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Qualitative and Quantitative Assessment of Sediments Pollution with Heavy Metals of Small Water Reservoirs

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1. Introduction

Silting of reservoirs is a very complex process of entrainment, transport and deposition of sediment in reservoir basins, which has major impacts and several effects on river system and its environment (Batuca & Jordaan, 2000). The silting process is initiated when the river damming is completed and ends when the reservoir basin is completely filled with sediment. The silting process is naturally caused and anthropically influenced and the prevention of the original state of the reservoir is impossible. Silting of water reservoirs is one of the main factor limiting their proper operation. Erosion processes in catchment basins are the factor limiting the life-time of water reservoirs. Considerable amount of erosion products coming into the reservoirs is transported and supplied into reservoirs where it is deposited. Together with trapped small fraction of sediment, organic and inorganic compounds including heavy metals, are also deposited. Quantity of heavy metals concentration in water reservoir sediments is regarded as the environmental pollution index. Heavy metals are treated as elementary pollution commonly distributed in natural environment and their concentration corresponds with natural concentrations whose natural source in minerals or soils (O' Neil, 1993). However increase in concentration value of heavy metals in the environment grow at a considerable extent within the latest decades due to human activity (Preuss & Kollman, 1974; Prater, 1975).
Determination of sediment quantity ant their quality is especially vital in causes of small water reservoirs. This is due to the specificity of the silting process characterized by considerable intensity which can be expressed by means of the annual silting intensity ratio. According to Hartung [1959] the mean annual reservoir capacity loss in the case of the big reservoirs is 0.25%, of medium reservoir 0.5%, and of small ones 3,0%. According to Lara and Pemberton's criterion (1963) large water reservoirs are characterized by capacity exceeding 1 km^3, capacity of medium water reservoirs exceeds 0.1 km^3, whereas, small ones are objects of some thousand m^3 capacity. In Poland ("Program of small retention…" 2004) and in Romania (Batuca & Jordaan, 2000) small water reservoirs are distinguished as water bodies of capacity below 5 million m^3. In Great Britain, on the other hand, an object of small capacity less than 1 million m^3 which closes a catchment area below 25 km^2 is regard as a small water reservoir (White et al., 1996). According to World Commission on Reservoirs (Sawunyama, 2005) small reservoir capacity equals from 50 thousand m^3 to 1 million m^3.

With regard to quick reduction of small water reservoir capacity in a relatively short time there arises the necessity of sediment removal and its utilization. It is essential to determine the period after which the reservoir is silted in such a degree that removal of sediment accumulated in it will prove to be a necessity. This time may be determined basing upon the elaborated silting forecast by use of empirical and theoretical methods. The up till now applied Orth's empirical method from the year 1934 (Michalec, 2008), Gončarov's from 1962 (Wiśniewski & Kutrowski, 1973) and Łapszenkov's from 1957 (Batuca & Jordaan, 2000) where elaborated in results of investigations of silting of water reservoirs located in various geographical regions. Reliable calculations results of capacity reduction of a water reservoir can be obtained by use of these methods, maintaining similarity between hydrological conditions prevailing in the catchment area or hydraulic and hydrodynamic condition in the reservoir and conditions for which they were elaborated. Empirical methods serving at silting forecast concern mainly medium and large water reservoirs. These were elaborated in results of investigations carried out on those reservoirs but their application in silting forecast of small water reservoirs often leads to faulty results.
Small water reservoirs undergo quick silting. As given Dendy (1982) the mean annual silting ratio of twenty water reservoirs in the basin of the Rio Grande of original capacity from 0.2 do 1.2 million m^3 was from 0.6 to 4.5%. According to Soler-López (2001) water reservoirs in Puerto Rico of original capacity of 0.76 to 6.4 millions m^3 characterized by an average silting degree from 0.5 to 1.5%. According to Batuca and Jordaan (2000) the average annual silting degree of four small water reservoirs in Austria, whose original capacity were from 0.7 to 2.1 millions m^3 was from 0.5 to 2.5%. With regard to quick reduction of small reservoirs capacity these reservoirs are subjected desilting every ten or so or even tens of years. The mineral material removed from these reservoirs is often utilized for agricultural purposes or earth work carried out in the cachment area. The reservoir sediments may constitute of territories degraded by industry. Such utilization of chemically uncontrolled bottom sediments is connected with risk of causing increase in harmful substances content – including heavy metals in the soil environment. Determination of the quantity of sediment pollution, including concentration of heavy metals, is essential not only with regard to estimation of utilization possibilities of the removed sediment, but my also be helpful in evaluation of state of the environment. There is, however, some hardship in evaluation of sediment quality concerning not only small water reservoirs and this is lack of univocal criteria of determination of thresholds values as well as lack of advised methods referring determination of sediment pollution indices and their classification. Caeiro et al. (2005) assessing heavy metals in Sado Estuary sediment proved on the basis of analysis of eight from the presented sixteen indices that some among then gave equivalent information or supplied some additional enriching data concerning pollution or background enrichment indices and ecological risk indices. According to Caeiro et al. [2005] application of these indices requires elaboration of method of their standardization to make comparison of the obtained results possible. These criteria should be specified by directives of the European Parliament and should be related to the Water Framework Directive. It should be remembered according to Borja et al. (2004) that in European Water Framework Directive (WFD; Directive 2000/60/EC) the question "water" is referred to 373 occasions, but other matrices, such as sediment or biota (biomonitors), are mentioned explicitly only 7 and 4 times, respectively. Changes and supplements in the water directive were to be introduced by the Directive of the European Parliament and Council approved in 2007. According to

point 1 of Article 3 in the „Environmental Quality Standards (EQS) Applicable to Sediment and/or Biota (2007)" were defined that: „In accordance with Article 1 of this Directive and Article 4 of Directive 2000/60/EC, Member States shall apply the EQS laid down in Annex I, Part A, to this Directive in bodies of surface water". Whereas, according to point 2a of this Article it was defined that one can: „establish and apply EQS other than those mentioned in point (a) for sediment and/or biota for specified substances. These EQS shall offer at least the same level of protection as the EQS for water set out in Annex I, Part A". Can, thus, in connection of a given harmful substances in water be the basis of the determination of the sediment pollution level? Should be the evaluation criteria of sediment quality be separately identified? If quality criteria were to be defined for sediment, then monitoring would be required to establish compliance with such criteria? Response to these questions was obtained by defining concentration of three heavy metals in the water flowing into the studied small water reservoirs and in their bottom sediments. Investigations results on silting of twelve small water reservoirs in South Poland (fig. 1) were presented in this paper.

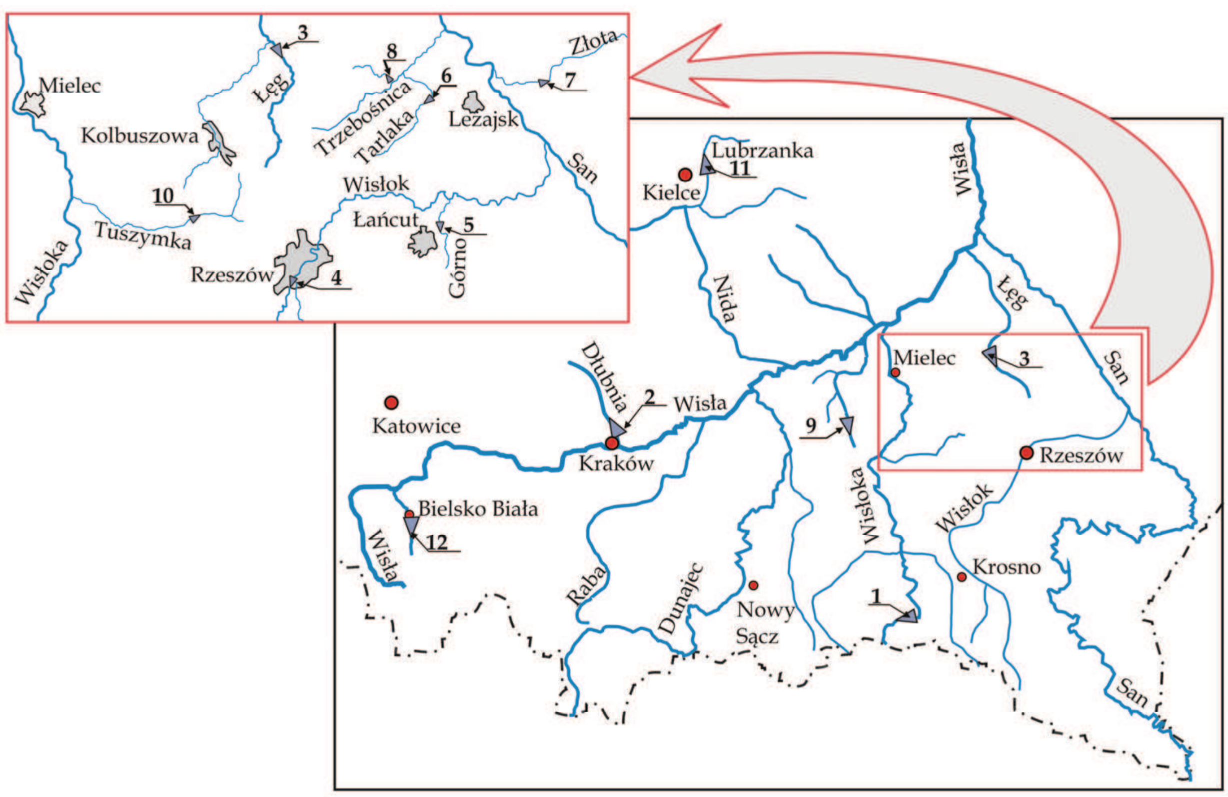

Fig. 1. Location of studied small water reservoirs: 1) Krempna, 2) Zesławice, 3) Maziarnia, 4) Rzeszów, 5) Głuchów, 6) Brzóza Królewska, 7) Ożanna, 8) Niedźwiadek, 9) Narożniki, 10) Cierpisz, 11) Cedzyna, 12) Wapienica

These results permitted elaboration of a method of determination of sediment quantity accumulated in small water reservoirs. This method bases upon indices determining silting intensity. The aims of this paper are: elaboration of a method of determination of the sediment quantity accumulated in small water reservoirs basing upon indices characterizing silting intensity and carrying out assessment of sediment pollution whit heavy metals applying Environmental Quality Standards (EQS) as well as other standard criteria of admissible concentrations of heavy metals in sediments.

2. Characteristics of research objects

Water reservoirs whose capacity, in agreement with the adopted in Poland criterion according to "Program of small retention…" (2004), is 5 millions m^3 were chosen for studies. This criterion is used for classification of small water reservoirs, among others in Romania (Batuca & Jordaan, 2000). Their average depth reaches from 0.8 m to 2.7 m, except the reservoirs at Wapienica whose average depth is above 6 m (table 1). Their surface of water table is from 1.5 ha to 160 ha. The length is also different from 0.34 km to 6.7 km.

Water reservoir / water-course	Water reservoir capacity [10^3 m^3]	Surface of the water table [ha]	Mean depth [m]	Length of the reservoir [km]
Krempna-1 / Wisłok	112.0	3.20	3.50	0.40
Krempna-2 / Wisłok	119.1	3.20	3.72	0.40
Zesławice-1 and Zesławice-1 / Dłubnia	228.0	9.50	2.40	0.65
Maziarnia / Łęg	3 860.0	160.00	2.41	6.51
Rzeszów / Wisłok	1 800.0	68.20	2.64	6.70
Głuchów / Graniczny	22.6	1.50	1.51	0.64
Brzóza Królewska / Tarlaka	48.8	6.13	0.80	0.44
Ożanna / Złota	252.0	18.00	1.40	0.95
Niedźwiadek / Górno	124.5	8.10	1.54	0.55
Narożniki / Dęba	283.0	28.00	1.01	2.00
Cierpisz / Tuszymka	34.5	2.30	1.50	0.34
Cedzyna / Lubrzanka	1 554.0	64.00	2.43	2.20
Wapienica / Wapienica	1 100.0	17.50	6.29	1.00

Table 1. Chosen basic parameters of studied small water reservoirs

The basins of the studied water reservoirs are mainly under agricultural use. The general feature of the chosen reservoirs is their quick capacity reduction being a result of the trapped small fractions of sediment. These reservoirs belong mainly to water reservoirs of uncontrolled water management. From the twelve reservoirs only four of them are located on water flows being under hydrological observations. These are: Krempna on the river Wisłoka, Zesławice on the river Dłubnia, Maziarnia on the river Łęg, and Rzeszów on the river Wisłok. With regard to the executed desilting works and rebuilding of two water reservoirs i.e. Krempna and Zesławice additional denotation of these reservoirs were introduced in presentation of the research results. In consequence of desilting and rebuilding of the Krempna reservoir in 1986 i.e. after 15 years of operation that caused decrease in its capacity from 119 thousands m^3 to 112 thousands m^3 its denotation Krempna-1 and Krempna-2, before and after desilting respectively, were introduced. This distinction was necessary with regard to change hydraulic characteristics of water flow through the reservoir which influenced the results of analysis of its silting process. The Zesławice water reservoir was also desilted and rebuilt without introduction any changes of its capacity. But, the character and quantity of water flow changed as a consequence of division of the total water flow in the water branching point on the inflow in the reservoir when a part of the flow was directed to a new built side reservoir. Hence, denotation Zesławice-1 and Zesławice -2 respectively for the period before and after desilting were introduced.

3. Methods

Surveys of the deposited sediment volume of studied water reservoirs consisted in determination of the change of ordinates of the reservoirs bottom in cross-section corresponding with post-execution cross-section and in points beyond these cross-sections. These measurements were performed from a boat by use a rod probe. With regard to the considerable depth of the reservoirs Wapienica, Cedzyna and Maziarnia a Human Bird 1000 echo-sounder was used in measurements of depth. Disposing of post-execution projects of the studied water reservoirs changes of cross-section surface were determined. Surveys of the deposited sediment volume of the studied water reservoirs were performed by a team directed by the author in years 1996-2006 at various time intervals.

3.1 Methods of assessment of silting intensity of studied reservoirs

The obtained surveys results were supplied with archival data. Basing upon the calculated volume of the sediment deposited in the reservoir (V_{dep}) the silting ratio of each of the studied water reservoirs in particular years of operation was calculated. The silting ratio (S) was calculated as a quotient of volume of the sediment deposited in the reservoir (V_{dep}) and its original volume (V_{res}). The mean annual silting ratio (S_A) was also calculated as a quotient of silting ratio determined on the basis of silting measurements in a given years of operation and number of years of operation. The calculated annual silting ratio was compared with the value of the mean annual silting ratio calculated by use Hachiro's formula (Batuca & Jordaan, 2000) elaborated on the basis of investigations of 106 water reservoirs in Japan and 39 in USA and one in Taiwan. Hachiro elaborated the regressive relation of the mean silting ratio (S_A) and the capacity-inflow ratio (C-I) in form:

$$S_A = 0.214 \cdot (\text{C-I})^{-0.473} \tag{1}$$

The capacity -inflow ratio (C-I) is the relation of the original reservoir capacity (V_{res}) and the sum of average annual runoff (Q) to the reservoir.
Another characteristic describing the silting process is the silting rate (W_z) defined as the volume of sediment deposits in water reservoir in given time interval referred to the cachment area. It is expressed in $m^3 \cdot km^{-2} \cdot year^{-1}$. The silting ratio calculated on the basis of the results of measurements of sediment volume deposited in the studied water reservoirs was compared with the value of this rate calculated by use of the Khosl's formula. This rate was elaborated on the basis of the results of measurements of water reservoirs silting in Europe, India, and USA which close small and medium catchment of area W<2500 km^2:

$$W_Z = 3180 \cdot W^{0.72} \tag{2}$$

Silting intensity (S_i) according to Šamov (Batuca & Jordaan, 2000) was also determined:

$$S_i = \frac{V_{res}}{V_{SS}} \tag{3}$$

Where (V_{res}) is the original water reservoir capacity, and (V_{SS}) is the mean annual volume of sediment flowing into the reservoir.
Simultaneously with the measurements of silting bottom sediments were sampled in cross-sections of the reservoirs in part close to the dam, in middle part and in the part of back

waters. In each of the parts of the reservoir samples were collected from the bottom sediment surface (i.e. at the depth 0-15 cm – upper layer) and at the depth 40-55 cm under sediment surface (lower part). Samples were collected by use of a standard sampler Beeker, made by Eijkelkamp company, according to the methods elaborated by Madeyski (2002). Sediment samples collected in twelve water reservoirs were subjected to analysis of granulometric composition and content of organic matter. In the sampled bottom sediments of water reservoirs: Krempna-2, Zesławice-2, Cierpisz, Wilcza Wola, Niedźwiadek and Narożniki concentration of heavy metals i.e. lead, cadmium, and nickel as well as chromium, zinc, and cooper were determined. Annual means and maximal concentration of lead, cadmium and nickel in the water inflowing into reservoirs were also determined.
The granulometric composition of bottom sediments was determined by Cassagrande's method modified by Prószyński in agreement with the Polish standard PN-R-04032 from the year 1998 (Michalec, 2008). In this method 1.5 g of Na_2CO_3, which is a deflocculant causing decomposition of flocculi and particle aggregates into elementary particles is added to the solution of suspended mater. The granulometric composition was determined on the basis of granular analysis of particular grains of sediment. Specific density was pictometrically determined and bulk density by of sand replacement method. Content of organic matter (O_m) was determined according to the annealing method.

3.2 Methods of determination of heavy metal contents in sediments

Determination of heavy metal contents in sediments was carried out by means of the method Flame Atomic Absorption Spectrometry method (FAAS) by use of a spectrophotometer Solaar M6 of Unicam mark. Performance of analysis was preceded by preparation of samples in the mineralization process carried out by use of a mixture of acids $HClO_4$ and HNO_3 in proportion 1 to 3 and dissolution in heat of dry residue in HCl in proportion 1 to 1. Determination was performed in flame of a gas mixture air-acetylene with deuterium correction of the background (Tarnawski, 2009). Determination of lead, cadmium, and nickel content in water inflowing into the six studied reservoirs were performed by use of the Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES) in an apparatus Viacan Vista-MPX PU 7000. After collecting water samples and proving them into Teflon container HNO_3 and 30%H_2O_2 was added. The sample fixed in this way was transported to the laboratory were it was subjected to a two-stage pressure microwave mineralization and subsequently subjected to spectroscopic analysis ICP-AES. Water samples were collected within three years i.e. in the period 2003-2005 in water inflowing to the reservoirs Krempna-2 and Niedźwiadek, in the period 2004-2005 in water inflowing to the reservoir Zesławice-2, in the period 2001-2003 in water inflowing to the reservoirs Cierpisz and Maziarnia, and in the period 2003-2005 in water inflowing to the reservoir Narożniki. Water samples for determination of heavy metals content (Pb, Cd, Ni) were collected four times every year i.e. in spring in April, in summer in July, in autumn in November and in winter in January. When collecting water samples suspended mineral matter should be taken into regard since in pollution transport it plays a significant role. Majority of chemical reactions occurring in the water environment proceeds at the interphase border solid body – solution. Hence, majority of trace elements especially of heavy metals do not stay in dissolved form for a long time but is often accumulated on particles of suspension. Therefore, in agreement with Polish instructions given in Measurement Programs of Integrated Monitoring of Natural Environment (Kostrzewski et al., 2006) when determining concentration of heavy metals in surface waters the sample after fixing should be immediately filtered off. The filtering off process may be neglected in the case of clean surface waters. According to this instruction water samples collected in the tributaries of the studied water reservoirs were not filtered off since sampling took place mainly during period of medium and low water discharges when the content of solid substances in samples was small since concentrations of the suspended sediment were from some to ten or so $mg \cdot l^{-1}$. The water samples collected during freshet when suspended sediment concentrations were above 100-150 $mg \cdot l^{-3}$ were subjected to filtering off by so called hard filters of diameter equaling 18,5 cm of the type 360 firm VEB Spezialpapierfabrik Niederschlag. During collecting water samples for determination of heavy metals content measurements of suspended sediment concentration were performed by use of a photooptic apparatus Portable Suspended Solids and Turbidity Monitor System 770.

3.3 Methods of determination of sediment transport

Apart from measurements of suspended sediment concentration made during water sampling in tributaries of the chosen six reservoirs series of suspended sediment concentration were also performed in cross-sections of the rivers which were under permanent hydrological observations carried by the Institute of Meteorology and Water Management. These were rivers flowing into the reservoirs Krempna, Zesławice, Maziarnia and Rzeszów. These measurements made possible determination of the amount of suspended sediment transport. Calculations of suspended sediment transport were made on the basis of series of data comprising average 24 hours' flows (Q) and corresponding with them suspended sediment concentration (Pp) determined at the station point of regular water sampling. The lacking data of suspended sediment concentration were complemented using the elaborated relations of suspended sediment concentration in function of water flow. The relation curves Pp=f(Q) for each of these seasons served for determination of suspended sediment transport in periods without measurements of suspended sediment concentration (Michalec, 2008). Heterogeneity of hydrological data concerning measurements of water flow in gauging station was studied applying a non-parametric rank-sum test.

The complemented hydrological data permitted to calculate the so called mean 24 hours' suspended sediment transport U_i [$g \cdot s^{-1}$] which is the product of daily suspended sediment concentration P_p [$g \cdot m^{-3}$] and daily water discharges (Q) [$m^3 \cdot s^{-1}$]. Subsequently a 24 hours', monthly, and yearly sediment transport in a given cross-section of the rivers was calculated. These calculations were performed on the basis of measurements in the point of regular water sampling. In calculation of suspended sediment transport a suspended sediment concentration in the whole cross-section should be considered. Aiming at it measurements of suspended sediment concentration in the whole cross-section of studied rivers were performed and the mean suspended sediment concentration (P_m) in the cross-section was determined. The calculated corrective coefficient "k" being the quotient of the mean suspended sediment concentration in the river cross-section (P_m) and the suspended sediment concentration in the point of the river cross-section (P_p), permitted calculation of intensity of the sediment transport.

The mass of sediment delivering to the other retention reservoirs, i.e. Głuchów, Brzóza Królewska, Ożanna, Niedźwiadek, Narożniki, Cierpisz, Cedzyna and Wapienica, located on small streams without hydrological data, was calculated by use of the DR-USLE method. The USLE equation (Wischmeier & Smith, 1965) in this method enables calculation of the annual mean mass of erosion products in catchment area. The amount of erosion products

delivered to the rivers was determined by means of parameter DR (delivery ratio) according to Roehl (1962).
The calculated mass of sediment delivered into the water reservoirs permitted determination of silting intensity defined by Šamov (Batuca & Jordaan, 2000) as the quotient of the original capacity of reservoir (V_{res}) and the annual mean of the sediment volume entering the reservoir (V_{SS}). In order to determine on the basis of calculated sediment transport intensity, expressed in mass units, the sediment volume delivered to the reservoir the determined volumetric density of sediments was used.

3.4 Methods of assessment sediments pollution

Determined values of heavy metals content in sediments collected from six water reservoirs made determination of maximal, minimal, and mean concentrations of given chemical element possible. Evaluation of sediment quality as pollution with heavy metals was carried out according to the binding Regulation of the Minister of Environment concerning soil quality standards (Dz. U. Nr 165, poz. 1359) and following instructions and method:

- geochemical classification of water sediments (table 2) elaborated and applied by the Polish Geological Institute (PIG) and State Inspection of Environment Protection (SIEP).

According to the instruction PGI and SIEP contents of heavy metals are determined in a separated sediment fractions of grain diameter less than 0.2 mm since this fraction constitutes particles of cohesive soils reflects due to its adhesive properties the amount of heavy metals in the environment. However, according to Bojakowska and Sokołowska (1998) small grain fractions are characterized by a higher trace metals content as compared with coarser fraction of the same sample. Therefore, making use of smallest sediment fractions for investigations leads to overestimation of results. In spite of this provision the method of trace element determination in sediment was adopted. This classification was first attempt to standardization of the results of bottom sediment studies and in spite of provision and doubts it is applied for assessment of every year investigation results under monitoring. In later years i.e. in 2001, following Canadian and American classification, a IV class classification of water sediments was introduced (table 2), based on threshold values which consider the harmful effect of accumulated in sediments pollution on aquatic organisms (Bojakowska, 2001).

Component	Geochemical background	Classes						
		1998			2001			
		I	II	III	I	II	III	IV
Elements (mgkg^{-1})								
Ar	5	10	20	50	7	30	70	>70
Cd	0.5	1	5	20	0.7	3.5	6	>6
Cr	5	20	100	500	50	100	400	>400
Cu	6	20	100	200	20	100	300	>300
Pb	10	50	200	500	30	100	200	>200
Hg	0.05	0.1	0.5	1.0	0.2	0.7	0.7	>0.7
Ni	5	30	50	100	16	40	50	>50
Zn	48	200	1000	2000	125	300	1000	>1000

Table 2. Qualitative classification of bottom sediments applied by the Polish Geological Institute and the State Inspection of Environment Protection

According to this classification of following classes were distinguished: I class – unpolluted sediments, no harmful effects of trace elements and toxic organic compounds on aquatic organisms are observed; II class – sediments moderately polluted, harmful effect of trace elements on aquatic organisms occurs occasionally; III class – sediments of medium pollution in which content of at least one harmful component exceeds the threshold content for sediments of II class, hence, sediments in which contamination is present in concentrations of which the harmful effect on aquatic organisms is frequently observed, but the content of harmful chemical elements is lower than the admitted content; and IV class – sediments heavily polluted in which at least for one of the components the admissible for III class is exceeded.

- instruction elaborated by the Institute of Soil Science and Plant Cultivation (Kabata-Pendias et al., 1995). The ISSPC instructions distinguish six degrees of contamination (table 3) ascribing to each degree the way of agricultural utilization of soil, characteristics tillage and possible recultivation works: degree 0 – unpolluted soils of natural content of trace metals, degree I – soils of increased metal content, degree II – soils slightly polluted, degree III – soils of medium pollutions, degree IV – soils heavily polluted, degree V – soils extremely polluted.
- Müller's method according to which the geoaccumulative index (I_{geo}). In this method the metal content is related to the natural content in sediments constituting the geochemical background of the given heavy metal (Müller, 1981). The index permits to distinguish seven classes: from unpolluted sediments – class 0 (I_{geo} <0) to very heavily polluted sediment – class VI (I_{geo} >5).

A sediment pollution index (SPI) was established according to Singht et al. (2002). Singh et al. (2002) introduced the concept of sediment pollution index (SPI). The SPI is a multi-metal approach for an assessment of sediment quality with respect to trace metal concentrations along with metal toxicity:

$$\mathrm{SPI} = \Sigma(\mathrm{EF_m} \cdot \mathrm{W_m}) / \Sigma W_m \quad (4)$$

where EF_m is ratio between the measured metal concentration (C_n) and the reconstructed background metal concentration (C_R) instead of the average metal concentration in shale. W_m is toxicity weight. Toxicity weight 1 was assigned for Cr and Zn, 2 for Cu and Ni, and 5 for Pb (Singh et al., 2002). The following classification is given for the SPI: 0–2 = natural sediment, 2–5 = low polluted sediment, 5–10 = moderately polluted sediment, 10–20 = highly polluted sediment, and >20 = dangerous sediment.

Evaluation of sediments was also made according to the criteria of admissible environmental levels of heavy metals concentrations adopted in Germany, Denmark, USA, and Canada (table 4) and presented in the paper Yau and Gray (2005) and also according to the criteria given by Sullivan (Chen & Lin, 2001) for dredged sediments.

Apart from the evaluation of sediments quality according to the above given criteria assessment was also performed according to Environmental Quality Standards of pollution with heavy metals: Pb, Cd and Ni of sediments and waters flowing into the six studied water reservoirs: Krempna-2, Zesławice-2, Cierpisz, Wilcza Wola, Niedźwiadek and Narożniki. This comparative assessment will permit to state whether the environmental pollution level determined on the basis of heavy metal concentration in water corresponds whit the level of the environmental pollution determined on the basis of heavy metals contamination in sediments.

Metal	Soil group	Degree of soil pollution [mg·kg^{-1}]					
		0	I	II	III	IV	V
Pb	a	20	70	100	500	2500	>2500
	b	40	100	250	1000	5000	>5000
	c	60	200	500	2000	7000	>7000
Zn	a	50	100	200	700	1500	> 1500
	b	70	150	300	1000	3000	>3000
	c	100	250	500	2000	5000	>5000
Cu	a	10	30	50	80	300	>300
	b	20	50	80	100	500	>500
	c	25	70	100	150	750	>750
Cd	a	0,3	1,5	2	3	5	>5
	b	0,5	2	3	5	10	>10
	c	1,0	3	5	10	20	>20
Ni	a	10	30	50	100	400	>400
	b	25	50	75	150	600	>600
	c	50	75	100	300	1000	>1000
Cr	a	20	40	80	150	300	>300
	b	30	60	150	300	500	>500
	c	50	80	200	500	1000	>1000

Table 3. Limits of heavy metals content in soils of various pollution degree (according to Kabata-Pendias et al., 1995), where: group a – soils containing 10-20% of washed off particles and of pH < 5.5; group b – soils containing 10-20% of washed off particles and of pH > 5.5 and soils containing more than 20% of washed off particles and of pH < 5.5; group c – other soils i.e. soils containing over 20% of washed off particles and of pH > 5.5

Background levels	Metal concentration [µg·g^{-1}]				
	Cd	Cu	Fe	Pb	Zn
Canadian background levels	1.1	25	31000	23	65
US background levels	–	20	28000	23	88
Minimum German background levels	0.15	10	–	12.5	50
Maximum German background levels	0.6	40	–	50	200
Dutch Target (DT) values	0.85	36	–	85	140
Dutch Intervention (DI) values	1.2	190	–	530	720

Table 4. Background concentration and quality objectives for heavy metals in sediments of freshwater ecosystems according to Woitke (Yau and Gray 2005)

4. Results and discussion

The volume of sediment trapped in the studied water reservoirs, determined on the basis of measurement results enables calculation of the silting ratio (S) in consequent years of operation (table 5, column 6).

Reservoir	Original capacity V_p [m³]	Year	Years of operation	Volume of deposited sediment [m³]	Silting ratio S [%]	Mean annual silting ratio S_A [%]	Capacity-inflow ratio C-I [%]
1	2	3	4	5	6	7	8
Krempna-1	119100	1986	15	35665	30.0	2.00	0.261
Krempna-2	112000	1996	9	27041	24.1	2.68	0.265
		1997	10	30464	27.2	2.72	0.255
		1998	11	34637	30.9	2.81	0.242
		1999	12	38002	33.9	2.83	0.231
		2000	13	40144	35.8	2.76	0.224
		2002	15	44200	39.5	2.63	0.212
		2003	16	44901	40.1	2.62	0.210
		2005	18	45810	40.9	2.27	0.207
Zesławice-1	228000	1968	2	26968	11.8	5.92	0.585
		1969	3	70425	30.9	10.30	0.458
		1970	4	75780	33.2	8.31	0.443
		1971	5	76251	33.4	6.69	0.441
		1974	8	86192	37.8	4.73	0.413
		1983	17	116091	50.9	3.00	0.326
Zesławice-2		1999	14	56162	24.6	1.76	0.786
		2005	20	75315	33.0	1.65	0.682
		2006	21	77232	33.9	1.61	0.673
Maziarnia	3860000	1999	10	504876	13.1	1.31	8.377
		2002	13	609600	15.8	1.21	8.116
		2003	14	625300	16.2	1.16	8.039
Rzeszów	1800000	1986	13	1188000	66.0	5.08	0.306
Głuchów	22570	2002	7	4126	18.3	2.61	0.104
Brzóza Królewska	48970	2002	17	4184	8.5	0.50	0.103
Ożanna	252000	1998	20	26000	10.3	0.52	0.634
		2003	25	30206	12.0	0.48	0.710
Niedźwiadek	124500	2003	5	3214	2.6	0.52	0.696
Narożniki	283800	2005	4	1646	0.6	0.15	2.317
Cierpisz	34500	1990	34	15000	43.5	1.28	5.770
		2001	11	6100	17.7	1.61	0.157
		2003	13	6745	19.6	1.50	0.229
Cedzyna	1550000	1999	26	145000	9.4	0.36	0.224
		2003	30	168500	10.9	0.36	4.032
Wapienica	1100000	1967	36	24250	2.2	0.06	3.964
		2003	71	46800	4.3	0.06	2.843

Table 5. Volume of deposited sediment and silting ratio of the studied reservoirs in individual years of operation

Considerable increase in silting ratio in consequent years of operation indicates it, and this is evidenced by results of calculations performed for the reservoirs: Krempna-2, Zesławice-1, Zesławice-2 and Maziarnia. It was stated that loads depositing in the reservoirs Krempna-1, Krempna-2 and Zesławice-1, Zesławice-2 increase their volumes very quickly. During the fifteen years of their operation, the 30 and 39.5% of the reservoirs Krempna-1 and Krempna-2 was silted up. During seventeen years operation before desilting and twenty one years operation after desilting, the silting ratio of the Zesławice reservoir is equal 50.9% and 33.9%. Directing a part of inflowing water and sediment into the building assistant reservoir for the time of the main reservoir desilting contributed to decrease in silting intensity of the main reservoir, i.e. reservoir Zesławice-2. The water reservoir Rzeszów is characterized by highest silting rate. During the thirteen years of its operation, 66% of its capacity was silted up.

Within the over 10 years of operation period the value of silting ratio, in the case of some studied reservoirs, is above 30-40% giving evidence of the silting process intensity. The silting ratio of small water reservoirs varies from 8 to 66%, already after a couple of years of operation. Reservoirs Brzóza Królewska, Niedźwiadek, Narożniki, and Wapienica, located in catchment areas covered in majority by forests and meadows are characterized by a lower silting ratio. Studied small water reservoirs are characterized by a considerably differentiated value of the mean annual silting degree ranging from 0.06 to 10.3% of the initial reservoir capacity. Whereas, the mean annual silting ratio (S_A) undergoes a relatively quick reduction what may be stated on the basis of its values calculated for the mentioned water reservoirs (table 5, column 7).

Reservoir	Years of operation	Annual mean silting ratio S_A [%] acc. to		Silting rate W_z [$m^3 \cdot km^{-2} \cdot year^{-1}$] acc. to	
		sediment volume surveys	Hachiro	sediment volume surveys	Khosl
1	2	3	4	5	6
Krempna-1	15	2.0	4.2	13.5	125881
Krempna-2	18	2.3	4.3	15.4	125881
Zesławice-1	17	3.0	2.3	31.3	153503
Zesławice-2	21	1.6	1.9	16.9	153503
Maziarnia	14	1.2	0.7	191.7	161036
Rzeszów	13	5.1	3.3	44.3	773602
Głuchów	7	2.6	5.0	47.9	19371
Brzóza Królewska	17	0.5	2.3	8.1	37162
Ożanna	25	0.5	1.1	8.9	109462
Niedźwiadek	5	0.5	1.3	34.3	26241
Narożniki	4	0.2	0.8	16.5	32281
Cierpisz	34	1.5	3.5	8.1	56576
Cedzyna	30	0.4	0.9	40.1	111594
Wapienica	71	0.1	1.1	11.9	57344

Table 6. Annual mean silting ratio of studied reservoirs in the year of last silting measurement and silting rate

The mean annual silting ratio, determined in the last year in which silting measurements were made, was compared with the mean annual silting ratio calculated according to Hachiro's formula (table 6). The value S_A calculated according to Hachiro's equation is from 0.9 to 19 times higher than that determined on the basis of sediment volume surveys. Also the silting ratio calculated according to Khosl's formula is higher than that established on the basis of measurements and being on the average 6000 higher.

4.1 Determination of silting intensity of small water reservoirs

The obtained results of calculated silting ratio (S) of studied reservoirs (table 5, column 6) indicate at considerable silting intensity of small water reservoirs, whose capacity is lower than 5 millions m^3 and capacity-inflow ratio is lower than 10%.

Water reservoir	Average annual mass of delivered sediment R_u [t]	Bulk density ρ_0 [$t \cdot m^{-3}$]	Average annual volume of sediment delivered to the reservoir V_{Ru} [m^3]	Silting intensity acc. to Šamov S_i [-]
1	2	3	4	5
Krempna-1	3990	1.23	3244	37
Krempna-2	3990	1.23	3244	35
Zesławice-1	16400	1.03	15922	14
Zesławice-2	16400	1.03	15922	14
Maziarnia	97310	1.65	58976	65
Rzeszów	206110	1.41	173202	10
Głuchów	872	1.25	697	32
Brzóza Królewska	308	1.14	270	181
Ożanna	1644	1.19	1382	182
Niedźwiadek	737	1.11	664	188
Narożniki	720	1.07	673	420
Cierpisz	744	1.32	563	61
Cedzyna	7092	1.12	6332	245
Wapienica	919	1.29	712	1544

Table 7. Average annual sediment transport and silting intensity of the water reservoirs established for the last silting measurement

Calculation of silting intensity according to the ratio defined by Šamov (Batuca & Jordaan 2000) required estimation of annual mean volume of sediment flowing into the reservoir. The amount of sediment transport delivered to the reservoirs Krempna, Zesławice, Maziarnia and Rzeszów, located on hydrologically controlled streams, was calculated on the basis of measurements of water flow and suspended sediment concentration taking into a count the corrective coefficient "k" in each measurement cross-section in streams. The corrective coefficients "k" calculated by use of program Statistica for Windows equal respectively: k=0.906 for the river Wisłok (reservoir Krempna), k=1.065 for the river Dłubnia (reservoir Zesławice), k=1.148 for the river Łęg (reservoir Maziarnia) and k=1.034 for the river Wisłok (reservoir Rzeszów). Regression equations were established with the confidence interval equal 95%. The mass of delivered suspended sediment to the other reservoirs was calculated by use of the DR-USLE method. In table 7 there are presented the results of calculation of mean annual mass of suspended sediment delivered to the studied reservoirs and mean bulk density of deposited sediments, established on the basis of six samples of bottom sediments collected in each reservoir (table 7). The relation of the mean annual silting ratio (S_A), calculated in the last year of operation of studied small water reservoirs, and determined according to Šamov (Batuca & Jordaan, 2000) silting intensity (S_i) was given in figure 2.

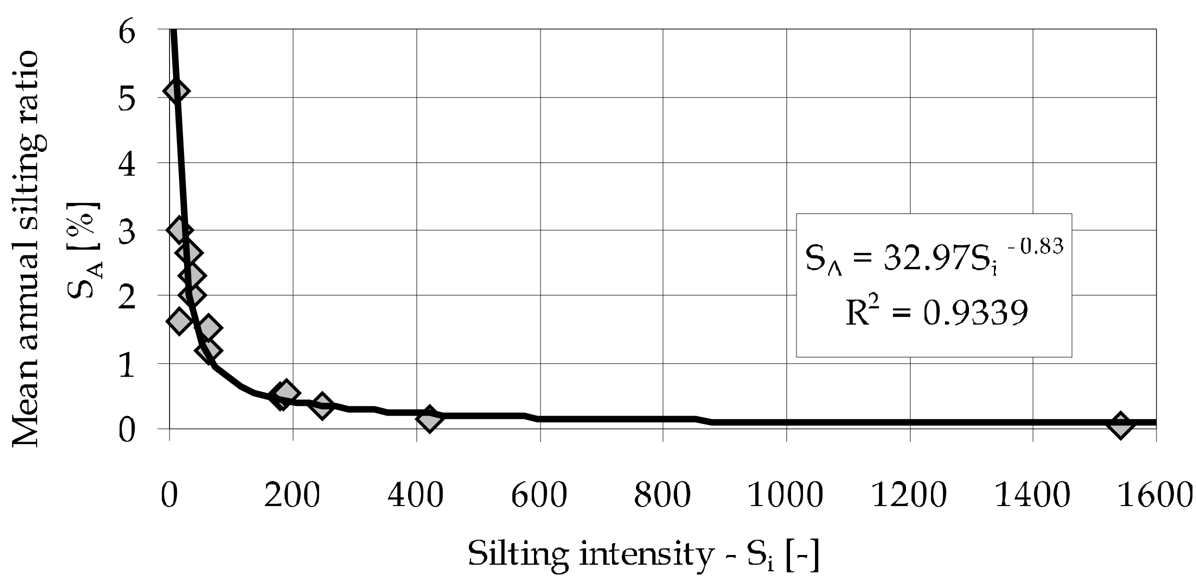

Fig. 2. Regression dependence of the mean annul silting ratio (S_A) defined on the basis of measurements and silting intensity (S_i) according to the Šamov's equation

This equation in form $S_A = 32.97S_i^{-0.83}$ enables recognition of the mean annual silting ratio of small water reservoirs (fig. 2), whose capacity-inflow ratio is lower than 10%. Disposing of the volume of suspended sediment delivered to the reservoirs (V_{SS}) and its original capacity (V_{res}) it is possible, on the basis of silting intensity calculated by use of Šamov's formula (3), to determinate the annual silting ratio, and on its basis the annual mean volume of sediment deposits accumulated in a small water reservoir may be estimated. On the basis of annual mean volume of sediments accumulated in the reservoir and on the bulk density of sediments the mean annual mass of sediments, deposited in reservoir, may be determined. Disposing of the so determined mass of sediments in the small water reservoir and knowing the heavy metal concentration appointed in the sample the total mean annual pollution burden of sediment may be forecasted. The lack of possibility of determination of suspended sediment mass delivered to the reservoir or of sediment volumetric density makes application of the relation presented in figure 2 impossible.

The mean annual silting ratio, calculated on the basis of the last measurement of silting was related to capacity-inflow ratio (C-I) with the determined for its original capacity. The relation presented in figure 3 may serve for estimation of silting intensity of small water reservoirs.

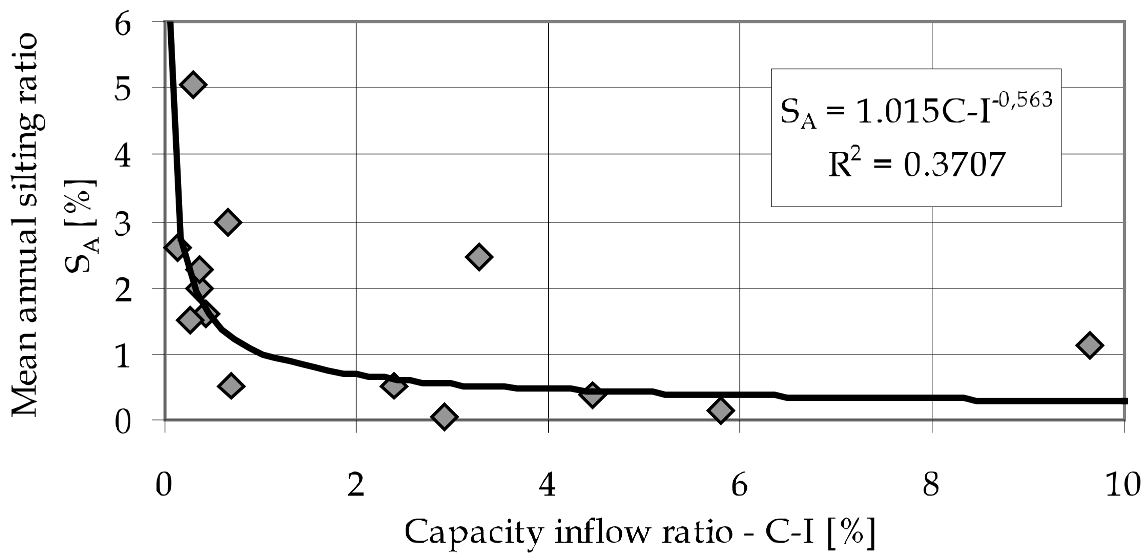

Fig. 3. Regression dependence of the mean annul silting ratio (S_A) defined on the basis of measurements and capacity-inflow ratio (C-I)

4.2 Characteristic of bottom sediment of studied small water reservoirs

The determined bulk density of sediments of lower layers in the inflow part of studied reservoirs ranges from 1.28 $t \cdot m^{-3}$ do 1.67 $t \cdot m^{-3}$ (table 8). These sediments are mostly constituted by sorted layers, forming clayey sands or clays. In the outflow parts of the reservoirs the surface layers of sediments are built from clayey or dusty mineral material of density from 0.68 $t \cdot m^{-3}$ to 1.19 $t \cdot m^{-3}$. The average specific density equals 2.54-2.63 $t \cdot m^{-3}$, whereas content organic matter in sediments does not exceed 10%. Fine grains of sediment deposited in the inflow part are characterized by bigger grain diameters as compared with the sediment trapped in the middle and in the outflow parts. Coarse grains of diameters above 2 mm are trapped above the inlet to the reservoirs. Variability of granulation in particular deposits layer was also stated. The upper layer of bottom sediment is constituted by a fines mineral material.

Bottom sediments collected from the water reservoirs: Krempna-2, Zesławice-2, Cierpisz, Wilcza Wola, Niedźwiadek and Narożniki were subjected - also apart from determination of physical properties – to evaluating of concentration of heavy metals: lead, cadmium and nickel as well as chromium, zinc and cooper. On the basis of six sediment samples collected in each water reservoirs the mean, minimal, and maximal concentration of heavy metals were determined in the analysed samples. Disposing of the mean concentration of the given metal its mass in sediments accumulated to the year in which last silting measurement was performed. The mass of sediments was calculated on the basis of sediment volume and mean volumetric density and subsequently the percentage content of metals in sediment was determined (table 9).

Water reservoir	Bulk density of sediment deposits ρ_0 [t·m^{-3}]							Content of organic matter O_m [%]
	1D	1G	2D	2G	3D	3G	m	
1	2	3	4	5	6	7	8	9
Krempna-2	1.28	1.31	1.32	1.16	1.17	1.16	1.23	0.82-7.22
Zesławice-2	1.47	0.78	1.16	0.80	1.30	0.68	1.03	3.35-7.36
Maziarnia	1.67	1.59	1.71	1.62	1.67	1.65	1.65	1.65-5.53
Rzeszów	1.62	1.51	1.47	1.22	1.42	1.19	1.41	4.86-7.87
Głuchów	1.41	1.27	1.33	1.24	1.14	1.09	1.25	3.22-6.89
Brzóza Królewska	1.51	1.08	1.38	0.91	1.11	0.87	1.14	1.69-4.98
Ożanna	1.42	1.07	1.38	1.12	1.23	0.94	1.19	2.41-8.12
Niedźwiadek	1.39	0.91	1.31	0.93	1.30	0.79	1.11	3.37-9.14
Narożniki	-	-	-	-	1.19	0.94	1.07	5.53-7.88
Cierpisz	1.65	1.23	1.53	1.03	1.44	1.06	1.32	2.89-4.19
Cedzyna	1.38	1.01	1.31	0.92	1.37	0.83	1.12	1.08-7.31
Wapienica	1.39	1.22	1.36	1.23	1.37	1.19	1.29	2.11-3.29

Table 8. Values of bulk density of sediment deposits and mean content of organic parts, where: 1 – outlet part, 2 – middle part, 3 – inlet part of the reservoir and G – upper layer, D – lower layer of deposits, m – mean value

Reservoir	Value	Heavy metals (μg·g^{-1})						Percentage content of heavy metals in sediments [%]					
		Pb	Cd	Ni	Cr	Zn	Cu	Pb	Cd	Ni	Cr	Zn	Cu
Krempna-2	Min.	9.8	0.1	42.3	8.4	49.1	19.2	1.75	1.03	5.29	1.04	7.56	5.08
	Mean	17.5	0.3	52.9	10.4	76.5	50.8						
	Max.	21.0	0.5	66.1	11.2	92.8	78.6						
Zesławice-2	Min.	10.5	0.1	14.7	16.9	34.9	6.9	2.00	0.05	1.62	1.85	7.29	1.07
	Mean	20.0	0.5	16.2	18.5	72.9	10.7						
	Max.	30.2	0.9	17.5	20.1	129.9	14.0						
Cierpisz	Min.	1.0	0.1	5.1	14.2	12.5	0.5	0.54	0.09	0.74	1.73	6.46	0.19
	Mean	5.4	0.9	7.4	17.3	64.6	1.9						
	Max.	10.5	2.8	12.6	19.8	208.5	6.0						
Maziarnia	Min.	8.7	0.1	8.4	10.1	23.9	4.5	0.95	0.03	0.93	1.15	2.46	0.52
	Mean	9.5	0.3	9.3	11.5	24.6	5.2						
	Max.	11.5	0.5	11.2	12.6	34.5	6.7						
Niedźwiadek	Min.	11.1	0.5	19.2	25.4	45.0	12.6	2.38	0.13	2.37	2.99	5.78	2.76
	Mean	23.8	1.3	23.7	29.9	157.8	27.6						
	Max.	34.3	1.9	25.4	33.2	230.0	33.8						
Narożniki	Min.	8.3	0.6	19.1	7.2	71.5	7.5	1.24	0.08	2.34	0.95	7.73	1.26
	Mean	12.4	0.8	23.4	9.5	77.3	12.6						
	Max.	15.2	1.2	29.6	11.0	83.8	15.3						

Table 9. Content of heavy metals Pb, Cd, Ni, Cr, Zn and Cu in sediments deposited in the small water reservoirs at Krempna-2, Zesławice-2, Maziarnia, Niedźwiadek and Narożniki

4.3 Assessment of sediment pollution with heavy metals

Water samples for determination of heavy metals content (Pb, Cd, Ni) were collected within three years four times every year. With regard to a short period, comparing only three years, no seasonal differentiation of concentration of heavy metals was stated. Table 10 shows the minimal, maximal, and mean annual concentration of the researched heavy metals.

Water reservoir	Value	Heavy metals in sediments (μg l^{-1})			Heavy metals in water (μg l^{-1})		
		Pb	Cd	Ni	Pb	Cd	Ni
Krempna-2	Min.	7.97	0.04	34.39	1.20	0.01	9.50
	Mean	14.19	0.28	43.03	2.40	0.03	12.30
	Max.	17.07	0.37	53.74	3.10	0.05	14.10
Zesławice-2	Min.	10.19	0.10	14.27	1.80	0.01	6.80
	Mean	19.44	0.47	15.73	3.10	0.04	8.90
	Max.	29.32	0.87	16.99	4.90	0.09	10.60
Cierpisz	Min.	0.76	0.08	3.86	0.10	0.01	1.30
	Mean	4.11	0.64	5.61	0.60	0.03	2.10
	Max.	7.95	2.12	9.55	1.40	0.05	2.80
Maziarnia	Min.	5.27	0.06	5.09	1.10	0.01	2.20
	Mean	5.77	0.16	5.64	1.50	0.03	3.70
	Max.	6.97	0.27	6.79	1.90	0.05	6.10
Niedźwiadek	Min.	10.00	0.41	17.30	1.30	0.02	6.30
	Mean	21.47	1.18	21.35	5.00	0.04	8.70
	Max.	30.90	1.71	22.88	6.10	0.08	11.20
Narożniki	Min.	7.76	0.56	21.20	0.90	0.03	5.90
	Mean	11.59	0.75	23.87	1.90	0.06	7.80
	Max.	14.21	1.12	28.32	2.40	0.07	9.30

Table 10. Content of heavy metals Pb, Cd and Ni in sediments and in water of water-course of six small water reservoirs

According to the proposition presented by Foernster (2007) determination of harmful substances content in water, including heavy metals, should be performed in agreement with one of two standards. According to the first standard evaluation of pollution level should be performed on the basis of the mean value established during at least one year. The mean value of substance concentration determined in such a way should be compared with threshold values of the Environmental Quality Standards. Whereas, according to the second standard the maximal recorded concentration of a given chemical element is compared with threshold values of the Environmental Quality Standards. In spite of the fact that chemical analyses of researched heavy metals were performed within the period of three years so with regard to low frequency of these measurements the pollution level of water was established according to the second standard proposed by Foernster (2007).

The recorded maximal concentrations of lead, cadmium and nickel (table 10) do not exceed the threshold values established in the Environmental Quality Standards according to which for the second water purity class the content of cadmium should be lower than 0.08 μg l^{-1}, whereas, the content of lead and nickel should be respectively not higher than 7.2 and 20 μg l^{-1}.

Application of the Environmental Quality Standards for evaluation of heavy metal pollution of bottom sediments of the studied water reservoirs required change of weight concentration of lead, cadmium, and nickel into bulk concentration expressed in $\mu g \cdot l^{-1}$ (table 10). For this purpose the established mean bulk density of bottom sediments was used. The limits of admissible concentrations of Pb, Cd and Ni given in the Environmental Quality Standards were compares with maximal concentration in the sampled sediment. Contrary to the appraised water quality as pollution with lead, cadmium, and nickel in concerned the sediments of the studied water reservoirs contained metal concentrations exceeding limits of Environmental Quality Standards. In three water reservoirs i.e. in Krempna-2, Niedźwiadek and Narożniki, content of Pb, Cd and Ni in sediments is higher than admitted. In the other water reservoirs content of nickel did not exceed 20 $\mu g \cdot l^{-1}$. Content of cadmium in sediments in all studied reservoirs is higher than the admissible concentration equaling 0.08 $\mu g \cdot l^{-1}$. With regard to lead content which did not exceed 7.2 $\mu g \cdot l^{-1}$, only sediments in water reservoir Maziarnia may be, according to the concentration limits admitted by Environmental Quality Standards, regarded as unpolluted. A similar evaluation may be obtained in the sediments basing upon the mean lead, cadmium and nickel contamination.

Sediments accumulated in six water reservoirs were subjected to assessment of quality according to the instruction of PGI and SIEP, ISSPC instructions, and according to Müller's method with regard to mean concentrations of lead, cadmium, and zinc as well as chromium, zinc, and copper. The contamination degree of sediments was determined for mean concentrations of heavy metals according to the ISSPC instructions limits of heavy metals content corresponding with soils of group c (table 3) were adopted. As researches results of Michalcec and Tarnawski (2009) showed the pH of the studied reservoirs is within range 5.5-8.0. The results are given in table 11.

Reservoir	Method	Heavy metals ($\mu g \cdot g^{-1}$)					
		Pb	Cd	Ni	Cr	Zn	Cu
Krempna-2	PGI and SIEP	I	I	III	I	I	II
	ISSPC	0	0	I	0	0	I
	Müller's	0,16 / I	-1,32 / 0	2,43 / II	-0,24 / 0	-0,69 / 0	1,8 / II
Zesławice-2	PGI and SIEP	I	II	II	I	I	I
	ISSPC	0	0	0	0	0	0
	Müller's	0,82 / I	3,58 / IV	1,43 / I	1,73 / II	-0,21 / 0	-0,10 / 0
Cierpisz	PGI and SIEP	I	II	I	I	I	I
	ISSPC	0	0	0	0	0	0
	Müller's	-0,84 / 0	-0,68 / 0	-1,21 / 0	1,60 / II	0,48 / I	-1,91 / 0
Maziarnia	PGI and SIEP	I	I	I	I	I	II
	ISSPC	0	0	0	0	0	0
	Müller's	-0,76 / 0	-1,67 / 0	-0,61 / 0	0,14 / I	-2,12 / 0	-1,75 / 0
Niedźwiadek	PGI and SIEP	I	II	II	I	II	I
	ISSPC	0	0	0	0	I	II
	Müller's	-0,13 / 0	1,34 / I	0,33 / I	-0,96 / 0	0,62 / I	0,17 / I
Narożniki	PGI and SIEP	I	I	II	I	I	I
	ISSPC	0	0	0	0	0	0
	Müller's	-1,47 / 0	-0,71 / 0	0,83 /I	-0,54 / 0	-0,27 / 0	0,49 / I

Table 11. Assessment of heavy metal pollution in bottom sediments

In order to establish geoaccumulative index (I_{geo}) according to Müller concentration of metals was determined sieved separated in a part of sediment grains smaller than 2 mm and the total concentration of trace metals were measured in <1 mm fraction of sediment, the background concentration in the shale sediment was adopted in agreement with Wedepohl (1995) as elemental concentrations in the continental crust.

Both according to the criteria PGI and SIEP, ISSPC and according to the Müller's method the studied reservoirs are characterized by highest pollution with nickel and chromium. Whereas, taking into consideration the obtained pollution classes (PGI and SIEP, Müller's method) and contamination degree (ISSPC) with particular heavy metals the heaviest polluted sediments are stated in water reservoirs Zesławice-2, Niedźwiadek and Krempna-2.

According to PGI and SIEP classification, assessed sediment contamination with trace metals may be classified as class I and II. They are characterized by toxic substances concentrations that do not have any ill effect on live organisms or this effect is occasional only. According to this assessment least polluted are sediments of the biggest reservoir i.e. Maziarnia as well as sediments of reservoirs Cierpisz and Narożniki. Sediments of these reservoirs are not contaminated with heavy metals (class I), except moderate contamination of sediments of the reservoir Maziarnia (class II) with copper, sediments of the reservoir Cierpisz contaminated with cadmium (class II) and sediments of the reservoir Narożniki with nickel (class II). With regard to the directives of ISSPC the sediments corresponds with soils of contamination degree from 0 to II. The lowest degree of pollution points at the possibility of unrestricted agricultural utilization of soils and in the case of sediments of this degree 0 there is an unlimited possibility of their agricultural utilization. With regard to a low content of lead, cadmium, nickel, chromium, zinc and copper such sediments are characterized of the reservoirs Maziarnia, Cierpisz, Narożniki and Zesławice-2. The other sediments were classified to soils poorly polluted (degree II) with regard to content of even one of the particular heavy metals indicating at the II degree of contamination. Out of this reason utilization of sediments from the water reservoirs Krempna-2 and Niedźwiadek is not admitted for recultivation or enrichment of agricultural soils used for some horticulture purposes, such as carrot, salad, spinach, since these plants assimilate heavy metals intensively.

This assessment confirmed by values of the sediment pollution index (SPI) according to according to Singht et al. (2002). These are for sediments of reservoirs Zesławice-2, Niedźwiadek and Krempna-2 respectively 5.12, 4.32 and 4.01; this indicates a moderately polluted sediment of the water reservoir Zesławice-2 water reservoir and low polluted sediment of the water reservoirs Niedźwiadek and Krempna-2. In the case of the other reservoirs i.e. Cierpisz, Narożniki and Maziarnia the obtained assessment indicated natural sediment since the obtained SPI values equal 1.49, 1.35 and 1.11 respectively.

According to the background levels in sediments adopted in Germany, Denmark, USA, and Canada (Yau & Gray, 2005), presented in table 4, the sediment quality may be appraised with regard to pollution with cadmium, cooper, iron, lead, and zinc. According to Canadian and USA levels of environmental pollution with lead only the sediments from the reservoir Niedźwiadek do not satisfy requirements with regard to its medium concentration. In this context the most restrict minimum German background levels of environmental pollution with lead of sediments both in the reservoir Niedźwiadek as well as in reservoirs Krempna-2 and Zesławice-2. Concentrations of lead in sediments of six studied reservoirs are lower than the environmental levels of the other criteria. Content of cadmium, according to the

Canadian, USA, and Danish criteria indicate that sediments from water reservoirs Ciepisz and Niedźwiadek exceed the admissible values. Whereas, according to the minimum German background levels mean concentrations of cadmium qualify the sediments as polluted. Sediments of reservoirs Krempna-2, Zesławice-2 and Niedźwiadek, similarly, as well as sediments from the reservoir Narożniki may be qualified as polluted sediments with regard to mean zinc concentration according to the environmental background levels of USA, Canada, and minimum German background levels. Trespassing the maximum German background levels of pollution and Dutch Target values with zinc was recorded only in the case of sediments from the reservoir Cierpisz and Niedźwiadek taking into regard only maximal concentrations of this chemical element. With regard to the mean zinc concentration only sediments from reservoirs Krempna-2, Zewławice-2, Niedźwiadek and Narożniki may be assessment according to minimum German background levels as polluted. Mean concentration of zinc in sediments from water reservoir Krempna-2 exceed additionally the Canadian and USA background levels and Dutch Target values. Taking into regard the highest number of exceeded concentration limits of Pb, Cd, Zn and Cu according to the above criteria the sediments of the reservoir Niedźwiadek are most intensively polluted. Sediments of the reservoirs Krempna-2, Zesławice-2, Cierpisz and Narożniki are characterized by a lower general pollution. Lowest pollution is found in the sediments of water reservoir Maziarnia.

The ISSPC directives are stricter in assessment of dredged sediments in comparison to the criteria given by Sullivan (Chen, Lin 2000). This follows from the fact that assessment of reservoir sediments according to the ISSPC directives takes into consideration not only quantities of trace elements pollution but also with regard to nature-agricultural use of sediments and accumulation heavy metals in cultivated plants. This caused establishment of lower admissible thresholds of heavy metal concentrations in sediments. According to criteria given by Sullivan (Chen, Lin 2000) dredged sediments should not contain nickel, chromium, zinc, and copper higher than 100 $\mu g \cdot g^{-1}$ and more than of 50 $\mu g \cdot g^{-1}$ lead. Neglecting cadmium, which was not included in Sullivan's criterion, sediments of the studied reservoirs satisfy the criterion given by Sullivan except zinc content. Only sediments of the water reservoir Niedźwiadek are characterized by moderate zinc concentration equaling over 100 $\mu g \cdot g^{-1}$. Hence, it would be advisable to apply the ISSPC directives for assessment of possibilities of dredged sediments utilization. It is so important because due to a very intensive silting process small water reservoirs require desilting even after only a few years of operation. In the case of agricultural utilization of the dredged sediments substances present in it may cause contamination agricultural cultivated soils. Carrying on researches concerning determination of heavy metals content in sediments and recording their changes in time of small water reservoirs operation is extremely important with regard to environmental condition and human health protection.

5. Conclusions

The mean silting ratio (S_A) of small water reservoirs whose capacity does not exceed 5 millions m^3 is within range from 0.06% to 10.3%. The considerable differentiation of values of silting ratio results both from the way in which the catchment is used, its physiogeographic parameters as well as from extreme hydrological-meteorological phenomena or different hydraulic water flow conditions through the reservoir. A high silting ratio is characteristic of water reservoirs Krempna, Zesławice, Maziarnia, Rzeszów, Głuchów and Cierpisz (table 5, column 6). The mean silting ratio of these reservoirs shows intensive silting. The silting intensity is influenced by the way of catchment area cultivation. Crop lands cover over 45% of catchment areas of the studied reservoirs. The considerable participation of arable land is conductive to surface erosion processes of mineral material which is carried away from the catchment.

Small water reservoirs whose capacity-inflow ratio is lower than 10% are characterized by a quick reduction of capacity in a relatively short time and their annual silting ratio is 2.5%. With regard to the intensity of the silting process their capacity is reduced within a dozen of years of operation on the average by about 40% (table 5). Assessment of the Hachiro's and Khosl's formulas for determination the mean annual silting ratio of the studied small water reservoirs proved to the impossible since the obtained results differed considerably for the mean annual silting ratio calculated on the basis of silting measurements.

The elaborated relation in form $S_A = 32.97S_i^{-0.83}$ permits calculation of the mean annual silting ratio of the small water reservoirs whose capacity-inflow ratio is lower than 10%. For this purpose it is necessary to determine the mean annual volume of carried suspended sediment entering the reservoir (V_{SS}) and this makes calculation of silting intensity (S_i) possible using Šamov's formula (3). In case of the volume of the carried sediment entering the reservoirs is not available the mean annual silting ratio can be assessed by use of the relation $S_A = 1.015C\text{-}I^{-0.563}$. Admittedly on the basis of the determination coefficient equaling 0.3707 poor agreement accordance of the regression model to the data at disposal was found, the correlation coefficient 0.61 indicates at average strength of the correlation. Hence, the calculation results obtained by use of this formula should be treated only as approximate values. Extension of researches over a bigger number of small water reservoirs located in various catchment areas could enable verification of the proposed equations and possibility their modification.

In the studied water reservoirs a fine fractions of sediment smaller than 1 mm is accumulated. Mean bulk density of bottom sediments is from 1.03 to 1.65 $t{\cdot}m^{-3}$, and the content of the organic matter does not exceed 10%. The content of heavy metals in bottom sediments of six small water reservoirs does not exceed on the average a few percent of sediment mass deposited in the reservoirs. Appraising pollution of sediments with trace metals according to the Environmental Quality Standards it was stated that concentration of metals in deposits exceed the EQS limits. According to the assessment of environmental pollution elaborated on the basis of assessment of lead, cadmium, and nickel concentrations in waters flowing into the studied water reservoirs which do not exceed the threshold value defined in EQS no threat of environmental pollution of the reservoirs ecosystem may be stated. The obtained researches results shows that correct environmental assessment of rivers, streams and dam reservoirs based on surface water monitoring results cannot be guaranteed. Identical level of heavy metal pollution in sediment and in biota cannot be serving at assessment of environment pollution on the basis of the concentration of heavy metals in surface water. Hence, fulfillment of notation of EQS Article 2 concerning environmental quality, saying that Member States shall arrange for the long term trend analysis of concentrations of priority substances, that tend to accumulate in sediment and/or biota on the basis of monitoring of water status carried out. They shall take measures aimed at ensuring, that such concentrations do not significantly increase in sediment and/or relevant biota. With regard to lack of extensive and reliable information in the European Community on concentration of priority substances in fauna and flora and in sediments one cannot confine oneself to establishing standards of environmental quality

basing on surface water assessment. It is assumed that Member States are supposed to establish more in detail Environmental Quality Standards or its supplement. Thus, is important to perform a comparison of standards of particular states serving for assessment of pollution not only of sediments but also of fauna and flora. These constitute important matrices for monitoring of some substances for assessment of long term effect of human activity and control if the Member States ensure no increase in pollution level of biota as well as of sediments. The exceeded assessment of chosen criteria of admissible levels of environmental concentrations of heavy metals adopted in Germany, Denmark, USA, and Canada showed that according to these criteria great differentiation of quality of sediments accumulated in the studied water reservoirs was recorded. Assessing sediment quality to the background levels in sediments it was stated, that the most restrictive criteria are the German ones with regard to minimum background levels. This is in particularly noticeable in the case of cadmium concentration. Sediments of each of the analysed reservoirs do not satisfy the criterion of admissible concentration of this metal. Both the maximal and medium concentrations of cadmium in sediments are higher than admissible ones in background concentration levels adopted in Germany, Denmark, USA, and Canada. Whereas, according to PGI and SIEP sediments of three reservoirs, i.e. Zesławice-2, Cierpisz and Niedźwiadek, are sediments moderately polluted (class II) with regard to cadmium concentration. Sediments of the other reservoirs according to this criterion are not polluted with cadmium and are classified as class I. This indicates at adoption of unified criteria of determination of contamination level of bottom sediments, that may enable gaining comparable assessment of long term effects oh human activity. Criteria of sediment assessment should not be treated neglecting the influence sediments on live organisms. The classification elaborated and applied in Poland by the Polish Geological Institute and the Inspection of Environment Protection State are an example of introduction of such criteria.
Elaboration of more accurate normatives of Environmental Quality Standards, based on heavy metals content in surface waters and sediments, requires the elaboration of more precise comparison methods and tools for the assessment of heavy metals pollution levels and contaminants constant monitoring. Currently, more reliable surface water quality assessments are still demanded.

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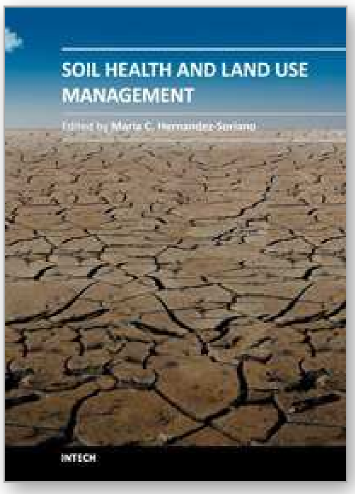

Soil Health and Land Use Management

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Soils play multiple roles in the quality of life throughout the world, not only as the resource for food production, but also as the support for our structures, the environment, the medium for waste disposal, water, and the storage of nutrients. A healthy soil can sustain biological productivity, maintain environmental quality, and promote plant and animal health. Understanding the impact of land management practices on soil properties and processes can provide useful indicators of economic and environmental sustainability. The sixteen chapters of this book orchestrate a multidisciplinary composition of current trends in soil health. Soil Health and Land Use Management provides a broad vision of the fundamental importance of soil health. In addition, the development of feasible management and remediation strategies to preserve and ameliorate the fitness of soils are discussed in this book. Strategies to improve land management and relevant case studies are covered, as well as the importance of characterizing soil properties to develop management and remediation strategies. Moreover, the current management of several environmental scenarios of high concern is presented, while the final chapters propose new methodologies for soil pollution assessment.