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Heavy metals in recent alluvium of the Odra River

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Together with its tributaries, the Odra River is a receiver of huge amount of industrial waste water produced in territories of Poland, the Czech Republic, and Germany in connection with (among others) extraction of mineral raw materials and operation of metallurgical and coking industries as well as many other industrial plants. Municipal sewage from cities situated on the river are also disposed to the Odra River. A huge amount of dissolved salts is not the only load transported by the waste water; also, a large amount of heavy metals is other load being brought to the Odra water. As a result of self-purification process of the river, a considerable portion of these metals is subject to accumulation in the river bottom deposits.

As a total, 153 samples of alluvial sediments were collected for laboratory determinations; they were collected at a distance of each 5 km along the Odra course. Additional samples (115 in total number) were collected from the Odra tributaries, from sampling points located near each tributary's confluence to the Odra. Grain size fraction < 0.2 mm was used to determine concentrations of Ag, Cd, Cu, Cr, Co, Ni, Pb, and Zn. The Inductively Coupled Plasma Atomic Emission Spectrometry was employed to make these determinations. The content of Hg was measured using the Cold Vapour Atomic Absorption Spectrometry.

Heavy metals in alluvium of the upper and middle Odra tracts covered by this study occur in concentrations exceeding many times the geochemical background values for particular elements. On the contrary, alluvium in the lower Odra course (downstream from the confluence of the Warta River) contains markedly less concentrations of heavy metals, in general near their geochemical background. High concentrations of Cu, Hg, Pb, and Zn characterise alluvium of the upper and middle Odra. Accumulation of these metals in the Odra alluvium is visibly under the influence of mine water disposal practised by hard coal (bar) mining zinc-lead ore mining and metallurgy (zinc and lead), copper ore mining and metallurgy (copper, lead, and zinc), and the production of effluents in chemical plants (mercury).

INTRODUCTION

Being the second river in Poland in respect of its size, the Odra fulfils important functions in: transport (on a local and international scale), agriculture and forestry (maintaining suitable water-and-soil conditions in adjoining areas), industry and municipal development (industrial water intakes, also the receiver of disposed wastes and salty mine waters), and power industry (hydroelectric power plants). The headwaters of the Odra rise in the Oder Mts. in the Silesian–Moravian zone of the Czech Republic; the total river length is 854.3 km, of which 741.9 km remains in the territory of or along Poland's border (8 km on the border with the Czech Republic and 179 km on the border with the Federal Republic of Germany). Below Widuchowa at the distance of 704.1 km away from its outflow, the Odra divides into two arms: the Eastern Odra (with the Regalica being its lower tract) emptying into Dąbie Lake and the Western Odra with its outlet to the southern part of the Lagoon of Szczecin (Roztoka Odrzańska).

The Odra River and its tributaries are the receivers of huge amount of industrial waste water from territories of Poland, the Czech Republic, and Germany. In its upper course the Odra receives industrial waste water disposed in the Karvina–Ostrava Coal Basin by coke-making plants, chemical plants, and iron and steel works. In Poland, its upper and middle courses receive waste water connected with extraction and processing of mineral raw materials within both the Upper and Lower Silesian areas, being disposed by coal mining, coking industry and power engineering, and mining and metallurgy of zinc-lead as well as copper ores; machine building, chemical, and electronic industries (among others) have also their share in waste water disposal to the Odra River (K. Baran *et al.*, 1995; J. Bielecki *et al.*, 1995; T. Błaszczak *et al.*, 1995; K. Całujek *et al.*, 1995; J. Janik *et al.*, 1995; L. Jarzębski,

1995; J. Mendaluk, 1995). Cities located on the Odra also discharge their sewage to the river; a list of such cities includes: Racibórz, Kędzierzyn-Koźle, Zdzieszowice, Krapkowice, Gogolin, Otmęt, Opole, Brzeg, Oława, Jelcz–Laskowice, Wrocław, Brzeg Dolny, Ścinawa, Prochowice, Orsk, Głogów, Nowa Sól, Krosno Odrzańskie, Eisenhüttenstadt, Frankfurt, Słubice, Kostrzyn, Schwedt, Szczecin, and Police. In addition, other sources of pollution affecting the river are leachates from industrial waste disposal sites and municipal landfill sites situated in the Odra valley in Racibórz, Kędzierzyn-Koźle, Zdzieszowice, Krapkowice, Opole, Brzeg, Wrocław, Nowa Sól, and Szczecin. In many cases these sites are located in idle workings of gravel aggregate with no sealing bed in substratum and no system of leachate disposal and treatment; despite such conditions not only municipal wastes but also industrial wastes (including those of I and II harmful categories) are disposed there.

A huge volume of waste water is disposed to smaller and bigger Odra tributaries: the Olza, Ruda, Bierawka, Kłodnica, and Mała Panew Rivers. They receive pollutants contained in mine waters disposed from both coal and zinc-lead ore mines, in effluents disposed by power stations and smelters, and in sewage produced at municipal treatment plants in the Upper Silesian area. Industrial and municipal effluents reaching the Ślęża, Widawa, and Bystrzyca Rivers are produced in Wrocław; and the Kaczawa, Rudna, and Zimnica are the rivers to which are discharged waste waters produced in the area of the Legnica–Głogów Copper District. Surface runoff from areas within the zone of impact of industrial emissions is another source of pollution entering the Odra and its tributaries. All of these pollution sources carry to the Odra not only a huge amount of dissolved salts (thus contributing to the increase of salinity of river waters) but also remarkable amount of heavy metals that accumulate in the river bottom sediments as a result of self-purification of river waters.

Aqueous deposits play an important part in the functioning of aqueous ecosystem and circulation of elements in the surface water environment. As polluted deposits might be long-term sources of toxic constituents, the accumulation in aqueous deposits of heavy metals exerts a serious threat to the biosphere. A portion of elements contained in deposited material can be made mobile and available for living organisms due to chemical and biochemical processes taking place in aqueous deposits (for instance: biodegradation of organic matter, reduction of iron compounds) or change in environmental conditions (an increase of salinity or acidity)(W. Salomons, W. M. Stigliani, 1995). Heavy metals can also be collected from aqueous deposits by benthic organisms in a direct way. Negative effect of polluted deposits on living organisms may occur even when composition of water over deposits meets quality requirements. Deposits of high concentrations of heavy metals are also dangerous to land ecosystems; as a result of translocation of polluted alluvium during floods or high river stages the pollution of soils within flood plains has been noted in many places. (I. Bojakowska *et al.*, 1996; I. Bojakowska, G. Sokołowska, 1986; D. Cocking *et al.*, 1991; E.V. Axtmann, S. N. Luoma, 1991; K. Kucharzewski *et al.*, 1991).

SCOPE OF THE STUDY

Samples for laboratory determinations were collected from alluvial sediments (153 in total number) at each 5-km sampling point along the Odra course. Other batch of samples (115 in total number) was collected from tributaries, at each tributary's confluence to the Odra. Samples of active sediments were collected from river-bank zones of the river bottom, on the opposite side to the current, where material transported by the river is subject to deposition.

For the purpose of analytical study, a fraction less than 0.2 mm was selected. After treatment with aqua regia, the obtained solutions were used to determine concentrations of Ag, Cd, Cu, Cr, Co, Ni, Pb, and Zn. These elements were determined using the Inductively Coupled Plasma Atomic Emission Spectrometry method (ICP-AES) while mercury was determined by the Cold Vapour Atomic Absorption Spectrometry (CV-AAS). All of chemical analyses were made at the Central Chemical Laboratory of the Polish Geological Institute.

RESULTS OF THE STUDY AND DISCUSSION

The study disclosed that content of heavy metals in the Odra sediments is many times their characteristic geochemical background value for aqueous deposits in Poland. Most common in sediments polluted in an anthropogenic way are increased concentrations of silver, cadmium, chromium, copper, mercury, nickel, lead, and zinc — all of wide applications to industry and economics.

Silver in sediments of unpolluted rivers occurs in concentrations < 1 ppm; its higher concentrations suggests its anthropogenic origin. Silver in the Odra River sediments under this study was noted in the range of from <1 to 3 ppm (Table 1). The increased silver content was recorded in sediments deposited in the Odra in the proximity of greater cities such as Racibórz, Kędzierzyn-Koźle, Brzeg, and Wrocław; the same deals with many samples collected from the Odra tract be-

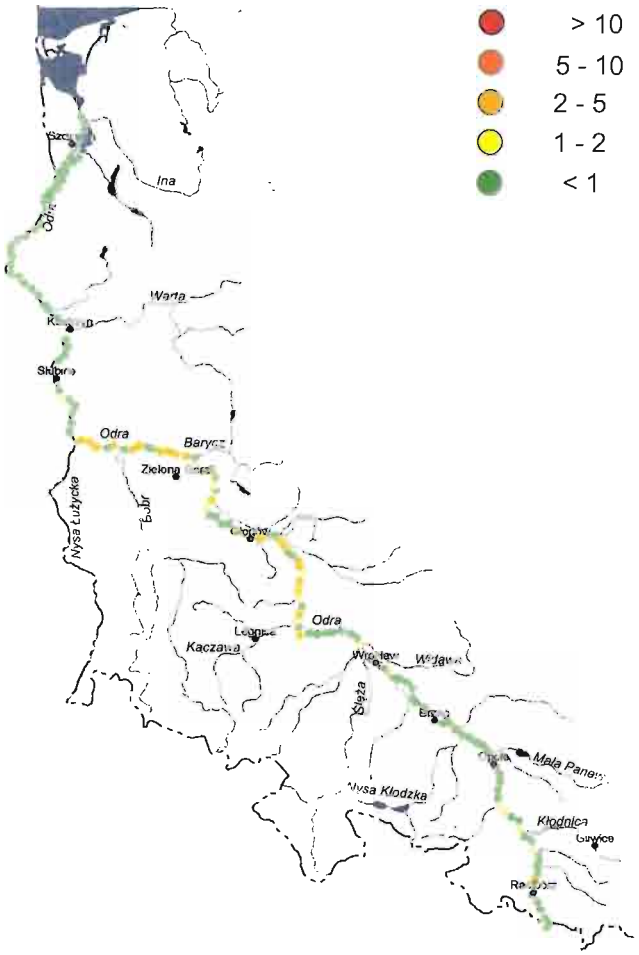

Fig. 1. Silver in recent alluvium of the Odra River in ppm (mg/kg)

Srebro we współczesnych aluwiach Odry w ppm (mg/kg)

tween confluences of the Kaczawa and the Nysa Kłodzka Rivers (Fig. 1). In alluvium of the Odra tributaries the increased Ag content was found in the Ślęża and a small water course in Wrocław, the Kaczawa, Zimnica and the Rzuchowska Struga Rivers, as well as a stream in the Eisenhüttenstadt area and a water course flowing into the Odra downstream from Frankfurt. The occurrence of silver in the Odra sediments deposited in its course between the Kaczawa and Nysa Łużycka confluences can be connected with the extraction of polymetallic ores and copper metallurgy while elevated Ag content in alluvium in proximity of cities is most often the effect of the disposal of wastes from photographic laboratories and hospitals.

Natural content of **cadmium** in water sediments does not exceed 1 ppm (as reported by J. Lis, A. Pasieczna, 1995 — its geochemical background in aqueous deposits in Poland is <0.5 ppm). The content of cadmium in alluvium of the Odra River was noted between <0.5 and 11.9 ppm (its arithmetic mean was 2.3 ppm while its geometric mean — 1.5 ppm and median — 1.8 ppm). Almost all alluvial samples representing the Odra sediments in its upper and middle course (downstream from the border of the state at Chałupki to the Warta

Table 1

Statistical parameters of elements in Odra aqueous deposits (n = 153) in ppm

Element	Minimum content	Maximum content	Arithmetic mean	Geometric mean	Median
Silver	<1	3	<1	<1	<1
Cadmium	<0.5	11.9	2.3	1.5	1.8
Cobalt	<1	18	7	7	7
Chromium	2	144	42	29	31
Copper	1	276	60	36	41
Mercury	0.01	5.16	0.97	0.41	0.48
Nickel	1	42	19	15	19
Lead	3	681	66	47	53
Zinc	11	1703	614	378	512

confluence) contain cadmium in concentrations > 1 ppm (Fig. 2). Relatively high cadmium concentrations were noted in the Odra alluvium downstream from the confluences of the Kaczawa, Zimnica, Rudna, and Mała Panew Rivers, as well as in the samples collected in Jelcz, Wrocław, and Krosno Odrzańskie. The cadmium content in alluvium of the Odra lower course is, in general, close to its geochemical background; its increased concentration is observed only downstream from Frankfurt. Cadmium in river sediments of the Odra tributaries is ranging from 0.5 to 45.8 ppm. The highest cadmium content was recorded in alluvium of the Mała Panew; this is due to the disposal to this river of pollutants from a smelter at Miasteczko Śląskie and other industrial plant in Tarnowskie Góry and Strzybnica. Alluvium of water courses in Wrocław and those flowing through Hohensaaten, Frankfurt, and Eisenhüttenstadt also display elevated cadmium content. If cadmium occurs in concentration over 1 ppm, this indicates the pollution of the environment; such values are detected in those surface waters to which effluents are disposed from mines, zinc-lead works and the metallurgical, electronic, paint and varnish, and plastics works (I. Bojakowska, 1995; D. Ciszewski, 1994).

Content of **cobalt** in river sediments of non-industrialized areas does not exceed several ppm. In principle, the content > 10 ppm is connected with anthropogenic activity, predominantly that of metallurgical industry. Cobalt concentrations in excess of its geochemical background are relatively scarce in sediments. Its occurrence in the Odra sediments is ranging between < 1 and 18 ppm (Fig. 3). Concentrations > 10 ppm are noted in alluvium of the Odra course between Kędzierzyn-Koźle and Kostrzyn. Elevated Co concentration is predominantly connected with effluents disposed to the Odra by mining and copper metallurgical industry in the Legnica–Głogów District. Particularly high cobalt content has been noted in sediments deposited in the Odra arms with a characteristic slow water flow. The Stara Odra arm with Co concentration of 90 ppm is given here as the example of the case. Elevated cobalt concentrations in the Odra tributaries have been detected in sediments of the Jodłówka, Stobrawa, Chruścińska Struga Rivers and a stream flowing through Eisenhüttenstadt.

5 ppm is the geochemical background of **chromium** in sediments in Poland. Content greater than 20 ppm is con-

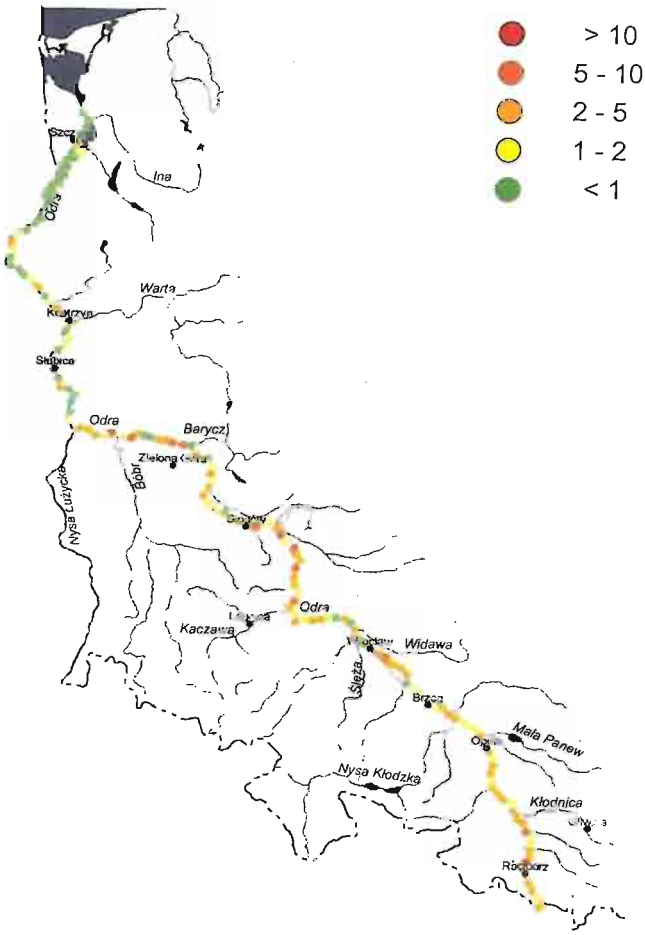

Fig. 2. Cadmium in recent alluvium of the Odra River in ppm (mg/kg)

Kadm we współczesnych aluwiach Odry w ppm (mg/kg)

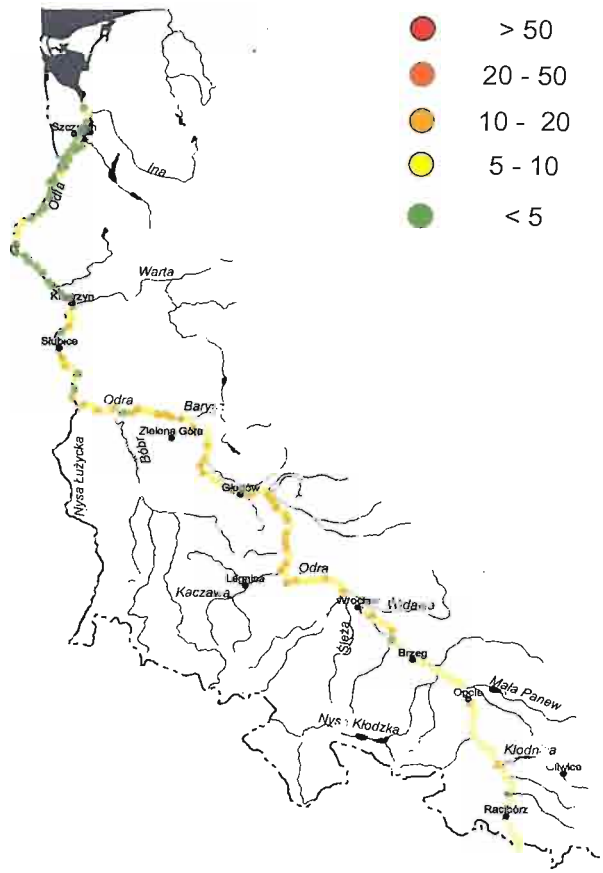

Fig. 3. Cobalt in recent alluvium of the Odra River in ppm (mg/kg)

Kobalt we współczesnych aluwiach Odry w ppm (mg/kg)

nected with the pollution of the environment, the origin of which is predominantly the disposal of waste water from tanneries, chromium-rich dye-producing plants and chromium-plating plants; the production of refractories and the percolation of leachates from waste disposal sites are other sources of chromium. In alluvium of the Odra, chromium has been found to occur within a great range of concentrations between 2 and 144 ppm (Fig. 4). Increased chromium content in sediments of the Odra have been observed downstream from the confluence of the Nysa Łużycka, in area of Wrocław, and in many alluvial samples collected downstream from the confluence of the Kaczawa to the confluence of the Warta, as well as downstream from Kostrzyn, Frankfurt, and Hohensaaten. High Cr concentrations in the Odra tributaries have been found in sediments of the Widawa, Ługowina, Ślęża, Pląśnica, and Kaczawa Rivers and water courses flowing through Frankfurt and Eisenhüttenstadt.

Copper occurs in the Odra alluvium in amount ranging from 1 to 276 ppm (natural content of Cu in fluvial sediments is less than 20 ppm while its background in the same environment in entire territory of Poland is 6 ppm). The accumulation of copper-rich sediments with concentration over 100 or even 200 ppm occurs between the confluences to the Odra of the Kaczawa (at Prochowice) and the Warta (Fig. 5). Copper ore extraction- and treatment-related effluents are the source of copper in these sediments; they are disposed by the "Głogów", "Lubin", and "Polkowice" copper ore mines and the "Legnica" and "Głogów" copper smelters. The increased Cu concentrations have also been noted in the regions of Racibórz, Opole, Brzeg, Wrocław, and Frankfurt. The highest Cu concentrations in alluvium of the Odra tributaries have been recorded in the Rzuchowska Struga Stream and the Bystrzyca, Ślęża, Ługowina, Rudzica, Zimnica, Kaczawa, and Rudna Rivers as well as water courses flowing through Hohensaaten, Frankfurt, and Eisenhüttenstadt. The highest concentrations are connected with those rivers to which waste water are disposed; extraction of copper ore and polymetallic deposits as well as copper smelters are those industrial branches that are responsible for the waste water discharging.

Mercury in alluvium of the Odra occurs in concentrations from < 0.01 to 5.16 ppm while in sediments of pollution-free rivers it is predominantly less than 0.1 ppm. Concentrations over 0.1 ppm indicate the anthropogenic pollution of surface water environment, for instance by the waste water disposal from chlorium producing plants where a mercury method is employed, synthetic fibre plants (catalyst), textile plants (dyes, mordants, and mercury-rich fungicides), and the disposal of storm waters (emission of Hg to the atmosphere as a result of massive-scale burning of coal). The Hg content > 0.1

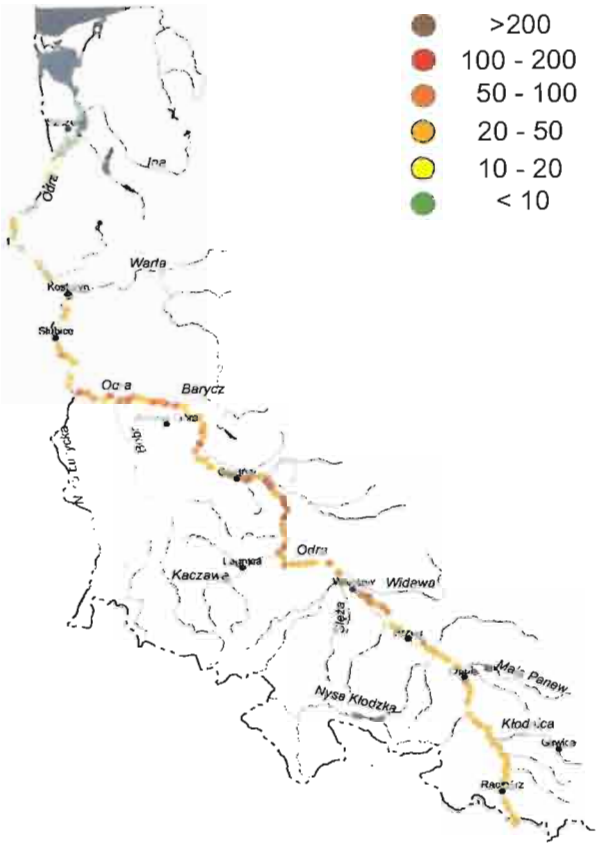

Fig. 4. Chromium in recent alluvium of the Odra River in ppm (mg/kg)

Chrom we współczesnych aluwiach Odry w ppm (mg/kg)

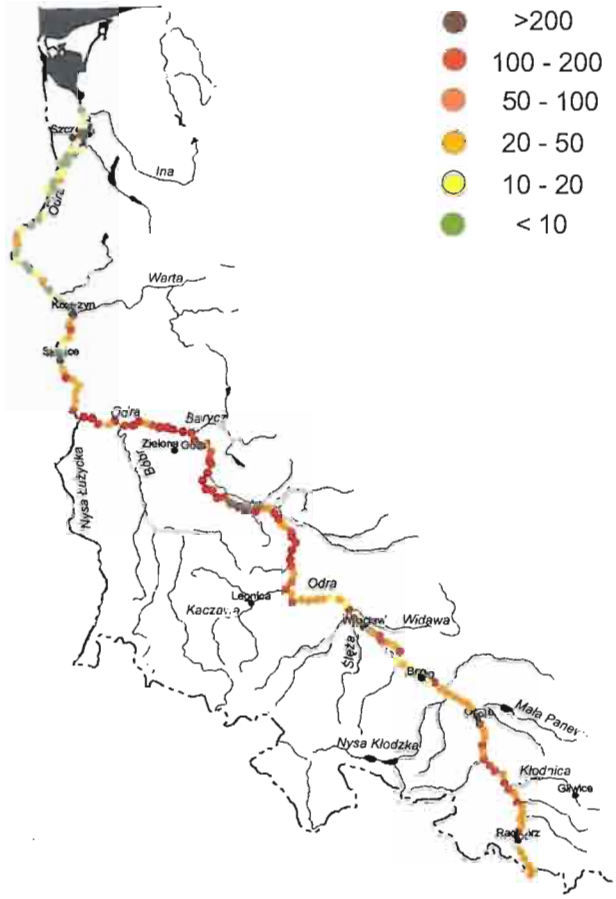

Fig. 5. Copper in recent alluvium of the Odra River in ppm (mg/kg)

Miedź we współczesnych aluwiach Odry w ppm (mg/kg)

ppm has been recorded in the Odra sediments extending downstream from Chałupki to Kostrzyn, and > 1 ppm — in the Odra course downstream from Brzeg Dolny to the confluence of the Nysa Łużycka River (Fig. 6). Increased Hg content was also noted in the Hohensaaten and Schwedt regions. The content > 1 ppm was also observed in sediments of some Odra tributaries such as the Sulechówka (receiving effluents from Sulechów), the Kaczawa, and a small stream in Wrocław and water courses flowing through Eisenhüttenstadt and Frankfurt; particularly high Hg content (9 ppm) is contained in sediments sampled in the water course in the area of Hohensaaten.

In general, natural content of **nickel** in river sediments in Poland does nor exceed 10 ppm. In sediments of the Odra River it ranges between 1 and 42 ppm (Fig. 7). Alluvium of the upper and middle Odra courses contains as much as 23 ppm of nickel while its average content in the lower Odra course is several times less — 6 ppm, close to its geochemical background. In alluvium of the Odra tributaries the higher Ni content occurs, for instance, in the Ługowina in the Wrocław area, the Kaczawa with its arm (the Bobrek), and the Młynna flowing through Lubiąż. Usually, the content of nickel in excess of 20 ppm indicates an anthropogenic anomaly connected with the waste water disposal from metallurgical and electronic plants and smelters as well as the disposal of effluents originating in the process of production of starting batteries and cadmium accumulators.

Lead in sediments of the Odra is ranging from 3 to 681 ppm (its geochemical background in Poland is 11 ppm). The natural increase of Pb content occurs in the region of zinc-lead ore outcrops in Upper Silesia. Concentration >30 ppm as the evidence of pollution of sediments occurs in the majority of samples collected even from the lower Odra course — where average Pb content in sediments equals to 52 ppm. Alluvium with high lead content occurs in the Odra tract downstream from the confluence of Kaczawa to the confluence of the Warta as well as in the areas of Kędzierzyn-Koźle, Opole, Szczecin, Frankfurt, Słubice, and Schwedt. As to alluvium in tributaries, the highest Pb content was found in the Mała Panew, a small water course at Krapkowice, some rivers in the Wrocław area, Kaczawa, Rzuchowska Struga (at Wróblin Głogowski), and the Rudzica (at Nowa Sól). The lead content in excess of 100 ppm was recorded in the streams flowing through Frankfurt and Eisenhüttenstadt. The high Pb content in alluvium of the upper and middle Odra and some its tributaries is the effect of discharging to these rivers of waste

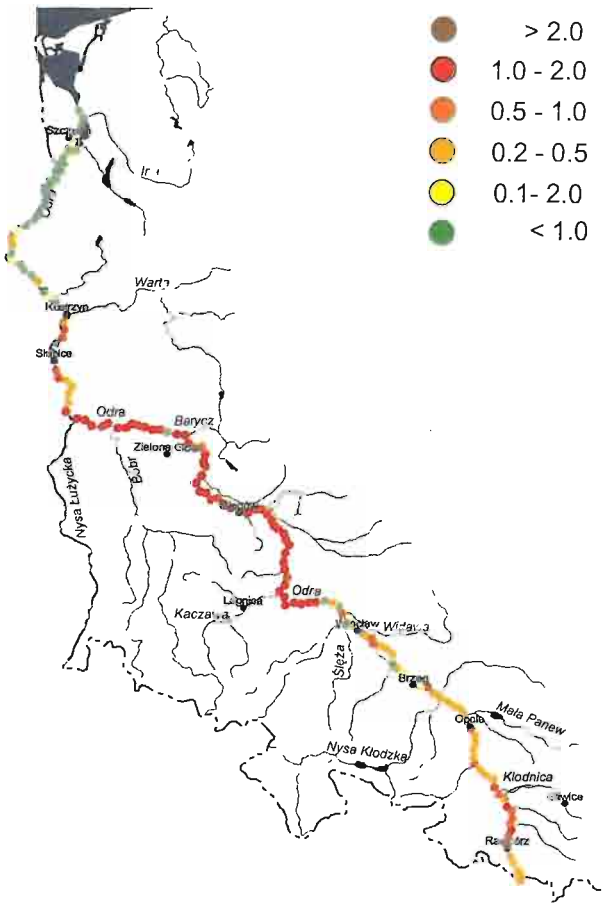

Fig. 6. Mercury in recent alluvium of the Odra River in ppm (mg/kg)

Rtęć we współczesnych aluwiach Odry w ppm (mg/kg)

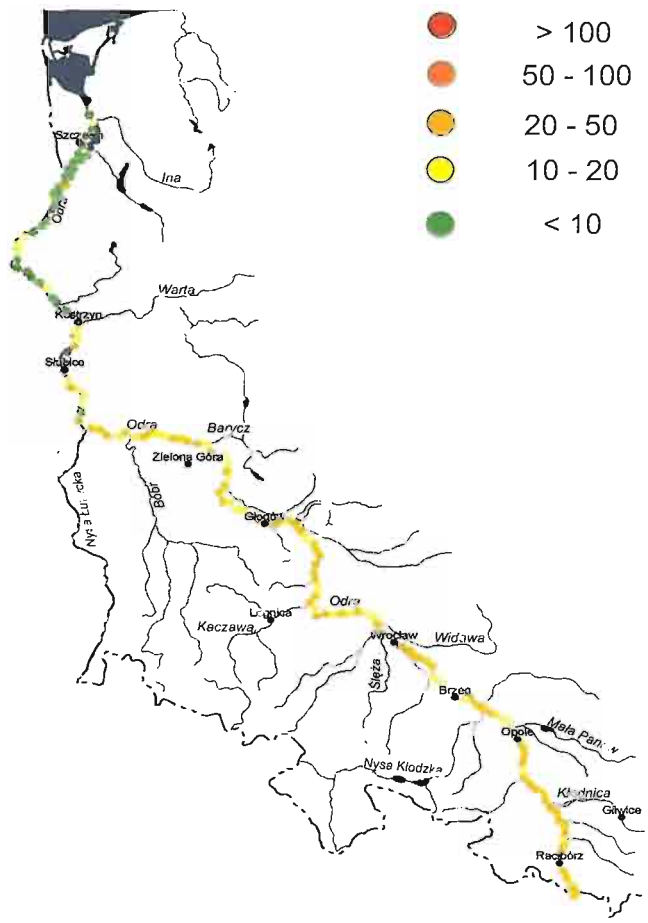

Fig. 7. Nickel in recent alluvium of the Odra River in ppm (mg/kg)

Nikiel we współczesnych aluwiach Odry w ppm (mg/kg)

water from mines and zinc-lead works, polymetallic-ore processing plants (ores being extracted in the Legnica–Głogów District); the production of pigments (white lead and chrome yellow) also contributes to high Pb content. Lead from exhaust gases emitted by motor-cars is also another source of pollution of river sediments in cities and villages, and in general, in the proximity of speed-ways.

Zinc in the Odra sediments is contained in a wide range between 11 to 1703 ppm (Fig. 9). In sediments of unpolluted rivers in Poland it occurs in concentrations reaching several dozen ppm, and naturally elevated Zn concentrations in alluvium are present in those area where exposures of mineralized rocks are common. Very high Zn concentrations were found in the upper and middle Odra in the regions of Racibórz, Kędzierzyn-Koźle, Krapkowice, Brzeg, Wrocław, and Nowa Sól. The Zn content in sediments of the lower Odra appears in amount close to its geochemical background; however, increased amount of Zn can be found in the area of Szczecin and Frankfurt and downstream of Hohensaaten. The considerably increased zinc content was noted in alluvium of tributaries of the Odra, which particularly deals with the Mała Panew, all rivers in Wrocław, a small unnamed stream near Oława, the Rudzica at Nowa Sól, and the water courses flowing through Frankfurt, Eisenhüttenstadt, and Hohensaaten. Since zinc has found a wide application to the industry and building engineering, its increased content in water sediments is common. The highest zinc concentrations of anthropogenic origin are noted in sediments accumulating in rivers near outfalls of effluents from zinc-lead extraction and processing plants and works, and metallurgical and chemical plants (in particular from the production of zinc white).

RECAPITULATION

The study revealed that the content of heavy metals in sediments of the Odra is many times their geochemical background characteristic for water sediments in Poland. Except for the Carpathians and the Sudetes, natural content of heavy

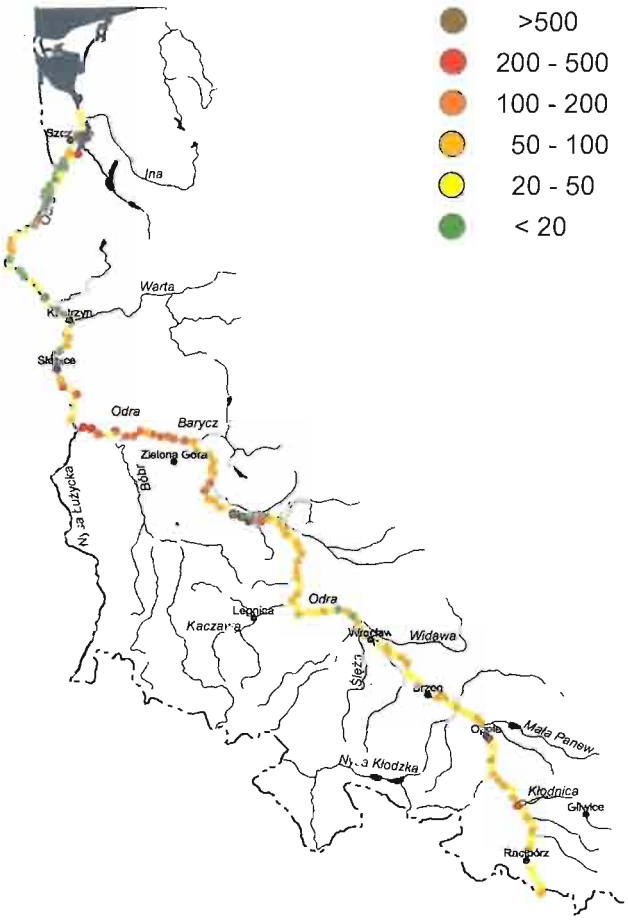

Fig. 8. Lead in recent alluvium of the Odra River in ppm (mg/kg)

Ołów we współczesnych aluwiach Odry w ppm (mg/kg)

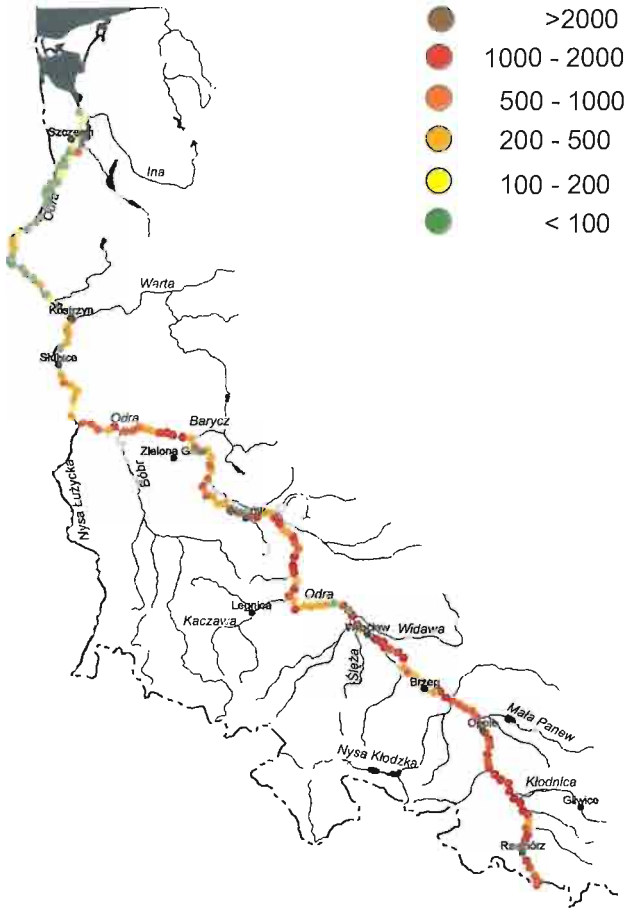

Fig. 9. Zinc in recent alluvium of the Odra River in ppm (mg/kg)

Cynk we współczesnych aluwiach Odry w ppm (mg/kg)

metals in water sediments in Poland is very poor, not exceeding several ppm for cobalt, chromium, nickel, and lead, 1 ppm for silver, 0.5 ppm for cadmium, 0.01 ppm for mercury. Alluvium of the Odra, particularly in its upper and middle course, are characterized by a high content of heavy metals, especially of Cu, Hg, and Zn. Accumulation in the Odra of sediments of high copper content, frequently in excess of 100 or even 200 ppm, occurs within the river tracts downstream from the confluence of the Kaczawa at Prochowice to the confluence of the Warta. Elevated mercury content (>0.1 ppm) in sediments have been noted downstream from the state border at Chałupki to Kostrzyn, with the highest concentration in excees of 1 ppm occurring within the river tract between Brzeg Dolny and the confluence of the Nysa Łużycka River. The majority of samples collected from the upper and middle course of the river were characterized by zinc concentrations over 500 ppm. Very high zinc concentrations were recorded in the regions of Racibórz, Kędzierzyn-Koźle, Krapkowice, Brzeg, Wrocław, and Nowa Sól. Also, sediments of the Odra are characteristic because of elevated content of silver within the river tract downstream from the confluence of the Kaczawa to the confluence of Nysa Łużycka. Increased concentrations of cadmium characterises the Odra tract downstream from Chałupki to the Nysa Łużycka and of chromium — downstream from Brzeg to the confluence of the Nysa Łużycka River.

Heavy metals are transported to the Odra and its tributaries such as the Olza, Ruda, Kłodnica, Mała Panew, Ślęża, Widawa, Kaczawa, and Nysa Łużycka Rivers by mining and industrial effluents disposed from mines and zinc-lead processing plants in Upper Silesia and polymetallic sulphide ores in the Legnica–Głogów District. Municipal-industrial wastes disposed from (among others) Racibórz, Opole, Wrocław, Brzeg Dolny, Głogów, Kostrzyn, Frankfurt, and Szczecin are also other sources of heavy metals. The discharging of waste water from mining plants and zinc-lead works has an important bearing on the increased content of zinc, lead, and cadmium in river sediments; waste water from mining plant and copper works — on the content of copper, lead, zinc, and silver, and effluents from a chemical plant in Brzeg Dolny — on pollution of alluvium in the Odra by mercury.

Sediments deposited in the lower course of the Odra downstream from the confluence of the Warta are characterized by the considerably smaller content of heavy metals, in general near the values of their geochemical background. To large extent this is connected with the dissolution of pollutants in the Odra after it is mixed with waters of the Warta being a river of high flow (the average flow in the Odra is 180

m^3/s while its rate of flow downstream from the confluence with the Warta — 240 m^3/s). The increased content of the majority of heavy metals in the lower Odra sediments is observed only in the regions of Eisenhüttenstadt, Hohensaaten, Frankfurt, and Szczecin.

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METALE CIĘŻKIE WE WSPÓŁCZESNYCH ALUWIACH ODRY

Streszczenie

Odra i jej doplywy są odbiornikiem olbrzymich ilości ścieków przemysłowych z terenów Polski, Czech i Niemiec, m.in. z kopalni węgli i surowców mineralnych, hut Zn-Pb i Cu, koksowni oraz licznych zakładów przemysłowych. Do Odry odprowadzane są także ścieki komunalne z miast położonych nad rzeką, np. z Raciborza, Opola, Brzegu, Wrocławia, Głogowa, Frankfurtu i Szczecina. Wszystkie te ścieki wnoszą nie tylko ogromne ładunki rozpuszczalnych soli, ale także znaczne ilości metali ciężkich. Znaczna część tych metali ulega akumulacji w osadach dennych rzeki w wyniku zachodzących w niej procesów samooczyszczania.

Do badań pobrano 153 próbki osadów aluwialnych wzdłuż biegu rzeki, co 5 km, oraz oraz 115 próbek z jej dopływów w pobliżu ich ujścia. Do badań wykorzystano frakcję <0,2 mm, w której oznaczono zawartości Ag, Cd, Cu, Cr, Co, Ni, Pb i Zn, przy zastosowaniu spektralnej analizy emisyjnej ICP, oraz rtęci metodą ASA z zastosowaniem techniki zimnych par.

Badania wykazały, że zawartości wielu metali ciężkich w osadach Odry wielokrotnie przekraczają wartości tła geochemicznego charakterystycznego dla osadów wodnych Polski. Udział srebra waha się od <1 do 3 ppm; podwyższone jego zawartości stwierdzono w osadach deponowanych w pobliżu Raciborza, Kędzierzyna-Koźla, Brzegu i Wrocławia. Kadm występuje w ilościach od <0,5 do 11,9 ppm. W niemalże wszystkich próbkach osadów pobranych z górnej i środkowej Odry jego zawartość wynosiła > 1 ppm, podczas gdy w dolnym odcinku Odry była na ogół zbliżona do tła geochemicznego. Ilość kobaltu w osadach Odry wahała się od < 1 do 18 ppm, a chromu od 2 do 144 ppm; podwyższone zawartości Cr w osadach Odry obserwowane były poniżej ujścia Nysy Kłodzkiej, na terenie Wrocławia oraz w wielu próbkach aluwiów pobranych poniżej ujścia Kaczawy aż do ujścia. Miedź występowała w ilości od 1 do 276 ppm. Akumulację osadów o wysokich zawartościach miedzi, przekraczających 100 ppm, stwierdzono poniżej ujścia Kaczawy w Prochowicach do ujścia Warty. Ponadto podwyższone zawartości Cu w aluwiach Odry obserwowane są w rejonie Raciborza, Opola, Brzegu, Wrocławia i Frankfurtu. Stężenie rtęci wahało się od <0,01 do 5,16 ppm; udział rtęci >0,1 ppm, wskazujący na zanieczyszczenie środowiska, stwierdzono w osadach Odry od granicy państwa do ujścia Warty, a na odcinku Odry od Brzegu Dolnego aż do ujścia Nysy Łużyckiej stężenia tego pierwiastka przekraczały 1 ppm. Nikiel występował w ilości od 1 do 42 ppm, a ołów od 3 do 681 ppm; stężenia ołowiu > 30 ppm, świadczące o zanieczyszczeniu osadów, notowano w większości badanych próbek Odry, nawet w jej dolnym odcinku. Cynk w osadach Odry wykrywany był w ilościach od 11 do 1703 ppm. Bardzo wysokie jego zawartości stwierdzono w aluwiach górnej i środkowej Odry w rejonie Raciborza, Kędzierzyna-Koźla, Krapkowic, Brzegu, Wrocławia i Nowej Soli. W osadach dolnej Odry zawartości cynku zbliżone są do tła geochemicznego, jedynie na terenie Szczecina i Frankfurtu oraz poniżej Hohensaaten jego zawartości są podwyższone.

Zawartość metali ciężkich w badanych osadach w górnym i środkowym odcinku Odry wielokrotnie przekraczały wartości tła geochemicznego w

osadach wodnych Polski. Osady w dolnym odcinku Odry, poniżej ujścia Warty, zawierały metale ciężkie w ilościach znacznie niższych, najczęściej zbliżonych do tła geochemicznego. Aluwia górnej i środkowej Odry charakteryzowały się wysokimi zawartościami Cu, Hg, Pb i Zn. Na akumulację tych metali w aluwiach Odry wyraźny wpływ wywierają: odprowadzanie ścieków z kopalni i hut cynkowo-ołowiowych (cynk i ołów), zrzuty ścieków z kopalni i hut miedzi (miedź, ołów i cynk), a także ścieki zakładów chemicznych (rtęć).