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ASSESSING THE RISK OF CORROSION OF ASBESTOS-CEMENT PIPES IN KRAKÓW'S WATER SUPPLY NETWORK

The water supply network in Kraków, Poland, originally included approximately 40 km of asbestos-cement pipes, which are gradually being replaced due to intensive failure of joints as well as pressure from the general public. At this time, however, most asbestos-cement pipes remain in use, and the concentration of asbestos fibres in the water being distributed is of concern. To investigate this, the corrosivity of water produced by four water treatment plants supplying the urban area of Kraków has been evaluated based on monthly records of physical and chemical parameters of water quality, which were provided by the local waterworks company. These records span a 4 year period, from January 1998 to December 2001. The American Water Works Association Aggressive Index (AI) has been calculated for water produced by each treatment plant, and indicates that all of the water is stable in respect of the cement matrix of asbestos-cement pipes. This conclusion was strengthened by the measurement of asbestos concentrations in water samples from Kraków's water supply network itself. Results show concentrations at various locations to consistently be an order of magnitude below the US Environmental Protection Agency (US EPA) standard.

1. INTRODUCTION

Currently, there are health concerns in Kraków, Poland, over the concentration of asbestos fibres in drinking water, as just under 40 km of asbestos-cement pipes remain in the water supply system, which represents about 2–3% (by length) of the total distribution network. At present, waterborne asbestos fibres are not believed to be carcinogenic when ingested, although their high concentration may cause gastrointestinal ulcers or polyps. There are, however, many ways for waterborne asbestos fibres to become airborne and enter the respiratory system – such as showering, dishwashing, and laundry – and the carcinogenic impact of these fibres on human lungs is unques-

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tionable. The European Community and World Health Organisation have yet to formally address these concerns by setting limits on the concentration of asbestos fibres in the water supply, meaning Kraków is not required by legislation to take action on this issue. The United States Environmental Protection Agency (US EPA), however, has set a limit of 7 million fibres (longer than 10 μm) per litre, which this paper will regard as the standard for safe drinking water.

Kraków's asbestos-cement pipes are already being replaced, due mostly to public pressure, but also to modernisation, as there is a low reliability of connections between these pipes. Furthermore, it has been proved [2], [3], [4] that waters produced by Kraków's treatment plants are stable and of low corrosivity, so there is low risk that asbestos from these pipes would enter into the water flow. The goal of this study was to ascertain whether the remaining asbestos-cement pipes do in fact pose a threat to Kraków's public health. It did so by evaluating the corrosivity of water supplied to the distribution network, and determining whether it is likely to be causing asbestos-cement pipes to deteriorate and deposit asbestos into the water supply stream. The likelihood was corroborated by sampling water in the distribution network for actual asbestos concentrations.

2. WATER PROPERTIES

Kraków is supplied with fresh water from several surface intakes. The Dobczyce Reservoir on the Raba River provides about 50% of the water, while a small collection of other regional rivers – Rudawa, Dłubnia, and Sanka (Bielany intake) – provide the rest. The Raba River flows through granite rock and a calcium poor soil basin in its upper reaches, causing its waters to have lower total alkalinity and higher corrosivity than those of the other rivers, which are well buffered by the calcium rich clay through which they flow. The water taken from each of the sources is treated individually, and after coagulation all finished water from each of the treatment plants is stabilized with respect to calcium carbonate, if necessary. The range of physical-chemical parameters measured in the preliminary evaluation of the finished water's corrosivity towards iron, cast iron, and concrete are summarized in table 1.

The stability of waters with respect to calcium carbonate was evaluated elsewhere, [2], by calculating the Langelier Saturation Index [6] both with [4] and without [2] the inclusion of the ion pair effect. The results of these previous studies showed the waters to be stable.

As a preliminary evaluation, the parameters presented in table 1 were compared to a selection of corrosivity standards, [9], [11], [13]. All of the finished waters, except those from the Dobczyce Reservoir, may be classified as non-corrosive towards iron and cast iron. Table 1 shows small concentrations of aggressive carbon dioxide, but our analysis of stability was based on the Langelier Saturation Index [2] and standard analytical methods [12] much more reliable than those used for predicting CO_2 aggressiveness.

Table 1

Range of physical-chemical parameters and average values of finished water produced by each intake for the period 1998–2001 – based on data provided by the local waterworks company

Parameter	Dobczyce (Raba River)	Rudawa	Dłubnia	Bielany (Sanka River)
Temperature [°C]				
average/st. dev.	10.87/5.23	13.03/4.51	8.91/3.27	11.15/4.60
range	2.49–19.65	5.56–19.95	3.53 – 14.08	4.00–17.96
pH				
range	7.57–8.20	7.47–8.02	7.43 – 8.04	7.24–7.92
Total alkalinity [mval/dm^3]				
average/st. dev.	2.14/0.16	4.23/0.22	5.05/0.20	3.84/0.12
range	1.73–2.38	3.71–4.59	4.62 – 5.59	3.53–4.11
Calcium [g/m^3]				
average/st. dev.	36.74/3.03	94.78/6.45	96.12/3.60	88.82/3.19
range	31.26–46.77	81.18–106.23	86.51 – 104.88	80.89–94.76
Free CO_2 [g/m^3]				
average/st. dev.	1.97/0.89	6.51/2.53	9.86/3.65	8.53/1.59
range	0.62–5.02	2.52–13.97	5.10 – 24.33	5.10–12.47
Aggressive CO_2 [g/m^3]				
average/st. dev.	0.44/0.52	0/0	0.12/0.42	0.07/0.16
range	0.0–2.13	0.0–0.0	0.0 – 2.65	0.0–0.74
TDS [g/m^3]				
average/st. dev.	137.7/12.95	302.6/37.8	245.4/20.7	330.1/19.6
range	111.5–163.8	162.5–468.5	190.5 – 295.3	292.5–395.0
Conductivity [µS/cm]				
average/st. dev.	267.7/35.06	604/42.7	483.1/41.1	660.2/39.3
range	144.2–322.5	507.5–668	379.0 – 541.5	585.0–790.0

3. AGGRESSIVE INDEX

The American Water Works Association (AWWA) developed the Aggressive Index (AI) specifically for the evaluation of corrosive properties of water on asbestos-cement pipes [11], the formulation for which is shown in equation (1):

$$AI = pH_a + \log_{10}([Alk_T][Ca]) + f(TDS,T). \quad (1)$$

The AI is typically a function of actual pH, pH_a, total alkalinity, $[Alk_T]$, and calcium hardness, [Ca], but the evaluation also compensates for differences in the ionic strength and temperature of the water, which is expressed as a function of total dissolved solids and temperature, f(TDS,T).

According to the AWWA, water is recognized to be non-aggressive for AI > 12, slightly aggressive for 12 > AI > 10, and strongly aggressive for AI < 10. The values of AI for all finished waters are presented in figures 1–4. The results show that all of the finished waters have AI values above the limit of 12, except those from the Dobczyce Reservoir which has some values slightly below 12. Therefore, the finished waters supplying Kraków are generally non-corrosive towards asbestos-cement pipes – but not without minor lapses – and so it is unlikely that much asbestos is leaving the pipe walls and entering the water stream.

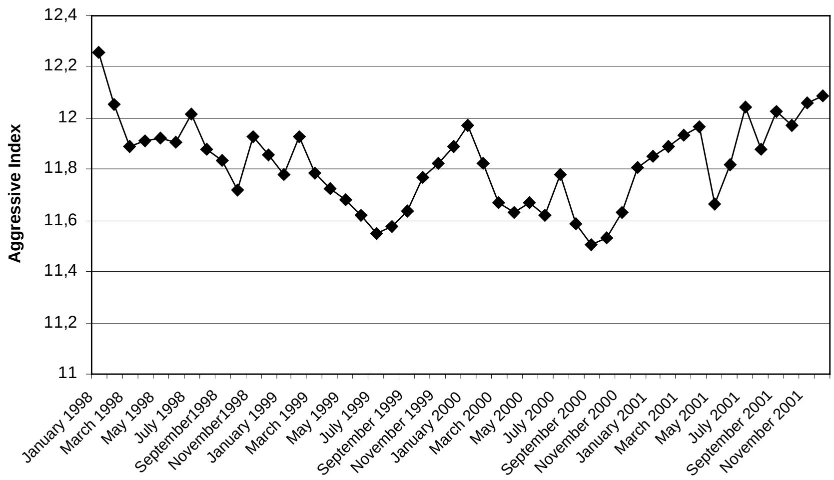

Fig. 1. Aggressive Indices calculated for finished water produced by the Dobczyce Reservoir WTP – based on data provided by the local waterworks company

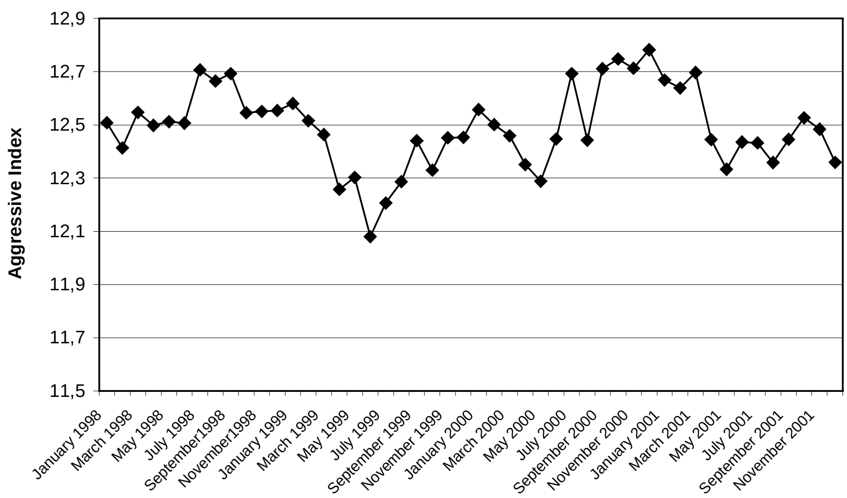

Fig. 2. Aggressive Indices calculated for finished water produced by the Rudawa River WTP – based on data provided by the local waterworks company

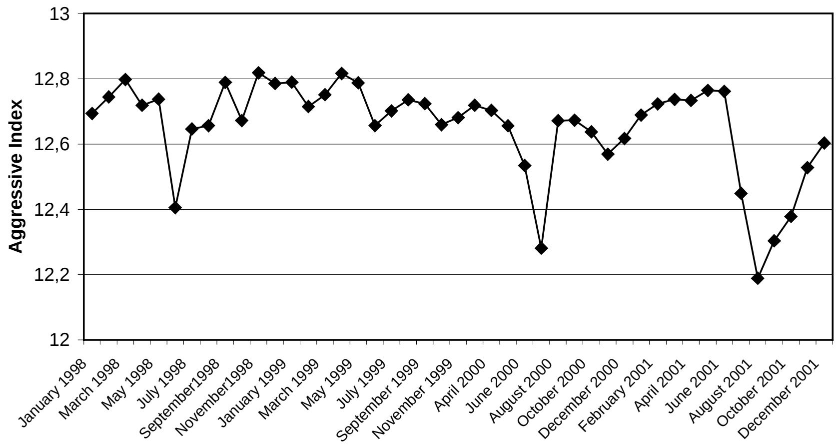

Fig. 3. Aggressive Indices calculated for finished water produced by the Dłubnia Reservoir WTP – based on data provided by the local waterworks company

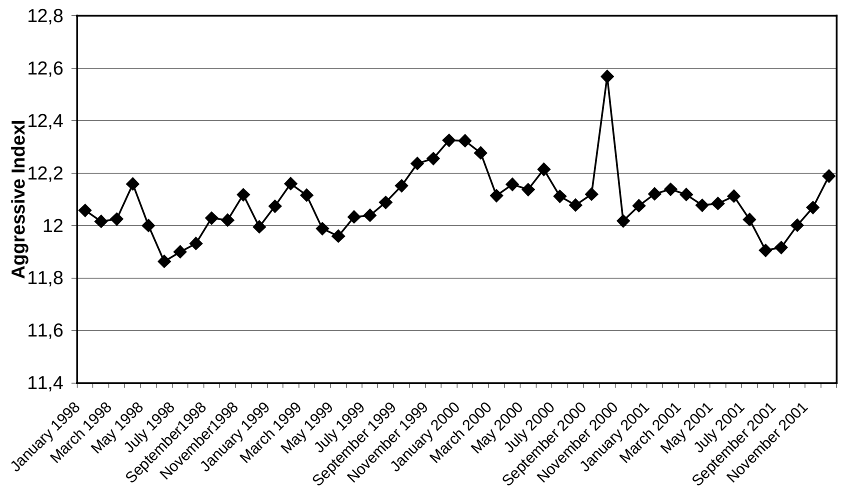

Fig. 4. Aggressive Indices calculated for finished water produced by the Bielany WTP (the Sanka River) – based on data provided by the local waterworks company

4. SAMPLING AND MEASUREMENTS

To corroborate the prediction that the pipes were not releasing asbestos into the water stream, water samples were collected at seven locations around Kraków. The sampling points were chosen according to where the waterworks company reported asbestos pipes to be located and used, and are shown in figure 5. All samples were collected between the hours of 8 am and 9 am, so as to hopefully sample water that had sat in the asbestos-cement sections of pipe overnight. For each sample, asbestos fibres were measured using a Thom cell and high quality optical microscope. The limit of detection for the microscope was slightly above 0.5 μm, which was very well suited to the purpose of our measurements. For a detailed description of the methodology for counting asbestos fibres, please see [6] and [9].

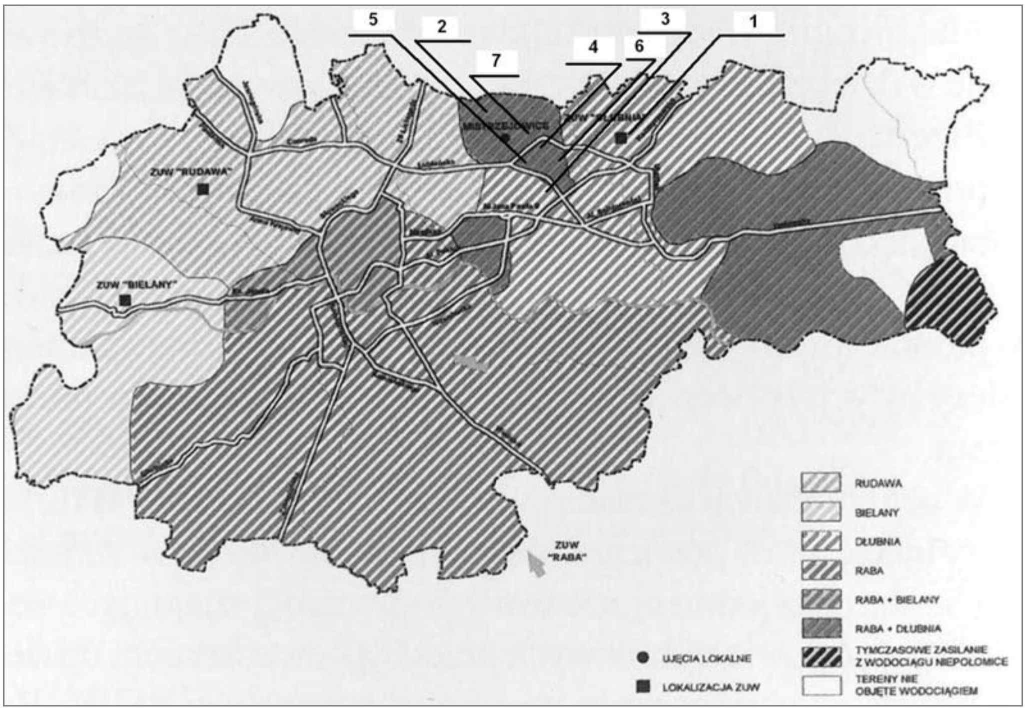

Fig. 5. Sampling points (numbered 1 through 7) and water supply zones by intake
(based on the data published by the local waterworks company [13])

5. RESULTS

All fibres of length above and below 10 μm were counted, and the corresponding concentrations calculated. The results of these measurements are presented in table 2. The highest concentration of asbestos fibres longer than 10 μm was 840,000 per litre, a mere 12% of the US EPA standard. It can thus be concluded that the presence of asbestos-cement pipes in Kraków's water supply network does not create a discernable risk for consumers.

Table 2

Results of asbestos fibre measurements in different locations around Kraków

ID No. on map in fig. 5	No. of samples	Meas. per sample	Avg. number of fibers [thousands/dm^3]		Standard deviation	
			>10 μm	<10 μm	>10 μm	<10 μm
1 (Architektów St.)	3	5	120	320	20014	7500
2 (Powstańców St.)	3	5	110	400	12520	6020
3 (Albertyńskie)	3	5	90	600	14023	40320
4 (Kalinowe)	3	5	70	200	17243	3700
5 (Strusia)	3	5	840	5200	9645	322530
6 (Wysokie)	3	5	750	4200	60553	210470
7 (Kombatantów)	3	5	550	3200	110326	241050

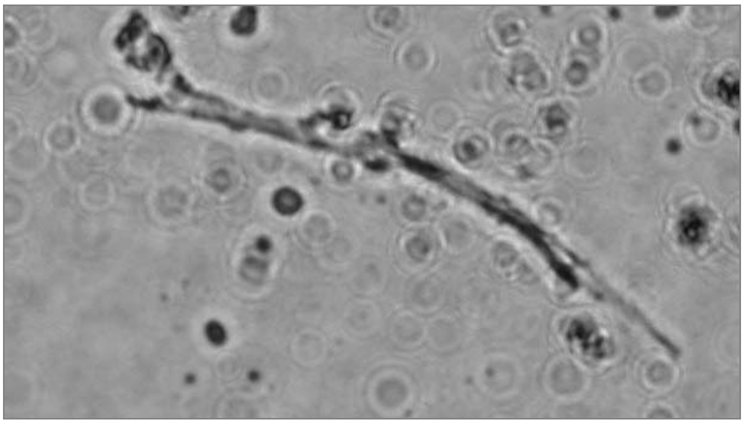

Photo 1. A standard asbestos fibre with characteristically sharp edges in one of the samples

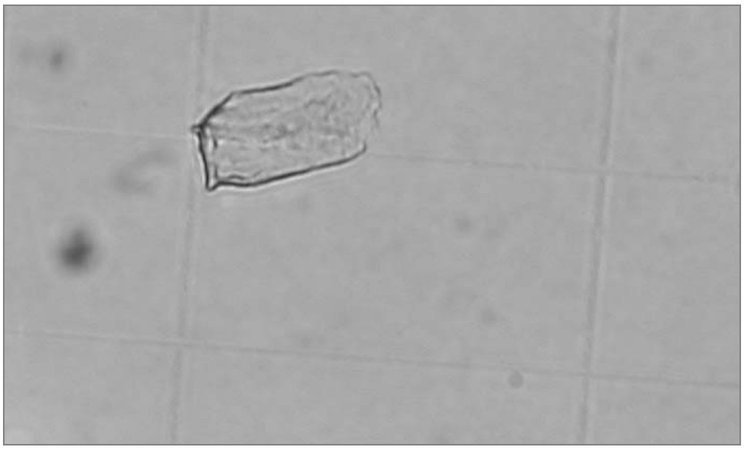

Photo 2. A fibre of unknown origin in one of the samples

Furthermore, it should also be noted that at times it was difficult to determine the origin of fibres longer than 10 µm; some exhibited the characteristically sharp edges of asbestos, while others did not. A standard asbestos fibre with characteristically sharp edges is presented in photograph 1, and a fibre of unknown origin is presented in photograph 2.

All fibres over 10 µm were counted and included in the results, while not all of them were necessarily asbestos. As such the results calculated and presented in table 2 should be recognized as upper bounds, and the real concentration of asbestos in Kraków's water supply network is likely to be an extremely small fraction of the US EPA standard.

There was also the possibility that asbestos fibres entered the water supply network before coming into contact with the asbestos-cement sections of pipe. To investigate the effect of this possibility on results, finished water samples were collected from each of the water treatment plants and their asbestos concentrations were measured. The results of these measurements are presented in table 3.

Table 3

Concentrations of fibres detected in finished water samples collected from intakes supplying the distribution system

Water treatment plant	No. of samples	Meas. per sample	Average number of fibres [thousands/dm^3]		Standard deviation	
			>10 µm	<10 µm	>10 µm	<10 µm
Dobczyce (the Raba River)	1	10	4	5600	800	22401
Rudawa	1	10	25	250	5000	40337
Dłubnia	1	10	40	2000	7000	32499
Bielany (the Sanka River)	1	10	0	4400	0	40053

Very few fibres longer than 10 µm were detected and their concentrations were several times lower than the already small concentrations measured at points throughout the water supply system. As with the samples from the distribution system, these results included fibres that were not necessarily asbestos. These results tend to indicate that asbestos fibres present in the municipal water supply largely originate from places within the water distribution network, not finished waters from treatment plants.

6. CONCLUSIONS

The waters produced by the treatment plants supplying Kraków with drinking water can be generally characterised as having Aggressive Index (AI) values above

12. The largest water intake from the Raba River and the smallest intake from the Sanka River sometimes delivered finished water with an AI value very slightly below 12. AI values greater than 12 indicate non-aggressive waters in respect of asbestos-cement pipes, so finished waters entering Kraków's distribution system are largely non-corrosive. Previous evaluations have come to the same conclusion with respect to corrosivity towards iron and cast iron [2], [3], [4]. Our observations of iron and cast iron water mains aged 30 years and older confirm low losses of material due to corrosion. It can be safely concluded that finished water from Kraków's water treatment plants will not corrode asbestos-cement pipes in the distribution system nor create unacceptably high concentrations of asbestos in the municipal water supply.

This conclusion has been corroborated by the measurement of actual asbestos concentrations in sections of the water distribution network that are known to have asbestos-cement pipes. The highest sampled concentration of asbestos fibres longer than 10 μm was 840,000 per litre, 12% of the US EPA standard. Furthermore, the sampling method assumed all fibres longer than 10 μm were asbestos, meaning that the real asbestos concentration is even lower. Asbestos concentrations in finished waters from treatment plants were several times lower than in the distribution network, indicating that, though few, asbestos fibres in the water supply are picked up in the distribution network. It can be concluded that waterborne asbestos does not present a discernable risk to inhabitants of Kraków.

REFERENCES

[1] BENEFIELD L.D., JUDKINS J.F., WEAND B.L., *Process chemistry for water and wastewater treatment*, Prentice-Hall, Inc. Englewoods Cliffs, New Jersey, 1982.

[2] DĄBROWSKI W., BUCHTA R., MACKIE R.I., *Impact of water blending on calcium carbonate equilibrium in water distribution systems – technical note*, Environmental Engineering Journal, ASCE, 2004.

[3] DĄBROWSKI W., ZIELINA M., KANIEWSKI J., GAJEWSKI A., *Difference between buffer capacities of water flowing through land of various geological origin*, XXI Congresso Nazionale di Merceologia con partecipazione internazionale, Fioggia, September 22–24, 2004, WIP Edizioni, Bari, 2005, Vol. 1.

[4] DĄBROWSKI W., BUCHTA R., *Statistical evaluation of calcium carbonate equilibrium in natural water*, Lakes & Reservoirs: Research and Management, 2000, 5, 99–104.

[5] EPA Method number 100.2. *Determination of asbestos structures over 10 micrometers in length in drinking water.*

[6] LANGELIER W.F., *The analytical control of anti-corrosion water treatment*, Journal AWWA, 1936, 28(10), 1500.

[7] PANKOW J.E., *Aquatic Chemistry Concepts*, Lewis Publishers, Michigan, 1991.

[8] PISIGAN R.A., SINGLEY J.E., *Calculating the pH of calcium carbonate saturation*, Journal AWWA, October 1985.

[9] ROQUES H., *Chemical Water Treatment – Principles and Practice*, VCH Publishers Inc., New York–Weinheim–Cambridge, 1996.

[10] BUZIO S., PESANDO G., ZUPPI G., *Hydrological study on the presence of asbestos fibres in water of northern Italy*, Water Research, 2000, Vol. 34, No. 6, 1817–1822.
[11] STUMM W., *Investigation on the corrosive behavior of waters*, Journal of the Sanitary Engr. Div. Proc. ASCE, 1960, 86(SA 6).
[12] STUMM W., MORGAN J.J., *Aquatic chemistry*, 2nd edition, Wiley, New York, 1981.
[13] WIERZBICKI R., *Water supply system in Krakow*, 2001, Municipal Water and Sewage Company in Krakow (in Polish).

KOROZYJNOŚĆ WÓD ORAZ STĘŻENIA WŁÓKIEN AZBESTU W SIECI DYSTRYBUCJI WODY W KRAKOWIE

Wyznaczono współczynniki korozyjności wód z poszczególnych ujęć zasilających sieć wodociągową Krakowa. Dokonano tego, opierając się na wynikach ciągłego pomiaru fizycznych i chemicznych parametrów jakości wody z okresu pięciu lat dokonywanego w zakładzie wodociągowym. Współczynniki korozyjności wyliczono zgodnie z wytycznymi The American Water Works Association. We wszystkich przypadkach świadczyły one o większej lub mniejszej stabilności wód w odniesieniu do betonu znajdującego się w rurach azbestocementowych. W Krakowie sieć zaopatrzenia w wodę oryginalnie tworzyły rury azbestocementowe o łącznej długości 40 kilometrów. Obecnie, pod naciskiem opinii publicznej oraz w wyniku zorganizowanych akcji, systematycznie wymienia się kolejne odcinki tego typu przewodów. Jednak wiele z nich jest nadal w użyciu, stanowiąc potencjalne źródło włókien azbestu o podwyższonym stężeniu. Na podstawie przeprowadzonych pomiarów wyznaczono stężenia włókien azbestu w wodzie przepływającej przez obszary, gdzie rury azbestocementowe wciąż jeszcze nie zostały usunięte. Uzyskane wartości stężenia azbestu były zdecydowanie niższe od wartości dopuszczanych przez wytyczne Amerykańskiej Agencji Ochrony Środowiska, co może wynikać właśnie z niskiej korozyjności wód.