CHEMICAL PLANTS AS A SIGNIFICANT SOURCE OF MERCURY CONTAMINATION IN THE CENTRAL AND EASTERN EUROPEAN REGION

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Content

1. Introduction

The body of scientific knowledge about the harms to human health and environment caused by mercury exposure has grown over the last several decades. Mercury is a substance of global concern due to its long-range transport, persistence, ability to bioaccumulate, and toxicity. Many governments have taken some steps to control human activities causing release of mercury into the environment. However, because mercury is a global pollutant, no national government acting alone can protect its people and its environment from the harms caused by mercury pollution.

In 2009, the Governing Council of the United Nations Environment Programme (UNEP) decided to develop a global legally binding instrument on mercury to reduce risks to human health and the environment. The first meeting of the Intergovernmental Negotiating Committee to prepare a global legally binding instrument on mercury took place in Stockholm in June 2010. The negotiations were completed three years later. The Minamata Convention on Mercury was adopted in October 2013 at a diplomatic conference in Kumamoto in Japan.

The major highlights of the Minamata Convention on Mercury include a ban on new mercury mines, the phase-out of existing ones, control measures on air emissions, international regulation of the informal sector for artisanal and small-scale gold mining, reducing mercury pollution from the chemical industry, and decontamination of sites contaminated by mercury due to chemical industry activities.

The chemical industry in the former Soviet Union and aligned countries left many heavily contaminated sites and polluting factories that are subject to the treaty provisions. This study evaluates the effectiveness of the Minamata Convention on Mercury to reduce mercury pollution from the chemical industry and to clean mercury contaminated sites in the Central and Eastern Europe (CEE) and Commonwealth of Independent States (CIS).

1.1 Impacts of mercury on human health

Mercury has been well known as an environmental pollutant for several decades. The toxic effect of mercury depends on its chemical form and route of exposure. The most toxic form is methyl-mercury. Once mercury enters a human organism it acts as a neurotoxin, i.e. it adversely influences the nervous system. It has been found that mercury exposure can negatively impact the human immune system. Exposure represents a big risk in particular for pregnant women and small children. The exposure of a foetus to mercury during its development in its mother's body, or a child during first years of its life, can cause mental retardation, cerebral palsy, deafness or blindness.

The pathways and fate of mercury in aquatic environments are important because it is in waters, sediments, and wetland soils that inorganic mercury is converted into methyl-mercury, which concentrates in animals at the top of a food chain. The majority of human exposure to mercury, and the health risk that comes with mercury exposure, is from consumption of fish and marine foods. Thus, the most studies of mercury contamination focus on aquatic ecosystems and mercury levels in fish.

1.2 Mercury in chemical industry

There are several manufacturing processes intentionally involving mercury that are recognized by the Minamata Convention on Mercury. These processes are mercury based chlor-alkali production; sodium and potassium methylate or ethylate production using mercury cell electrolysis; vinyl chloride monomer, acetaldehyde, and polyurethane production using mercury as a catalyst. These applications of mercury in the chemical industry are addressed by *Article 5: Manufacturing processes in which mercury or mercury compound are used*. Some uses of mercury in chemical industry are to be phased-out while others are to be restricted. Moreover both inorganic and organic mercury compounds are used in many consumer products manufactured by the chemical industry such as pesticides or paints. Uses of mercury in products are addressed by *Article 4: Mercury-added products* of the Minamata Convention on Mercury.

1.2.1 Chlor-alkali production

Chlor-alkali production is an industrial process that uses electrolysis to produce chlorine gas or other chlorine compounds, sodium hydroxide and hydrogen gas. Some older chlor-alkali plants still use a mercury-cell technology which is very polluting and releases large quantities of mercury into the environment. These plants employ an electrolytic process in which electricity is passed through a salt-water solution. The anode is usually made from graphite and the cathode is a large pool of mercury that may weigh several hundred tonnes. When electrical current is passed across the electrodes, it creates chloride gas at the anode and a sodium-mercury amalgam at the cathode. Subsequently, a reaction between the metallic sodium in this amalgam and water is induced to produce sodium hydroxide.

Although many chlor-alkali factories were replaced by alternative technology in the last decade, approximately 25 % of total capacity to produce chloride and caustic soda in Europe still uses mercury-cell technology (EuroChlor 2014). According to the Global Inventory of Mercury-Cell Chlor-Alkali Facilities in 2012 there were still at least 75 chlor-alkali plants using mercury worldwide (UNEP 2012). Two of them in EU had already ceased (EuroChlor 2014). The UNEP's inventory mentions twelve mercury based chlor-alkali plants still operating in CEE and CIS countries: three in Russian Federation; two in both Czech Republic and Serbia; and one in Romania, Slovakia, Hungary, Poland, and Turkmenistan. The only chlor-alkali plant in Azerbaijan was closed in 2011.

No new mercury based chlor-alkali plants are being constructed, though many older plants remain to be converted. Former mercury based chlor-alkali plants may constitute contaminated sites that continue to release mercury to the environment for many years (UNEP 2013). There are dozens of abandoned chlor-alkali plants in the CEE and CIS countries (at least 50 sites).

1.2.2 Vinyl chloride monomer production

Vinyl chloride monomer (VCM) is the main feedstock in the manufacture of polyvinyl chloride (PVC). VCM is produced using acetylene as a raw material. The acetylene is combined with hydrogen chloride and flows through mercuric chloride catalyst to produce the VCM. Amounts of mercury that may be emitted in this process are unknown, because release pathways are not fully quantified. Therefore VCM production does not appear in UNEP air emission inventories.

The production of VCM in most countries does not use any mercury catalyst but instead uses a different manufacturing process. However, the mercury catalyst method remains in large-scale commercial use in the manufacture of VCM, and this use appears to still growing. Most of the increasing production of VCM occurs in China, and it is estimated that consumption of mercury in China may exceed 1,000 tonnes per year. The same process was also used in the past in the CEE and CIS countries, although the only remaining confirmed VCM production facilities using the mercury process in these regions were located in Russia (at least four in 2002). All of the other known facilities in the region have either closed or converted to mercury-free processes. Former mercury-catalysed VCM plants may pose mercury contaminated sites. There are at least seven such sites in the CEE and CIS countries: two in Croatia, Russian Federation, and Macedonia; and one in Albania (Regional Environmental Center for Central and Eastern Europe 2002).

1.2.3 Acetaldehyde production

The tragedy of Minamata disease was caused by a chemical plant that used mercury sulphate as a catalyst in the production of acetaldehyde. It appears that mercury catalysts are no longer being used in the industrial production of acetaldehyde (Bell et al. 2014). A listing of mercury contaminated sites due to acetaldehyde production in the CEE and CIS countries is not available, but there is at least one heavily contaminated site in Kazakhstan.

1.2.4 Pesticides production

One of the major uses of mercury compounds as pesticides was as seed dressing. These uses have been restricted or banned in many countries because of their toxicity to people, their ability to contaminate food, and their toxicity to aquatic organisms. The most serious case of mercury-containing pesticide poisoning was the Basra Poison Grain Disaster. In 1971, 10,000 people died and 100,000 were severely and permanently brain damaged in Iraqi port of Basra after a shipment of barley and wheat treated with methyl-mercury, intended for use as seed grain, had been used as food (Bakir et al 1973). Certain limited uses of mercury-containing pesticides still remain in some countries mostly from stocks. Former chemical factories for production of these pesticides may be mercury contaminated sites in the CEE and CIS countries. There are at least five former pesticide facilities storing banned mercury-containing seed protectants in Russian Federation (Regional Environmental Center for Central and Eastern Europe 2002) and one former chemical factory in Germany causing transboundary contamination of a water reservoir in Czech Republic.

1.3 Alternatives in the chlor-alkali industry

There are three main electrolysis technologies for producing chlorine and caustic soda: mercury, membrane, and diaphragm. In each process, a salt solution (sodium or potassium chloride) is electrolysed by the action of direct electric current which converts chloride ions to elemental chlorine. Chlorine is also produced in a number of minor ways, for example, by electrolysis of molten sodium or magnesium chloride to make elemental sodium or magnesium metal; by electrolysis of hydrochloric acid; and by non-electrolytic processes.

Mercury cell electrolysis was the first method used at the end of the nineteenth century to produce chlorine on an industrial scale. The mercury process is the least energy-efficient of the main three technologies. Mercury cell technology is becoming less common in the chlor-alkali industry as other, more cost-effective processes are adopted.

In diaphragm cell electrolysis, an asbestos diaphragm separates a cathode and an anode, preventing the chlorine forming at the anode from re-mixing with the sodium hydroxide and the hydrogen formed at the cathode. This technology was also developed at the end of the nineteenth century. Diaphragm cells are not burdened with the problem of preventing mercury discharge into the environment. On the other hand diaphragm methods produce alkali that is quite dilute and of lower purity than do the mercury cell method. Moreover this technology uses material with proven health risks – asbestos.

Development of membrane cell technology began in the 1970s. The electrolysis cell is divided into two "sections" by a cation permeable membrane acting as an ion exchanger. This method is more efficient than the diaphragm cell and produces very pure caustic soda or caustic potash. The more energy-efficient membrane technology accounted for about 60% of 2014 European chlorine capacity (EuroChlor 2014) and is the most progressive chlorine production technology worldwide. The membrane cell method is the least environmentally destructive alternative of the main three chlor-alkali technologies.

Generally, the best alternative is decline of chlorine usage overall. Many toxic compounds including PCDD/Fs, polychlorinated biphenyls (PCB), and hexachlorobenzene (HCB) are released to the environment due to production, usage, and disposal of consequential chlorinated compounds, such as PVC or chlorinated solvents. PCDD/Fs, PCB, HCB are unintentionally produced toxic chemicals listed in Annex C of the Stockholm Convention on Persistent Organic Pollutants.

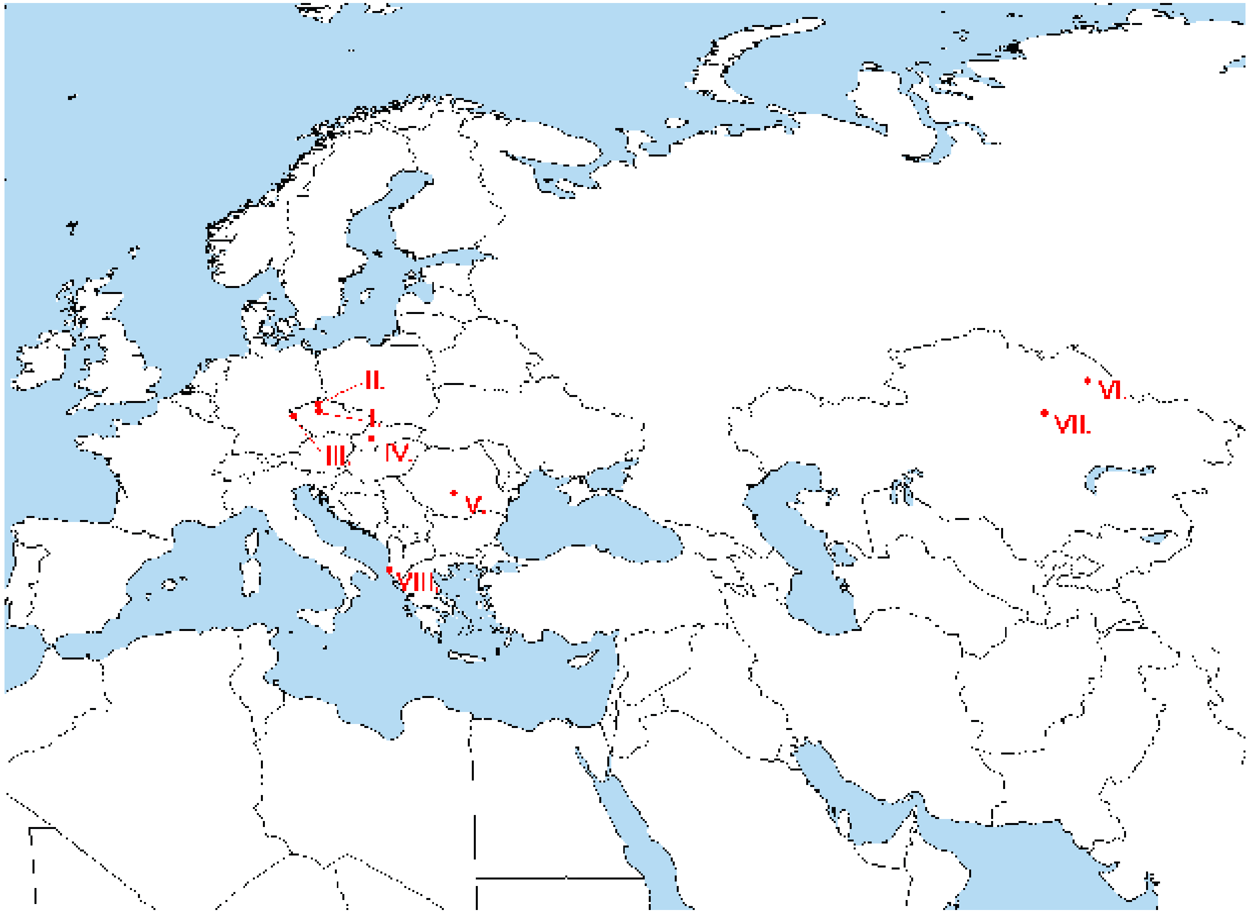

Fig. 1: Localization of the case studies in the CEE and CIS region. I. - Spolana Neratovice, II. - Spolchemie in Ústí nad Labem, III. - Former Marktredwitz Chemical Factory, IV. – Fortischem in Nováky, V. - Oltchim in Râmnicu Vâlcea, VI. - Former Chemical Complex in Pavlodar, VII. - Former chemical factory Karbid in Temirtau, VIII. - Former Soda PVC Plant in Vlora.

Tab. 1: List of case studies.

Source of contamination	Country	Industry type based on mercury	Presently operating?	Contaminated area	Comments
Spolana in Neratovice	Czech Republic	chlor-alkali plant	yes	fish from the River Labe; air in Neratovice; soils and sediments in the floodplain area	planned phase-out in 2017
Spolechemie in Ústí nad Labem	Czech Republic	chlor-alkali plant	yes	air in Ústí nad Labem, soil in the industrial area; sediments in the River Bílina; fish in the River Labe;	planned phase-out and replacement by membrane-cell process till end of 2015
Marktredwitz Chemical Factory	Germany/ Czech Republic	pesticides production plant	no	water and sediments in the Kössein water stream, the River Reslava, the River Ohře, and Skalka Reservoir; fish from the Skalka Reservoir	place of former factory completely decontaminated
Fortischem in Nováky	Slovakia	chlor-alkali plant	yes	sediments and sludge around the factory; fish from the River Nitra	planed phase-out till 2017
Oltchim in Râmnicu Vâlcea	Romania	chlor-alkali plant	yes	water, sediment, and fish in the Babeni Reservoir; human hair in Râmnicu Vâlcea	partly replaced by membrane-cell process
Chemical Complex in Pavlodar	Kazakhstan	chlor-alkali plant	no	water, sediments, and fish in the Lake Balkyldak	closed in 1993
Karbid in Temirtau	Kazakhstan	acetaldehyde plant	no	water, sediments, and fish in the River Nura; soils in the floodplain; human hair in Temirtau	closed in 1999
Soda PVC Plant in Vlora	Albania	chlor-alkali and VCM production plant	no	soil and air in the chemical complex; water, sediments, and fish in the Vlora Bay; human hair in Vlora	closed in 1992

2. Case studies of mercury contaminated sites in the region

In this publication we present eight case studies of sites contaminated due to former or recent chemical factories using mercury in the CEE and CIS countries. Tab. 1 introduces these sites, the source of mercury contamination, and specification of contaminated area. Geographical locations of the sites are shown in Fig. 1.

2.1 Current chlor-alkali plant Spolana Neratovice (Czech Republic) – a source of mercury pollution of the Labe (Elbe) River

2.1.1 Background and history

Spolana Neratovice is the largest chemical factory in Czech Republic with a chlor-alkali production plant and plant for manufacturing of PVC plastic. Aside from chlorine, caustic soda, and PVC plastic the factory manufactures raw materials for production of construction plastics, commercial fertilizers, and inorganic chemicals (hydrochloric acid, sulphuric acid). In the past, the factory manufactured a broader range of substances, e.g. linear olefins, viscose staple, and chlorinated pesticides. The factory is located in Neratovice, a town with 16,400 inhabitants situated 30 km north from Prague. The factory, with area of 262.5 ha, is positioned close to the Labe (or Elbe) River.

The first chemical factory in Neratovice was established in 1898, but real development of a chemical complex started when the factory was bought by the company "Spolek pro chemickou a hutní výrobu" (Company of chemical and metallurgical production) in 1939. The first chlor-alkali plant based on mercury cell technology has been in operation at the site since 1948. From 1950 the factory was separated from Company of chemical and metallurgical production and was called "Spolana Neratovice". Between 1965 and 1968 the factory produced the chlorine herbicide 2, 4, 5-T. The former communist regime controlled the company delivered the 2,4,5-T through various traders to Vietnam where U.S. Army used that as a component for an infamous herbicide Agent Orange. During its production, a huge amount of dioxins (PCDD/Fs) was created and the former factory buildings were one of the most contaminated places in the world[1]. In 1975 a new chlor-alkali plant based on mercury

1

Dioxin contamination in former herbicide produciton area was remediated recently. Remediation done by BCD (Base Catalyzed Dechlorinaiton) technology was finished in 2007, however there is still present contamination by PCDD/Fs in former amalgam electrolysis buildings.

was activated in the factory and replaced the first one. The supplier of the new production plant was Italian company De Nora.

The Spolana Neratovice was transformed into a joint-stock company in 1992 and is currently owned by the Polish company Anwil. The mercury based chlor-alkali plant has a production capacity of 135,000 tonnes of chlorine per year. In sum there are forty-four mercury cells in the factory with the total electrolysis capacity of 230 tonnes of mercury. According to a EuroChlor information for 2012 there are totally 215 tonnes of mercury in the current chlor-alkali plant in Spolana Neratovice, from which 214 tonnes is used in cells and 1 tonne is stored in the facility. The factory is planning to phase out mercury use for chlorine production before the end of June 2017. According to previous company information, no membrane cell chlor-alkali plant was planned to replace the current plant, however this position has changed according personal communication with Spolana management in June 2015. Company planned to import ethylene-dichloride, what should be very risky for the environment and public health due to its health effects and potential leakage during its transport. Membrane electrolysis is most likely replacement for mercury cells in the case of Spolana.

Data from the PRTR system in Czech Republic provide a good basis for following the scope of mercury releases from specific facilities across the country including amounts of mercury transferred in wastes. From a comparison of releases at Spolana with total reported releases for mercury it is clear that this facility is together with the another chlor-alkali plant in Ústí nad Labem and the waste incinerator in Ostrava the single largest source of mercury released into different environmental elements in the Czech Republic. According to EuroChlor a total mercury emission and the waste disposal from the factory were 0.53 g per tonne of chlorine and 0.87 g per tonne of chlorine in 2013, respectively.

2.1.2 Mercury contamination of the area

Serious mercury pollution in the area surrounding Spolana Neratovice has been demonstrated in several studies. This pollution comprises an elevated mercury concentration in air, an old environmental burden of mercury in soils of the chemical complex, and high mercury concentrations in fish from the River Labe.

2.1.2.1 Mercury in air

Arnika Association has measured high levels of mercury in outdoor air at some points on the edge of the chlor-alkali plant (Arnika Association and IPEN Heavy Metals Working Group 2013). Even more visible is the long-standing burden of mercury in the results of measurements by Suchara and Sucharová (2008) in oak bark in Fig. 2.

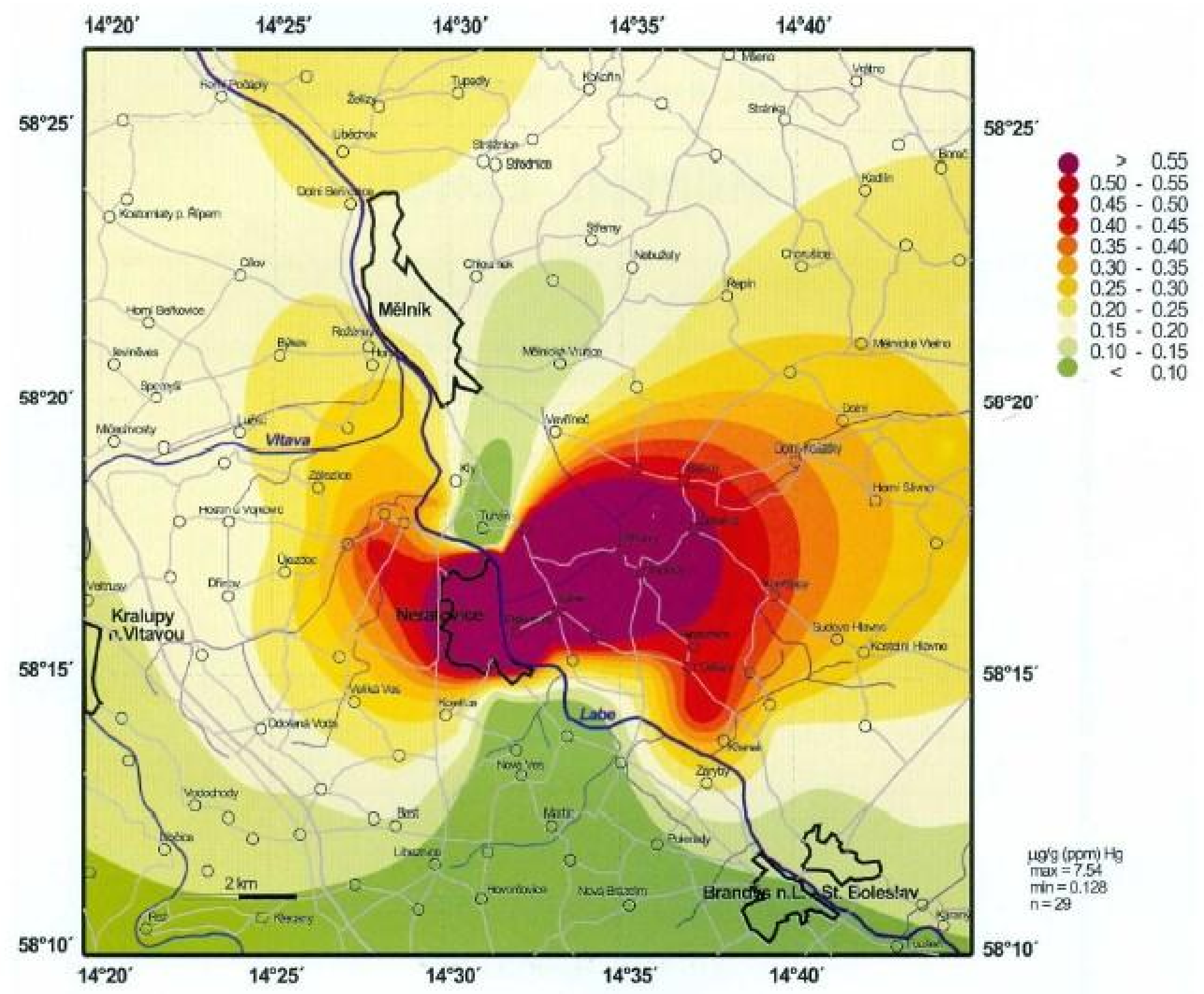

Fig. 2: Determined and interpolated mercury concentrations in oak bark in the investigated area in the surrounding of Spolana Neratovice. Source: Suchara et Sucharová 2008.

2.1.2.2 Mercury in soils and sediments

Spolana Neratovice also contains an unresolved environmental burden – contamination of the old amalgam electrolysis (in operation from 1948 to 1975) by both mercury and dioxins. At least 250 tonnes of mercury were left at the former chlorine production site as a mercury contamination of several production buildings and an enormous amount of soil in the River Labe flooding area. Mercury concentrations found in the factory were ordinarily between 1500 and 3600 mg/kg of soil, but the maximum mercury concentration reached up to 37,000 mg/kg of soil (Greenpeace Czech Republic 2002). This can also be a significant source of mercury pollution into the River Labe through underground water as well as surface water flow during the rain. However, this contamination spreads further since contaminated sediments are carried into Germany especially during the floods like the large flood in 2002. During this event about 90% of the area of the chemical complex was flooded up to 3 metres.

2.1.2.3 Mercury in fish from the River Labe

The River Labe is one of the most polluted aquatic ecosystems in the Czech Republic. Mercury accumulated in the sediments of the River Labe downstream from Spolana is source of contamination of local fish. The effect of Spolana Neratovice and other chemical factories on one species of fish in the River Labe was studied by Randák et al. (2009). They found that a mean mercury concentration in chub (*Leuciscus cephalus L.*) caught in the parts of the river close to the factory (Tab. 2) exceeded the threshold of 0.5 mg/kg wet weight (w.w.) established by the World Health Organisation (WHO) for total mercury in non-carnivorous fish (WHO 2004). The results were corroborated following an investigation by the Arnika Association in 2012 and by a scientific report of Žlábek et al. (2005). Mercury concentrations as high as 1.58 mg/kg w.w. were found in the muscle of a common bream (*Abramis brama*) during the investigation of the Arnika Association, with a mean of 0.57 mg/ kg w.w. (Arnika Association and IPEN Heavy Metals Working Group 2013). The latest investigation (Musil et al. 2015) reported that different fish caught downstream from the waste-water outfall are highly contaminated by mercury with a significant contribution of methyl-mercury. In this report a mean mercury concentration in muscles of common bream (*Abramis brama*) was 0.98 mg/ kg w.w. Moreover mercury contamination was also found in fish from nearby Mlékojedy quarry lake. A mean mercury level in muscles of perch (*Perca fluviatilis*) caught in nearby Mlékojedy quarry lake was 0.63 mg/ kg w.w. Angling has a long history in the city of Neratovice and a local group of Czech Fishing Union continues to encourage fish population for angling in the Labe River and Mlékojedy quarry lake.

Tab. 2: Mercury levels in muscle of male chub (Leuciscus cephalus L.) at Neratovice (Spolana) and Ústí nad Labem (Spolchemie). Source: Randák et al. 2009.

locality	**mean mercury concentrations [mg/kg w.w.]**
around Pardubice (downstream from plants)	0.157
around Neratovice	0.664
around Ústí nad Labem	0.260

2.2 Current chlor-alkali plant Spolchemie in Ústí nad Labem (Czech Republic) – a source of mercury pollution to the Labe (Elbe) River

2.2.1 Background and history

Spolchemie, by another name "Spolek pro chemickou a hutní výrobu" (Union for chemical and metallurgical production), is one of the oldest chemical factories in the Czech Republic. One of the two chlor-alkali production plants in the Czech Republic is a part of the Spolchemie chemical complex. Aside from the electrolysis of sodium chloride solution there are also units for electrolysis of a potassium chloride solution in the factory. The chemical factory produces range of organic (synthetic resins, epichlorohydrine, chlorinated solvents) and inorganic compounds (especially chlorine, caustic soda, caustic potash). The factory is placed near the city centre of Ústí nad Labem - a city with 100,000 inhabitants situated in the north part of the Czech Republic. Ústí nad Labem is located on the confluence of the River Labe and River Bílina. The city is situated 90 km downstream from Neratovice and 20 km upstream from the German-Czech border. The River Labe is the major Czech river which flows through Germany into the North Sea.

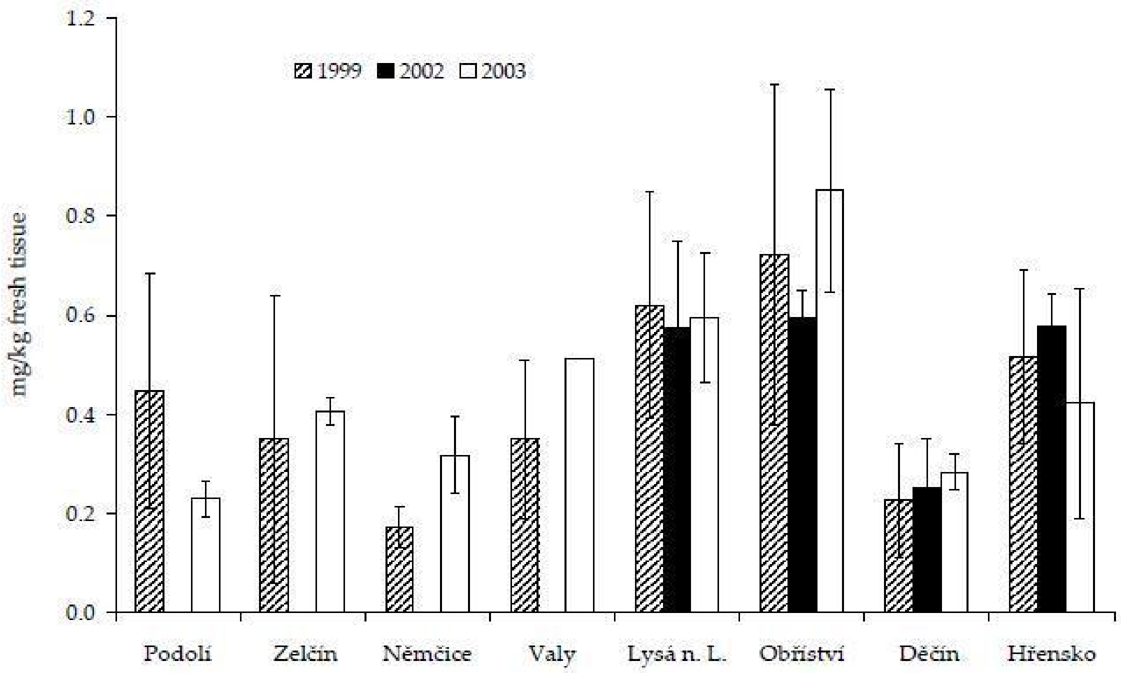

Fig. 3: Comparison of mercury levels in the muscles of bream (Abramis brama) from the monitored sites of the River Labe. The location Obříství is situated downstream from outfall of the chlor-alkali plant Spolana Neratovice and the location Děčín and Hřensko is situated downstream from the chlor-alkali plant Spolchemie. Source: Žlábek et al. 2006.

The Union for chemical and metallurgical production was established in 1856. The first relevant mercury cell chlor-alkali production based on the electrolysis of sodium hydroxide started in north-east part of the factory (Fig. 4) in 1928. The production based on electrolysis of potassium hydroxide began close to the first chlor-alkali plant in 1935. An extensive reconstruction with an amplifying of capacity of the chlor-alkali production was carried out in 1960s. Production capacity of the sodium chloride electrolysis was 41,000 tonnes of chlorine per year and 47,000 of caustic soda per year while production capacity of the potassium chloride electrolysis was 8,000 tonnes of chlorine per year and 12,200 tonnes of caustic potash per year in 1980s.

The company was transformed into a joint-stock company in 1990. Nowadays the mercury based chlor-alkali plant in Spolchemie has a production capacity of 61,276 tonnes of chlorine per year. In sum there are forty-five mercury cells in the factory with total capacity of electrolysis 210 tonnes of mercury. According to EuroChlor information for 2012 there is a total of 151 tonnes of mercury in the current chlor-alkali facilities in Spolchemie, of which 133 tonnes is used in mercury cells and 18 tonne is stored in the facility. The factory is planning to cease the mercury based chlor-alkali production and replace it by a membrane cell process till the end of 2015. The new membrane based chlor-alkali plant is already constructed partly with financial support from the European Union (EU).

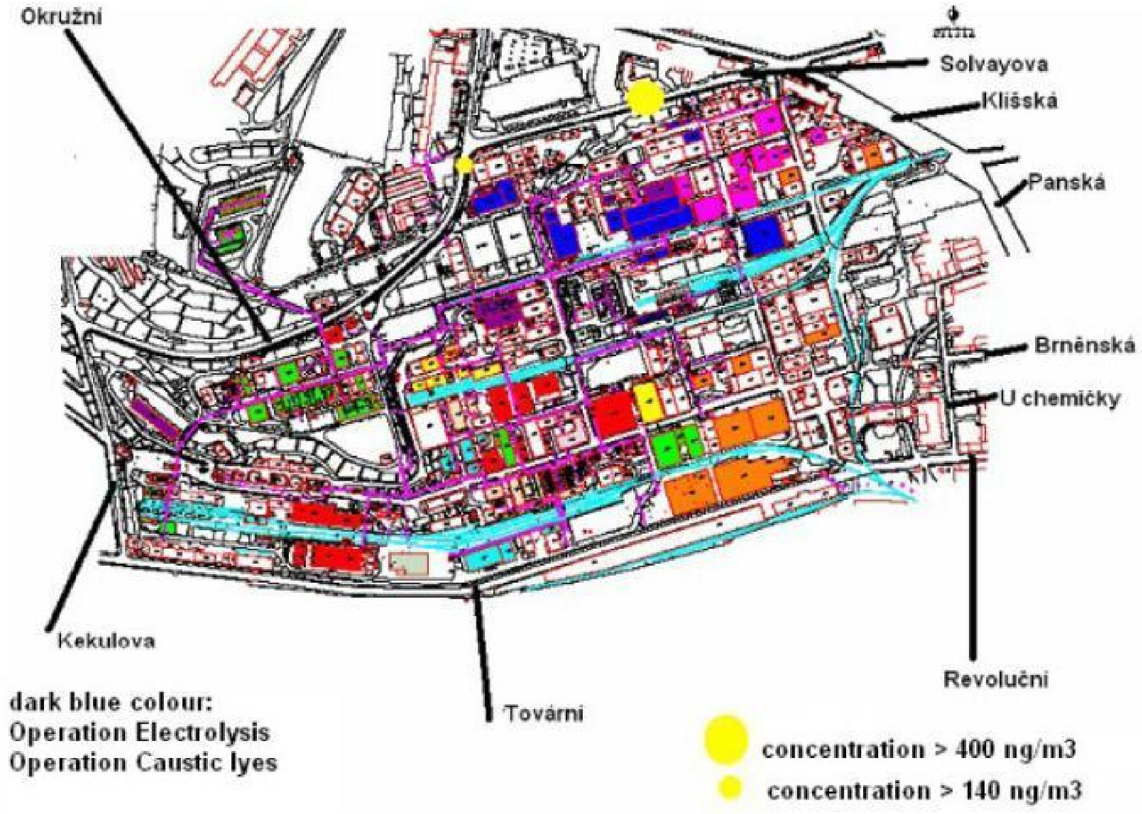

Fig. 4: Places where the highest mercury concentrations in the air were found in the vicinity of the chlor-alkali plant in Spolchemie (yellow points). Source: Kuncová 2006.

Waste-waters from the chlor-alkali plant were discharged to the Klíšský water stream 200 meters before its entry to the River Bílina. This river is a tributary of the River Labe and flows alongside the Spolchemie in Ústí nad Labem. The confluence of the River Bílina and the River Labe is one kilometre downstream from the factory. Although recently wastewater from the chlor-alkali plant has been treated in a plant for mercury separation, an amount of mercury is still released to the river system and other environmental elements. According to EuroChlor the total mercury emissions and the waste disposal from the factory was 0.73 g per tonne of chlorine and 10.3 g per tonne of chlorine respectively in 2013. This factory is one of the single largest sources of mercury released into different environmental elements in the Czech Republic, as mentioned above.

2.2.2 Mercury contamination of the area

Due to the operation of the mercury based chlor-alkali plant, both the surrounding environment and the chemical complex itself were heavily polluted with mercury. Mercury contamination is reported in soils at the area of Spolchemie, in sediments of the River Bílina, and in fish from both the River Labe and the River Bílina.

2.2.2.1 Mercury in air around the factory

The mercury concentrations found in certain areas outside the Spolchemie premises - especially in Solvayova Street and at the corner of Okružní and Solvayova Streets - exceeded the value of tens and hundreds ng/m^3 (Fig. 6). In certain parts of Solvayova Street, mercury concentrations in the air were in the range from the limit of detection (2 ng/m^3) up to the highest found value of 412 ng/m^3 (Kuncová 2006).

2.2.2.2 Mercury in soil in the area of the chemical complex

The contaminated soil in the area of the chemical complex Spolchemie represents a legacy environmental burden resulting from the operation of the chlor-alkali production in the past. At least 350 tonnes of mercury and a range of other chemicals (e.g. chlorinated hydrocarbons) were left at the former chlorine production site. The old environmental burden of mercury is part of a large decontamination project which started in 2005 and is planned to be finished in 2017.

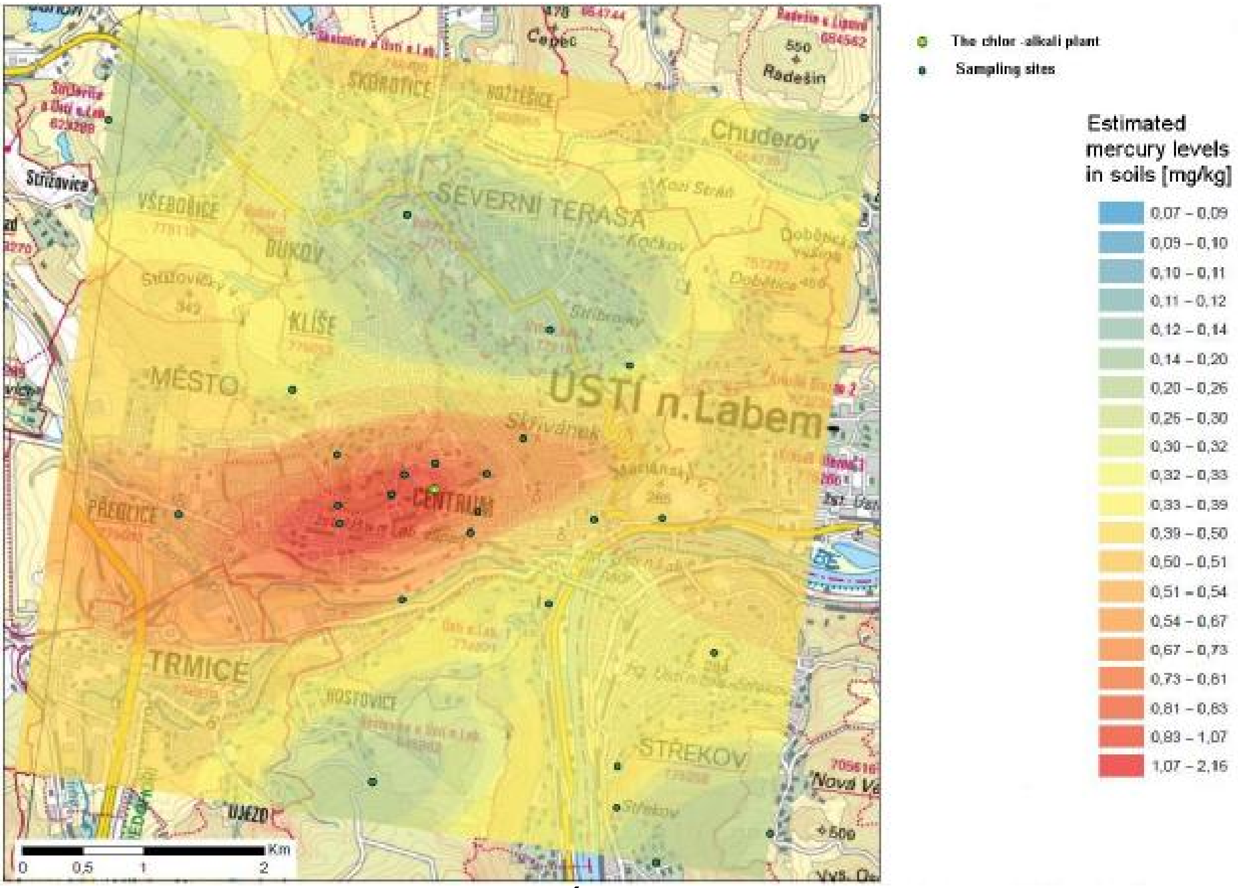

Fig. 5: Estimated mercury levels in soils in Ústí nad Labem. Source: Novák et al. 2012.

The highest mercury concentration in soils was 2400 mg/kg dry matter (d.m.). This mercury level was detected at the depth of 23-25 metres below the ground level at the site of the old amalgam electrolysis. The highest mercury concentration at the depth about one meter was 1200 mg/kg d.m. This distribution shows that the mercury contamination on the site is situated mainly in deep layers of underground sediments. Through the years the mercury plume is gradually spreading in the direction of the groundwater flow.

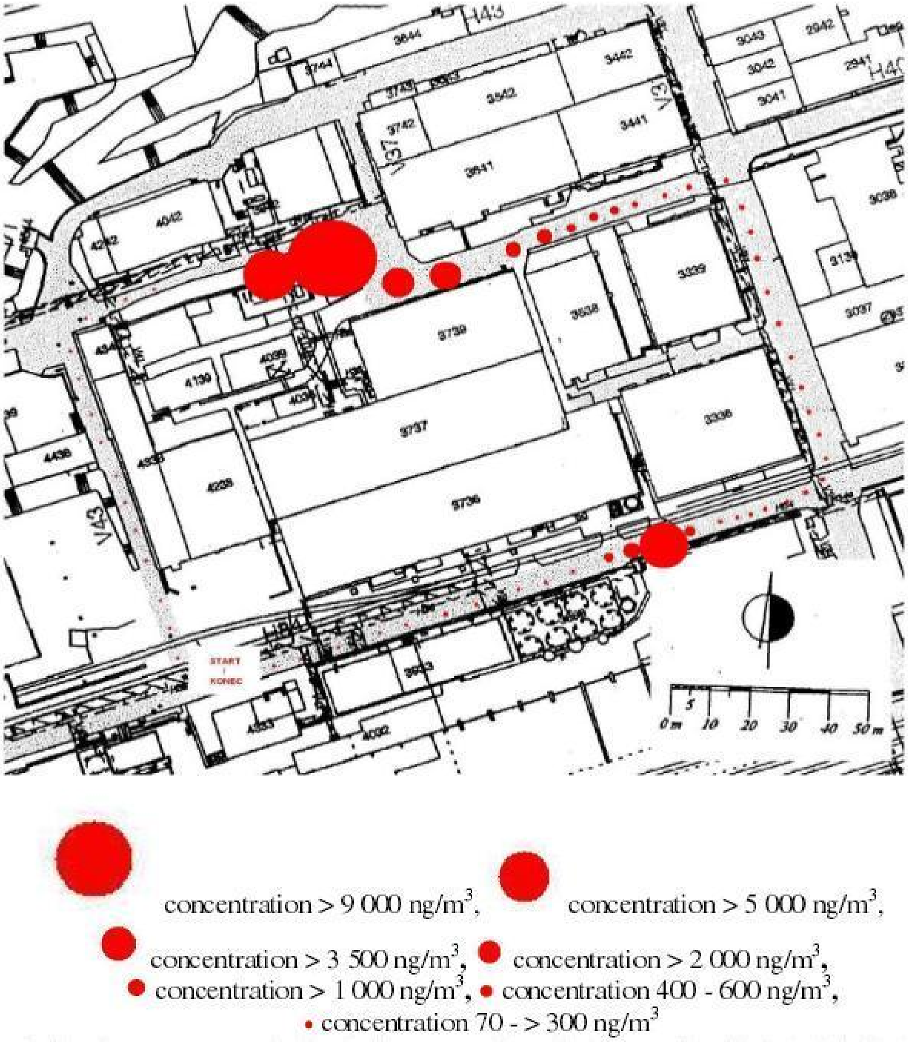

Fig. 6: Mercury concentrations in the surrounds of the electrolysis technology building in the Spolchemie. Source: Kuncová 2006.

2.2.2.3 Mercury in the River Bílina

Levels of mercury in sediments in the River Bílina downstream from Spolchemie were up to almost 32 mg/kg d.m. The mercury concentration in biofilm in the River Bílina at Ústí nad Labem was 6.7 mg/kg. This value was the highest level of mercury observed in biofilm among all Czech rivers (Pokorný et al. 2011).

2.2.2.4 Mercury in fish from the River Labe

Many investigations were done to find out mercury levels in fish at sites on the River Labe downstream from the Spolchemie. Although mercury levels in fish were highly elevated in comparison with natural level of mercury, directly downstream from the Spolchemie mean mercury concentrations in fish did not exceeded the threshold of 0.5 mg/kg w.w. established by the WHO (WHO 2004) for total mercury in non-carnivorous fish. Randák et al. (2009) found that the mean mercury concentration in chub (*Leuciscus cephalus L.*) caught downstream of the factory was 0.26 mg/kg w.w. The similar mean value of 0.28 mg/kg w.w. was found in the investigation by the Arnika Association and IPEN in 2012 in muscle of common bream (*Abramis brama*) (Arnika Association and IPEN Heavy Metals Working Group 2013). If the stricter US EPA (US EPA 2001) reference dose of 0.22 mg/kg is used, eating fish from the River Labe downstream from the confluence with the River Bílina poses a health risk. Moreover results of scientific research by Žlábek et al. (2005) found that mean mercury levels in common bream (*Abramis brama*) from the River Labe 20 km downstream from the Spolchemie exceeded the WHO limit (Fig. 3). It could be explained by mercury transport and accumulation in sediments to downstream parts of the river.

2.3 Former Marktredwitz Chemical Factory (Germany) – a source of transboundary contamination of Skalka Reservoir (Czech Republic)

2.3.1 Background and history

As a pioneer of the industrial age, Germany has a long history of mercury use at manufacturing sites, including a pesticides production plant in Marktredwitz, a small town in Bavaria. Marktredwitz Chemical Factory was the oldest chemical production site in Germany and one of the oldest chemical manufacturing facilities in the world. The site of former factory is a 0.5 square kilometre area located in the city centre of Marktredwitz - a municipality close to the Czech border. Marktredwitz is placed on the Kössein water stream in the watershed of the River Labe.

The “Chemische Fabrik Marktredwitz AG” (Marktredwitz Chemical Factory) was established in 1788. The product range comprised all groups of agrochemicals such as fungicides, herbicides, insecticides, plant growth inhibitors and stimulators, plant germination inhibitors, and fertilisers. The substances produced contained mercury, atrazine, lindane, and many more chemicals of concern. Ever since it was founded, mercury-containing products have been prepared there. The synthesis of organo-mercury fungicides was started in the 1950s. Due to an inadequate management of the factory, the company buildings, soils, groundwater and the surrounding land were seriously contaminated with organo-mercury compounds and other pollutants during the factory's operation. Because the latest production list contained 24 different inorganic and 18 different organic mercury compounds, there was a definite possibility that organic mercury compounds would be constantly discharged into the environment. Moreover, accidents such as the rupture of a sewage water pipeline in 1984 increased the levels of pollution. In 1985, after nearly 200 years of operation, the factory was closed.

Initial site investigations conducted in 1986 indicated that high mercury contamination was present in and around buildings of the factory, and specifically in the surface of the brickwork (400-3300 mg/kg of mercury) and in the soil (1000-4000 mg/kg of mercury). The factory's waste-water contained concentrations of mercury as high as 200 mg/l. The site of the factory was contaminated with mercury to a depth of about 4 metres - even more in some places (Defregger 1995). In 1988, the State of Bavaria decided to fund remedial action on the site.

Nowadays there is a shopping place, a cinema, and parking place in the area of former chemical factory. To clean up the site, a plant was built to treat 70,000 tonnes of mercury-contaminated soil and rubble. This treatment involved a combined process of soil washing and vacuum distillation. The plant was a prototype, built for the first time on an industrial scale. The soil decontamination plant for mercury-contaminated soils was the first in the world of this order of magnitude, and therefore has special technical significance as a pilot project for the remediation of hazardous waste sites. A full-scale washing and distillation plant went into operation in 1993 (PRC Environmental Management Inc. 1996). The treated material and a low contaminated material (less than 50 mg/kg of mercury) were disposed of in a new landfill next to the treatment plant. Cleaned material still remained contaminated with lower levels of mercury bellow 50 mg/kg. In 1994 during rehabilitation works, the Skalka Reservoir, beds of the River Reslava and the River Ohře were additionally contaminated when the sediments of the Kössein water stream were exposed and washed away.

2.3.2 Mercury contamination of the area

Despite expensive mercury decontamination in the past, a lot of mercury still remains in the River Ohře watershed. It is the result of the 200 year long period when waste-waters from the chemical factory were discharged in the Kössein water stream, a tributary of the River Reslava which afterwards flows to the River Ohře. Mercury is chemically bound to sediment particles. Therefore sediments in the Kössein water stream, the River Reslava, and the River Ohře pose a secondary source of mercury pollution. During flood events mercury is transported with suspended particles and accumulated in a flooding area and in the Skalka Reservoir. Sediments with elevated mercury levels can be found in the flooding area of the Kössein water stream (from Marktredwitz to the mouth), the Reslava River (from the Kössein inflow to the river's mouth), the River Ohře (from the River Reslava inflow to the parts downstream from the Skalka Reservoir) (Titl et al. 2011).

2.3.2.1 Mercury in the Kössein water stream and the River Reslava

Sediments from the Kössein water stream showed very high levels of mercury. The maximum value found was 269 mg/kg. There were found both methyl-mercury and ethyl-mercury in the water stream (Fig. 7). Ethyl-mercury, also a highly toxic form of mercury, originated from waste-waters of the fungicide plant, because their latest production list contained four ethyl-mercury species (Hintelmann et al. 1995).

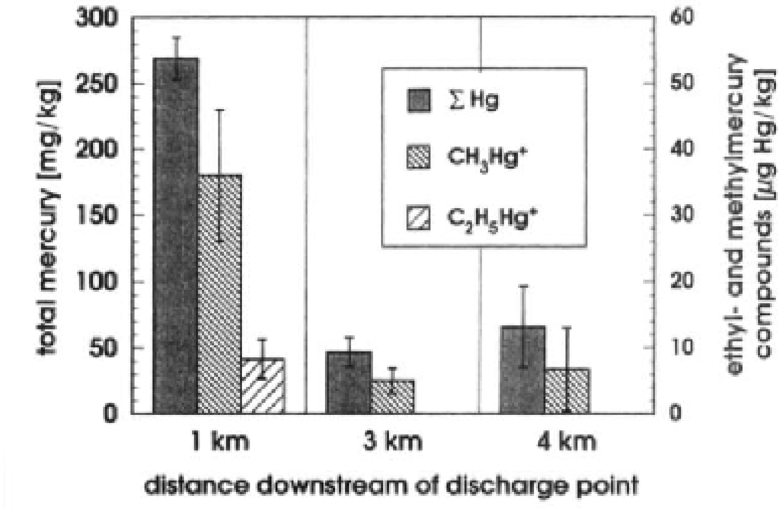

Fig. 7: Levels of total mercury and organic mercury compounds in sediments of the Kössein water stream at different point downstream from the discharge from the factory. Source: Hintelmann et al. 1995.

The water in the River Reslava has high mercury concentrations. Elevated annual mercury concentration was measured as high as 0.2 µg/l in 2010, but during a flood event in September 2002 it raised up to 1.22 µg/l (Titl et al. 2011). In the same year an annual mercury concentration (435 mg/kg d.m.) was the highest annual mercury concentration measured in sediments of the River Reslava from the beginning of the monitoring of mercury in 1983.

2.3.2.2 Mercury in water and sediments of the Skalka Reservoir

The Skalka Reservoir was built in 1964, and its surface area is 3.78 km^2. The main purpose of the reservoir is to provide for at least minimum flow rates in the River Ohře. The reservoir should also provide a degree of protection of areas downstream of its dam against floods, generate hydroelectricity, and serve as a place for recreation and water sports.

At least 456,000 m^3 of sediments in the Skalka Reservoir are highly contaminated with mercury. This volume of sediments covers 67 hectares of the reservoir. According to an investigation a mean mercury concentration in sediments of the reservoir is 12.9 mg/kg (Titl et al. 2011).

2.3.2.3 Mercury in fish from the Skalka Reservoir

Consumption of fish from the Skalka Reservoir poses a major health risk. An investigation on the reservoir (Maršálek et al. 2005) showed that mercury contamination of fish is very high, and that methyl-mercury was almost the exclusive form of mercury in fish muscle tissue (Tab. 3). All thirty fish of seven species examined in the study of Maršálek et al. (2005) exceeded the threshold of 0.5 mg/kg w.w. established by the WHO (WHO 2004) for total mercury in non-carnivorous fish. Moreover, eight fish of predatory species (asp, eel, and wels catfish) exceeded the WHO threshold of 1 mg/kg w.w. for total mercury in predatory fish. Total mercury in muscle tissue of the asp (*Aspius aspius*, as the representative of predatory species) and the bream (*Abramis brama,* as the representative of non-piscivorous species) averaged 3.11 mg/kg w.w. and 0.96 mg/kg w.w., respectively. All total mercury in muscle tissue of the asp and the bream was in methyl-mercury form.

The situation was aggravated by the changes in water level height, particularly in 1976 and 1982, when the reservoir was completely drained and filled with water again, followed by a twofold increase of mercury levels in fish.

Tab. 3: Total mercury and methyl-mercury concentrations in muscle of different fish species and methyl-mercury to total mercury ratios. Source: Maršálek et al. 2005.

species	number of samples	mean methylmercury concentration (range) [mg/kg w.w.]	mean total mercury concentration (range) [mg/kg w.w.]
Big head carp	7	0.90 (0.56-1.26)	0.83 (0.53-1.04)
Bream	8	1.04 (0.59-1.33)	0.96 (0.55-1.23)
Roach	5	0.87 (0.65-1.37)	0.81 (0.58-1.27)
Silver bream	2	0.95 (0.91-0.99)	0.86 (0.81-0.91)
Asp	4	3.41 (3.00-4.05)	3.11 (2.93-3.40)
Eel	3	1.85 (1.66-2.11)	1.80 (1.52-2.26)
Wels	1	1.11	0.96

2.4 Current chlor-alkali plant Fortischem in Nováky (Slovakia)

2.4.1 Background and history

Fortischem a.s. is one of the Slovakia’s key chemical manufacturing sites and has been identified as one of Slovakia’s pollution “hotspots”. There is a mercury cell chlor-alkali production plant at the site. The factory is engaged in production of a wide range of organic and inorganic products, and with a primary focus on chlorinated chemicals and PVC plastic. In addition, the plant has the capacity to manufacture some finished PVC products, including flexible flooring, rigid window profiles and other PVC building products. The factory is placed in an industrial area including a coal-fired power station Nováky. The power plant was ranked by the European Environment Agency as the industrial facility that is causing the highest damage costs to health and the environment in Slovakia and the 18th worst in entire EU. The industrial area is located nearby Nováky – a town in western Slovakia 140 km north east of Bratislava. The factory is located near the River Nitra flowing around the industrial area. The River Nitra is a tributary of the River Váh in the River Danube watershed.

The factory known as “Novácké chemické závody” (Nováky Chemical Plant) was built for the first time in the mid-1930s, with the chlor-alkali plant being installed in 1940. PVC plastic production began in the late 1940s and expanded rapidly over the following decades. The plant extended into finished PVC products in the 1960s and both resin and product manufacture continued to expand through the 1970s. PVC plastic is made from VCM, which could be manufactured by chlorinating either acetylene or ethylene. The VCM production from acetylene use mercury for catalyst, but manufacturing from ethylene does not require mercury catalysts. According to company information, Fortischem has the capacity for both processes, buying in ethylene but also generating acetylene as a by-product of calcium carbide production (Labunská et al. 2002). Hence it is possible that aside from the chlor-alkali production, mercury is used also for the VCM production in the factory.

The Nováky Chemical Plant was transformed into a joint-stock company in 1990 and continued under the same name until a bankruptcy of the company in 2009. The Nováky Chemical Plant was sold to Fortischem a.s. in 2011, which is a subsidiary of the Czech company Energochemica. The company plans to construct a new chlorine plant based on membrane electrolysis at the town Strážské which is in the east part of Slovakia. At the same time Fortischem is expected to cease chlorine production at Nováky in 2017 (Young 2014).

The factory discharges liquid wastes directly to the River Nitra channel from two waste-water outfalls. For plants such as Fortischem, engaged in the manufacture of PVC and other chlorinated organic compounds, the by-production of a range of chlorinated hydrocarbon contaminants is unavoidable. Danube Pollution Reduction Programme Final Report (Danube Pollution Reduction Programme 1999) identified the factory as a pollution "hotspot". Data collected for the Danube Pollution Reduction Programme also indicate that discharges from the factory are resulting in substantial elevations in concentration in the River Nitra for a range of pollutants, including mercury and chlorinated hydrocarbons. Mercury concentrations in river water 6 km downstream from the plant have been recorded to be more than 100 times higher than background concentrations measured upstream. Nevertheless, concerns also relate to the factory as a substantial point source of pollutants to the atmosphere. According to EuroChlor, mercury emissions to the atmosphere, via products, and in the waste-water from the factory were 1.36 g per tonne of chlorine, 0.24 g per tonne of chlorine, and 0.09 g per tonne of chlorine respectively in 2010.

2.4.2 Mercury contamination of the River Nitra

There are only sporadic reports about the degree of mercury pollution of the ambient environment in the surrounding region. Two scientific studies of mercury in fish were carried out on a few sites on the River Nitra downstream from the factory. Moreover, in 2002, Greenpeace International collected samples in the vicinity of the factory (Fig. 8) in order to characterise in more detail the waste streams discharged into the river.

2.4.2.1 Mercury in waste-water discharges and in sedimentation lagoon to the River Nitra

Data collected from the waste-water discharges confirmed that the factory is an important point source of mercury and toxic chlorinated organic compounds to the River Nitra. Waste-water samples and sediments from the main discharge channel located on the western side of the factory contained high levels of the toxic metal mercury. Waste-water from the main waste-water discharge reached up to 112 μg/l of mercury and sediment from the channel was contaminated up to 131 mg/kg of mercury (Labunská et al. 2002). Waste-water sampled from the second waste-water discharge contained 2.6 μg/l of mercury and level of mercury in sediment from inside the pipe was 27 mg/kg, both significant but lower than in the main discharge (Labunská et al. 2002). Both waste-water samples showed evidence of heavy contamination with a wide range of chlorinated organic compounds (chlorinated ethenes, chlorinated benzenes, chlorinated butadienes, VCM, chloroform, dioxins, and chlorinated propanes).

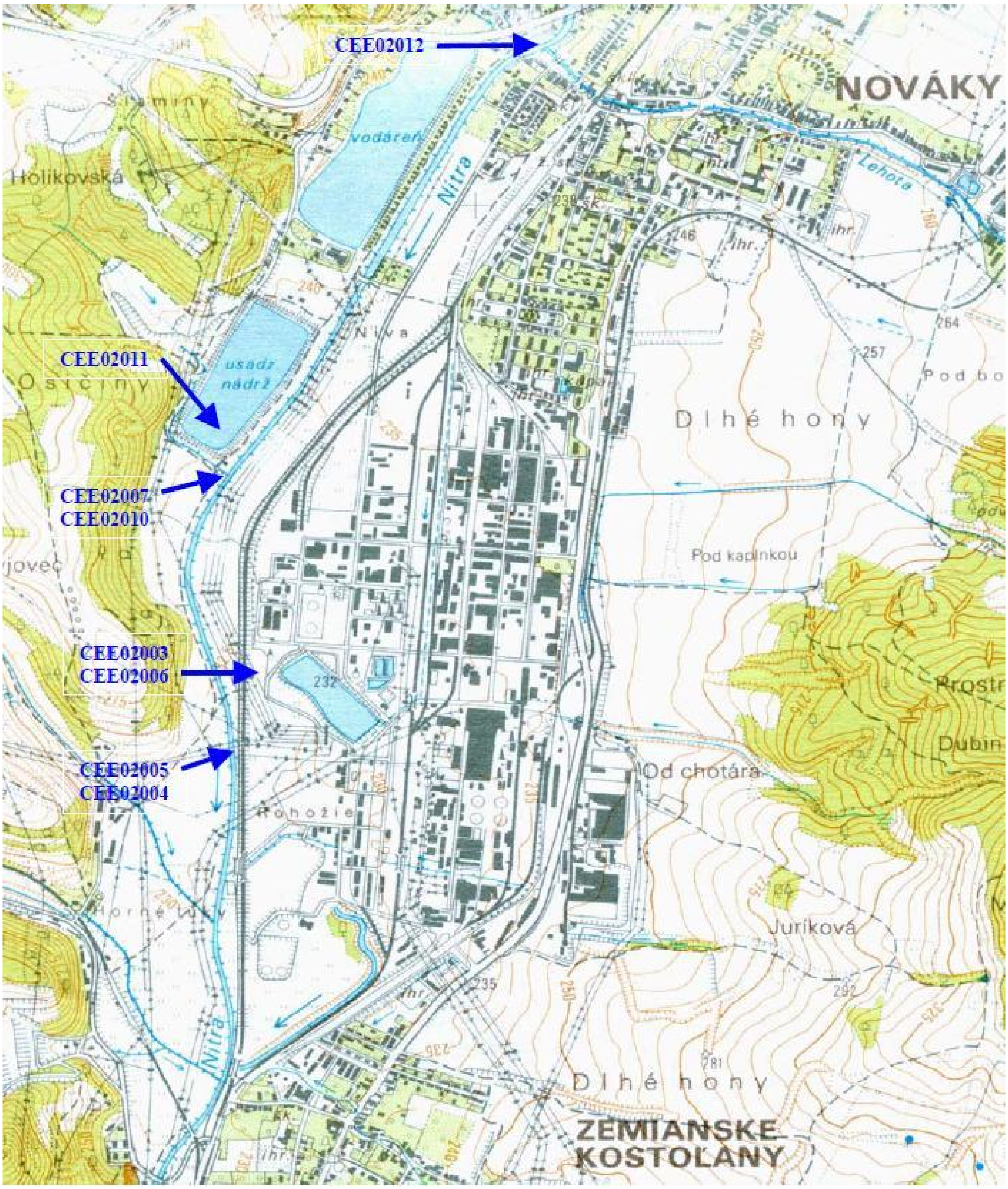

Fig. 8: Location of the chlor-alkali plant Fortischem in Nováky. Blue arrows mark sites of water and sediment sampling by Greenpeace. Source: Labunská et al. 2002.

Moreover, mercury is a component of solid waste in an open lagoon situated on the banks of the River Nitra, close to the north-western boundary. With mercury at 197 mg/kg (Labunská et al. 2002), these solid deposits could act as an additional point source of the mercury discharge to the river and the wider environment. This was the most heavily mercury contaminated waste sampled by Greenpeace (Labunská et al. 2002). For that reason the sedimentation lagoon with solid wastes represents a heavily contaminated site.

2.4.2.2 Mercury in fish from the River Nitra

The consumption of fish from the River Nitra is not recommended due to mercury contamination. Results of the two scientific reports indicate a hazardous contamination of mercury in the muscle of eight examined fish species from a long stretch of the River Nitra downstream the factory. Mercury levels in the muscle of fish caught about 20 km downstream from the factory in the Partizánske village exceeded the maximum allowed level in all samples (Tab 4). The mean value of mercury concentration in fish muscle was 2.85 mg/kg w.w. (Andreji et al. 2005). The WHO limit for mercury content in fish muscle is 0.5 mg/kg w.w. (WHO 2004). This limit was exceeded as much as 2.70–3.04 times in all the analysed samples.

Tab. 4: Mercury content in muscle of different fish species from the River Nitra at Partizánske village. Source: Andreji et al. 2005.

species	mean mercury concentration (range) [mg/kg w.w.]
Chub	2.30 (1.35-3.88)
Barbel	3.40 (1.93-4.57)
Roach	1.90 (1.52-2.18)
Perch	4.50 (2.73-6.52)
all samples	2.85 (1.35-6.52)

Fish from the lower River Nitra in the Bánov village about 100 km downstream from the factory also pose a high health risk. Total mercury concentration in muscle of fish ranged from 0.34 to 3.64 mg/kg w.w., with mean value 0.88 mg/kg w.w. (Tab. 5) in that part of the river (Andreji et al. 2006). The concentrations of mercury were significantly higher than allowed values in the Codex Alimentarius valid in the Slovak Republic and the values recommended by WHO. This limit was exceeded (1.2–7.3 times, an average 2 times) in 82.1% of all analysed samples. Concentration of methyl-mercury in the muscle of fish varied from 0.08 to 1.2 mg/kg w.w., with a mean value of 0.38 mg/kg w.w. The methyl-mercury percentage part of total mercury content in fish samples reached on the average 44.1%.

Tab. 5: Total mercury and methyl-mercury content in muscle of different fish species from the River Nitra at Bánov village. Source: Andreji et al. 2006.

species	mean total mercury concentration (range) [mg/kg w.w.]	mean methylmercury concentration (range) [mg/kg w.w.]
Chub	0.76 (0.35-1.41)	0.30 (0.30-0.49)
Common carp	0.70 (0.46-0.95)	0.22 (0.13-0.27)
Prussian carp	0.65 (0.34-1.10	0.29 (0.08-0.50)
Roach	0.78 (0.15-1.02)	0.38 (0.30-0.56)
Wels catfish	1.53 (0.44-3.64)	0.73 (0.30-1.20)
all samples	0.88 (0.34-3.64)	0.38 (0.08-1.20)

2.4.3 Potential threat for human health

Beyond Slovakia, the Novácké Chemical Plant was perhaps best known for its notoriety as a source of case studies of human liver cancer (angiosarcoma) resulting from prolonged worker exposure to VCM, primarily during the 1950s and 1960s (Bátora et al. 1998). Today the Fortischem is clearly acting as a point source of mercury and hazardous chlorinated organic compounds to the surrounding environment, in particular to the River Nitra. The river is a contaminated water-body as far as 100 km downstream from the chemical factory. Given that metallic mercury is partly transformed to highly toxic methyl-mercury, significant impacts on the food chains of freshwater organisms in the river and also on human health are likely. Children that live in the surroundings of the Fortischem had significant higher mercury levels in hairs and nails. A medical study (Simko 2000) showed higher breathing and nerve illnesses, illnesses in the brain and the digestive channel in the surroundings of the factory. Attention levels and memory of researched children were considerably lower, and they had enlarged incidents of trembling hands, less accuracy in slow movements and eye-hand coordination.

2.5 Current chlor-alkali plant Oltchim in Râmnicu Vâlcea (Romania) – a source of mercury pollution of the Babeni Reservoir

2.5.1 Background and history

Oltchim S.A. is one of the largest chemical factories in Romania, and the largest chlor-alkali plant in Central and Eastern Europe at the same time. Aside from chlorine and caustic soda the factory produce many other chemical compounds such as macromolecular and organic synthesis products. The factory is sited in an industrial complex including salt processing and a thermal power station. The industrial complex is located close to the River Olt, the largest Romanian tributary of the River Danube, in Râmnicu Vâlcea - a large urban area of about 90 km^2 and 110,000 inhabitants (Fig. 9).

The factory was established in 1966 under the name Râmnicu Vâlcea Chemical Works and was transformed into a joint-stock company, called Oltchim S.A. in 1990. The first chlor-alkali unit with mercury cells was put into operation as the first plant of the factory in 1968 with production capacity of 100,000 tonnes caustic soda per year. Another chlor-alkali unit with mercury cells was opened in 1974 with production capacity of 210,000 tonnes caustic soda per year. The first unit was closed in 1999, whilst the latter one is still operating. Another unit with capacity of 100,000 tonnes caustic soda per year, based on mercury-free diaphragm electrolysis, was in use between 1984 and 1993. Finally, a unit with capacity of 120,000 tonnes caustic soda per year, based on membrane technology, was activated in 2000.

Since 1974, the chlor-alkali plant has been discharging mercury into the River Olt just upstream from the Babeni Reservoir. The reservoir is one of the 19 reservoirs built during the 1970s along the River Olt for flood prevention and power generation. The reservoir has a mean volume of 35.3 km^3, a surface area of 9.05 km^2, a mean depth of 3.9 metres and a maximum depth of 16 metres. The Babeni Reservoir is eutrophic with relatively high concentrations of phosphorus and total nitrogen. The reservoir is a warm-temperate water-body which can reach 25°C in surface waters during summer.

There is no available data about the historical releases from the chlor-alkali plant into the River Olt and the reservoir. An investigation (Bravo et al. 2008) of historical records from sediment cores of the reservoir showed a generally decreasing trend from maximum mercury pollution in 1987 to the present. This decrease probably reflects the technological progress in control of emissions from the mercury based chlor-alkali industry. However, no further improvement was observed after 1999, when the first mercury-based production unit was decommissioned. The report from 2014 documented that mercury level in water from the factory greatly exceeded the maximum allowable concentrations of environmental quality standards (70 ng/l) established by the European Directive (Water Framework Directive 2008) regulatory limits. (Bravo et al. 2014)

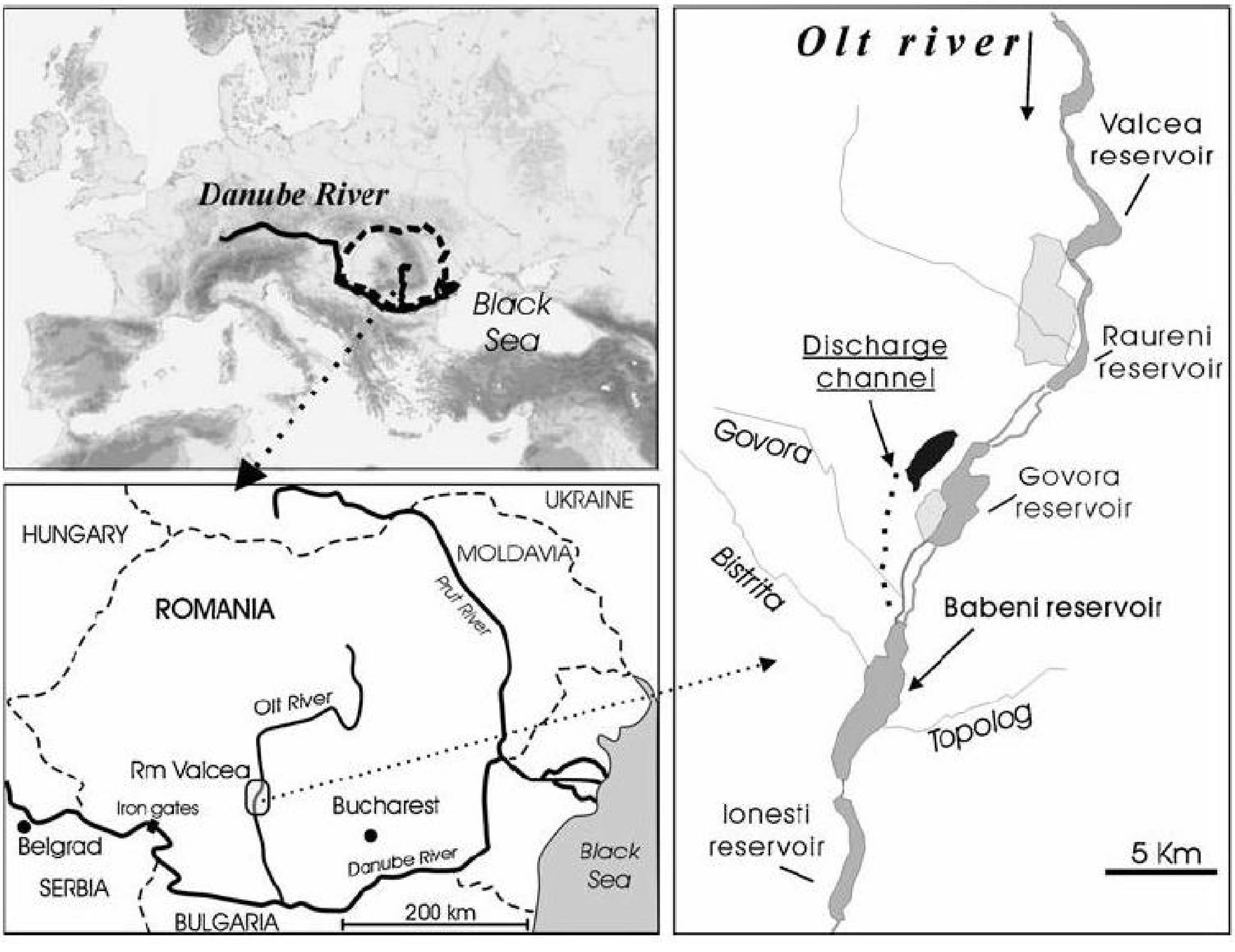

Fig. 9: Localization of the chlor-alkali plant Oltchim in Romania and on the River Olt. Source: Bravo et al. 2010.

2.5.2 Mercury contamination of the Babeni reservoir

Little is known about the degree of mercury pollution of ambient environment in the region. Scientific research of mercury pollution were carried out only in the Babeni Reservoir which is located directly after the waste-water discharge from the factory (Fig. 9). Reports from Babeni Reservoir revealed unsafe mercury contamination in surface and interstitial water, sediments, fish, and hair of peoples consuming fish from the reservoir due to discharge of waste-water from the chlor-alkali plant. There is not enough information about contamination with mercury in the cascade of next eleven reservoirs that were built on the River Olt downstream from the Babeni Reservoir except the Ionesti Reservoir located just downstream from the Babeni Reservoir.

2.5.2.1 Mercury in water and sediments

According to the latest report (Bravo et al. 2014) the mean value of total mercury and methyl-mercury concentrations of surface water in the Babeni Reservoir were 5.8 ng/l and 0.98 ng/l, respectively. Total mercury concentration in interstitial water was in a range between 0.038-72µg/l. Methyl-mercury concentrations in interstitial water reached to 206 ng/l. The percentage of methyl-mercury to total mercury in interstitial water was higher than that found in sediments, and reached up to 40%. (Bravo et al. 2009b) This strong methylation potential constitutes the main problem as methyl-mercury is much more dangerous in its effects on ecosystems and human health.

Mercury contamination of surface sediments in the Babeni Reservoir is too high with respect to the sediment quality guidelines and is one order of magnitude higher than the local background concentrations measured in sediments from the upstream Vâlcea Reservoir (Bravo et al. 2009a). Mercury concentration in sediments varied from 0.8 to 6.6 mg/kg (Bravo et al. 2009b). Although the most contaminated sediments are now 20 years old and buried, they can be potentially reworked or re-suspended by dredging or flushing (Bravo et al. 2009a).

The major problem from the aspect of risk assessment is the methylation of these sediments and the mercury availability to transfer along the food web. The presence of dark laminae sediments suggest that suboxic conditions, favourable for mercury methylation, develop periodically in the sediment. The highest methyl-mercury percentage was measured close to inlet of the waste water discharge channel of the chlor-alkali plant (Bravo et al. 2009b).

2.5.2.2 Mercury in fish and other biota

Elevated mercury concentrations were found in plankton, benthos, and macrophytes in the Babeni Reservoir (Tab. 6). An increase of mercury concentrations observed along the food chain lead to the highest values found in fish (Bravo et al. 2014). Due to bioaccumulation ninety-two percent of the fish from the Babeni Reservoir examined in the study of Bravo et al. (2010) exceeded the threshold of 0.5 mg/kg w.w. established by the WHO (WHO 2004) for mercury in non-carnivorous fish (Tab. 7). The mercury concentrations found in fish of the Babeni and Ionesti reservoirs are among the highest ever reported in the world, which underscores the strong mercury biomagnification in the River Olt reservoirs. A mean mercury concentration found in fish from the Babeni Reservoir was 5.99 mg/kg d.m. (Bravo et al. 2014). Most of the mercury present in fish was in the form of highly toxic methyl-mercury

(Tab. 8). Although there is no professional fishing in the Babeni Reservoir, angling is very popular and provides a considerable food resource for numerous families.

Tab. 6: Inorganic mercury and methyl-mercury concentrations for plankton, benthic organism, macrophytes, and fish collected in the Babeni Reservoir. Source: Bravo et al. 2014.

organism	mean inorganic mercury concentration [mg/kg d.m.]	mean methylmercury concentration [mg/kg d.m.]
plankton >65 µm	0.32	0.41
plankton >200 µm	0.21	0.5
fish	0.89	5.2
benthos	2	0.03
macrophytes	1.7	0.3

Tab. 7: Total mercury and methyl-mercury concentrations in different fish species in the Babeni Reservoir. Source: Bravo et al. 2010.

species	number of samples	mean total mercury concentration [mg/kg w.w.]	mean methylmercury concentration [mg/kg w.w.]
Bleak	7	2.8	2.6
Prussian carp	7	1.6	not measured
European carp	1	0.5	not measured
Eurasian ruffle	2	1.1	not measured
European perch	4	1.6	not measured
Roach	2	1.7	not measured
Zander/pike-perch	1	0.4	not measured
all samples	24	1.8	not measured

Tab. 8: Total mercury concentrations in different fish species collected in the Babeni and Ionesti reservoirs. Mercury concentrations are expressed as per sample d.m. Source: Bravo et al. 2014.

species	age [year]	Babeni Reservoir		Ionesti Reservoir	
		number of samples	mean total mercury concentration [mg/kg d.m.]	number of samples	mean total mercury concentration [mg/kg d.m.]
Bleak	0+	3	2.7	0	-
	2+	6	9.6	0	-
	3+	3	7.3	0	-
Common carp	1+	1	5.5	0	-
	2+	5	4.6	0	-
Gudgeon	unknown	1	2	0	-
Ruffe	1+	6	5	0	-
	2+	3	6.3	3	4.2
	3+	2	5.75	0	-

	4+	4	7.7	0	-
Perch	0+	1	6.2	0	-
	1+	0	-	3	5.1
	2+	0	-	3	6.5
	3+	0	-	4	6.5
Roach	1+	8	5.7	2	4.7
	2+	5	5.9	5	4.7
	3+	7	6.2	6	5.2
	4+	1	7.5	0	-
Zander	1+	3	6	1	7
all samples	-	78	6.3	27	5.4

2.5.3 Potential threat for human health

A significant scientific study (Bravo et al. 2010) reveals the transfer of mercury from the Babeni Reservoir to humans via fish consumption and documents that the severe mercury contamination of sediment and fish in the reservoir results in a high mercury concentration in the hair of a population consuming fish from the reservoir. Hence the mercury contamination of the Babeni Reservoir and other parts of the River Olt poses a severe health risk to those consuming large amounts of fish from there.

2.6 Chlor-alkali plant in the Pavlodar Chemical Complex (Kazakhstan) – a mercury contamination of the Lake Balkyldak

2.6.1 Background and history

The Pavlodar Chemical Plant, formally known as Khimprom, is a former industrial factory that was designed as a dual-purpose production factory capable of manufacturing both civilian chemicals and agents of chemical warfare. The civilian chemical production site at the factory included a chlor-alkali plant that utilized mercury cell electrolysis to produce chlorine and caustic soda. The factory is located in the northern industrial zone of the Kazakh city of Pavlodar, a major industrial centre with a population of over 300,000 people that also contains other chemical plants, an oil refinery, and several power stations. The chlor-alkali plant is situated 2 kilometres south of Lake Balkyldak and 5 kilometres east from the River Irtysh (Fig. 10). The lake is an artificial storage pond formed from a natural depression without an outlet and has an estimated surface area of approximately 15 km^2.

Construction of the Pavlodar Chemical Plant was started in 1965. The chlor-alkali plant started production with 72 mercury cells ten years later, in 1975. The next 8 mercury cells started functioning in 1984 so the electrolysis building contained a maximum of 80 mercury cells. Since 1986 when major repairs were conducted 68 mercury cells were in operation until the end of mercury based chlor-alkali production. The design load of metallic mercury for one cell amounted 2.4 tonnes, while the scheduled load was 2.75 tonnes. The annual industrial output of the chlor-alkali plant was equal to 112,700 tonnes of caustic soda and 100,000 tonnes of chlorine. After the production of chlorine and caustic soda was terminated in 1993, the mercury cell chlor-alkali plant was completely dismantled, with the majority of debris and contaminated soil consigned to an on-site landfill lined with 0.5 metre of clay and 2.5 metres of cement, and capped with both clay and asphalt. In 2011, the factory has once again commenced production of chlorine and caustic soda following a transition to membrane cell electrolysis.

Total mercury losses to the environment during plant operations between 1975 and 1993 have been estimated at approximately 1000 tonnes through both atmospheric mercury emissions and the seepage of elemental mercury into the soil and groundwater (Lushin et al. 1990). Industrial and domestic waste-water from the plant was discharged to the Lake Balkyldak. The lake received industrial waste-water from about 1970, and mercury-containing waste-water from 1975 when the chlor-alkali plant started production. Apart from mercury, waste-waters also contained other heavy metals, sulphate, and organic pollutants.

The factory itself was located on a semi-consolidated sand aquifer, primarily comprised of coarse and medium-grained sand, with limited quantities of fine-grained sand and clay and with a relatively shallow groundwater table located 10 metres below the surface. Therefore large amounts of mercury have seeped through the soil below the plant and have entered to groundwater. In addition, soils at the plant and in its surroundings have been contaminated by atmospheric mercury emissions, and a considerable amount of mercury has entered the nearby lake.

The ineffective operation of the waste-water treatment plant at the factory has resulted in the majority of the mercury in the waste-water entering the lake. The chlor-alkali plant contained an integrated waste-water treatment plant where effluents were treated by sulphide precipitation. The treated waste-water was pumped via a 5000 m^3 accumulator tank to the lake. However, as the treatment plant was not working effectively, until 1979 the majority of the mercury in the waste-water has entered the lake. Typical waste-water volumes at the time were 20–25 $m^{3/}$/h, and total mercury concentrations were generally between 15 and 40 mg/l. From 1979 onwards the waste-water was cleaned by an ion exchange unit and was pumped to evaporation ponds which had been specifically constructed for this purpose by the lake. Overall, these sludge lagoons are thought to have received between 2.0 and 2.5 t of mercury with waste-water, and up to 150 t of mercury with sludge from brine purification and other solid mercury containing wastes. Direct mercury inputs to the lake with waste-water up to 1990 are thought to be on the order of 10 to 15 tonnes (Lushin et al. 1990).

2.6.2 Mercury contamination of the area

The former mercury cell chlor-alkali plant near Pavlodar operated for 18 years and caused serious widespread contamination of the surrounding environment with mercury. The most contaminated was Lake Balkyldak which appears to be receiving continued mercury inputs via the old outfall pipe. (Ullrich et al. 2007a). But also other aquatic ecosystems were impacted. Sediments from the River Irtysh were only slightly impacted, but compared to the river channel mercury concentrations in sediments, water, and fish were higher in the oxbow lakes, which is likely due to surface run-off from the surrounding flood plain.

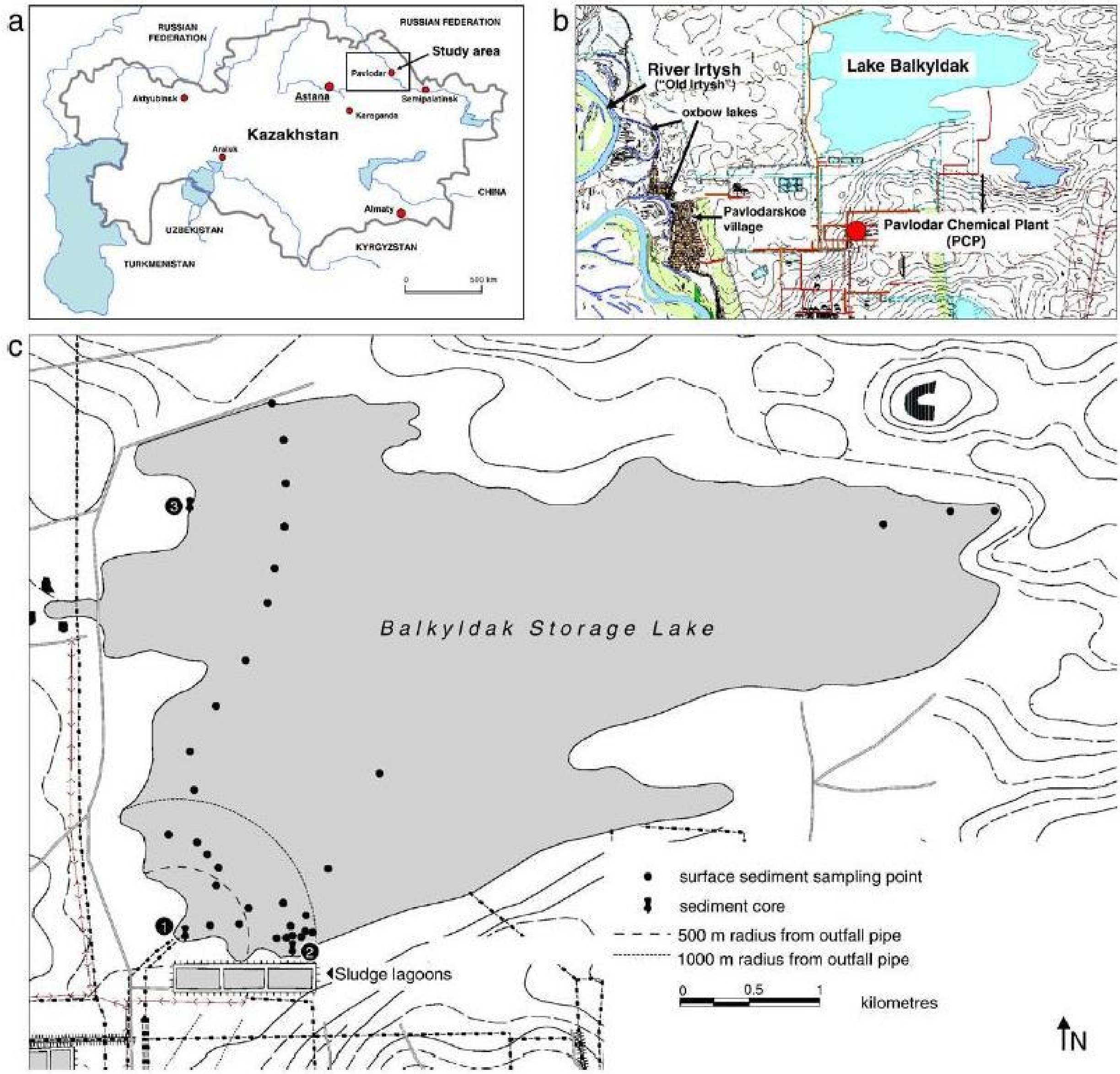

Fig. 10: a) Map showing the location of Pavlodar in Kazakhstan. b) Map of the Pavlodar Industrial Zone with key areas indicated. c) The Balkyldak Lake – the outfall pipe from the factory is indicated by dashed and dotted line and effluents enter the lake close to point 1. Source: Ullrich et al. 2007a.

2.6.2.1 Mercury in water and sediments of the Lake Balkyldak

Sediments from the Lake Balkyldak are very heavily contaminated with mercury (Tab. 9). The total mercury concentrations in the surface layer reaching up to 1500 mg/kg near the waste-water outfall pipe (Ullrich et al. 2007a). Contaminated lake sediments are prone to wind-driven resuspension and are acting as a strong source of mercury to the water column. Mercury concentrations in unfiltered water samples ranged from 0.11 μg/l, in the less contaminated northern part of the lake to 1.39 μg/l near the pollutant outfall in the south, but can reach up to 7.3 μg/l on windy days (Ullrich et al. 2007a). A comparison with other aquatic systems contaminated by mercury from chlor-alkali plant, effluents indicate that the Lake Balkyldak could be the most severely impacted lake ecosystem known to date.

Tab. 9: Mercury concentrations in surface sediments of the Lake Balkyldak, the River Irtysh and oxbow lakes near Pavlodarskoye village. Source: Ullrich et al. 2007a.

site	sediment depth [cm]	number of samples	mean total mercury concentration (range) [mg/kg]
Lake Balkyldak	0-2.5	23	151.5 (0.36-617)
	2.5-5	23	48.9 (0.41-439
River Irtysh	0-10	16	0.012 (0.001-0.046)
	10-20	16	0.009 (0.001-0.040)
Oxbow lakes	0-10	9	0.148 (0.020-0.280)
	10-20	9	0.157 (0.010-0.360)

2.6.2.2 Mercury in aquatic biota of the Lake Balkyldak and the River Irtysh

Several species of fish were investigated from the highly polluted Lake Balkyldak and from the River Irtysh and floodplain oxbow lakes. Mercury levels in fish caught from the lake (Tab. 10) ranged from 0.16 to 2.2 mg/kg (Ullrich et al. 2007b). The majority of fish exceeded current human health criteria established by the WHO for mercury (WHO 2004). Fish from the River Irtysh and floodplain oxbow lakes contained between 0.075 and 0.159 mg/kg of mercury.

Tab. 10: Mercury concentrations in different species of fish caught in the Lake Balkyldak. Source: Ullrich et al. 2007b.

species	number of samples	mean total mercury concentration (range) [mg/kg w.w.]
Carp	30	0.96 (0.54-1.39)
Dace	7	1.31 (0.98-2.20)
Trench	15	0.59 (0.16-1.12)
River perch	3	0.70 (0.19-1.68)
all samples	55	0.89 (0.16-2.20)

2.6.3 Potential threat for humans

The highly contaminated lake presents a significant risk to human health and the environment. Ullrich et al. (2007a) stated in their scientific research that “the highly contaminated Lake Balkyldak poses a threat and is in need of remediation”.

Although the lake is not a natural lake but a waste-water storage reservoir, it is used regularly by fishermen who catch fish both for their own consumption and for selling it on the local market. This raises potentially serious health concerns, as inorganic mercury can be microbially methylated and transformed into organic methyl-mercury. Because of the past and present usage of the lake as a waste-water settling pond, fish are also likely to contain other pollutants, such as persistent organic pollutants, and heavy metals. For these reasons the consumption of contaminated fish from the lake presents a significant health risk. Unfortunately, according to the sociological investigation in the area (Kajenthira et al. 2012) risk alerts are unlikely to achieve the desired effect of stopping people from fishing in the lake.

Soils nearby the former plant were found to be impacted by past atmospheric emissions of mercury. Cattle grazing in the surroundings of the factory are exposed to mercury from contaminated soils, plants, and surface water. The most vulnerable to the contamination of these terrestrial ecosystems is the village of Pavlodarskoye with population approximately 5,000. The village is situated directly by the River Irtysh approximately 4–5 kilometres from the former plant.

2.7 The Karbid acetaldehyde plant in Temirtau (Kazakhstan) – mercury contamination of the River Nura

2.7.1 Background and history

The Plant of Synthetic Rubber or “Karbid” chemical factory in the North Central Kazakhstan was similar to the infamous Chisso plant at Minamata in Japan. The factory operated for nearly 50 years, using mercuric sulphate as a catalyst for the production of acetaldehyde, the main component for the production of synthetic rubber. The abandoned factory is situated in an industrial area including a coal-fired power station, a steel works, and chemical production plants. The industrial area is situated on the west bank of Samarkand Reservoir on the Nura River north-west of Temirtau, city with 170,000 inhabitants in the Karaganda Region (Fig. 11).

The River Nura where the factory discharged untreated and partially treated waste-water is a major watercourse in the semiarid steppe of the northeast-central Kazakhstan. The river is about 978 kilometres long and drains an area of 58,100 km^2. The river rises in the Karkaralinsk Mountains in the north-east and passes through the heavily industrialised Karaganda Region before it flows a further 260 km to Astana, and on to the internationally important terminal wetlands of the Kurgaldzhino National Park, one of the most important wetland sites in Central Asia which is listed as a UNESCO World Heritage Site.

The acetaldehyde production with mercury catalyst in the Plant of Synthetic Rubber started-up in 1950. The annual production capacity was approximately 76,500 tonnes of acetaldehyde. Waste-water from the acetaldehyde plant where mercury was used as a catalyst was discharged to the River Nura without treatment for a period of more than 25 years. During this time, total mercury concentrations in the effluent are suspected to have reached up to 50 mg/l, and the average annual input of mercury to the river between 1950 and 1976 has been estimated as 22-24 tonnes.

From the mid-1970s, waste-water received partial treatment by sulphide precipitation, and the amount of mercury entering the river was considerably reduced. The treated waste-water was then sent to a municipal sewage works where part of the remaining mercury was bound to an organic solid waste fraction. The mercury containing waste-water was eventually discharged into the Zhaur swamp, through the main waste-water channel passing through the Chkalovo village. The Zhaur swamp is drained by a channel flowing into the River Nura, 9 km downstream from the Samarkand Reservoir.

In later years the amount of mercury entering the river decreased further due to a reduction in the overall level of acetaldehyde production. During the 1980s and most of the 1990s, approximately 1 tonne of mercury annually entered the river. The acetaldehyde plant finally closed in 1999, but in total between 2000 to 3000 tonnes of mercury was discharged into the River Nura and surrounding areas from the plant. Facilities and buildings have been dismantled. In addition, excavation of soils within the industrial area and in the vicinity of the plant has been carried out. Contaminated materials have been disposed at the special landfill. Mercury contaminated technogenic silt deposits along the River Nura bank have not been treated due to shortage of funds.

The project of the World Bank ($60 million from World Bank and $60 million from Kazakhstan Government) to clean the River Nura of mercury was realized in 2005-2013. As a criterion for cleaning, the mercury content of 10 mg/kg was used for selection of sediment for decontamination. About 3.5 million cubic meters of contaminated materials was excavated and buried near Temirtau, but the contractors CGS Ltd. (China) and Poch & Partners (Austria) flagrantly violated numerous project requirements and legislation. As a result there was additional contamination of water, soils, and the residential areas. Sediment removal was conducted with numerous violations and without any measures to ensure environmental safety. Many of the project's activities had not been implemented. A World Bank examination confirmed violations of requirements, but failed to change the behaviour of contractors.

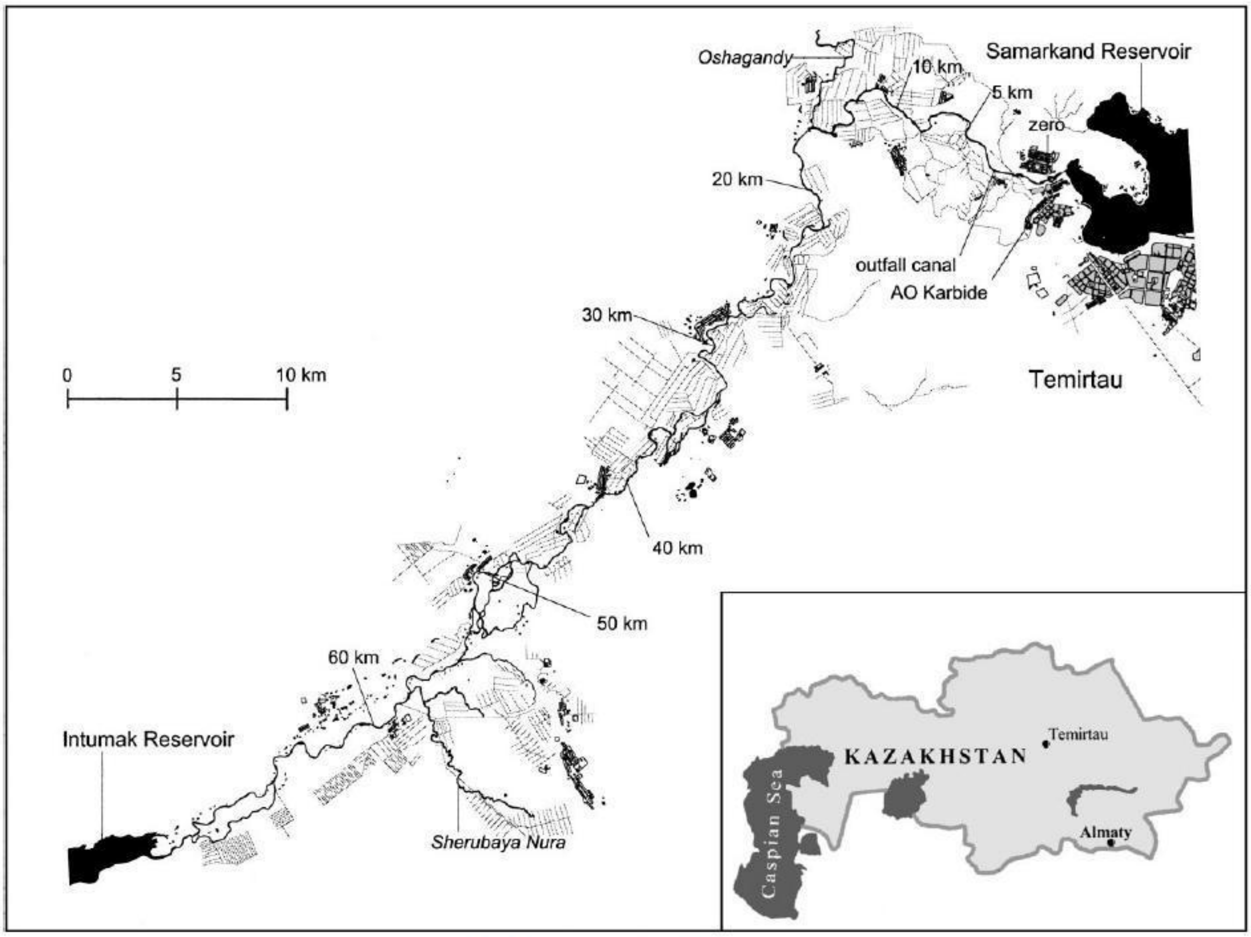

Fig. 11: Localization of the former acetaldehyde plant Karbid in Kazakhstan and a map of the River Nura floodplain between the Samarkand and Intumak reservoirs. Source: Heaven et al. 2000a.

2.7.2 Mercury contamination of the area

Despite the closure and the decontamination of the plant, there is still high mercury contamination of the surrounding area and a long stretch of the River Nura. Mercury has been found in the soils of the factory's surroundings, the waste-water treatment works, River Nura sediments, floodplain soils, river fish, and hair of people living in the city of Temirtau, and nearby villages, all of which are now highly contaminated.

2.7.2.1 Mercury in water and sediments of the River Nura

High levels of mercury were found in river bed sediments, particularly in the first 25 km downstream from the waste-water discharge in Temirtau, with the average total mercury concentration of 150–240 mg/kg in this section and the mercury levels in excess of 200 mg/kg in the first 9 km from the source (Heaven et al. 2000a). Investigation by Ullrich et al. (2007c) found that mercury concentrations in river sediments reached up 306 mg/kg in the most contaminated section. The total volume of contaminated silts in the riverbed between Temirtau and the Intumak Reservoir, located 75 km downstream, has been calculated as 463,500 m^3. Forty-six percent of the volume of contaminated silts is located in the upper 25 km of the river (Heaven et al. 2000a). The mercury distribution in the river bed clearly indicates that large quantities of polluted sediment are removed from the river bed in times of flood and deposited on the low-lying lands adjacent to the river. The most recent report by Arnika Association (Šír 2015), conducted after the clean-up project finished in 2013, documented high mercury concentrations of sediment at many sampling points. The highest mercury level was as high as 174 mg/kg.

A peak of mercury concentrations of unfiltered surface water, during a larger than usual flood event in 2004, was in the order of 1600–4300 ng/l (Ullrich et al. 2007c). The majority of the particulate-bound mercury in silt in the river is suspended in the Intumak Reservoir. Background concentrations of mercury in the river water are not reached until at least 200 km downstream of the source of pollution, and during the flood period mercury is also detected in the terminal wetlands of the river.

Tab. 11: Dissolved and suspended mercury concentrations in water of the River Nura. Source: Heaven et al. 2000a.

locality	number of samples	mean total mercury concentration (range) [µg/l]
2.5 km upstream from the outfall	6	0.13 (0.04-0.2)
the outfall canal	8	2.49 (0.46-5.36)
3 km downstream from the outfall	12	0.77 (0.52-1.03)
50 km from the outfall	12	0.47 (0.19-0.79)
Intumak Reservoir (outlet)	4	0.84 (0.73-1.03)

2.7.2.2 Mercury in soils of the River Nura floodplain

Over the past 40 years a large proportion of the contaminated sediments from the river were deposited on the 70 km of banks and in the floodplain below the pollution source (Fig. 12). During spring floods the highly contaminated silts are transported downstream and are dispersed over the floodplain, leading to widespread contamination of the land. Mercury concentrations in the top-soils of the floodplain reached up 100 mg/kg (Heaven et al. 2000b). The mean mercury concentrations in river bank deposits was 73.3 mg/kg in the most contaminated section of the river and remains as high as 13.4 mg/kg at a distance of 70 km downstream from the waste-water discharge.

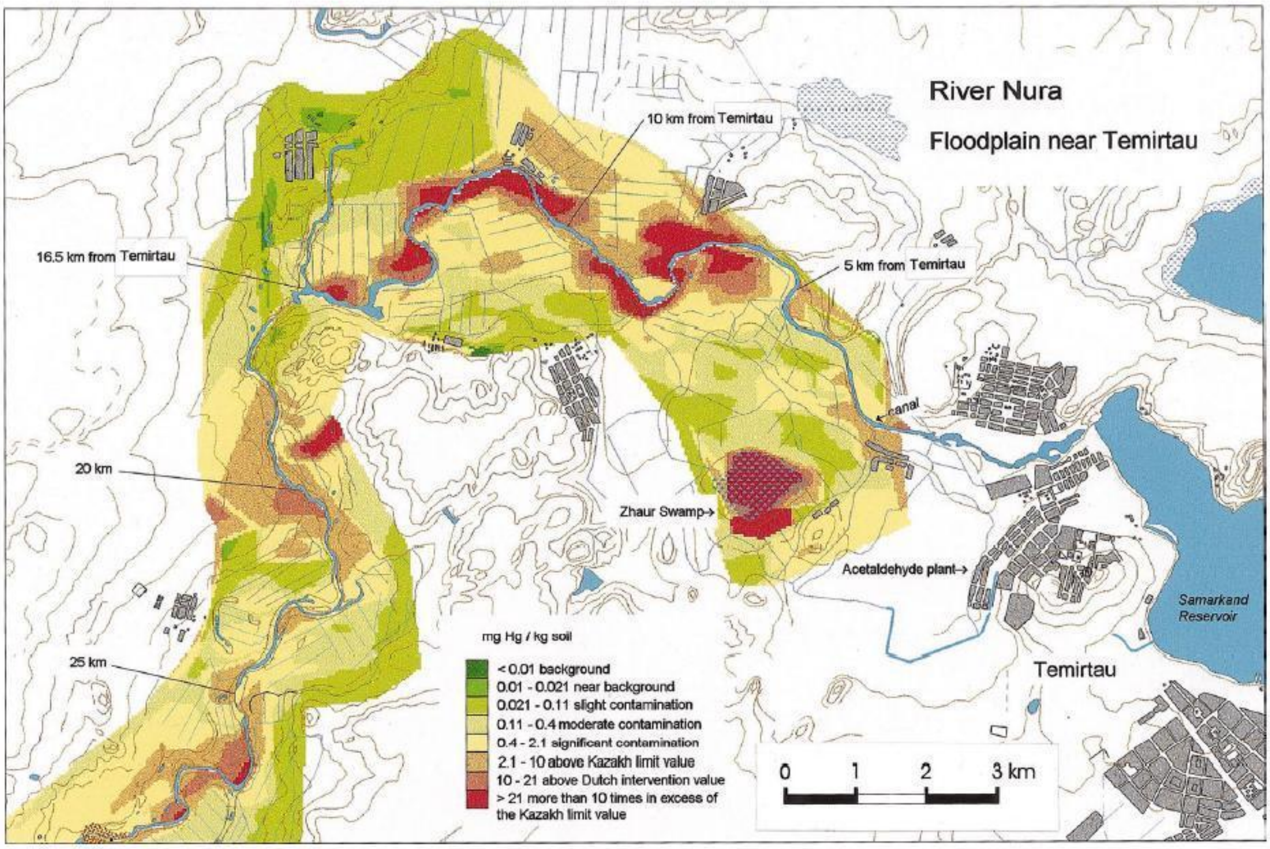

Fig. 12: Spatial distribution of mercury in the top-soils of the floodplain in the first 25 km from Temirtau. Source: Heaven et al. 2000b.

2.7.2.3 Mercury in fish and other biota in the River Nura

Mercury concentrations in biota in the most contaminated section of the river were 15–20 times higher than background levels. Mercury concentrations in narrow-leaf cattail *(Typha angustifoli*a) growing on the banks of the river was 0.63 mg/kg near the effluent outfall channel (Ullrich et al. 2007c). Fish in the river are impacted for more than 125 km downstream from the source. Bottom feeding fish (roach, carp, bream, and gudgeon) are predominant in the most contaminated section of the river. These species are contained on average between 0.3 and 0.5 mg/kg w.w. of mercury. This does not exceed the threshold of 0.5 mg/kg w.w. established by the WHO (WHO 2004), but is higher than the EPA (US EPA 2001) reference dose of 0.22 mg/kg. Mercury levels in predatory fish species such as perch were even higher than in bottom feeders and reached up to 0.94 mg/kg w.w. at the Mill house dam (14.2 km from the waste-water discharge) (Ullrich et al. 2007c). Elevated mercury levels of fish caught in the Intumak Reservoir were also reported by Ministry of environment of the republic of Kazakhstan. Mean mercury levels of carp (*Cyprinus carpio* L.) and bream (*Abramis brama*) were 0. 41 mg/kg w.w. and 0.31 mg/kg w.w. respectively (Ministry of Environment of the republic of Kazakhstan, Republican State Enterprise „Kazhydromet“ 2013). These concentrations exceeded maximal allowed levels of mercury for freshwater fish in Europe and Kazakhstan which is set at 0.3 mg/kg w.w. of mercury. The latest report by Arnika Association (Šír 2015) detected the highest mecury levels of fish caught from Intumak Reservoir which exceeded also WHO limits. Mercury levels of perch (*Perca fluviatilis*) and roach (*Rutilus rutilus*) from the reservoir were 1.38 mg/kg w.w. and 0.63 mg/kg w.w. respectively. This report also shows that methyl-mercury contributes significantly to total mercury levels of fish from the reservoir.

2.7.3 Potential threat for human health

Mercury concentrations in hair of 289 Temirtau residents reached up to 5.184 μg/g with a mean of 0.577 μg/g (Tab. 12). Nearly 17% of the population exceeded 1 μg/g for hair mercury, which corresponds to the reference of dose 0.1 μg/kg body weight/day developed by the United States Environmental Protection Agency (Hsiao et al. 2011). Especially, anglers have elevated mercury exposure levels in their hair. Moreover there is positive correlation between mercury concentrations in hair and frequencies of river fish consumption. Hence, people are exposed to high levels of mercury due to the frequent consumption of fish caught from the polluted River Nura or the neighbouring lakes.

Tab. 12: Mercury concentrations in hair of residents in different municipalities around the former chlor-alkali plant in Temirtau. Source: Hsiao et al. 2011.

place	number of samples	mean total mercury concentration (range) [μg/g]
Temirtau old town	50	0.396 (0.021-2.690)
Temirtau new town	52	0.458 (0.052-4.947)
Chkalovo	45	0.512 (0.057-4.558)
Gagarinskoye	67	0.388 (0.009-4.083)
Samarkand	42	0.806 (0.014-4.620)
Rostovka	32	1.244 (0.165-5.184)
total	288	0.577 (0.009-5.184)

Several thousand people live in the polluted valley of the River Nura. People who live in the residential area of Temirtau and the riverine villages use the water from the channel, wells, and the river as an important water supply. The water is extensively used for domestic water supply, livestock watering, and irrigation of gardens, as well as for recreation and commercial fishing. Lifestyles of local people vary, depending on the inhabitation and family financial status. Some residents maintain their livelihoods by working in the industries in Temirtau, whilst others tend to consume home-produced food such as vegetables and beef and locally caught fish. Consumption of local food results in mercury accumulation in the residents' bodies. According to the screening studies (Hsiao et al. 2011, Hsiao et al. 2010) the most vulnerable groups are males, people aged over 45, and anglers who have elevated mercury levels in their hair.

A especially significant health threat for humans is the formation of highly toxic methyl-mercury in the river sediment that was also found at less contaminated sites downstream from the source of contamination. Methyl- mercury levels in river sediment ranged between 4.9 and 39 µg/kg (Ullrich et al. 2007c).

2.8 Former Soda-PVC plant in Vlora (Albania) – a hot-spot of mercury contamination

2.8.1 Background and history

North of Vlora in Albania is the site of a former chemical manufacturing complex consisting of a chlor-alkali plant and plants for production of VCM and PVC plastic. In July 2002, a mission of UNEP had identified this site as a mercury pollution "hot-spot" (Lazo et Raif 2013). The former chemical factory is situated in a sandy area positioned near the Vlora Bay, a part of the Adriatic Sea, along a coastal forest, following the Vlora-Zvërnec Road. It covers an area of about 20 ha. Between the former chemical factory and the coast there is another area used as dump for disposal of contaminated sludge. The former chemical complex is located five kilometres north of the city of Vlora and about four kilometres from the Narta Lagoon. Vlora with 80,000 inhabitants is the biggest city located in the south-west part of Albania.

The factory called "Soda PVC Plant" started operation in 1967. During its normal operation the factory produced three main products: caustic soda, soda and PVC plastic. At its peak, the plant produced 15,000 tonnes of caustic soda and 10,000 tonnes of PVC plastic annually. Mercury chloride adsorbed to activated carbon as a catalyser was used for producing VCM. Mercury was also used as the cathode during the process of the electrolysis of salt water in electrolysis cells. The periodic cleaning of the mercury cells and of filters of activated carbon caused the mercury pollution of the area during the operation of the plant. Liquid wastes with a volume of about 500 m^3/h containing 1.1 mg/l of mercury were discharged directly into the Vlora Bay, without any treatment. The polluted sludge was deposited in an open dump (25 ha) very near the seashore, during the period 1977-1983 and was estimated at about 65 tonnes.

The plant was closed in 1992, and its buildings have been completely destroyed since that time. However, the dumped sludge remains near the shore with no precautions taken to prevent further contamination of the bay or nearby residents. Families live on and around the former chemical complex. The first residents arrived after the factory had ceased operation in 1992; others came fleeing the civil uprising in 1997. UNEP (2000) reported that "families with domestic animals are living in extremely hazardous, mercury contaminated conditions at the area of the former PVC factory". Government efforts to relocate these families have been ineffective. While there are no exact up-to-date figures on number of families residing at the site and on their exact distribution, the estimate is that several dozens of families remain living on the site (CEE Bankwatch 2008).

In 2001 the Czech government approved the allocation of EUR 792 000 for the revitalisation of the mercury contaminated area in the former factory. Over the course of the project lifetime

(2002-2006) Czech GEOtest Brno a.s. and German Research Centre for Biotechnology assessed mercury contamination, designed a decontamination technology and cleaned up the mercury contamination epicentre – the electrolysis plant. Mercury contamination at the remaining parts of the former chemical complex and its vicinity was left without treatment and the majority of contamination remains on the site.

2.8.2 Mercury contamination of the area

The mercury contamination at the former chemical complex and its vicinity has been widely reported for more than one and half decades. Very high mercury concentrations were found in soils and in air at the factory site. UNEP observed drops of metallic mercury in the hall of the electrolysis plant and in all of its drainage channels. As a result of spreading contamination, high concentrations of mercury were found in the sediments, seawater, and biota in the area near the former factory (Lazo et Raif 2013).

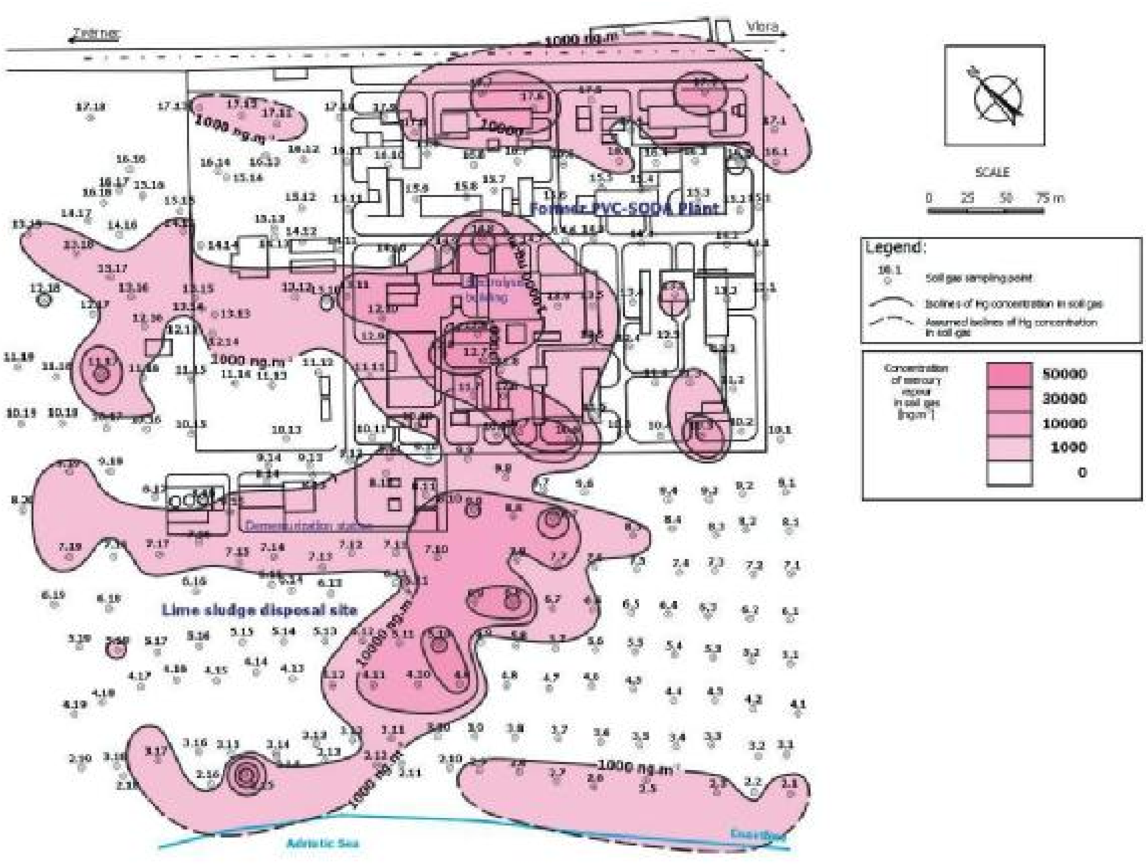

Fig. 13: A map of mercury concentrations in soil gas at a depth of 0.3 – 0.5 below the ground level at the former chlor-alkali plant in Vlora. Source: Bicaku et Abeshi 2007.

2.8.2.1 Mercury in soil and air at the former PVC plant

The soil territory of about 50,000 – 60,000 m^2 of the former factory is contaminated with mercury to a depth 1.0 – 1.5 meters below the ground level (Fig. 13). The most contaminated territories were the electrolysis and the polymerization plants where the mean mercury concentrations in soil were 311.8 mg/kg d.m. and 398 mg/kg d.m., respectively (Lazo et Raif 2013). The content of mercury in sludge deposited between the factory and the seashore ranges from 0.33 to 156 mg/kg (Beqiraj et al. 2008). The contaminated soils and sludge are a source of contamination of a larger area. Mercury levels in soil is increased in the western direction of the plant towards the seashore. This is caused by the transport of mercury by erosion during the rainy season. The transport of mercury from soils to the seawater and marine sediments will continue for many years.

Very high levels of mercury vapour are in the ambient air on the site of the former chemical complex (Fig. 14). According to scientific investigations, mercury concentration in ambient air exceeded the emission limit of 50 ng/m^3 in about 40 % of measurements. The maximum reached 50,000 ng/m^3 (Lazo et Raif 2013).

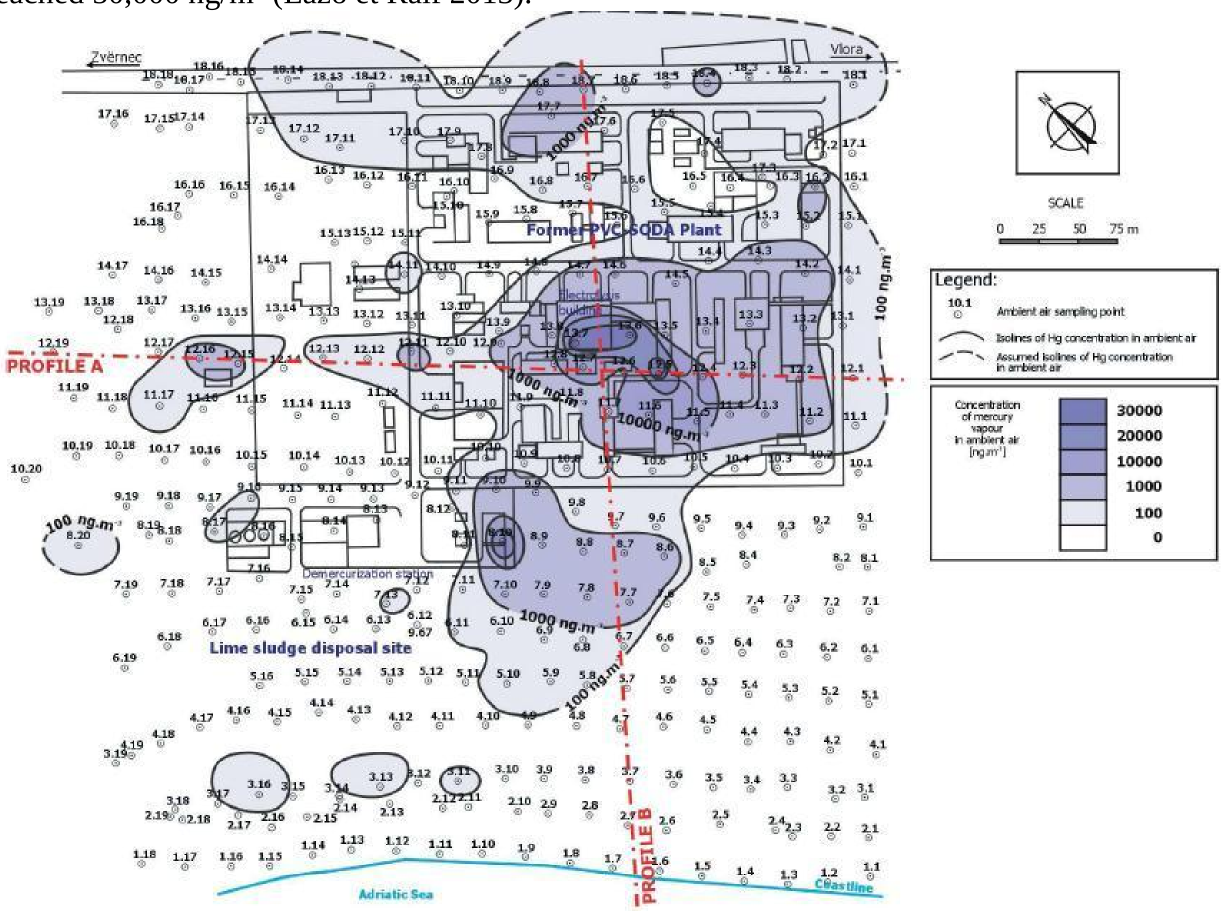

Fig. 14: Map of mercury concentrations in ambient air at 0.15 metre above ground level at the former chlor-alkali plant in Vlora. Source: Bicaku et Abeshi 2007.

2.8.2.2 Mercury in sediments and seawater

Both marine sediments and water samples taken near the plant showed high levels of mercury. The mercury concentration of 0.68 mg/kg was found in marine sediment as far as 700 metres from shoreline (Çullaj et al. 2004). Similarly marine water has elevated mercury levels in the Vlora Bay. The average mercury concentration in marine water is 0.1 mg/l in distance 300 metres from the shoreline (Qarri et al. 2014). These data show that the mercury contamination can affect life in the semi-enclosed Vlora Bay.

2.8.2.3 Mercury in biota

Biota in the Vlora Bay and its surrounding is already widely contaminated by mercury. Many scientific reports showed elevated mercury concentrations in algae, plants, mussels, and fish in the bay. A mean mercury concentration in green algae *Cladophora* from the bay was 0.271 mg/kg (Tab. 13) (Mankolli et al. 2008). A concentration of mercury in shoots of *Medicago sativa L.* reached 12.9 mg/kg on the most contaminated area of the former chemical complex (Tab. 14) (Shehu et al. 2014). A mercury concentration in Mediterranean mussel (*Mytilus galloprovincialis*) was in range 0.17-0.26 mg/kg d.m. (Corsi et al. 2011).

Tab. 13: Mercury concentrations in the plants taken from the area close to the sea coast near the former chlor-alkali plant in Vlora. Source: Mankolli et al. 2008.

plant species	**mean total mercury concentration [mg/kg]**
Juncus acutus	0.155
Phlomis fruticosa	0.213
Cardus pycnocefal	0.158
Graminace sp.	0.174
Kladofora sp.	0.271

Tab. 14: Mercury levels in plants near the former chlor-alkali plant in Vlora. Source: Shehu et al. 2014.

plant species	**mean total mercury concentration [mg/kg]**
Dittrichia viscosa (L.) W. Greuter	5.14
Echium plantagineum L.	0.19
Tamarix dalmatica Baum.	5.34
Zea mays L.	3.33
Limonium anfractum Salmon.	0.79
Euphorbia paralias L.	1.71
Crithmum maritimum L.	4.36
Medicago sativa L.	12.92
Phragmites communis Trin.	0.21
Typha angustifolia L.	0.20
Imperata cilindrica (L.) P.B	0.64

The most considerable is mercury levels in fish, because the Vlora Bay is important fishing area. The study made by the Arnika Association, Eden Center and IPEN in 2013 reported that a mean mercury concentration in mullet *(Mullus surmuletu*s) was 0.617 mg/kg w.w. (Eden Center et al. 2013) and a majority of mullets exceeded current human health criteria for mercury established by the WHO (WHO 2004) and was nearly three times higher than the EPA (US EPA 2001) reference dose of 0.22 mg/kg. Other studies have also found high mercury levels in fish from the area. A mercury concentration in muscle of red mullet *(Mullus barbatu*s) from the bay reached 1.06 mg/kg d.m. (Corsi et al. 2011). In the 1990s, mercury levels of 0.14 ppm - 3.39 ppm were found in small sharks *(Galeus melastomu*s) from the Adriatic Sea (Storelli et al. 1998).

2.8.3 Potential threat for humans

The mercury contamination of the area has existed at high levels for more than two decades. Very high concentrations of mercury in the territory of former plant present a real threat to the residents living very near the former chemical complex. The same conclusion was reached by Mankolli et al. (2008) who found high mercury levels in plant species at the site and concluded that "the area presented in the survey requires urgent intervention by means of mid and long term projects, because of the high content of mercury. This area with the high mercury content becomes a cause not only for environmental pollution, but also pollution in animal and human beings".

The main intake of mercury for humans – the fish is distributed from the Vlora Bay to all cities in Albania. Moreover, the bay is of paramount interest to the Albanian fishing industry since it serves as a natural nursery for many fish species of economic importance. To prevent continuous mercury contamination of sea ecosystems and fish serving as food for the local community and tourists in Vlora, there are few measures to prevent further releases from the contaminated area and wastes into the sea. Offshore breakwater structures were built around the coast near the mercury contaminated area. In addition, there is a protective wall on the coast between dumped sludge and the sea. But only a complete decontamination of the site can stop releasing mercury to both the local environment and contribute to global mercury pollution. Realization of an environmental remediation plan should be priority of an Albanian government.

2.9 Comparison of mercury emissions and contamination at the study sites

Mercury is released from chemical plants into different environmental compartments: product, soil, water, and air. Moreover mercury is transferred in wastes for disposal. Emission

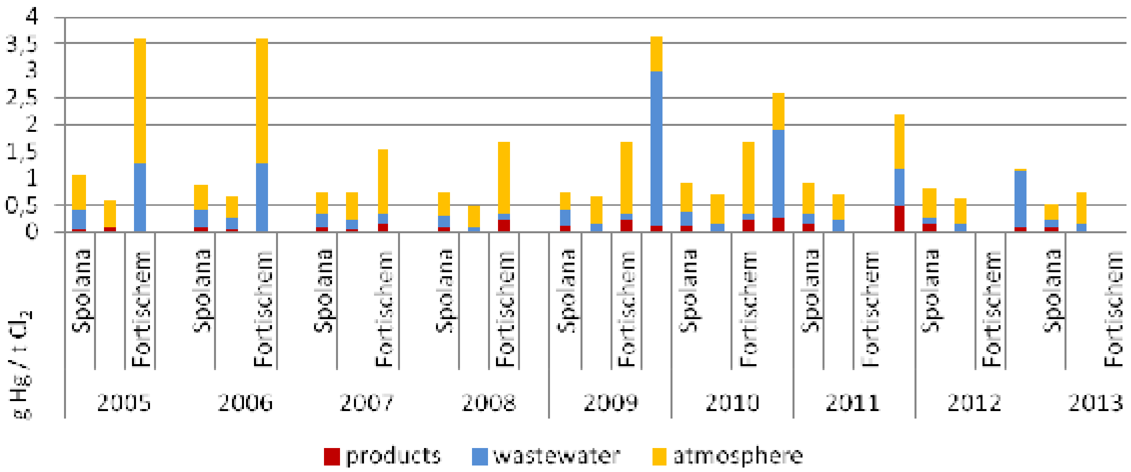

Fig. 15: Relative mercury emissions into different environmental compartments from specific facilities in the CEE region are expressed in grams of mercury per one tonne of produced chlorine. Mercury emission data from 2005 to 2013 according EuroChlor (EuroChlor 2015).

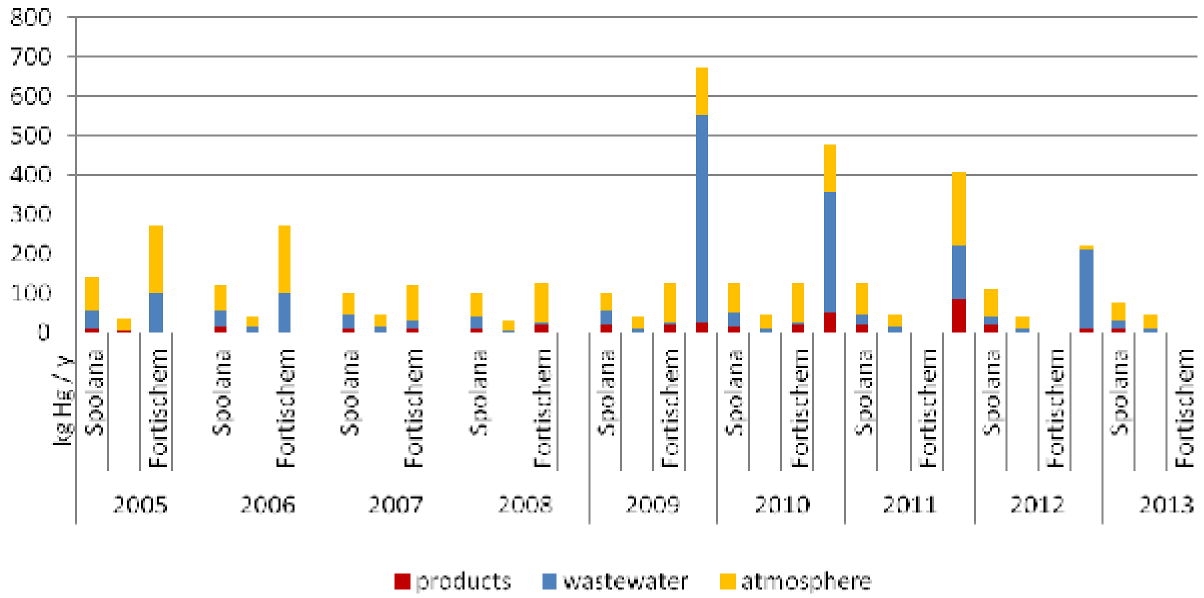

Fig. 16: Total mercury emissions into different environmental compartments from specific facilities in the CEE region are expressed in kilograms of mercury per one year. It is calculated according to the mercury emission data and chlorine production capacity published by EuroChlor (EuroChlor 2015).

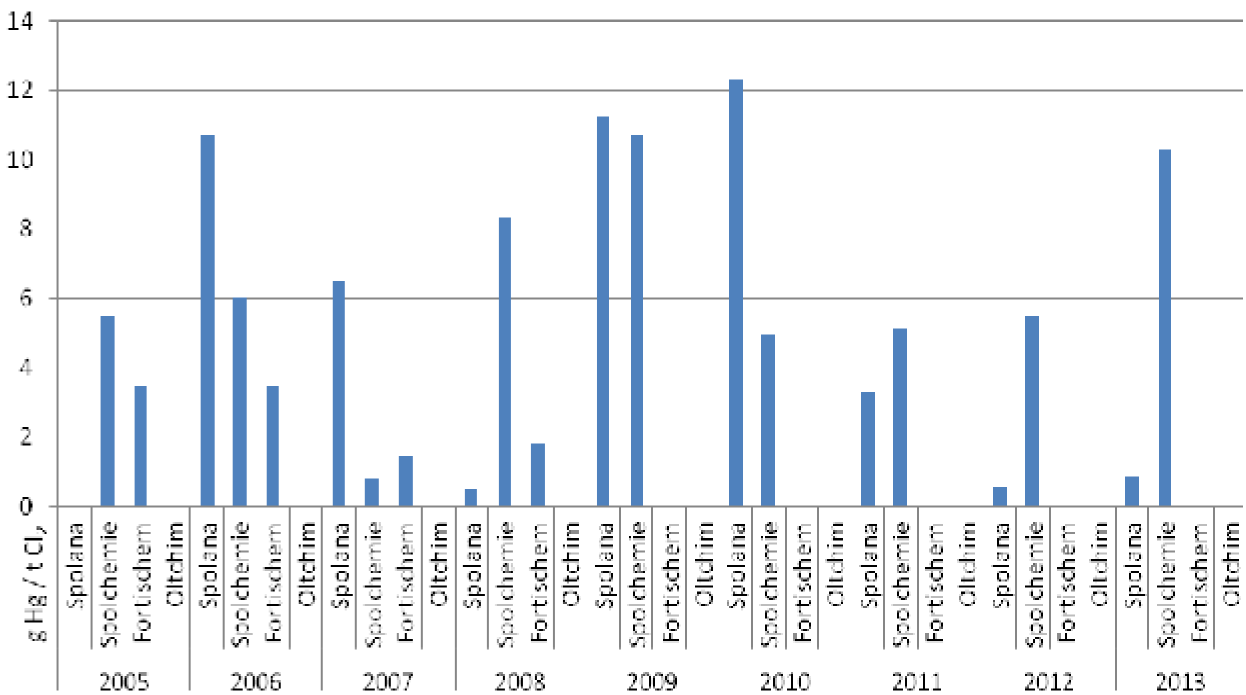

Fig. 17: Mercury transferred in wastes for disposal from specific facilities in the CEE region, expressed in grams of mercury per one tonne of produced chlorine. According mercury emission data from 2005 to 2013 published by EuroChlor (EuroChlor 2015).

data collected by EuroChlor for all recent chlor-alkali plants referred to in this study since 2005 are presented below. There are relative mercury emissions and total mercury emissions in Fig. 15 and Fig. 16 respectively. Fig. 17 shows mercury transferred in wastes for disposal.

Mercury levels in fish are a suitable indicator of mercury contamination of the environment in consideration of human intake of toxic methyl-mercury. Tab. 15 shows mercury levels of non-piscivorous fish collected in the most contaminated water bodies polluted by the chemical plants referred to in this study. All mercury levels in this table exceed the threshold of 0.5 mg/kg wet weight (w.w.) established by the World Health Organisation (WHO) for total mercury in non-carnivorous fish. As mercury concentrations increase with trophic level, mercury concentrations in carnivorous fish are still higher (Tab. 16).

Tab. 15: Mean levels of mercury in muscle of non-piscivorous fish on contaminated site.

Chemical factory	**Place where fish were caught**	**Fish species**	**Mean mercury level [mg/kg w.w.]**	**Reported by**
Spolana in Neratovice	the River Labe at Obříství	bream (*Abramis brama L.*)	0.85 (n = 2)	Žlábek et al. 2005
Spolechemie in Ústí nad Labem	the River Labe at Hřensko	bream (*Abramis brama L.*)	0.6 (n = 5)	Žlábek et al. 2005
Marktredwitz Chemical Factory	the Skalka Reservoir	bream (*Abramis brama L.*)	0.96 (n = 8)	Maršálek et al. 2005
Fortischem in Nováky	the River Nitra at Partizánske	roach (*Rutilus rutilus*)	1.9 (n = 8)	Andreji et al. 2005
Oltchim in Râmnicu Vâlcea	the Babeni Reservoir	common bleak (*Alburnus alburnus*)	2.8 (n = 7)	Bravo et al. 2010
Chemical Complex in Pavlodar	the Lake Balkyldak	Siberian dace (*Leuciscus baicalensis*)	1.31 (n = 7)	Ullrich et al. 2007b
Karbid in Temirtau	the Intumak Reservoir	roach (*Rutilus rutilus*)	0.63 (n = 2)	Šír 2015
Soda PVC Plant in Vlora	the Vlora Bay	red mullet (*Mullus barbatus*)	1.06 (n = 20)	Corsi et al. 2011

Tab. 16: Mean levels of mercury in muscle of piscivorous fish on contaminated site.

Chemical factory	**Place where fish were caught**	**Fish species**	**Mean mercury level [mg/kg w.w.]**	**Reported by**
Spolana in Neratovice	the River Labe at Obříství	perch (*Perca fluviatilis* L.)	1.5 (n = 2)	Žlábek et al. 2005
Spolechemie in Ústí nad Labem	the River Labe at Děčín	perch (*Perca fluviatilis* L.)	0.5 (n = 5)	Žlábek et al. 2005
Marktredwitz Chemical Factory	the Skalka Reservoir	Asp (*Aspius aspius*)	3.41 (n = 4)	Maršálek et al. 2005
Fortischem in Nováky	the River Nitra at	perch (*Perca fluviatilis*	2.73 (n = 6)	Andreji et al. 2005

	Partizánske	L.)		
Oltchim in Râmnicu Vâlcea	the Babeni Reservoir	perch (*Perca fluviatilis* L.)	1.6 (n = 4)	Bravo et al. 2010
Chemical Complex in Pavlodar	the Lake Balkyldak	perch (*Perca fluviatilis* L.)	0.7 (n = 3)	Ullrich et al. 2007b
Karbid in Temirtau	the Intumak Reservoir	perch (*Perca fluviatilis* L.)	1.38 (n = 2)	Šír 2015

3. Impact of the Minamata Convention on Mercury to contaminated sites in Central and Eastern Europe

This study questions effectiveness of the Minamata Convention on Mercury to protect human health and environment from the harms caused by mercury pollution from current chemical plants and sites contaminated by chemical industry. Although many manufacturing processes using mercury, such as acetaldehyde production or production of polyurethane, are rarely used in modern times, mercury is still frequently used in the following two processes: chlor-alkali and VCM production. These two manufacturing processes are the most common usage of mercury in the chemical industry and continue to release mercury to the environment. As a result of chemical manufacturing processes there are many sites heavily contaminated with mercury. Mercury at these contaminated sites is slowly creeping to surrounding environments and increasingly creates risks for humans in vicinity of contaminated sites. Reported case studies from the CEE and CIS countries arouse one's curiosity about how the Minamata Convention on Mercury might mandate actions 1) to stop further pollution of environment from current chemical plants and 2) to eliminate mercury pollution of the environment and fish from contaminated sites.

3.1 Chemical plants using mercury – locking the barn door after the horse is gone

The mercury treaty takes a range of approaches to manufacturing processes that intentionally use mercury under Article 5. Industrial processes that are subject to prohibition or regulation are listed on Annex B of the mercury treaty. The treaty's approach to different industrial processes is either complete “phase-out” over time or “restriction”, which includes commitment to using less mercury within the industrial process. Phased-out processes using mercury include chlor-alkali production and acetaldehyde production using mercury or mercury compounds as a catalyst. Restricted processes allow continued use of mercury with no current phase out date. These include the production of VCM, sodium or potassium methylate or ethylate, and polyurethane.

Mercury based chlor-alkali and VCM plants are only two kinds of chemical manufacturing facilities still frequently using mercury. VCM production using a mercury catalyst is unique to China and this process is sporadic in the CEE and CIS countries. Although there is a mercury-free alternative of VCM production (chlorination of ethylene), the mercury treaty does not schedule VCM production with mercury catalyst for phase-out. Mercury based VCM production is a potentially enormous source of mercury releases, but this process does not appear in UNEP air emission inventories due to lack of data.

The major issue for the CEE and CIS countries is phase-out date of mercury based chlor-alkali plants. The mercury treaty specifies a phase-out date for mercury based chlor-alkali production in 2025. Under the circumstances it seems not to be an ambitious target in selected regions or worldwide. There are still twelve mercury based chlor-alkali plants in operation in the CEE and CIS countries. As conversion of chlorine production plants is required by EU directive, six of these plants located in EU have phase-out date in 11th December 2017. It is the same case for all current chlor-alkali plants presented in this study and the other two plants (one in Poland and one in Hungary).

The late phase-out date is also evident on a worldwide scale. As many as 29 mercury-based chlor-alkali plants located in EU will cease mercury-based operations by 2017 - eight years before mercury treaty's phase out date in 2025. It is as much as 40% of 73 mercury based chlor-alkali plants across the world. Moreover it could be expected that many other mercury based chlor-alkali plants outside the EU will phase out mercury voluntarily, so the mercury treaty's phase-out date seems to be a case of locking the barn door after the horse is gone. It is similar as the mercury treaty's phase-out date for acetaldehyde production with mercury catalyst in 2018. This process is believed to have already been phased-out.

The late phase-out date for mercury based chlor-alkali plants is unnecessary as *Article 6: Exemptions available to a Party upon request* allows parties to register exemptions from the phase-out dates listed in Annex B. An earlier phase-out date in 2020 could effectively facilitate pressure to simultaneously stop ongoing mercury pollution of the environment from chlor-alkali industry and allow some specific chlor-alkali plants to operate.

3.2 Mercury contaminated sites - the creeping threat

As stated by UNEP in its Global Mercury Assessment "Highly contaminated industrial sites and abandoned mining operations continue to release mercury". The report is even more specific in another instance: "Contaminated sediments at the bottom of surface waters can serve as an important mercury reservoir, with sediment-bound mercury recycling back into the aquatic ecosystem for decades or longer." (UNEP 2002). Moreover, contaminated sites are considered as a significant source of anthropogenic mercury emissions into the atmosphere. The mercury emission from contaminated sites into the atmosphere is in the range of 70-95 tonnes per year that counts 4.2% of total anthropogenic mercury emissions In addition total releases to aquatic environments from contaminated sites are estimated to be 8.3-33.5 tonnes per year (UNEP 2013).

Under *Article 3: Mercury supply sources and trade,* countries are required to "take measures" to ensure that when a chlor-alkali plant closes, the excess mercury is disposed of according to treaty requirements and not subject to recovery, recycling, reclamation, direct re-use, or alternative uses. This is good because it should prevent this mercury from re-entering the market and help to prevent new contaminated sites. However, good mechanisms are still needed to ensure that parties to convention will meet this requirement.

The treaty, in *Article 12: Contaminated sites*, does not require the clean-up of contaminated sites and leaves the matter to voluntary action. The treaty text only states that parties "shall endeavour". Possible voluntary actions include developing strategies for identifying and assessing contaminated sites and actions to reduce risks, incorporating "where appropriate" an assessment of risks to human health and the environment. Considering the lack of action at the mercury contaminated sites such as Pavlodar, Temirtau or Vlora since the chemical factories were closed, voluntary actions to address these sites seem unlikely to happen.

Mercury in soils and sediments at such contaminated sites are still slowly releasing and seeping to the broader environment during hydrological events and make the mercury contamination harder and more expensive to clean up. If we consider that there are dozens of sites contaminated due to chemical industry in CEE and CIS countries alone, it is clear that mercury contamination poses a real and creeping threat for human health and the environment.

In addition, the Conference of the Parties shall adopt a guidance on managing contaminated sites. The guidance on managing contaminated sites includes topics such as site identification and characterization; engaging the public; human health and environmental risk assessments; options for managing the risks posed by contaminated sites; evaluation of benefits and costs; and validation of outcomes. The problem is that the treaty does not provide a deadline for the guidance and its preparation was postponed at the Intergovernmental Negotiating Committee (INC) 6, held in Bangkok in November 2014.

Finally, to address contaminated sites funding will be needed for developing and transition countries. A clause requiring funding was removed by negotiators at the fifth session of the Intergovernmental Negotiating Committee to prepare a global legally binding instrument on mercury in January 2013. However, since the treaty links compliance with funding and since action on contaminated sites is not obligatory, it is likely that no funding will be available through the treaty's financial mechanism to address contaminated sites. Moreover there is no mention of a role for polluters to contribute financially to the clean-up of mercury contaminated sites or any requirement to compensate the victims. This seems to be a major failure of the Minamata Convention in application of "polluter pays" principle.

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