ARCHIVES OF ENVIRONMENTAL PROTECTION

vol. 35 no. 3 pp. 73 - 85 2009

PL ISSN 0324-8461

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APPRAISAL OF BOTTOM SEDIMENT POLLUTION WITH HEAVY METALS OF SMALL WATER RESERVOIRS LOCATED IN SOUTH POLAND

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Keywords: Small water reservoirs, bottom sediment, pollution with heavy metals.

Abstract: In result of a few years' investigations of silting of small water reservoirs located in South Poland, intensity of the silting process as well as the granulometric and chemical composition of bottom sediments were evaluated. The content of heavy metals i.e. copper, lead and cadmium was determined in samples collected in various parts of five small water reservoirs. The content of heavy metals was appraised according to the regulation of the Minister of Environment, according to the criteria of Polish Geological Institute, of Inspection for Environmental Protection, of Institute of Soil Science and Plant Cultivation, and according to the Müller's method. The obtained results of determination of the examined heavy metals concentrations were compared with the values of reservoir and river sediment concentrations determined by other authors in Europe. Appraisal of silt quality, respectively to the adopted criteria, showed only an insignificant degree of pollution. Concentrations of microelements do not exceed the toxic concentrations for soils and environment but may have a harmful influence on living organisms. Recording of changes of heavy metal pollution during many years' operation of small water reservoirs, considering changes occurring in the basins, requires continuation of investigations. It will enable to record changes of pollution during a longer period of operation of reservoirs, also against the background of changes occurring in river basins.

INTRODUCTION

With increasing pollution of water and soil environment the studies are more and more often to focus on the evaluation of sediment quality in retention reservoirs. Monitoring studies of water and bottom sediment quality of bigger rivers and of small and medium-size water reservoirs in Poland are performed by the Polish Geological Institute (PIG) and by the Inspection for Environmental Protection (PIOŚ) [5]. Till the 1990s no complex investigations of sediment quality in small water reservoirs were carried out in Poland. The first significant elaborations concerned sediment contamination in water reservoirs located in polluted areas due to intensive industrial activity connected with hard coal exploitation and metallurgic industry. In result of investigations of water reservoirs Chechło, Włocławek, Rybnik, Kozłowa Góra, Goczałkowice located on these territories, higher values of metals: Ag, Ba, Cr, Cu, Ni, Pb and Zn were found as compared with natural values, whereas Cd, Hg exceeded admissible values constituting serious threat to water environment considering eco-toxicological reasons [6, 10, 15, 30]. At the same time studies of small water reservoirs located in rather small agricultural regions were initiated. The results showed low concentrations of trace heavy metals exceeding occasionally admissible values established by the binding classification [19, 20, 31].

Small water reservoirs projected within the framework of "Small retention" may be characterized by a short life period manifested by intensive reduction of storage volume [29]. Periodical desilting works must be taken into consideration during their operation. With regard to scarce data concerning quality and quantity of polluted sediments with heavy metals and to the lack of information on chemical properties of sediments of small water reservoirs, there are no instructions concerning decision as to the way of their management and utilization of muds. Utilization of bottom sediments is relatively rare and that is why there are no detailed instructions concerning conditions of their utilization for agricultural purposes in dependence on their chemical composition. Evaluation of their quality can be done per analogue with the chemical composition of soils or of waste substances introduced into the environment, e.g. for recultivation of soils. Another additional problem is lack of explicit governmental regulations concerning evaluation of the quality and pollution of water reservoirs sediments by heavy metals. In evaluation of water reservoir sediment pollution with trace metals, the Regulation of the Minister of Environment from 9th September 2002 concerning soil quality standards [11] and differentiating three groups of soils can be applied. However, there is a note in this Regulation saying that bottom sediments deriving from reservoirs of stagnant or flowing waters utilized in earth works should satisfy the criteria of admissible concentration values of polluting substances, in agreement with standards of soil quality determined in this Regulation. Apart from this Regulation there are applied concomitantly classification criteria of water sediments elaborated and applied by the Polish Geological Institute (PGI) and by the Inspection for Environmental Protection (IEP) [5]. There are also applied instructions elaborated by the Institute of Soil Science and Plant Cultivation (ISSPC) that determine maximal admissible values of heavy metals in the upper layer of soil, taking into regard the values of pH and the granulometric composition [13]. The Müller's method [23] is applied according to the geoaccumulative index of pollutions (I_{geo}) – comparing metal contents in relations to natural content in sediments that constitutes the geochemical background of it. With regard to the differentiated criteria and threshold values of classification of pollution with heavy metals, introduction of a unified procedure standardizing appraisal of quality of water reservoir sediments in Poland is necessary. Disposing of such a procedure is very important, since in the case of designed water reservoirs a schedule of evaluation of the effect of utilized reservoir sediments on the environment should be elaborated. Therefore, monitoring investigations of the degree of sediment pollution of small water reservoirs are absolutely necessary.

The performed investigations are devoted to the evaluation of the degree of pollution with heavy metals: copper, lead, zinc and cadmium of bottom sediments. The investigations are realized on five small water reservoirs located in the Małopolska and Podkarpacie districts. The content of heavy metals was appraised according to the Regulations of the Minister of Environment, to PGI's criteria and ISSPC's criteria and according to Müller's method. The obtained determination results of the studied heavy metals concentrations were compared with concentration values of reservoir and river sediments determined by other authors in Europe.

CHARACTERISTIC OF STUDIED OBJECTS

The contents of heavy metals in bottom sediments were studied in five small water reservoirs: Zesławice on the River Dłubnia, Cierpisz on the River Tuszymka Duża, Bagna Rzeszowskie on the River Czarna, Wilcza Wola on the River Łęg, and Krempna on the River Wisłoka. These reservoirs are located in the basin of the Upper Vistula. Their location is shown in Figure 1.

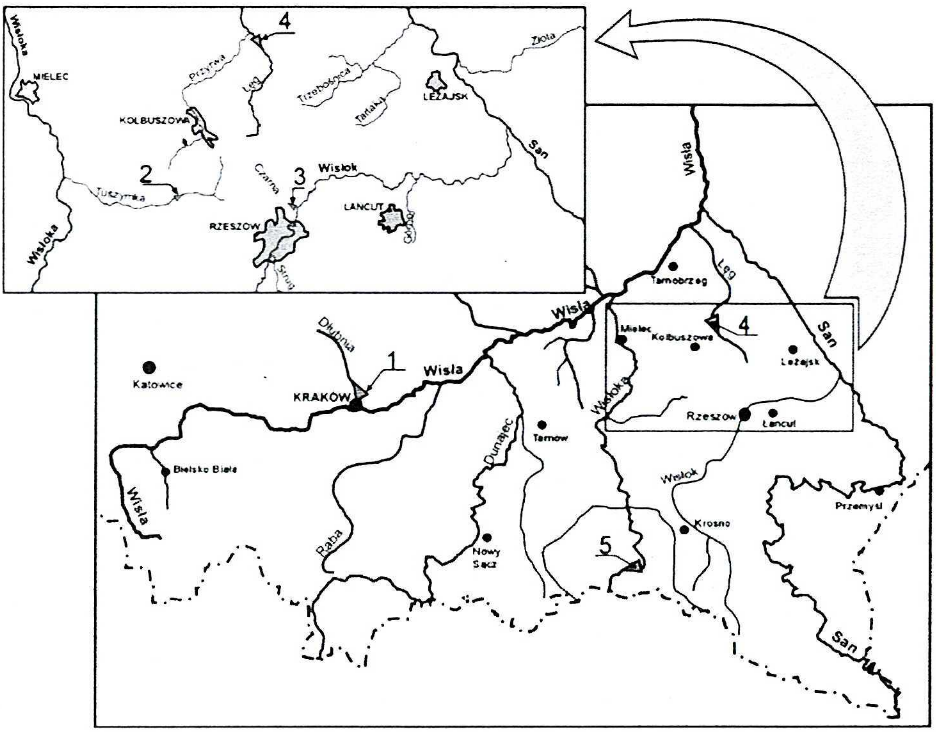

Fig. 1. Location of the studied water reservoirs in the basin of the Upper Vistula
1 – reservoir Zesławice, 2 – reservoir Cierpisz, 3 – reservoir Bagna Rzeszowskie, 4 – reservoir Wilcza Wola, 5 – reservoir Krempna

The reservoir Zesławice on the River Dłubnia is located on the territory of Krakow in the Nowa Huta quarter. This reservoir was put into operation in 1966. Its storage volume is 228 000 m^3 at reservoir area equal 9.5 ha. The surface area of the basin to the reservoir dam at Zesławice which is on the 8.7 km of the river Dłubnia course equals 218.1 km^3. The basin is of agricultural character with 78% of arable lands, of which 9.5% is covered with forests, and green land constitutes 1.6% of the basin area. Technical infrastructure occupies the rest, i.e. 10.8% [2]. Apart from intensive agricultural development of the basin, the kind of soils covering the basins of the reservoir Zesławice has great influence on the quantity of mineral material denudation from the basin. Loess susceptible to surface rain-wash is the dominating kind of soils in the basin. In consequence of intensive erosive processes the reservoir Zesławice got silted in 50% already after 17 years of operation. This situation caused the necessity of carrying out restoration treatments in 1986. In 1987 the reservoir, after desilting was again given out for exploitation. In 2003 silting of about 33% was stated.

The water reservoir Cierpisz on the River Tuszymka Duża, a tributary of the River Wisłoka was built in 1955. The storage volume is 34.5 thousand m^3 and the surface area of reservoir area equals 2.3 ha. The basic function of the reservoir is collecting water for agricultural purposes. During the winter time of 1990/91 desilting works were carried out removing over 8000 m^3 of silt. The reservoir closes the basin of 54.5 km^2 surface area. The basin of the reservoir Cierpisz is of lowland character of poorly diversified surface with few elevations and hill chains. The area of the basin is covered by clayey soils. Arable land constitutes 20.2%, green land 33.1%, and forest 43% of the total basins area [4].

The reservoir Bagna Rzeszowskie was built on the River Czarna, a tributary of the River Wisłoka. The initial storage volume was equal 48 000 m^3 at reservoir area of 1.5 ha. Since the time the reservoir started to operate in 1973 no desilting works have been undertaken. The degree of silting determined by measurements performed in 2006 was equal 52.8% [32]. The River Czarna 22.8 km long crosses the basin of an area of 204.2 km^2 of a typically agricultural character. Arable land constitutes 57.2% of the basin area, green land 18.4%. In spite of small denivelations of the territory, intensive erosive phenomena take place in the basin area, especially on territories of intensive tillage. Only the upper – North-Western and Northern parts of the basin are covered with forests. These territories cover 21.6%, and the rest, less than 3% is waste land or urbanized area.

The reservoir Wilcza Wola of the storage volume 3.86 million m^3 was built on the River Łęg and put into operation in 1989. The surface area of the reservoir is 160 ha. Its main aim is storing water for land reclamation purposes, supplying water for fish ponds, local tap water needs, and partial reduction of flood wave. Basing upon silting measurements performed after 14 years of operation it was found that the reservoir was silted in over 16% [33]. The surface area of the basin to the section of the reservoir dam equals 233 km^2. Arable land constitutes 46.3% of the basin area. The basin is wooded in 11.6% and green land and technical infrastructure constitute 21.9% and 20.3% respectively of the whole basin area [3].

The reservoir at the locality Krempna of 112 000 m^3 storage volume was put into operation in the 1972. In 1987, after 15 years, the reservoir was desilted and rebuilt. In result of rebuilding its storage volume was increased to 119 thousand m^3. After 16 years of operation following it's rebuilding the storage volume decreased by about 40% [21]. The surface area of the reservoir basin is 165.3 km^2. Only 4% is under agricultural cultivation, whereas green land occupies 14%, technical infrastructure 2% and forests about 80% of the basin area. In a great part they belong to the National Landscape Park of Magura [12]. Soils formed of dusty and silty clays prevail in the territory of the basin.

METHODS

Sediment samples were taken in the period 2001–2003 by use of a pipe sampler from three zones of each reservoir, i.e. the: inflow, middle, and outflow. From the outflow zone of reservoir Wilcza Wola sediment samples were collected under water level since there the depth exceeded 4 m. In order to get representative data for the sampled sediment, three sediment samples were collected in each zone by use of a standard Beeker's sampler

Eijkelkamp according to the procedure elaborated by Madeyski [11] and Tarnawski [31]. Application of PCV pipes of 5 cm diameter and 100 cm length enables sampling not only from the upper layers of the sediment but also from its deeper layers.

The samples collected from the surface mud layer (top layer), i.e. at the depth of 0–15 cm and from the depth of 40–55 cm under the mud surface (bottom layer) were subjected to the analysis of granulometric composition and of organic particles content. Granulometry of the fine fraction mineral material was determined according to Cassagrande's method modified by Pruszyński [28]. Specific weight was determined pictometrically and unit weight by use of sand replacement method. The content of organic matter (O_R) was determined according to the annealing method [16].

The content analysis of heavy metal: copper, lead, zinc, and cadmium in sediments was proceeded by mineralization process with use of acids: $HClO_4$ and HNO_3 (1 + 3). Subsequently, after evaporation of the remains of acids, the dry matter was dissolved in HCl (1 + 1) at high temperature. Determinations were performed by use of flame atomic absorption spectrophotometry (FAAS) using a Solaar M6 Unicom spectrophotometer. During determination of Cd, Pb, Cu, Zn content, flame from burning a mixture of gas air and acetylene was used. Deutoral correction of the background according to the procedure by Ostrowska *et al.* [26] was made.

Appraisal of sediment pollution by heavy metals was carried out according to the binding Regulation and following the instructions and method:

- the binding Regulation of the Minister of Environment (RME) concerning soil quality standards [11],
- the geochemical classification of water sediments elaborated and applied by the Polish Geological Institute (PGI) and the Inspection for Environmental Protection (IEP) [5],
- instruction elaborated by the Institute of Soil Science and Plant Cultivation (ISSPC) [13],
- Müller's method [23] based on the geoaccumulative index (I_{geo}).

RESULTS AND DISCUSSION

The granulometric composition of bottom sediments of water reservoirs Zesławice, Cierpisz, Bagna Rzeszowskie, Wilcza Wola, and Krempna is presented in Figure 2.

The diameter d_{50} of the reservoir sediments is within the range form 0.011 mm to 0.180 mm. In the reservoir Zesławice, fine fraction sediment having diameter d_{50} is 0.011–0.031 mm was trapped. In the reservoir Krempna the diameter d_{50} is equal 0.012–0.074 mm. In the reservoir Cierpisz and Bagna Rzeszowskie the sediment of a diameter within the range 0.060– 0.130 mm and 0.041–0.120 mm respectively was trapped. With regard to the kind of soil covering the basin of the reservoir Wilcza Wola, i.e. dusty sands, sediments of this reservoir are characterized by biggest diameters of grains d_{50} equal 0.052–0.230 mm. The content of dusty and clayey fractions whose diameters is below 62 μm is high constituting 72–92% in reservoir Zesławice, 36–50% in reservoir Cierpisz, 38–62% in reservoir Bagna Rzeszowskie, 26–52% in reservoir Wilcza Wola, and 38–89% in reservoir Krempna.

Mean volumetric densities of sediments trapped in the reservoirs are within the range from 0.87 $Mg \cdot m^{-3}$ to 1.62 $Mg \cdot m^{-3}$ and mean specific densities range from 2.27 $Mg \cdot m^{-3}$ to

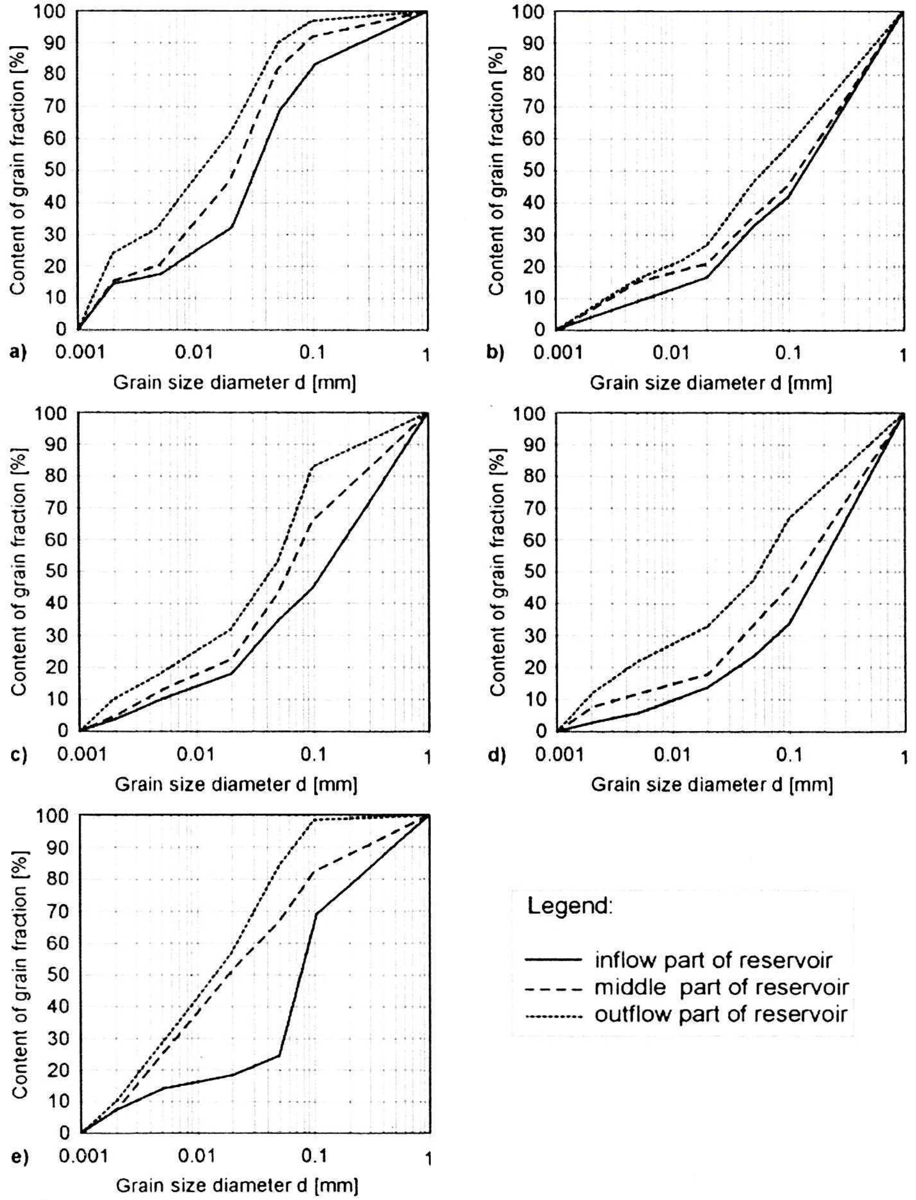

Fig. 2. Granulometric curves of bottom sediments sampled in the inflow, middle, and outflow part of water reservoirs: a) Zesławice, b) Cierpisz, c) Bagna Rzeszowskie, d) Wilcza Wola, e) Krempna

2.63 $Mg \cdot m^{-3}$. When analyzing diversification of load granulation in particular parts of the reservoir attention should be paid to the changeability of the value of volumetric density of sediments in particular mud layers of the inflow, middle, and outflow zone of the reservoirs (Tabs 1 and 2).

Table 1. Values of volumetric density of sediment deposits and range of pH

Reservoir	Volumetric density of sediment deposits ρ_0 [Mg·m^{-3}]							Range of pH
	1U	1L	2U	2L	3U	3L	M	
Zesławice	1.30	0.68	1.16	0.80	1.43	0.78	1.03	7.6–8.0
Cierpisz	1.38	1.37	1.16	1.60	0.90	1.48	1.32	5.5–5.6
Bagna Rzeszowskie	0.43	1.11	0.38	1.36	0.35	1.56	0.87	6.3–7.1
Wilcza Wola	1.59	1.67	1.62	1.71	1.67	1.65	1.65	5.6–6.4
Krempna	1.31	1.28	1.16	1.32	1.16	1.17	1.23	7.4–7.76

1 – outflow part, 2 – middle part, 3 – inflow part of the reservoir;
U – upper layer, L – lower layer of bottom sediments, M – mean value

Table 2. Values of bulk density of sediment deposits and content of organic parts

Reservoir	Bulk density of sediment deposits ρ_s [Mg·m^{-3}]							Content range of organic matter [%]
	1U	1L	2U	2L	3U	3L	M	
Zesławice	2.58	2.59	2.62	2.56	2.64	2.64	2.61	7.6–8.0
Cierpisz	2.63	2.67	2.57	2.62	2.46	2.65	2.60	5.5–5.6
Bagna Rzeszowskie	2.55	2.52	2.58	2.61	2.54	2.60	2.57	6.3–7.1
Wilcza Wola	2.62	2.67	2.60	2.60	2.63	2.66	2.63	5.6–6.4
Krempna	2.64	2.53	2.56	2.64	2.61	2.60	2.60	7.4–7.76

1 – outflow part, 2 – middle part, 3 – inflow part of the reservoir;
U – upper layer, L – lower layer of bottom sediments, M – mean value

Sediments of lower layers are characterized by higher volumetric density values. It was also stated that volumetric density of deposited load in the inflow part of the reservoirs show higher values as compared witch deposit found in the inflow part. After Brown [7], Morris and Fan [22], granulometric composition, period of consolidation, depth of sediments, and frequency and time after which the sediments emerge above the water surface are the main factors affecting the value of sediment volumetric density. The content of organic matter in sediments is within the range from 1.65% to 14.8%.

In spite of distinct diversification of the granulometric composition, volumetric density of sediments sampled from the inflow, middle and outflow part of the reservoir, no diversification of the content of the studied heavy metals was found.

Van Aardt and Erdmann [34] state after Ochsenbein and Santos Bermejo that heavy metals such as copper, nickel, zinc are usually deposited in reservoir sediments in their layers less than 15 cm deep. In the case of the studied reservoirs pollution trace metals Cu, Pb, Zn, and Cd were also in deeper layers 40–55 cm below the sediments surface.

The content of maximal, minimal and mean concentrations of Cu, Pb, Zn, and Cd in sediments of the studied reservoirs is presented in Table 3.

Evaluation of pollution with heavy metals of reservoir sediments, for maximal concentration of trace metals in samples, was carried out basing upon determined pollution degrees according to the adopted instructions and methods (Tab. 4).

Table 3. Content of heavy metals Cu, Pb, Zn and Cd in bottom sediments of small water reservoirs Zesławice, Cierpisz, Bagna Rzeszowskie, Wilcza Wola and Krempna

Reservoir	Value	Heavy metals [$\mu g \cdot g^{-1}$]			
		Cu	Pb	Zn	Cd
Zesławice	mean	10.73	20.02	72.88	0.48
	minimum	6.90	10.50	34.90	0.10
	maximum	14.00	30.20	129.9	0.90
Cierpisz	mean	1.92	5.42	64.58	0.85
	minimum	0.50	1.00	12.50	1.00
	maximum	6.00	10.50	208.50	2.80
Bagna Rzeszowskie	mean	27.57	23.83	157.83	1.31
	minimum	12.60	11.10	45.00	0.45
	maximum	33.80	34.30	230.00	1.90
Wilcza Wola	mean	5.20	9.52	24.56	0.26
	minimum	4.50	8.70	23.90	0.10
	maximum	6.70	11.50	34.50	0.45
Krempna	mean	50.80	17.45	76.52	0.34
	minimum	19.20	9.80	49.10	0.05
	max	78.60	21.00	92.80	0.45

Table 4. Assessment of heavy metal pollution in bottom sediments

Heavy metals	Criterion	Reservoir				
		Zesławice	Cierpisz	Bagna Rzeszowskie	Wilcza Wola	Krempna
Cu	RME	A	A	B	A	B
	PGI	I	I	II	I	II
	ISSPC	0	0	I	0	II
	I_{geo}	-0.10/0	-1.91/0	0.17/I	-1.75/0	1.8/II
Pb	RME	A	A	A	A	A
	PGI	II	I	II	I	I
	ISSPC	0	0	0	0	0
	I_{geo}	0.82/I	-0.84/0	-0.13/0	-0.76/0	0.16/I
Zn	RME	B	B	B	A	A
	PGI	II	II	II	I	I
	ISSPC	I	II	II	0	I
	I_{geo}	-0.21/0	0.48/I	0.62/I	-2.12/0	-0.69/0
Cd	RME	A	B	B	A	A
	PGI	II	II	II	I	I
	ISSPC	I	II	I	I	I
	I_{geo}	3.58/IV	-0.68/0	1.34/II	-1.67/0	-1.32/0

RME – regulation of the Minister of Environment, PGI – Polish Geological Institute, ISSPC – Institute of Soil Science and Plant Cultivation, I_{geo} – the Müller's method

According to the classification contained in the binding in Poland Regulation of the Minister of Environment (RME) concerning soil quality standards [11], the studied sediments of five small water reservoirs, with regard to the content of investigated heavy metals, correspond to soils of group A and B. These are sediments which may find agricultural utilization and are no threat to soil environment, since they correspond with the quality of soils of protected areas (group A) and quality of soils of forest, agricultural, waste land and urbanized areas (group B). According to this assessment, sediments of the reservoir Wilcza Wola are least polluted and with regard to the content of each of the analyzed heavy metals, the bottom sediments were classified as group A.

Assessing pollution with trace metals, according to the classification elaborated by the Polish Geological Institute (PGI), it was stated that the studied sediments may be classified as classes I and II of muds. They are characterized by toxic substances concentrations having no harmful effect on living organisms or this effect is only occasional. According to this assessment, sediments of the biggest investigated reservoir Wilcza Wola are not polluted with any of the determined trace elements (class I). Sediments of the reservoir Krempna could also be included in class I but a higher content of Cu classifies them as class II indicating a moderate contamination with heavy metals. Bottom sediment of the other water reservoirs, i.e. Zesławice, Cierpisz, and Bagna Rzeszowskie, may be considered as moderately polluted with heavy metals since their classification of sediments as class II prevails.

With regard to the instruction provided by the Institute of Soil Science and Plant Cultivation (ISSPC), the investigated sediments correspond with soil of contamination degree from 0 to II. The highest degree 0 indicates the possibility of full agricultural useability of soils and in the case of sediments its agricultural application is possible without any limitations. The sediments of the reservoir Wilcza Wola can be regarded as such sediment because of low content of copper, lead and zinc. However the content of Cd classifies them as soils of increased content of metals (I degree). The sediment of the reservoir Zesławice is included in the I degree of pollution because of the content of Zn and Cd. This degree limits cultivation of plants for food production requiring particularly low level of harmful substances – food for children. The other sediments, with regards to the content of only one of the examined heavy metals were classified as soil of low pollution (II degree). Out of this reason, application of these sediments for recultivation or enrichment of arable soil designed for some horticulture purposes such as growing carrots, lettuce, spinach – is not admitted since these plants assimilate heavy metals intensively.

Determined geoaccumulative index of sediments (I_{geo}) shows that, with regard to the content of investigated heavy metals, all sediments except those collected in Zesławice can be classified as class 0 to II. Only in the reservoir Zesławice the presence of cadmium reduces these sediments to class IV, i.e. highly polluted sediments.

An attempt was undertaken at comparing the results of assessment of pollution with cooper, lead, zinc, and cadmium of five small water reservoirs considering particular pollution degrees with each of the heavy metals; total sediment pollution was determined according to each classification arranging the water reservoirs in order from the least polluted with heavy metals to the most polluted one (Tab. 5).

As it follows from Table 5 no univocal general evaluation of the reservoirs is possible as pollution with heavy metals such as cooper, lead, zinc, and cadmium is concerned. It may only be stated in general that sediments of the water reservoir Wilcza Wola are least polluted, whereas the reservoirs Bagna Rzeszowskie shows highest pollution with the investigated metals. The bottom material of this reservoir shows highest level of organic matter content what, as investigations of a number of authors [14, 15, 18, 20]

Table 5. Investigated small water reservoirs order according to the criterion of contamination with Cu, Pb, Zn, and Cd

Criterion	Reservoirs contaminated with heavy metals – from the lowest to the highest contamination degree
RME	Wilcza Wola < Zesławice and Krempna < Cierpisz < Bagna Rzeszowskie
PGI	Wilcza Wola < Krempna < Cierpisz < Zesławice < Bagna Rzeszowskie
ISSPC	Wilcza Wola < Zesławice < Cierpisz < Krempna and Bagna Rzeszowskie
I_{geo}	Wilcza Wola < Cierpisz < Krempna < Bagna Rzeszowskie < Zesławice

RME – regulation of the Minister of Environment, PGI – Polish Geological Institute, ISSPC – Institute of Soil Science and Plant Cultivation, I_{geo} – the Müller's method

show, may contribute to a more intensive accumulation of heavy metals in sediments. Other heavy metals whose content in sediments could influence the evaluation of sediment quality of the investigated water reservoirs were not taken into consideration in the elaborated analysis.

Values less that 20 ppm for copper in river sediments are regarded as natural for the territory of Poland. Occurrence of high Cu contents in sediments was found in European rivers into which waste waters from copper exploitation and flotation, copper works, brass foundries, and galvanization were discharged [1, 27]. Investigations of Lake Zurych in Switzerland showed maximal Cu values of 78 ppm [35], whereas the content of 240 ppm was stated by Müller *et al.* [25] in sediments of Malter Reservoir in Germany. In the case of the reservoirs Zesławice, Cierpisz and Wilcza Wola the obtained copper concentrations are lower than those given by van Aardt and Erdmanna [34]. Whereas, in reservoirs Bagna Rzeszowskie and Krempna copper concentrations are considerably higher, and mean copper concentrations are respectively 27.57 $\mu g \cdot g^{-1}$ and 50.80 $\mu g \cdot g^{-1}$.

Sediments of the investigated reservoirs are not polluted with lead since they are within the interval 1.0–34.3 $\mu g \cdot g^{-1}$, and lead content does not exceed 50 ppm for unpolluted sediments in the southern part of Poland. Comparable high content of lead is known in the reservoir Włocławek, considered as one of the most polluted reservoirs in Poland, located in the Polish lowland. Determined values of lead are within the interval 11–85 ppm [6]. Much higher values were found in investigations of sediments of Lake Zurich – 150 ppm [35] and of Malter Reservoir – 740 ppm [25]. Highest pollution with lead is stated in river alluvia to which wastewaters from mining and metallurgy are discharged. They are characterized by values reaching up 10000 ppm – alluvia of river Luszówka and Chechło in Upper Silesia (West Poland) [10] and of the river Gail and Drau in Austria [24].

High values of Zn equaling maximally 1900 ppm were stated in consequence of investigations of sediments of the River Rote Weisseritz flowing across Saxony in Germany and in the Reservoir Malter located on this river [25]. The mean values of Zn in sediments of Polish waters in rivers and reservoirs were 73 ppm [6]. In sediments of the reservoir Włocławek the range of values from 51 samples collected by Bojakowska *et al.* [7] was highly diversified ranging from 48 to 809 ppm.

The concentration of cadmium in the investigated sediments ranges from 0.05 $\mu g \cdot g^{-1}$ to 2.8 $\mu g \cdot g^{-1}$ and is comparable with the world range of Cd content in unpolluted soils from 0.06 $\mu g \cdot g^{-1}$ to 10 $\mu g \cdot g^{-1}$ as given by van Aardt and Erdmann [34] after Laegerid *et al.*, whereas in big reservoirs examined by van Aardt and Erdmann [34] Cd concentrations ranged from 20 $\mu g \cdot g^{-1}$ to over 100 $\mu g \cdot g^{-1}$. A similar range of values was stated by

Müller *et al.* [25] in sediments of Malter Reservoir; the values however did not exceed 91 ppm. Considerably less polluted are sediments of Lake Zurich in Switzerland. As stated by von Gunten *et al.* [35] these sediments are characterized by maximal Cd content not exceeding 19 ppm.

In the territory of Poland the cadmium content in river sediments is detected in territories of mining and zinc-lead metallurgy, e.g. alluvia of the rivers Chechło and Luszówka, with its values exceeding 100 ppm [10]. Waste waters discharged from metallurgical, electronic, synthetic resin industry as well as from dye-works are also a serious source of pollution of surface waters with cadmium; e.g. in Taiwan (1400 ppm of cadmium) [9]. It was found in the vicinity of synthetic resin production works. Surface run off from fields under cultivation which for many years were fertilized with phosphoric fertilizers are also one of the causes of pollution.

SUMMARY AND CONCLUSIONS

Small water reservoirs located in the southern part of Poland are silted witch fine fraction mineral material characterized by dominating dusty and clayey fractions. Mean density of sediments is contained in the interval from 0.87 $Mg \cdot m^{-3}$ to 1.65 $Mg \cdot m^{-3}$ and the mean specific density is 2.57–2.63 $Mg \cdot m^{-3}$. The content of organic matter in sediments does not exceed the value of 14.8%.

According to the general appraisal of investigated sediments of small water reservoirs in South Poland they do not show any considerable pollution with heavy metals. According to individual classifications of contamination with heavy metals, sediments of small water reservoirs can be considered as bearing no threat to the nature and sediments removed during desilting works can be utilized for agricultural needs.

Classifying sediments according to the criteria given in the Regulation of the Minister of Environment, PGI, ISSPC and Müller's method different values of evaluation of pollution with analyzed heavy metals were obtained. This results from diversification of threshold values of concentrations of particular elements that consider various factors influencing their value. An example are concentration threshold values assumed in the method of the Polish Geological Institute (PGI) and this one applied by the Inspection for Environmental Protection established with regard to toxic effect on living organisms differing from values established in Müller's method that considers only the geochemical background of a given element. Discordance of evaluation of quality of the mineral material collected from reservoirs is especially visible in the case of the reservoir Zesławice. According to the Regulation of the Minister of Environment (RME), PGI's and ISSPC's classification, these sediments, with regard to the content of cadmium, are not classified as mineral material bearing threat of contamination to soil environment. Whereas, according to classification based on geoaccumulative indices, these sediments are highly polluted and are not of agricultural useability. Such a discrepancy of evaluation of reservoir sediment pollution indicates that in spite of application in Poland of the basic criterion of evaluation which the binding Regulation of the Minister of Environment on quality standards of soil is, consideration of other criteria is essential, these are such criteria as criteria applied in PIG's method and in ISSPC and Müller's method. The authors of investigations of bottom sediments quality refer their results to one of the above mentioned methods allowing to carry out a comparative analysis of results. Hence, elaboration of a uniform method of appraisal of pollution of water sediments witch heavy metals, which would consider various aspects of contamination effect, seems necessary.

Recording of changes of pollution with heavy metals during many years' operation of small water reservoirs should take into consideration the individual character of the reservoir and comprise complex investigations of physical and chemical properties. This will enable to elaborate of a complex evaluation of sediments quality, so important especially at the staged planned renovatory works that require removal and utilization of considerable volumes (masses) of silts.

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Received: October 27, 2008; accepted: April 7, 2009.

OCENA ZANIECZYSZCZENIA METALAMI CIĘŻKIMI OSADÓW MAŁYCH ZBIORNIKÓW WODNYCH POLSKI POŁUDNIOWEJ

W wyniku kilkuletnich badań zamulania małych zbiorników wodnych południowej Polski oceniono intensywność przebiegu procesu zamulania oraz określono skład granulometryczny i chemiczny osadów dennych. Zbadano zawartość metali ciężkich miedzi, ołowiu, cynku i kadmu w próbach osadów pobranych w różnych częściach pięciu małych zbiorników wodnych. Zawartość metali ciężkich została oceniona według zaleceń: Rozporządzenia Ministra Środowiska, kryteriów Państwowego Instytutu Geologicznego, Instytutu Uprawy i Nawożenia Gleb oraz według metody Müllera. Otrzymane wyniki oznaczeń stężeń badanych metali ciężkich porównano z wartościami stężeń osadów zbiornikowych i rzecznych określonych przez innych autorów w Europie. Ocena jakości namułów, w odniesieniu do przyjętych kryteriów, wykazała nieznaczny stopień ich zanieczyszczenia. Stężenia mikroelementów nie przekraczają wartości toksycznych dla środowiska glebowego, ale mogą szkodliwie oddziaływać na organizmy żywe. Ocena zmian zanieczyszczenia metalami ciężkimi w czasie wieloletniej eksploatacji małych zbiorników, z uwzględnieniem zmian zachodzących w zlewniach, wymaga kontynuacji badań. Kontynuacja badań pozwoli na rejestrację zmian zanieczyszczenia w czasie wieloletniej eksploatacji zbiorników, również na tle zmian zachodzących w zlewniach rzek.