RZĘTAŁA[1*]

THE DEVELOPMENT OF FRESHWATER DELTAS AND THEIR ENVIRONMENTAL AND ECONOMIC SIGNIFICANCE

ROZWÓJ I ZNACZENIE ŚRODOWISKOWO-UŻYTKOWE DELT W ZBIORNIKACH ŚRÓDLĄDOWYCH

Abstract: The article presents the results of studies concerning the delta forms that arise as a result of the sedimentation of the debris fed to water bodies by watercourses. The study covered several dozen anthropogenic water bodies in the Upper Silesia region, which is well known for its high degree of urbanisation and industrialisation. Basic research work included morphometric measurements of deltas, analyses of the mechanical and chemical composition of delta sediments and analyses of the chemical composition of the common reed growing on the deltas. The research has demonstrated that the deltas exhibit certain characteristics typical of anthropogenic forms that result from the pollutants found in watercourses. In delta sediments, grains of sand usually dominate, but in many cases the share of the < 0.02 mm fraction is as high as ca. 30%. Sediments often contain fine coal and other organic pollutants, which is reflected by high weight loss on ignition. The content of trace elements in delta sediments is usually many times higher than the geochemical background for all types of sedimentary rocks. Deltas are an environment where pollutants accumulate and some of them are assimilated by plants. The content of macro elements in common reed tissues from different deltas does not vary widely while the content of trace elements often results from their content in the sediments. The material that forms deltas can be extracted and in some cases even used as fuel.

Keywords: fluvial geomorphology, sedimentation, deltas, anthropogenic water bodies, Upper Silesia

The morphodynamic nature of the confluence zone where river water enters the basin of a lake, whether natural or man-made, leads to the development of a delta, or a sedimentation fan if its size is smaller. As the river deposits part of the material it carries from the catchment area upstream, its water undergoes its initial qualitative and quantitative transformation in a limnic water body [1-4]. For this reason research into the development of the delta will not only help understand the processes of lake siltation, but will also provide insights into the environmental risks involved in the inflow of allochtonic material [2, 3, 5]. This type of research is far from popular and the topic of fluvial sedimentation in lakes tends to be

[1] Faculty of Earth Sciences, University of Silesia, ul. Będzińska 60, 41-200 Sosnowiec, Poland, phone +48 32 368 93 60
[2] Institute of Environmental Protection and Engineering, University of Bielsko-Biala, ul. Willowa 2, 43-309 Bielsko-Biała, Poland, phone +48 33 827 91 87, email: ajagus@ath.bielsko.pl
[*]Corresponding author: mrz@wnoz.us.edu.pl

considered in the wider context of limnic bottom sedimentation [6-9]. While the bulk of delta research is devoted to sea and ocean deltas, including the Nile [10], Huang He and Yangtze [11, 12], Mississippi [13] and Danube [14], many researchers have noticed a need for the quantitative and qualitative investigation of deltas in freshwater bodies, including their potential uses for social and economic purposes [15-21]. An example of an inland delta that has been subject to detailed sedimentological research is the River Selenga delta in Lake Baikal [22]. The disproportion in the amount of research available between freshwater and maritime deltas is likely to be caused by the incomparably smaller size of freshwater deltas, which reduces their environmental significance to just the local scale. Polish delta research has focused largely on deltas in manmade reservoirs in mountainous areas and for this reason exposed to intensive silting [23].

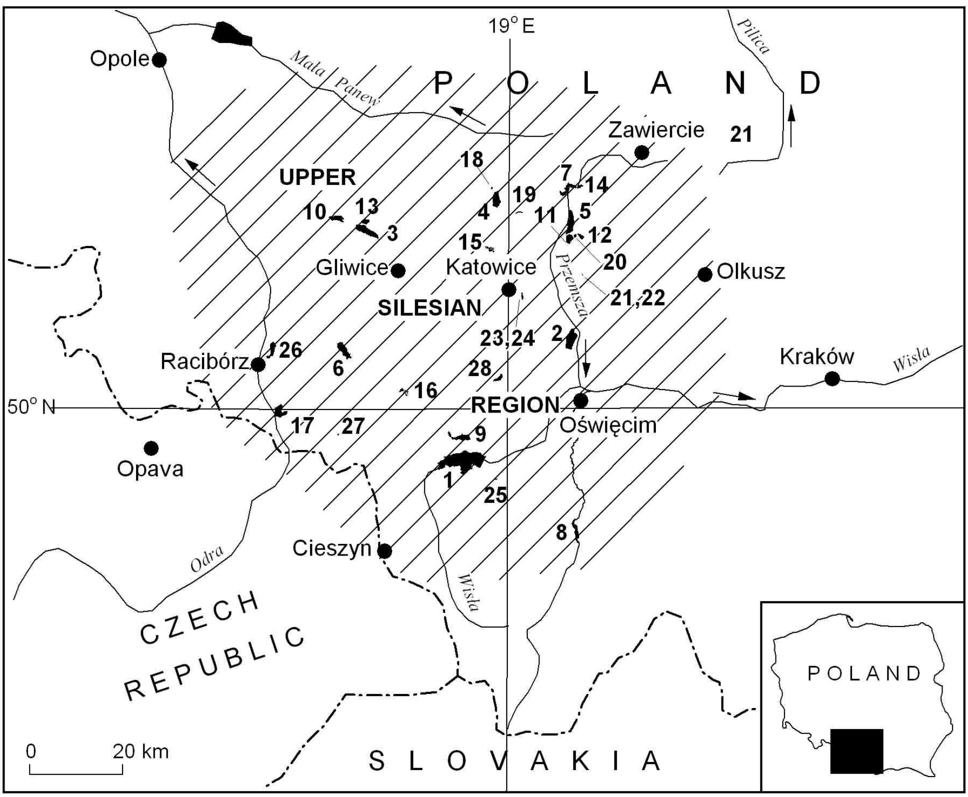


Fig. 1. The Upper Silesia region and reservoirs studied: 1 - Goczalkowice, 2 - Dzieckowice, 3 - Dzierzno-Duze, 4 - Kozlowa Gora, 5 - Kuznica Warezynska, 6 - Rybnicki Reservoir, 7 - Przeczyce, 8 - Porabka, 9 - Laka, 10 - Plawniowice, 11 - Pogoria III, 12 - Pogoria I, 13 - Dzierzno Male, 14 - Pond at the confluence of the Mitrega, 15 - Zabie Doly, 16 - Pond at Zory, 17 - Wielikat Pond, 18 - Ostroznica, 19 - Rogoznik I, 20 - Pogoria II, 21 - Sosnowiec-Klimontow (bowl N), 22 - Sosnowiec-Klimontow (bowl E), 23 - Milicyjny Reservoir, 24 - Reservoir on the Lesny Stream, 25 - Pond in the Wapienica valley, 26 - Lezczok, 27 - Reservoir in the Mszanka valley, 28 - Paprocany

The authors of this paper undertook delta research in freshwater bodies in the Upper Silesia region of southern Poland (Fig. 1). Located close to Poland's border with the Czech Republic and Slovakia the region has a varied lowland-upland configuration and is regarded as one of the most urbanised and industrialised in Poland. Upper Silesia owed its development to accessible natural deposits, including coal, zinc and lead ores, dolomite and other minerals. The centre of the region is dominated by mining, steel, machinery manufacturing and processing industries with accompanying services, while agriculture occupies the peripheries of the region. Economic development has changed the local water relations and a growing water demand for industrial and municipal purposes has seen the establishment of thousands artificial water reservoirs for flood retention and potable and industrial water abstraction [24]. These water bodies vary in origin (including dam-retained reservoirs, flooded quarry pits, subsidence basins, ponds surrounded by dykes, sedimentation ponds and pools) and are subject to various anthropogenic influences. Small reservoirs of the order of several hectares dominate, but the few larger lakes are characterised by a discernible environmental influence. The largest of these include: Goczalkowice (3200 ha; 167.0 hm^3), Dzieckowice (730 ha; 52.8 hm^3), Dzierzno Duze (615 ha; 94.0 hm^3), Kozlowa Gora (587 ha; 15.3 hm^3), Kuznica Warezynska (560 ha; 51.1 hm^3), Rybnicki Reservoir (555 ha; 24.0 hm^3), Przeczyce (470 ha; 20.7 hm^3), Porabka (380 ha; 26.6 hm^3), Laka (350 ha; 11.2 hm^3), Plawniowice (240 ha; 29.2 hm^3), Pogoria III (208 ha; 12.0 hm^3).

As the density of reservoirs increased with time, and especially as flow-through lakes were formed, new geomorphologic processes involving fluvial transport were started resulting in the emergence of numerous deltas which have become a feature of the region's geographical environment [25]. The development of delta forms in the study area is a dynamic process. This largely results from the young age of many water bodies. A considerable majority of them formed during the past 50 years and the increase in the water surface area has led to the emergence of a new lake district [24]. Observations related to the changes in delta formation zones or water body shores point to an early stage of development of bottom and littoral forms [25].

This research project had the objective of investigating the delta forms in Upper Silesian water bodies that were subjected to various kinds of anthropopressure, including urban, mining, industrial, municipal and agricultural. The potential for developing the deltas was also investigated. These objectives were selected in view of the perceived deficit of assessments of the environmental role of lake deltas and their economic potential, as well as the unique nature of Upper Silesian deltas as a product of human impact on the local natural environment.

Research methods

The project involved several dozen reservoirs in the region. This paper is based on a selection of the lakes (Fig. 1). Documentation concerning the development of deltas was collected from the mid-1990s until 2010. Studies of the composition and contamination of delta sediments were conducted on the basis of irregular sampling of sediments from 1998 until 2008 and the results obtained have been averaged and are presented as such in the article. The common reed study was carried out once in 2008.

The research involved:

– Taking stock of the delta landforms;
– Measuring the volume of rubble supply and its sedimentation in the lakes;

- Measuring landforms in the delta build-up zones and the deltas themselves (using a tachymeter, theodolite and an echosounder);
- Determining the mechanical composition (using the sieve and sieve/aerometer methods) and the physicochemical properties of the sediment deposited;
- Determining the chemical composition of the stems and leaves of the common reed (*Phragmites australis* (Cav.)Trin. ex Steud) growing on the deltas.

Most of the lab work was performed using standard methods. Concentrations of certain elements in the sediment (*ie* Au, As, Br, Co, Cr, Hf, Hg, Ir, Mo, Rb, Sb, Sc, Se, Ta, Th, U, W, La, Ce, Nd, Sm, Eu, Tb, Yb and Lu) were determined by instrumental neutron activation analysis (INAA) using a 2MW Pool Type research reactor ($5x10^{11}$ n $cm^{-2} \cdot s^{-1}$ stream of thermal neutrons; gamma radiation measured with Ge ORTEC and CANBERRA detectors typically after seven days of exposure). Other elements (SiO_2, TiO_2, Al_2O_3, Fe_2O_3, MnO, MgO, CaO, Na_2O, K_2O, P_2O_5, Ba, Sr, Zr, Y, Be and V) were determined by atomic emission spectroscopy with inductively coupled plasma (ICP). Here a 0.2 g prepared sample was coupled with lithium metaborate and then dissolved in 15% HNO_3 and analysed using the ICP method. The method was also used to determine another set of elements, *ie* Cu, Pb, Zn, Ag, Ni, Cd and Bi, after completely dissolving 0.25 g samples in 10 cm^3 HCl-HNO_3-$HClO_4$-HF at 200ºC and then diluted to 10 cm^3 in *aqua regia*. X-ray fluorescence analysis was used to determine the concentration of Nb, Rb, Pb, Ga, Sn and S where samples took the form of 32 mm pastilles pressed down from 6 gram portions with polyvinyl alcohol as the binding substance. And finally, the plant material was analysed for the presence of As, Ba, Br, Ca, Co, Cr, Fe, K, Na, Sb and Zn by means of the INAA method. Plant material was collected in the middle of the vegetation growth period. Samples included above-ground parts of common reeds consisting of stems and leaves. The material collected was dried at a temperature of 105°C. After they had been dried, the samples were homogenised using an agate mill. In the plant material thus prepared, the presence of As, Ba, Br, Ca, Co, Cr, Fe, K, Na, Sb and Zn was determined using the INAA method. Measurements were performed at Activation Laboratories Ltd. in Canada.

Results and discussion

Development of deltas

The survey exercise showed that permanent deltas are particularly frequently found in large flow-through lakes formed in abandoned quarries and pits (*eg* Dzierzno Duze, Pogoria I) and dam-retained lakes (*eg* Przeczyce, Kozlowa Gora), but they also occur in smaller lakes of various origins. In general the formation of deltas is directly linked to the mineral and organic material loading of the watercourses ending up in lakes. The quantity of such material normally depends on the type of lithology of the river basin, but in Upper Silesia much of the material carried by the river is the result of human activity, including waste-water or industrial effluent discharge, coal-mine drainage, erosion of mining wastes or agrocoenoses, the flushing of dust-polluted surfaces, etc. With ongoing large-scale underground mining operations in the area fluvial transport is strongly influenced by the lithology of the resources exploited. This is particularly true of hard coal and is translated into the presence of coal tailings in fluvial and limnic sediments. Tailings containing coal dust and waste rock are formed in sedimentation ponds and are then transported into local watercourses, which transport them to their accumulation zones in the deltas and on lake beds [26]. In other words, the supply of mineral and organic substances into the flow-through reservoirs of Upper Silesia is a consequence of anthropogenically stimulated quantitative and qualitative changes in the water circulation. Watercourses that drain urban and industrial zones tend to carry much more debris than watercourses in areas without strong anthropopressure. The degree of river training also plays its role in the scale of the volumes transported and if a river is fully channelled it will carry nearly all of its transported debris to a final deposition zone.

The study showed that the discharge of material to the region's reservoirs varies. For example [26] the amount of dragged and rolled material measured in the confluence reaches of the watercourses ranged from 12 mg/s in the Pogoria III reservoir, to 150 mg/s in the Przeczyce reservoir, to 138 mg/s in the Kozlowa Gora reservoir up to no less than 0.37 kg/s in the Dzierzno Duze reservoir. The variation was equally great in terms of the suspended and floating material at: 1.6 g/s (Pogoria III), 9.2 g/s (Przeczyce), 7.7 g/s (Kozlowa Gora) and 448.0 g/s (Dzierzno Duze). Some of the material is deposited in the reservoir basins, starting from the delta development zones. In his study of the Dzierzno Duze reservoir, Kostecki [27] showed that 90% of the rubble carried by an inflowing river was deposited within 10-20 minutes of the water entering the reservoir bowl.

The morphometrics of the reservoir basin, especially of its bed within the contact zone between the fluvial and limnic waters, plays a crucial role in the formation of a delta. Another factor is the water level fluctuation, which in Upper Silesia is driven primarily by the economic use of the retention function. Taking into account factors that drive the water levels, Rzetala [28] differentiates between two types of reservoirs, *ie* those controlled by natural factors and others controlled by anthropogenic factors. Water bodies in the former category (*eg* Pogoria III, Plawniowice) function in a way that resembles the water level fluctuations in natural lakes, while the latter (*eg* Dzierzno Duze, Laka, Dzierzno Male) offer a model case of human impact on water level fluctuation. The amplitude of water level fluctuation determines the zone of change in the levels of the erosion base and by this, also, the spatial extent of the direct impact of the erosion and sedimentation processes along the reaches of the confluence. The debris deposition zones were found to shift depending on the water level in the reservoirs. At the times of highest water level, sedimentation is concentrated in the back-water zone, while when the water is low the zone shifts towards the reservoir's open waters. The study observed shifts in the sedimentation zone by hundreds of meters and in extreme cases even more than one kilometre. One more effect of the water level in the reservoir is the size of the exposed delta surface, which in turn affects the scale of vegetation succession and the intensity of the subsequent process of organic matter sedimentation.

One of the largest deltas in the region has developed in the Dzierzno Duze reservoir in the River Klodnica catchment. This is characterised by strong urban and industrial anthropomorphisation (Fig. 2). At times of low water level, the delta has a surface area of more than one square kilometre and its thickness exceeds ten meters. The delta drops sharply towards the reservoir turning into a fine-fractioned bottom sediment ranging in thickness from 10-20 cm to 1.5 metres. The volume of the delta itself is estimated at slightly more than 2 million cubic metres while another 2 million cubic metres have been accumulated in its direct vicinity. This is, however, an exceptionally large example in a region dominated by much smaller deltas with volumes ranging typically between single to thousands cubic metres, their surface areas varying from single to hundreds of square metres and whose average thickness is no greater than a figure between less than 20 centimetres and several tens of centimetres. They have peculiar structures as a result of being built by various anthropogenically influenced processes.

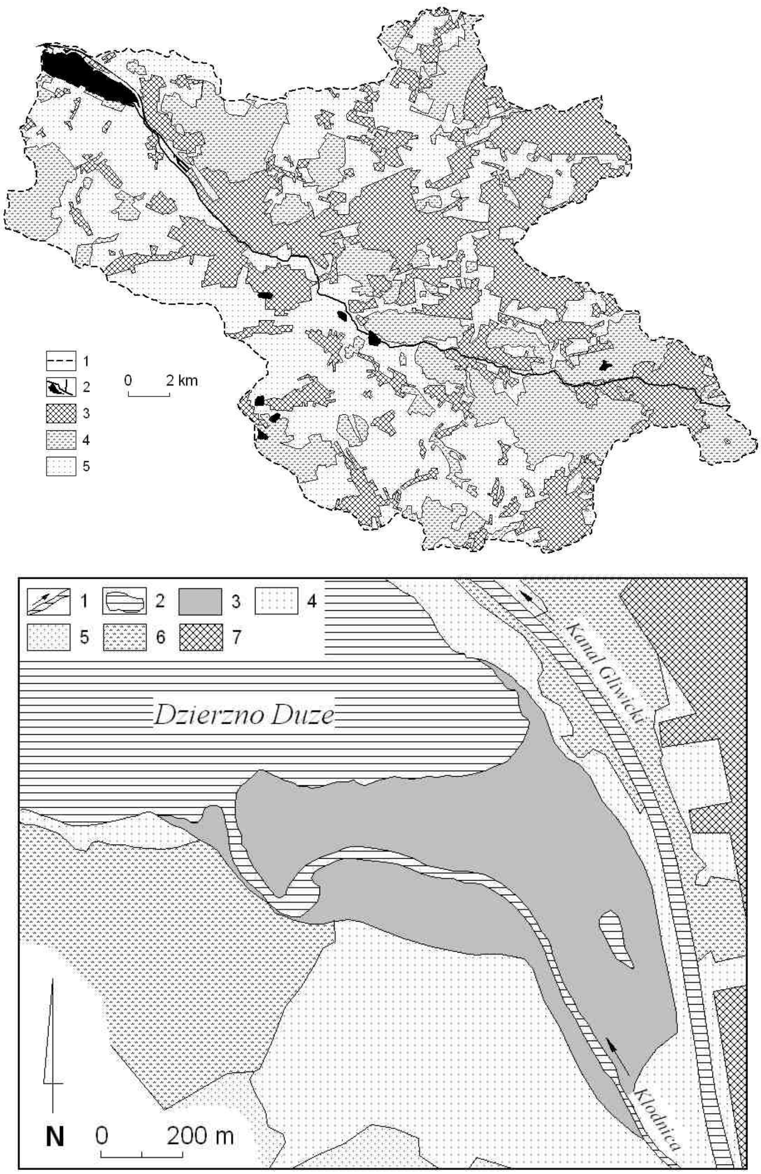
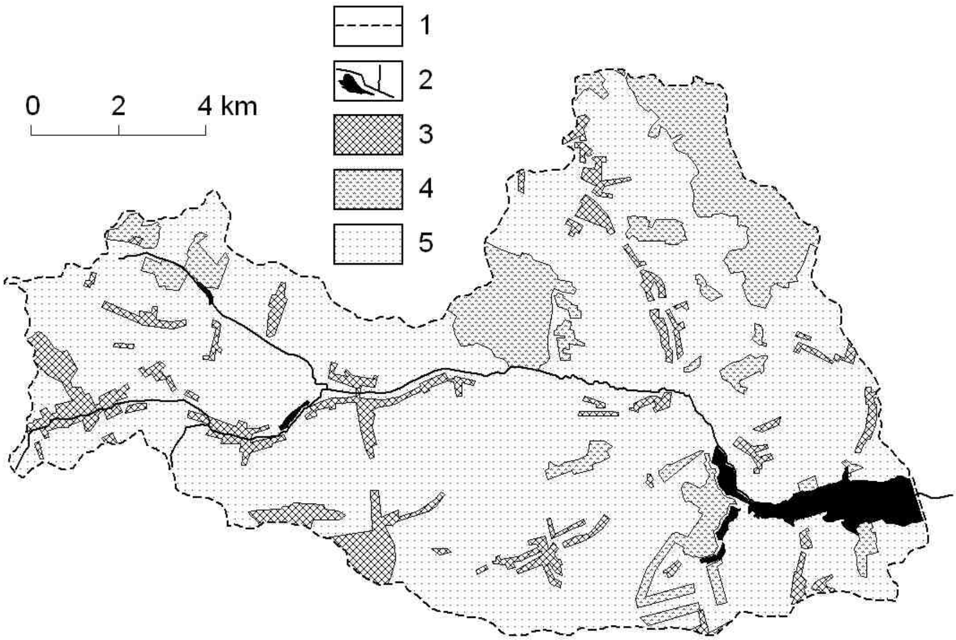


Fig. 2. Development in the Dzierzno Duze reservoir catchment (up) and the delta of Klodnica River in this reservoir (down) [26, 28]. Legend up: 1 - river catchment boundaries, 2 - surface waters, 3 - urban areas (including industrial), 4 - woodland, 5 - agricultural land. Legend down: 1 - watercourses, 2 - water reservoirs, 3 - deltas, 4 - meadows and turf vegetation, 5 - arable land, 6 - woodland and forested land, 7 - industrial land



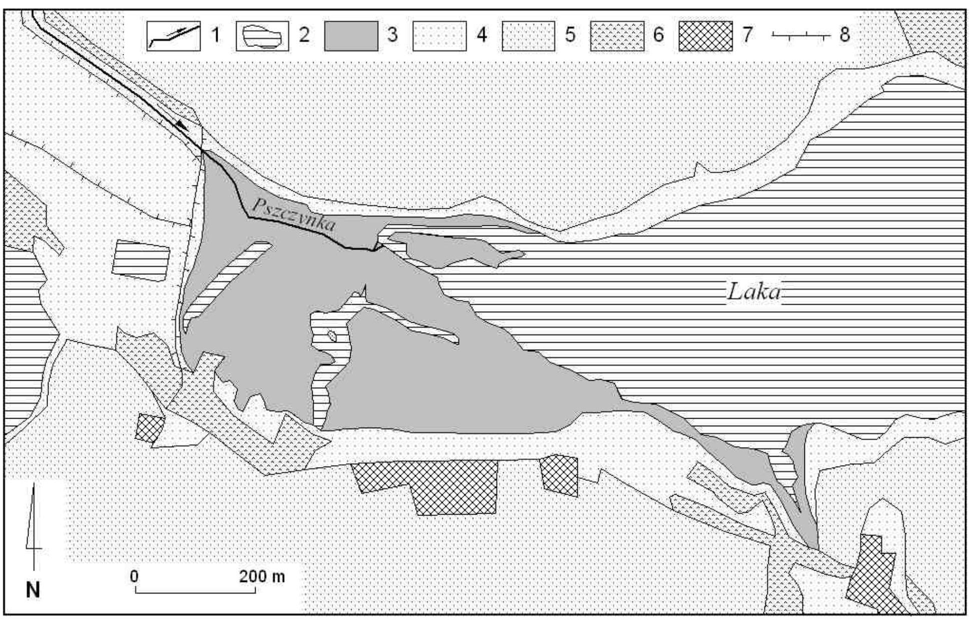


Fig. 3. Development in the Laka reservoir catchment (up) and the delta of Pszczynka River in this reservoir (down) [25, 28]. Legend up: 1 - river catchment boundaries, 2 - surface waters, 3 - urban areas (including industrial), 4 - woodland, 5 - agricultural land. Legend down: 1 - watercourses, 2 - water reservoirs, 3 - deltas, 4 - meadows and turf vegetation, 5 - arable land, 6 - woodland and forested land, 7 - industrial land, 8 - dykes, dams and embankments

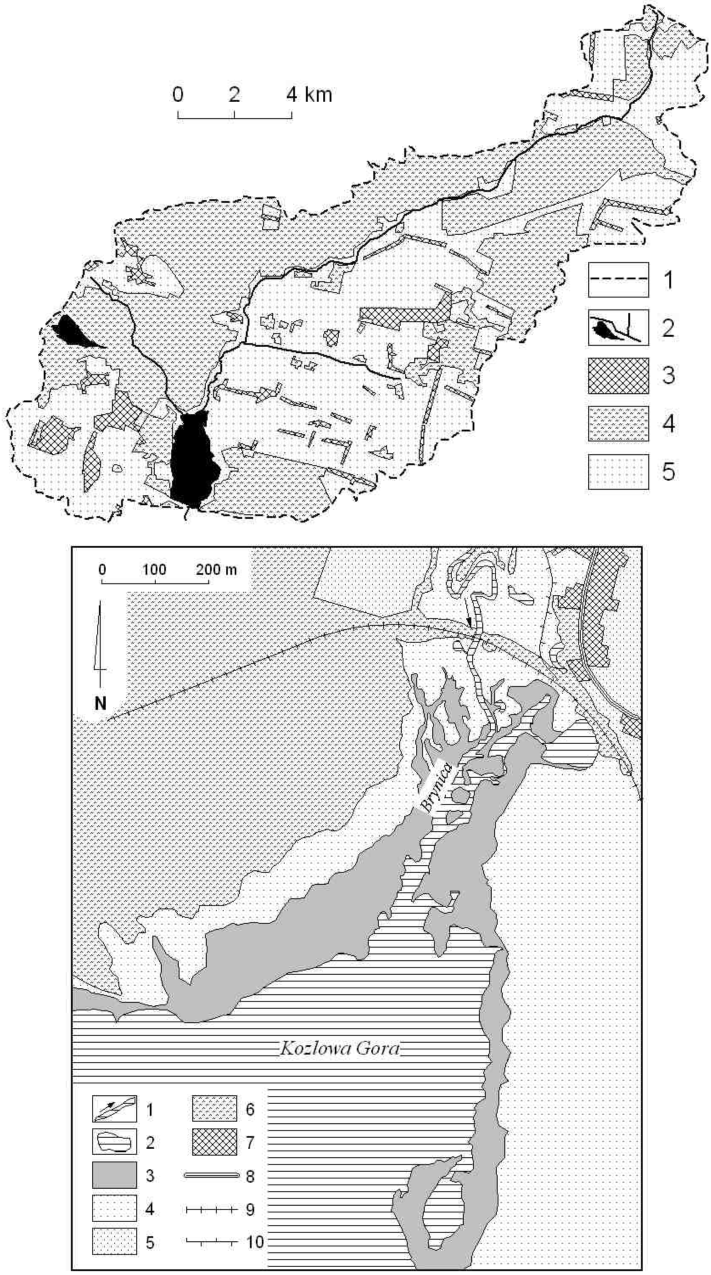


Fig. 4. Development in the Kozlowa Gora reservoir catchment (up) and the delta of Brynica River in this reservoir (down) [25, 28]. Legend up: 1 - river catchment boundaries, 2 - surface waters, 3 - urban areas (including industrial), 4 - woodland, 5 - agricultural land. Legend down: 1 - watercourses, 2 - water reservoirs, 3 - deltas, 4 - meadows and turf vegetation, 5 - arable land, 6 - woodland and forested land, 7 - industrial land, 8 - dirt-roads, 9 - elevated track of abandoned narrow-gauge railway, 10 - dykes, dams and embankments

An example of a delta that has developed under strong agricultural anthropopressure on the river Pszczynka is that in the Laka reservoir (Fig. 3), while a characteristic delta formed by a river in a largely wooded river basin is found on the river Brynica in the Kozlowa Gora reservoir (Fig. 4). An interesting delta form has been formed by the Pogoria Stream in an abandoned sandpit known as the Pogoria I reservoir. Indeed, some of the material in the delta comes from the edge of the old pit. Deltas were also found in water bodies functioning as cascades.

Properties of delta sediments

Basic composition and physicochemical testing of the delta deposits revealed that they were related to the river catchment lithology, although they had often been anthropogenically transformed, including by pollution (Tables 1-3). For example the delta sediments of the Pogoria I reservoir correspond to the sandy formation predominant in the river catchment. Similarly the deltas in the Kozlowa Gora and Przeczyce reservoirs are built of sediments related to Triassic, Jurassic and Neogenic formations found in many areas of the respective river catchments. A good example of an anthropogenic delta sediment is the delta of the River Klodnica in the Dzierzno Duze reservoir. The sediment's granularity is dominated by various sizes of coal tailings, silt and sand. The sandy fraction is clearly dominant, but there is a considerable concentration of dust and clay fractions. The underlying autochthonic formations and the delta fringes are 100% sandy. Overall, the deltas of Upper Silesia are characterised by their variety and the differences include sediment granularity (Tab. 1). The sediments are dominated by grain sizes larger than 0.1 mm, which are estimated at approximately 54% on average, while the remaining part is almost equally split between the 0.02-0.1 mm fraction (ca. 21%) and grains smaller than 0.02 mm (ca. 25%).

Table 1

Average mechanical composition (grain size) of sediments in certain delta formations (after Rzetala et al [26] with additional data)

Water reservoir	> 0.1 mm	0.1-0.02 mm	< 0.02 mm
	[% by weight]		
Dzierzno Duze	67.4	20.1	12.5
Pogoria I	63.3	9.3	27.4
Pogoria III	59.0	8.0	33.0
Przeczyce	57.8	24.0	18.2
Kozlowa Gora	44.0	27.3	28.7
Zabie Doly	39.2	29.7	31.1
Dzierzno Male	52.5	25.4	22.1
Plawniowice	72.8	11.4	15.8
Pond at Zory	50.3	35.0	14.7
Wielikat Pond	19.7	24.3	56.0

The chemistry of the delta sediments varies widely (Table 2). It is dominated by SiO_2 and organic matter, as expressed by the loss on ignition (LIg), but Al_2O_3, Fe_2O_3 and sometimes also CaO have their significant shares as well. The sediments from the delta in the Dzierzno Duze reservoir had nearly 50% loss on calcination and the SiO_2 concentration was low (25.44%). Trace element contamination was equally varied in the delta sediments (Table 3). For example arsenic concentration ranged from less than 20 ppm to several tens of ppm, zinc varied from hundreds to thousands ppm and cadmium from *ca*. 1 ppm to several tens ppm. In most cases trace element contamination exceeded by several times the geochemical background, *ie* natural values typical for all sedimentary rocks [29].

Table 2

Average basic composition of sediments in selected deltas

Water reservoir	**SiO_2**	**Al_2O_3**	**Fe_2O_3**	**MnO**	**MgO**	**CaO**	**Na_2O**	**K_2O**	**P_2O_5**	**LIg***
	[%]									
Dzierzno Duze	25.44	9.05	6.20	0.06	1.55	2.54	0.36	1.21	0.71	48.74
Pogoria I	63.38	13.60	8.56	0.14	1.37	1.61	0.65	2.49	0.24	7.06
Pogoria III	61.83	14.20	5.08	0.08	1.82	2.94	0.49	2.48	0.11	10.34
Przeczyce	53.10	8.60	6.32	0.21	1.03	6.13	0.41	1.61	0.72	19.89
Kozlowa Gora	55.74	8.23	4.79	0.09	0.50	1.88	0.47	1.27	0.30	25.67
Zabie Doly	57.42	8.32	6.09	0.23	0.79	6.80	0.58	1.65	0.19	16.32
Dzierzno Male	36.00	6.67	2.93	0.07	0.74	21.84	0.38	1.12	0.32	28.12
Plawniowice	45.05	6.96	2.26	0.05	0.55	13.43	0.40	1.22	0.33	27.21
Pond at Zory	65.24	7.22	2.90	0.04	0.45	0.97	0.67	1.57	0.27	19.04
Wielikat Pond	66.56	11.43	3.49	0.03	0.97	0.99	0.90	2.16	0.20	12.09

*LIg - loss on ignition

Table 3

Average concentration of elements in sediments of selected deltas

Water reservoir	**Ba**	**As**	**Be**	**Cu**	**Pb**	**Zn**	**Ni**	**Cd**	**Co**	**Cr**
	[ppm]									
Dzierzno Duze	1673	19.3	2.0	104.5	122.6	723	48.1	7.3	20.6	103.0
Pogoria I	679	19.3	3.3	44.0	239.3	1276	50.0	15.3	22.0	132.3
Pogoria III	455	12.0	2.0	24.0	59.0	208	41.0	1.1	18.0	111.0
Przeczyce	533	19.0	2.0	35.0	517.0	1336	28.0	10.6	15.0	92.0
Kozlowa Gora	1080	41.0	2.5	60.0	479.0	1729	26.5	18.1	16.0	74.0
Zabie Doly	763	62.3	3.0	63.3	956.7	3610	39.7	31.6	18.0	78.0
Dzierzno Male	445	12.0	1.5	20.0	63.5	317	21.0	2.2	14.0	59.5
Plawniowice	460	13.1	1.6	23.6	89.6	408	19.0	17.7	11.1	66.0
Pond at Zory	416	14.3	1.3	23.7	67.3	165	22.3	1.9	7.7	65.3
Wielikat Pond	475	11.3	2.0	29.7	43.3	116	32.3	0.8	8.7	84.0

Water reservoir	**Cs**	**Sb**	**La**	**Ce**	**Nd**	**Sm**	**Eu**	**Sc**	**U**	**Th**
	[ppm]									
Dzierzno Duze	8.2	5.0	24.2	45.6	18.2	4.3	1.0	9.8	4.2	10.5
Pogoria I	10.0	3.5	56.1	108.7	53.3	9.6	2.1	13.9	4.2	14.2
Pogoria III	11.0	1.5	44.2	94.0	39.0	7.6	1.6	13.7	3.7	13.3
Przeczyce	8.5	3.1	34.7	66.0	27.0	5.8	1.0	7.8	3.0	9.3
Kozlowa Gora	5.1	3.3	33.2	64.0	26.0	5.7	1.1	8.5	5.3	9.4
Zabie Doly	6.2	6.6	30.1	58.0	25.3	5.1	1.3	8.5	4.1	10.4
Dzierzno Male	4.2	1.9	23.7	54.5	24.0	4.2	0.9	6.4	2.9	7.4
Plawniowice	3.6	1.7	27.9	57.5	24.5	4.6	0.9	5.9	3.8	10.2
Pond at Zory	3.0	1.7	25.3	49.3	27.0	2.9	1.2	6.0	2.6	7.0
Wielikat Pond	6.3	1.3	34.7	70.0	34.7	4.2	1.3	10.3	3.2	7.6

In the Upper Silesian reservoirs the geochemical background is exceeded not just in the deltas, but also in other parts of the reservoir basins and the degree of the contamination excess makes these water bodies unique on a global scale. This is revealed by comparative studies on heavy metal concentrations in the bottom sediments of many reservoirs/lakes around the world (Table 4). Very few reservoirs in other parts of the world have higher concentrations of chromium, nickel and copper, while the levels of zinc, cadmium and lead found in the bottom sediments in Upper Silesia are unprecedented on a global scale.

Table 4

Heavy metal concentrations (range of variation or average) in the bottom sediments of selected limnic water bodies of the world

Water reservoir	Cd	Pb	Cu	Zn	Cr	Ni
	[ppm]					
Upper Silesian reservoirs (Poland) [28]	0.9-51.8	32-1620	9-197	177-4790	66.1-146.0	7-74
Tresna (Poland) [30]	0.0-1.7	25-62	15.7-36.2	83-177	11.5-56.0	30.7-66.2
Reservoir 111 (Germany) [31]	-	7.8-31.4	-	12-186	4.4-26.2	1.1-28.9
Balaton (Hungary) [32]	0.1-0.7	2.4-160.0	0.7-36.0	13-150	5.7-66.0	4.4-55.0
Stockholm lakes (Sweden) [33]	2.1-4.7	75-413	31-1125	170-1539	15.2-38.0	32.0-53.1
Lakes near Murmansk (Russia) [34]	<0.5-3.5	1-176	5-6495	17-1327	-	7-25790
Seliger lake system (Russia) [35]	0.0-1.2	0.9-68.2	1.1-29.8	5.3-170.0	1.2-48.5	-
Sapanca (Turkey) [36]	0.1-0.6	10.1-17.8	17.3-35.5	39.0-75.3	13.1-22.5	20.1-34.3
Hazar (Turkey) [37]	-	-	10-64	46-210	17-79	38-130
Koronia (Greece) [38]	1.0-1.1	16.3-24.5	14.8-18.8	72.1-99.6	27.3-37.0	-
Volvi (Greece) [38]	0.7-0.8	10.5-14.4	14.0-16.2	47.9-58.9	20.1-25.3	-
Wadi El Natrum (Egypt) [39]	23.0-29.0	37-71	27-231	20-91	-	26-28
Lake Nasser (Sudan/Egypt) [40]	3.0-11.0	12-29	8.5-68.5	30.0-96.5	4.5-50.0	91.5-145.0
Lake Victoria (Tanzania) [41]	2.5	29.6	21.6	36.4	11	-
Rift Valley Lakes (Kenya) [42]	0.1-1.2	10.9-39.0	1.9-20.9	96.2-229.6	1.9-4.8	11.7-39.7
Taihu (China) [43]	3.9-8.9	258.9-495.4	9.7-102.2	71.6-370.3	84.0-162.1	33.5-124.0
Kolleru (India) [44]	0.0-0.3	2.5-5.1	270-572	356-622	44-66	0.2-2.2
Tuttle Creek (USA) [45]	0.3-0.6	16-160	20-44	65-150	48-120	19-77
Texoma (USA) [46]	1.0-3.0	5-15	9-136	33-242	12-51	6-31
Macquarie (Australia) [47]	<0.1-0.2	5.5-17.0	6-17	12-68	7-45	11-57

Significance of the deltas

The study showed that the deltas formed in the Upper Silesian reservoirs either play or have a potential to play a significant role in the natural environment of the region and in the economy. With their quantitative and qualitative differences and their location in the environment, deltas have a multitude of potential uses.

In terms of the natural environment the main significance of deltas has to do with increasing the local water retention capacity and providing ground for new habitats thus contributing to a greater biodiversity of areas, many of which are recovering from degradation. Indeed, deltas overgrown with reed bed vegetation, as well as some other types of vegetation, provide a good breeding ground for fish and birds and the latter can also use them as wintering areas because of the relatively long ice-free spells of the running water. An example of a delta with a high quality habitat is found in the Kozlowa Gora reservoir (Fig. 4). The river Brynica runs through the delta forming wetlands occupied with marshy ecosystems, hosting numerous wetland bird species. This has earned the delta and its surrounding area the status of a national bird refuge. Deltas of the kind have been or may be given legal protection. They contribute to making a landscape that promotes nature education (*eg* nature trails), tourism and recreation (angling, hunting, survival). For this potential to be realised deltas require some enhancement of their appeal in the form of fishing shelters, boardwalks, angling platforms, etc.

Table 5

Concentration of certain elements in the leaves and stems of common reed in deltas (after Rzetala et al [48] with additional data)

No. of reservoir (see Fig. 1)	**As**	**Ba**	**Br**	**Co**	**Cr**	**Sb**	**Zn**	**Na**	**Fe**	**K**	**Ca**
	[ppm]								**[%]**		
3	< 0.01	24.0	29.5	0.8	1.7	0.07	52.0	2910	0.02	0.7	0.7
13	0.14	53.0	8.4	0.3	0.6	0.09	82.0	295	0.02	1.1	0.8
10	0.29	51.0	17.5	0.4	0.5	0.07	21.0	998	0.02	1.8	0.8
18	0.35	45.0	22.5	0.6	0.8	0.27	107.0	479	0.02	2.9	0.5
4	0.58	33.0	11.0	0.4	0.6	0.14	250.0	768	0.02	1.0	0.7
19	0.08	22.0	3.0	0.2	0.4	0.1	48.0	860	0.01	0.8	0.6
12	0.13	36.0	2.5	0.2	0.5	0.13	62.0	635	0.02	0.9	0.6
20	0.22	62.0	11.0	0.4	0.4	0.12	200.0	534	0.02	0.8	1.2
11	0.21	47.0	12.5	0.4	0.4	0.15	80.0	277	0.02	1.5	0.7
21	< 0.01	13.0	12.5	0.4	0.4	0.12	20.0	614	0.02	1.0	0.2
22	0.17	22.0	31.5	0.8	0.4	0.11	36.0	1350	0.02	1.1	0.5
15	0.69	6.0	13.0	0.5	1.0	1.16	94.0	398	0.02	1.5	0.4
23	< 0.01	34.0	14.5	0.4	0.4	0.13	52.0	350	0.01	1.0	0.4
24	0.16	37.0	13.0	0.4	0.6	0.18	140.0	658	0.02	1.1	0.5
25	< 0.01	34.0	4.8	0.2	0.6	0.07	20.0	652	0.02	0.9	0.8
26	< 0.01	25.0	6.6	0.2	0.5	0.05	38.0	235	0.02	0.9	0.5
17	< 0.01	40.0	71.5	1.7	< 0.3	0.07	48.0	758	0.01	1.3	0.7
27	< 0.01	18.0	34.5	0.8	< 0.3	0.05	21.0	2080	0.01	1.5	0.2
28	0.15	31.0	5.0	0.2	0.6	0.06	76.0	751	0.01	0.7	0.5
1	0.14	13.0	5.4	0.2	0.3	0.05	43.0	1050	0.01	1.4	0.4

Deltas also play a role in river water treatment as the decelerating water sheds some of its load and with it the absorbed pollution. Delta formation zones are seen to function much like a pre-treatment sedimentation tank in waste water treatment technology. Additionally many delta sediments are found to be rich in nutrients and for this reason deltas lend themselves to vegetation succession. Studies have shown that delta surfaces are mostly overgrown with common reed (*Phragmites australis* (Cav.)Trin. ex Steud), which has a wide range of ecological tolerance [49]. With reeds on top of the delta its purification effect can be enhanced due to biological assimilation processes, although studies have not found any clear relationship between the chemical composition of the common reed and the fertility of the delta environment. The study found the composition in terms of certain elements (*eg* iron, potassium and calcium) to be rather similar in different deltas, but in the case of micro pollution (*eg* arsenic, antimony and zinc), its concentration in the sediment did have some impact on the concentration of the element in plants (Table 5). Large quantities of certain elements were linked to local industrial anthropopressure, such as the case of zinc pollution occurring in a location where a zinc smelting or processing plant was located nearby, or at least within the river catchment. Several of the deltas studied, such as that in the Laka reservoir (Fig. 3), where the delta is of the polder type with transversal dykes, may be seen to play a purification role. Periodically stagnant water creates an environment that is conducive to vegetation growth thus developing a kind of biofilter.

Deltas can have a valuable role in economic terms by providing a source of debris material for various purposes. Large scale exploitation is conducted within the delta of the Dzierzno Duze reservoir (Fig. 2). The operation started less than 20 years ago as a part of a scheme to clean the reservoir and prevent its silting-up and the extracted material, containing a large concentration of coal tailings, is mainly used as fuel. A mechanical stage separates the flammable and combustible fractions from the clay fraction, which is diverted back to the reservoir. The technology separates the debris in flotation and the final effect of several subsequent enrichment processes is a fuel that accounts for 70-80% of the delta sediment. According to a report by Environmental Research and Monitoring Centre [50] the sediment contained the following elements: arsenic - 7.72 mg/kg dry mass, chromium - 43.2 mg/kg dry mass, zinc - 464.0 mg/kg dry mass, cadmium - 6.5 mg/kg dry mass, copper - 15.3 mg/kg dry mass, nickel - 21.5 mg/kg dry mass, lead - 21.5 mg/kg dry mass, mercury - less than 0.05 mg/kg dry mass, benzo(a)pyrene - 0.640 mg/kg dry mass, benzo(b)fluoranthene - 1.16 mg/kg dry mass, benzo(k)fluoranthene - 0.34 mg/kg dry mass, benzo(g,h,i)perilene - 0.133 mg/kg dry mass, dibenzo(a,h)anthracene - 0.120 mg/kg dry mass, benzo(a)anthracene - 0.46 mg/kg dry mass, indeno(1.2.3)pirene - 0.066 mg/kg dry mass, PCB - less than 100 μg/kg dry mass. The quality of the fuel produced meets the requirements of coal fuel at 10 000-10 500 kJ/kg heating value [51].

Deltas similar to the one in the Dzierzno Duze reservoir can also be used as a source of biogas (*eg* methane and hydrogen) with a fermentation technology known from the processes used to remove landfill gas from municipal landfill and the biogas can then be converted into electricity or heat with special generators or burners.

The fieldwork performed in this study has shown that it is possible to use delta surfaces for agriculture or forestry. The deltas need to be sufficiently large and stabilised with turf, scrubs and tree vegetation. Such deltas are normally treated as unused land and so should lend themselves to forestry by natural regeneration or forest planting schemes, a land use choice typically applied in areas unsuitable for agriculture, in watershed areas and on the fringes of water reservoirs. The Upper Silesian deltas tend to be young, as they mostly started developing no more than several dozen years ago. For this reason only a very few of them, such as the Przeczyce reservoir delta; are permanently overgrown with shrubs and trees. The agricultural use of the deltas should concentrate on the production of non-food crops as there is a risk of excessive micro pollution in the sediment. Potential species include energy willow, wicker willow, decorative shrubs, etc.

Conclusions

The formation of deltas in newly created reservoirs is the result of a spontaneous change in natural conditions in response to a shift in the erosion base level. In sparsely developed areas, the material building the deltas is related to the lithology of the catchment, while under strong anthropogenic pressure conditions, like in the Upper Silesian region, it has the features of an anthropogenic deposit. Owing to anthropogenic character of researched deltas, they are also unique subjects for environmental studies. As a result of the research it can be concluded:

1. The significant loading of watercourses (up to 370 g/s of dragged and rolled and up to 448 g/s of suspended and floating particles) with material originating from human activity favours the development of deltas. Delta accumulation zones are subject to frequent changes resulting from the regulation of water levels in reservoirs; permanent delta forms are a typical feature in particular of large reservoirs.
2. Deltas material is dominated by SiO_2 and organic matter. It is polluted however, which is reflected above all by trace element concentrations that exceed natural geochemical background levels. The accumulation of pollutants within deltas can be seen as improving the quality of surface waters.
3. The development of deltas is associated with the formation of new habitats that increase the biodiversity of the area in question. The high fertility of the delta environment favours plant succession within which *Phragmites australis* (Cav.) Trin. ex Steud dominates. However, vegetation assimilates not only nutrients but also micropollutants. The content of trace elements often results from their content in the sediments.
4. Owing to its mineral and chemical composition, delta material can be used for a variety of purposes. Where it exhibits high coal dust content, it can be successfully used as an energy fuel.

Acknowledgements

We would also like to thank Dr. Martin Cahn for correcting the English language of the manuscript.

References

[1] Wiatkowski M, Paul L. Surface water quality assessment in the Troja River catchment in the context of Wlodzienin Reservoir construction. Pol J Environ Stud. 2009;18(5):923-929. www.pjoes.com/index.php?s=abs_id&id=2009180520.

[2] Wiatkowski M, Czerniawska-Kusza I. Use of the preliminary Jedlice Reservoir for water protection in the Turawa Reservoir on the Mala Panew River. Oceanol Hydrobiol St. 2009;38(1):83-91. DOI: 10.2478/v10009-009-0006-8.

[3] Kasperek R, Mokwa M, Wiatkowski M. Modelling of pollution transport with sediment on the example of the Widawa River. Arch Environ Prot. 2013;39(2):29-43. DOI: 10.2478/aep-2013-0017.

[4] Wiatkowski M, Rosik-Dulewska C, Kuczewski K, Kasperek L. Water quality assessment of Wlodzienin Reservoir in the first year of its operation. Roczn Ochr Środow. 2013;15,Part 3:2666-2682.

[5] Rzetala M, Jagus A, Rzetala MA, Rahmonov O, Rahmonov M, Khak V. Variations in the chemical composition of bottom deposits in anthropogenic lakes. Pol J Environ Stud. 2013;22(6):1799-1805.

[6] Prieto GFJ. Shoreline forms and deposits in Gallocanta Lake (NE Spain). Geomorphology 1995;11:323-335.

[7] Wang J, Chen X, Zhu X, Liu J, Chang WYB. Taihu Lake, lower Yangtze drainage basin: evolution, sedimentation rate and the sea level. Geomorphology 2001;41:183-193. DOI: 10.1016/S0169-555X(01)00115-5.

[8] Devi MRK, Singh T. Morphotectonic setting of the Ganga Lake, Itanagar capital complex, Arunachal Himalaya. Geomorphology 2006;76:1-11. DOI: 10.1016/j.geomorph.2005.08.011.

[9] Sapota T, Håkanson L, Aldahan A, Possnert G. Sediment flux to Lake Baikal (Siberia, Russia): Modeling approach. Geomorphology 2006;80:105-113. DOI: 10.1016/j.geomorph.2005.09.009.

[10] Stanley DJ. Nile delta: extreme case of sediment entrapment on a delta plain and consequent coastal land loss. Mar Geol. 1996;129:189-195. DOI: 10.1016/0025-3227(96)83344-5.

[11] Saito Y, Yang Z, Hori K. The Huanghe (Yellow River) and Changjiang (Yangtze River) deltas: a review on their characteristics, evolution and sediment discharge during the Holocene. Geomorphology 2001;41:219-231. DOI: 10.1016/S0169-555X(01)00118-0.
[12] Liu S, Zhang W, He Q, Li D, Liu H, Yu L. Magnetic properties of East China Sea shelf sediments off the Yangtze Estuary: Influence of provenance and particle size. Geomorphology 2010;119:212-220. DOI: 10.1016/j.geomorph.2010.03.027.
[13] Day JW, Barras J, Clairain E, Johnston J, Justic D, Kemp GP, et al. Implications of global climatic change and energy cost and availability for the restoration of the Mississippi delta. Ecol Eng. 2005;24:253-265. DOI: 10.1016/j.ecoleng.2004.11.015.
[14] Stanica A, Dan S, Ungureanu VG. Coastal changes at the Sulina mouth of the Danube River as of human activities. Mar Pollut Bull. 2007;55:555-563. DOI: 10.1016/j.marpolbul.2007.09.015.
[15] Lampert W, Rothhaupt KO. Limnology in the Federal Republic of Germany, the 24th Congress of the IATAL. Munich: International Association for Theoretical and Applied Limnology; 1989.
[16] Owczinnikow GI, Pawłow SH, Trzcinskij JB. Izmienienije gieołogiczeskoj sriedy w zonach wlijanija angaro-jenisiejskich wodochraniliszcz. Nowosybirsk: Izdatielstwo Nauka; 1999 (in Russian).
[17] Fernex F, Zarate-del Valle P, Ramirez-Sanchez H, Michaud F, Parron C, Dalmasso J, et al. Sedimentation rates in Lake Chapala western Mexico: possible active tectonic control. Chem Geol. 2001;177:213-228. DOI: 10.1016/S0009-2541(00)00346-6.
[18] Janský B, Šobr M. Lakes of the Czech Republik. Prague: Charles University; 2003 (in Czech).
[19] James LA. Sediment from hydraulic mining detained by Englebright small dams in the Yuba basin. Geomorphology 2005;71:202-226. DOI: 10.1016/j.geomorph.2004.02.016.
[20] Bakoariniaina LN, Kusky T, Raharimahrfa T. Disappearing Lake Alaotra: Monitoring catastrophic erosion, waterway silting, and land degradation hazards in Madagascar using Landsat imagery. J Afr Earth Sci. 2006;44:241-252. DOI: 10.1016/j.jafrearsci.2005.10.013.
[21] Verstraeten G, Bazzoffi P, Lajczak A, Radoane M, Rey F, Poesen F, et al. Reservoir and pond sedimentation in Europe. In: Soil Erosion in Europe. Boardman J, Poesen J, editors. Oxford: John Wiley & Sons Ltd.; 2006:757-774.
[22] Romashkin PA, Williams DF. Sedimentation history of the Selenga Delta, Lake Baikal: simulation and interpretation. J Paleolimnol. 1997;18:181-188.
[23] Łajczak A. Deltas in dam-retained lakes in the Carpathian part of the Vistula drainage basin. Prace Geograficzne UJ 2006;116:99-109.
[24] Rzętała M, Jaguś A. New lake district in Europe: origin and hydrochemical characteristics. Water Environ J. 2012;26:108-117. DOI: 10.1111/j.1747-6593.2011.00269.x.
[25] Rzętała MA, Machowski R, Rzętała M. Sedymentacja w strefie kontaktu wód rzecznych i jeziornych na przykładzie zbiorników wodnych regionu górnośląskiego. Sosnowiec: Wydział Nauk o Ziemi Uniwersytetu Śląskiego; 2009 (in Polish).
[26] Rzętała MA, Jaguś A, Rzętała M. Samooczyszczanie wód w procesie tworzenia form deltowych. Roczn Ochr Środow. 2013;15:2510-2525.
[27] Kostecki M. Zawiesina jako element zanieczyszczenia antropogenicznego ekosystemu wodnego na przykładzie zbiornika zaporowego Dzierżno Duże (woj. śląskie). Arch Ochr Środ. 2000;26(4):75-94 (in Polish).
[28] Rzętała M. Funkcjonowanie zbiorników wodnych oraz przebieg procesów limnicznych w warunkach zróżnicowanej antropopresji na przykładzie regionu górnośląskiego. Katowice: Wyd Uniwersytetu Śląskiego; 2008 (in Polish).
[29] Kabata-Pendias A, Pendias H. Biogeochemia pierwiastków śladowych. Warszawa: Wyd Nauk PWN; 1999 (in Polish).
[30] Magiera T, Strzyszcz Z, Kostecki M. Seasonal changes of magnetic susceptibility in sediments from Lake Zywiec (south Poland). Water Air Soil Pollut. 2002;141:55-71. DOI: 10.1023/A:1021309301714.
[31] Büttner O, Becker A, Keliner S, Kuehn K, Wendt-Potthoff K, Zachmann DW, et al. Geostatistical analysis of surface sediments in an acidic mining lake. Water Air Soil Pollut. 1998;108:297-316. DOI: 10.1023/A:1005145029916.
[32] Nguyen HN, Leermakers M, Osán J, Tfrfk S, Baeyens W. Heavy metals in Lake Balaton: water column, suspended matter, sediment and biota. Sci Total Environ. 2005;340:213-230. DOI: 10.1016/j.scitotenv.2004.07.032.
[33] Lindström M, Håkanson L. A model to calculate heavy metal load to lakes dominated by urban runoff and diffuse inflow. Ecol Model. 2001;137:1-21. DOI: 10.1016/S0304-3800(00)00440-3.

[34] Dauvalter V. Heavy metals in lake sediments of the Kola Peninsula, Russia. Sci Total Environ. 1994;158:51-61. DOI: 10.1016/0048-9697(94)90044-2.

[35] Kosov VI, Kosova IV, Levinskii VV, Ivanov GN, Khil'chenko AI. Distribution of heavy metals in Lake Seliger bottom deposits. Water Resour. 2004;31:46-54.

[36] Duman F, Aksoy A, Demirezen D. Seasonal variability of heavy metals in surface sediment of Lake Sapanca, Turkey. Environ Monit Assess. 2007;133:277-283. DOI: 10.1007/s10661-006-9580-3.

[37] Özmen H, Külahci F, Cukurovali A, Dğgru M. Concentrations of heavy metal and radioactivity in surface water and sediment of Hazar Lake (Elaziˇg, Turkey). Chemosphere 2004;55:401-408. DOI: 10.1016/j.chemosphere.2003.11.003.

[38] Gantidis N, Pervolarakis M, Fytianos K. Assessment of the quality characteristics of two lakes (Koronia and Volvi) of N. Greece. Environ Monit Assess. 2007;125:175-181. DOI: 10.1007/s10661-006-9250-5.

[39] Taher AG, Soliman AA. Heavy metal concentrations in surficial sediments from Wadi El Natrun saline lakes, Egypt. Int J Salt Lake Res. 1999;8:75-92.

[40] Moalla SMN, Awadallah RM, Rashed MN, Soltan ME. Distribution and chemical fractionation of some heavy metals in bottom sediments of Lake Nasser. Hydrobiologia 1998;364:31-40.

[41] Kishe MA, Machiwa JF. Distribution of heavy metals in sediments of Mwanza Gulf of Lake Victoria, Tanzania. Environ Int. 2003;28:619-625. DOI: 10.1016/S0160-4120(02)00099-5.

[42] Ochieng EZ, Lalah JO, Wandiga SO. Analysis of heavy metals in water and surface sediment in five rift valley lakes in Kenya for assessment of recent increase in anthropogenic activities. B Environ Contam Tox. 2007;79:570-576. DOI: 10.1007/s00128-007-9286-4.

[43] Wang H, Wang CX, Wang ZJ, Cao ZH. Fractionation of heavy metals in surface sediments of Taihu Lake, East China. Environ Geochem Health. 2004;26:303-309. DOI: 10.1023/B:EGAH.0000039594.19432.80.

[44] Chandra Sekhar K, Chary NS, Kamala CT, Suman Raj DS, Sreenivasa Rao A. Fractionation studies and bioaccumulation of sediment-bound heavy metals in Kolleru lake by edible fish. Environ Int. 2004;29:1001-1008. DOI: 10.1016/S0160-4120(03)00094-1.

[45] Juracek KE, Mau DP. Metals, trace elements, and organochlorine compounds in bottom sediment of Tuttle Creek Lake, Kansas, USA. Hydrobiologia 2003;494:277-282. DOI: 10.1023/A:1025447223154.

[46] An YJ, Kampbell DH. Total, dissolved, and bioavailable metals at Lake Texoma marinas. Environ Pollut. 2003;122:253-259. DOI: 10.1016/S0269-7491(02)00291-9.

[47] Roach AC. Assessment of metals in sediments from Lake Macquarie, New South Wales, Australia, using normalisation models and sediment quality guidelines. Mar Environ Res. 2005;59:453-472. DOI: 10.1016/j.marenvres.2004.07.002.

[48] Rzetala MA, Rahmonov O, Jagus A, Rahmonov M, Rzetala M, Machowski R. Occurrence of chemical elements in common reeds (Phragmites australis) as indicator of environmental conditions. Res J Chem Environ. 2011;15(2):610-616.

[49] Engloner AI. Structure, growth dynamics and biomass of reed (Phragmites australis) - A review. Flora 2009;204:331-346. DOI: 10.1016/j.flora.2008.05.001.

[50] Charakterystyka urobku pochodzącego z pogłębiania czaszy zbiornika Dzierżno Duże oraz jego status prawny w aspekcie gospodarki odpadami. Katowice: Ośrodek Badań i Kontroli Środowiska Przedsiębiorstwo Państwowe; 2006.

[51] Charakterystyka paliwa węglowego pozyskanego ze zbiornika Dzierżno Duże, Portu Gliwickiego oraz sekcji 6 i 5 Kanału Gliwickiego - dokumentacja pracy badawczo-usługowej. Katowice: Główny Instytut Górnictwa; 2004.

ROZWÓJ I ZNACZENIE ŚRODOWISKOWO-UŻYTKOWE DELT W ZBIORNIKACH ŚRÓDLĄDOWYCH

[1] Wydział Nauk o Ziemi, Uniwersytet Śląski
[2] Instytut Ochrony i Inżynierii Środowiska, Akademia Techniczno-Humanistyczna w Bielsku-Białej

Abstrakt: Przedstawiono wyniki badań form deltowych, powstających w wyniku sedymentacji rumowiska wnoszonego przez cieki do zbiorników wodnych. Badaniami objęto kilkadziesiąt zbiorników antropogenicznych w regionie górnośląskim, wyróżniającym się silną urbanizacją i uprzemysłowieniem. Podstawowe prace badawcze obejmowały: pomiary morfometryczne delt, analizy składu mechanicznego oraz chemicznego osadów deltowych, analizy składu chemicznego trzciny porastającej delty. Prace badawcze wykazały, że delty mają cechy form antropogenicznych, wynikające z zanieczyszczenia cieków. W osadach delt dominują zwykle ziarna piasku, lecz w wielu przypadkach frakcja < 0,02 mm stanowi nawet około 30%. Osady nierzadko zawierają miał węglowy i inne zanieczyszczenia organiczne, co wyrażają wysokie wartości strat wagowych po prażeniu. Zawartość pierwiastków śladowych w osadach deltowych najczęściej wielokrotnie przekracza tło geochemiczne wszystkich rodzajów skał osadowych. Delty są środowiskiem akumulacji zanieczyszczeń. Część z nich jest asymilowana przez roślinność. Zawartość makropierwiastków w tkankach trzciny z różnych delt jest mało zróżnicowana, natomiast zawartość mikropierwiastków często jest pochodną zawartości w materiale osadowym. Materiał tworzący delty może być wydobywany - w niektórych przypadkach posiada nawet cechy opałowe.

Słowa kluczowe: geomorfologia fluwialna, sedymentacja, delty, antropogeniczne zbiorniki wodne, region górnośląski