Hindawi Publishing Corporation
International Journal of Chemical Engineering
Volume 2010, Article ID 940206, 9 pages
doi:10.1155/2010/940206

Review Article

Monitoring of Lead in Topsoil, Forage, Blood, Liver, and Kidneys in Cows in a Lead-Polluted Area in Slovenia (1975–2002) and a Case of Lead Poisoning (1993)

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Received 15 January 2010; Revised 4 June 2010; Accepted 30 July 2010

Academic Editor: Josiane Nikiema

The paper presents the results of a prolonged research in a lead-polluted area. Extensive systematic studies of lead concentrations in topsoil, forage, blood, liver, and kidney in cows on farms within 1–10 km around the lead mine and smelter were carried out. After installation of a filter in 1978, lead concentrations began to decrease. However, when toxic levels of lead were within normal reference values, the authorities stopped to finance the project. In 2002, the research was concluded. A review of studies showed that the protective filter was effective; during the period 1975–2002 mean lead in forage dropped from 584.0 ± 324.0 to 5.5 ± 2.9 mg/kg, and the mean blood lead levels dropped from 1.251 ± 0.580 to 0.069 ± 0.041 mg/kg. Three years after the filter was installed the amount of lead in the liver and kidneys had normalized. Closely related to our research was also a case of cow lead poisoning.

1. Introduction

Lead is a bluish white to gray heavy metal that was probably the first toxic element recognized by man. Lead is ubiquitous in the manmade environment, because of its numerous uses and yet still has great relevance today [1]. Very frequent and potential source of lead content in animal tissues are forage produced on agricultural surface or cattle grazing on pastures contaminated by airborne emissions from nearby smelters [2–5]. Chronic and nonapparent poisoning due to ingesting smaller quantities of lead contaminated forage over a longer period of time is characterized by nonspecific signs which may be expressed as loss of appetite, weight loss, reproduction disorders, anemia, osteoporosis and immunosuppression [6–9]. Environmental pollution in the vicinity of lead-ore processing factories can result in varying degrees of poisoning with lead [2, 10–12]. Cows blood lead levels is a good bioindicator of environmental contamination [2, 7, 13]. Concentration of lead in whole blood and milk resulting from the daily exposure to lead does not produce any clinical evidence of disease [13]. In dead and slaughtered animals lead was usually analyzed in the liver, kidneys, and muscles [13–15].

The contamination of food of animal origin with lead in some areas of Slovenia was presented in amounts higher (>0.500 mg/kg WW) than the levels allowed by national guidelines [16]. One of these areas is the Upper Meža Valley. From the point of polluted environment and emissions of lead gasses and dust, the valley is ranked into the 4th class of national classification for environmental pollution [17]. It is an area with stationary contamination of upper layers of soil and with very limited air self-cleansing possibilities [17, 18]. Lead content in tissues and blood of animals that live in polluted areas is usually elevated and risk of acute or chronic poisoning is increased [2, 3, 19–21]. Lead has a particular affinity for bones and causes osteoporosis; it also enters the liver and kidney. It interferes with iron metabolism and may cause anemia. Most of the symptoms relate to the neurotoxicity of lead. Affected cattle may charge around, press their heads against a wall, and later they develop ataxia [1, 7].

Lead mining in the Meža River Valley (Slovenia) dates from 1424. The year 1893 can be considered the beginning of mining-metallurgic activity in the area [2]. In 1962, a factory of storage batteries became an integral part of the plant. In 1989, technology changed and the primary raw material, lead sulphide ore (galenite), was replaced by secondary raw material (old lead storage batteries) [2, 18]. Today, the lead mine is closed but the smelter and big recycling plant is in full use. Vegetation and soil in Upper Meža Valley has been contaminated by mining and smelter operations for more than a century [18, 22].

Prpić-Majić [2] reported that in 1976, 1982, 1984, and 1988 the characteristic indicators of lead absorption (lead in blood, δ-ALA-D) were determined in a representative number of cows ($n = 120$) from pasture in Upper Meža Valley and from one pasture in the control area. Lead in blood and δ-ALA-D showed a trend towards normal values after the bag filter installation. But even ten years later the differences in lead in blood and δ-ALA-D in cows from exposed and control areas were still highly significant indicating that the environment of Meža Valley was still contaminated by lead [2, 23].

At our Clinic, the first investigation was performed in 1975 [6]. From 1979 to 2002, lead effects on health condition and fertility in cows from farms in this area were studied systematically. The study in cows was initiated to verify the hypothesis that lead absorption in cows was in direct relationship with the environmental pollution of air, water, soil, and lead contaminated of forage [2, 24, 25]. There were endless arguments among cattle breeders and mine management because of economic losses in spite of the installation of an expensive bag filter system in 1978 to prevent further lead pollution from the smelter [2, 3, 26]. Before 1990, there were numerous complaints and reimbursements for the animals that were slaughtered for salvage and those that were clinically normal, yet at slaughter showed elevated lead contents in the liver and kidneys which could mean a nonapparent poisoning of animals that adversely affected production and reproduction [19, 27]. Via a 25-year-long systematic investigation on lead concentration in topsoil, forage, liver, kidneys and blood of cows we gathered valuable data on lead contamination of the environment [2, 3, 19].

Via a systematic, several years lasting investigation on lead concentrations, we gathered valuable data on contamination rate of hay and silage and lead absorption in the organism of the animals [28–30].

The aim of this review was to determine the dynamics of yearly lead content in the topsoil, forage (hay, silage), liver, kidneys, and blood of cows on exposed farms after emission was put under control.

Reported is also yet a source of environmental contamination associated with the improvement of marshy pastures on a farm with gravel and dump material from mine and smelter which caused acute lead poisoning of cows.

2. Material and Methods

2.1. Location of the Research Area. Farms under the investigation are located in the Upper Meža Valley, which is a steep mountain valley with poor ventilation. It is situated in the Northern part of Slovenia, bordering on Austria (Figure 1). For over 100 years mining operations had been going on, and in 1989 the mine was closed for the lack of primary raw ore material and replaced by a big smelting plant for old car batteries.

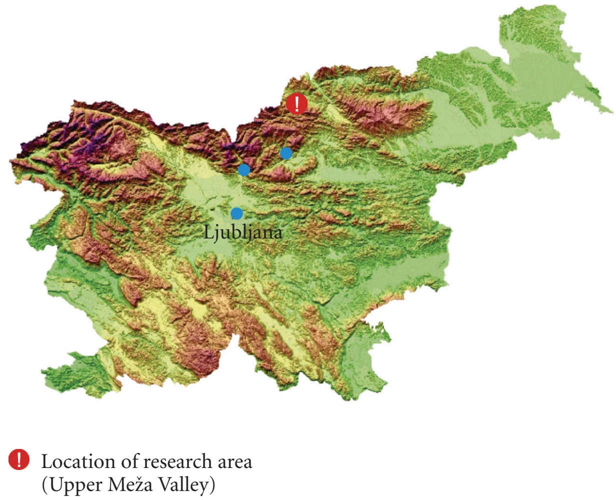

Figure 1: Map of Slovenia with the research area and the three areas of the control groups.

On these traditional Alpine farms, the feeding of animals was based on exclusively home produced forage. The cattle had been chronically exposed to ingesting vegetation and soil contaminated by atmospheric fallout until 1978, when a modern bag filter system was installed to decrease the emission of lead gasses and dust to the environment.

2.2. Sampling Procedure and Laboratory Analyses. The first investigation on lead content in the hay and blood of cows was carried out in 1975. During 1976 the systematic work continued. Between 1977 and 1978, our Clinic did not take part in the research activities. Questioning, registering of clinical data, and collecting biological material were done each year at the end of April or first day of May. From the year 1979 to 2002, with the exception of 1988, the workers of the Clinic visited the exposed farms each year.

Topsoil ($n = 116$), hay ($n = 259$), silage ($n = 35$), liver ($n = 23$), kidney ($n = 23$), and blood ($n = 1,279$) samples were taken, depending on yearly financial support, from 1 to 14 of the most exposed farms, 1 to 10 km around a lead mine and smelter area.

Most of cows were Simmental breed and were during the winter season kept in classic tied-housing systems with hay bedding. All cows received exclusively home-produced forage twice a day. Because of the highly polluted environment the grazing of animals on farms near the mine and smelter was banned until 1982. After 1982, the farmers on some farms started of with grazing because of high availability of pasture.

Liver ($n = 23$) and kidney ($n = 23$) samples were collected individually from 1979 to 1985. Each year the samples were collected at slaughter houses. The owners sent for slaughter the cows that were in poor condition

Table 1: The examined biological material, total number of samples ($n = 1,734$), and measurements units from 1975 to 2002 on farms ($n = 1$ to 14) around the mine area and smelter in the Upper Meža Valley.

Samples of biological materials	Samples (n)	Measurement units(mg/kg)
Topsoil to 10 cm	116	mg of lead/kg
Hay samples	259	mg of lead/kg DM
Silage samples	35	mg of lead/kg DM
Liver samples	23	mg of lead/kg WW
Kidney samples	23	mg of lead/kg WW
Whole blood of cows samples	1,279	mg of lead/kg WW
Total number	1,735	

Table 2: Mean ± SD lead concentrations in the blood of 32 cows from the three control areas in Slovenia.

Year of research	Area of research	Number of cows	Mean lead concentration in the blood of cows (mg/kg)
1976	Ljubno ob Savinji	22	0.0600 ± 0.002
1995	Below Krvavec Mountain	6	0.0390 ± 0.001
2002	Moste heating plant in Ljubljana	4	0.0375 ± 0.004
Total		32	0.0455 ± 0.012

and losing weight. Afterwards, the fresh liver and kidneys were sent to our laboratory for analyses. If the lead content exceeded the normal values the owners were reimbursed for the slaughtered animals.

Blood was taken from the jugular vein. Thirty mL (3 tubes/10 mL) of whole blood was obtained by venipuncture in Pb-free heparinized tubes. The blood was cooled to 4°C for 24 h, frozen, and stored for 2 months at −20°C. All samples were analyzed on the same day. On each farm, blood samples were collected from 2 to 5 cows ($n = 1,279$; mean age = 6.7 ± 2.3 years).

The biological material, total number of samples, and measurement units are given in Table 1.

Lead analysis was performed using flame Atomic Absorption Spectrophotometry (Varian, Australia) [31]. To control the contamination at the sampling, along the contaminated samples, blank samples of all investigated materials containing nondetectable amount of lead were analyzed. Analytical procedure was controlled using samples spiked with appropriate amount of lead.

2.3. Control Group of Cows. During the research period (1975–2002), the blood samples for comparative lead concentrations were taken from 32 control cows from three areas in Slovenia: The Savinja Valley (1976), below the Mount Krvavec (1995), and the surroundings of the heating plant Moste in Ljubljana (2002).

2.4. Statistical Analysis. All data was statistically analyzed with SPSS STATISTICS 17.0 (One-Way ANOVA).

3. Results

Table 3 presents the results of mean lead concentrations in topsoil, hay, silage, liver, and kidney of cows from farms near former lead mine and current big smelter operating plant.

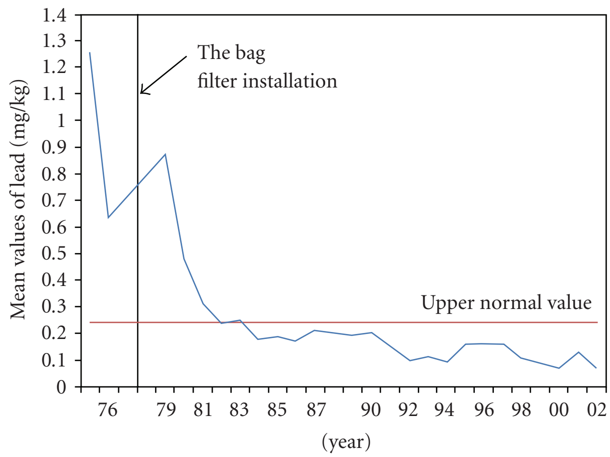

Figure 2: Mean concentration of lead in the blood of cows before (1975-1976) and after the installation of bag filter system.

Table 4 and Figure 2 present the dynamics of lead concentration in the blood of cows. Table 2 presents mean lead concentrations in control groups of cows. Table 5 presents results of lead concentrations on blood, liver, kidney, and feces in one of the cows dead on pastures with typical clinical signs for acute lead poisoning. On the farm with the lead poisoning incident, we also took soil and water samples to establish concentration of lead. Two months after poisoning, blood samples from all cows ($n = 27$) on farm were taken (Table 4, year 1993). Of the 27 animals, three had concentration of 0.710, 0.310, and 0.280 mg of lead/kg blood, respectively.

3.1. A Case of Lead Poisoning in Cows. Until 1985, the veterinary service registered several cases in the acute, subacute and chronic of lead poisoning in cows on monitored farms. In 1993, it was reported that on the farm that was not

Table 3: Mean lead concentrations in topsoil, hay, silage, liver, and kidney of cows from farms near the lead mine and smelter before the installation of bag filter system in 1975/1976 and after the installation from 1979 to 2002.

Year of research	Topsoil* (min-max or mean mg/kg)	Hay (mg/kg DM)	Silage (mg/kg DM)	Liver (mg/kg WW)	Kidney (mg/kg WW)
1975	192 to 1,558 ($n = 33$)	584.0 ± 324.0 ($n = 4$)	—	—	—
1976	—	821.0 ($n = 1$)	—	—	—
1979	—	69.10 ± 61.3 ($n = 13$)	—	5.23 ± 2.3 ($n = 3$)	8.12 ± 3.1 ($n = 5$)
1980	—	48.9 ± 28.2 ($n = 13$)	—	3.06 ± 1.9($n = 7$)	6.23 ± 1.9 ($n = 6$)
1981	—	34.5 ± 29.6 ($n = 13$)	—	1.74 ± 0.7 ($n = 8$)	6.49 ± 1.4 ($n = 5$)
1982	350.4 ± 331.3 ($n = 9$)	13.6 ± 3.8 ($n = 13$)	—	0.44 ($n = 1$)	5.93 ± 0.9 ($n = 4$)
1983	320.6 ± 198.8 ($n = 9$)	22.2 ± 8.1 ($n = 13$)	—	6.67 ± 0.8 ($n = 2$)	1.20 ($n = 1$)
1984	370.2 ± 278.3 ($n = 9$)	34.1 ± 18.2 ($n = 13$)	—	8.00 ($n = 1$)	5.62 ($n = 1$)
1985	51.3 − 310.5 ($n = 9$)	23.3 ± 12.6 ($n = 13$)	—	0.85 ($n = 1$)	1.21 ($n = 1$)
1986	42.5 − 720.4 ($n = 5$)	17.8 ± 13.0 ($n = 11$)	—	—	—
1987	390.4 ± 281.3 ($n = 9$)	18.5 ± 11.1 ($n = 10$)	—	—	—
1989	400.4 ± 239.1 ($n = 9$)	18.0 ± 8.3 ($n = 12$)	—	—	—
1990	—	17.2 ± 9.7 ($n = 12$)	—	—	—
1991	—	18.1 ± 10.4 ($n = 12$)	—	—	—
1992	—	13.6 ± 7.4 ($n = 12$)	—	—	—
1993	—	8.0 ± 2.4 ($n = 2$)	—	—	—
1994	—	3.4 ± 2.1 ($n = 4$)	—	—	—
1995	—	11.4 ± 4.2 ($n = 4$)	—	—	—
1996	—	6.9 ± 3.1 ($n = 6$)	12.5 ± 3.6 ($n = 4$)	—	—
1997	—	6.5 ± 3.8 ($n = 14$)	12.8 ± 1.2 ($n = 10$)	—	—
1998		8.3 ± 4.2 ($n = 12$)	3.5 ($n = 1$)	—	—
1999	619.1 ± 321.9 ($n = 3$)	10.3 ± 3.9 ($n = 13$)	15.0 ± 3.6 ($n = 3$)	—	—
2000	454.8 ± 278.2 ($n = 3$)	7.2 ± 4.6 ($n = 14$)	7.3 ± 2.6 ($n = 6$)	—	—
2001	283.6 ± 189.2 ($n = 8$)	6.5 ± 3.7 ($n = 12$)	4.7 ± 1.8 ($n = 6$)	—	—
2002	347.5±300.1 ($n = 10$)	5.6 ± 3.3 ($n = 12$)	8.8 ± 2.2 ($n = 5$)	—	—

*Research of topsoil samples encompassed the farms nearby the smelter [2, 3, 22].

included in systematic monitoring, four cows showed clinical signs of plumbism (neurological signs) during the first week of pasture. One cow survived and three died. Tissue samples were collected from one of these animals. Samples were also taken and lead content was measured where cows licked soil along with samples from the drinking water (Table 5).

4. Discussion

4.1. Lead in Topsoil. Almost 3 decades lasting measurements of total lead in the topsoil on farms in the vicinity of the mine and smelter enabled an insight into prolonged soil contamination with this heavy metal. Because of the careless attitude of the smelter management towards the environment, lead intensively accumulated in the vegetation and soil until 1978. The main source of contamination was the emission of gasses and dust from the mine and smelter operations. Data gathered from the local farmers confirmed that the emission was extremely high, especially around the smelter plant in Upper Meža Valley until 1978 when the bag filter system had been installed [2, 12, 18, 24, 33]. The consequences are still visible today; nature around the smelter is devastated and called the "dead valley" (Figure 3). The studies show that lead concentration depended on the distance from the main source of emission (vicinity of the smelter). In the Upper Meža Valley, the first research

Figure 3: Upper Meža Valley is ranked into the 4th class of environmental pollution (dead valley). It is an area with stationary lead contamination of upper layers of soil and with very limited air self-cleansing possibilities [17].

Table 4: Mean, standard deviation (SD), and minimal-maximal concentrations of lead in the blood of cows before (1975-1976) and after the installation of bag filter system.

Year of research	Number of farms	Number of cows	Mean lead concentration in blood (mg/kg)	± SD of lead in blood (mg /kg)	Min. – max. of lead in blood (mg /kg)
1975*	2	9	1.251	0.580	0.501–2.301
1976*	5	28	0.645	0.239	0.251–1.130
1979	13	43	0.870	0.410	0.351–1.890
1980	13	57	0.478	0.290	0.180–2.080
1981	13	60	0.320	0.062	0.140–0.450
1982	13	53	0.241	0.127	0.080–0.660
1983	13	58	0.248	0.134	0.103–0.960
1984	13	60	0.179	0.048	0.094–0.311
1985	13	58	0.191	0.065	0.100–0.410
1986	12	57	0.173	0.051	0.070–0.270
1987	10	44	0.213	0.087	0.110–0.430
1989	12	60	0.195	0.041	0.120–0.320
1990	12	59	0.202	0.073	0.060–0.380
1991	12	60	0.150	0.034	0.061–0.230
1992	12	60	0.098	0.072	0.040–0.320
1993	1	27	0.112	0.138	0.050–0.710
1994	2	15	0.095	0.013	0.070–0.113
1995	6	106	0.158	0.052	0.070–0.280
1996	6	30	0.164	0.039	0.095–0.238
1997	14	59	0.161	0.028	0.021–0.580
1998	14	59	0.109	0.022	0.010–0.267
1999	14	58	0.087	0.019	0.015–0.129
2000	14	57	0.073	0.011	0.024–0.160
2001	12	51	0.131	0.143	0.002–0.581
2002	12	51	0.069	0.041	0.004–0.174

*Time before the installation of bag filter system.

Table 5: Lead concentration in soil of pasture, drinking water, blood, liver, kidney, and feces of one dead cow, and mean ±SD ($n = 27$) and min-max blood lead concentration in cows from the farm with acute lead poisoning two months after incident.

Samples ($n = 1$)	Lead concentration mg/kg	Lead concentration in the blood of cows two months after poisoning ($n = 27$)
Blood	0.350 ↑	
Liver	6.32 (WW) ↑	
Kidney	11.28 (WW) ↑	Mean = 0.112
Feces	14.71 (DM) ↑	±SD = 0.138
Pasture soil where cows licked it	295 ↑	Min – max = 0.050 – 0.710
Drinking water	<0.050 mg/L	

↑ Increase concentration [7, 32].

activities began already in 1968 and 1969. Lead was measured in 184 soil samples at 33 locations. Samples were taken from different altitudes and arranged in accordance with the direction of the wind and distance (from 979 m to 7,250 m) from the source of dust emission. In the topsoil, from 191 mg/kg to 1,558 mg/kg of lead was measured [2, 22, 33]. The same authors carried out research also in the years 1970 and 1971. Table 3 presents the results of the analyses of the topsoil samples to the depth of 10 cm. A comparison of mean lead concentration in soil from 1982 to 1989 and concentrations during 1968/69 revealed that, on most farms for many years after the filters had been installed, no decline of lead concentration in the upper layers of soil occurred [2, 33, 34]. The measured high lead content in the topsoil is the result of prolonged direct emission of lead gasses and dust, which accumulated in vegetation and soil. Lead is changed into insoluble form that may remain in the soil practically indefinitely [34]. Prpić-Majić et al. [35] and Prpić-Majić [2] reported that lead content in the soil significantly depends on the distance of the farm from the source of emission, direction of the wind, configuration of terrain, altitude, meteorological conditions, and cultivation of the soil. We conclude that persistency of lead in soil is a risk for contamination of other areas when the soil is exposed and moved to be used at other locations.

4.2. Lead in Hay and Silage. Several epidemics of lead poisoning in domestic animals have been recorded throughout the world [7, 32]. From Table 3, it is evident that mean lead content (584 ± 324 mg/kg DM) in four hay samples (1975) and in one (1976) was 23- to 32-times higher than in two control hay samples (20.0 and 29.0 mg/kg DM) in the Upper Savinja Valley [27]. Also other authors reported on high lead concentrations in contaminated grass (12.3 to 886.4 mg/kg DM) and hay (5.4 to 409.6 mg/kg DM) from the Meža Valley [2, 30, 34]. According to older people, trees in the area around the smelter were silvery-bluish from the dust from the chimneys. An interesting monitor for veterinary service and people were cats, especially the young ones that licked their hair after the night hunt and frequently died in spasms from acute plumbism. Besides cattle and horses also sheep were affected, especially the young ones [2, 27]. Table 3 also shows that after the installation of filters mean lead concentrations in hay progressively declined until 1992. Up to 2002 mean values were within the reference range (<10,0 mg lead/kg DM). After 1990, we did not detect any acute lead poisoning in cows. However, cattle reared in the vicinity of the smelter are at present still exposed to the risk of acute and especially chronic lead poisoning. As it is known from the literature, acute plumbism most commonly occurs in cattle if lead content in silage is above 140.0 mg/kg DM [7, 13, 36] and in hay above 150.0 mg of lead/kg DM [7, 35]. The established dynamics of mean lead hay concentrations can be explained by somewhere lower and somewhere higher contamination of grass from the upper layers of soil. It is well known that grazing cattle commonly have up to 10% soil in their diet [36]. The results of forage analyses showed high mean ash content (10.52 ± 1.21%) therefore we may claim that fodder was contaminated via the soil especially during pasture and hay/silage making [3]. According to the literature, the lead amount in the soil is in weak correlation to the lead amount in the above ground parts of the plants because roots inhibit the transport of lead into shoots [37, 38].

4.3. Lead in Cow Liver and Kidney. Literature reported that tissue lead levels in cattle from industrial areas are significantly higher (liver 0.230 mg/kg WW, kidney 0.420 mg/kg WW) than in cattle from clear air zone (liver and kidney less that 0.100 mg/kg WW) [7, 14, 15, 32].

The first liver samples from cows that died or were slaughtered because of suspect lead poisoning were examined in 1979, a year after the modern filter system was installed. All samples contained over 2.0 mg of lead/kg WW. This is the amount that may cause clinically manifested lead poisoning [7, 11, 32]. In all such cases, owners of animals were reimbursed for the loss of the cows. In 1980, five of seven delaminated samples of liver contained over 2.0 mg of lead/kg WW (2.73–4.82 mg of lead/kg WW). A year later, the amount of the examined lead in all samples ($n = 8$) was below 2.0 mg of lead/kg WW (0.81–1.99 mg of lead/kg WW). In 1982, only one sample of liver was delivered; the lead content was only (0.44 mg of lead/kg WW) [26].

The samples of kidneys, which were delivered from 1979 to 1982 lead concentrations, did not exceed the critical level of 10 mg of lead/kg WW, the amount that according to Rosenberger [32] may cause clinical signs of plumbism. The majority of samples contained less than 5.0 mg of lead/kg WW.

From the data, it may be concluded that lead concentration in the internal organs of affected or slaughtered animals decreased linearly with the lead amount in hay, silage, and blood [26].

After 1985, no samples of liver or kidney were delivered for examination, so lead content in the blood of cows became the major indicator of plumbism.

4.4. Lead in Blood. Lead levels in the blood provide a reliable indicator of cattle exposure to the lead-contaminated environment [39]. Lead is usually absorbed via intestines and respiratory system [7, 32, 40]. Whole blood levels of lead in normal ruminants are usually below 0.05–0.250 mg/kg; poisoned animals usually have levels above 0.350 mg/kg and deaths begin at 1.0 mg/kg [7, 40]. Table 4 and Figure 2 present the dynamics of lead in the blood of cows. It is evident that mean lead concentrations in 1975/76 were 1.251 ± 0.580, respectively, 0.645 ± 0.239 mg/kg. After 1978, these high lead concentrations gradually dropped. In 1982, mean concentration reached the level that most researches claim to be within the reference values (0.050 to 0.250 mg of lead/kg of the blood) [7, 27]. For comparison of concentrations between polluted and unpolluted areas, lead content was measured in the blood of 32 cows from 3 control areas. Mean lead concentration was 0.047 ± 0.012 mg of lead/kg of blood. For example, Villegas-Navarro et al. [11] established mean values 0.035 ± 0.013 mg of lead/kg in the blood of cattle from an unpolluted area. After 1982, mean lead concentrations of lead in the blood of cows were within normal reference values. However, the lowest mean concentration (0.069 ± 0.041 mg/kg) in 2002 was still 2-times higher compared to the concentrations in unpolluted areas in Slovenia. It was established that lead concentration in the blood of cows dropped simultaneously with the concentrations in hay and silage.

4.5. A Case of Lead Poisoning. In the literature, similar reports on lead poisoning in cattle are numerous [41–44]. Lead poisoning occurs most commonly in cattle at pasture, particularly if the pasture is poor and the animals are allowed to forage in unusual places. Cattle on lush pasture may also

Figure 4: Part of pasture where >300 m^3 of gravel from the mine was temporarily stored in 1992; on this location (behind the tractor) is also the drinking place for animal.

Figure 5: Waste material (>30 m^3), parts of asphalt, gravel, lead plates which was used for building the road to the pasture, and drinking water; the photo shows a lead plate 20x60 cm and weighing about 3 kg.

seek out foreign material to chew [7, 32]. In many countries the incidence of plumbism is highest in cattle in the spring of the year a few days after the animals have been turned out onto pasture [7].

We diagnosed accidental lead poisoning as a consequence of melioration works (pasture, road) on that farm in 1992 where greater amounts of gravel (>300 m^3) were used from the near lead mine as well as some dross (30 m^3) from the smelter mixed with lead chips (Figures 4 and 5). A sample of soil contained 295 mg of lead/kg. A sample of drinking water contained less than 0.050 mg of lead/L. From Table 5, it is evident that lead concentration in soil, blood, liver and kidney of dead animal without signs of lead poisoning exceeded the allowed recommended lead levels [7, 32].

Licking and ingestion of dross caused clinical poisoning and death of three out of 27 cows as well as increased lead concentration (0.710; 0.310; 0.280 mg of lead/kg) in blood samples of three cows on that farm, collected two months after the incidence. Our finding is confirmed also by hay analysis containing 10.7 mg of lead/kg DM that is slightly above the normal value. According to Rosenberger [32], poisoning does not occur if hay or silage contain between 2–8 mg of lead/kg DM.

In our case, poisoning was caused also by factors associated with early spring pasture (deficiency of roughage and energy, protein surplus, pica, and postpartum period).

5. Conclusion

The mine, big smelter, and lead recycling plant in Upper Meža Valley has been operating over a hundred years. The investigation of lead concentration in topsoil, forage, blood, and tissues of cows began in 1975 and lasted till 2002. Until 1978, when protective filters were installed in the plant chimneys, the farms around plant had been exposed to heavy industrial-metallurgic effluent.

Early measurements (1968 to 1975) of high lead (>600.0 mg of lead/kg) in the topsoil and continuing investigations (1981 to 2002) showed no significantly decreased lead after the installation of filters.

Mean lead in hay and silage samples gradually decreased. In 1975, lead concentrations in 4 samples of hay were 227.0 to 953.0 mg/kg DM. In 2002 ($n = 12$), mean lead concentrations were about 100-fold lower (5.6 ± 3.3 mg of lead/kg DM).

A similar trend of decreasing lead concentration occurred also in the blood and tissues (liver, kidney) of cows. After 1982, mean cow lead blood concentration were within normal reference values (<0.250 mg of lead/kg). Mean lead contents in the blood of cows dropped (1975–2002) from 1.251 mg/kg to 0.069 mg of lead/kg of blood. However, during 1992 to 2002, mean lead concentrations have still been 1- to 2-fold above the values measured in blood of animals ($n = 32$) from 3 control nonpolluted areas in Slovenia.

After 1985, no samples of liver ($n = 23$) and kidney ($n = 23$) showed increased values (>2.0 or >10.0 mg of lead/kg WW).

Blood lead levels in cows proved a good bioindicator of environmental contamination.

Today, twenty-five years after filters were installed, we are of the opinion that the major source of forage contamination was high lead content in the topsoil, which contaminated grass especially after heavy rains and haymaking.

The established lead concentrations in the blood of cows were the result of prolonged ingestion of the lead contaminated grass, hay, and silage as well as mobilization of lead from the bones. Because lead may persist in the soil practically indefinitely, we are of the opinion that, under certain circumstances, cattle in this area is still at risk to develop subclinical and even clinical manifestations of plumbism.

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