

Effects of Flooding on the Contamination of Floodplain Sediments with Available Fractions of Trace Metals (Western Poland)

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Abstract

The total content and available forms of trace metals (Cd, Cr, Cu, Ni, Pb, Zn) in fluvial sediments has been determined for surface samples (0-30 cm) collected in 2009 and after the flood in 2010 from the flood plain of the Odra River in western Poland. Total metal concentrations were obtained after mineralization with HNO₃, and the available forms of trace metals were obtained by single extraction procedure using soft extractant – 0.01M CaCl₂. Measurements of physico-chemical parameters also were performed: grain size fraction analysis, Eh, pH, organic matter, and calcium carbonate contents. The conducted analyses revealed that metal samples collected after the flood in 2010 varied in terms of physico-chemical parameters, total contents, and actually available forms of the studied trace metals. It has also been stated that the total contents of Cd, Cr, Cu, Ni, Pb, and Zn are strongly correlated with the participation of very coarse-grained (from 2000 to 1000 μm) and medium-grained (from 500 to 250 μm) sediments as well as with the content of organic matter (excluding Cd). On the other hand, the actually available Cr forms may increase along with the increase in CaCO₃ content.

Keywords: trace metals, floodplains, fluvial sediments, single-stage extraction, Odra River

Introduction

In the aquatic environment 90% of the trace metal content is connected with the suspension and fluvial sediments [1]. The rhythms of flood events affect the processes taking place in the fluvial sediments [2]. The change in physico-chemical conditions that occurs in the sediments at that time affects the release of trace metals and their introduc-

tion to the natural environment [3-5]. These phenomena are controlled by the following processes: sorption/desorption, precipitation/dissolution, coagulation, and complexing reactions [6]. It has been stated that the mobility of trace metals in fluvial sediments is conditioned to the largest extent by pH and redox potential (Eh), as well as by granulometric composition and the content of organic matter and carbonates [4, 7, 8].

The availability of trace metals accumulated in the fluvial sediments depends on their binding form in sediment [9]. The total contents of trace metals do not have the same

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content as the actually available ones that threaten the natural environment [10, 11]. The application of single-stage extraction procedures allows for the determination of metal forms dissolved in the extractants selected so that they reflect the biological assimilation properties of a given metal for plants or organisms (assimilable forms) and their susceptibility to leaching [10, 11]. So-called “soft extractants” are mainly used, which include neutral salt solutions (e.g. CaCl_2 , KCl , NaNO_3) [10]. The extraction with 0.01M CaCl_2 allows for the determination of trace metal forms described as actually available, usually exchangeable bound with the constant or changeable amount of mineral or organic components of the sediment [12, 13]. These forms may be released to water as a result of a rapid change in physico-chemical parameters of the sediments, that is pH, Eh [14]. It is also observed that the trace metals determined after extraction with 0.1M CaCl_2 correspond with the contents actually available for plants [15-17].

As a result of inundating the floodplain sediments during flood, the aerobic conditions may change into anaerobic ones and, consequently, a slow and stable decrease in Eh and increase in pH may occur [7]. Both parameters strongly influence the decrease of metal dissolution properties in the conditions of soil sediment inundation. In the aerobic conditions, Mn, Fe, and S occur in oxidized forms, which are indirectly linked to high Eh values [18]. In the immobilization of trace metals, the hydrated oxides play a crucial role. They are considered to be weakly soluble [19] and they affect the immobilization of metals by their sorption [20]. It should be underlined that along with the Eh decrease as a result of sediment inundation, the solubility of Fe and Mn oxides increases due to the effect of processes of reductive dissolution [i.a. 7, 21, 22]. In consequence, a release of the adsorbed trace metals occurs.

The aim of this paper was to determine the changes in the total and actually available from contents of cadmium, chromium, copper, nickel, lead, and zinc in fluvial sediments in the Middle Odra River following the flood in the year 2010. Moreover, the correlations between the physico-chemical parameters of the studied sediments (that is Eh,

Table 1. Characteristics of the sampling sites.

Sampling sites	N	E
1	52°31'54.5"	14°36'25.6"
2	52°32'55.2"	14°36'30.2"
3	52°31'55.9"	14°36'35.6"
4	52°51'56.6"	14°36'39.9"
5	52°30'04.3"	14°38'07.4"
6	52°30'04.7"	14°38'07.8"
7	52°30'04.7"	14°38'08.2"
8	52°30'05.0"	14°38'08.5"
9	52°28'30.4"	14°36'51.1"
10	52°28'30.0"	14°36'51.8"
11	52°28'30.0"	14°36'52.6"
12	52°28'29.6"	14°36'53.3"
13	52°21'19.1"	14°33'15.1"
14	52°21'18.7"	14°33'17.3"
15	52°21'18.4"	14°33'19.1"
16	52°21'18.0"	14°33'21.2"

pH, organic matter content, participation of granulometric fractions of sediments) and the concentrations of the studied trace metals were analyzed.

Materials and Methods

Study Area

The study area was located between the 585th and 609th km of the Odra River, where 16 sampling points were established (Fig. 1, Table 1). In recent decades this area has been affected by two serious floods, in 1997 and 2010.

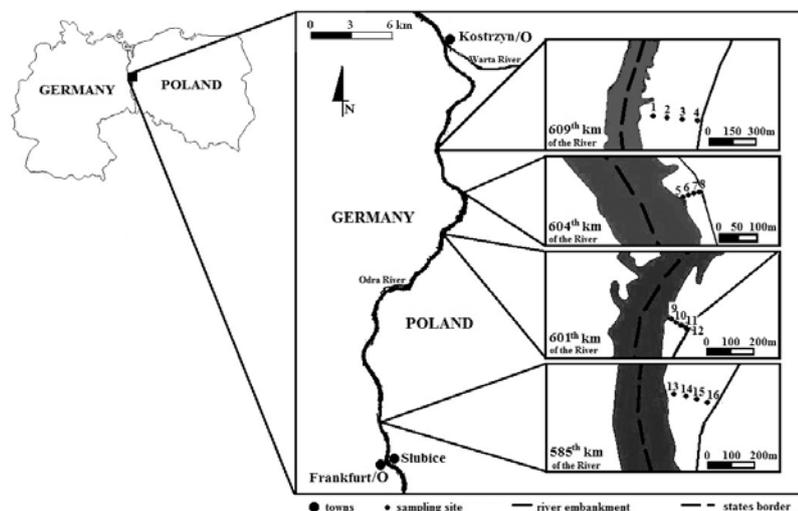


Fig. 1. Field site location.

Table 2. Water table characteristics in the period from 1998 to 2009 in Słubice, danger point level – 370 cm.

Water table characteristics	Water table level [cm]											
	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Lower Low Water	134	119	129	143	128	73	85	102	86	98	95	116
Mean Water Level	240	251	216	252	239	190	174	201	217	198	197	220
Higher High Water	342	446	407	443	405	470	399	427	516	349	300	424

The flood in 1997 was called the flood of the millennium and it was caused by long-lasting and intensive rainfall in the upper catchment of the Odra River. The water height exceeded the danger point level, amounting to 370 cm, for 33 days, reaching its highest value of 627 cm. During the flood in 2010 the water stayed above the danger point level for 28 days. During that flood, the highest water level was observed on 29.05.2010, and it amounted to 574 cm. The analysis of characteristic water levels in Słubice in the years between the two described floods indicated that only in the years 1998, 2007, and 2008 did the water in Słubice not exceed the danger point level (Table 2).

Field Study

The sampling took place in November 2009 and 2010. Five sub-samples from the surface layer (0-30 cm) were collected at each sampling site. The samples were collected with a stainless steel scoop into polyethylene bags. In the field, Eh was also measured *in situ* using a platinum electrode and a silver chloride reference electrode (RL-100 Hydromet).

Sample Preparation

In the laboratory, the sub-samples from each sampling site were mixed thoroughly to get a representative sample and they were dried at room temperature. Every sample was split into two halves. For grain size analysis, one of the halves was passed through sieves with mesh sizes of (μm): 4000, 2800, 2000, 1400, 1000, 800, 630, 500, 400, 315, 250, 200, 160, 125, 100, 90, and 50, according to the Polish Norms [23, 24]. The grain size fractions [25] analysis was performed using grain size analysis program Gradistat v. 6.0. The remaining half was sieved through a non-metallic sieve with 2.0 mm and taken into physico-chemical analysis. The $\text{pH}_{\text{H}_2\text{O}}$ was measured in a soil-in-water suspension (1:2.5) with laboratory electrode EH-02 Hydromet. In order to determine the content of organic matter (OM), the air-dried sediment samples were combusted at 550°C. The contents of calcium carbonate were determined by the Scheibler method [26]. The pseudo total metal concentrations were determined by digesting 1g sediment with 10 ml concentrated HNO_3 at 95°C \pm 5°C using slightly modified EPA Method 3050B [27] in a Mars 5 Xpress microwave digestion system (CEM, Matthews, North Carolina, United States). The sediments were digested in two stages: Stage 1 – 1200 W for 5.30 min, Stage 2 – 600 W for 4.30 min.

The concentrations of the available fractions of the metals were obtained after a single-stage extraction with 0.01M CaCl_2 with the ratio 1:10 sediment/solution, and they were mixed by shaking on an end-over-end shaker for 3 h [13]. Every sediment sample was analyzed three times and the result was calculated as the average value.

Analytical Technique

The trace metals were determined using an atomic absorption spectrometer with acetylene-air flame atomization (F-AAS). A fast sequential atomic absorption spectrometer SpectrAA 280 FS (Varian, Australia) was used. The samples were batched using an SPS3 autosampler (Varian, Australia). The reagents used in the analyses were analytically pure, and the water was deionized to a resistivity of 18.2 M Ω -cm in a Direct-Q® 3 Ultrapure Water System apparatus (Millipore, France). Standard solutions were prepared using Merck commercial standards for AAS (Merck, Darmstadt, Germany). The accuracy of the total heavy metal measurements was determined on the basis of certified reference material (CRM055-050), with a recovery rate of (%): 98.0 for Cd, 98.3 for Cr, 98.6% for Cu, 97.5% for Ni, 99.4 for Pb, and 98.1% for Zn.

Statistical Analysis

The statistical analysis of the results was performed in the Statistica v. 8.0 program. Along with the basic statistical parameters, the analysis of the correlation between the variables at the relevance levels $\alpha < 0.05$ was conducted. The measurement of the correlation forces was determined based on the values of correlation coefficient, and strong correlation was determined based on the $r > 0.50$ value.

Results and Discussion

Physico-Chemical Characteristics

Precise granulometric analysis of the collected sediments was difficult because their density had a bimodal distribution. There consist of mineral grains with densities corresponding to mineralogical densities of the minerals involved, and fragments of organic matter with densities close to 1 g-cm⁻³. In the size fractions where the grain size distribution could not be obtained by sieving (<50 μm), the separation of the individual size categories of particles by

Table 3. Physico-chemical characteristics of the sediment samples collected in 2009 and 2010.

Sampling years	Statistical parameters	Eh [mV]	pH _{H₂O}	MO [%]	CaCO ₃ [%]	Percentages of particular granulometric fractions [μm]					
						2000-1000	1000-500	500-250	250-100	100-50	<50
2009	minimum	285	5.52	3.39	2.03	1.50	5.00	15.0	4.10	0.42	0.18
	maximum	422	7.52	21.1	5.40	43.5	47.6	44.8	41.1	5.30	2.30
	average	360	6.21	20.5	3.17	21.2	28.2	31.1	16.3	2.01	0.87
2010	minimum	172	5.74	5.11	2.22	5.60	13.3	7.96	3.37	1.00	0.43
	maximum	426	7.20	19.8	4.90	33.2	44.5	40.1	42.6	5.02	2.18
	average	314	6.43	12.6	3.39	17.1	22.5	26.6	17.7	3.02	1.31

the usual sedimentation method (based on Stoke' Law) is thus strongly influenced [28]. With respect to these difficulties, the finest fractions (silt and clay) were not separated. However, the content of silt and clay in the analyzed sediment samples was low and did not exceed 2.30% (Table 3). Moreover, most sediment samples collected in 2009 and 2010 were classified as coarse sands and medium-grained sands. They were poorly sorted, symmetrically skewed and their distribution was mesokuric. It was revealed that for the sediment samples collected in 2010, the participation values of coarse-grained sand fraction (from 1500 to 1000 μm) and medium-grained sand fraction (from 500 to 250 μm) were much lower, while the values of very fine sand participation (from 250 to 100 μm), clay, and silt (<50 μm) were much higher (Table 3). Similar conclusions, indicating the increase in the content of the finest sediments, are shown in the literature data [5, 29].

The conducted studies indicated that after the flood in 2010, the redox potential values were marked by lower average values. However, these were not statistically significant changes (Table 3). According to the literature data, it is noteworthy that during the flood the aerobic conditions change into anaerobic ones and reduction takes place as well as the decrease in Eh value [7, 30]. The reduction intensity is higher in the presence of organic matter because the fall of O₂ content occurs as a result of the activity of soil microorganisms [7, 30].

After the flood that took place in the studied area, it was also shown that the pH_{H₂O} values were much higher (Table 3). This is linked to the fact that along with the decreasing Eh values during the flood, the increase in pH values occurs towards the neutral value [7, 30]. Most reductive reactions cause the use of H⁺, which results in the pH rise in acidic soils. In reality, CO₂ in the reduced soils buffers pH in the range from 6 to 7 through H₂CO₃-HCO₃⁻ reactions [7].

Moreover, the analysis of the fluvial sediment samples conducted in 2010 revealed that the contents of organic matter were higher in comparison with the contents shown in 2009 (Table 3). However, the statistical relevance between the results of organic matter content was not found. Many authors draw attention to the changes in the

process of organic matter decomposition in fluvial sediments after the flood [30, 31]. However, the median values (from 9.97% to 16.7%) determined for the content of organic matter in the samples of the studied fluvial sediments are much higher than those found in the fluvial sediments from the Middle Wisła River, collected after the flood in 2010 in the area of Wilkowo and Janowiec, which amounted to 1.9% to 2.4% [31].

Also, the CaCO₃ contents were higher after the flood, but in the case of this parameter the statistically significant differences were not shown (Table 3). Considering the fact that pH_{H₂O} of the analyzed sediment samples collected after the flood of 2010 was significantly higher in terms of statistics, at the simultaneous increase in CaCO₃ content, higher concentrations of trace metals in the studied fluvial sediments should be expected. Such correlation is indicated by the previously conducted studies of trace metal contents in sediments [32].

The above results are different from the results obtained for fluvial sediments of the Middle Wisła River conducted after the flood in 2010 [31], for which no influence of flood on the changes in physico-chemical parameters of sediments was shown.

Total Content

In the samples of fluvial sediments collected in 2009, the highest maximum contents were determined for Zn (1,270 mg·kg⁻¹), Pb (340 mg·kg⁻¹), Cu (243 mg·kg⁻¹), Ni (96.8 mg·kg⁻¹), Cr (83.5 mg·kg⁻¹), and Cd (20.2 mg·kg⁻¹) (Fig. 2). On the other hand, the highest maximum values determined in the sediment samples from 2010 were higher (with the exception of Ni and Cu) and they amounted to (mg·kg⁻¹): 1,544 for Zn, 404 for Pb, 234 for Cu, 80.2 for Ni, 133 for Cr, and 86.7 for Cd (Fig. 2). For total Ni contents, it was also shown that the total contents determined after the flood were much lower. Those maximum concentrations were higher than the background values obtained in bottom sediments in Poland [33] and in floodplain sediments in Europe [34] (Table 4). Besides, in the case of Cd, Cu, Pb, and Zn the limits specified in Polish regulations [35] for the upper layers of soils in agricultural use were also exceeded (Table 4).

Table 4. Background values and permitted levels of trace metals [mg·kg⁻¹].

Metal	Background values		The limits specified in Polish regulation [35]
	Bottom sediments in Poland [33]	Floodplain sediments in Europe [34]	
Cd	<0.5	0.3	4
Cr	5	59	150
Cu	6	17	150
Ni	5	22	100
Pb	10	22	100
Zn	48	65	300

The analysis of average contents of the studied metals showed lower values for Cu, Ni, and Zn in the samples collected in 2010 (Fig. 2). The biggest difference between the contents determined in 2009 and 2010 was shown for Cu and Ni, which amounted to 8-9 mg·kg⁻¹. Similar results are shown with relation to fluvial sediments of rivers in Poland

and Europe [i.a. 7, 31, 36-38]. The decrease in the contents of the studied metals in fluvial sediments after flood may be indirectly caused by the decreased Eh values and, consequently, the increased solubility of Fe and Mn. The hydrated oxides of Fe and Mn may affect the immobilization of metals by their sorption [20]. It should be underlined that the Eh relation and metal availability are also influenced by other factors, such as their sensibility to Eh value changes, buffer capacity of sediments, microbiological activity, and diagenetic processes [38, 39]. On the other hand, the higher average total contents in fluvial sediments were shown for Cd, Cr, and Pb in 2010 (Fig. 2). In the case of Cd, its concentration in sediment samples collected after the flood were much higher. This finding is partly inconsistent with the results of studies conducted in the Middle Odra River by the Provincial Inspectorate for Environment Protection in Zielona Góra after the flood of 1997 [40]. These studies revealed that the flood sediments of the Middle Odra River investigated in 1997 were characterized by high, but not statistically significant, concentrations of Cd, Cr, Cu, Ni, Pb and Zn. It is also indicated that during massive floods, pollutants originating from punctual and non-punctual sources are diluted and, as a result, their concentrations may

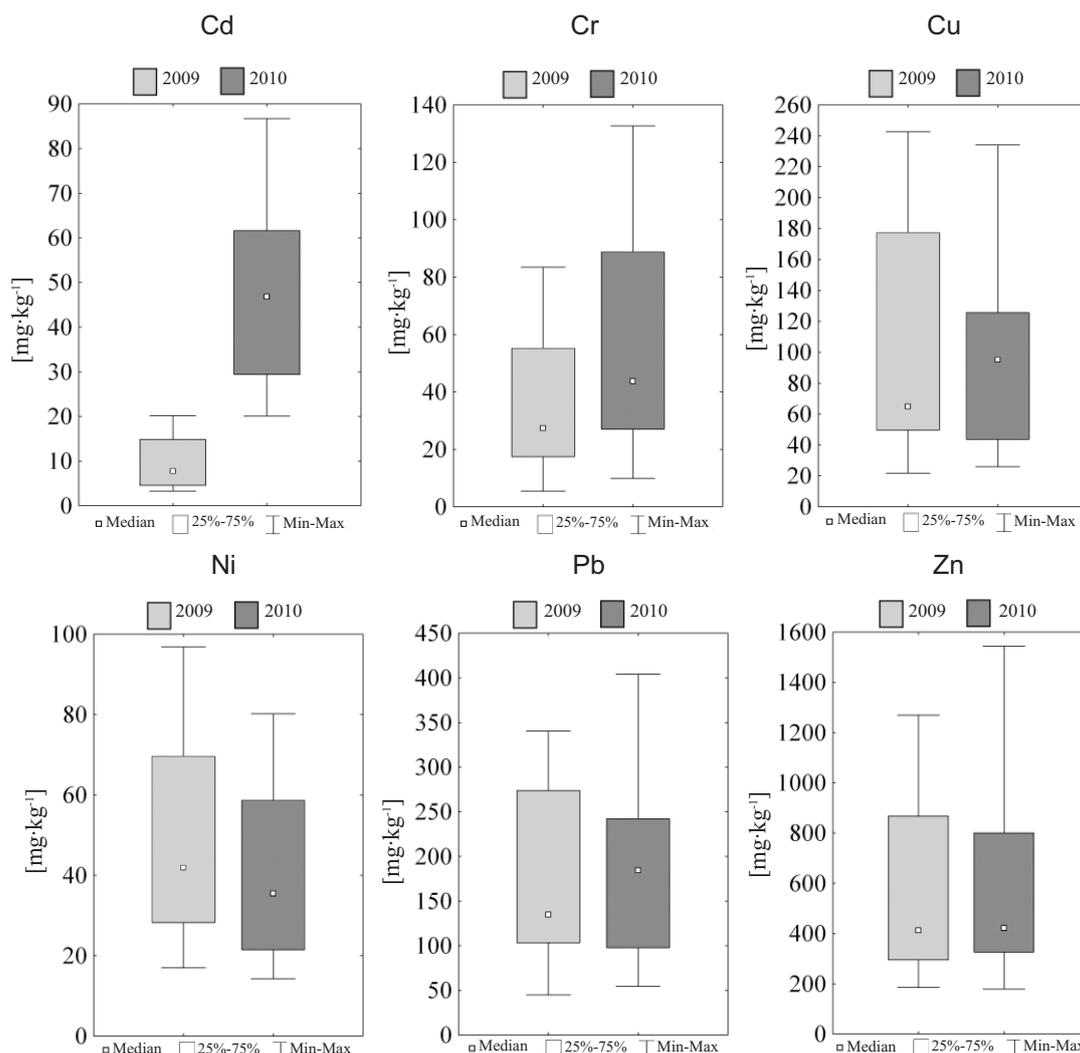


Fig. 2. The total content of metals found in sediment samples collected in 2009 and 2010.

decrease in river bed sediments and in floodplain sediments in terms of trace metals, that is Cr, Cu, Ni, Pb, and Zn [29]. Also, studies of the contamination of the Odra River flood sediments and arable soils of the former flood terraces after the flood of 1997 show that the trace metal contents do not increase [41, 42]. This may be linked to the fact that the studies comprised the former flood areas, separated from the floodplains by a flood levee. The concentrations of trace metals in such sediments are much lower than in the present flood areas [43]. As a result, the changes in the concentrations may be minor and difficult to determine.

Actually Available Forms of Metals

In the fluvial sediment samples collected in 2009, the highest concentrations of actually available forms of Zn ($44.1 \text{ mg}\cdot\text{kg}^{-1}$), Pb ($3.03 \text{ mg}\cdot\text{kg}^{-1}$), Ni ($1.67 \text{ mg}\cdot\text{kg}^{-1}$), Cu ($0.53 \text{ mg}\cdot\text{kg}^{-1}$), Cd ($0.23 \text{ mg}\cdot\text{kg}^{-1}$), and Cr ($0.09 \text{ mg}\cdot\text{kg}^{-1}$) were determined (Fig. 3). The highest maximum concentrations determined in sediment samples from 2010 were (with the exception of Cu, Pb and Zn) higher, and they

amounted to ($\text{mg}\cdot\text{kg}^{-1}$): 35.2 for Zn, 2.05 for Pb, 1.71 for Ni, 0.33 for Cu, 0.45 for Cd, and 0.18 for Cr (Fig. 3). In the case of Cr, Cu, and Pb the changes in concentrations after the flood were statistically significant. The average contents of actually available forms of metals after the flood of 2010 were (with the exception of Cd, Cr, and Pb concentrations) lower in comparison with the contents determined in 2009 (Fig. 3). The largest changes in concentrations were observed for Ni and were higher than $4 \text{ mg}\cdot\text{kg}^{-1}$. The maximum contents of actually available forms of Cd and Cr, as well as the average contents of Cr and Pb were, similar to their total contents, higher in the sediments collected after the flood of 2010 (Figs. 2, 3). The high correlation for the actually available forms of each of the analyzed trace metals and their total contents was not found. Such correlations for the total contents of trace metals with their available forms have been shown in the literature data [44, 45].

The comparison of the total contents of the determined trace metals with the concentrations of their actually available forms showed that in the samples of fluvial sediments collected in 2009, 0.01M CaCl_2 extracted maximally about

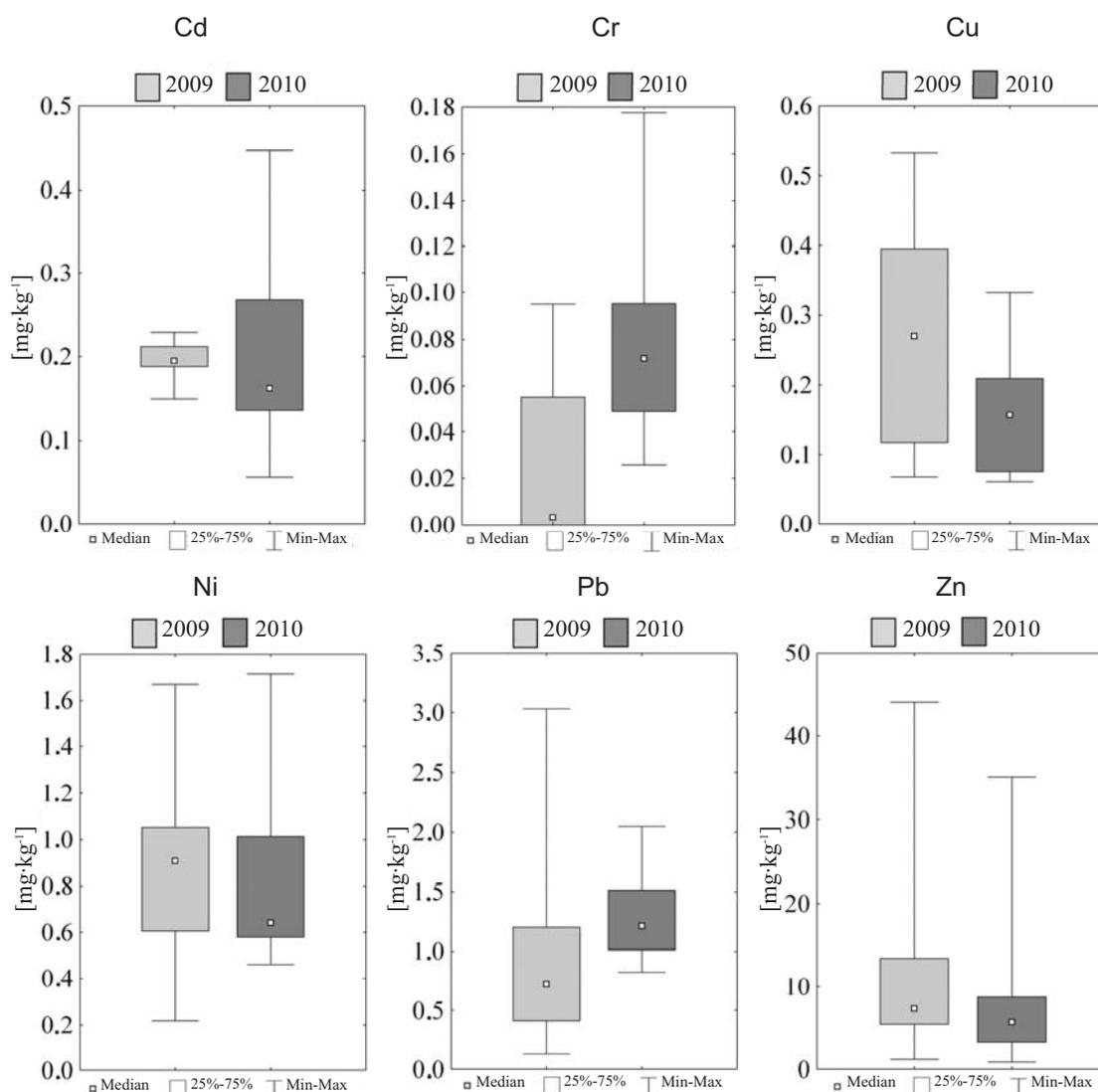


Fig. 3. The content of available fractions of metals (0.01M CaCl_2 extractable) found in the sediment samples collected in 2009 and 2010.

14% for Zn, 6.0% for Cd and Ni, 3.0% for Pb, 1.0% for Cu, and 0.3% for Cr (Fig. 4). In the sediment samples collected after the flood in 2010, this reagent extracted maximally about 4.0% for Ni, 3.0% for Zn, and <1% for Cd, Cr, Cu, and Pb. It has also been shown that the percentage participation values observed for Cd and Pb were much lower for the samples of the studied sediments collected in 2010 (Fig. 4). On the other hand, their total contents and the contents of actually available forms of Cd were higher in these sediments (Figs. 2, 3). The increase in the concentrations of these metals was therefore synonymous with their immobilization. In the case of Cu and Zn it was shown that in the sediment samples collected after the flood of 2010 there was a dramatic decrease in the values and their percentage participation (Fig. 4) and a simultaneous decrease in their total content and actually available forms of these metals (Figs. 2, 3). However, it was found for Cr that along with the significant increase in its concentration in sediment samples after the flood, there was a significant increase in the values of percentage participation (Fig. 3).

The determined concentrations of actually available forms of Cd, Cr, Cu, Ni, Pb, and Zn in sediment samples collected in both years were much lower than the total contents. Soft extractants, such as 0.01M CaCl₂, are marked by the low extraction capacity in comparison with the complexing agents and diluted acids [30]. Therefore, obtained concentrations of actually available fractions were lower than the background values [33, 34] and the limits specified in Polish regulation [35] (Table 4). In spite of this, it should be underlined that low concentrations of available forms of trace metals may get into ground water and become a potential source of threat for the environment [45]. In fluvial sediments, high total contents of trace metals are also often determined, as well as low contents of actually available forms extracted with 0.01M CaCl₂ and high contents of metals in earthworms and snails [45].

Moreover, it should be underlined that the determined concentrations of actually available fractions of trace metals in sediment samples collected both in 2009 and 2010 may be considered too high as they are higher than the con-

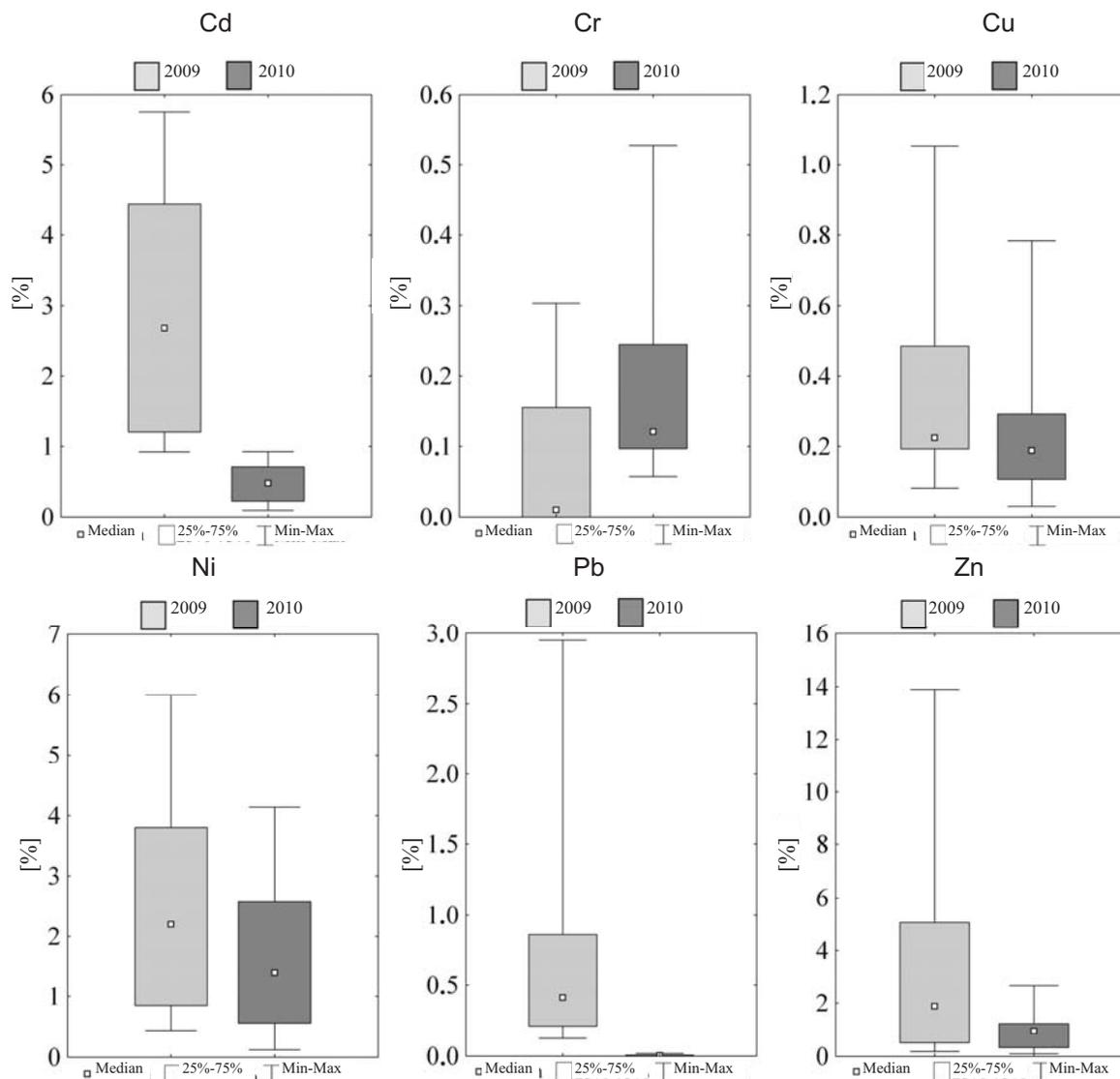


Fig. 4. The amount of available fractions of metals (0.01M CaCl₂ extractable) found in the sediment samples collected in 2009 and 2010.

centrations determined in the surface layer of uncontaminated fluvial sediments of the River Rhine in Holland. The mean concentrations of actually available fractions determined there amounted to ($\text{mg}\cdot\text{kg}^{-1}$): 0.001 for Cd, 0.004 for Cr, 0.06 for Cu, 0.004 for Ni, and 0.004 for Pb [46]. Furthermore, the fluvial sediments of the River Rhine were characterized by higher pH values (average 7.31) and lower concentrations of organic matter (average 5.99%). It was also indicated that the contents of actually available fraction of metals determined in sediment samples of the Odra River were higher than, or were at a similar level to, the concentrations determined in the surface layer sediments (0-2 cm) of the rivers Keersop and Dommel in Belgium, contaminated with industrial waste from a plant producing zinc [3]. This conclusion concerns Cd (from 0.59 to 1.05 $\text{mg}\cdot\text{kg}^{-1}$), Cu (from 0.03 to 0.09 $\text{mg}\cdot\text{kg}^{-1}$), Ni (from 0.26 to 0.31 $\text{mg}\cdot\text{kg}^{-1}$), and Zn (from 13.5 to 17.4 $\text{mg}\cdot\text{kg}^{-1}$). The fluvial sediment samples collected in Belgium also were characterized by low pH values (from 4.72 to 5.47), which could be favorable for the release of the studied trace metals.

Correlations Found for the Concentrations of Trace Metals and Physico-Chemical Parameters of Sediments

For the total contents of each of the analyzed trace metals, strong positive correlation with the participation of the very coarse-grained fraction from 2,000 μm to 1,000 μm (r from 0.65 to 0.87) was found, both for sediment samples collected before and after the flood. Also, with the exception of Cd, such a correlation was found for the organic matter content (r from 0.56 to 0.73).

Strong negative correlation with the participation of medium-grained sand fraction from 500 μm to 250 μm was also observed. The increase in the content of organic matter in fluvial sediments of the investigated study area after the flood of 2010 could be affected by the increase in Cr and Pb concentrations. No positive correlation for Cd concentrations and the content of organic matter was shown, and the significantly higher concentrations of this metal observed in the sediment samples collected after the flood confirm its high mobility. The obtained results comply with the previously conducted studies of fluvial sediments, according to which, along with the increase in the correlation of organic matter and the decrease in the participation value of medium-grained sediments (from 500 to 250 μm), the total contents of trace metals may rise [8, 45, 47-49].

In the case of actually available contents of the studied forms of trace metals, the occurrence of strong positive correlation was only shown for Cr and CaCO_3 content ($r = 0.68$). Therefore, only in the case of actually available forms of Cr can it be concluded that the rapid change in the physico-chemical parameters of sediments, that is the increase in CaCO_3 content that occurs during flood, may cause a rise in the actually available forms of trace metals extracted with 0.01M CaCl_2 [14]. On the other hand, no correlation has been shown for the actually available forms of the investigated trace metals with the organic matter con-

centration and with the participation of the finest sediment fractions (<50 μm), which has been shown by many researchers [i.a. 45, 46, 50]. The lack of correlation between the contents of the actually available forms of metals and the finest sediment fractions can be caused by the fact that, in the case of the analyzed fluvial sediment samples, the participation of these fractions was very low (Table 3).

Conclusions

The obtained results reveal the role of flood as an agent carrying significant amounts of trace metal, as well as influence of change of physico-chemical parameters on their availability. An analysis allows one to draw the following conclusions:

- In the samples of fluvial sediments collected after the flood of 2010, the statistically significant increase in the total contents of cadmium, chromium, copper, lead, and zinc was not found in comparison with the concentrations determined in 2009. However, the total contents of copper, cadmium, chromium, lead, and zinc in the sediment samples before and after the flood exceed the background values and the limits specified in Polish regulation. After the flood of 2010, the concentrations of actually available forms (extracted with 0.01 M CaCl_2) of cadmium and nickel increased insignificantly, with the significant increase in content found for chromium. Moreover, the current concentrations of the studied trace metals are not strongly correlated with their total contents.
- The percentage participation values for the actually available forms of chromium (extracted with 0.01 M CaCl_2) were much higher in sediment samples collected after the flood of 2010, while for cadmium, copper, lead and zinc, significantly lower percentage participation values were shown in comparison with the values determined for sediment samples collected in 2009.
- In the sediment samples collected after the flood of 2010, the change in the average values of physico-chemical parameters was shown, that is of the participation of coarse-grained, medium-grained, fine-grained fractions, silt and clay, as well as the $\text{pH}_{\text{H}_2\text{O}}$ value, organic matter content, and CaCO_3 .
- It was shown that the total contents of the studied trace metals may increase along with the increasing participation of very coarse-grained fractions (from 2,000 to 1,000 μm) of sediments and the participation of organic matter content (except Cd). The concentrations of actually available forms of Cr grow with the increase of CaCO_3 content.

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