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Original Research

Changes in the Meandering Upper Odra River after Flooding in 1997 and 2010 Part II. Sediment and Water

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Abstract

River erosion combined with the settling and sedimentation of deposits contributed to silting of the original meanders, cutting them off and forming two oxbow lakes. After the floods in 1997 and 2010 the valley of the meandering Odra River underwent further changes concerning water and sediment qualities. Since that time the quality of both water and sediments has been gradually improving, similar to that of surface waters. The analysis of water quality measurement results for the Odra at Chałupki showed that the values of water temperature, reaction, ammonia, and electrolytic conductivity do not exceed the limiting levels for class I. It appears that the Odra waters are not sensitive to pollution by nitrogen compounds from agricultural sources. The measurements of water sampled from the Odra show that indicators such as water temperature, dissolved oxygen, reaction, nitrites, and ammonia nitrogen meet the requirements for inland waters being the living environment for fish from the Salmonidae and the Cyprinidae families in natural conditions.

Keywords: Odra River, meanders, floods, sediment, water

Introduction

The rules for the management of water resources are set out in legislation on the protection of inland waters and water ecosystems at both national and community levels. The Water Law Act [1] specifies that all surface and underground water resources must be managed rationally and comprehensively and in a manner that takes into account their quality and quantity. Directive 2000/60/EC provides a coherent legislative basis for sustainable water management [2]. Sediment research on the Odra in the region of the Polish-Czech meanders was carried out by several authors. Kasperek et al. [3] found that in the 1990s (before the flood in 1997) sediments from the Oder in the Chałupki section included increased contents of bar and zinc, exceeding 200 ppm. However, after the 1997 flood (in 2002-05) increased WWA concentrations of line 53 ppm, bar 659 ppm, and arsenic 60 ppm were observed. Kasperek and Parzonka [4] performed measurements of riverbed armoring and sediment transport calculations in the Upper Odra River (region of border meanders).

In consequence of the disastrous flood in 1997 and smaller ones (2001, 2002, 2005, 2006, 2007), there followed an intensifying of the pavement process of the bottom in the region of meander M1. The sediment bed was received with the method of freezing to a depth of 40 cm. Investigations by authors in 2005-07 indicate considerable thickening in relation to the period from before the 1997

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flood and producing cover of about 10 cm thick ($d_{50\%}$ = 4.7 cm, $d_{95\%}$ = 9.4 cm).

According to Zieliński the geological formation of the Odra valley is simple and homogeneous [5]. Under the surface, terraces appear in a continuous 2-3 m deck of loamy fen soil that is compact, where the sediment erodes with difficulty. In the immediate vicinity channel of the Odra one ought to expect bed alluvia – mule sand or the sandy fen soil covered by sandy gravel. Under the fen soil sometimes appears a deck of sand about 1-2 m thickness. The lowest link of river sediments is constituted by a thick (5-10 m) series of sandy gravels. Generally, sediments of the Odra valley are most often resistant to the erosion of loamy fen soils. Only around the waist along the river do less loamy sediments appear that are more susceptible to erosion.

This work aims to analyse the fluvial processes occurring on the Polish-Czech meandering reach of the Odra, with particular emphasis on the influence of historical floods in 1997 and 2010. The author has conducted several-years-long site measurements of the meandering area. These measurements include the sampling of bottom sediments and the testing of water quality. The presented results are a continuation of the studies described in my previous paper [6].

Materials and Methods

Over the investigated Odra reach there are altogether six curves-meanders (see Part I in this issue). The Odra reach being investigated spreads between the bridges and is unique in its hydrological regime, the high variation of stages and flows, and the sudden surges. Its location and the river's regime results in intensive fluvial: erosion of small particles in the drainage basin, sediment transport, and sedimentation of solid particles. The flow of surface waters through the inter-embankment zone of the Odra causes intensive bottom/downward and bank/sideward erosion. Konečná et al. [7] have carried out research on the influence of land use changes and erosion and flood control measures on a reduction of harmful effects of extreme rainfall-runoff events at the experimental Němčický stream basin since 2005. It has been documented by obtained results of rainfall and discharge gauging and by water sample analyses that sediment transport significantly corresponds with the cover efficiency of agricultural crops. Based on the analysis of particular comparable rainfall-runoff episodes, it can be stated that the protection (e.g. grassing, growing of narrowrow crops) of slopes adjacent to watercourses has a crucial influence on the reduction in surface water pollution with insoluble substances. In such cases the efficiency of grass cover is 90-99% compared to bare soil, while the efficiency of narrow-row crops is 50-80% in comparison with bare soil. The efficiency of narrow-row crops at the time of maximum vegetation stand is close to that of permanent grasslands.

Research Methods

The author sampled sediments from the Odra River channel in the area of meander M1 (see Part I in this issue). The physical properties of the investigated aggregate mud were determined using the methods typical for soil mechanics. The fundamental parameters describing the physical properties of investigated materials are: density of soil skeleton, grain composition, natural moisture, and volumetric concentration. Soil samples for the measurements were collected from the river channel, right upstream of the meander, from river outwashes at various depths, and from the oxbow lake (Fig. 1). The geotechnical analysis of bottom sediments was carried out by the Polish Geological Institute and Provincial Inspectorate of Environmental Protection [8-10].

The assessment of water quality for the Odra was carried out based on the hydro-chemical measurements conducted at the Chałupki cross-section by the Provincial

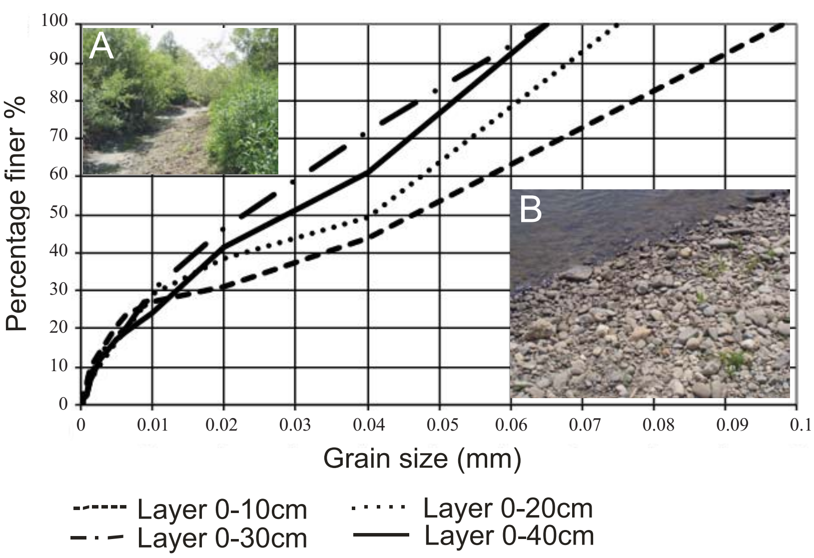

Fig. 1. Aggregate mud and overgrown oxbow lake (A), the recent sediment bed (B), and grain size distribution curves of bed material collected after the 2010 flood in meander M1, Odra River.

Inspectorate for Environmental Protection in Katowice: N_{tot}, NO_3^-, NO_2^-, NH_4^+, P_{tot}, BOD_5, dissolved oxygen, water temperature, water reaction, electrolytic conductivity, and total suspension [11-13]. The quality of water in the Odra River was assessed in line with the decisions of the Minister for the Environment of 20 August 2008 [14], 23 December 2002 [15], and 4 October 2002 [16].

Results and Discussion

During flood flows road bridge B2 (see Part I) concentrates and suppresses the stream, increasing the flow velocity downstream. As a result, bottom erosion takes place and considerable amounts of rubble are washed out. This rubble is transported down the river and forms natural obstacles such as sand and gravel outwashes, which deteriorate the hydraulic conditions and hinder the flow of flood waters. Apart of the bottleneck at bridge B2, there are no embankments on the Polish or Czech sides of the entire meandering reach of the Odra. This leads to sudden outflows of water carrying bottom sediments onto the flooded terraces, and flow velocity decreases in the entire inter embankment zone. This results in increased sedimentation of solid particles at the entrance to the meandering zone and contributes to the formation of outwashes and islands. The observations and measurements made by the authors over the last dozen or so years show that these outwashes and islands intensively develop upstream of the river, on the reach from the entrance to meander M1 to the border bridges B1 and B2 at Chałupki and Bohumin.

Erosion, Transport, and Deposition of Sediments

The admissible velocities that do not scour the non-cohesive soil are as follows: sands 0.55-0.65 $m\cdot s^{-1}$, gravels 0.65-1.2 $m\cdot s^{-1}$, pebbles 1.2-2.4 $m\cdot s^{-1}$, stones 2.4-3.9 $m\cdot s^{-1}$, and rocks – over 3.9 $m\cdot s^{-1}$. A comparison of the mean velocities with the limiting non-scouring values leads us to believe that for flows of 44 $m^3\cdot s^{-1}$ both sands and gravels are transported, and for $Q\geq150$ $m^3\cdot s^{-1}$ also the pebbles and stones begin to move. The flow velocities corresponding to the above wave parameters for the 1997 and 2010 floods were about 3-4 $m\cdot s^{-1}$. This led to the bottom sediments to be washed out and the bumps to appear on the Odra reach downstream of the Chałupki-Bohumin road bridge. A massive transport of rubble (both fine and coarse) followed. The rubble was deposited at the entrance to meander M1. On the Polish left bank washouts were formed. In 2010 the bottom material eroded on the same river reach as during the flood in 1997. This material was deposited on the existing washouts. Their thickness and dimensions have greatly increased. A further vigorous growth of vegetation (both trees and bushes) followed.

Geology and Sediments

According to Zieliński, the geological structure of the Odra valley is relatively homogeneous. The present river channel cuts through the sediments of a vast terrace, which spreads over a strip of several kilometres. Under the terrace surface there is a 2-3 m deep layer of silty fen soil – a dark brown deposit difficult to erode.

The previous research of Urbański and Wołoszyn (carried out in the 1980s) [17] shows that the Odra bottom on the Chałupki-Olza reach consists of multi-fractional material, i.e. sands, gravels, and pebbles of 14 mm in diameter on average, with the gravels being the predominant fraction (40-70%). On the basis of site measurements from 2004-05 and 2012 conducted by Kasperek, it was concluded that:

- The river reach right upstream of the meanders is characterized by its strongly cobbled bottom, with the average rubble diameter having more than tripled over the last 30 years – i.e. from 14 mm to 46 mm. However, the maximum diameter is as high as 97 mm (Fig. 1). The deeper layers of soil (at 30-40 cm below the surface), have grains of 23-28 mm on average with maximum diameter of 64 mm.
- Before entering the meandering zone and in the old channel there are islands built of river alluvia and aggregate mud. Measurements of these channel forms indicate that their formation processes are highly dynamic.

The measurements of aggradate mud sampled from the old channel show that the natural moisture is about 47%, the volumetric concentration stands at 32%, and the density of solids is at 2.50 $g\cdot cm^{-3}$. Based on the gradation analysis of the above-mentioned sediments, their content and particle size were determined. The predominant fraction of sediments deposited in the oxbow lake of meander M1 are dusts (grain size 0.002-0.05 mm). Their content was measured to be 59%. The finest of all was the silt fraction (grain size below 0.002 mm), which constituted approx. 11%. The remaining 30% of these sediments/aggregate muds were sands with diameters of more than 0.05 mm. The average grain size of these sediments was 0.029 mm and therefore they should be classified as dusty clay.

Water Quality

The concentration of nitrates in water sampled from the Odra at Chałupki ranged from 10.05 to 26.70 $mgNO_3^-\cdot dm^{-3}$, and the mean value of this indicator over the entire testing period was 13.63 $mgNO_3^-\cdot dm^{-3}$. The concentration of nitrites over the testing period was highly variable. The highest levels of this indicator were observed during the flood in 2010 (May-June), at 1.72 $mgNO_2^-\cdot dm^{-3}$. The concentration of ammonia varied from 0.064 to 0.977 $mgNH_4^+\cdot dm^{-3}$ and the mean value of this indicator over the entire testing period was 0.373 $mgNH_4^+\cdot dm^{-3}$. In the case of the total concentration of nitrogen, the analysis of water sampled from the Odra revealed that its lowest level was 3.04 $mgN\cdot dm^{-3}$ and the highest was 7.22 $mgN\cdot dm^{-3}$. As regards the total concentration of phosphorus, the lowest concentration level was 0.07 $mgP\cdot dm^{-3}$ and the highest 0.21 $mgP\cdot dm^{-3}$ (observed during the flood in May and June). The mean level of the total concentration of phosphorus observed over the testing period (January-

December 2010) was 0.125 mgP·dm^{-3}. The concentration of BOD_5 varied from 1.5 to 6.0 mgO_2·dm^{-3} and the mean value of his indicator over the entire testing period was 3.608 mgO_2·dm^{-3}. The oxygen content in the Odra varied from 6.5 to 13.6 mgO_2·dm^{-3}. The mean dissolved oxygen content at the measuring point was 10.19 mgO_2·dm^{-3}. The reaction of water sampled from the Odra varied from 7.6 to 7.8. The measurement also revealed that the temperature of water in the Odra in 2010 varied from 1.2ºC to 20.1ºC. The electrolytic conductivity at the measuring point varied from 324 to 799 µS·cm^{-1}. The highest level of total suspension (112 mg·dm^{-3}) was observed during the surge in the Odra basin in May and June 2010. As shown by the data presented in the Provincial Inspectorate of Environmental Protection (WIOŚ) report from 2010, there was no improvement in the quality of water compared to the situation in 2009. However, the number of indicators classified as water quality of classes III and IV increased and the number of indicators classified as water quality of classes I, II, and V decreased. It must be emphasized that the results of water quality tests in 2010 were greatly influenced by the flood over the months of May and June.

The analysis of water quality measurement results for the Odra River at Chałupki showed that the values of water temperature, reaction, ammonia, and electrolytic conductivity do not exceed the limiting levels for class I. However, the concentration of dissolved oxygen, BOD_5, total nitrogen, and total phosphorus qualify the Odra waters at Chałupki as water quality class II. All other indicators such as total suspension and nitrates exceed the limiting levels of water quality indicators for surface water bodies in natural watercourses, such as a river, which is characteristic for class II. Waters of the Odra have been found to be eutrophic. The mean yearly concentration of nitrates exceeded the limiting value for this indicator (10 $mgNO_3$·dm^{-3}).

It was noted that the Odra waters are not sensitive to pollution by nitrogen compounds from agricultural sources, since the mean yearly concentration of nitrates is below the recommended level (50 $mgNO_3^-$·dm^{-3}). The measurements of water sampled from the Odra showed that the indicators such as water temperature, dissolved oxygen, reaction, nitrites, and ammonia nitrogen meet the requirements for inland waters being the living environment for fish from the Salmonidae and the Cyprinidae families in natural conditions. The most adverse living conditions for the fish are caused by total phosphorus content, which exceeds the required levels of 0.2 $mgPO_4$·dm^{-3} and 0.4 $mgPO_4$·dm^{-3} for the Salmonidae and the Cyprinidae, respectively. The concentration of BOD_5 exceeds the required level of 3 mgO_2·dm^{-3} for the Salmonidae and total suspension content, which in turn exceeds the required mean yearly value of 25 mg·dm^{-3}. Compared to the water quality testing results for the Odra at Chałupki for 2004-05, which were presented in earlier works by Kasperek and Wiatkowski and showed these waters to be of class IV (water of unsatisfactory quality), in 2010 the quality of water improved.

Köse et al. [18] evaluated the water quality of Seydisuyu Stream (main branch of the Sakarya River, Turkey) by determining sonic physiochemical (temperature, conductivity, salinity, TDS, pi I, ORP, dissolved oxygen, and nitrate) and chemical (boron and arsenic) parameters. All of the data obtained experimentally were compared according to the criteria of SKKY (Water Pollution Control Regulation in Turkey) and evaluated as drinking water according to the criteria of TS266 (Turkish Standards Institute), the EC (European Communities), and WHO (World Health Organization). According to the results of Factor analysis, four factors explained 84.78% of the total variance, and according to the results of cluster analysis, three statistically significant clusters were formed. In a macroscopic view, the monitoring station has class I-II water quality in terms of arsenic and class IV water quality in terms of boron. It was also determined that arsenic and boron accumulations in Seydisuyu Stream water were much higher than drinking water limits.

Quality of Bottom Sediments

The sediment samples collected from the Odra at Chałupki in 2002 demonstrated high concentrations of heavy metals, with lead at 50 ppm and barium at 300 ppm. Low concentrations were measured for cadmium (below 0.5 ppm). The concentrations of polycyclic aromatic hydrocarbon (PAHs) were as follows: sum A (total of three cyclic PAHs: acenaphthene, fluorene, phenanthrene, anthracene) 0.5 ppm, sum B (total of four cyclic PAHs: fluoranthene, pyrene, benzo(a)anthracene, chrysene) 1.8 ppm, sum C (total of five cyclic PAHs: benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[e]pyrene, benzo[a]pyrene, terylene, dibenzo(ah)anthracene) 1.1 ppm, and sum EPA (sum A + sum B + sum C + sum D) of 3.6 ppm. In 2003 the sediments collected from the Odra had the following metal content: arsenic 7 ppm, cadmium below 0.5 ppm, chromium 19 ppm, and zinc 162 ppm. The PAH concentrations calculated as the total of sums A, B, C, and D (total of six cyclic PAHs: indeno[1,2,3-cd]pyrene and benzo[ghi]perylene) and EPA in these sediments sampled in 2003 did not exceed 2 ppm. The Odra sediments from 2004 were characterized by their high concentration of barium (659 ppm). The content of other metals was as follows: cadmium 0.5 ppm, lead 60 ppm, copper 40 ppm, and mercury 0.38 ppm. The total concentrations of PAHs were the following: sum A 1.5 ppm, sum B 3.6 ppm, sum C 1.8 ppm, sum D 0.7 ppm, and an overall total of 7.7 ppm.

Ibragimow et al. [19] determined the total content and available forms of trace metals (Cd, Cr, Cu, Ni, Pb, Zn) in fluvial sediments 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. 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. The total contents of Cd, Cr, Cu, Ni, Pb, and Zn are strongly correlated with the participation of very coarse-grained (from 2,000 to 1,000 µm) and medium-grained (from 500 to 250 µm) sediments as well as with the content of organic matter (excluding Cd). 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}). 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. For total Ni contents, it was also shown that the total contents determined after the flood were much lower. Duman, Dry, and Kar [20] investigated the changes of metal concentrations in Kilicozu Creek (Kirsehir, Turkey) sediments, depending on station and sampling period variation. They observed that the metal concentration means per annum were Zn>Cr>Ni>Cu>Pb>Cd. Highest seasonal values of heavy metals were observed as follows: Pb (14.4 µg/g), Ni (43 µg/g), and Cd (6.2 µg/g) in autumn, Cr (55.7 µg/g) and Zn (71.9 µg/g) in summer, and Cu (42.5 (µg/g) in spring. Cd contamination exceeded the limit values in this stream sediment. According to the reference values, Zn or Pb contamination in the creek sediment has not reached the effective level.

Similarly to previous years, in 2005 the content of arsenic in the meandering Odra River was the highest of all and exceeded several times the geometric mean. The maximum content of arsenic stood at 60 ppm. Moreover, high concentrations were measured for the following elements: barium, cadmium, and mercury. In the sediments sampled in 2005 the sum of polycyclic aromatic hydrocarbons was 53.65 ppm.

Kasperek et al. [21] have performed the variation analysis of the select pollution indexes in the Widawa River (inflow of the Odra River) during 1993-2006. This analysis indicates insignificant fluctuations in the last years and large stabilization of most parameters. At present the bacteriological state of the Widawa River has been improved, and the average-annual values describing the eutrophication process at one station have been exceeded only for phosphorus. At the second station, below the Dobra River mouth, these values have been exceeded for all parameters with the exception of chlorophyll *a*. The quality of deposits from the Widawa River is I-III class. The highest concentrations (II-III class) of compounds were: 103 ppm for chromium, 80 ppm for copper, 530 ppm for zinc, 380 ppm for barium, and 0.5 ppm for mercury. The lowest concentrations of compounds were (I-II class): 6-15 ppm for arsenic, 0.5-3.1 ppm for cadmium and 5-40 ppm for lead.

Conclusions

The quality of bottom sediments keeps improving, similarly to that of surface waters. The analysis of water quality measurement results for the Odra River at Chałupki showed that the values of water temperature, reaction, ammonia, and electrolytic conductivity do not exceed the limiting levels for class I. However, the concentration of dissolved oxygen, BOD_5, total nitrogen, and total phosphorus qualify these waters as class II. All other indicators – such as the total suspension and nitrates – exceed the limiting levels of quality indicators for water of class II as set out for surface water bodies in natural watercourses such as a river. Due to the content of nitrates, Odra waters were found to be eutrophic. It appears that Odra waters are not sensitive to pollution with nitrogen compounds from agricultural sources. The measurements of water sampled from the Odra show that the indicators such as temperature of water, dissolved oxygen, reaction, nitrites, and ammonia nitrogen meet the requirements for inland waters being a living environment for fish from the Salmonidae and the Cyprinidae families in natural conditions. The most adverse living conditions for the fish are caused by total phosphorus, BOD_5, and total suspension.

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