

Problems with meeting new (10 µg/L) standard for lead in drinking water: Polish perspectives

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ABSTRACT

In the current (2011) edition of 'Guidelines for Drinking-water Quality', the World Health Organization sets the guideline value for the concentration of lead in drinking water at 10 µg/L. This value, however, is a provisional one on the basis of treatment performance and analytical achievability. It is extremely difficult to achieve lower concentrations by central conditioning, such as phosphate dosing. Council Directive 98/83/EC of 3 November 1998 on the quality of water intended for human consumption has set 10 µg/L as a target parametric value. The parametric value was 25 µg/L until December 2013. In Poland, the 10 µg/L standard came into force on 1 January 2013. A tap survey based on random daytime sampling (RDT) was conducted in 15 water supply zones in Poland. A total of 1440 RDT samples were collected during the period 2007–2012. The survey revealed that on average 8.4% of samples collected show lead concentrations exceeding 10 µg/L. In some water supply zones, the percentage of non-compliant samples reached 60%. This suggests that a substantial number of water companies in Poland will have to undertake significant measures to achieve proper quality standards in water supplied to consumers.

Key words | drinking water, lead, Poland

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INTRODUCTION

Lead is the most common heavy metal, accounting for 13 mg/kg of the Earth's crust. This metal has accompanied man for centuries (Callataj 2005). Due to its characteristic properties such as high density, softness, ductility and malleability and relatively high resistance to corrosion, lead has been widely used in industry.

Until the early 1980s lead service pipes were commonly used in water supply in many countries (Hayes & Skubala 2009; IWA 2010). Lead pipes were also used extensively within buildings but their use was largely superseded by copper piping from the 1950s. It is estimated that in Europe and North America, from <5 to 50% of domestic dwellings contain lead. In the older districts of many cities and towns, the percentage of dwellings with a lead pipe can be much higher, up to around 90% (IWA 2010).

The toxicity of lead has long been recognised, with both acute and chronic effects arising from lead exposure. Lead in drinking water is considered the most bioavailable

source of lead because soluble lead is more readily absorbed in the intestine than lead from dietary sources (Quinn & Sherlock 1990; Fertmann *et al.* 2003; Troesken 2006). The adverse health effects of lead exposure include interference with haem biosynthesis, gastrointestinal irritation, dullness, restlessness, irritability, poor attention span, headaches, muscle tremor, kidney damage, hallucinations, and loss of memory, encephalopathy, hearing impairment (Schwartz & Otto 1991), gonad dysfunction (Assennato *et al.* 1987), violent behaviour, hypertension (Moore 1977; Pocock *et al.* 1994), and reduction in IQ (Tong *et al.* 1996; Canfield *et al.* 2003). Infants and fetuses are the most susceptible groups to adverse health effects as they absorb four to five times more lead than adults and the biological half-life is thought to be considerably longer (Bryce-Smith & Ward 1987; Jones 1989; Chiodo *et al.* 2007).

The World Health Organization issued 'WHO International Standards for Drinking-water' in 1958 (WHO 1958).

It was the first document concerning the quality of water intended for human consumption. On the base of health criteria, WHO recommended a maximum acceptable concentration of lead in drinking water of 100 µg/L. This value was lowered to 50 µg/L in the second edition in 1963 (WHO 1963). The upper concentration limit was decreased further to 10 µg/L in the third edition (WHO 1971). This level was accepted in many countries because such water had been consumed for many years without apparent ill effects and it was difficult to reach a lower level in countries where lead pipes were used.

In the first edition of the 'WHO Guidelines for Drinking-water Quality' (WHO 1984) a health-based guideline value of 50 µg/L was recommended. In the second edition, published in 1993, WHO proposed a health-based value of 10 µg/L (WHO 1993). The guideline value was established on the basis of the provisional tolerable weekly intake (PTWI) calculated by a Joint FAO/WHO Expert Committee on Food Additives (JECFA) for infants and children, as infants are considered to be the most sensitive subgroup of the population. This guideline value was maintained in the third edition (WHO 2004). In its latest edition of 'Guidelines', the concentration of 10 µg/L was proposed as a provisional value (WHO 2011). Because the dose-response analyses do not provide any indication of a threshold for the key effects of lead, JECFA concluded that it was not possible to establish a new PTWI that would be considered to be health protective and it was withdrawn. JECFA reaffirmed that because of the neurodevelopmental effects, fetuses, infants and children are the subgroups that are most sensitive to lead.

The first EU Drinking Water Directive (80/778/EC) set a standard for lead in drinking water of 50 µg/L (EC 1980). Most Member States interpreted the qualification 'in running water' to mean that either the standard applied to the water flowing through the distribution network or it applied to samples taken after flushing from consumer taps. With this approach, very few or no problems with lead in drinking water were identified in these countries.

The 'Council Directive 98/83/EC of 3 November 1998 on the quality of water intended for human consumption' specified an interim parametric value for lead at consumers' taps of 25 µg/L (which should be met by 25 December 2003). It also specified a final parametric value of 10 µg/L. This should come into force from 25 December 2013 (EC 1998).

In Poland, national sanitary regulations followed WHO guidelines. In 1961, the Polish Health Minister specified a standard for lead in drinking water of 100 µg/L. The standard was lowered to 50 µg/L in 1990 and then to 10 µg/L in 2000, but in 2002 the standard value was revised back to 50 µg/L. In this regulation an interim standard of 25 µg/L was set (for the period from 1 January 2006 to 31 December 2012) and a final standard of 10 µg/L (to come into force on 1 January 2013). This was confirmed in the two following regulations issued in 2007 and 2010 which means that Poland is practically one year ahead of all other EC countries in enforcing the 0.01 mg/L standard for lead.

For nearly 10% of Polish water supplies it may be difficult to fulfil this stringent standard. Despite the fact that lead was never commonly used in water supply systems in Poland, there are documented cases of the presence of lead in drinking water with concentrations exceeding 25 µg/L and even 100 µg/L (Postawa & Witczak 2011). Cases with lead concentrations exceeding 10 µg/L in distributed water are much more common. One must remember that if distributed water contains lead in concentrations slightly below 10 µg/L, it should be expected that it may be difficult to meet the lead standard at consumers' taps (Skotak *et al.* 2007). In contact with brass fittings, especially those of poor quality, water can easily be 'enriched' in lead to concentrations above the standard value of 10 µg/L.

The main goal of this study was to assess the magnitude of the lead problem in Poland. The period analysed comprises the years 2007–2012. The results of a tap survey used for the purposes of a part of the study (years 2007–2010) comes from a joint project 'Metals and related substances in drinking water in Poland' which was coordinated by AGH University (Postawa & Witczak 2011). Data for the years 2011 and 2012 were obtained from tap surveys supervised and coordinated by the author.

MATERIALS AND METHODS

Sampling issues

The current EU Drinking Water Directive 98/83/EC states that the parametric value applies to a sample of water intended for human consumption obtained by an adequate

sampling method at the tap and taken so as to be representative of a weekly average value ingested by consumers. The sampling and monitoring methods must be applied in a harmonised fashion and must take account of the occurrence of peak levels that may cause adverse effects on human health (EC 1998). The problem of implementing this note through practical sampling and monitoring schemes has not been solved by the Member States. As a result there are still many different sampling methods used in European countries. The most common are:

- routine spot sampling from selected points considered to be representative of the supply as a whole. Samples are usually taken after prolonged flushing (FF);
- stagnation sampling at selected reference points or using pipe rigs – the sample is taken after a specified contact time with the metal pipe;
- random daytime sampling (RDT) – a dwelling is selected at random and a sample of 1 L is taken from the point of use (kitchen tap) without flushing.

It is not surprising that using different methods we obtain different, not comparable and not reliable, representative results.

Extensive studies conducted in the 1990s proved that in terms of cost, practicality and consumer acceptance the RDT protocol is the most favourable (Van den Hoven *et al.* 1999). In comparison to the results obtained using the proportional composite sampling method, RDT was capable of detecting about 80% of the properties that exceeded the parametric value of 10 µg/L. However, the RDT protocol is not capable of detecting about 20% of non-complying properties. The concentration of metals obtained by using the RDT method cannot be considered capable of providing results representative of the weekly average value for a single consumer. This will vary depending on the composition of the local distribution network and domestic distribution systems. In addition, the reproducibility of RDT is poor. The study concluded that, despite its disadvantages, the RDT protocol is the most practicable and representative method for compliance purposes. RDT is recommended by many scientists and practitioners (Hoekstra *et al.* 2009; IWA 2010).

The present study is based upon 1,440 samples in 15 selected water supply zones located in 13 towns and cities

in Poland. All samples collected for the purposes of this study were collected in the years 2007–2012 using the RDT protocol. Samples of 1 L were taken during the normal working day from randomly selected properties within the water supply zones investigated. The initial selection of sampling points was performed on the basis of a simple orthogonal grid overlaid on a map of the water supply zone investigated. The intention was to collect samples as close to the centre of each grid cell as possible (Figure 1).

Areas investigated

Poland is probably the EU country with the highest number of water supply companies (over 12,000 in 2007). Small water supply companies with a daily production of less than 1,000 m³ dominate the Polish water supply system. The number of water supply companies and the production of drinking water has been systematically decreasing during the last decade due to the reconstruction of the economy, which is a typical situation for East European countries. Groundwater has become the dominant source of drinking water, providing about 70% of the total supply.

A preliminary selection of water supply zones for more detailed investigation was performed on the basis of the results of the national monitoring of drinking water quality in 2007. In Poland this kind of monitoring is coordinated by the State Sanitary Inspection service and is a responsibility of the Chief Sanitary Inspectorate. Data collection and management is the task of the National Institute of Public Health. Compliance with drinking water standards is assessed on the basis of geographical/administrative areas. The results are collected in a database and are aggregated into 16 voivodships (provinces) and 2,479 gminas (communes). Samples for compliance purposes are taken at the points of end use. Sampling points are usually located in public buildings and less often at the properties of individual consumers. All samples are collected using the full flush (FF) procedure.

The following were considered as the main criteria for selection:

- number of consumers in the supply zone exceeding 5,000;

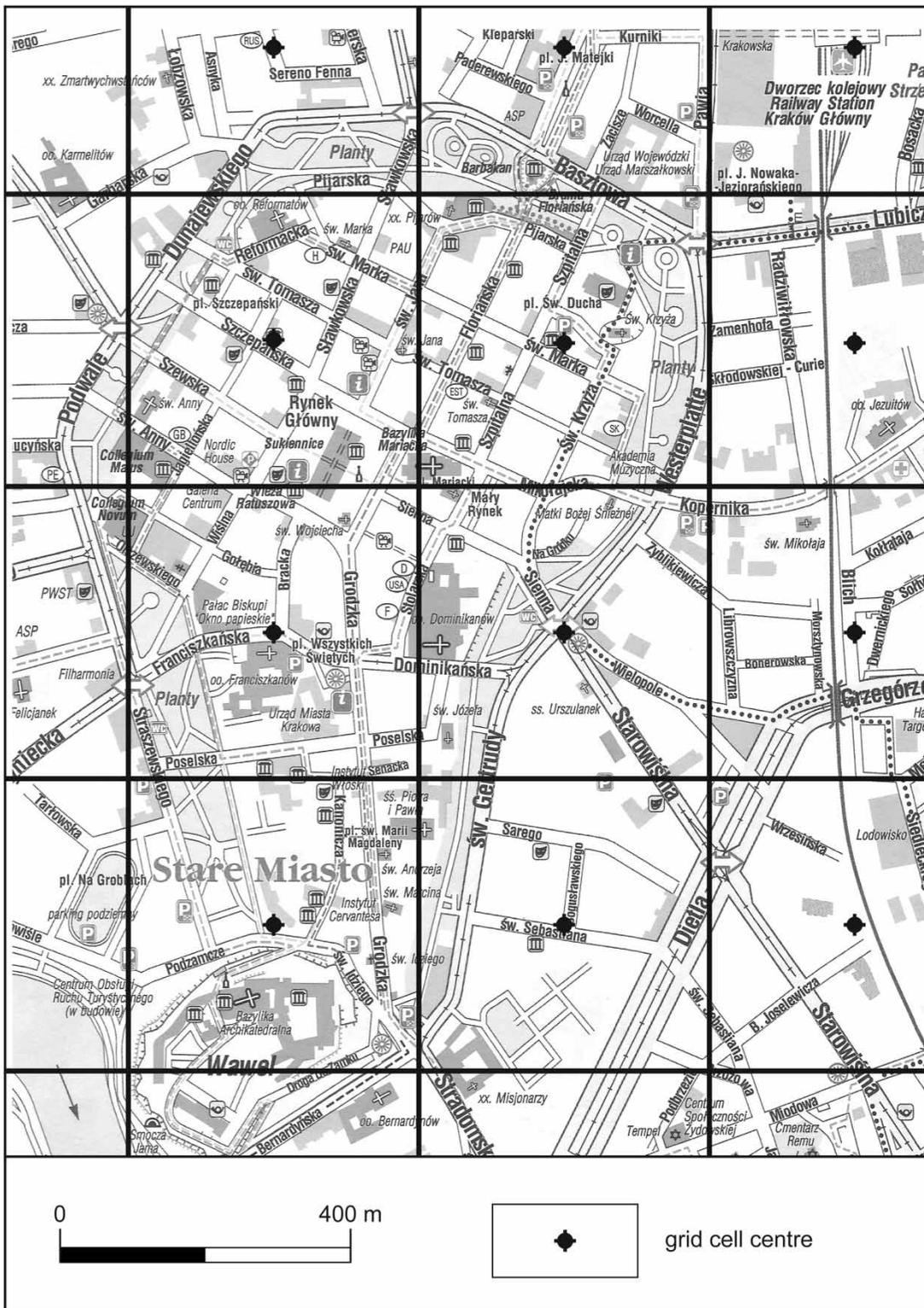


Figure 1 | Schematic construction of sampling grid (Krakow).

- chemical composition of raw water and treated water (presence of lead, high concentrations of iron and/or manganese);
- materials used in the distribution network (reported presence of lead pipes);
- age of buildings and pipework in a water supply zone exceeding 30 years;
- prior problems with high concentrations of metals reported by a sanitary inspection or customers.

The locations of the selected water supply zones are presented in Figure 2. In most cities, groundwater intakes serve as a source of raw water. In one case (Poznan) the zone selected is supplied from an infiltration intake. Two zones are supplied with a mixture of infiltration and surface waters – Warsaw, and infiltration water and groundwater – Nowy Sacz. The materials used in the distribution network are presented in Table 1. Those used most frequently are cast iron, steel and PVC.

In all sampling locations, householders and operators of distribution networks were asked about the materials and age of the pipes used for making domestic pipework, connections to the mains and the mains themselves. Unfortunately there is very limited knowledge of this kind of information amongst householders. Over 55% of them

declare no knowledge of the age of connection pipes or the materials that have been used. There are no official records of the use of lead pipes for mains or connections to them in any of the zones investigated. However, the presence of connecting pipes made of lead was reported by owners or administrators in a few buildings in Krakow, Jaworzno, Choszczno and Raciborz, usually constructed before the Second World War. In all investigated water supplies, at least 50% of the buildings and distribution networks were constructed at least 30 years ago. In some zones (Raciborz, Kamienna Gora) the oldest parts of the distribution networks are more than 100 years old.

Analytical procedures

All the samples investigated were delivered to a laboratory within 24 hours of collection. In the laboratory, samples were divided and a portion of each sample was acidified with nitric acid to pH <2 and then analysed for lead (and other metals). The remaining portion was used for other determinations (alkalinity, chlorides and sulphates).

Chemical analyses were performed by two certified (accredited) laboratories. Samples from Krakow, Jaworzno, Myszkow, Raciborz, Kamienna Gora, Nowy Sacz, Olkusz and Przemysl were analysed by the hydrochemical



Figure 2 | Locations of investigated water supply zones.

Table 1 | Materials used in distribution network in selected cities

City (zone)	Cast iron	Asbestos/		PE	PVC	Unknown
	(%)	Steel	cement			
Choszczno	50 ^a	5 ^a	10 ^a	15 ^a	15 ^a	5
Jaworzno	38	37	–	14	11	–
Kamienna Gora	56	7	29	3	5	–
Krakow	33	17	10	4	37	–
Lidzbark	45	5	20	–	30	–
Myszkow	30	25	3	11	11	–
Nowy Sacz	51	14	–	35	–	–
Olkusz	40 ^a	20 ^a	10 ^a	15 ^a	15 ^a	–
Poznan	55	6	5	10	23	1
Przemysl	50 ^a	5 ^a	10 ^a	10 ^a	15 ^a	5
Raciborz	39	1	3	12	45	–
Szczecin	42	22	3	17	11	5
Warsaw	80	12	5	–	3	–

^aEstimated values.

laboratory at the Faculty of Geology, Geophysics and Environmental Protection, AGH University in Krakow. Samples from Warsaw, Lidzbark, Szczecin, Choszczno and Poznan were analysed by the laboratory of the National Institute of Public Health – National Institute of Hygiene. Both laboratories used ICP-MS spectrometers for the determination of lead content, an Elan 6100 (Perkin–Elmer) in the AGH laboratory; an Xseries II CCT (Thermo Electron Corporation) in NIPH.

In all cases, the limit of determination was lower than 0.001 mg Pb/L, as is required by the drinking water directive 98/83/EC (EC 1998).

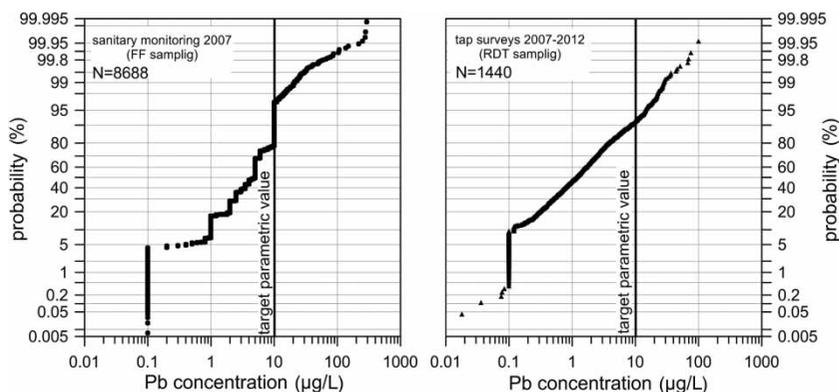
RESULTS AND DISCUSSION

The aggregated results of the tap surveys conducted in the years 2007–2012 revealed that 8.4% of the samples collected showed a lead content exceeding 10 µg/L (Figure 3). However, it should be remembered that averaging unifies and ‘dissolves’ the problem. It reflects the general situation at national level but, in practice, lead problems in some water supply zones are much more serious than in the others.

According to the classification presented in a ‘Best Practice Guide on the Control of Lead in Drinking Water’ (IWA 2010), the presence of 5–10% of non-compliant samples indicates that system-wide measures are required in addition to resolving any localised problems.

The non-compliance ratio obtained as a result of the tap survey is over 2.5 times higher than the results of the Polish national monitoring of drinking water (sanitary monitoring). This may result from the different sampling protocol used (RDT instead of FF) and from the fact that the supply zones for tap surveys were preselected, focusing on locations where lead problems were expected. Nevertheless the situation is far from satisfying since 3.2% of the samples taken using the FF protocol (FF samples) showed lead concentrations exceeding 10 µg/L.

It is to be expected that fully flushed samples, if properly taken, would usually show lower concentrations of lead and other metals, an effect of the very short contact time between the water and the pipes (Van den Hoven *et al.* 1999; IWA 2010, 2012). High concentrations of lead in FF

**Figure 3** | Lead in drinking water in Poland 2007–2012.

samples may indicate that either lead originates from the distribution network or that the samples were not collected properly. Both possibilities are alarming and should be further investigated.

Lead pipes were never a popular material in the water supply industry in Poland. According to official data, presented by the Supreme Audit Office in 2002, the length of lead pipes in use in Polish drinking water distribution systems was only 12 km. This figure is, however, rather unrealistic. There is other information which suggests that lead pipes are present and serve as connection pipes or in internal installations, especially in buildings constructed prior to the Second World War. Lead was also extensively used in Poland during the construction of water mains and distribution networks that were made of cast iron (as sealing in bell and spigot connections). In many cases people tend to save money and buy the cheapest pipes and fittings when constructing or refurbishing water pipes inside buildings and apartments. What is obvious is that the cheap material usually means very low quality. This is especially important with brass fittings since low quality brass constitutes an important source of lead in drinking water. Another

common mistake is the partial replacement of lead pipe-work (if found) or damaged pipework made of other materials, and the mixing of pipes made of different metallic materials (e.g. copper and galvanised iron). Such a situation facilitates galvanic corrosion and may result in accelerated dissolution of corrosion products present inside pipes that were not replaced. The non-compliance ratio in the water supply zones investigated during the tap survey reached from 0 up to 60% (Table 2).

The worst situation was found in Jaworzno. In 60% of RDT samples, the concentration of lead was higher than 10 µg/L and 15% of samples showed lead concentrations exceeding 25 µg/L. The maximum concentration recorded was 100 µg/L. High concentrations of lead were accompanied by high concentrations of iron (up to 2 mg/L) which indicates that the distribution network in this zone is in very poor condition. Corrosion of old cast-iron water mains may cause iron discolouration (red-water). In such cases, the loose iron corrosion deposits can settle within a lead pipe and absorb lead. It is likely that this absorption enhances lead dissolution from the lead corrosion deposit. Any disturbance of the loose deposits can cause elevated

Table 2 | Lead in drinking water in Poland on the base of 2007–2012 tap surveys

City (zone)	Treated water					Tap survey (RDT) Pb >10 µg/L (%)
	pH	Alkalinity (mgCaCO ₃ /l)	Chlorides (mg/L)	Sulphates (mg/L)	Lead (µg/L)	
Choszczno	7.2–7.5	140–160	46–51	51–58	<5–15	9
Jaworzno	7.4–8.0	180–290	39–48	79–94	<5–20	60
Kamienna Gora	6.5–7.2	55–70	10–14	44–75	11–23	13
Krakow (Srodmiescie, Kazimierz)	7.4–8.5	60–240	8–38	26–28	<3–5	0
Krakow (Podgorze, Lagiewniki)	7.5–8.5	60–240	8–19	18–50	<3–6	3
Krakow (Nowa Huta)	7.4–8.2	105–370	15–93	20–43	<3–5	0
Lidzbark	7.4–7.9	120–195	20–46	14–33	<4–4.5	3
Myszkow	7.0–8.0	85–300	3–28	32–100	<1–6.7	14
Nowy Sacz	7.4–7.7	110–210	11–17	23–34	0.1–0.3	2
Olkusz	7.2–7.5	120–220	7–33	23–148	<0.05–6	0
Poznan	7.4–7.8	165–200	42–59	69–99	<0.5–1	1
Przemysl	7.4–8.2	95–185	6–9	13–23	<2	2
Raciborz	6.5–7.5	130–295	13–33	37–168	<1–3	1
Szczecin	7.3–7.9	65–140	52–56	86–98	0.03–1	5
Warsaw	7.0–7.7	95–190	45–248	55–81	<0.5	7

concentrations of lead in the drinking water. Lead concentrations can double as a consequence of interaction with loose iron deposits (IWA 2010). However, it does not fully explain the high lead content. About 34% of water mains in this area are made of cast iron and 11% of steel. Unfortunately very few of the consumers interviewed were able to give any information about the material from which the connection pipes were made and none of them had any knowledge of the presence of lead pipes. On the other hand, over 40% of them declared that fittings were installed within the last 10 years.

The chemical composition of the water supplied to this zone does not give a clear indication of possible lead problems. The source of raw water during a tap survey was groundwater from the Galmany intake. Historical data indicate that in distributed water coming from the Galmany intake, lead concentration was sporadically up to 20 µg/L. Due to varying water demand and other technical conditions, the water sources supplying this zone periodically change. On average 34% of the water comes from groundwater intakes: Galmany (34%), Dobra (14%), Jaroslaw Dabrowski (7.5%) and Bielany (0.5%), and the dewatering system of the Jaworzno sand pit (43%). The final water is of low to moderate alkalinity (Table 2) with the pH slightly alkaline. However, it should be expected that the mixing of water of different origins (and chemical composition) may result in a lack of chemical stability. This fact, in conjunction with the poor condition of the distribution network and the possible presence of lead pipes as connections or in internal installations, may explain the high concentrations of lead registered during the tap survey.

Considering all the factors mentioned above, it should be stated that without immediate system-wide measures it will not be possible to achieve compliance with the 10 µg/L standard. The most appropriate, but most expensive, way to solve this problem seems to be the total replacement of all corroded pipes in the distribution network and domestic installations. However, this solution is not acceptable from an economic standpoint.

Ortho-phosphate dosing proved to be a very successful way of reducing the concentration of lead at consumers' taps. Experience from the UK has shown that this method can effectively help to eliminate the lead problem. According to Hayes *et al.* (2008), using ortho-phosphate dosing it

is possible to achieve over 99% compliance with the standard of 10 mg/L. This process will not bring an immediate reduction in lead concentrations. Setting a new equilibrium in a system may take from a few months to several years.

A surprising relationship can be observed (see Table 2): there are numerous cases of high lead content in drinking water connected with water supply zones in which groundwater is the source of the raw water (e.g. Jaworzno, Kamienna Gora, Myszkow, Choszczno). This is interesting since according to the widely accepted view, lead in drinking water is not a natural constituent of raw water but is released from materials used in the construction of the distribution network, the connections and the internal installations and fittings (IWA 2010). On the other hand, in most cases high concentrations of iron and manganese often accompany increased concentrations of lead. This may attest to the existence of a general problem of corrosion of the distribution network. An additional factor is that the water from groundwater intakes is very often supplied to a distribution network without any treatment or after very basic treatment such as iron and manganese removal.

Water from surface intakes is usually subject to a much more advanced treatment process which includes alkalinity and pH correction. The chemical stability of water can also be controlled. However, even the most advanced treatment will not guarantee 100% compliance with the 10 µg/L standard if the distribution network and/or connection and/or internal pipework are in poor condition or if materials containing lead were used.

CONCLUSIONS

The data collected indicate that many water supplies in Poland will be affected by the lead problem. Even in zones where lead pipes were not used, lead concentrations at consumers' taps may exceed the 10 µg/L standard. Assuming that the average non-compliance ratio reaches 8.4%, this may suggest possible complications for many water supply companies in Poland. This problem requires urgent attention and a system solution. The first step should be a broadly conceived tap survey at national level focused on lead. This will bring more detailed information on the lead problem in a larger number of water supply zones. The

information obtained would serve as the basis for a more proactive approach to hazard identification, risk assessment and risk management. It would also be a good step towards a water safety planning approach which is recommended by the Protocol for Water and Health and the World Health Organization.

In the zones where the non-compliance ratio exceeds 50%, immediate corrective action should be undertaken. It should be considered using an alternative source of raw water for zones supplied from catchments where the natural level of lead is high and occasionally (or frequently), exceeds 10 µg/L (Jaworzno, Choszczno, Kamienna Gora). A more detailed investigation should be undertaken in all zones where the non-compliance ratio exceeds 2% of RDT samples. This should allow the identification of which part of the distribution network or domestic installation serves as a source of the lead present in tap water. The investigation should be based on a combination of first draw samples, fully flushed samples and sequential 30 minute stagnation samples. However, in the specific conditions in Poland it may be extremely difficult to find localised sources of lead in the form of lead pipes, since lead was very rarely used as a material for pipes. It is more probable that the sources of lead are dispersed. High concentrations of lead in tap water in Poland are usually accompanied by elevated concentrations of iron, zinc (and sometimes manganese and copper). This suggests that corroded pipes made of galvanised iron may serve as the main source of lead in tap water. Such pipes dominate in domestic pipework in Poland, especially in buildings older than 30–40 years.

Even taking immediate radical action, such as the replacement of all lead pipes (if found) or corroded pipes made of other materials and the introduction of corrosion inhibitors, will not bring an immediate effect. It may take months to years. A useful interim control procedure pending pipe replacement is to increase the pH to 8.0–8.5 after chlorination (in soft waters, e.g. in Kamienna Gora).

RDT at consumers' taps seems to be the most appropriate method for determining the extent of problems with lead in drinking water within a supply zone. However, the number of samples taken must be far greater than the minimum sampling frequencies required by the EU drinking water directive and Polish national regulations.

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