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# AN ATTEMPT TO ASSESS THE IMPACT OF ANTHROPOPRESSURE ON THE ECOLOGICAL STATE OF URBANISED WATERCOURSES OF KRAKOW CONURBATION AND THE DIFFICULTIES ENCOUNTERED*

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Abstract

Rivers and streams in cities are treated as urbanised watercourses because of their significant transformation. Their load, channeling and incorporation into the water-sewerage infrastructure are often so considerable that such watercourses can hardly be recognised as an intrinsic component of surface waters. Anthropopressure, as reflected in quantitative and qualitative degradation caused by flow regulation and economic development in the drainage basin area, makes evaluation of the impact of human activity on the aquatic environment somewhat difficult. Based on the recommendations of the Water Framework Directive, an attempt has been made to assess the ecological state of selected tributaries of the Prądnik-Białucha River within the Krakow Conurbation. Aquatic environment sampling of the Sudół Dominikański (Rozrywka) watercourse was performed (September 2005) in order to determine some physicochemical, chemical and biological parameters, paying particular attention to macrophytes. The parameters measured on site: pH, electrolytic conductivity and Eh of water and bottom sediments, and sozological observations, were subjected to analysis. In the laboratory, concentrations of heavy metals, both in water and in solid particles (sediments and suspended matter) and anions in water were determined. The environmental state of the Sudół Dominikański watercourse was compared with that

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in the area of the Prądnik-Białucha River valley, for which an assessment had been conducted in the previous year (September 2004).

Key words: ecological state, watercourse, sediments, macrophytes.

**PRÓBA I TRUDNOŚCI WYKONANIA OCENY WPŁYWU ANTROPOPRESJI NA STAN EKOLOGICZNY W CIEKACH ZURBANIZOWANYCH KRAKOWSKIEGO ZESPOŁU MIEJSKIEGO (KZM)**

Abstrakt

Rzeki i strumienie w miastach, wskutek ich znacznego przekształcenia, traktuje się jako cieki zurbanizowane. Często ich obciążenie i zabudowa infrastrukturą wodno-kanalizacyjną są tak znaczne, że trudno nadal uznawać je za jednolite części wód powierzchniowych. Antropopresja przejawiająca się degradacją ilościową i jakościową w wyniku regulacji przepływu i zagospodarowania zlewni powoduje, że ocena skali wpływu działalności człowieka na środowisko wodne nie jest prosta. Na podstawie zaleceń Ramowej Dyrektywy Wodnej podjęto próbę oceny stanu ekologicznego wybranych dopływów rzeki Prądnik-Białucha, w obrębie Krakowskiego Zespołu Miejskiego. Wykonano opróbowanie środowiska wodnego cieku Sudół Dominikański (Rozrywka – wrzesień 2005 r.), w kierunku określenia niektórych elementów fizykochemicznych, chemicznych oraz biologicznych, szczególnie zwracając uwagę na makrofity. Analizie poddano mierzone w terenie wskaźniki: pH, PEW i Eh wody i osadów dennych oraz obserwacje sozologiczne. W laboratorium zmierzono zawartość metali ciężkich zarówno w wodzie, jak i cząstkach stałych (osadach i zawiesinach) oraz zawartość anionów w wodzie. Stan środowiska cieku Sudół Dominikański porównano ze stanem w rejonie doliny rzeki Prądnik-Białucha, dla której ocenę wykonano rok wcześniej (wrzesień 2004 r.).

Słowa kluczowe: stan ekologiczny, ciek wodny, osady wodne, makrofity.

# INTRODUCTION

Achieving good ecological state of waters, both qualitatively and quantitatively, means that surface waters should stay as shaped by nature. At the same time, in defined sections or areas, they should be suitable for public water supply, bathing, sustaining fish life of the *Salmonidae* or at least the *Cyprynidae* family and they should meet appropriate requirements in protected areas (M.P.03.33.433 (Act)). Activities serving to achieve this objective will include limiting pollution from communal and industrial point sources by constructing, expanding and modernising sewerage systems and wastewater treatment plants; in the case of point sources and agricultural area sources of pollution, the overall objective should be reached through appropriate storage and use of natural fertilisers, and the use of organic and mineral fertilisers in accordance with Good Agricultural Practices (Dz.U.04.176.1827 (R)). The recommendations contained in the Ecological Policy of Poland and the rules which ensure coherence of the European Community's environmental protection policy prove that without eliminating direct pollution sources in drainage basins it will not be possible to achieve the priority aim, i.e. improved quality of surface waters, by 2010 nor even by 2015 (2000/60/EC). For the sake of water management, uniform parts of surface waters are distinguished as separate and significant elements of surface waters, such as a stream, brook, river, channel or their parts. Artificial or strongly altered waters are distinguished from intrinsic components of surface waters (Dz.U.05.239.2019 (Act)).

The problems encountered while evaluating the effect of arthropopressure on the ecological state of urbanised watercourses are due to the lack of defined reference conditions. These watercourses are omitted from regional monitoring studies – sometimes their mouth area is sampled just in order to determine the impact of pollution carried into bigger rivers. The area drained by these watercourses and the quality of waters they carry are rarely a subject of studies, as the local monitoring of surface waters has been abandoned. Some scattered and non-standardised studies of urbanised watercourses have been carried out in the Krakow Conurbation, called the Krakow Metropolitan Area in current planning documents, which is territorially larger than the recognized boundaries of the Krakow Urbanised Area and much bigger than the City of Krakow. Such studies were conducted, for instance, to prepare the City of Krakow Atlas (TRAFAS 1998), the Geochemical Atlas of the City of Krakow and its Surroundings (LIS, PASIECZNA 1995), the Sozological Map, Local Land Development Plans and the Small Retention Programme of the Province of Małopolska (www.wrotamalopolski.pl) together with detailed studies concerning the regulation of individual streams where there is a flood risk.

The Study of Determinants and Land Development Plans of Krakow (2003) contained a category of River Parks, which should be established in the surroundings of river valleys because of their special conditions and natural resources. The ranking list for Krakow is the following: *Urban Parks*: Błonia Węgrzynowickie (Kościelnicki Stok), Fort Mistrzejowice – Park Complex „Mistrzejowice", Mydlniki Quarry, Kliny-Zacisze, Rakowski Forest, Płaszów-Camp, Ruczaj, Rżąka, Skotniki, Tetmajera, Wróblowicki; *River Parks*: the Dłubnia (with the Baranówka), the Drwinka and the Serafa with the Malinówka, the Kościelnicki Stream, the Prądnik with tributaries (including the Białucha, the Sudół from Modlnica, the Bibiczanka and the Sudół Dominikański), the Rudawa (with the Młynówka Królewska), the Wilga (including the Cyrkówka and the Potok Siarczany), the Vistula and *Sections of River Parks*: Aleksandra (part of River Park of the Drwinka and the Serafa with the Malinówka), Dębnicki (fragment of the Vistula River Park), the Drwinka (part of the River Park of the Drwinka and the Serafa with the Malinówka), John Paul II (part of the Wilga River Park), the Młynówka Królewska (the Rudawa River Park area), Nadwiślański (part of the Vistula River Park), Płaszów – the Gardens (part of the Vistula River Park), the Potok Siarczany (part of the Wilga River Park), the Rozrywka (part of the

Prądnik and Tributaries River Park), the Wilga-Rydlówka (the Wilga River Park area), Zakrzówek (BPTK area; refers to the Vistula River Park) (www.krakow.pl/prasowka). These areas, due to their significant transformation, are strongly urbanised. It is necessary to make their inventory, to eliminate pollution sources and to monitor them periodically. Some watercourses in towns, not only formally but also actually, due to their the load, culverting and incorporation into the water-sewerage infrastructure, being piped into a sewer system, losing hydrological continuity of some sections, and being subjected to periodical flow shortages etc., can hardly be recognised as uniform parts of surface waters or be treated as their significant elements. However, according to the implementation rules of the Water Framework Directive and in compliance with the Water Law standards, it is necessary to undertake actions to gradually eliminate pollution with priority substances and to stop or gradually eliminate the emission, draining and losses of priority hazardous substances (Dz.U.04.126.1318 (R)).

Anthropopressure, as reflected by quantitative and qualitative degradation, being the result of flow regulation and economic development of the drainage basin, makes an assessment of the scale of the human impact on the aquatic environment somewhat difficult. The survey of areas through which small watercourses flow, both within the district boundaries of the Krakow Urbanised Area and in the District of Krakow, shows that the areas drained by such streams are largely neglected and untidy and the described state is recognised only in critical and extraordinary situations, at times of environmental hazard of anthropogenic nature or during natural disasters, i.e., high water or flooding. The Water Framework Directive demands that particular attention be paid to biological elements such as environmental status indices or – in the case of urbanised watercourses – the ecological potential.

Based on the recommendations of the Water Framework Directive, an attempt has been made to assess the ecological status of selected tributaries of the Prądnik-Białucha River within the Krakow Conurbation. In this particular region, as reported by the media, the plans to create River Parks are at the highest risk of being abandoned. One reason is that the land allocated for this project is in part private property. The area within the park boundaries around the Sudół Dominikański (from Lublańska Road to the administrative boundaries of Krakow) and in the Prądnik Valley (from the administrative boundaries to Opolska Road) is planned for multi-storey development, which is confirmed by applications submitted by land developers to the Department of Architecture (www.biznespolska.pl/wiadomosci/prasa).

The objective of the study has been to verify the following hypothesis: the current method of land development and water and sewage management in the Sudół Dominikański Valley and in the area of the Prądnik-Białucha River lead to their quantitative and qualitative degradation.

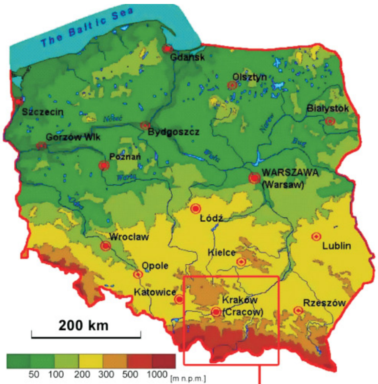
# THE AREA UNDER STUDY

## Site studies

The Sudół Dominikański Stream has its source in the area of Zielonki District and flows to the City of Krakow from the north, where it loses its hydrological continuity with the natural channel and joins the Prądnik-Białucha River by means of a collecting pipe, thus becoming its highly urbanised left tributary (Figure 1). The length of the stream is 7 km. As it flows, it drains Basutów and Batowice, passes behind Batowicki Cemetery, and appears in Czerwony Prądnik from the east. On the website of the Prądnik Association, the following can be read: "Here, every couple of years, following a bigger rainfall, it gives us a hard time, flooding Majora Street and basements of nearby blocks of flats. It disappears into underground pipes near the junction of Majora Street and Dobrego Pasterza Road, to reappear once more for a couple of hundred meters between Dobrego Pasterza and Lublańska Roads. Some time ago, in the neighbourhood of the Dominican Friars Mill, it joined the waters of the Mill Stream (flowing from a weir on the Biały Prądnik). Before the roadway of Lublańska Road, it disappears again in a concrete underground collector, near the old slaughterhouse, by Olszecka Road. It joins the Białucha near Olszyny Road." (www.republika.pl/towpradnik).

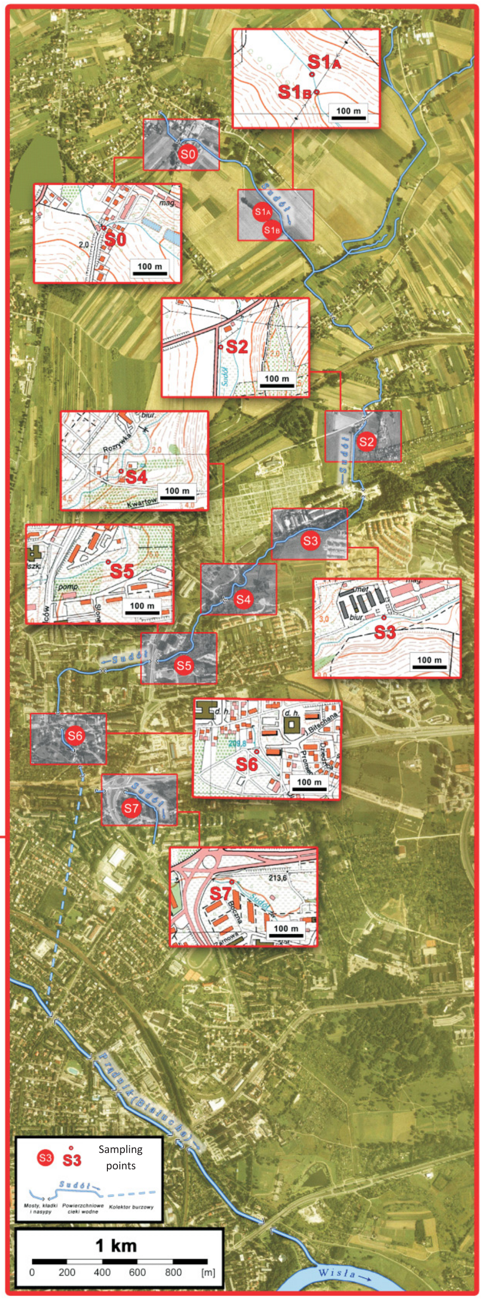
In its upper section, the stream is an insignificantly transformed watercourse, flowing through an area densely covered by vegetation. It cuts across farmland, meadows and idle green areas. There are only private farmsteads on the land along the channel. In the City of Krakow, it flows among dense urban settlements, transport routes and near many local pollution sources. The watercourse encounters places of significant environmental transformation. Its channel has been subject to multiple, often "wild" regulations and in places its flow totally disappears. In its final section, the stream has been piped twice and where its waters are directed to the Prądnik-Białucha, the watercourse is a concrete collector, which functions as a storm-water drain.

The drainage basin of the Sudół Dominikański covers an area within two geological structures: the Silesian-Krakow Anticlinorium and the Pre-Carpathian Sink. Its south-eastern part, called Krakow Upland, is built of rocky and shoal limestone (with flints) and plate limestone, which form characteristic outliers and slope rocks emerging from a layer of loess clay and loess (Gradziński 1972). Along its nearly entire length, it flows on Holocene floodplain terraces (clays, fen soil, sand and pebbles) lying on Quaternary loess (thickness *ca* 15 m), into which it cuts in places. In the valley slopes, some older formations appear, e.g. Upper Jurassic, Middle and Upper Cretaceous and Miocene sediments (Bukowy 1956).




Map 1. Physical Map of Poland


Map 2. Administrative Map of the Małopolska Province




Map 3. Orthophotomap of the Krakow area including the location of sampling points

Fig. 1. Location of environmental sampling sites along the Rozrywka (Sudół Dominikański) Stream

The pollution sources of the stream's aquatic environment are:

- general domestic sewage (no sewerage systems, leaking septic tanks) and communal waste;
- disturbed hydro-relations;
- farming, gardens and allotments (plant pesticides, fertilisers, organic waste);
- industry (dry and wet atmospheric deposition, surface run-offs from storehouses and workshops);
- transport (heavy metal and oil product pollution, run-offs from transport bases and filling stations);
- civilisation pollution (corrosion and degradation of industrial infrastructure remains, area degradation, e.g. pits of a former brickyard in Zielonki filled illegally with communal waste, from which the run-offs infiltrate together with rainfall water and groundwater to surface and underground waters.

## SCOPE AND METHODS

### Site studies

During the site studies (September 2005), a detailed sozological-ecological mapping of the Sudół Dominikański Stream Valley was performed. Particular attention was paid to the existing or potential pollution sources of the stream, shape and conservation of the natural state of the channel, type of economic development and the green cover, presence of macrophytes growing in the watercourse or partly submerged ones, type of water flow, disappearance or loss of hydrological continuity. Environmental samples were taken for laboratory analyses at 8 points (Figure 1), the exact position of which was determined using a GPS receiver. They covered the following material:

- water (6 samples, S1-S6);
- bottom sediments, surface layer (8 samples, S1-S7);
- bottom sediment cores (2 cores, S2 and S7);
- macrophytes, in most cases waterside, single specimens growing in the watercourse (evenly along the entire sampling route).

After performing tests for indices sensitive to transport or storage conditions (pH, Eh and electrolyte conductivity), the samples were protected and stored cooled, isolated from light and oxygen until analysed in the laboratory. Water samples were filtered through 0.45 μm pore membrane filters. The samples for metal cation concentration assays were acidified.

The state of the aquatic environment of the Sudół Dominikański watercourse was compared with that of the Prądnik-Białucha River studied in the previous year (September 2004).

**Laboratory analyses**

Water samples were analysed for the concentration of heavy metals: Cd, Cu, Pb and Zn, with the use of inductively coupled plasma atomic emission spectroscopy (ICP-AES Perkin-Elmer Plasma 40 instrument). The anion content ($Cl^-$, $NO_3^-$, $SO_4^{2-}$, $PO_4^{3-}$) was determined using an ion chromatograph (Dionex DX-100 Ion Chromatograph). The suspension density in the water samples was determined. In the aqueous suspension (fraction > 0.45 µm) and bottom sediments (fraction < 0.063 mm), concentration of the metals was determined after solubilising them by extraction with concentrated nitric acid (65%) at 130°C and using flame atomic absorption spectrometry (AAS-PU 9).

## RESULTS ANALYSIS AND DISCUSSION

### Water samples

The water in the Sudół Dominikański Stream showed a high degree of turbidity, especially in its upper section, where engineering works were being carried out and the channel was mostly free from crust vegetation. The pH values of water samples did not vary essentially along the stream course, ranging between 7.60 and 7.98. Oxidative conditions were found with the Eh (mV) values from +135 to +190, whereas the electrolytic conductivity EC (mS cm$^{-1}$) was within the 0.96-1.47 range (average value 1.25) – Table 1.

Table 1

Parameters determined for water samples from the Sudół Dominikański Stream

| Sample | Parameter | | |
|---|---|---|---|
| | pH | Eh (mV) | EC (mS cm$^{-1}$) |
| S1a | 6.90 | +125 | 0.47 |
| S1b | 7.30 | +98 | 0.52 |
| S2 | 7.60 | -135 | 0.59 |
| S3 | 7.55 | -95 | 0.98 |
| S4 | 7.53 | -85 | 1.03 |
| S5 | 7.41 | -35 | 0.58 |
| S6 | 7.65 | -71 | 0.39 |
| S7 | 7.55 | +30 | 0.73 |
| Min | 6.91 | -135 | 0.39 |
| Max | 7.65 | +125 | 1.03 |

The concentration of anions determined in water samples varied, generally increasing downstream. Concentrations (mg dm$^{-3}$) of $Cl^-$, $NO_3^-$, $SO_4^{2-}$, $PO_4^{3-}$ varied within the ranges 35-76 (average value 58), 1.5-23 (average value 10), 55-92 (average value 80) and 6.7-10 (average value 9.4), respectively (Table 2).

Table 2

Concentration of some anions in water samples from the Sudół Dominikański Stream

| Sample | $Cl^-$ | $NO^-_3$ | $SO_4^{2-}$ | $PO_4^{3-}$ |
|---|---|---|---|---|
| | (mg dm$^{-3}$) | | | |
| S1 | 34.8 | 1.47 | 54.6 | <1.2* |
| S2 | 74.1 | <0.3* | 91.6 | 6.74 |
| S3 | 41.1 | <0.3* | 75.9 | 7.02 |
| S4 | 54.8 | 3.04 | 79.4 | 6.73 |
| S5 | 66.2 | 12.0 | 89.3 | 10.3 |
| S6 | 76.2 | 23.2 | 87.0 | 9.26 |
| Min | 34.8 | 1.47 | 54.6 | 6.73 |
| Max | 76.2 | 23.2 | 91.6 | 10.3 |
| Mean | 57.8 | 9.9 | 79.6 | 9.41 |

* threshold level acc. to Wójcik et al. (1999)

Maximum amounts (μg dm$^{-3}$) of Cd, Cu, Pb and Zn were at the level of 0.045, 5.00, 0.30 and 24.2, respectively (Table 3).

Table 3

Concentration of some metals in water samples from the Sudół Dominikański Stream

| Sample | Cd | Cu | Pb | Zn |
|---|---|---|---|---|
| | (μg dm$^{-3}$) | | | |
| S1 | 0.045 | 2.30 | 0.20 | 11.7 |
| S3 | 0.036 | 4.30 | 0.30 | 24.2 |
| S6 | 0.020 | 5.00 | 0.20 | 10.0 |

## Bottom sediment and water suspension samples

Bottom sediments from the Sudół Dominikański showed insignificant differences in the pH value, which varied in the range 6.90-7.65, and highly varying redox potentials: in the initial and final sections the conditions were oxidative, whereas in the middle section they were reductive. The electrolytic conductivity (EC) values (mS $cm^{-1}$) of sediments of similar degree of hydration ranged between 0.39 and 1.03 (average 0.66) – Table 4.

Table 4

Parameters of bottom sediment samples from the Sudół Dominikański Stream

| Sample | Parameter | | |
|---|---|---|---|
| | pH | Eh (mV) | EC (mS $cm^{-1}$) |
| S1a | 6.90 | +125 | 0.47 |
| S1b | 7.30 | +98 | 0.52 |
| S2 | 7.60 | -135 | 0.59 |
| S3 | 7.55 | -95 | 0.98 |
| S4 | 7.53 | -85 | 1.03 |
| S5 | 7.41 | -35 | 0.58 |
| S6 | 7.65 | -71 | 0.39 |
| S7 | 7.55 | +30 | 0.73 |
| Min | 6.91 | -135 | 0.39 |
| Max | 7.65 | +125 | 1.03 |

In the case of bottom sediment cores sampled at the point S2, both in its top zone (-211 mV) as well as in its bottom zone (-134 mV), reductive conditions were found (Figure 2). Both depth profiles show a difference with respect to lithology. The first one, sampled in the upper section of the stream (S2) down to 20 cm depth, is composed of dark sediments, highly nourished, turning into brown sandy sediments in the lower zones. A sediment core taken in the downstream section of the stream (S7) is formed of uniform, dark, sandy-silt with an insert of clay sediments appearing only at the depth of 13-14 cm.

Bottom sediments were characterised by variable particle size distribution. The finest grained samples, for which 90 wt.% was the powdery-clay fraction, were collected in the upper section of the stream. The other samples contained 2–89 wt. % of the powdery-clay fraction. The content of metals found in the bottom sediments generally showed a rising tendency downstream. The amounts (mg $kg^{-1}$) of Cu, Pb and Zn ranged between 7-73 (average 27), 16-124 (average 46) and 47-943 (average 257), respectively. The values that exceeded the geochemical background (also local) were mostly found for lead (Table 5).

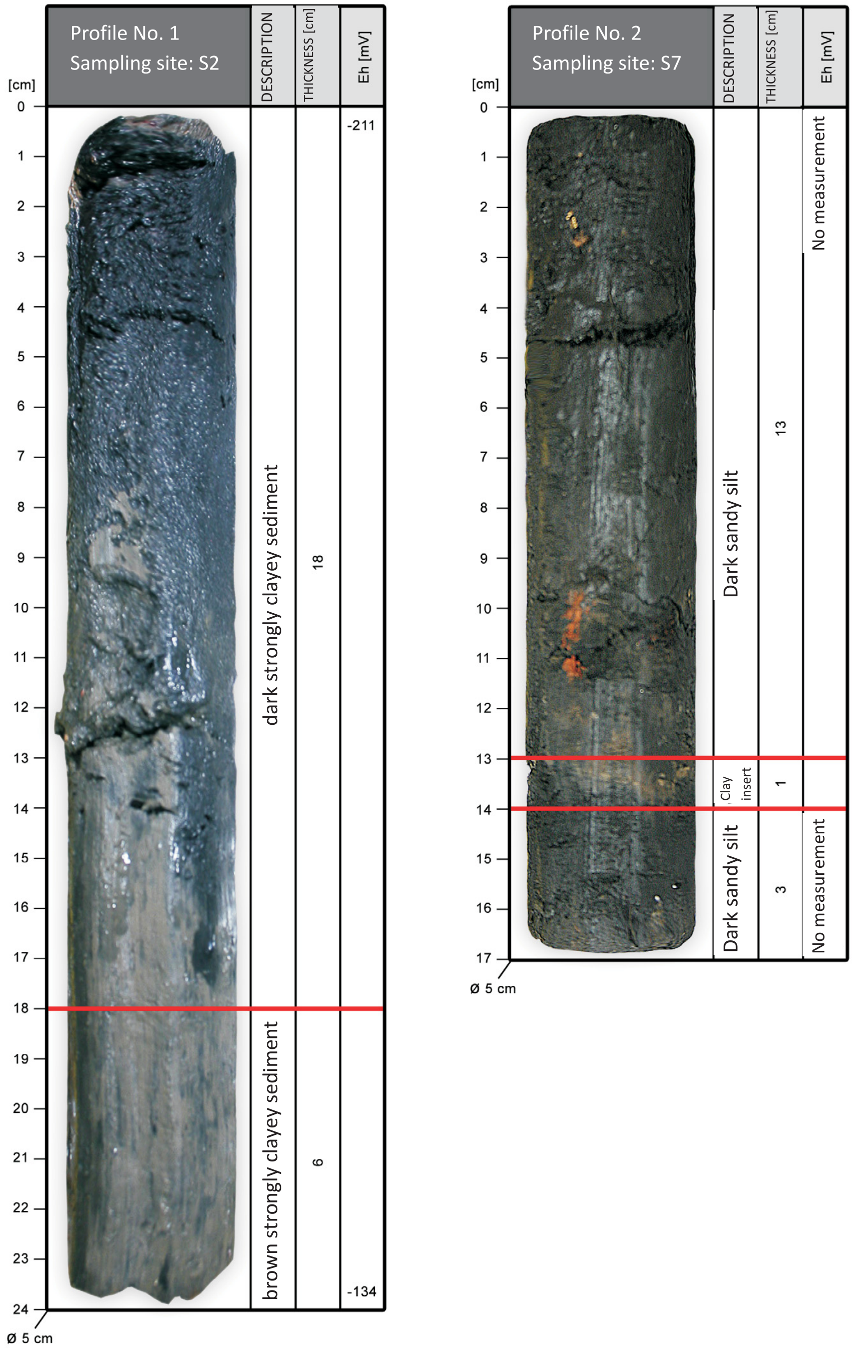



Fig. 3. Changes in lithology in the bottom sediment cores from the Sudół Dominikański Stream

Table 5

Concentration of some metals in bottom sediment samples
from the Sudół Dominikański Stream

| Sample | Parameters | | | |
|---|---|---|---|---|
| | fr.<0.063 mm (%) | Cu (mg kg$^{-1}$) | Pb (mg kg$^{-1}$) | Zn (mg kg$^{-1}$) |
| S1a | 97.3 | 12 | 16 | 47 |
| S1b | 88.6 | 19 | 22 | 102 |
| S2 | 42.6 | 24 | 33 | 161 |
| S3 | 63.7 | 12 | 23 | 58 |
| S4 | 43.7 | 35 | 38 | 263 |
| S5 | 77.8 | 7 | 28 | 55 |
| S6 | 1.6 | 73 | 124 | 943 |
| S7 | 50.3 | 33 | 85 | 426 |
| Min | 1.63 | 7 | 16 | 47 |
| Max | 97.30 | 73 | 124 | 943 |
| Mean | 41.80 | 27 | 46 | 257 |
| Local background for the Vistula River (Helios-Rybicka 1986) | | 40 | 45 | 110 |
| Geochemical background (Turekian, Wedepohl 1961) | | 45 | 20 | 95 |

The suspension density ranged between 0.001 and 0.078 (g dm$^{-3}$). The most polluted suspension samples were found, as in the case of bottom sediments, in the lower section of the stream, and the Pb and Zn content (mg kg$^{-1}$) there reached 8600 and 2800, respectively.

Strong linear correlations were found between the analysed metals. The linear correlation coefficient ($R^2$) takes values >0.8 (Figure 3).

The results were compared to the current Polish regulations and, in the case of sediment samples, also the German ones.

Water assessment:

– Minister for the Environment Regulation of 11 February on the classification for presenting the state of surface and underground waters, the method for conducting the monitoring, the method for interpretation of the results, and the presentation of the state of these waters (Dz.U. 04.32.284(R)) (cancelled – none currently in force);

Bottom sediment assessment:

– classification of aqueous sediments based on geochemical criteria (Bojakowska, Sokołowska 1998),

– German classification of sediments and aqueous suspension LAWA (Imer 1997, LAWA 1998),
– classification based on the geoaccumulation index – Igeo (MÜLLER 1981).

With respect to the five-degree classification of surface waters (Dz.U. 04.32.284(R)), no cases of exceeded concentration of $Cl^-$ or $SO_4^{2-}$ anions were found (Class I), whereas the amount of $NO^{-3}$ anions was slightly elevated in the downstream section (Class II). Phosphates occured in the highest concentrations and therefore the tested water samples were classified as Class V. According to the LAWA (1998) classification, the sediments in the upper section of the stream may be recognised as non-polluted with respect to the concentration of the concerned metals (Class I and I-II), in the mid-

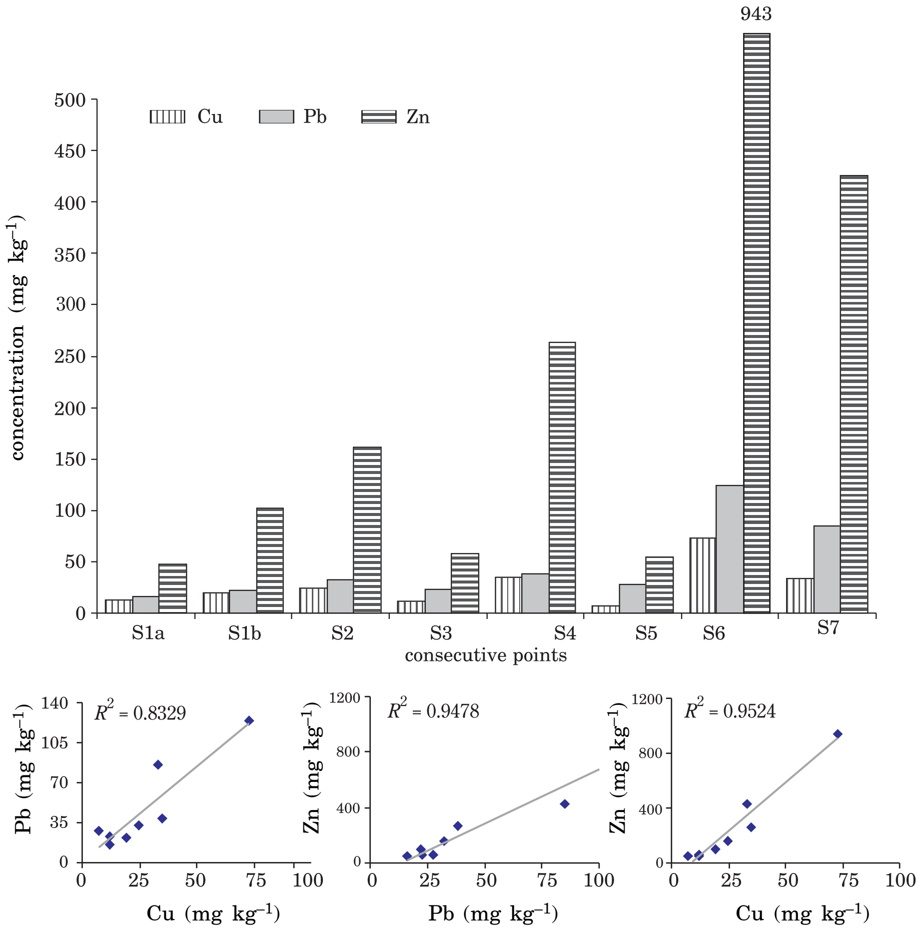



Fig. 3. Variability in Cu, Pb, and Zn concentrations in sediments sampled downstream of the Sudół Dominikański Stream and linear dependences between concentrations of individual metals

dle section as slightly polluted and in the lower section as highly polluted. In the case of the two other classifications, the situation looks similar (Table 6).

Table 6

Classification of bottom sediments from the Sudół Dominikański Stream with respect to their Cu, Pb and Zn concentration

| Sample | Parameters | | | | | | | | | General assessment | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cu (mg kg$^{-1}$) | | | Pb (mg kg$^{-1}$) | | | Zn (mg kg$^{-1}$) | | | | | |
| | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 |
| S1a | I | I | 0 | I | I | 0 | I | I | 0 | I | I | 0 |
| S1b | I | I | 0 | I | I | 0 | I-II | I | 0 | I-II | II | 1 |
| S2 | I-II | II | 0 | I-II | I | 1 | I-II | I | 1 | I-II | I | 1 |
| S3 | I | I | 0 | I | I | 0 | I | I | 0 | I | I | 0 |
| S4 | I-II | II | 0 | I-II | I | 1 | II | II | 1 | II | II | 1 |
| S5 | I | I | 0 | I-II | I | 0 | I | I | 0 | I-II | I | 0 |
| S6 | II | II | 1 | II-III | II | 3 | III | II | 3 | III | II | 3 |
| S7 | I-II | II | 0 | II | II | 2 | II-III | II | 2 | II-III | II | 2 |

1) acc. to LAWA classification (1998)
2) acc. to geochemical classification by BOJAKOWSKA, SOKOŁOWSKA (1998)
3) acc. to geoaccumulation index Igeo (MÜLLER 1981)

## Vegetation

The studies of aquatic vegetation, as indices of the changes in the ecological state of the Sudół Dominikański Stream, should be treated at this stage as preliminary ones, i.e. making an inventory. Studies on aquatic vegetation should be integrated into the monitoring of the state or the ecological potential of the watercourse, which includes assays of the pH value, concentration of salts and oxygen content in the sediments, as well as the content of heavy metals. In a relatively simple way, with the aid of hydrobotany experts, it will be possible to complement the studies with biological elements recommended by WFD (SZOSZKIEWICZ et al. 2002).

In the Sudół Dominikański Valley, at sections (S1-S6) adjunct to the sampling points, the following plants were found:

– S1. Reed canary grass (*Phalaris arundinaceae*), marshpepper knotweed (*Polygonum hydropiper*), hedge bindweed (*Calystegia sepium*), stinging nettle (*Urtica dioica*), common amaranth (*Amaranthus retroflexus*);
– S2. Hairy willow herb (*Epilobium hirsutum*), tansy (*Tanacetum vulgare*), marshpepper knotweed (*Polygonum hydropiper*), mugwort (*Artemisia vulgaris*), nodding beggartick (*Bidens cernua*), burning nettle (*Urtica urens*), greater celandine (*Chelidonium majus*);

– S3. Creeping buttercup (*Ranunculus repens*), wood avens (*Geum urbanum*), bluegrass (*Poa sp.*), shepherd's purse (*Capsella bursa pastoris*), bishop's goutweed (*Aegopodium podagraria*), tansy (*Tanacetum vulgare*), hedge woundwort (*Stachys sylvatica*);
– S4. Water chickweed (*Myosoton aquaticum*), marshpepper knotweed (*Polygonum hydropiper*);
– S5. Brome grass (*Bromus sp.*), reed canary grass (*Phalaric arundinaceae*), unbranched bur-reed (*Sparganium emersum*);
– S6. Creeping bentgrass (*Agrostis stolonifera*).

Among 21 species found on the bank slopes during the studies, as many as 11 belong to apophytes (native taxons preferring transformed sites), and further three are characterised by a high degree of hemerophily (positively respond to the growth of transformation). Among the identified apophytes, typically ruderal species dominate, including celandine (*Chelidonium majus*), burning nettle (*Urtica urens*), common amaranth (*Amaranthus retroflexus*) and tansy (*Tanacetum vulgare*). Most of the species tolerant to transformation occurred at site S2. All the 7 species found at this site respond positively to anthropogenic pressure. The species found at site S3 indicate its significant shading and a potential forest site.

## Comparison of the cleanliness of the Sudół Dominikański and the Prądnik-Białucha River

Based on the results of the studies on the Sudół Dominikański Stream (September 2005) and the Prądnik-Białucha River fed by this stream (September 2004), a comparison was made between the cleanliness of both watercourses. It allowed us to state whether the Sudół Dominikański Stream could be a source of heavy metal pollution of the Prądnik-Białucha River. First, the ranges of the parameters determined for these watercourses, pH, Eh and electrolytic conductivity, were compared for both watercourses (Table 7). The pH values vary in both cases in the range from slightly acidic to slightly alkaline. It may be said that the aquatic environment of the

Table 7

Comparison of some parameter value ranges (averages) for the Sudół Dominikański Stream and the Prądnik-Białucha River

| Parameters | The Sudół Dominikański | The Prądnik - Białucha |
|---|---|---|
| pH | 6.91: 7.65 | 6.74: 7.34 |
| Eh (mV) | +125 : -135 | 178 : - 350 |
| Electrolytic conductivity (mS $cm^{-1}$) | 0.391: 1.030 (0.660) | 0.418 : 1.080 (0.810) |
| Cu (mg $kg^{-1}$) | 7 : 73 (27.0) | 151 : 729 (321.7) |
| Pb (mg $kg^{-1}$) | 16 : 124 (46.1) | 27 :108 (64.7) |
| Zn (mg $kg^{-1}$1) | 47 : 943 (257) | 148 : 675 (331.7) |

sediments from the Prądnik-Białucha River are more reduced than those from the stream flowing into it. This might result from the presence of sediments of greater thickness in the bed of the Prądnik-Białucha River than in the smaller and shallower Sudół Dominikański. In both cases, the salt concentration, expressed by electrolytic conductivity, may be described as relatively small. However, in the case of heavy metals, the average Cu concentration is more than 10-fold higher in the sediments of the Prądnik-Białucha River than in those from the Sudół Dominikański. For Pb, both the concentration plots, and the mean concentration are at a level close to 50 (mg $kg^{-1}$). A greater span of values was observed for Zn concentration ranges in the sediments from the Sudół Dominikański, whereas this range for the sediments from the Prądnik-Białucha was narrower but its average value was higher.

By comparing the results of the analysis of the above parameters for two sites located at the Prądnik-Białucha River, before and after the outlet of the Sudół Dominikański collector, we looked for any significant differences (Table 8). Taking into account the fact that the differences in metal concentrations in sediments are generated by many factors (such as grain size distribution and mineral composition of the sediments, sampling site, other 'enriching' sources or factors making the sediments lean), it is thought that the outlet of the storm water drain, such as the Sudół Dominikański collector, slightly cleans the sediments from heavy metals. The phenomenon of washing out metals from sediments in an acidic environment, characteristic of storm waters in the City of Krakow, is also confirmation of this thesis. It seems that such a remarkable difference in the pH values in the bottom sediment environments, as well as the oxidation of bottom sediments from the value of -67 mV to +142 mV, may be explained by the action of storm sewers. It was also checked if there was a relationship between the cleanliness of both watercourses by comparing the results of measurements made at two sites localised at the Prądnik River, upstream and downstream of the place where the Sudół Dominikański joins the Prądnik (Table 8).

Table 8

Summary of some parameter values for the Prądnik-Białucha River upstream (I) and downstream (II) of the Sudół Dominikański Stream inflow

| Parameters | I | II |
|---|---|---|
| pH | 7.80 | 4.16 |
| Eh (mV) | -67.0 | 142 |
| Electrolytic conductivity (mS $cm^{-1}$) | no data | 0.32 |
| Cu (mg $kg^{-1}$) | 42 | 22 |
| Pb (mg $kg^{-1}$) | 56 | 44 |
| Zn (mg $kg^{-1}$) | 211 | 148 |

ADYNKIEWICZ-PIRAGAS and DRABIŃSKI (2001) assessed the impact of hydrotechnical development projects on the environmental state of the Smortawa River. The channel regulation carried out in the lower section of the river and the construction of dam type weirs and fall stages generally caused a decrease in species diversity and changes in the species composition of macrophyte assemblages (aquatic, off-bankside and bankside zones), plankton and periphyton, in comparison to the non-regulated section. Also the ecomorphologic valorisation, performed by Ilnicki method (ILNICKI, LEWANDOWSKI 1997) showed a fall in the naturalness of the hydrotechnically transformed section.

## SUMMARY AND CONCLUSIONS

The waters of the Sudół Dominikański, because of their pH value and the Zn, Pb and Cu content, correspond to Class I purity waters with respect to the current standards. However, because of their high phosphate content in all the studied sites, the waters are classified as Class V, which means non-potable water. This low assessment with regard to water purity class is also affected by the concentration of river suspension.

The Cu, Pb and Zn content in the sediments and the suspension increase downstream, which is certainly affected by the rise in the urbanisation of the valley. According to the classification assumed for the purposes of assessment of the pollution of sediments with heavy metals, the sediments in the upper section of the stream may be recognised as non-polluted, in the middle section as slightly polluted and in the lower section as highly polluted.

The aquatic environment of the Prądnik-Białucha sediments is more reductive than the Sudół Dominikański Stream flowing into it, with the pH values in both cases varying from slightly acidic to slightly alkaline, while the salt content of both watercourses may be described as relatively low. In the Prądnik-Białucha sediments, the average concentration of Cu is over 10-fold higher but and that of Pb is similar in both samples (*ca* 50 mg $kg^{-1}$). A larger span of values characterises the Zn concentration ranges in the sediments of the Sudół Dominikański. The Zn range for the Prądnik-Białucha is narrower but shows a higher average concentration.

A positive process of sediment purification by storm waters is observed downstream the collector outlet, where it is compunded by the washing out of the metals with the acidic environment characteristic of storm waters in Krakow. In the vicinity of both watercourses, particularly the Sudół Dominikański, the presence of exceptionally adverse factors was observed (incorrect constructions around the banks, no access to the channel, the presence of illegal rubbish dumps, non-regulated water and sewage management).

Our preliminary survey of aquatic vegetation (small total abundance of macrophytes and a large share of ruderal species of apophytes) points to very strong anthropopressure associated with morphological transformations and eutrophication. In the places where the morphological stressor exceeded the limits of ecological tolerance of macrophytes, we observed total disappearance of tracheophytes and the appearance of resistant, macroscopic structural algae of the *Cladophora* genus.

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