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**Accumulation of trace elements in cattle from rural and industrial areas in Belgium**

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7 **Accumulation of trace elements in cattle from rural and industrial**  
8 **areas in Belgium**  
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**Abstract**

Trace element concentrations were determined in meat, kidney and liver tissue of cattle, which had resided more than 18 months in areas historically contaminated by emissions from the non-ferrous metal industry or in regions with normal background metal contamination levels in Belgium. Trace element levels were determined by inductively coupled plasma-mass spectrometry. Lead, arsenic and cadmium concentrations in meat were low for all cattle. The concentrations in kidneys were respectively 1.8-, 2.2- and 2.5-fold higher in cattle from the contaminated areas compared to animals from reference areas. The European maximum level for cadmium in kidney was exceeded by 75% of the kidneys from contaminated areas and 47% of the kidneys from reference areas. Lead, arsenic and cadmium concentrations in bovine livers from contaminated areas were increased by about a factor of 2.3. Zinc levels in livers and kidneys were within normal ranges, but 20% higher in the contaminated areas compared to reference areas. Copper levels in livers were high in all areas. Dairy cattle accumulated significantly higher levels of cadmium in kidneys and of lead in liver and kidneys than did beef cattle.

**Keywords :** *cadmium, lead, arsenic, zinc, copper, kidney, liver, meat*

## Introduction

Industrial and agricultural processes have resulted in the release of toxic trace elements into the environment, although for some specific elements relatively high concentrations can naturally occur in the soil. Cadmium, lead and arsenic are causing most concern because of their transfer through the food chain, bearing a potential risk to animals and humans (Friberg et al., 1979; López-Alonso et al., 2002). The major sources of toxic trace elements in agricultural soils include atmospheric deposition (De Temmerman et al. 2003), animal manure, agrochemicals and mineral fertilizers (Nicholson et al., 1999). Cattle originating from farms located within a 20-km radius around zinc refinery plants in the Netherlands, had 2.5 times higher average cadmium levels and 1.5 times higher average lead levels in organs when compared to controls (Spierenburg et al., 1988). Cadmium and lead levels in calves from a polluted area in northern Spain, were significantly higher than those in calves raised in a rural area, whereas arsenic levels in no case differed between calves from both areas (Miranda et al., 2005). In Belgium, some rural areas have been contaminated by emissions of the non-ferrous metal industry (Lauwerys et al., 1990). This has led to increased trace element levels in soils and humans (Staessen et al., 1994; Cornelis et al., 2006). Trace element concentrations in tissues of animals raised in these regions have, however, not yet been studied.

The objective of this study was to determine toxic and trace element concentrations in tissues of cattle that resided for more than 18 months in areas close to non-ferrous metal plants, and to compare the results with cattle from areas at ambient metal levels in the environment.

## Materials and methods

### *Sampling*

Kidneys, livers and muscle tissue of bovine animals were sampled at random by the Belgium Federal Agency for the Safety of the Food Chain (FASFC) in 2005. The samples were taken as part of the official control program of the FASFC in three contaminated areas and in regions with normal background metal levels in the environment, which will be further called the reference area. The contaminated areas were (i) *site A* - a rural area in the north-eastern part of the Kempen region near three primary zinc smelters, of which one has been closed since the 1970s, (ii) *site B* - a rural area south of the city of Antwerp near a precious metals refining facility, which processes secondary raw materials and wastes to extract and refine non-ferrous metals such as lead, copper and precious metals, and (iii) *site C* - a rural area in the south of the Antwerp Kempen region near a copper refining facility and a cobalt production plant (Figure 1). The so-called reference area consists of several rural areas throughout Belgium, away from point sources of toxic and trace elements. Belgium is divided in 10 major agricultural regions, from which seven were included in the current research (Zandstreek, Zandleemstreek, Leemstreek, Kempen, Weidestreek, Condroz and Ardennen). The division is based on differences in soil geochemical properties.

[insert Figure 1 about here]

Besides sites A, B & C there are other contaminated areas in Belgium, but no samples were taken in those areas because of their negligible cattle or milk production activities. The number of samples taken by the FASFC was determined in the official

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4 control program. The methodology developed for the program is based on risk  
5 evaluation, statistical tools and current scientific knowledge (Maudoux et al., 2006). In  
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7 total, 99 animals from the reference area and 53 animals from the contaminated areas  
8  
9 were investigated. Each bovine animal in Belgium is obligatory marked by an ear tag  
10  
11 and has a bovine passport. Together with each sample, a copy of the passport was  
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13 received, containing information on the date of birth, sex and type of the animal and on  
14  
15 the farms where the animal resided. Farms where the animals had resided for more than  
16  
17 18 months, were contacted and the farmers were asked to further participate voluntarily.  
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19 A questionnaire was filled out with the farmers, rendering information about, amongst  
20  
21 others, the feed supplied to the animals. In total, 19 farmers in the reference area  
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23 (covering 20 animals) and 34 farmers in the contaminated areas (covering 38 animals)  
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25 were visited.  
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### 35 *Analytical methods*

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37 The animal tissues were sampled by officially appointed veterinarians and according to  
38  
39 the rules outlined in the control program of the FASFC. The animal tissues were  
40  
41 immediately deep frozen and stored in a freezer until analysis. At the time of analysis,  
42  
43 the tissues were partially thawed and mixed in a home mixer to homogenize the  
44  
45 samples. Consequently, the kidney cortex and medulla, which contain unequal trace  
46  
47 element concentrations, were homogeneously mixed and metal concentrations are  
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49 expressed on the whole organ. For each tissue, two homogenized sub-samples were  
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51 mineralised by acid digestion (nitric acid) in pressure vessels of an X-PRESS  
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53 microwave digestion system (CEM Corporation, Matthews, NC, USA). Trace element  
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55 concentrations in all digests were quantified by inductively coupled plasma-mass  
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4 spectrometry (ICP-MS, VG PQ-ExCell, TJA, US). Each batch of 20 samples  
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6 additionally included one procedure blank, one certified reference material (IAEA-407  
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8 Fish tissue) and one laboratory control material. In case of deviations from a set of  
9  
10 common criteria for tolerable variations of blanks, and for values obtained for the  
11  
12 reference materials, the analyses in a batch had to be repeated. The analyses of As, Cd  
13  
14 and Pb in meat and organs were performed under accreditation, following the 17025  
15  
16 ISO norm. The limit of quantification (LOQ) for the analyzed trace elements was  
17  
18 calculated as 10 times the standard deviation of 10 procedure blanks, multiplied with  
19  
20 the dilution factor. The LOQ values, expressed on a fresh weight basis, equalled to  
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22 0.002 mg Cd kg<sup>-1</sup>, 0.006 mg Pb kg<sup>-1</sup>, 0.030 mg As kg<sup>-1</sup>, 0.04 mg Cu kg<sup>-1</sup> and 0.90 mg Zn  
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24 kg<sup>-1</sup>, respectively.  
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### 33 *Statistical analysis*

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35 Statistical analyses were performed with UNISTAT Statistical Package, Version 5.5.06  
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37 (UNISTAT Ltd, London, UK). Measured values were used for samples below the LOQ,  
38  
39 unless stated otherwise, so that distributions would not be distorted. The normal  
40  
41 distribution of data was verified by the Kolmogorov-Smirnov test with Lilliefors  
42  
43 correction. Basic statistics were calculated on untransformed data. Data that were log-  
44  
45 normally distributed, were log-transformed before further analysis. Data were analysed  
46  
47 by one-way analysis of variance (ANOVA) followed by Duncan's multiple range test  
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49 ( $\alpha = 0.05$ ). Two animals from the reference areas were excluded from statistical  
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51 analysis because they were highly contaminated with metals and the source of  
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53 contamination could not be traced.  
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## Results and discussion

Many animal studies have shown that in chronic exposure experiments, the largest amounts of Cd are found in the liver and the kidneys (e.g. Kotsonis and Klaassen, 1978). Muscles, on the other hand, contain a relatively small part of the total body Cd (Neathery et al., 1974). Lead is distributed to both soft tissues (blood, kidney, liver, ...) and mineralising systems (bones, teeth). Among soft tissues, the liver and kidney contain the highest Pb concentrations in mammals while muscles contain the lowest concentrations. In the current study, As, Cd, Pb and Cu concentrations in meat were low compared to their respective concentrations in kidney and liver (Table I), which is in line with the earlier findings stated above. In the reference areas, the majority (57-82%) of the As, Cd and Pb concentrations in meat were below the LOQ, while in the contaminated areas 91% of the As concentrations, 28% of the Cd concentrations and 77% of the Pb concentrations were below the LOQ. Mean Cd and Cu concentrations in meat were significantly higher in the contaminated areas when compared to the reference area. For As, Pb and Zn, no significant differences could be observed between both areas. Although mean Cd concentrations are significantly different between the contaminated and the reference area, the Cd concentrations in all meat samples were far below the European maximum level of 0.05 mg kg<sup>-1</sup> fresh weight (EU, 2006) and fell within previously reported ranges in other countries (e.g. Langlands et al., 1988; Jorhem et al., 1991; López-Alonso et al., 2000; Olsson et al., 2001). The Pb concentrations in meat samples from the reference and contaminated areas were as well far below the European maximum level of 0.1 mg kg<sup>-1</sup> fresh weight (EU, 2006).

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4 Arsenic showed a higher accumulation in meat than did Cd and Pb, whereas an opposite  
5 tendency could be seen in liver and kidney (Table I). Arsenic, Cd and Pb concentrations  
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7 were higher in kidney than in liver. It is known that kidney Cd concentrations exceed  
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9 the liver concentration following prolonged exposure (Kotsonis and Klaassen, 1978),  
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11 except at very high exposures (Bernard et al., 1980). In case of repeated exposure, liver  
12  
13 Cd levels increase rapidly and a re-distribution of Cd to the kidney occurs over a period  
14  
15 of time. The major source of renal Cd in chronic exposure is derived from hepatic Cd,  
16  
17 which is transported in the form of Cd-metallothionein (Chan and Cherian, 1993).  
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23 [Insert Table I around here]  
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26 Within the reference area there were no significant differences in As and Cd  
27  
28 concentrations in kidney between the different agricultural regions within the reference  
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30 area. The geometric mean values for As in kidney ranged from 0.026 to 0.044 mg kg<sup>-1</sup>  
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32 while the Cd concentrations ranged from 0.661 to 0.894 mg kg<sup>-1</sup> between the seven  
33  
34 agricultural regions. The Pb concentrations in kidney were significantly different  
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36 between the Zandstreek on the one hand (geometric mean: 0.246 mg kg<sup>-1</sup>) and the  
37  
38 Kempen, Weidestreek, Condroz and Ardennen on the other hand (range of geometric  
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40 means: 0.077-0.122 mg kg<sup>-1</sup>). The Zn concentrations in kidney differed significantly  
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42 between the Ardennen (geometric mean: 20 mg kg<sup>-1</sup>) and the Kempen and Weidestreek  
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44 (geometric mean: 14 and 15 mg kg<sup>-1</sup> respectively). There were no significant differences  
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46 in Cd or Zn concentrations in liver within the reference area. The geometric means for  
47  
48 Cd in liver ranged from 0.116 to 0.190 mg kg<sup>-1</sup>, those for Zn ranged from 28 to 41 mg  
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50 kg<sup>-1</sup>. The Pb concentrations in liver significantly differed between the Weidestreek  
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52 (geometric mean: 0.025 mg kg<sup>-1</sup>) and the Zandstreek, Zandleemstreek and Leemstreek  
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54 (of geometric means: 0.060-0.090 mg kg<sup>-1</sup>). Mean As, Cd, Pb and Zn concentrations in  
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4 liver and kidney were all significantly higher in the contaminated areas than in the  
5 reference area (Table I). The mean concentrations in liver were 2.2-, 2.3- and 2.4-fold  
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7 higher for As, Cd and Pb, respectively, in the contaminated areas when compared to the  
8  
9 reference area. The average Cd concentration in livers of cattle around several zinc  
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11 refinery plants in the Kempen area (The Netherlands) was 0.370 mg kg<sup>-1</sup> fresh weight,  
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13 whereas it was 0.170 mg kg<sup>-1</sup> fresh weight in a control area (Spierenburg et al., 1988;  
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15 original data given on a dry weight basis, recalculated to fresh weight by means of the  
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17 given dry matter content of liver). These values are comparable to the data found in the  
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19 current study (0.446 and 0.190 mg Cd kg<sup>-1</sup> fresh weight). The mean concentrations in  
20  
21 kidneys were 1.8-fold, 2-fold and 2.5-fold higher for Pb, As and Cd, respectively, in the  
22  
23 contaminated areas when compared to the reference area. Average Cd concentrations in  
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25 kidneys in the Dutch Kempen area were 0.83 and 2.04 mg kg<sup>-1</sup> fresh weight in the  
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27 control and polluted area respectively (Spierenburg et al, 1988), which is slightly lower  
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29 than 1.14 and 2.86 mg Cd kg<sup>-1</sup> fresh weight found in this study. Such pronounced Cd  
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31 concentrations in kidneys have not been found in other EU countries so far (Antoniou et  
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33 al., 1989; López-Alonso et al., 2000; Miranda et al., 2001; Olsson et al., 2001). These  
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35 Cd levels in kidneys do cause a lot of concern as they frequently exceed the European  
36  
37 maximum level (EU, 2006). In the contaminated areas, 75% of the kidneys were above  
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39 the European maximum level of 1 mg kg<sup>-1</sup> fresh weight and should not enter the food  
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41 chain. The situation for kidneys in the reference area also causes concern as 47% of the  
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43 samples exceed the European maximum level. Cadmium concentrations in livers  
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45 exceeded less frequently the European maximum level of 0.5 mg kg<sup>-1</sup> fresh weight,  
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47 although still 25% of the livers from the contaminated areas and 4% of the livers from  
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49 the reference area did not comply with the legislation. The Pb concentrations were  
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4 above the European maximum level of 0.5 mg kg<sup>-1</sup> fresh weight for 19% of the kidney  
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6 samples from the contaminated areas, 8% of the kidney samples from the reference  
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8 area, 6% of the liver samples from the contaminated areas and 1% of the liver samples  
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10 from the reference area. The age of the animals is an important factor in the  
11  
12 accumulation of trace elements, and especially Cd, in organs (Andersen and Hovgård  
13  
14 Hansen, 1982; Antoniou et al., 1989). There was, however, no significant difference in  
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16 the mean age of animals from the contaminated areas when compared to the reference  
17  
18 area, neither were there any significant differences in age within the reference area  
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20 (Table II). Zinc levels in livers and kidneys were within normal ranges (Korsrud et al.,  
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22 1985; Spierenburg et al., 1988; López Alonso et al., 2000 and references therein), but  
23  
24 20% higher in the contaminated areas compared to other regions. Zinc is known to be  
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26 widely distributed in body tissues, but reaches its highest concentrations in liver, bones,  
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28 muscles and kidneys (Eisler, 1973). Liver copper levels varied widely among all  
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30 animals (1.9-395 mg kg<sup>-1</sup> fresh weight; Table I) and mean levels were high compared to  
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32 literature data as well in the reference areas as in the contaminated areas (Spierenburg et  
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34 al, 1988; López Alonso et al., 2000 and references therein).

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42 [Insert Table II around here]

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44 Interactions between trace element uptake and accumulation may be synergistic  
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46 or antagonistic. Cadmium raises for example Zn levels in kidneys and liver because of  
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48 active transport from the blood and the formation of metallothioneins, which bind both  
49  
50 Cd and Zn (Thijs et al., 1992). Tabel III presents Pearson correlation coefficients  
51  
52 between trace element concentrations in kidney and liver. These correlations show  
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54 indeed increased Zn levels with Cd accumulation in kidney and liver, both in the  
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56 reference area as in the contaminated areas. Also Pb, Cu and Zn were positively  
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4 correlated to each other in kidneys. Cadmium and Cu in kidneys were not correlated  
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6 with each other in the reference area. In liver, Cd and Cu were negatively correlated.  
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8 Antagonistic interactions have been reported for Cd and Cu (Rice et al., 1973).  
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10 Cadmium causes a depression in the serum level of ceruloplasmin, the protein which is  
11  
12 responsible for Cu transport. Such interactions might lead to a Cu deficiency, which  
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14 might explain the very low liver Cu concentrations ( $< 5 \text{ mg kg}^{-1}$ , which is definitive for  
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16 Cu-deficiency) that have been found in some animals (Table I). Copper levels in liver  
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18 were also negatively correlated with Pb in liver. This negative correlation was also  
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20 observed by Spierenburg et al. (1988). It is not clear if a competition such as between  
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22 Cu and Cd can also explain the negative correlation between Cu and Pb. Increasing  
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24 trace element concentrations in kidneys were also accompanied by increased  
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26 concentrations of the same element in liver, except for Cu. The liver is known to be the  
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28 major storage organ for Cu.  
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35 [Insert Table III around here]  
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38 Dairy cattle from the reference area accumulated significantly higher levels of  
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40 Cd in kidneys than did beef cattle (Table IV). Similarly, the Pb concentration in kidneys  
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42 and in livers of dairy cattle was significantly higher than its concentration in kidneys  
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44 and livers of beef cattle. López-Alonso et al. (2003) found higher levels of Cd and Pb in  
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46 livers of dairy cattle compared to beef cattle, but not in kidneys. They suggested that the  
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48 differences in metal accumulation could be associated with a higher metal dietary intake  
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50 and a higher hepatic metabolism associated with milk production. Beef cattle in the  
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52 study of López-Alonso et al. (2003) received a diet essentially based on pasture whereas  
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54 the dairy cattle received a supplementation with corn silage and concentrates, in  
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56 addition to pasture. Differences in feed between beef and dairy cattle in the current  
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4 study were less pronounced, although beef cattle received in general about 60% corn  
5 silage and 40% pasture (fresh pasture and silage) whereas beef cattle received in general  
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7 50% corn silage and 50% pasture. The diet was supplemented with concentrates, both  
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9 for beef and dairy cattle. The ratio of concentrates/roughage differs between dairy and  
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11 beef cattle. In Belgium, this ratio is about 40/60 for dairy cattle and 50/50 for beef  
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13 cattle. Concentrates are generally purchased and therefore comply with the Belgian  
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15 legislation concerning maximum allowable trace element levels. Roughage is, on the  
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17 other hand, very often locally grown by the farmer and not submitted to any compliance  
18  
19 control. Whether there are differences in the metal content of the roughage, will be  
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21 further investigated. The major difference between beef and dairy feed is, however, the  
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23 daily dry matter intake. The daily dry matter intake by dairy cattle is 16-20 kg, while it  
24  
25 is only about 10 kg for beef cattle (Pauwels, 1998; Römkens et al., 2007). Given the fact  
26  
27 that differences in Cd accumulation between dairy and beef cattle are only significant in  
28  
29 the kidney, suggests that the difference in dietary exposure is the most important reason  
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31 for the larger Cd accumulation in dairy cattle kidneys. The higher Pb concentrations in  
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33 liver and kidney of dairy cattle compared to beef cattle may be explained by a higher  
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35 dietary exposure and by Pb mobilisation from bones during dairy cattle lactation, as  
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37 suggested by López-Alonso et al. (2003).  
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47 [Insert Table IV around here]  
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49 Cattle originating from site A had higher average Cd concentrations in kidney  
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51 and liver than cattle from site C and the reference areas (Figure 2). Site A is well known  
52  
53 to be contaminated with Cd (Lauwerys et al., 1990; Staessen et al., 1994). The average  
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55 Cd concentrations in kidney and liver at site B were also higher than in the reference  
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57 areas. There are no differences in Pb concentrations in kidney and liver of cattle from  
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4 the three contaminated sites although the yearly average air Pb concentration in PM<sub>10</sub>  
5 dust at site B (173 ng m<sup>-3</sup> in 2006) was increased compared to air Pb emissions at site A  
6 (33 ng m<sup>-3</sup> in 2006) and ambient background concentrations (13 ng m<sup>-3</sup> in 2006), and  
7 the yearly average air Pb deposition level at site B (274 μg m<sup>-2</sup> d<sup>-1</sup> in 2006) was  
8 increased compared to ambient background concentrations (8 μg m<sup>-2</sup> d<sup>-1</sup> in 2006)  
9 (MIRA, 2007; VMM, 2007). Copper concentrations were elevated in liver of cattle  
10 originating from site C, near a Cu refining plant, but not in kidney (Figure 3).  
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21 [Insert Figure 2 around here]  
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23 [Insert Figure 3 around here]  
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## 28 **Conclusion**

29  
30 Toxic and trace element concentrations have been measured in meat, kidney and liver  
31 samples of cattle from contaminated and reference areas in Belgium. Although As, Cd  
32 and Pb concentrations in meat were low in all areas, Cd and Pb concentrations in kidney  
33 and liver regularly exceeded the European maximum levels, both in the contaminated  
34 and the uncontaminated areas. Zinc levels in livers and kidneys were within normal  
35 ranges, while liver copper levels varied widely among all animals and mean levels were  
36 high compared to literature data. Dairy cattle accumulated significantly more Cd in  
37 kidneys and Pb in liver and kidneys compared to beef cattle, which is probably due to a  
38 larger dietary exposure compared of dairy cattle and by Pb mobilisation from bones  
39 during lactation. It is important to pay attention to the fact that a considerable  
40 contamination of toxic elements takes place in cattle originating from Belgium, as  
41 heavy metals can be transferred through the human food chain and cause food safety  
42 problems.  
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6 Figure 1. Geographical location of the sampling areas. The contaminated sites A, B and C are  
7 indicated as white ovals. Shaded areas represent sampling areas at ambient environmental  
8 metal levels, which are considered as reference areas.  
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15 Figure 2. Average cadmium and lead concentration in kidney and liver as a function of the  
16 origin of the cattle. Bars with the same letter on top are not significantly different ( $p < 0.05$ )  
17 following Duncan multiple range test on log-transformed data. The data are retransformed  
18 into natural numbers.  
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27 Figure 3. Average copper concentration in kidney and liver as a function of the origin of the  
28 cattle. Bars with the same letter on top are not significantly different ( $p < 0.05$ ) following  
29 Duncan multiple range test on log-transformed data. The data are retransformed into natural  
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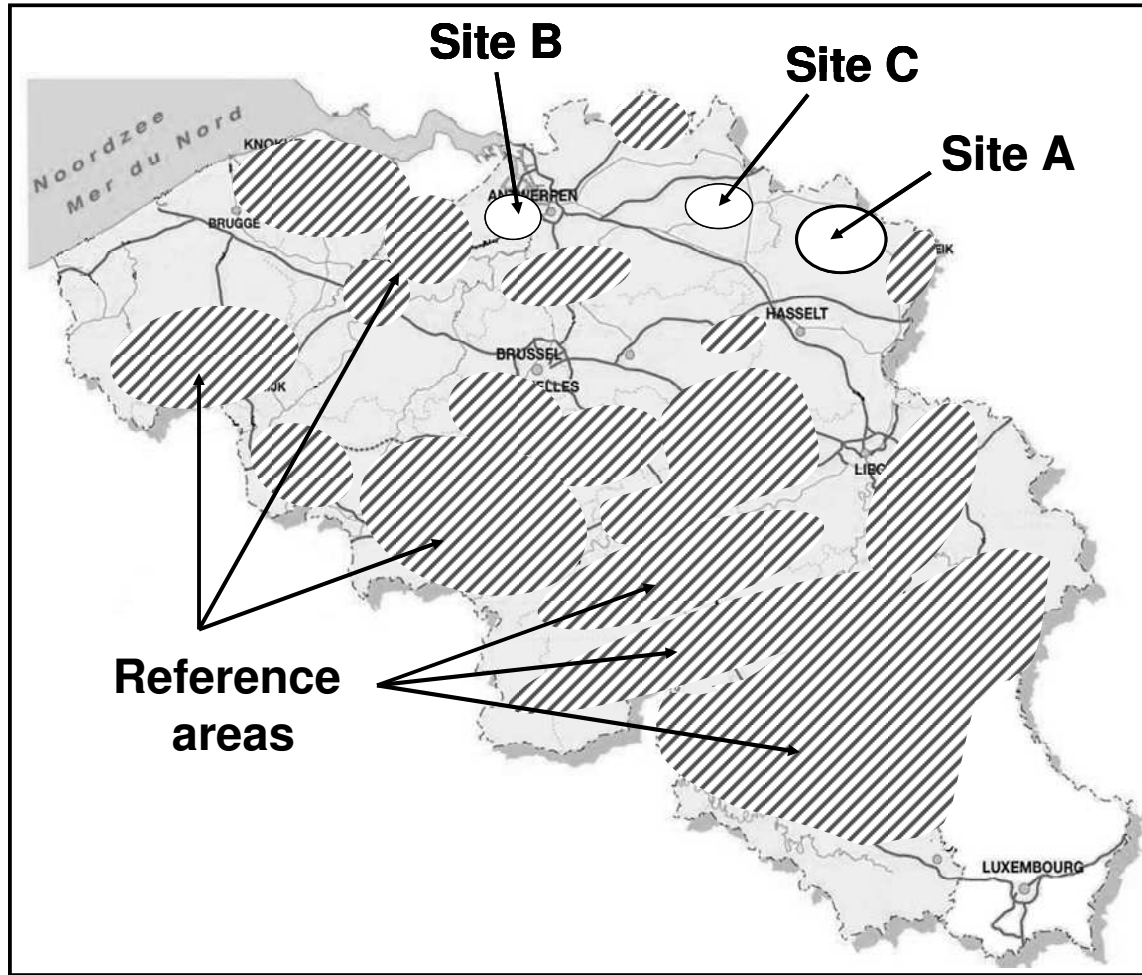


Fig. 1

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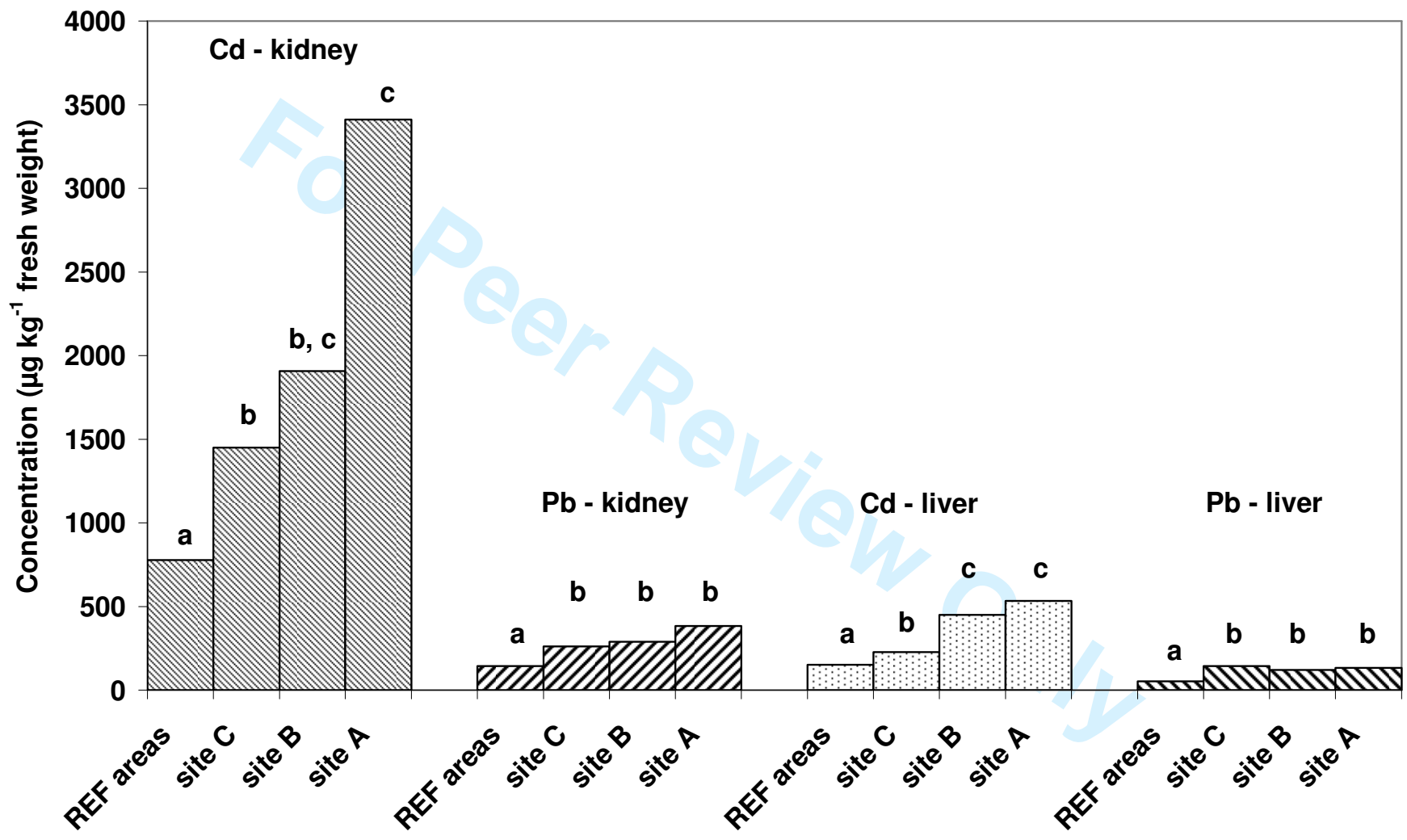


Fig. 2

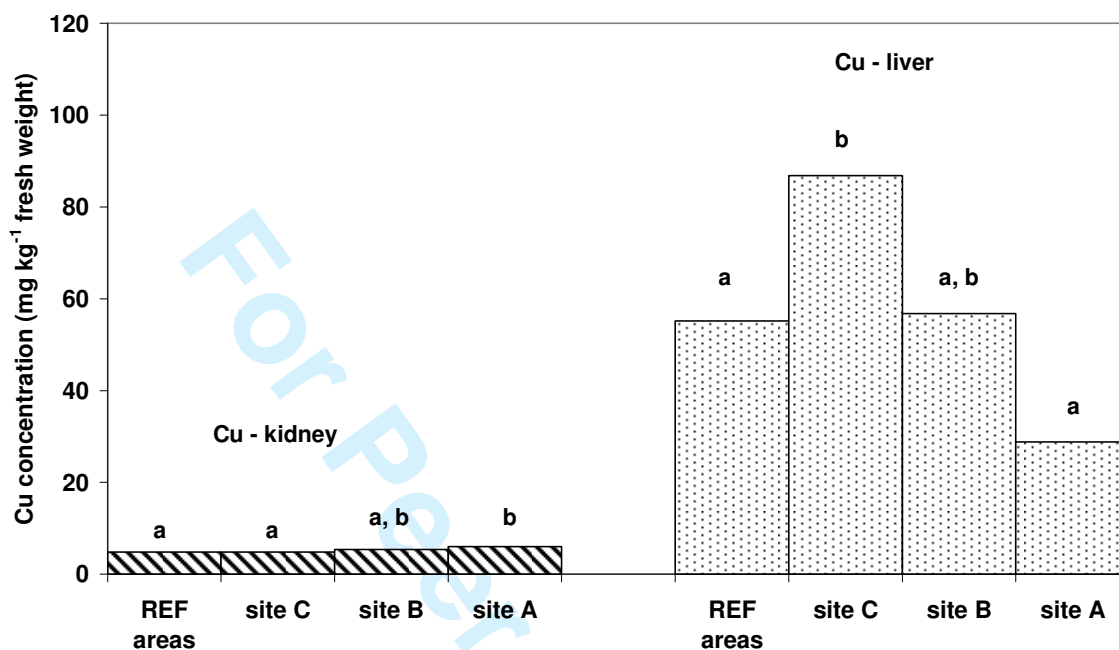


Fig. 3



**Table I.** Descriptive statistics of trace element concentrations in bovine kidney, liver and meat collected in a reference area (n = 97) and in polluted areas (n = 53). The concentrations are expressed on a fresh weight basis.

Tissue	Area		As mg kg <sup>-1</sup>	Cd mg kg <sup>-1</sup>	Pb mg kg <sup>-1</sup>	Cu mg kg <sup>-1</sup>	Zn mg kg <sup>-1</sup>
		LOQ	0.030	0.002	0.006	0.04	0.90
Kidney	<i>Reference area</i>	Mean ± stdev	0.043 ± 0.023	1.142 ± 0.922	0.212 ± 0.209	4.97 ± 1.67	18.3 ± 5.8
		Geometric mean	0.035	0.778	0.144	4.75	17.5
		Min-max	0.001 <sup>*</sup> -0.147	0.093-4.22	0.022-1.21	2.60-12.5	9.20-44.2
	<i>Polluted area</i>	Mean ± stdev	0.093 ± 0.078	2.862 ± 3.159	0.373 ± 0.318	5.31 ± 1.26	22.0 ± 5.7
		Geometric mean	0.074	1.842	0.290	5.17	21.4
		Min-max	0.006 <sup>†</sup> -0.543	0.193-15.3	0.061-1.91	2.20-9.20	14.2-41.6
Liver	<i>Reference area</i>	Mean ± stdev	0.017 ± 0.011	0.191 ± 0.136	0.082 ± 0.126	80.1 ± 66.7	40.3 ± 22.2
		Geometric mean	0.014	0.152	0.053	55.2	36.5
		Min-max	0.001 <sup>‡</sup> -0.064	0.029-0.642	0.009-1.149	1.86-395	18.1-164
	<i>Polluted area</i>	Mean ± stdev	0.037 ± 0.025	0.446 ± 0.473	0.194 ± 0.181	92.7 ± 71.8	53.9 ± 68.4
		Geometric mean	0.029	0.317	0.136	62.7	43.2
		Min-max	0.006 <sup>§</sup> -0.111	0.055-2.655	0.017-0.984	3.1-279	21.4-518
Meat	<i>Reference area</i>	Mean ± stdev	0.023 ± 0.024	0.002 ± 0.002	0.003 ± 0.003	1.6 ± 0.5	43.3 ± 9.3
		Geometric mean	0.016	0.002	0.002	1.5	42.4
		Min-max	0.001 <sup>§</sup> -0.208	0.001 <sup>  </sup> -0.012	0.001 <sup>#</sup> -0.018	0.7-2.7	27.2-77.3
	<i>Polluted area</i>	Mean ± stdev	0.017 ± 0.009	0.004 ± 0.004	0.004 ± 0.003	2.2 ± 0.5	41.2 ± 6.6
		Geometric mean	0.015	0.003	0.003	2.1	40.7
		Min-max	0.001 <sup>**</sup> -0.047	0.001 <sup>††</sup> -0.019	0.001 <sup>‡‡</sup> -0.013	0.7-3.0	25.5-60.4

\* n < LOQ = 32; † n < LOQ = 3; ‡ n < LOQ = 88; § n < LOQ = 28; || n < LOQ = 70; # n < LOQ = 55; # n < LOQ = 80; \*\* n < LOQ = 48; †† n < LOQ = 15; ‡‡ n < LOQ = 41.

**Table II.** Detailed information on the age of the animals in the seven agricultural regions of the reference area and of the animals from the three contaminated areas.

Area	Mean $\pm$ stdev	Geometric mean	Min-max	n° of samples
Zandstreek	3.4 $\pm$ 1.6	3.1	1.4-7.3	16
Zandleemstreek	5.1 $\pm$ 3.1	4.1	1.5-11.4	17
Leemstreek	4.6 $\pm$ 2.7	4.0	1.6-11.6	26
Kempen	3.8 $\pm$ 1.3	3.6	2.0-5.3	7
Weidestreek	5.4 $\pm$ 2.1	5.0	2.4-8.3	10
Condroz	3.9 $\pm$ 2.5	3.2	1.0-8.1	9
Ardennen	5.4 $\pm$ 2.4	4.9	1.6-9.7	12
Site A	4.0 $\pm$ 1.7	3.7	1.7-7.2	11
Site B	3.7 $\pm$ 1.7	3.4	2.0-7.2	12
Site C	4.9 $\pm$ 2.1	4.4	0.6-10.9	30

**Table III.** Pearson correlations between trace element contents in organs for cattle from polluted areas and from the reference area. Correlation coefficients were calculated on log-transformed trace element concentrations in fresh kidneys and livers.

	Kidney				Liver			
	Cd	Pb	Cu	Zn	Cd	Pb	Cu	Zn
Kidney-Cd	-	0.59 <sup>***</sup>	0.31 <sup>*</sup>	0.61 <sup>***</sup>	0.75 <sup>***</sup>	0.25 <sup>*</sup>	-0.27 <sup>*</sup>	0.00
Pb	0.63 <sup>***</sup>	-	0.27 <sup>*</sup>	0.41 <sup>**</sup>	0.60 <sup>***</sup>	0.68 <sup>***</sup>	-0.33 <sup>**</sup>	0.06
Cu	0.07	0.24 <sup>**</sup>	-	0.50 <sup>***</sup>	0.17	-0.33 <sup>**</sup>	-0.15	0.04
Zn	0.44 <sup>***</sup>	0.50 <sup>***</sup>	0.73 <sup>***</sup>	-	0.43 <sup>***</sup>	0.15	-0.16	0.36 <sup>**</sup>
Liver-Cd	0.82 <sup>***</sup>	0.52 <sup>***</sup>	-0.09	0.26 <sup>**</sup>	-	0.51 <sup>***</sup>	-0.33 <sup>**</sup>	0.06
Pb	0.57 <sup>***</sup>	0.88 <sup>***</sup>	0.10	0.39 <sup>***</sup>	0.58 <sup>***</sup>	-	-0.21	0.30 <sup>*</sup>
Cu	-0.36 <sup>***</sup>	-0.36 <sup>***</sup>	0.14	-0.14	-0.21 <sup>*</sup>	-0.32 <sup>***</sup>	-	0.19
Zn	0.32 <sup>***</sup>	0.51 <sup>***</sup>	0.26 <sup>**</sup>	0.47 <sup>***</sup>	0.44 <sup>***</sup>	0.56 <sup>***</sup>	0.02	-

Upper right half: cattle from polluted areas.

Lower left half: cattle from the reference area.

\* p < 0.05

\*\* p < 0.01

\*\*\* p < 0.001

**Table IV.** Cadmium and lead concentrations (in mg kg<sup>-1</sup> fresh weight) in kidney and liver of dairy and beef cattle from the reference area.

	Cadmium		Lead	
	Dairy cattle	Beef cattle	Dairy cattle	Beef cattle
Kidney	1.21*	0.62	0.31*	0.11
Liver	0.20	0.13	0.12*	0.04

\* Significant differences between dairy and beef cattle at  $p < 0.05$  following Duncan multiple range test on log-transformed data. The data are retransformed into natural numbers.