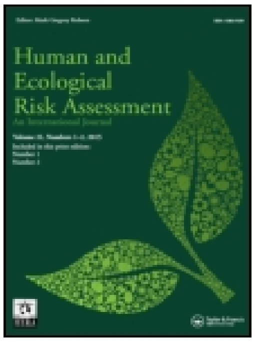

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Exposure to lead and cadmium and associated factors in children 0–17 years of age living in an area contaminated by metals

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ABSTRACT

This article analyzes some characteristics and conditions associated with Pb and Cd exposure using an exploratory approach, relating them to the levels of Pb and Cd in blood (blood lead levels [BLL] and blood cadmium levels [BCL]) in children 0–17 years of age living in an area contaminated by metals. BLL and BCL values were determined for each child and questionnaires were applied to their parents. Significant differences were found in mean BLL values according to race ($p = .03$), family history of intoxication by Pb ($p = .004$), if a family member was a metallurgy worker ($p = .047$), if a family member performed activities in the area of metallurgy ($p = .03$), and mother's employment status ($p = .014$). The following characteristics were associated with increased risk of BLL above 5.0 mg/dL in children: race, having a family record of intoxication by lead, and having a parent who worked at the plant. BLC values are not significantly associated with any of the studied characteristics. It may be concluded that BLL values are influenced by the social indicators of the population.

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lead and cadmium in blood; exposure to metals; contaminated area; child population

Introduction

Exposure to the metals lead (Pb) and cadmium (Cd) is an aspect of concern given the risks and negative effects that these elements have on human health. The most sensitive targets for lead toxicity are the nervous, hematological and cardiovascular systems and the kidneys. However, due to the multiple actions of lead in biological systems, it could potentially affect any system or any organ in the body (Agency for Toxic Substances and Disease Registry [ATSDR] 2007; Murata *et al.* 2009). According to Landrigan (1989), Moreira and Moreira (2004), and Carvalho *et al.* (2003), the effects of Pb toxicity are not always easy to identify as

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they sometimes involve subtle clinical or biochemical effects and multiple organs, systems, and biochemical activities.

According to the National Toxicology Program (NTP) of the United States there is sufficient evidence that blood lead levels (BLL) <10 μg/dL and <5 μg/dL are associated with adverse health effects in children and adults. Decreased academic achievement, intelligence quotient (IQ), and specific cognitive measures, increased incidence of attention-related behaviors and problem behaviors are the principal health effects in children associated to BLL <5 μg/dL (Lanphear *et al.* 2000). Delayed puberty, reduced postnatal growth, decreased IQ and decreased hearing are related to BLL $<10\mu$g/dL (NTP 2012). Exposure when still in the womb or in early childhood may also slow mental development and decrease intelligence coefficients (ATSDR 2007). The International Agency for Research on Cancer (IARC) classifies inorganic lead and lead compounds as carcinogenic to humans (2B group). In the priority list of hazardous substances, ATSDR ranks Pb in second place according to its occurrence in contaminated sites and toxicity (ATSDR 2007). Moreover, the child population is more susceptible because they can absorb about 40% to 50% of ingested Pb (ATSDR 2007). Lead is stored in the bone for decades, causing long-term internal exposure. The half-life of lead varies from about one month in blood, 1 to 1.5 months in soft tissue, and about 25 to 30 years in bone (ATSDR 2007).

The BLL limit associated with adverse health effects in children has been constantly revised and no safe BLL has been determined (ATSDR 2007). There are multiple effects due to Pb exposure that begin in childhood and extend over the entire human lifespan (Schwartz and Hu 2007).

Cd is a bio-accumulative toxic element, with a half-life of about 15 to 30 years in the human body (ATSDR 2012), which is similar to the half-life of lead in bones. Children who are exposed can have long-term consequences (ATSDR 2012). The health effects in children are expected to be similar to those in adults and are related mainly to kidneys and bones. IARC also classifies Cd and its compounds as probably carcinogenic to humans (I group).

According to ATSDR (2012), under conditions of chronic exposure the kidney is the most affected organ. Cd exposure can cause renal cell damage characterized by a dysfunction in the proximal tubule re-absorption. Decreases in bone mineral density, increases in the risk of fractures, and increases in the risk of osteoporosis have also been observed in populations living in cadmium contaminated areas. Some factors that increase cadmium absorption following oral ingestion are low intake of iron, calcium, zinc, copper, or protein (Hays *et al.* 2008).

Several variables influence the health effects due to Cd and Pb exposure, including the doses (how much), durations (how long), and the exposure pathways. However, once exposure takes place, factors such as individual variability, associated with biological factors such as age, gender, nutritional status, genetics, lifestyle, and health status can affect the absorption, distribution, metabolism and excretion of contaminants (ATSDR 2007). Together these factors determine the health effects that may result from exposure and should be taken into consideration when estimating the risk to human health that these elements can pose.

Children are more susceptible to the potential exposure routes and toxicities of environmental contaminants. They inhale and swallow house dust and ingest contaminated soils as they explore the environment with their hands and mouths (ATSDR 2012; Cunha *et al.* 2005). Moreover, vulnerability is exacerbated by the child's developmental stage. There are critical periods of structural and functional development when the bodies are particularly sensitive to toxic effects.

This article analyses some of the possible characteristics and conditions associated with exposure to Pb and Cd in children 0–17 years old living in an urban area contaminated by these metals near a closed metallurgy plant.

Previous studies and problem description

From 1956 to 1993, intense lead metallurgic activities took place in an urban area of the town of Santo Amaro, state of Bahia, Brazil. The main product of the metallurgy was a galena (PbS) concentrate and the plant used the following processes: classical sinter-roasting, where a Dwight-Lloyd sintering machine was used for the agglomeration; smelting, which used a water-jacket furnace; and refining. The smelter could process approximately 46.2×10^3 Tons/year of galena concentrate (De Oliveira 1977). The poor waste management and the intensive emission of contaminants from the lead production process have significantly affected the local soil and vegetation with impacts on the health of the population living near the plant (De Oliveira 1977; Silvany-Neto *et al.* 1996; Carvalho *et al.* 2003; Machado *et al.* 2004).

During the operation, the residues of the production processes were used in several ways by the local authority and the population. These include its use as a road base and as backyard landfills. In this article, the term lead debris is used to embrace the slag and all the other residues generated by the past metallurgical activities that were inappropriately disposed of in the study area. The volume of residues disposed of in the town was estimated to be 55,000 m^3, whereas for the area surrounding the metallurgy this volume was estimated to be 180,000 m^3 (Machado *et al.* 2004). The residue is classified as a Class I material (dangerous material) according to the Brazilian standard NBR 10004/2009 (Anjos 2003; Machado *et al.* 2004).

The impacts of the metallurgic activities have been studied since the 1970s (Machado *et al.* 2004). Many studies evaluating the effects of the contamination on human health and the environment have been carried out in the area, demonstrating the severity of this contamination case (Anjos 1998, 2003; Carvalho *et al.* 1984, 1985, 1987, 1989, 1997, 2003; Machado *et al.* 2003, 2004; Silvany-Neto *et al.* 1985; Tavares *et al.* 1989; Tavares and Carvalho 1992).

According to Carvalho *et al.* (1984), in 1980 the concentration of lead in the hair of children increased as the concentration of lead in the soil increased; the hair lead concentration increased by about 0.024 mg/kg when the lead concentration in the soil increased 1 mg/kg. According to Tavares *et al.* (1989), in 1985 89% of the population in the vicinity of the metallurgical plant had lead concentrations in the blood above 10 μg/dL. In 1998 (5 years after the metallurgical plant was closed), a new study was performed with children up to 5 years old. According to Carvalho *et al.* (2003), 31.9% of these children presented levels of lead in the blood above 20 μg/dL, although they were born after the plant closed in 1993. The authors also found that children living in places near the lead debris had higher average lead concentrations (18.7 μg/dL) in their blood compared to children living in places without the presence of lead debris (15.5 μg/dL).

Recent studies have confirmed the persistence of metal contamination in the backyards of the houses near the plant. This is apparently derived from two different sources: past atmospheric emissions and the presence of lead debris in the vicinity of the sampling points (Rabelo 2010; Machado *et al.* 2013).

Analysis of 223 superficial soil samples from Rui Barbosa Street, in the neighborhood where the plant is located, showed that approximately 80% were above the lead limits established by CONAMA No. 420/2009 (Brasil 2009) for investigation in residential areas (300 mg/kg). Furthermore, 50% of the samples had concentrations above the limit adopted for industrial areas (900 mg/kg). For cadmium, 26.6% of the samples were above the agricultural investigation limit (3 mg/kg), and 11.7% of the samples were above the residential investigation limit (8 mg/kg) (Machado *et al.* 2013).

Magna *et al.* (2013) reported the presence of Pb and Cd in plant food species at levels ranging from 0.18 to 118.2 mg/kg and 0.04 to 7.29 mg/kg, respectively. In all the fruits analyzed, the average of both contaminants was higher than the WHO limit for both contaminants.

Magna *et al.* (2014) studied the impact of the ingestion of vegetables cultivated in the backyards in the exposure of children 0 to 17 years old to Pb and Cd. According to the authors, the estimated doses for both contaminants exceeded the values recommended by WHO. The results show that the consumption of vegetables plays an important role in the exposure of the population to metals. About 655 inhabitants currently live in Rui Barbosa Street, in the vicinity of the closed plant.

Methods and materials

Subjects

The study evaluated 95 children of 0–17 years age living in the vicinity of the closed plant (see Figure 1). All the studied population live less than 1.280 m from the metallurgy chimney (Machado *et al.* 2013).

Field campaigns

Preliminary field campaigns were carried out in the study area in order to inform the families of children about the research objectives as well as to request their consent for participation. If they responded positively, the parents or guardians of the children signed a consent form and were interviewed using questionnaires. The studies were performed over the period 2009–2012. As well as data collected in the field campaigns described in this article, the results of superficial soil and plant foods sampling campaigns, carried out by Machado *et al.* (2013) and Magna *et al.* (2013) respectively, were used to provide complementary information for the analysis performed.

Questionnaires

The questionnaire was designed to collect background information about children, families, and households. The questionnaire was structured in two parts. The first part collected general information concerning the child's family, such as socioeconomic, demographic, and environmental data, as well as information about health and family lifestyle. The second part focused on the children, addressing issues such as physiological characteristics,

Figure 1. Study area around the former lead smeltery.

behaviors, and habits associated with exposure to metals. The questionnaires covered 25 factors presumably associated with population exposure to the metals of concern which were classified into four different groups: (1) Children's characteristics, (2) household characteristics, (3) family characteristics, and (4) children's behaviors and habits.

After the questionnaire was drawn up, a preliminary campaign was carried out in a population located outside the study area. This campaign focused on assessing the questionnaire. Based on the difficulties encountered some questions considered too complex were modified or suppressed, as well as questions considered rude, redundant or unnecessary. After this stage, the questionnaire was applied in the population of the study area.

A child's age affects the way they interact with the world. At a tender age children use their mouth and hands to explore the space around and therefore they are more susceptible to contamination. As well as this, they present a higher absorption of lead and cadmium by the gastrointestinal system and different ages will probably reflect different exposure periods. Therefore, the child's age was used as a selection criterion. Two age groups (0 to $\leq$7 and $>$7 to 17 years) were used. The age of seven was chosen considering about half of the exposure period after the closure of the metallurgy, the number of children available for the study and the fact that 7 years is a transitional age for children's behavior, marking the beginning of compulsory schooling in Brazil. Only one child living in the house for each age group was chosen for the study. In the case of houses where there was more than one child of the same age group, the older child was chosen to be included in the study. All the children who participated in the study were born after the closure of the plant in 1993.

Children blood sampling

Blood sampling for BLL and BCL took place in the residences of the children and was performed by a specialized team. A clean, bright and comfortable area in the house was prepared to perform the procedure. Before blood collection, the skin of the child was cleaned with 70% ethanol. The blood sampling was performed by an authorized nurse. The local physician supervised and supported the field work enabling the research team to take advantage of their previous knowledge of the problem on an individual scale. The blood sampling was always performed in the presence of the project researchers and the family of the child/children. The contents of Pb (μg/dL) and Cd (μg/dL) in the whole blood of ninety-five (n = 95) children 0–17 years old was evaluated. About 10mL of blood was collected from each individual and placed in vacuum tubes with anticoagulant for a complete hemogram (erythrogram, leukogram, and platelet count) and metal measurement. The blood samples were stored in a Styrofoam box filled with ice in order to keep the temperature below 4°C before analysis. The temperature was monitored throughout the whole process. All the obtained results were returned in person to the children's parents through a technical report explaining the results and their impact on their child's health.

Ethical considerations

This study followed the ethical principles established by Resolution 196/96 of the National Commission of Ethics in Research of Brazil, and was approved by the Committees of Ethics in Human Research of the Research Center Gonçalo Moniz (FIOCRUZ) and the Catholic University of Salvador (UCSAL). Parents or guardians previously signed a consent letter for the inclusion of their child in the study.

BLL and BCL determination

Analyses of BLL and BCL were undertaken following the procedure proposed by Parsons and Slavin (1993), with a dilution of 50 μL of blood in 450 μL of matrix modifier to stabilize the atomization. The metals in whole blood were quantified using graphite furnace atomic absorption spectrometry (G-FAAS). An atomic absorption spectrometer Z-220, graphite furnace GTA 110, trademark Varian, with background correction was used. The graphite furnace was equipped with a graphite tube and platform, where the diluted aliquot was deposited in a 110 Programmable Sample Dispenser (PSD 110).

The standard solutions used for calibration of the atomic absorption spectrometer were 1.0; 2.0 and 3.0 (μg/L) for Cd and 10.0; 20.0 and 30.0 (μg/L) for Pb, diluted in a matrix modifier. Calibration standard solutions were prepared from stock standard solutions National Institute of Standards and Technology (NIST) traceable concentration of 1000 (mg/L) in HNO_3, and lyophilized human blood was used as reference material for both Cd and Pb (BCR-636), certified by BCR (Community Bureau of Reference), under the responsibility of IRMM (Institute for Reference Materials and Measurements) of the European Commission.

Statistical treatment of the data

A descriptive analysis of characteristics such as the use of lead debris in the house, social and economic characteristics of the family, children's habits and behaviors were performed. Statistical measures of central tendency and dispersion of data such as arithmetic mean (mean), standard deviation (SD) and coefficient of variation (CV) were determined when appropriate.

Statistical differences in the mean BLL and BCL values were analyzed according to the exposure factors cited above. The non-parametric tests U Mann-Whitney and Kruskal-

Wallis were employed. All the analyses were performed for both Pb and Cd. A significance level of 5% was used throughout the study. Chi-square tests were also performed to evaluate association with exposure factors. In this case, a BLL value of 5.0 μg/dL was used as a cutoff point. This analysis was not performed for the BCL values because all the results were above the reference value of 0.1 μg/dL established by the Human Biomonitoring Commission of the German Federal Environmental Agency and recommended by the European Community (EC) (Wilhelm *et al.* 2004).

In order to evaluate possible associations between the characteristics related to Pb exposure, a new analysis was performed using where appropriate Chi-squared contrast test and/or Fisheŕs exact test. Only a single characteristic was considered when a correlation was detected between similar variables using as a criterion the possible influence on the BLL values.

Non-conditional logistic regression models were constructed. The covariables shown by the bivariate analysis as having an association with the BLL (with p-values $< .20$) were selected for inclusion in the regression models. The backward stepwise regression was used in this analysis.

Results and discussion

Site and population characterization

The studied population presented 41% (39) of children aged between 0–7 years. 50.5% (n = 48) of the children were male. About 58.6% of the children presented some degree of malnutrition (mild, moderate, or severe) according to their body mass index values (BMI) (WHO 1995). These results are worrying because good nutrition status decreases the absorption of Pb and Cd (ATSDR 2007, 2012). Furthermore, 28 cases of anemia were reported by the children's parents, of which 82.1% correspond to iron-deficiency.

Concerning the socioeconomic and demographic background of the children's family, in 96.8% of the households between 1 and 3 children were born after 1993, when the plant was closed. The parents' current employment was given by 75.5% of the fathers and 62.1% of the mothers. Of the children's parents (Father's Activity), 54.3% had a job related to lead exposure such as a car-repairman and welder operator. The main job activities of children's mothers were related to the service sector such as sales and education. More than half of the households (53.3%) declared their family income (monthly income) to be between 626 USD to 939 USD and 37% said they earned below the minimum wage (313 USD).

About 30.5% of the respondents reported having a family member who had worked in the plant and 26.3% reported a family member living in the house who had been diagnosed as intoxicated by Pb in the past. In addition, 47.7% said that a family member uses the area around the plant to perform some kind of activity, such as practice sports (soccer mainly) and/or to collect fruits.

Regarding the characteristics of households, the time of residence in the study area varied from 1 to 57 years with a mean value of 23 years. Fifty-two percent of the respondents said that they were aware of the use of the slag as construction material or presence of lead debris in the backyards. Furthermore, 60.9% of children live less than 640 m (half of the maximum distance to the metallurgy chimney in the study area) from the area of the plant. Most homes have ceramic floors (77.9%), followed by 17.9% with a cement floor. Ninety seven percent of the walls are painted. Fifty-two percent of householders reported cleaning the house two or more times per day and 30.5% once a day.

The Pb and Cd concentrations in superficial soil samples were compared with limits for investigation in residential areas proposed by Brazilian National Council for Environment (CONAMA No. 420/2009). These limits are used to define situations where there are potential direct or indirect risks to human health, considering a standardized exposure scenario, in this case residential use of the land. Eighty-one percent of the samples collected in the backyards of the study area revealed Pb concentrations above 300 mg/kg and 70.6% had Cd concentrations above 8 mg/kg, the CONAMA limits for Pb and Cd, respectively (more details about these values are provided by Machado *et al.* 2013).

About 48.9% of the respondents confirmed that they ate plant foods cultivated in the backyards. Pb and Cd in plant foods grown in backyards and consumed by the population were detected in mean concentrations that greatly surpass the reference values for both contaminants by the World Health Organization (Magna *et al.* 2013).

It is important to highlight that the town of Santo Amaro was flooded by the Subaé River in April 2010, affecting every backyard in the area, months before this study was performed. Of respondents, 56.8% mentioned that their backyards were flooded and 86.7% of them (n = 38) stated that the sediments deposited by the river were not removed and were left in place until they dried.

BLL and BCL values

About 40% of the children presented BLL concentrations over 5.0 μg/dL, the recommended value adopted by the Advisory Committee on Childhood Lead Poisoning Prevention of the Centers of Disease Control and Prevention in the United States (ACCLPP-CDC 2012). The BLL results are summarized in Table 1.

Mattos *et al.* (2009) reported a mean BLL value of 5.5 μg/dL in children of 0–16 years old (n = 64) living in a community next to a lead emission source in Rio de Janeiro, Brazil. Ferron *et al.* (2012) evaluated BLL in children of 0–5 years old (n = 97) in Vila Dique, Porto Alegre, Southern Brazil. A median value of 5.2 μg/dL was obtained and the potential source of contamination was apparently related to waste recycling activities.

It is important to emphasize that acute intoxication by lead still occurs around the world (Astete *et al.* 2009; Lo *et al.* 2012; Haefliger *et al.* 2009). Additionally, the consequences of chronic exposure at low concentrations remain an important public health issue, particularly among socioeconomically deprived populations (Mattos *et al.* 2009).

Considering only the data from the study area, a clear decrease in the BLL values can be noted over time, although the obtained results are still comparable with values detected in areas with active sources of contamination (Mattos *et al.* 2009; Ferron *et al.* 2012). In 1985,

Table 1. Blood lead levels and blood cadmium levels detected in children 0–17 years old. Sampling performed in 2010. Santo Amaro, BA, Brazil, 2010.

	n	Min-Max (μg/dL)	Mean (SD) (μg/dL)	CV %	Median (Q_1-Q_3) (μg/dL)
BLL	95	2.28–11.42	4.90 (1.91)	38.9	4.40 (3.52–5.85)
BCL	95	0.23–2.62	1.08 (0.42)	38.8	1.06 (0.76–1.36)

SD: Standard deviation; CV: Coefficient of variation; Q_1: Percentile 25%; Q_3: Percentile 75%.

89% of the population in the vicinity of the metallurgy presented blood lead concentrations >10 μg/dL (Tavares 1990). In 1998, a new study was performed with children aged up to five years old (Carvalho *et al.* 2003); 31.9% of these children presented levels of lead in the blood >20 μg/dL despite being born after the plant closed. In synthesis, this study confirms the continuing decrease in the BLL values over time, compared to previous studies. The probable reasons for the BLL decrease over time are related to the closure of the plant, as mentioned above, the educational campaigns targeting this population in recent years and the fact that public health staff use specific protocols when performing regular health services in the local population. However, there are still active contamination routes in the field, leading to BLL values above reference values (Magna *et al.* 2014).

All the children presented BCL values above the reference value of 0.1 μg/dL (see Table 1) with a mean value of 1.08 μg/dL. Costa (2001) found a mean BCL of 1.50 μg/dL in the same population reported by Carvalho *et al.* (2003). This suggests a smoother BCL decrease over time in children living in the study area.

The very long biological half-life of Cd (10–30 years) in the human body is one of its most important toxicological properties (World Health Organization 1992). Furthermore, factors such as low iron availability in the human body may increase Cd absorption up to four times (Jin *et al.* 2002). Therefore, BCL values can reflect chronic cadmium exposure effects, particularly in low level exposure scenarios.

Factors associated with BLL and BCL values

Table 2 summarizes the results obtained from statistical tests performed to investigate possible associations between the different variables studied.

With regard to race, children classified as black presented a higher mean BLL. The differences between mean BLL values according to race were statistical significant ($p = .03$). In fact the race variable is generally associated with many social aspects such as family income, nutritional status, housing conditions, mother's employment status, and so on (Pinheiro *et al.* 2008). Although there are studies in the literature that consider race also a physiological factor, according to Kemp *et al.* (2007), African-American children present higher gastrointestinal absorption of Pb compared to those with less pigmented skin, the authors believe the social factors linked to race are more important in this study. Similar results were observed by Freitas *et al.* (2007) in children from 0 to 12 years of age living in a contaminated area in the city of Bauru, Brazil.

Mean BLL results for houses with Pb backyard soil concentrations higher than 300 mg/kg were statistically different from houses with Pb concentrations lower than 300 mg/kg ($p = .024$). No statistical differences were found regarding the presence or absence of lead debris in households ($p = .343$). It is important to highlight that this information was declared by the residents (presence or absence of lead debris in households). This result is contrary to the findings reported by Carvalho *et al.* (2003) in the study area. According to this author, children living in places near the lead debris had higher lead concentrations in their blood compared with children living places where no debris was detected. Despite this, exposure to lead debris can be considered occasional. Several tests performed using lead debris samples indicate that this material is classified as Class I (hazardous materials) because of its toxic characteristics, according to the Brazilian standard NBR 10004/2009 (Anjos 2003; Machado *et al.* 2004).

Table 2. Factors associated with exposure to lead according to mean and recommended value of blood lead levels of children 0 to 17 years old, Santo Amaro, Bahia, Brazil, 2010.

		BLL (μg/dL)				BLL (μg/dL) %		
Characteristics	n	Min	Max	Mean (SD)	p-value*	<5.0	≥5.0	p-value*
Age groups (years)								
0 to ≤7	32	2.28	11.25	5.18 (1.88)	0.127	53.1	46.9	0.165
>7 to 17	63	2.39	11.42	4.75 (1.93)		63.5	36.5	
Gender								
Male	48	2.39	10.48	4.83 (1.61)	0.858	58.3	41.7	0.369
Female	47	2.28	11.42	4.96 (2.19)		61.7	38.3	
Race								
White	8	2.56	11.42	5.31 (2.77)	0.03*	50.0	50.0	0.002*
Black	26	3.06	11.25	5.97 (2.21)		34.6	65.4	
Brown	61	2.28	10.48	4.38 (1.42)		72.1	27.9	
Family record of intoxication by Pb								
Yes	25	2.28	11.25	5.79 (2.16)	0.004*	32.0	68.0	0.001*
No	61	2.39	1.42	4.55 (1.72)		72.1	27.8	
Parent who worked at the factory								
Yes	29	2.81	11.25	5.32 (1.75)	0.047*	41.4	58.6	0.01*
No	62	2.28	11.42	4.68 (1.99)		69.3	30.6	
Mother's employment status								
Employed	59	2.28	11.42	5.26 (2.07)	0.014*	54.2	45.8	0.142
Unemployed	36	2.44	7.82	4.29 (1.56)		69.4	30.5	
Pb investigation limit for residential areas (mg/kg)								
≤300	17	2.28	11.12	4.13 (1.19)	0.024*	82.4	17.6	0.017*
>300	77	2.77	11.42	5.07 (2.01)		54.6	45.5	
Lead debris								
Presence	50	2.28	11.12	4.93 (1.78)	0.343	52.0	48.0	0.05*
Absence	21	2.77	11.42	4.99 (2.44)		76.2	23.8	
Distance from the factory chimney (m)								
≤640	56	2.28	10.48	5.00 (1.74)	0.095	51.8	48.2	0.025*
>640	36	2.39	11.42	4.78 (2.23)		72.2	27.8	
Play with soil								
Yes	35	3.08	11.25	5.28 (2.03)	0.120	51.4	48.6	0.179
No	58	2.28	11.42	4.66 (1.84)		65.5	34.5	
Hand to mouth activity								
Yes	74	2.28	11.42	5.05 (2.06)	0.297	56.8	43.2	0.230
No	18	2.39	6.60	4.34 (1.16)		72.2	27.8	
Thumb-sucking habit								
Yes	7	3.74	11.12	6.30 (2.38)	0.023*	28.6	71.4	0.082
No	82	2.28	11.42	4.81 (1.88)		62.2	37.8	
Consumption of vegetables foods from backyards								
Yes	45	2.51	11.42	5.07 (2.14)	0.693	60.0	40.0	0.483
No	47	2.28	10.48	4.76 (1.72)		59.6	40.4	
Place to play								
Indoor home	31	2.39	11.42	4.79 (2.03)	0.620	64.5	35.5	0.095
Backyard	18	2.28	11.12	5.46 (2.39)		38.9	61.1	
Street	35	2.44	11.25	4.80 (1.77)		65.7	34.3	
Factory area	5	3.86	6.43	5.07 (0.96)		40.0	60.0	

*Statistically significant (p-value < .05) related to U Mann-Whitney or Kruskal-Wallis test.
**p-value related to statistical chi-squared contrast test. The number of samples differs due to the loss of information on some variables.

Concerning the historical background of the parents, mean BLL values in children with parents diagnosed as intoxicated by Pb in the past were higher than in children without parents diagnosed as intoxicated ($p = .004$). The same can be said if a family member worked in the metallurgy ($p = .047$). These observations corroborate the results published by Zheng *et al.* (2008). The authors detected an association between BLL values in children of 1–7 years old and parents who work with electronic waste.

Mean BLLs were higher in children with family members who performed activities in the area of the plant ($p = .03$). These activities may bring contaminated soil into households via shoes and clothes and this might constitute an active exposure pathway.

Mean BLL values were higher when the employment status of mother was employed ($p = .014$). These results are similar to the findings reported by Sepúlveda *et al.* (2000) in children living in urban area highly contaminated by metals in Antogafasta, Chile. In this case, the variations in BLL values were influenced by the mother's employment status, among other factors.

Statistically significant different BLL values were observed in children who have a thumb-sucking habit compared to children who do not. However, only five children had this habit.

In the case of BCL values, no statistical significant differences were observed according to all the factors analyzed. This could indicate that the values of BCL of children are probably related to other factors that were not investigated in this study. Furthermore, the lack of association between BLC and other studied variables is probably linked to the higher mobility of Cd in the environment compared to Pb, as discussed by Machado *et al.* (2013).

According to Rabelo (2010) and Machado *et al.* (2013), Cd concentrations in superficial soils are much lower than Pb and the spatial distribution of Cd contents are much more erratic. This behavior is coherent with the higher mobility assumption of Cd and contributes to the lack of association of the BCL values with the other variables. Another important finding mentioned by Rabelo (2010) that corroborates this higher mobility assumption are the Cd and Pb concentrations found in an ancient branch of the Subaé river. Sediment river samples present much higher Cd to Pb ratios than superficial soil samples collected in the study area. This indicates that runoff water plays an important role in the migration of Cd in the superficial soil.

Factors associated with BLL values above 5.0 μg/dL

Fifty children lived in households where the presence of lead debris was stated by the respondents against 21 children who live in places where the presence of lead debris was excluded. Considering this population (n = 71, excluding the cases where it was not possible confirm or exclude the use of lead debris), 48% presented BLLs above 5.0 μg/dL (see Table 2) in places with the presence of lead debris against 23% without. Contrary to what was presented in the previous item (mean differences), this result is coherent with the observations made by Carvalho *et al.* (2003). The removal of the lead debris from the backyards could reduce the number of cases with BLLs above 5.0 μg/dL. The association between BLL and the presence of lead debris was statistically significant ($p = .05$).

About 68% of children with some type family record related to intoxication by Pb showed BLL above 5.0 μg/dL. This result was higher (about 2.5 times) compared to the group without a family record of intoxication. The association between BLL and the family record factor was statistically significant ($p = .001$).

BLLs above 5.0 μg/dL were found in 59% of children with some family member who had worked in the old plant compared to 30% in the other group of children. The association was statistical significant ($p = .01$).

About 48.2% of children living at a distance from the plant of ≤640 m had BLLs above 5.0 μg/dL compared to 27.8% living at a distance from the plant of >640 m ($p = .025$). Concerning the Pb soil concentration, 45.5% of children living in households with a soil Pb concentration of ≥300 mg/kg had a BLL higher than 5.0 μg/dL.

Table 3. Factors associated with exposure to lead according to recommended value of blood lead levels of children from 0 to 17 years old, Santo Amaro, Bahia, Brazil, 2010—Multivariate analysis.

Characteristics	OR	95% CI	*p*-value
Race			
Black	8.06	1.37–47.51	.021
Brown	4.62	1.38–15.51	.013
White	1#		
Family record of intoxication by Pb			
Yes	4.11	1.27–13.25	.018
No	1#		
Parent who worked at the factory			
Yes	3.63	1.13–11.62	.030
No	1#		

OR = odds ratio; 95% CI = confidence interval; *p*-value < .05# reference group

The results of statistical tests performed to investigate correlations between the different studied characteristics showed no correlation between family record of intoxication by Pb and parent who worked at the factory. Factors such as Pb investigation limit for residential area, distance from the factory chimney and lead debris were correlated. Despite this, Pb investigation limit for residential area was selected as the condition of major relevance (main source of contamination in the area) and was included for the construction of the multivariate logistic regression model.

When evaluated in the multivariate logistic model adjusting simultaneously by selected characteristics, a statistically significant association between BLL above 5.0 μg/dL and race (black and brown), having a family record of intoxication by lead and having a parent who worked at the factory were remained (Table 3).

Conclusions

This research evaluates the influence of 25 possible characteristics associated with the impact of heavy metal contamination in the population. Some of these characteristics, such as the mother's employment status, race, family income and vegetable consumption were taken into account for the first time in this study. The article findings demonstrate that social characteristics can be used to develop customized strategies to identify and treat children who have elevated BLL

About 40% of the children in the sample had a BLL above the recommended value adopted by ACCLPP-CDC (2012). All the children evaluated had a BCL higher than the EU reference value (0.1 μg/dL). These values are certainly worrying considering that it has been almost 20 years since the plant ceased to operate.

Mean BLL values are statistically different and associated with characteristics such as race, a family history of Pb intoxication, a parent who worked in the old plant, a family member who performed activities in the area around the plant and mother's employment status.

BLL values may also be affected by behavioral habits such as thumb-sucking; playing with soil; consumption of plant foods grown in backyards; and places used to play. However, the differences were not statistically significant. The lack of significance in this case may be associated to factors such as type of plant food, frequency, and form of consumption.

Children classified as black and brown, with a family record of intoxication by lead and with a parent who worked at the factory were factors associated to exposure to Pb.

In the case of BCL, no statistical significant differences were observed. This indicates the presence of other exposure pathways for Cd that were not identified and evaluated in this work. The higher mobility of Cd in the environment compared to Pb, as discussed above, is another factor that may have contributed to the lack of significance in the BCL results.

Based on our findings the following recommendations are suggested in order to reduce contamination risks: the plant area must not be used for production and recreation purposes. An educational campaign must be performed highlighting the importance of house cleaning in order to avoid the accumulation of dust. Lead-free soil must be used to replace contaminated soil in the backyards to enable the cultivation of plant foods for safe consumption, especially in low-income families, since good nutrition status is an important factor in reducing Pb and Cd absorption in the human body. The population must avoid direct contact with the lead debris. The removal of the lead debris from the backyards or the use of a landfill over the lead debris could reduce the number of people with a BLL above 5.0 μg/dL.

The analyses presented here can be used to support actions taken by the competent authorities to mitigate the potential effects caused by routes of contamination that are still active in the study area.

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