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Lead concentration in the blood of the general population living near a lead–zinc mine site, Nigeria: Exposure pathways

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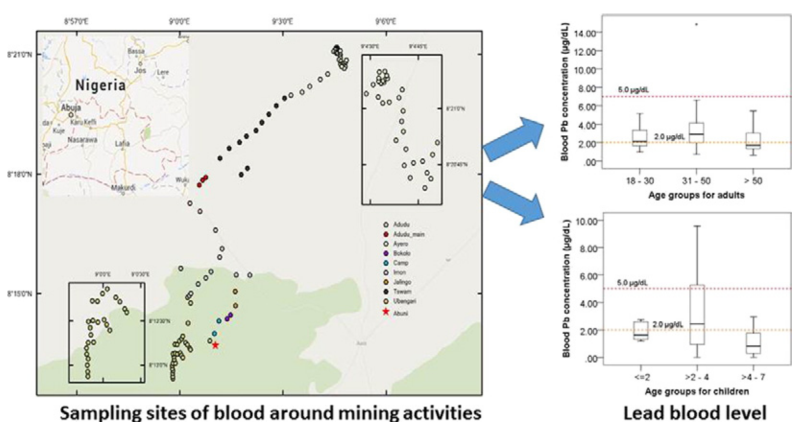
HIGHLIGHTS

- Concentrations of Pb in blood in both children and adults near Pb–Zn mine
- 11.4% of children's blood and 14% of adults' blood exceeded 5 μg/dL.
- 31% of children's blood and 68% of adults' blood exceeded 2 μg/dL.
- Children 2–4 years old have the highest blood Pb levels.
- Significant correlation between water Pb levels of adults and blood Pb levels.

GRAPHICAL ABSTRACT



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ABSTRACT

Lead (Pb) poisoning in children is a major public health catastrophe worldwide. This report summarises both exposure pathways and blood Pb levels in children below 7 years of age and adults (above 18 years) from the Adudu community living near a lead–zinc mine in Nasawara, Nigeria. The average and median blood Pb levels in children and adults were 2.1 and 1.3 μg/dL, 3.1 and 1.8 μg/dL, respectively. However, Pb in 14% of adults' blood exceeded 5 μg/dL, which is the recommended threshold blood Pb concentration in adults as established by the Centers for Disease Control and Prevention (CDC). Furthermore 68% of adults' blood exceeded blood Pb action level of 2 μg/dL. For children, 11.4% and 31% of the blood samples exceeded 5 μg/dL and 2 μg/dL, respectively, while no safe blood Pb level in children has been recommended. In Nasawara, a significant difference ($p < 0.05$) was observed between the various age groups in children with 2–4 years old having the highest levels and 6 year old children having the lowest Pb levels. Although this study did not detect elevated levels of Pb in children's blood in regions such as Zamfara, Nigeria and Kabwe, Zambia, a high percentage of samples exceeded 2 μg/dL. Soils, floor dusts, water and crops also reveal that Pb contamination in the study area could potentially be the major cause of blood Pb in the community exposed to mining. This study also observed a significant correlation between water Pb levels of adults and blood Pb levels, suggesting that water is the major exposure pathway. This analysis highlights

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the need to properly manage mining activities so that the health of communities living in the vicinity of a Pb–Zn mine is not compromised.

1. Introduction

Lead (Pb) is a heavy metal used in several industries such as the production of batteries, alloys, plastics, varnishes, etc. Inorganic lead compounds have been classified as probably carcinogenic to humans (Group 2A) despite the limited evidence for such carcinogenicity in humans but there is sufficient evidence concerning animals (Anders et al., 2004). Exposure to Pb can cause a variety of health problems. Prolonged exposure to Pb poses dangers to the normal functioning of the kidneys and nervous system, for example, leading to dysfunction or hypertension in adults and delays in children's physical and mental development including decreased intelligence quotient (Canfield et al., 2003; Cory-Slechta et al., 2012; Golub et al., 2010; Paoliello and De Capitani, 2005).

Children are more susceptible than adults to Pb poisoning and this is a major public health concern. High blood Pb levels have been reported from several regions worldwide including the USA and China (Lin et al., 2011). Children are usually exposed to Pb in their immediate residential environment such as house dust or yard soils due to their "hand to mouth and object to mouth" activities (Yabe et al., 2015). Moreover biological factors and nutritional deficiencies play a crucial role in increased Pb uptake in children (Bradman et al., 2011; Ziegler et al., 1978).

The level of lead in blood serves as a major biomarker for monitoring environmental exposure of Pb poisoning (Ettinger et al., 2010). In the United States, the CDC's Advisory Committee on Childhood Lead Poisoning and Prevention, has established a new reference blood Pb concentration of 5 μg/dL and this will be revised downwards every 4 years (Cory-Slechta et al., 2013). Recent studies reveal that the maximum permissible concentration for Pb will drop to 2 μg/dL in the UK (Grönqvist et al., 2014). Gilbert and Weiss (2006) justified reducing the blood Pb action level from 10 to 2 μg/dL because even a very low level of exposure can cause neurobehavioural problems in children. A previous study that documented neurological damage in children at low blood Pb level meant that there are no "safe" levels (Lanphear et al., 2005). Liou et al. (1994) reported that the average blood Pb level was 8.10 μg/dL in Taiwan's general population (1919 participants, aged >15 years), after adjusting age and sex distribution. They also reported that blood Pb level was associated with gender, ethnic group, education level, smoking, alcohol consumption, drinking water sources and residential location (Liou et al., 1994). Lin et al. (2011) investigated the environmental Pb pollution and its impact on children's blood Pb level in a rural area of China, reporting that 86% of 379 children (<15 years old) living near Pb mines and processing plants, had elevated levels of Pb (>15 μg/dL). In their study conducted in the Czech Republic, Cikrt et al. (1997) reported that the mean blood Pb level in school children was 11.35 μg/dL and several factors such as Pb level in soil, house distance from the smelter, consumption of locally grown vegetables/fruits, drinking water from local wells, mothers' education level, smoking and number of children in the family were positively linked to blood Pb levels.

A few reports on childhood Pb poisoning from Pb mines, smelters, paint and battery recycling centres have been published in different countries (Carrizales et al., 2006; Chen et al., 2012; Mathee et al., 2007; Nriagu et al., 1997; Tuakuila et al., 2013). Recently, a Pb catastrophe occurred in Zamfara State of Nigeria where it was reported that 400 children <5 years old were killed and thousands of people were affected (Plumlee et al., 2013). It was reported that the maximum blood Pb level was 370 μg/dL in these children which was nearly 70 times greater than the recommended level of Pb (<5 μg/dL) (CDC, 2012). In another more recent study, 100% of blood samples collected from children under the age of 7 years living near a Pb–Zn mine in Zambia had Pb >5 μg/dL. Of these, 8 children had a Pb blood level >150 μg/dL with the maximum being 428 μg/dL (Yabe et al., 2015).

This present study investigated the effect of mining on blood Pb level and exposure pathways in children below 7 years of age and adults living around a Pb–Zn mine in Abuni of Adudu community, which is located in Nasarawa, Nigeria. In particular it determines the following: (a) effect of mining on human blood Pb levels; and (b) pathways of exposure other than soils such as water and food crops people have consumed to evaluate the risk of Pb poisoning. To date no report on the blood Pb level in adults and children from this locality has been published.

2. Materials and methods

2.1. Sampling sites

The current study location is Abuni of Adudu Community in the Obi local government area, situated in Nigeria's Nasarawa state in the north-central part of the country. Adudu is the main town in Obi and there are several smaller 'satellite' towns around it with many villages surrounding these small towns. The small towns include Abuni, Bokolo, Jalingo, Imon, Ubangari, Ayero and Adudu. Adudu and its environs have a population of 68,000 and a land area of over 100 km^2, of which Pb deposits cover 56 km^2 of the total area. The Pb–Zn mine began operating in 1995 and many local people work in it.

All human blood samples were collected from people living in the Adudu community to investigate their potential exposure to Pb. One hundred families were chosen as the sampling source and the location of the sampling sites was determined by using a GPS device (Garmin eTrex 30; see Fig. 1) Blood samples from adults were collected from each sampling site to investigate the blood Pb level while the blood samples of 35 children (under the age of 7 years) were collected from the entire sampling area.

2.2. Sample collection, processing, analysis and ethical approval

This study was approved by the ethics committee of the Nigerian Medical Association (NMA) and informed consent was obtained from study subjects (both adults and for children from parents/guardians). All subjects included in this study were examined by medical practitioners and blood samples (5 mL) were collected in plastic tubes by qualified pathology technicians. All samples were clearly labelled and stored in a Ziploc bag to avoid cross-contamination. The blood samples were stored in a cold box with a salt-ice mixture and transported to the laboratory and kept in a freezer (−20 °C). All samples were transported from Nigeria to the Centre for Environmental Risk Assessment and Remediation (CERAR) laboratory located at the University of South Australia in a cooler on dry ice via DHL courier following standard quarantine procedures. The samples were then analysed immediately after arriving at the CERAR laboratory.

All chemicals were of analytical grade purity. Ammonia, EDTA, Triton X-100 and butanol were purchased from Sigma-Aldrich. MilliQ (Labpure) water was used to prepare the blood extraction solution. All samples, standards and quality control samples were diluted 20-fold using a solution containing 0.7 M ammonia, 0.01 M EDTA, 0.07% Triton X-100 and 1.5% butanol (Juhasz et al., 2009). Briefly, 0.5 mL of whole blood was placed in a 10 mL plastic tube to which 9.5 mL of blood extraction solution was added. The mixture was shaken and kept at room