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Quality of waters in the River Skawinka catchment basin (Southern Poland) in periods of low water level

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A b s t r a c t — On the basis of physico-chemical and bacteriological analyses the quality of waters in the Skawinka catchment basin was estimated. In spite of favourable conditions for the self-purification processes, a distinct effect of point pollution on the waters of the basin, particularly in the Cedron stream below the locality Kalwaria Zebrzydowska, was observed. In periods of low water level an effect of diffuse pollution was also manifested.

K e y w o r d s: rivers, streams, water quality, point and diffuse pollution, self-purification.

1. Introduction

In spite of being situated at a short distance from Kraków, which as an important scientific centre of Poland, the River Skawinka basin has not so far been described in the aspect of quality and purity of its waters. Currently, the problem has been undertaken by workers of the Kraków Institute for Physical Planning and Municipal Economy on account of projected protection zones for the water intake located in the lower part of the basin (the village of Radziszów). The Skawinka basin to the river gauge at Radziszów covers 90% of the total catchment area.

The aim of the investigation was to evaluate the quality of waters in this basin under variable hydrological conditions. In periods of low water the effect of point and diffuse pollution was investigated. In periods of higher level particular attention was paid to surface run-off pollution. This last problem will be the subject of the next work.

2. Study area

2.1. The river basin

To the river gauge at Radziszów the Skawinka basin covers 323 km² and is almost wholly included within the Pogórze Wielickie (Wieliczka Plateau) which form part of the region of the External Western Carpathians. A small southern fragment of the basin lies in the Silesian Beskids and a northern one in the mesoregion of Brama Krakowska (Kondracki 1978).

Nearly the entire basin is built of sedimentary rocks which compose the Carpathian Flysch, i.e. sandstones, conglomerates, and shales (Alexandrowicz 1975). The greater part of the basin is characterized

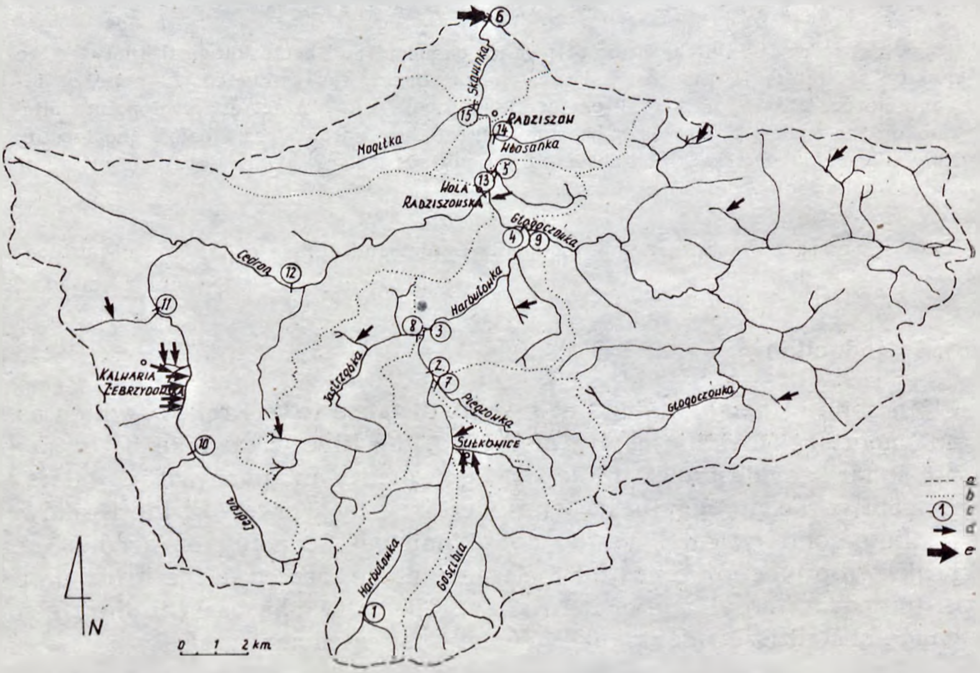

Fig. 1. Distribution of sampling stations and sources of point pollution in the Skawinka basin. a — boundaries of the basin; b — boundaries of partial catchment basins; c — station of water sampling; d — source of point pollution; e — tap water intake

by a submontane relief and lies in a moderately warm zone (Hess 1965). Prominent among the soils are skeletal, brown, and podzolic, loess silt covers (loess-like ones), and typical alluvial soils (Komornicki 1960). The basin is chiefly in agricultural use, arable occupying 66% and forests 23% of the area. It is inhabited by about 54 thousand people, including populations of 5000 each in two towns, Kalwaria Zebrzydowska and Sułkowice. The remainder are scattered in 38 villages.

According to the criterion of altitude of the spring sector the main hydrographic axis of the catchment basin is the Harbutówka stream, which becomes the River Skawinka from the mouth of the Cedron stream (fig. 1). The Skawinka is a right side tributary and drains into the River Vistula its waters at the 60th kilometre of its course. From the springs to the water intake at Radziszów the river is 31 km in length and the density of the hydrographic net 1.89 km/km^2. Streams in the basin are chiefly fed with surface waters, above all from rain and in a smaller measure from snow melt (Dynowska 1980). The chief affluents of the Skawinka are the Gościbia, Piegzówka, Jastrząbka, Głogoczówka, Cedron, Włosanka, and Mogiłka streams. According to Punzet (unpublished data), the Skawinka basin is characterized by low values of minimal discharges and by a considerable variability of flow. Unit discharges determined on the basis of average annual flow range from 13.3 dm^3 s^{-1} km^{-2} (Harbutówka, Sułkowice) to 10 dm^3 s^{-1} km^{-2} (the Cedron stream).

Fifteen stations for sampling water were situated at the following places: along the course of the Skawinka (Stations 1—6) from the spring sector to the station at the water intake at Radziszów (6.2 km of the river course); in the mouth sectors of streams flowing into the Skawinka: Piegzówka (Station 7), Jastrząbka (Station 8), Głogoczówka (Station 9), Cedron (Station 13), Włosanka (Station 14), and Mogiłka (Station 15), and additionally along the Cedron stream (Stations 10—12). The detailed analysis of waters of this last stream was necessitated by the fairly large load of pollution fed to it from the town of Kalwaria Zebrzydowska.

2.2. Factors affecting water quality

In periods of low water level the quality of water in the Skawinka basin is chiefly subjected to two antagonistic factors: the effect of pollution and the processes of self-purification.

No municipal water treatment plants have been installed in the basin. The most serious threat to the waters are the municipal wastes from Sułkowice, drained to the Skawinka in its upper course (71 kg BOD_5 d^{-1}), and from Kalwaria Zebrzydowska, fed to the Cedron stream (230 kg BOD_5 d^{-1}). Other sources of point pollution (PP) are some farms and a few small industrial plants (food and metallurgic industries), mostly located on the outskirts of the basin , i.e. favourably for the quality of waters taken in for municipal purposes (fig. 1). Untreated or insufficiently treated wastes from PP, reaching a total volume of 2215 m^3 d^{-1}, are fed to the waters of the Skawinka basin. They are mostly of municipal-domestic type. It should be mentioned that 50.4% of their volume is drained to the Cedron stream.

In the discussed basin none of the 38 villages has a sewage system, though in most of them a water pipe network has been installed. Municipal-domestic sewage is collected in septic tanks and from there transported to a treatment plant or used for agricultural purposes. However, fairly numerous households drain their wastes to streams, this constituting a source of a diffuse pollution (DP). The greatest effect of DP may be expected in the partial basins of the streams Piegzówka and Jastrząbka and in the spring sector of the Skawinka where the configuration of the terrain favours the concentration of farmsteads in valleys of running waters. In the basin of the Piegzówka stream 75% of houses are supplied with tap water. Also in the lower part of the basin the situation of the villages Wola Radziszowska along the Cedron stream and Radziszów along the River Skawinka suggests a strong effect of DP on the waters.

In the Skawinka basin two parts with different conditions for the self-purification process may be distinguished. In the southern part, which includes the basins of the streams Gościbia, Piegzówka, Jastrząbka, and upper and middle fragments of the basins of the Głogoczówka, Cedron, and Skawinka (Harbutówka), these conditions are more favourable. The streams are shallow and widely spread with a flow rate of 0.5 m s^{-1}. The current is chiefly turbulent. The stream bottoms are covered with cobbles which constitute a habitat for organism of periphyton and bottom fauna. There occur favourable light conditions. The water is characterized by slight turbidity, though fairly deep layers of detritus, chiefly of allochtonous origin, are observed on the bottom.

In the northern part of the Skawinka basin, which includes the lower part of the catchment area of the streams Głogoczówka and Cedron and also the partial basin of the Włosanka, the conditions for self-purification are less favourable. The occurrence of loess soils changes the character of the riverbeds here. They are much deeper (1—2 m), cut in loess and susceptible to erosion so that the type of stream bottom is gravelly-muddy. The abundance of peryphyton and macrobenthos organisms distinctly decreases (Czernoch, unpublished data). The slopes of the terrain and the flow rates associated with them are reduced. The current is chiefly laminar, the depth increasing to about 1 m, while the turbidity and colour of the water are more intense.

3. Material and method

The quality of the water was investigated from April 1983 to June 1984. Nine samplings of the water were carried out only in periods of low water level when there were the most favourable conditions for estimating the effect of PP and DP on the waters in the basin. The water flow was five times measured at all stations by the hydrometric float method.

The range of water analyses included 27 physico-chemical parameters and coli-titre of the faecal type. Zinc and copper were determined by means of atomic absorption spectroscopy (ASA) and other indices according to methods given by Hermanowicz et al. (1976). Coli titre was determined by the test-tube fermentation method on a lactose substrate at 44.5°C. The values of the coli titre given in the results indicate the smallest volume of water in which *Escherichia coli* bacteria were observed.

4. Results

4.1. Physico-chemical and bacteriological analyses of the water

Table I presents the results of physico-chemical analyses of waters from the Skawinka basin.

The greatest amplitude of changes in water temperature in the Skawinka basin were of calcium-carbonate type. Among anions the highest sector and 21°C in the lower course of the river). In the tributaries, at the stations near their outflow, the temperatures were in general 0.5—1.0°C lower than in the Skawinka. In the winter the variation of water temperature was negligible, only 0.5°C.

In the upper course of the River Skawinka and in the tributaries of the upper part of the basin (the Piegzówka and Jastrząbka streams) the index of water turbidity was smaller ($\bar{x} < 20$ mg SiO_2 dm^{-3}) than that found in the lower part of the catchment area ($20 \leqslant \bar{x} \leqslant 30$ mg SiO_2 dm^{-3}). The reaction of the water was alkaline and varied within the fairly narrow range of pH 7.04—8.48.

The ion-equivalent composition showed that the waters of the Skawinka basin were of calcium-carbonate type. Among anions the highest percentage participation was found for carbonates (61.0—74.1%) and among cations for calcium (58.2—71.4%). Sulphates (15.7—22.9%), chlorides (7.8—18.0%), magnesium (16.7—26.3%), sodium (8.0—14.6%), and potassium (1.4—2.6%) occurred in smaller amounts. In the lower part of the basin the total of anions and cations slightly exceeded that found in the upper part. The largest content of macroelements was found in the Cedron stream below the discharge of municipal sewage from Kalwaria Zebrzydowska. An increase in the value HCO_3^- and Cl^- anions and Na^+ and Ca^{++} cations was observed there (fig. 2). The waters of the Skawinka basin were characterized by moderate hardness within a small range of variation (3.0—4.5 mval dm^{-3}).

Table I. Ranges and mean values of physico-chemical parameters at stations along the course of the River Skawinka and at the inflow of its tributaries. x - values approximate on account of the method of measurement

Parameter	Stations	Harbutówka - Skawinka 1	2	3	4	5	6	Piegżówka 7
Flow[x]	$m^3\ s^{-1}$	0.03-0.07 / 0.05	0.10-0.69 / 0.24	0.21-0.73 / 0.35	0.32-0.83 / 0.46	0.70-0.86 / 0.77	0.49-1.25 / 0.79	0.04-0.20 / 0.10
Temperature	°C	0.5-19 / 11.0	0.5-21 / 12.0	0.5-22 / 12.7	1-22 / 12.5	1-21 / 12.5	1-22 / 13.4	0.5-20 / 11.4
pH		7.59-8.27 / 8.03	7.49-8.20 / 7.83	7.74-8.48 / 8.03	7.75-8.18 / 7.96	7.66-8.18 / 7.92	7.72-8.16 / 7.99	7.52-8.12 / 7.72
Colour	mg Pt dm^{-3}	7-15 / 11	12-21 / 17	14-23 / 17	17-26 / 22	16-25 / 20	18-26 / 20	10-24 / 16
Turbidity	mg $SiO_2\ dm^{-3}$	2-33 / 10	4-23 / 11	6-27 / 12	9-85 / 22	4-66 / 22	6-28 / 18	3-40 / 15
Total hardness	mval dm^{-3}	2.4-4.9 / 3.8	2.5-5.4 / 3.5	3.5-5.0 / 4.0	3.6-4.4 / 4.0	3.8-5.0 / 4.5	3.7-4.6 / 4.1	2.4-3.8 / 3.0
Alkalinity	mval dm^{-3}	2.0-3.6 / 3.1	1.7-3.9 / 2.5	2.3-3.4 / 2.9	2.1-3.2 / 2.8	2.3-3.4 / 3.0	2.4-3.5 / 3.1	1.2-2.4 / 2.0
Chloride	mg Cl dm^{-3}	8.5-17.7 / 11.6	14.2-28.4 / 21.2	18.8-28.4 / 24.1	22.7-46.1 / 29.0	20.9-38.8 / 28.4	22.3-31.9 / 26.2	16.0-24.1 / 18.5
Sulphate	mg $SO_4\ dm^{-3}$	12.3-45.6 / 35.5	29.0-50.2 / 40.7	39.7-56.4 / 46.1	34.3-54.7 / 45.4	37.6-52.0 / 43.9	38.3-58.4 / 46.9	29.4-45.9 / 36.2
Calcium	mg Ca dm^{-3}	45-68 / 59	33-72 / 47	44-68 / 59	48-60 / 55	51-66 / 60	43-63 / 57	32-41 / 35
Magnesium	mg Mg dm^{-3}	0.6-14.3 / 8.4	6.5-12.0 / 9.8	4.5-12.4 / 9.8	8.5-14.3 / 12.1	3.9-20.8 / 12.1	9.1-20.8 / 14.3	5.2-11.7 / 9.1
Kalium	mg K dm^{-3}	2.8-3.3 / 3.1	2.8-3.5 / 3.2	3.0-3.6 / 3.4	3.0-3.7 / 3.5	3.2-4.0 / 3.8	3.5-4.2 / 3.9	2.7-3.3 / 3.1
Natrium	mg Na dm^{-3}	8.9-10.2 / 9.6	9.0-10.2 / 9.7	9.1-9.9 / 9.7	9.6-10.8 / 10.3	9.9-11.2 / 10.8	10.6-12.0 / 11.2	8.9-10.4 / 9.6
Ammonia	mg $N\text{-}NH_4\ dm^{-3}$	0.01-0.56 / 0.12	0.07-1.64 / 0.41	0.08-0.42 / 0.23	0.06-0.52 / 0.26	0.13-0.60 / 0.29	0.06-0.36 / 0.22	0.04-0.44 / 0.18
Nitrite	mg $N\text{-}NO_2\ dm^{-3}$	0.01-0.03 / 0.008	0.006-0.118 / 0.040	0.015-0.063 / 0.039	0.006-0.03 / 0.019	0.006-0.027 / 0.019	0.003-0.034 / 0.017	0.005-0.024 / 0.012
Nitrate	mg $N\text{-}NO_3\ dm^{-3}$	0.36-1.36 / 0.79	0.28-1.36 / 0.85	0.42-1.48 / 0.91	0.04-0.72 / 0.42	0.16-1.20 / 0.58	0.12-0.84 / 0.47	0.16-1.36 / 0.67
Phosphate	mg $PO_4\ dm^{-3}$	0.02-0.19 / 0.06	0.06-0.66 / 0.22	0.06-0.25 / 0.17	0.08-0.23 / 0.12	0.08-0.30 / 0.14	0.02-0.40 / 0.13	0.04-0.19 / 0.10
Dissolved oxygen	mg $O_2\ dm^{-3}$	8.7-12.9 / 10.1	6.3-12.5 / 9.9	8.0-14.0 / 11.3	8.1-13.5 / 10.1	7.3-12.6 / 10.1	6.6-13.9 / 10.5	7.7-13.1 / 9.6
Oxygen saturation	%	71.1-100.1 / 90.0	57.3-115.7 / 91.6	75.7-136.7 / 108.0	73.2-109.8 / 95.9	67.2-110.4 / 94.3	59.3-131.5 / 100.4	73.2-100.3 / 87.1
BOD_5	mg $O_2\ dm^{-3}$	0.4-3.2 / 1.8	2.0-5.9 / 3.2	1.8-5.0 / 3.3	0.6-4.2 / 2.6	1.3-4.0 / 2.4	0.2-4.5 / 2.5	0.6-3.6 / 2.3
Oxidability	mg $O_2\ dm^{-3}$	0.3-4.0 / 2.0	2.2-5.5 / 3.4	2.0-5.1 / 3.3	2.1-5.5 / 3.5	1.3-5.1 / 3.4	1.7-4.8 / 3.7	1.9-4.5 / 3.1
Total residue	mg dm^{-3}	194-274 / 240	185-312 / 233	234-296 / 263	228-353 / 292	257-400 / 309	237-355 / 293	183-234 / 211
Dissolved matter	mg dm^{-3}	186-272 / 233	177-309 / 227	231-287 / 257	224-323 / 275	249-342 / 291	231-335 / 285	177-218 / 202
Total suspension	mg dm^{-3}	0-25 / 8	3-11 / 6	3-11 / 6	0-64 / 17	0-53 / 18	0-23 / 12	0-21 / 5
Total ferrum	mg Fe dm^{-3}	0.01-0.16 / 0.06	0.01-0.34 / 0.21	0.01-0.28 / 0.15	0.06-0.78 / 0.41	0.14-1.00 / 0.45	0.08-0.70 / 0.35	0.01-0.50 / 0.26
Zinc	μg Zn dm^{-3}	25-248 / 167	36-153 / 95	62-182 / 118	18-298 / 173	53-181 / 127	47-146 / 110	41-191 / 121
Copper	μg Cu dm^{-3}	1-64 / 24	0-9 / 4	1-8 / 4	0-20 / 7	1-48 / 19	1-21 / 8	3-5 / 4
Phenolic compounds	μg dm^{-3}	1-19 / 5	1-19 / 6	3-50 / 14	1-11 / 4	1-12 / 3	1-12 / 3	1-42 / 10
Detergents	mg dm^{-3}	0.08-1.40 / 0.35	0.06-0.47 / 0.22	0.07-0.53 / 0.29	0.10-0.53 / 0.28	1.10-0.43 / 0.25	0.07-0.35 / 0.23	0.05-0.49 / 0.23
Eter extract	mg dm^{-3}	1.6-8.4 / 4.0	1.8-9.2 / 4.7	1.8-9.4 / 4.8	1.2-10.0 / 4.2	4.0-14.4 / 6.1	1.4-9.6 / 5.1	2.0-8.8 / 4.6

cont. tab. I

Parameter	Stations	Jastrząbka 8	Głogoczówka 9	Cedron 10	Cedron 11	Cedron 12	Cedron 13	Włosanka 14	Mogiłka 15
Flow[x]	m^3s^{-1}	0.07-0.32 0.15	0.12-0.34 0.22	0.08-0.22 0.17	0.20-0.54 0.29	0.22-0.65 0.34	0.26-0.94 0.39	0.003-0.08 0.03	0.02-0.16 0.09
Temperature	^oC	0.5-20 11.6	0.5-21 12.1	0.5-19 10.8	0.5-21 11.2	0.5-21 12.0	3.0-21 13.0	0.5-22 12.7	0.5-22 11.1
pH		7.04-8.09 7.80	7.36-8.16 7.81	7.87-8.24 8.09	7.64-8.03 7.82	7.72-8.24 7.94	7.68-8.11 7.92	7.39-7.88 7.65	7.46-8.08 7.85
Colour	mg Pt dm^{-3}	17-24 21	16-36 27	9-19 13	16-38 25	21-29 24	19-28 23	15-26 19	16-46 29
Turbidity	mg SiO_2 dm^{-3}	7-32 13	4-70 20	7-14 30	16-56 29	4-20 13.5	6-64 30	10-38 23	7-46 29
Total hardness	mval dm^{-3}	2.0-4.8 4.2	3.4-5.0 3.8	5.5-7.1 6.2	5.1-6.0 5.7	4.2-5.6 4.9	4.4-7.0 5.3	4.7-8.3 5.7	5.3-7.2 6.0
Alkalinity	mval dm^{-3}	2.6-3.9 3.2	2.0-3.2 2.8	4.1-4.9 4.5	3.7-4.9 4.5	3.0-4.6 3.9	2.9-4.1 3.7	3.2-5.2 4.0	3.2-4.8 4.1
Chloride	mg Cl dm^{-3}	21.3-28.4 24.7	26.6-49.6 32.6	15.9-23.0 18.8	23.7-38.3 29.7	20.9-31.9 27.3	22.0-28.4 24.6	14.2-25.2 19.4	15.6-28.4 22.0
Sulphate	mg SO_4 dm^{-3}	33.5-49.8 42.8	37.4-63.5 47.4	44.0-58.0 50.2	42.0-58.0 47.4	23.1-47.7 41.9	34.4-56.8 46.8	45.0-69.5 54.6	37.0-64.6 52.8
Calcium	mg Ca dm^{-3}	54-63 58	44-62 52	46-84 68	64-84 74	58-78 69	56-82 66	73-82 80	72-85 77
Magnesium	mg Mg dm^{-3}	10.4-15.6 12.8	9.8-17.6 13.7	12.4-24.7 15.4	12.4-28.6 18.0	7.2-20.8 15.0	6.5-26.0 16.0	8.5-16.9 12.4	12.4-18.9 16.1
Kalium	mg K dm^{-3}	3.0-3.9 3.5	3.4-4.1 3.9	2.8-3.3 3.0	3.6-4.4 4.0	3.2-3.7 3.5	3.5-4.1 3.5	3.3-4.0 3.6	3.2-3.9 3.5
Natrium	mg Na dm^{-3}	9.9-11.8 10.8	9.5-10.8 10.3	9.6-10.9 10.1	10.2-11.4 10.8	10.0-11.2 10.5	9.8-11.2 10.5	10.4-11.8 11.2	10.6-11.8 11.0
Ammonia	mg N-NH_4 dm^{-3}	0.08-0.60 0.29	0.14-0.52 0.29	0.04-1.06 0.23	0.18-4.56 1.95	0.20-2.12 0.71	0.12-2.64 0.65	0.12-0.50 0.30	0.10-0.64 0.35
Nitrite	mg N-NO_2 dm^{-3}	0.008-0.037 0.020	0.003-0.027 0.011	0.005-0.027 0.012	0.027-0.202 0.067	0.008-0.160 0.055	0.003-0.037 0.024	0.003-0.024 0.012	0.006-0.022 0.011
Nitrate	mg N-NO_3 dm^{-3}	0.20-1.12 0.63	0.04-0.76 0.38	0.20-1.92 1.31	0.12-1.36 0.65	0.12-1.28 0.77	0.12-1.36 0.59	0.04-0.48 0.18	0.20-1.00 0.45
Phosphate	mg PO_4 dm^{-3}	0.05-0.23 0.11	0.08-0.19 0.11	0.02-0.21 0.08	0.19-2.00 0.75	0.03-0.47 0.29	0.08-0.31 0.19	0.04-0.08 0.05	0.04-0.42 0.13
Dissolved oxygen	mg O_2 dm^{-3}	7.4-12.4 9.9	7.6-12.4 9.9	8.1-13.0 10.0	3.3-13.1 7.5	7.4-13.5 9.5	7.6-12.8 9.8	6.5-12.7 8.7	7.4-12.9 10.2
Oxygen saturation	%	67.2-100.3 91.6	69.2-105.2 92.3	73.2-103.4 90.5	29.6-94.6 67.4	67.2-119.2 87.4	69.2-116.5 91.2	59.3-89.4 81.2	86.2-93.8 90.9
BOD_5	mg O_2 dm^{-3}	0.6-4.7 2.5	1.6-3.4 2.4	0.6-3.8 1.9	1.6-10.5 5.1	1.0-5.5 3.3	1.6-4.0 2.7	1.3-3.2 2.0	1.6-3.7 2.7
Oxidability	mg O_2 dm^{-3}	1.9-5.1 3.6	2.0-5.1 4.0	0.6-5.1 2.8	3.0-10.5 6.2	2.9-6.2 4.8	2.9-6.0 4.5	1.5-4.6 3.3	1.7-5.5 3.7
Total residue	mg dm^{-3}	260-316 285	253-329 289	260-399 335	333-418 360	216-353 321	276-526 333	269-328 297	274-410 339
Dissolved matter	mg dm^{-3}	248-306 274	241-318 278	255-358 328	317-395 344	216-356 315	271-378 300	263-311 282	254-386 311
Total suspension	mg dm^{-3}	0-26 11	0-33 11	2-19 7	4-36 16	0-11 5	4-17 10	3-38 16	3-78 27
Total ferrum	mg Fe dm^{-3}	0.20-0.50 0.35	0.28-0.70 0.54	0.06-0.40 0.15	0.16-1.10 0.49	0.07-0.48 0.36	0.16-0.84 0.48	0.20-0.84 0.49	0.34-0.82 0.50
Zinc	µg Zn dm^{-3}	40-349 186	35-419 206	93-256 163	36-466 252	56-383 160	60-181 136	-	-
Copper	µg Cu dm^{-3}	1-16 6	2-6 5	1-80 22	2-16 8	1-16 6	0-5 2	-	-
Phenolic compounds	µg dm^{-3}	1-11 3	4-15 5	1-8 3	1-6 3	1-9 3	2-12 3	1-16 6	0-16 9
Detergents	mg dm^{-3}	0.08-0.55 0.28	0.04-0.41 0.24	0.10-0.51 0.25	0.07-0.49 0.26	0.01-0.59 0.29	0.05-0.75 0.22	0.20-1.76 0.77	0.12-2.70 0.98
Eter extract	mg dm^{-3}	0.6-6.2 2.6	1.8-6.8 4.7	1.0-6.8 3.3	0.8-11.8 5.4	0.8-5.8 2.7	2.6-10.2 4.7	2.0-11.8 7.6	0.8-5.6 3.2

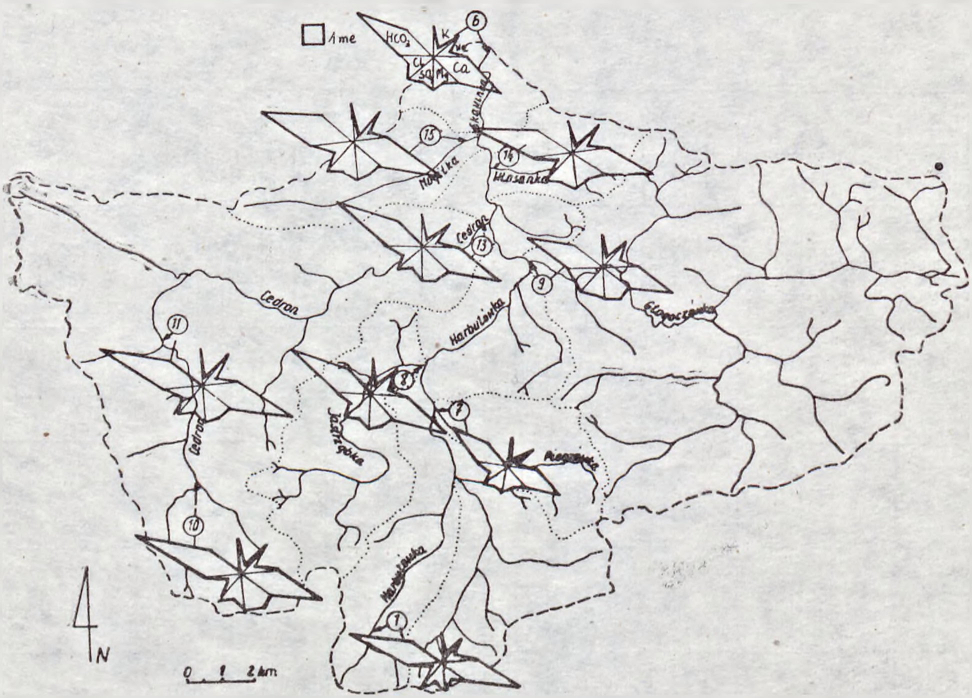

Fig. 2. Ionic composition of waters in the Skawinka basin at selected sampling stations

An increasing tendency was shown by the content of chlorides along the river course ($11.6 \leqslant \bar{x} \leqslant 29.0$ mg Cl dm^{-3}). In general, a higher concentration level occurred in the waters of the tributaries ($18.5 \leqslant \bar{x} \leqslant 32.6$ mg Cl dm^{-3}), particularly in the Głogoczówka and Cedron streams below Kalwaria Zebrzydowska.

The concentrations of sulphates varied from 12.3—69.5 mg dm^{-3}. Distinctly higher values ($\bar{x} \geqslant 47$ mg dm^{-3}) were noted at the stations in the lower part of the basin.

Increasing mineralization of waters, illustrated by the values of dry residue and dissolved parts, was observed along the river course. A similar increasing tendency was noted in the content of readily oxidizable organic compounds. The values of BOD_5 and oxidability of the water in the Skawinka basin were rather low (BOD_5 $1.8 \leqslant \bar{x} \leqslant 3.3$ mg O_2 dm^{-3}; oxidability $2.0 \leqslant \bar{x} \leqslant 4.0$ mg O_2 dm^{-3}), being characteristic for pure or slightly polluted waters. A distinctly larger content of organic pollution was noted in the Cedron stream at Station 11. Owing to the intensive process of self-purification the quality of the water decidedly improved in the lower course of this stream (fig. 3). However, in the mouth sector of the Cedron the quality of water was poorer than in the

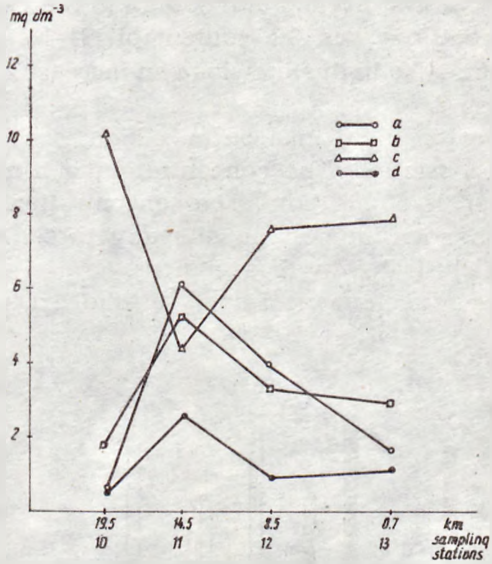

Fig. 3. The process of self-purification of waters along the course of the Cedron stream. a — BOD_5; b — oxidability; c — dissolved oxygen; d — $N—NH_4$

Skawinka. A similarly negative character of changes in the quality of the water was observed in the Skawinka at Stations 2 and 3 below the inflow of municipal wastes from Sułkowice (Table I). In the last case the values of BOD_5 and oxidability were lower, this indicating the weaker effect of wastes from Sułkowice on the waters of the Skawinka than that of sewage from Kalwaria Zebrzydowska on the waters of the Cedron stream.

The mean values of water colour varied from 11—29 mg Pt dm^{-3}, the higher ones being noted in the lower part of the basin. The waters of the Skawinka basin were characterized by a large content of dissolved oxygen ($7.5 \leqslant \bar{x} \leqslant 11.3$ mg dm^{-3}). In general the level of O_2 content was higher in the Skawinka than in the affluents (Table I). As might be expected, the lowest value of O_2 was found in the Cedron stream (Station 11), particularly during campaigns in the Fruit and Vegetable Processing Plant. The process of self-purification accounted for an increase in the O_2 content at the successive stations along the course of this stream (fig. 3). High oxygen saturation ($87 \leqslant \bar{x} \leqslant 108\%$) was noted in the water of the Skawinka basin with the exception of Station 11 ($\bar{x} = 67\%$). In general, the level of oxygenation was higher in the Skawinka than in the mouth sector of its affluents.

Mineral nutrients occurred in rather small quantities. In the whole basin the average concentration of $N—NH_4$ varied from $0.12 \leqslant \bar{x} \leqslant 0.41$ mg dm^{-3}, $N—NO_2$ $\bar{x} \leqslant 0.025$ mg dm^{-3}, $N—NO_3$ $0.16 \leqslant \bar{x} \leqslant 1.31$ mg dm^{-3}, and PO_4 $0.05 \leqslant x \leqslant 0.14$ mg dm^{-3}. Only in the Cedron stream from Station 11 to the outflow was the content of N—NH_4 (fig. 3) and PO_4 several times higher. Also in the Skawinka an increase in N—NH_4 content was found at Station 2.

In the waters of the Skawinka basin a high level of pollution with heavy metals was observed. The concentration of zinc was 18—466 μg dm^{-3} and of copper 0—80 μg dm^{-3}. The concentrations of ether extract, detergents, and phenols did not indicate any threat for water quality from the pollution illustrated by these indices.

The results of physico-chemical analyses showed a distinct negative

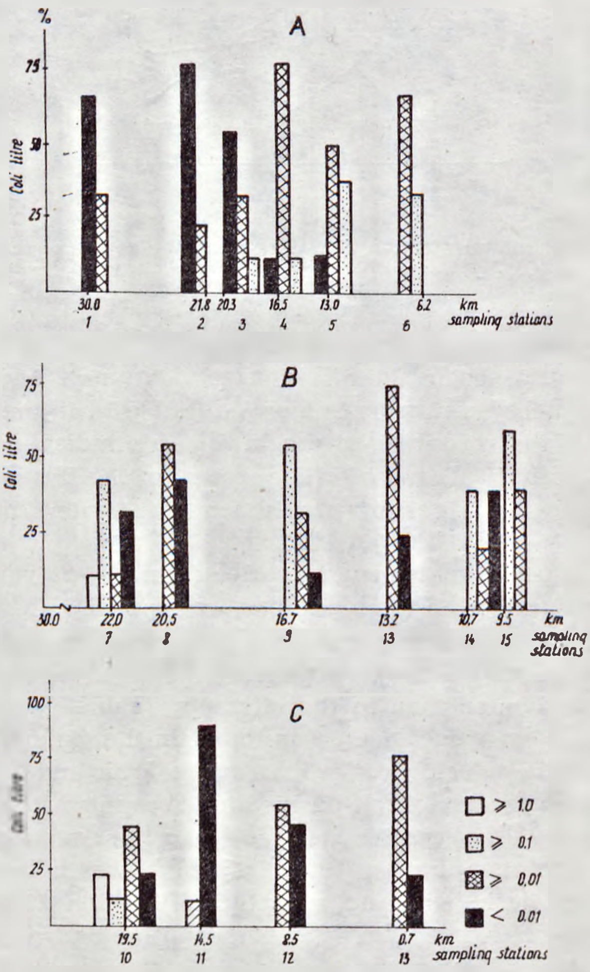

Fig. 4. Coli titre along the course of the Skawinka (A), in the mouth sectors of affluents (B), along the course of the Cedron stream (C). Explanation to the axis of ordinates in the text

effect of PP localized in the area of Kalwaria Zebrzydowska and Sułkowice. Bacteriological analyses fully confirmed this observation and yielded supplementary information concerning the effect of DP, since bacteriological pollution was much more pronounced in the upper part of the basin where numerous farmsteads lay along the running waters, i.e. in the spring sector of the Skawinka and at the outflow of the Piegzówka and Jastrząbka streams. Figure 4 presents the value of the coli titre at the particular stations. The numbers of analytical results corresponding to the value of the coli titre are expressed as percentages. In the spring sector of the Skawinka (Station 1) in most analyses *Escherichia coli* bacteria occurred in the $\leq$ 0.01 cm^3 water samples. Below Sułkowice (Station 2) bacteriological pollution increased owing to the inflow of municipal-domestic wastes. From Station 3 the quality of the Skawinka waters gradually improved (fig. 4). Among the affluents the greatest biological pollution successively occurred in the Jastrząbka, Cedron, and Piegzówka streams. In the case of the Cedron the inflow of municipal-domestic wastes from Kalwaria Zebrzydowska was decisive for the value of the coli titre; the Jastrząbka and Piegzówka received the same type of wastes but from DP.

4.2. Effect of pollution on water quality

The type of land use and particularly the occurrence of several sources of point pollution in the upper part of the basin (Sułkowice and Kalwaria Zebrzydowska) affected the quality of the Skawinka waters in periods of low water level. Also the relief of the area and the concentration of homesteads in the narrow valleys of streams, associated with improper sewage management, led to an observable effect of diffuse pollution on the waters of the basin. This was particularly manifested in the basins of the Piegzówka and Jastrząbka streams and in the spring sector of the Cedron and Skawinka. The effect of sewage, chiefly of the municipal-domestic type from point and diffuse sources, was illustrated by the following parameters: chlorides, sulphates, $N—NH_4$, PO_4, colour, dissolved oxygen, and coli titre.

It was found that the quality of the Skawinka waters was distinctly poorer in the upper course of the river than that of its affluents. The deterioration of water quality with regard to the content of $N—NH_4$, Cl, PO_4, and BOD_5 was brought about by the inflow of municipal wastes from Sułkowice. Owing to intensive self-purification processes and the inflow of waters from the Gościbia, Piegzówka, and Jastrząbka streams, the quality of the Skawinka waters gradually improved. However, in the lower part of the basin a reverse phenomenon was observed. The inflow of waters of the Cedron stream accounted for a renewed deterioration of quality in the Skawinka. The waters of this river were also affected by DP from the village of Radziszów.

Of the affluents of the Skawinka the Cedron stream showed the highest level of pollution, owing to the strong effect of municipal sewage from Kalwaria Zebrzydowska. In spite of the fact that the conditions of this stream were favourable for the process of self-purification its waters did not regain the purity observed in the upper sector, particularly in the case of PO_4 and $N—NH_4$ concentrations and the coli titre. An additional source of pollution of the Cedron was DP from the village of Wola Radziszowska, situated along its mouth sector. Therefore, it was estimated that in the Cedron stream, whose waters constituted 30—50% of water flow in the Skawinka in periods of low water level, the level of pollution was higher than in the recipient river.

The waters of the Piegzówka (Station 7), Głogoczówka (Station 9), Włosanka (Station 14), and Mogiłka (Station 15) streams at their ourflow to the Skawinka showed an insignificant level of pollution. The few sources of PP occurring in the basins of these streams are located in their upper parts. The high efficiency of self-purification processes eliminated the unfavourable effect of both PP and DP.

5. Discussion

With regard to physical and chemical properties the quality of water in the Skawinka basin shows traits characteristic for other right-side tributaries of the Upper Vistula, namely the Rivers Soła, Skawa, and Raba.

The great amplitude of variation of the temperature suggests that the waters of the Skawinka are rapidly warmed in summer. This is favoured by good transparency of the waters which contain only small amounts of suspension during periods of low water level. Also the slightly alkaline reaction (pH 7.0—8.5) is characteristic for waters of the neighbouring catchment areas — the Rivers Soła, Skawa, and Raba (Bombówna 1960, 1969, 1976, Maultz 1972).

The ion-equivalent composition shows that the waters of the Skawinka are of calcium-carbonate type, i.e., typical for rivers of the temperature zone (Alekin 1956). The percentage participation of ions chiefly depends upon the geological substratum and the soil cover in the basin (Starmach et al. 1976). The fact that the basins of the Skawa (Bombówna 1976) and the Skawinka are composed of rocks of the Carpathian Flysch accounts for the general similarity of the ion-equivalent composition of their waters.

The content of chlorides and sulphates slightly exceeded the values given for the River Soła (Bombówna 1960) and many times those reported by Stangenberg (1958) as characteristic for pure waters.

Higher concentrations of these ions in the waters of the Skawinka were chiefly brought by the influence of municipal-domestic sewage. An increase in the content of SO_4 along the river course is characteristic for rivers of the Western Carpathians (Maultz 1972).

In spite of the inflow of wastes the generally low content of organic matter, illustrated by BOD_5, oxidability, and the colour of the water, suggests intensive processes of self-purification in the Skawinka basin. This trait is typical for catchment areas of the Rivers Soła, Skawa, and Raba (Bombówna 1960, 1969, 1976). Apart from other factors described above, the processes of self-purification are favoured by the high oxygenation of waters in the Skawinka basin, characteristic for Carpathian rivers (Maultz 1972).

The effect of sewage, chiefly of the municipal-domestic type, was reflected in the content of nutrients. Compared with pure (at the time of the investigations carried out by Bombówna and Maultz) Carpathian rivers, higher concentrations of $N—NH_4$ and PO_4 were noted in the Skawinka basin, particularly at stations below Kalwaria Zebrzydowska and Sułkowice. In general, the concentrations of $N—NO_2$ were low and corresponded with the level found in the Rivers Soła, Skawa, and Raba (Bombówna 1960, 1969, 1976). In the case of $N—NO_3$, which occurred at lower concentrations, the situation was different. Maultz (1972) reported a high content of this compound in the Carpathian rivers and found that in the Soła and Skawa its concentration frequently exceeded 2.5 mg dm^{-3}. According to Bombówna (1960), the content of $N—NO_3$ in the River Raba usually exceeded 1.0 mg dm^{-3}. In the Skawinka the mean concentration for all stations was 0.59 mg $N—NO_3$ dm^{-3}. It is suggested that the hydrologic-meteorological conditions in the period of the study above all account for the smaller NO_3 content found in the water of the Skawinka basin. They prevented the effect of surface run-off pollution, rich in this constituent (soil leaching). Increased concentrations of NO_3 are observed in running waters of the Carpathian Plateau in periods of high water level. Similarly as in montane rivers, seasonal changes in the content of this constituent were observed. In this case they were chiefly brought about by the assimilation of NO_3 by periphyton algae (Czernoch, unpublished data) settled on the stony bottom in large numbers.

The content of zinc and copper was alarmingly large. The mean concentration of Zn in the Skawinka basin was 155 μg dm^{-3}, while in an investigation carried out in 1984 it was 137 μg dm^{-3} in the lower course of the River Soła and 103 μg dm^{-3} in the Skawa (Stachowicz, unpublished data). Much greater differences were found in determinations of copper content. In the Soła at a station below Oświęcim the mean concentration of Cu was 74 μg dm^{-3}, in the Skawa at Graboszyce 53 μg dm^{-3}, and in the Skawinka 9 μg dm^{-3} (Stachowicz, unpublished data). M o o r e and R a m a m o o r t h y (1984) reported that in unpolluted waters the level of zinc varied from 0.5—15 μg dm^{-3} and of copper 0.5—1.0 μg dm^{-3}. Large amounts of these metals are transported with precipitation waters. On the basis of numerous data from the literature the latter authors postulate that the spatial inflow of zinc transported in atmospheric air may amount to over 50% of the content of this metal found in surface waters. The quality of wastes fed to the Skawinka basin cannot account for such high concentrations of these elements, particularly of Zn. It is suggested that the investigated heavy metals also penetrate to waters of the Skawinka basin through atmospheric air and chiefly originate from the regions of Upper Silesia and Kraków.

6. Polish summary

Jakość wody w dorzeczu rzeki Skawinki (Polska Południowa) w okresach stanów niskich

W pracy przedstawiono charakterystykę fizyczno-geograficzną zlewni Skawinki oraz opisano te czynniki środowiska, które w decydujący sposób wpływają na jakość wód: zagrożenie ze strony zanieczyszczeń punktowych (PP) i zanieczyszczeń rozproszonych (DP) oraz warunki do przebiegu procesu samooczyszczania się wód.

Badania jakości wody prowadzono na 15 stanowiskach w dorzeczu, z których 6 zlokalizowanych było wzdłuż biegu Skawinki, 6 — w odcinkach przyujściowych większych dopływów Skawinki: potoki Piegzówka, Jastrząbka, Głogoczówka, Cedron, Włosanka i Mogiłka. Ze względu na dużą ilość zanieczyszczeń odprowadzanych do Cedronu, jakość wody w tym potoku analizowano na 3 stanowiskach (ryc. 1).

W tabeli I przedstawiono zakresy stężeń oraz wartości średnie 27 parametrów fizykochemicznych jakości wody. Szczególnie silne pogorszenie jakości wód w dorzeczu stwierdzono na stanowisku 11 poniżej dopływu ścieków miejskich z Kalwarii Zebrzydowskiej (230 kg BZT_5 d^{-1}) oraz na stanowisku 2 poniżej Sułkowic (71 kg BZT_5 d^{-1}). Skład jonorównoważnikowy wody w dorzeczu był mało zróżnicowany (ryc. 2). Największą sumę makroelementów notowano w Cedronie na stanowisku 11, poniżej dopływu ścieków z Kalwarii Zebrzydowskiej. Efekt procesu samooczyszczania się wód tego potoku obrazowany z pomocą BZT_5, utlenialności, N—NH_4 i O_2 rozpuszczonego przedstawiono na ryc. 3. Stwierdzono ogólnie wysoki poziom zanieczyszczenia bakteriologicznego wód w dorzeczu Skawinki (ryc. 4), spowodowany głównie negatywnym oddziaływaniem ścieków o charakterze bytowo-gospodarczym, pochodzących z PP i DP.

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