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Lead intoxicated children in Kabwe, Zambia

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ABSTRACT

Kabwe is a lead contaminated mining town in Zambia. Kabwe has extensive lead contaminated soil and children in Kabwe ingest and inhale high quantities of this toxic dust. The aim of this paper is to analyze the health impact of this exposure for children. Health data from three existing studies were re-analyzed. Over 95% of children living in the most affected townships had high blood lead levels (BLLs) > 10 μg/dL. Approximately 50% of those children had BLLs ≥ 45 μg/dL. The existing data clearly establishes the presence of a severe environmental health crisis in Kabwe which warrants immediate attention.

1. Introduction

Kabwe is the fourth biggest town and capital of the central province of Zambia. The town has a long history of mining, which operated for more than 90 years and produced large quantities of lead (Pb) and zinc (Zn) until closure in 1994.

Lead is a toxic substance and chronic exposure causes serious adverse health effects. The pathways of exposure are mainly ingestion of Pb contaminated soil and dust, but inhalation as a route of entry can also be significant. Pb can cause acute and chronic intoxication. High exposure can cause severe colic-like abdominal pains, neurological symptoms, seizures, encephalopathy and finally death (World Health Organization, 2010).

Infants are at higher risk due to specific risk behaviors such as playing on bare soil, relevant hand to mouth activity and thus their oral uptake is greater compared with adults (World Health Organization, 2010). While high blood Pb levels (BLLs) have been associated with extensive adverse effects, evidence of low BLLs causing serious negative health effects is extensive and conclusive. The negative effect of Pb exposure during pregnancy to the fetus and during early childhood on the regular development of the brain has enormous adverse implications (Advisory Committee on Childhood Lead Poisoning Prevention, 2016; Needleman et al., 1990).

The CDC Reference Level for Pb is 5 μg Pb/dL blood (https://www.cdc.gov/nceh/lead/acclpp/blood_lead_levels.htm). Between 5 and 44 μg Pb/dL, actions to lower the body burden are recommended In the former "Kabwe lead poisoning management protocol" a Pb level of 20 μg Pb/dL was considered as minimum level for individual follow up (Project Technical Committee - Zambia Consolidated Copper Mines Investments Holdings, 2006). The medical intervention level for children is 45 μg Pb/dL. Children with confirmed Pb encephalopathy need to be hospitalized and treated individually (Advisory Committee on Childhood Lead Poisoning Prevention, 2016; Thurtle et al., 2014). Data from a large treatment survey in Nigeria indicates that oral chelation treatment with Chemet® (succimer, DMSA) is both safe and effective (Thurtle et al., 2014). However, chelation therapy without environmental intervention may prove futile since re-exposure will likely occur.

2. Environmental assessments

Lead contaminated soils in Kabwe pose a serious environmental hazard. In 2003–2006, the "Copperbelt Environment Project" analyzed over 1000 soil samples for Pb in various townships. The results showed,

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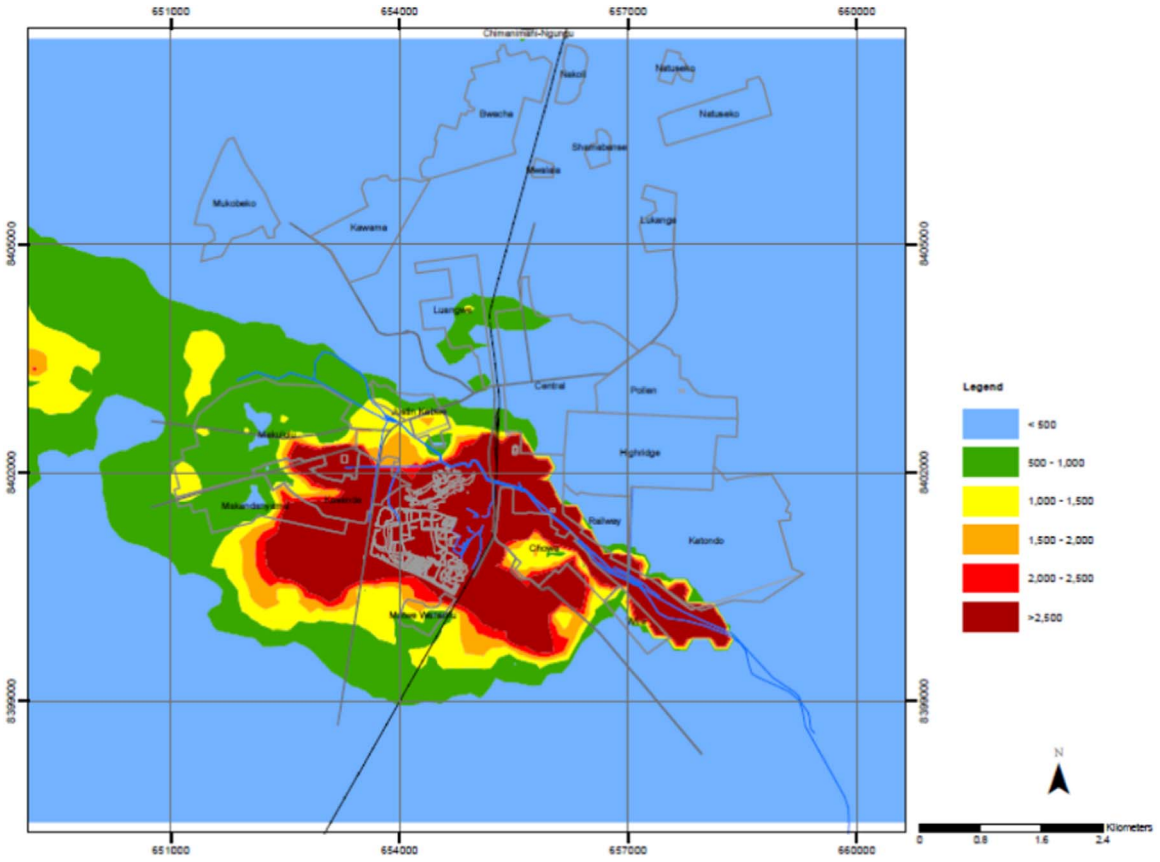

Fig. 1. Interpolated distribution of Pb in soil in the KSDS survey area based on district and township survey (Water Management Consultants Ltd, 2006).

that the soil "over a substantial area is highly contaminated with the metal". "Median Pb concentrations of soil in townships in the vicinity of the mine inducing Kasanda (3008 mg/kg), Makandanyama (1613 mg/kg), Chowa (1233 mg/kg), Mutwe Wansofu (1148 mg/kg), Makululu (870 mg/kg) and Luangwa (507 mg/kg) were recorded. All exceeded levels generally regarded as acceptable by international authorities with respect to residential areas" (Water Management Consultants Ltd, 2006).

The most affected townships are immediately adjacent to the former Kabwe mining complex and homes downwind from the smelter and the tailings (see Fig. 1).

Regrettably, the situation appears to have changed little in recent years as shown from work done by Pure Earth (formerly Blacksmith Institute) in 2014. Data shows townships close to the mining area are still polluted with Pb levels in soil well above recommended levels for residential areas. Soil samples analyzed with an Innov-x Delta series X-ray fluorescence by Pure Earth found median soil concentrations of 3212 mg/kg in Chowa, 6162 mg/kg in Kasanda, and 2286 mg/kg in Makululu (Caravanos et al., 2014; Office of Solid Waste and Emergency Response, 1994; Pure Earth, 2015). Citywide, surface soil Pb concentrations ranged from 139 mg/kg to 62,142 mg/kg, with a geometric mean concentration of 1470 mg/kg. Of the 339 soil tests, 86 readings (25.4%) were > 400 mg/kg.

This overview of results shows that the Pb contamination of soils in Kabwe is serious with townships close to the mining area being highly contaminated. Lead is not the only contaminant of concern in Kabwe; the different assessments showed high levels of cadmium (Cd) and Zn in the surrounding mining area and adjacent townships (Tembo et al., 2006; Water Management Consultants Ltd, 2006).

The aim of this paper is to analyze whether the high lead exposure has a health impact on children in Kabwe.

3. Health assessments

Presently, there are three information sources on childhood BLLs in Kabwe; (1) data from the Copperbelt Environment Project; (2) data from projects of Pure Earth and (3) data from a University of Zambia with collaborators from Hokkaido University, Japan. A summary of BLL data is provided below.

3.1. Copperbelt environment project

Commissioned by the Government of the Republic of Zambia, funded by World Bank, the "Copperbelt Environment Project" performed the Kabwe Scoping and Design Study (KSDS) from 2003 to 2006. One of the aims of the KSDS was to update health and environment data for Kabwe. A specific aim was to reduce the geometric mean of BLLs substantially below 25 μg/dL for children in Kabwe. In the KSDS report, data from approximately 2500 participants are presented. Children were recruited by study nurses from the different townships. BLLs were especially elevated in children 0–7 years old. Nearly all children were above the reference level of 5 μg/dL and in some highly exposed townships over 50% of the children had BLLs at which medical treatment was warranted (see Table 1 (Water Management Consultants Ltd., 2006)).

The survey showed that the geometric mean BLLs in townships closer to the mining sites were higher. As shown in Table 1, the geometric mean BLLs of children aged 0–7 years in the surrounding townships were: Chowa 31.7 μg/dL, Kasanda 32.8 μg/dL, Makandanyama 38.2 μg/dL and Makululu 31.3 μg/dL (Water Management Consultants Ltd, 2006). The BLLs were in the range, where negative health effects are likely. Children aged 8–16 years and adults as well had increased BLLs, although lower than levels in children aged 0–7 years.

Table 1
Lead levels by township and year in μg Pb/dL blood.

Township	Year	N	Mean BLL	Median BLL	Geom. Mean BLL	Minimum BLL	Maximum BLL
Kasanda[1]	2003–2006	119			32.8	5.7	185
1	2007	216			29.7	4.4	121.8
1	2009	189			30.4	5.6	128
1	2012	189			34.5	2.1	121.8
4	2014	31	51.6	55.2	49.7	26.7	65.0+
2	2015	100	82.2	74.9		5.4	427.8
Makandanyama[1]	2003–2006	59			38.2	13.6	84.6
1	2007	66			36.6	3.3	119.4
1	2009	96			39.1	14.2	90.4
1	2012	291			33.9	15.1	112
Makululu[1]	2003–2006	408			31.3	3.4	114
1	2007	388			37.8	5.8	120
1	2009	493			25.1	3.6	121.8
1	2012	1134			33.9	2.1	128.4
4	2014	39	49.2	48,7	47,3	20,9	65,0+
3	2015	559	36.4			8.5	99.2
2	2015	129	57.1	51.1		9.4	388.7
Railways[1]	2003–2006	101			17.5	3.5	86.9
1	2009	4			15.8	9.3	98.1
1	2012	44			18.1	6.4	48.5
Waya[1]	2003–2006	37			26.1	6.5	58.9
1	2009	8			23	7.5	51
1	2012	139			27.2	6.3	121
Luangwa[1]	2003–2006	45			18.4	5	44.4
Chowa[1]	2007	43			26.6	5	121.8
1	2009	82			22.1	5.6	128
1	2012	349			29.2	4.8	100.2
4	2014	38	49.8	50.4	47.1	14.5	65.0+
2	2015	17	39	39.3		15.6	79.7
Katondo[1]	2007	4			30	7.8	46.4
1	2012	24			22.2	5	44.2
Mutwe Wa Nsofu[1]	2012	29			31.8		
4	2014	12	48.3	41.0	46.2	30.7	65.0+
Riverside[1]	2012	64			24.1	8.2	120
4	2014	7	49.9	50.4	48.3	29.8	65.0+
Kabwe[4]	2014	196	48.3	52.3	45.8	13.6	65.0+
Chililalila[3]	2015	244	35.5			0	98.3
4	2014	15	48.5	43.3	46.4	29.9	65.0+
Moomba[3]	2015	186	38.8			3.1	98.2
4	2014	17	45.6	44.4	43.1	22.3	65.0+
Zambezi[3]	2015	177	37.7			8.7	93.4
4	2014	30	40.3	37.0	37.2	13.6	65.0+

BLL = Blood lead level in μg/dl.
[1] data from Misenge projects.
[2] (Yabe et al., 2015).
[3] (Mbewe et al., 2015).
[4] (Caravanos et al., 2014).

The KSDS report shows that a high percentage of inhabitants had BLLs above the "predetermined level of concern" of 25 μg/dL. In detail it was extrapolated that 12378 children aged 0–7, 7919 children aged 8–16 and 3973 adults would have BLLs > 25 μg/dL (see Table 1) (Water Management Consultants Ltd, 2006).

Misenge Environmental and Technical Services Ltd (METS) performed several blood sampling sessions in various townships. As is shown in supplement 1, the geometric mean levels varied over time. There was no clear trend in the findings but differences in the geometric means among the townships were seen. The results showed that increased BLLs in Kabwe were widespread, especially in Makululu, Makandanyama and Kasanda where BLLs of children were constantly very high.

Recent data from METS was published in 2015 by the University of Zambia, Department of Public Health. In that study, BLLs in 1166 children under five years of age from Makululu township were measured with a LeadCare II™ portable blood instrument ((Magellan Diagnostics, Inc., N. Billerica, Massachusetts). The reported BLLs in Makululu were: (Mbewe et al., 2015):

- 99.4% of the children > 10 μg/dL
- 73.2% of the children > 25 μg/dL
- Geometric mean was 32.6 μg/dL (see Table 1)

Mbewe et al. (2015) determined a statistically significant association between age and BLLs. The authors concluded that affected areas would "require an expansive and integrated program of Pb exposure prevention"; the program should be "implemented by government and co-operating partners" and that the program should also "take into account environmental management and disease surveillance" (Mbewe et al., 2015).

3.2. Pure earth projects

The previous findings were independently confirmed by BLL sampling performed in 2014 by Pure Earth (Caravanos et al., 2014). For the Pure Earth study, 196 children aged 2–8 years were selected from highly exposed townships. Their blood was tested with a LeadCare II™ analyzer. The mean BLL was 48.3 μg/dL and more than 50% of children would have needed medical treatment (see Table 1) (Blacksmith Institute, 2014; Caravanos et al., 2014). A substantial number (26.5%) of childhood BLLs exceeded the 65 μg/dL upper detection limit of the

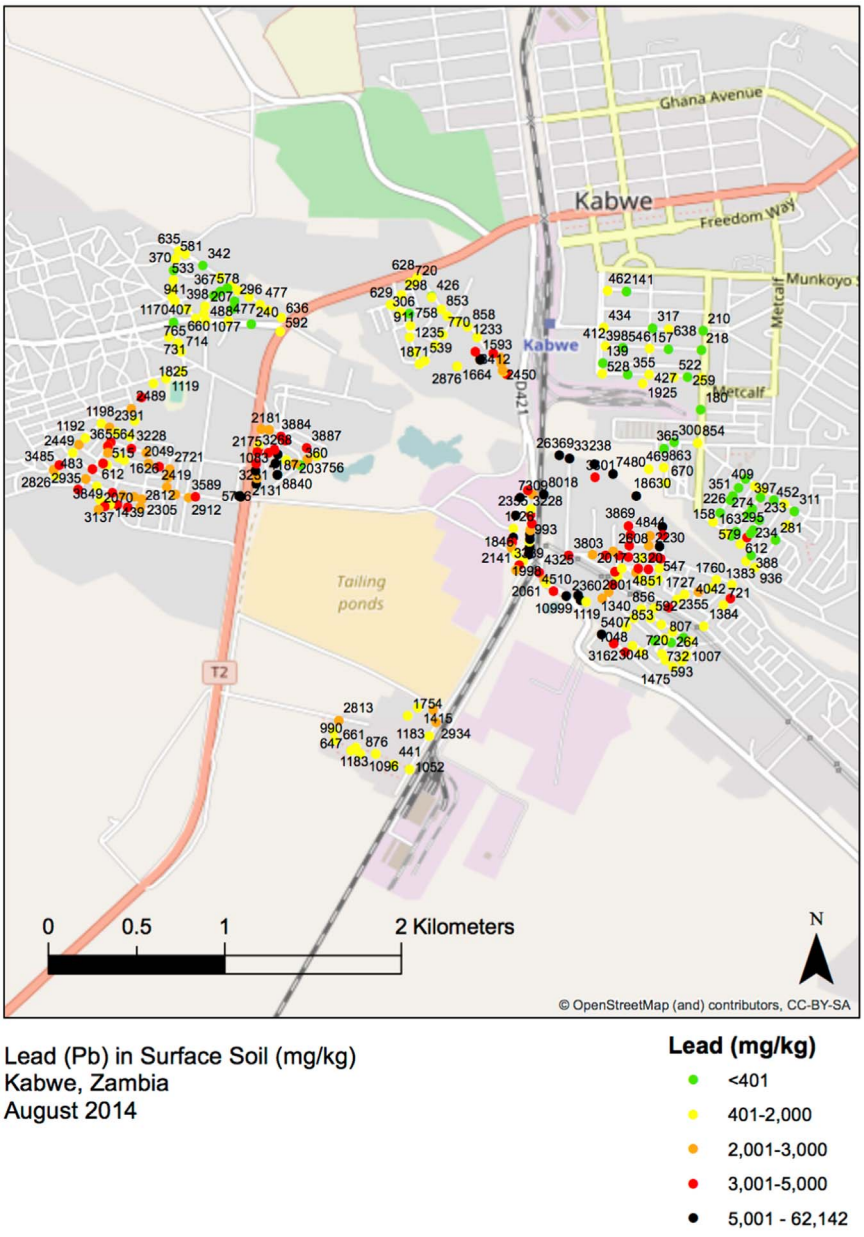

Fig. 2. Concentrations of lead in surface soil (August 2014).

LeadCare II™ instrument, which indicates that the poisoning was likely more severe than observed.

3.3. University of Zambia / JICA projects

Most recently a study in the three contaminated townships was conducted by the University of Zambia in collaboration with Hokkaido University. Children from the severely contaminated townships of Chowa, Kasanda and Makukulu were assessed. Blood lead levels were analyzed with ICP-MS analyzer (7700 series, Agilent technologies, Tokyo, Japan) in 246 children under the age of seven (Yabe et al., 2015). The results showed that 100% of the sampled children had BLLs > 5 μg/dL. Moreover, high BLLs of ≥ 65 μg/dL were recorded in: Chowa 18%, Kasanda 57% and Makululu 25%. Eight children in Kasanda and two children in Makululu had very BLLs of > 150 μg/dL, four children had extremely high BLLs of ≥ 300 μg/dL (for details see Table 1 and supplement 2).

Findings from Yabe et al. (2015) revealed extensive Pb poisoning in children in Kabwe and recommended chelation therapy, especially in children with BLL exceeding ≥ 45 μg/dL. This was critical so as to curtail the pernicious health impact of Pb poisoning in children. Moreover, through an individualized follow-up plan of the affected children at their homes and regular health check-ups at local health centers, it was observed that the quality of life of the affected children could be improved. The authors also observed that early detection and intervention could be useful to minimize overt cases of Pb poisoning such as persistent seizures, mental retardation and death. This would require enhanced community awareness of Pb poisoning and urgent interventions in the affected areas, with the full participation of local townships and various stakeholders for the sustenance of remedial measures.

Children with increased BLLs can develop clinical signs and symptoms of Pb intoxication. The data presented in this paper offers the most current and comprehensive reporting of BLLs in this highly contaminated city in Zambia. Three distinct groups of researchers have presented what appears to be continuing Pb poisoning on a major scale.

There is only one set of data set from UNZA / JICA containing some information about clinical findings from children in Kabwe. Data captured in questionnaires showed that 10 or more percent of children observed in 2012 had reported signs and symptoms, typical for chronic

Pb intoxication, such as anemia, intermittent abdominal pains, limb pains, memory problems, headaches, weakness in hands and feet, and seizures or convulsions (unpublished data). The nurses employed by METS caring for 200 children with increased BLLs reported verbally that they observed similar symptoms in children. Nurses and health care workers from Makululu, Kasanda and Chowa health centers report that children have severe intermittent abdominal pains, seizures, are smaller and do not develop well compared with other children. These are first indicators that the children in Kabwe suffer from Pb poisoning severely.

4. Discussion

The existing data clearly establishes the severity of Pb exposure in Kabwe. Environmental data also support the observation that in certain housing areas of Kabwe, the recommended tolerable soil Pb level of 400 mg/kg is clearly exceeded (see Fig. 1 and Fig. 2). The soil levels measured by Pure Earth 2014 are in general higher compared to those reported by KSDS in 2006. We suspect this results from enhanced granularity now available with a portable XRF (rather than an actual increase in concentrations).

Nearly all children in the townships close to the former mining area had BLLs ≥ 20 μg/dL, which is a value where urgent action is demanded to decrease the exposure immediately according to the KSDS study protocol. Since soil is the major pathway of exposure in Kabwe the most important task is to decrease exposure for all children by immediate and appropriate remediation.

In the most affected townships, approximately 50% of the children have BLLs ≥ 45 μg/dL, which is the threshold value above which medical antidote treatment is recommended. The former interventions of the KSDS project did not show any long term effect in reducing the environmental pollution nor the BLLs of children. In Makululu, Makandanyama and Kasanda, BLLs of children are even higher compared with other townships. Large proportions of children are not only highly exposed, but have high to extremely high levels of Pb in their bodies. From the KSDS survey it can be estimated that approximately 60% of children with BLLs ≥ 25 μg/dL might have BLLs of levels ≥ 45 μg/dL. According to threshold levels and international recommendation, the exposure has to be considerably reduced and the children need medical treatment. Children with BLLs ≥ 45 μg/dL should receive medical treatment (Agency for Toxic Substances and Disease Registry, 2010). However medical treatment without environmental and educational intervention will not be enough to sustain a safe and healthy population. A World Band funded project (ZMERIP) will soon enable the Government of Zambia to take action in Kabwe, incuding reduction of exposure and treatment for children.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.envres.2017.10.024.

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