ZAMBIA

Lead poisoning

Anglo American South Africa Limited

Leigh Day, in conjunction with Johannesburg attorneys Mbuyisa Moleele are currently preparing a class action against Anglo American South Africa Ltd in the Johannesburg High Court on behalf of Zambian communities living in the vicinity of the Kabwe lead mine who are suffering from lead poisoning. The purpose of the legal action will be to secure compensation for victims of lead poisoning, including the cost of an effective medical monitoring system for blood lead levels among the community.

Kabwe was the world's largest lead mine and operated from around 1915 until its closure in 1994. From 1925 to 1974, its most productive period, the mine was owned and operated and/or managed by Anglo American South Africa Ltd.

The mine is situated in close proximity to villages comprising around 230,000 residents. Tens of thousands of Kabwe residents are estimated to have developed high blood lead levels (BLLs), mainly through ingestion of dust contaminated by emissions from the mine smelter and waste dumps. A series of published reports has found very high levels of lead in the blood of a substantial proportion of the local population, in particular very young children.

According to the World Health Organisation (WHO), some of the problems associated with lead poisoning in children range from reduced IQ, behavioural problems and reduced growth to severe anaemia and kidney damage, and in the worst cases can cause brain damage and even death.

In Kabwe, in young children aged up to five years old, published studies have consistently found massively elevated BLLs. In the most affected townships around Kabwe around 50% of children have BLLs higher than 45µg/dL the threshold above which medical antidote treatment is required. Nearly all the children in these areas have BLLs above 20 µg/dL, the level at which urgent action is required to reduce exposure.

The scale of this environmental health disaster has been evident for decades. For example, a 1972 medical journal article referred to extreme lead pollution in the Kabwe area. A 1975 thesis by a Dr A.R.L. Clark from the London School of Hygiene and Tropical Medicine found that children in Kasanda, Kabwe District, especially infants of 1-3 years, had strikingly high average BLLs of up to 103 µg/dL.

The case will be brought in the South African courts where the head office company and proposed defendant, Anglo American South Africa Ltd, is based. It is alleged that from 1925 to 1974, Anglo American SA played a key role in the management of the medical, engineering and other technical services at the mine, and that it failed to take adequate steps to prevent lead poisoning of the local residents.

Main image Kabwe mine dump near Chowa in 2018, and the houses that border the dump **1:** Mbuyisa Moleele lawyer Tshego Raphuti and Leigh Day lawyer Charlotte Armstrong with Kabwe community representatives. **2&3:** Leigh Day Partner Richard Meeran talks to community members affected by lead poisoning in Chowa, Kabwe District.**4:** The former Kabwe mine and mine dump, April 2004. **5:** Kabwe mine dump, April 2004. The villages of Kabwe are situated in close proximity to these dumps.

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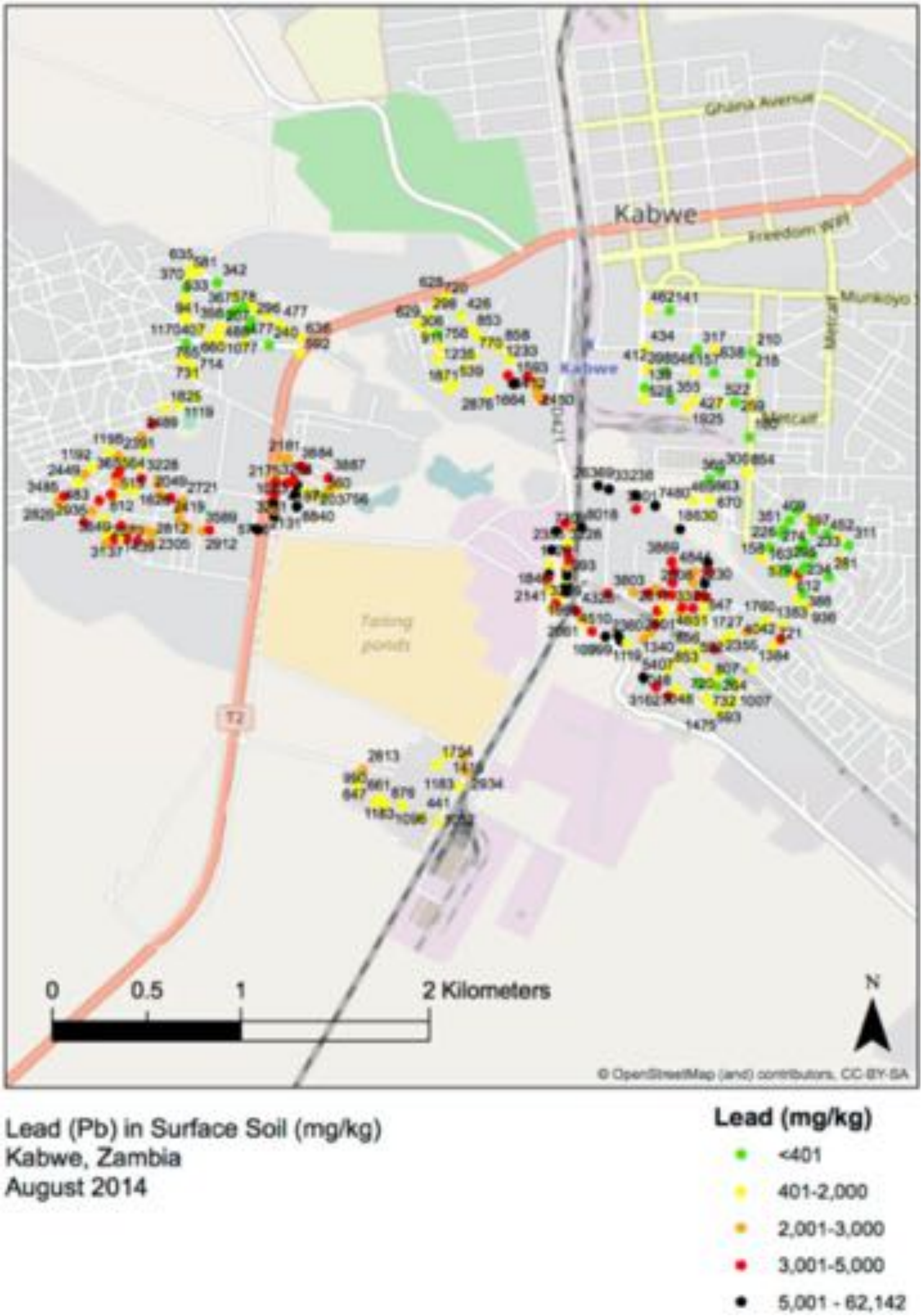

Fig. 2. Map of Kabwe showing distribution of Pb (mg/kg) in township soils around the Pb–Zn mining complex (Bose-O'Reilly et al., 2018).

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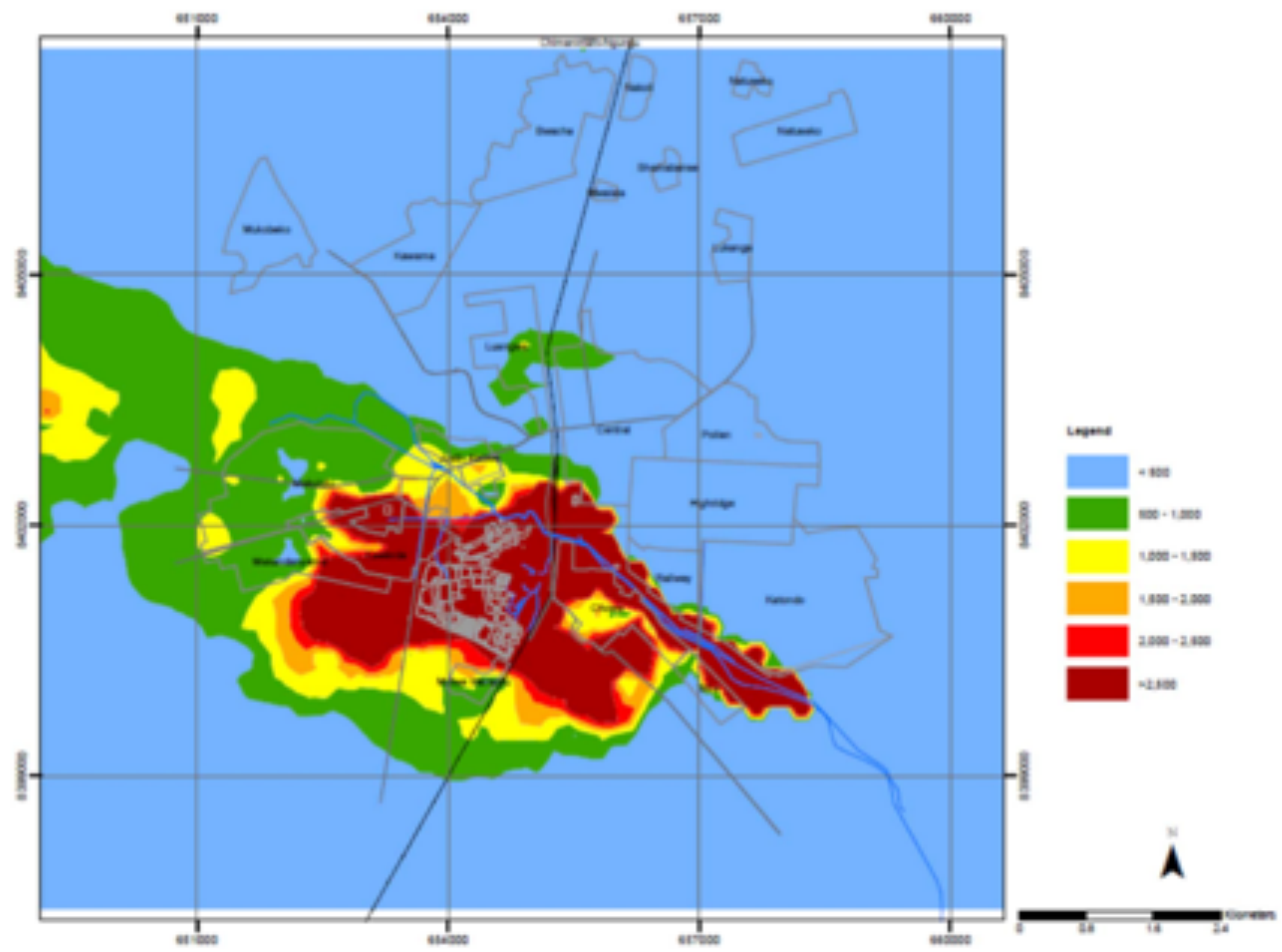

Fig. 1. Interpolated distribution of Pb in soil in the KSDS survey area based on district and township survey (Water Management Consultants Ltd, 2006).

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Current trends of blood lead levels, distribution patterns and exposure variations among household members in Kabwe, Zambia

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HIGHLIGHTS

- We measured blood lead in household members in Kabwe, which has a history of Pb–Zn mining.
- Blood Lead Levels (BLL) ranged from 1.65 to 162 μg/dL and were highest in children compared to parents.
- LeadCare II analyser provided prompt diagnosis to identify children needing chelation therapy.
- Age, distance from the mine and direction were the main factors influencing Pb exposure.
- Children living near the Pb–Zn mine are at serious risks of Pb and Cd poisoning.

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ABSTRACT

Childhood lead (Pb) poisoning has devastating effects on neurodevelopment and causes overt clinical signs including convulsions and coma. Health effects including hypertension and various reproductive problems have been reported in adults. Historical Pb mining in Zambia's Kabwe town left a legacy of environmental pollution and childhood Pb poisoning. The current study aimed at establishing the extent of Pb poisoning and exposure differences among family members in Kabwe as well as determining populations at risk and identify children eligible for chelation therapy. Blood samples were collected in July and August 2017 from 1190 household members and Pb was measured using a portable LeadCare-II analyser. Participants included 291 younger children (3-months to 3-years-old), 271 older children (4-9-years-old), 412 mothers and 216 fathers from 13 townships with diverse levels of Pb contamination. The Blood Lead Levels (BLL) ranged from 1.65 to 162 μg/dL, with residents from Kasanda (mean 45.7 μg/dL) recording the highest BLL while Hamududu residents recorded the lowest (mean 3.3 μg/dL). Of the total number of children sampled (n = 562), 23% exceeded the 45 μg/dL, the threshold required for chelation therapy. A few children (5) exceeded the 100 μg/dL whereas none of the parents exceeded the 100 μg/dL value. Children had higher BLL than parents, with peak BLL-recorded at the age of 2-years-old. Lead exposure differences in Kabwe were attributed to distance and direction from the mine, with younger children at highest risk. Exposure levels in parents were equally alarming. For prompt diagnosis and treatment, a portable point-of-care devise such as a LeadCare-II would be preferable in Kabwe.

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1. Introduction

Lead (Pb) poisoning accounts for about 0.6% of the global burden of disease (WHO, 2010), posing a serious public health concern worldwide. While acute toxicity is related to occupational exposure and is quite uncommon, low level chronic toxicity due to environmental pollution is much more common (ATSDR, 2017). Lead poisoning has devastating effects on neurodevelopment such as mental retardation and lowering of intelligence quotient (IQ) in children, which may further result in poor school performance, lower tertiary education attainment, behavioural disorders and poor lifetime earnings (WHO, 2018; Dapul and Laraque, 2014; Miranda et al., 2007; Canfield et al., 2003; Lidsky and Schneider, 2003). If not treated, Pb poisoning is characterized by persistent vomiting, anaemia, encephalopathy, lethargy, delirium, convulsions, coma and death (WHO, 2018; Flora et al., 2012; Pearce, 2007). The Institute for Health Metrics and Evaluation (IHME, 2017) estimated that in 2016 Pb exposure accounted for 540,000 deaths worldwide. In chronically exposed adults, significant health effects including renal dysfunction, hypertension and various reproductive problems have been shown even at low Pb exposures (Kumar, 2018; Wani et al., 2015). Cases of reduced fertility following chronic exposure have been reported in males (Benoff et al. 2000, 2003; Telisman et al., 2000) as well as miscarriages in pregnant women (Wani et al., 2015). Moreover, childhood Pb exposure poses significant economic losses in affected countries, especially in low- and middle-income countries (Attina and Trasande, 2013).

Clinical presentations of Pb poisoning vary widely depending upon the age, the amount and the duration of exposure, with some individuals seeming well at a blood lead levels (BLLs) that in others results in overt clinical signs (Bellinger, 2004). Given that detrimental effects of chronic Pb exposure are usually subclinical (Yabe et al., 2015, 2018), it may result in a delay in the appropriate diagnosis and chelation therapy, which has been recommended to be initiated at levels $\geq$ 45 μg/dL (CDC 2002; Needleman, 2004). Early diagnosis and chelation therapy are crucial as it has been reported that high BLLs exceeding 100 μg/dL in children can cause encephalopathy, convulsions, coma and death (CDC 2002). Therefore, measurement of BLLs plays a pivotal role in the diagnosis and management of patients as described in Pb poisoned children in Nigeria (Thurtle, 2014). Traditionally, BLLs have been measured using atomic absorption spectrophotometer (AAS), inductively coupled plasma mass spectrometry (ICP-MS), etc. Although highly sensitive to Pb measurement, these equipment are laboratory-based and require trained laboratory technologists. Moreover, they are expensive and would be time-consuming to ship samples to appropriate laboratories.

In a set-up like Kabwe town in Zambia, where historical Pb mining has resulted in alarming Pb poisoning, especially in children from townships in the vicinity of the closed mine and its tailing wastes (Yabe et al., 2018; Bose-O'Reilly et al., 2018; Yabe et al., 2015), prompt diagnosis and immediate chelation therapy would be required. Therefore, a portable point-of-care devise such as a LeadCare II analyser, which can be used on-site in remote medical facilities like Kabwe would be appropriate and preferable. Given that BLL results are read within 3 min, Pb poisoning would be diagnosed and chelation therapy initiated promptly. Therefore, the current study investigated trends of BLL using a LeadCare II Analyser in Kabwe to identify children that required medical management to minimize the toxic effects of Pb. In addition, factors influencing Pb exposure in Kabwe were analyzed and exposure patterns among household members including fathers, mothers and children were evaluated.

2. Materials and methods

2.1. Sampling sites

Kabwe town, with a population of about 230, 000 inhabitants and area size of 1, 547 km^2, is the fourth largest town in Zambia. It is the provincial capital of Zambia's Central Province and is located at about 28°26′E and 14°27′S. Kabwe has a long history of open-pit Pb–Zn mining, from 1902 to 1994. As observed by the Blacksmith Institute (2013), despite closure of the mine, scavenging of metal scraps from the abandoned tailings and wastes stored on the mine has continued to serve as a source of metal pollution, especially dusts emanating from the mine dumps (Fig. 1).

Moreover, some households were within 500 m of the tailings. As shown in Fig. 2, soils in townships in the vicinity of the mine and homes downwind from the tailings were highly polluted with Pb exceeding acceptable levels for residential areas (Bose-O'Reilly et al., 2018). In the current study, blood samples were collected from family members including fathers, mothers and children at health centres around the town of Kabwe, in July and August of 2017. More details about the study site and descriptions of townships that are within the vicinity of the mine can be obtained from the previous study (Yabe et al., 2015).

2.2. Sample collection

The study was approved by the University of Zambia Research Ethics Committee (UNZAREC; REF. No. 012-04-16). Further approvals were granted by the Ministry of Health through the Zambia National Health Research Ethics Board and the Kabwe District Medical Office. The study targeted households from areas diverse in the levels of Pb contamination based on the sample design in a parallel socioeconomic survey under the KAMPAI project (Hiwatari et al., 2018). 1000 target households were randomly chosen in two steps. In the first step, following the sampling frame of Central Statistical Office (CSO), which conducts official census in Zambia and has divided Kabwe town into 384 Standard Enumeration Areas (SEAs). Forty SEAs falling within the catchment area of health facilities were randomly selected (Fig. 3) while 25 households from each SEA were randomly selected in the second stage.

To conduct blood sampling, up to four household members (father, mother, and two children) were invited to local health centres. Younger non-school-going children up to 3 years old and older school-aged children older than 4 years were selected in the study. The age criterion was according to Yabe et al. (2015) who found significant differences BLL in children of the two age groups. Thirteen health centres with catchments areas covering the 40 SEAs were included. These included Kasanda, Chowa, Makululu, Katondo, Railway, Pollen, Mahatma Ghandi, Bwacha, Ngungu, Natuseko, Mpima Prison, Kang'omba and Hamududu with distances between the mine and the health centres ranging from 1.5 to 30 km (Fig. 3). After informed and written consent were obtained

Fig. 1. Figure showing men scavenging for scrape metals at the Kabwe Pb–Zn mine tailings (left) and houses located within 500 m to the tailings (right).

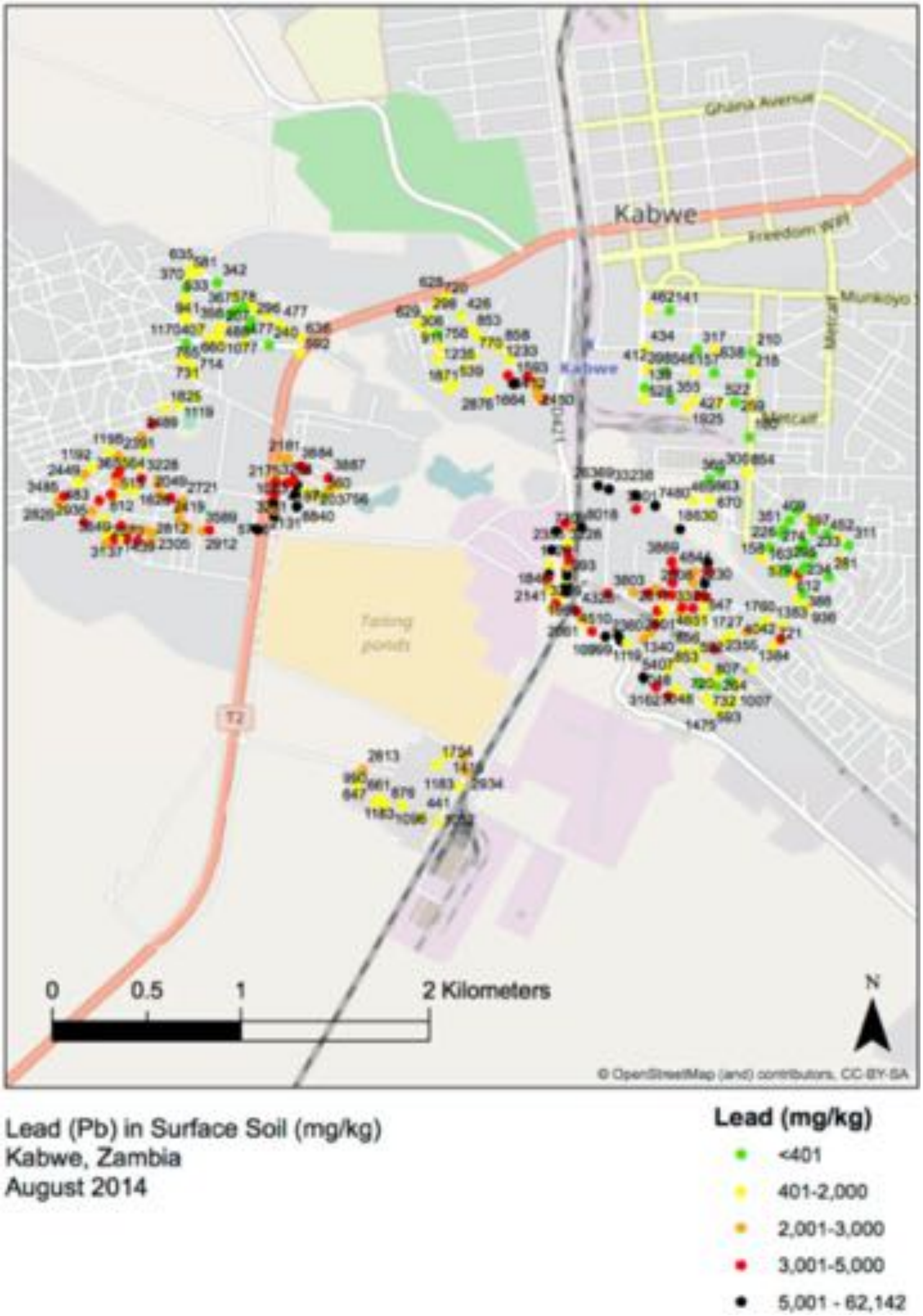

Fig. 2. Map of Kabwe showing distribution of Pb (mg/kg) in township soils around the Pb–Zn mining complex (Bose-O'Reilly et al., 2018).

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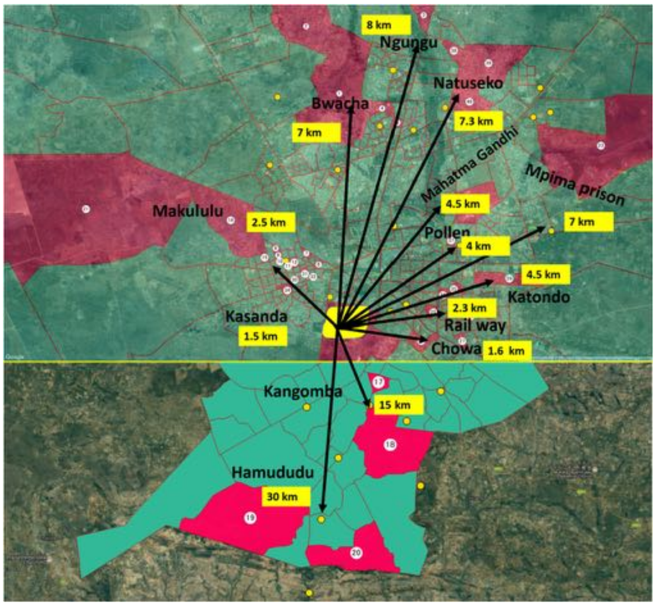

Fig. 3. Map of Kabwe showing the 40 selected SEAs (numbers 1–40 in white circles) widely distributed across the whole Kabwe town and the 13 health centres (yellow blocks) that were included in the study.

minimize contamination from dust. For infants, blood was collected by fingerstick after cleaning the finger with an alcohol swab. A new sterile lancet was used for each infant to penetrate a fingertip. The first drop of blood was wiped off with a clean and dry swab and 50 μL blood sample was collected with a pre-supplied LeadCare II capillary tube and transferred into the LeadCare II reagent vial. After collection, blood samples were immediately analyzed for Pb using a LeadCare© II analyser. The remaining samples were immediately stored at −20 °C at the health centres before being transported in cooler boxes on dry ice to the laboratory of the Kabwe District Health Offices where they were again stored at -20 °C.

2.3. Blood Pb analysis

Lead metal analysis in whole blood samples was done on-site immediately after blood sample collection using a point-of-care blood Pb testing analyser, LeadCare© II (Magellan Diagnostics, USA) according to the manufacturer's instructions. The analyser uses an electrochemical technique called Anodic Stripping Voltammetry (ASV) to determine the amount of Pb in a blood sample (Magellan Industries Inc, 2013). The analyser has been evaluated by several researchers including (Stanton and Fritsch, 2007; Sobin et al., 2011; Neria et al., 2014). Briefly, individual heparinized venous blood samples were drawn using the manufacturer-supplied LeadCare II capillary tubes (approximately 50 μL) and dispensed into labeled vials containing LeadCare II treatment reagent (250 μL of 0.1% of HCl). These were thoroughly mixed by tipping the bottle ten times to enhance red blood cell lysis, which released the bound Pb. About 50 μL of the blood/reagent mixture was then transferred to a sensor using the provided transfer dropper and analyzed for blood Pb concentration. Single analyses were performed with results reflected within 3 min in μg/dL on the analyser's screen. For quality assurance, the instrument was calibrated using a probe before each new lot of test supplies (every 48 tests). Standard controls, one high and one low blood-based controls supplied by the manufacturer were analyzed to assess accuracy, these fell within the manufacturer-specified acceptability limits of 6.9–13.7 μg/dL for the low control and 21.8–32.6 μg/dL for the high control. Since limits of quantitation were 3.3–65 μg/dL as the LeadCare II Analyser can only detect BLL above 3.3 μg/dL. The precise values of BLLs below the 3.3 μg/dL detection limit could not be determined. These BLLs below instrument detection limit were therefore treated as 1.65 μg/dL, the mean of 0 and 3.3 as suggested in other environmental studies (Wood et al., 2011; Ogden, 2010).

For samples above 65 μg/dL, a 3 times dilution was done using 0.1% HCl. Briefly, 50 μL of collected blood was added into 100 μL of 0.1% HCl. Then 50 μL of diluted blood was pipetted into the LeadCare II reagent. This was mixed thoroughly and analyzed in the same way as for undiluted blood. The blood specimens and blood/reagent mixtures were maintained at room temperature throughout the analytical process.

2.4. Statistical analysis

All data were combined into a single electronic database and checked for accuracy and outliers. Statistical analysis was performed using JMP version 10 (SAS Institute, USA). The data are presented as mean, geometric mean (GM), median and minimum-maximum values in μg/dL. Tukey Kramer test was used to analyse BLL differences among family members (younger child, older child, father and mother) as well as area difference. Different letters indicated significant difference. Principal component analysis (PCA) was used to evaluate the relatedness between BLL with age, wind direction and distance from the mine. The data of BLLs (μg/dL) were log-transformed before PCA analysis to stabilize variances.

3. Results

3.1. Subjects and BLL

The current study focused on blood samples that were collected from a total number of 1190 household members including 291 younger children (3 months–3 years old) with an average age of 1.9 years; 271 older children (4–9 years old) with an average age of 6.5 years; 412 mothers with an average age of 39 years and 216 fathers with an average age of 46 years. Participants were drawn from 13 health centres servicing Kasanda, Chowa, Makululu, Katondo, Railway, Pollen, Mahatma Ghandi, Bwacha, Ngungu, Natuseko, Mpima Prison, Kang'omba and Hamududu townships. The recorded BLL ranged from 1.65 to 162 μg/dL (Table 1).

3.2. Critical BLL values among household members

As shown in Table 2, of the 1, 190 participants, 30% had BLL below 5 μg/dL, which is the level of concern. These comprised 57 younger children, 59 older children, 151 mothers and 85 fathers. Of the total number of children sampled ($n = 562$), a total of 130 (23%) exceeded the 45 μg/dL, the threshold required for chelation therapy. A few children (total of 5) exceeded the 100 μg/dL whereas none of the parents exceeded the 100 μg/dL value.

3.3. Pb exposure patterns among household members

Tukey test was performed to analyse age differences in BLL accumulation among family members. Children had significantly higher BLL than parents. However, there was no accumulation difference in BLL between younger children between the ages of 3 months to 3 years and older children aged 4–9 years. Moreover, BLL between fathers and mothers were not different. Similarly, there was no sex difference in blood Pb concentrations as the BLL between boys and girls were not different (data not shown). A positive correlation was seen in the BLL of mothers and their infants (data

Table 1
BLL (μg/dL) exposure characteristics among household members in Kabwe, Zambia.

Category	All	Younger child	Older child	Mother	Father
	$n = 1190$	$n = 291$	$n = 271$	$n = 412$	$n = 216$
Mean	20.8	29.9	24.3	14.8	15.7
Geo. Mean	11.1	17.0	14.2	8.2	8.1
Standard Error	0.62	1.59	1.32	0.74	1.20
Median	13.0	22.0	17.3	10.8	8.6
Standard Deviation	21.4	27.1	21.7	15.0	17.7
Minimum	1.65	1.65	1.65	1.65	1.65
Maximum	162	162	103	86.7	88.2

Table 2
BLL (μg/dL) exposure characteristics among household members in Kabwe, Zambia.

Category BLL ranges	All Number (%)	Young child Number (%)	Child Number (%)	Mother Number (%)	Father Number (%)
BLL < 5 μg/dL	352 (30)	57 (20)	59 (22)	151 (37)	85 (39)
BLL 5−44 μg/dL	666 (56)	154 (53)	162 (60)	239 (58)	111 (51)
BLL 45−99 μg/dL	167 (14)	76 (26)	49 (18)	22 (5.3)	20 (9.3)
BLL > 100 μg/dL	5 (0.4)	4 (1.4)	1 (0.4)	0 (0.0)	0 (0.0)

not shown).

3.4. Relationship between BLL and age

A combined dot plot and box-whisker plot was performed to evaluate the relationship between BLL and age (Fig. 4). In terms of the median BLL, a general trend indicated a high peak in children around the age of 2 years and lower BLL in older children, albeit with fluctuations. Very high BLLs are also more frequently observed among young children although BLL above 45 μg/dL is observed in any age group.

3.5. Pb exposure differences among townships

In order to fully understand the Pb exposure patterns in Kabwe, differences in blood Pb accumulations in residents from the 13 townships were compared. Descriptive statistics of the BLL in residents enrolled at the 13 health centres are shown in Table 3.

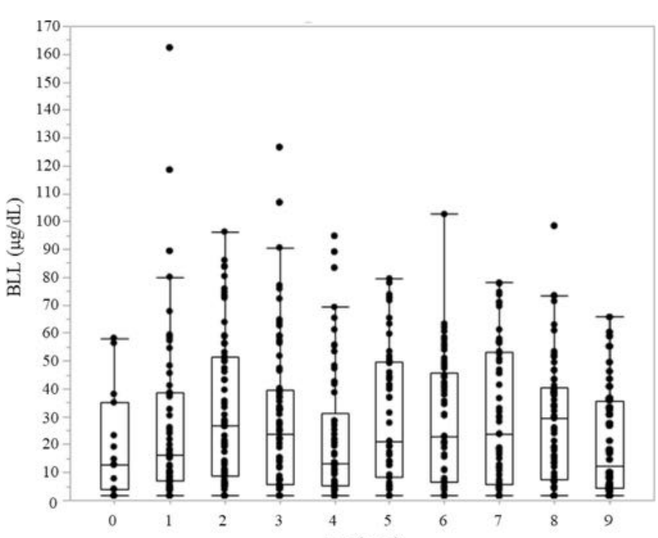

Fig. 4. Figure of combined dot plot and box-whisker plot showing relationship between BLL and age, with peak BLL recorded at 2 years old.

Residents in Kasanda Township, with mean BLL of 45.7 μg/dL accumulated higher BLL than residents in the other 12 locations. Makululu Township had second highest mean BLL (29.3 μg/dL) followed by Chowa and Railway townships. Similar but lower BLL were recorded in residents from Natuseko, Kang'omba, Ngungu, Mpima Prison, Katondo and Mahatma Ghandi followed by Bwacha and Pollen townships. Residents in Hamududu community had the lowest BLL, with a mean value of 3.3 μg/dL.

3.6. Factors contributing to Pb exposure patterns in Kabwe

Principle component analysis (PCA) was performed on log-transformed data to evaluate the relationships among BLL, age, direction and distance from the mine to the township health centres. As shown in Fig. 5, the results of PCA accounted for 44.3% of the variation by the first principal component (PC1) and 26.4% by the second principal component (PC2). Whereas PC1 was positively determined by distance as well as a slight positive influence by age and direction, it was negatively influenced by BLL. On the other hand, PC2 had a strongly positive relationship with age, but rarely with distance and BLL. It was indicated that distance from the mine had a strong and bigger negative relationship with BLL while direction and age had lower negative relationship with BLL.

4. Discussion

A portable LeadCare© II analyser was used and proved to be an effective point of care blood Pb analyser in Kabwe, where alarming childhood Pb poisoning was previously reported (Yabe et al., 2015). Moreover, the LeadCare II analyser is less invasive and suitable for infants as it requires a smaller finger stick blood sample. In an environment like Kabwe where non-specific clinical symptoms of cumulative Pb poisoning can easily be confused with other diseases like malaria, a rapid and appropriate diagnosis of Pb poisoning cannot be overemphasized. The current study analyzed Pb exposure patterns among family members in Kabwe, where household members shared similar risk factors such as area, direction and living conditions. The study revealed that not only children were at risk of the toxic effects of Pb in Kabwe town but women and men as well. Young age was a significant risk factor given that BLL were highest in children, with peak levels recorded at the age of two, in agreement with similar trends in earlier studies (Yabe et al., 2015;

Table 3
Area differences in BLL (μg/dL) among Kabwe residents from 13 health centres.

	Kasanda	Makululu	Chowa	Railway	Natuseko	Bwacha	Ngungu	Pollen	Mahatma Ghandi	Mpima Prison	Katondo	Kang'omba	Hamududu
Mean	45.7	29.3	16.5	11.4	8.58	6.78	5.38	4.70	4.51	5.41	6.51	8.48	3.31
St'd Error	1.64	1.01	1.02	1.97	0.98	1.10	0.59	0.98	0.63	0.59	1.09	1.01	0.41
Median	44.9	24.3	16.6	10.5	6.95	3.90	4.80	1.65	4.60	4.90	3.80	5.40	1.65
Standard Deviation	23.5	19.0	10.5	6.81	6.92	11.1	3.50	4.69	2.36	4.13	7.17	9.94	4.08
Minimum	1.65	1.65	1.65	3.30	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65
Maximum	162	119	48.3	26.2	34.3	94.8	14.2	16.8	9.00	23.3	38.7	63.5	35.6
Count	204	355	105	12	50	103	35	23	14	49	43	96	101

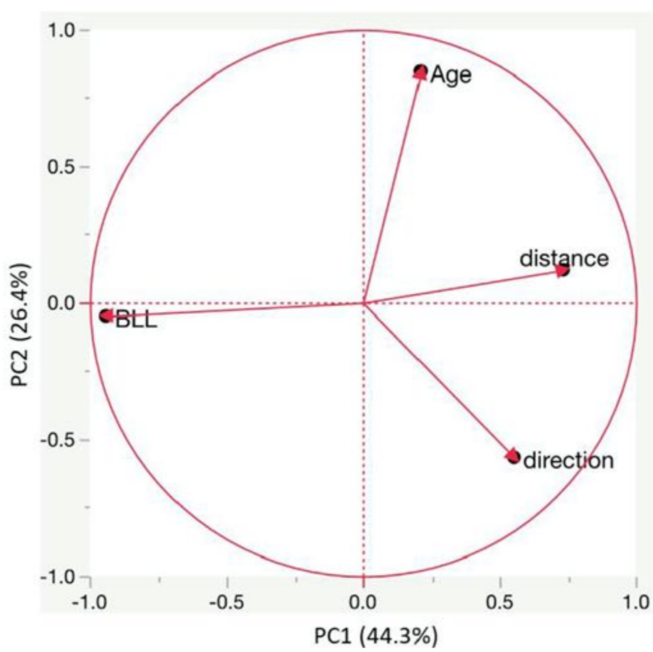

Fig. 5. Principal component analysis on log transformed data showing the influence of age, distance and wind direction on BLL among Kabwe residents.

Koller et al., 2004). This trend could be attributed to the hand-to-mouth or object-to-mouth (pica) behavior of children as they explore their environment after their onset of independent ambulation. In addition to increased exposure, children absorb a greater proportion of ingested Pb from the gastrointestinal tract than adults (Wani et al., 2015). Acute Pb poisoning exceeding 100 μg/dL can be fatal as seen in the Pb poisoning disaster in Nigeria, where more than 400 children died leaving numerous others with long-term neurological impairment (Dooyema et al., 2012; Lo et al., 2012). To minimize the pernicious effects of Pb toxicity in children, chelation therapy is recommended at levels ≥45 μg/dL as clinical symptoms such as abdominal pain, encephalopathy, convulsions, coma and death have been observed in BLLs >60 (CDC, 2002; Needleman, 2004). The current study revealed that of the 556 children, 29% had BLL that exceeded 45 μg/dL and were recommended for chelation therapy. Moreover, the children were followed up for further assessment including neuro-developmental impairment assessment (data not provided).

For the first time, the current study revealed high BLL in women in some areas in Kabwe, with concentrations up to 86 μg/dL. These findings were similar to BLLs reported in women of child-bearing age in Sub-Saharan Africa where the overall weighted mean BLLs of 24.73 μg/dL was recorded, with the highest mean of 99 μg/dL being recorded in women from Nigeria (Bede-Ojimadu et al., 2018). Most of the mothers that participated in current the study (58%) had BLL ranging between 5 and 44 μg/dL, a few (5%) were above 45 μg/dL with none exceeded 100 μg/dL. Exposure to Pb in the women could be attributed to multiple sources including dust inhalation, ingestion via diet or soil (pica), a habit that is common among pregnant women in Zambia, including Kabwe. Although most studies are focused on childhood Pb exposure, the findings in the current study should be considered carefully as increased BLLs in women of child-bearing age in Sub-Saharan Africa were associated with incidences of preeclampsia and hypertension (Bede-Ojimadu et al., 2018). Delayed puberty due to Pb exposure has also been observed in girls (Schoeters et al., 2008). With a half-life of many years to decades in adults, endogenous exposure to Pb due to increased bone resorption as seen in women during pregnancy and lactation (Rothenberg et al., 2000; Téllez-Rojo et al., 2002; Gulson et al., 2003; Manton et al., 2003) could also not be ruled out in the exposed mothers in Kabwe. When pregnant, blood Pb accumulation in women could pose a threat to the developing fetus given that maternal-fetal transfer is a major source of early life exposure to Pb (Chen et al., 2006; Gardella, 2001; Li et al., 2000; Lin et al., 1998). Additional Pb exposure to the infant can occur via breast milk as breastfeeding is a recognized source of postnatal Pb exposure (Counter et al., 2014). These exposure pathways could explain the alarmingly high BLL in infants in the current study, even before their ambulatory stage. This is critical as pediatric Pb poisoning during a vulnerable period of development can lead to negative neurodevelopmental impacts such as low IQ and cognitive impairments (Lanphear et al., 2005).

Similarly, increased Pb exposure in men from some Kabwe townships was recorded in the current study, with median BLLs of 8.60 μg/dL and maximum levels of 88.2 μg/dL. This is also the first time that Pb exposure is being investigated in men in Kabwe and the sources of exposure could be similar to those of women, with the exception of pica, a practice common especially among expectant mothers. Findings in the current study were similar to reports in Iran where mean BLL of 41.41 μg/dL were reported in male workers at a battery manufacturing plant (Sadeghniat haghighi et al., 2013). Given that chronic low level Pb exposure has been associated with health complications including reduced sperm quality (Wu et al., 2012; Apostoli et al., 1998), the findings of the current study highlight the reproductive health risks that men in Kabwe could be exposed to through chronic Pb exposure. Moreover, Pb exposure has an interactive relationship with socio-economic factors. While socioeconomic conditions have been established as important predictors of exposure to Pb (Elias et al., 2007; Sargent et al., 1995), health effects of Pb exposure can be the sources of economic losses that can impact families negatively (UMRSC and MNCEH, 2014; Attina and Trasande, 2013; Gould, 2009; Ogunseitan and Smith, 2007). While many studies may place emphasis only on health effects of Pb exposure, the impact of Pb exposure and poisoning in Kabwe could be broad and include healthcare, social, and behavioural costs.

Area differences in BLL exposure patterns among Kabwe residents were established in the current study, where residents from Kasanda Mine Township had the highest BLL followed by Makululu and Chowa Townships. BLLs in Railway, Natuseko, Katondo, Pollen, Mahatma Ghandi, Bwacha, Ngungu, Mpima Prison, Kang'omba were similar, with residents from Hamududu recording the lowest. These results reveal that severity to Pb poisoning risks among residents of Kabwe was different depending on area of residence. These differences could be attributed to distance from the mine and direction, with distance from the mine exerting the majority influence as seen on PCA analysis. It was shown that townships closest to the mine and lying in the western direction of the mine were affected the most, especially Kasanda, followed by Makululu. Since the wind direction is from east to west in Kabwe, more Pb contaminated dusts emanating from the mine tailings are likely to settle in Kasanda and Makululu than the other townships. Of interest was Natuseko Township, which is located in similar direction with similar distance from the mine as Bwacha and Ngungu Townships but recorded slightly higher BLLs than these two townships. Although not established, this could be attributed to transportation and piling of contaminated soils and stones from the mine in Natuseko Township many years ago (verbal communication from community members).

5. Conclusions

This is the first study that has revealed the true extent of Pb exposure in the whole Kabwe town, which poses a serious public hazard and should be given urgent attention. Exposure to Pb does not only affect children but their parents as well. Factors contributing to Pb exposure included age, distance and direction, with distance playing the major role. Therefore, younger children in townships closer to the mine and lying on the western side of the mine were the most vulnerable. To avert overt Pb toxicity, children with BLL exceeding 45 μg/dL would require chelation therapy. These children were referred to the office of the District Medical Director. Regular BLL monitoring using a portable analyser such as the LeadCare II should be considered for prompt diagnosis and initiation of treatment to avoid the irreversible Pb-induced neurological dysfunction in children. A thorough clinical evaluation of Pb poisoning among the affected children, including neurodevelopmental and cognitive impairments, would reveal the true extend of Pb poisoning in Kabwe. Measuring blood Pb in pregnant women and breast milk will be significant to clarify the exposure pathway from mother to child and recommend appropriate medical management and advice for the mother. Socio-economic factors contributing to Pb exposure and socio-economic impacts of Pb exposure also need to be thoroughly investigated to fully understand the Pb exposure-effect cycle. Moreover, urgent environmental remediation is required to reduce Pb exposure in Kabwe.

Declaration of competing interest

The authors declare no conflicts of interest.

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Lead poisoning in children from townships in the vicinity of a lead-zinc mine in Kabwe, Zambia

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Extensive childhood Pb poisoning in Zambia's Kabwe mining town may have serious health effects on the children ranging from neurological deficits to deaths.

Abstract

Childhood lead poisoning is a serious public health concern worldwide. Blood lead levels exceeding 5 µg/dL are considered elevated. In Kabwe, the capital of Zambia's Central Province, extensive Pb contamination of township soils in the vicinity of a Pb-Zn mine and posing serious health risk to children has been reported. We investigated BLLs in children under the age of 7 years in townships around the mine; where blood samples were collected and analysed using an ICP-MS. Almost all of the sampled children had BLLs exceeding 10 µg/dL. Children in these areas could be at serious risk of Pb toxicity as 18% of the sampled children in Chowa, 57% (Kasanda) and 25% (Makululu) had BLLs exceeding 65 µg/dL. Eight children had BLLs exceeding 150 µg/dL with the maximum being 427.8 µg/dL. We recommend that medical intervention be commenced in the children with BLL exceeding 45 µg/dL.

Keywords: Children; lead poisoning; Pb-Zn mine; Kabwe, Zambia.

1. Introduction

Childhood lead (Pb) poisoning is a serious public health concern worldwide (Tong et al. 2000). Exposure to Pb affects multiple organ systems resulting in numerous morphological, biochemical and physiological changes that include hematological disorders, nervous system disturbances and impairment of liver and kidney functions (Lockitch 1993; Al-Saleh 1994; Canfield et al. 2003; Needleman 2004). Young children are particularly vulnerable to Pb exposure and poisoning. This is because young children frequently explore their environment via hand-to-mouth and object-to-mouth activities; behaviors that are likely to increase Pb intake in children from polluted environments such as house dust or yard soils (Calabrese et al. 1997; Manton et al. 2000). Biological factors also play a significant role in increased Pb uptake in children as the average fractional gastrointestinal absorption of Pb is much greater in infants and young children than in adults (Ziegler et al. 1978). Moreover, Pb absorption is increased in the presence of nutritional deficiencies such as iron and calcium, which are more common in children than in adults (Bradman et al. 2001). Children are also more vulnerable to Pb poisoning compared to adults as the central nervous system is most sensitive to Pb toxicity during developmental stages (Bellinger 2004; Lidsky and Schneider 2003). Although the effects of Pb on the nervous system in adults tend to reverse after cessation of exposure (Baker et al. 1985), effects in children tend to persist (Needleman et al. 1990).

Lead concentration in whole blood (BLL) is the main biomarker used to monitor exposure and has been widely used in epidemiological studies (CDC 2009). The Centers for Disease Control and Prevention (CDC 2012) recently revised the blood lead "level of concern" from 10 to 5 μg/dL in response to reports that BLLs < 10 μg/dL can cause neurological abnormalities such as decreased intelligence quotient (IQ) in children

(Canfield et al. 2003). Therefore, a threshold below which Pb does not result in neurological deficits has not been determined (Needleman 2004). However, individuals differ widely in the BLL at which signs of Pb toxicity appear, with some individuals seeming well at a BLL that in others results in encephalopathy or even death (Bellinger 2004). The detrimental effects of elevated BLLs in the range of 10 to 45 μg/dL are usually subclinical and may include neurodevelopmental impairment (CDC 2002). Generally, BLLs > 10 μg/dL in children are considered elevated and it has been recommended that chelation therapy be initiated at levels ≥ 45 μg/dL (CDC 2002; Needleman 2004). At higher BLLs > 60 μg/dL, clinical symptoms such as abdominal pain and arthralgia become visible in children (Needleman 2004). Moreover, it has been reported that high BLLs exceeding 100 μg/dL can cause encephalopathy, convulsions, coma and death, especially in children (CDC 2002; TNO 2001).

In the last decade, BLLs in children have reduced significantly in a number of developed countries following the phasing out of leaded gasoline (Wilhelm et al. 2006). However, childhood Pb toxicity continues to be a major public health problem in most developing countries. In Africa, major sources of childhood Pb poisoning include Pb mining and smelting, paint and battery recycling (Nriagu et al. 1996; Mathee et al. 2007). The recent Pb poisoning disaster in Nigeria, where more than 400 children died leaving numerous others with long-term neurological impairment including blindness and deafness, was attributed to gold ore–mining and processing, especially that metals were processed in their dwellings (Blacksmith Institute 2011, Dooyema et al. 2012; Lo et al. 2012). In Kabwe Town, the capital of Zambia's Central Province, extensive Pb contamination of township soils in the vicinity of a Pb-Zn mine has been reported and poses a serious health risk to children in these townships (Tembo et al. 2006; Nakayama et al. 2011). In an earlier study, Pb poisoning and cases of encephalopathy were recorded in children from a township in the vicinity of the Pb-Zn mine in Kabwe (Clark APL, unpublished data).

Despite extensive Pb pollution in Kabwe, comprehensive studies of Pb exposure and poisoning in children in the vicinity of the mine are rare. In animal studies however, high concentrations of Pb were reported in wild rats (Nakayama et al. 2011; Nakayama et al. 2013) as well as blood and edible organs of cattle (Yabe et al. 2011; Ikenaka et al. 2012) and chickens (Yabe et al. 2013) reared in the vicinity of the mine in Kabwe. Therefore, the objectives of the current study were to investigate BLLs in children under the age of 7 years in townships around the Pb-Zn mine in Kabwe and to identify children with BLLs that require medical intervention.

2. Materials and methods

2.1 Sampling sites

Kabwe town, the provincial capital of Zambia's Central Province, is located at about 28°26′E and 14°27′S. Kabwe has a long history of Pb-Zn mining. The mine operated almost continuously from 1902 to 1994 without addressing the potential risks of metal pollution. Dense fumes rich in Pb and other metals were emitted from smelters and they polluted the environment in the surrounding communities extensively (Tembo et al. 2006). Despite closure of the mine, scavenging of metal scraps from the abandoned tailings and wastes stored on the mine has continued to serve as a source of metal pollution, especially dusts emanating from the mine dumps.

In the current study, blood samples were collected from children at health centers located in Chowa, Kasanda and Makukulu townships, in May-June of 2012. Kasanda Township lies west to the mine and its center is about 2.2 km from the smelter (Fig. 1).

However, some households in Kasanda are within 1 kilometer of the mine. Makululu Township is a large squatter compound that lies adjacent and to the west of Kasanda Township. These two townships are affected by dust emanating from the mine as the prevailing winds most of the time blow from the east to the west. Most houses in Makululu are made of mud brick walls, mud floors and thatched roofs. Moreover, lots of dust is emitted by vehicles as roads in the township are not tarred. Many households in the township use well water in addition to communal water taps and there are high levels of poverty in the community. Chowa Township is equally close to the mine as Kasanda but is least affected by dust as it lies on the windward side of the mine. In contrast to Makululu, houses in Kasanda and Chowa are made of concrete bricks and use indoor tap water. Children from these townships were selected because soil samples in these townships are highly polluted with Pb (9-51188 mg/kg) and other metals (Nakayama et al. 2011).

2.2 Blood collection

The study was approved by the University of Zambia Research Ethics Committee (UNZAREC) and the Ministry of Health, Zambia. After informed and written consent was obtained from the children's parents or guardians, blood samples were collected by qualified laboratory technicians at Chowa, Kasanda and Makululu clinics. Before sampling commenced, an awareness campaign about the research activities was conducted by community health workers in each township to encourage parents/guardians to take their children under the age of 7 to the health centers for sample collection. To avoid sample contamination, all blood collection supplies were kept in plastic ziploc storage bags before sample collection. For each child, data on the age, sex and residential area were recorded. Blood up to 10 mL was collected from the cubital vein of each child, after careful cleaning and sanitization of the venipuncture site with an ethanol swab to avoid contamination, into plain blood collection tubes for Pb analysis. The blood samples were immediately stored in freezers at -20 °C after sampling and then transported in cooler boxes on dry ice to the laboratories of the Kabwe District Health Offices and Kabwe Provincial Veterinary Offices where they were again stored at - 20 °C. After obtaining the material transfer agreement (MTA) clearance from the Zambia National Health Research Ethics Committee (NHREC), the blood samples were transported to Japan in cooler boxes on dry ice and analyzed for metal concentrations in Laboratory of Toxicology, Graduate School of Veterinary Medicine, Hokkaido University.

2.3 Sample preparation and metal extraction

All laboratory materials and instruments used in metal extraction were washed in 2 % nitric acid (HNO_3) and oven dried. The metal was extracted in blood samples using microwave digestion system (Speedwave MWS-2; Berghof) according to the manufacture's instruction. Metal extraction was done as recommended by Schweitzer and Cornett (2008). Briefly, 1 mL of each blood sample was placed in prewashed digestion flasks, and 5 mL of 60 % nitric acid (Kanto Chemical) and 1 mL of 30 % hydrogen peroxide (Kanto Chemical) were added. After digestion in the microwave for 52 minutes and temperatures of up to 190 ^{o}C, the digested samples were transferred into plastic tubes. The volume was then made up to 10 mL with bi-distilled and de-ionized water (Milli-Q).

2.4 *Metal analysis*

Blood Pb concentrations were analyzed by Inductively Coupled Plasma-Mass Spectrometer (ICP-MS; 7700 series, Agilent technologies, Tokyo, Japan). The precision and accuracy of the applied analytical method was evaluated by analyzing the recovery rate using digested blood samples and spiking Pb standard solutions. Using this method, a good recovery of 97% was obtained. Certified Reference Materials, DORM-3 (Fish protein, National Research Council of Canada, Ottawa, Canada) and DOLT-4 (Dogfish liver, National Research Council of Canada, Ottawa, Canada) were used to evaluate recoveries. Replicate analysis of these reference materials also showed good recoveries (95-105%). Instrument detection limit was 0.001 μg/L.

2.5 *Statistical analysis*

The data of BLLs were log transformed to stabilize variances. Statistical analysis was performed using JMP version 9 (SAS Institute, USA). The data are presented as mean, median and minimum-maximum values in μg/dL, wet weight. A stacked histogram was used to analyzed blood Pb accumulation trends in Kasanda and Makululu as well as in boys and girls. Stepwise multiple linear regression analyses on log-transformed data were used to estimate the influence of area, sex and age (0 – 3 years and 4 – 7 years old) on BLLs. Correlations between age and BLL were analyzed by both linear and quadratic regression analysis. Samples from Chowa were not included in the comparisons due to smaller sample size compared to Kasanda and Makululu. A p-value of less than 0.05 was considered to indicate statistical significance.

3. Results

3.1 Blood lead levels (BLLs)

A total of 246 blood samples were collected from children, up to 7 years old, at Chowa (n = 17 samples), Kasanda (n = 100) and Makululu (n = 129) health centres. Concentrations of Pb in blood samples are shown in Table 1.

As shown in Table 2, all of the sampled children had BLLs exceeding the guideline value that raise 'health concerns' (5 μg/dL). Numbers of children exceeding guideline values for initiating chelation therapy (45 µg/dL), toxicity level (65 - 149 µg/dL) and levels associated with encephalopathy and death (> 150 µg/dL) are also shown.

3.2 Blood Pb accumulation patterns

Using a stacked histogram, blood Pb accumulation patterns in children from Kasanda and Makululu as well as concentration differences between boys and girls in the two townships were analysed (Figure 2). Blood accumulation differences were highlighted as the highest BLLs were seen in younger children (0 – 3 years) than children aged 4 – 7 years (Figure 3).

3.3 Age and Sex differences

Stepwise multiple linear regression analyses were performed on log-transformed data to estimate the influence of independent variables (age as continuous variable, sex represented as 0 for girls and 1 for boys, location (area) represented as 0 for Makululu and 1 for Kasanda) on BLLs (Table 3). Concentrations in children from Kasanda were higher than levels in children from Makululu ($p < 0.05$). There was no difference in the BLLs between boys and girls from Kasanda whereas in children from Makululu, BLLs were higher ($p < 0.05$) in boys than girls. Younger children aged 0 - 3 years accumulated higher concentrations of Pb in blood than children aged 4 – 7 years in both Kasanda and Makululu ($p < 0.05$).

Combining the data of Kasanda and Makululu, significant negative correlations between age and BLL were observed by both linear and quadratic regression analysis. Peak BLLs were observed around the age of 2 years (data not shown).

5. Discussion

The current study has demonstrated alarming childhood Pb poisoning in Zambia's Kabwe town, revealing serious Pb exposure in the children under the age of 7 years in townships surrounding the closed Pb-Zn mine. The study analysed BLLs in children because it is well established that children are more vulnerable to Pb poisoning and sensitive to its neurotoxic effects than adults (Lidsky and Schneider 2003). All of the sampled children in the current study had indications of Pb poisoning, with BLLs exceeding the 5 μg/dL "level of concern" set by CDC (2012). Moreover, the current study revealed that children in these townships could be at serious risk of Pb toxicity as 18% of the sampled children in Chowa, 57% (Kasanda) and 25% (Makululu) had BLLs exceeding 65 μg/dL; the threshold widely considered to result in Pb toxicity (CDC 2002; Needleman 2004). Of the 246 children in the current study, 8 had BLLs exceeding 150 μg/dL, up to 427 μg/dL.

These findings agreed with reports in an earlier study before closure of the mine, where mean BLLs of 37 - 107 μg/dL were recorded in children from Kasanda Township (Clark APL, unpublished data). Of the 91 children between the ages of 1 - 2 years that were attended to at Kasanda clinic in the earlier study, 89% were reported to have accumulated BLLs > 60 μg/dL (Clark APL, unpublished data) compared to 61% of the sampled children from the same clinic in the current study. Therefore, there could be no difference between the severity of Pb poisoning during active mining period and almost 20 years after closure of the mine. Higher BLLs than the current study were recorded in children under the age of 5 years in Zamfara State in Nigeria, where the affected families processed metals in their dwellings (Blacksmith Institute 2010; Dooyema et al. 2012; Lo et al. 2012). In the study by Dooyema et al. (2012), BLLs exceeding 10 μg/dL were reported in all the 204 sampled children in Nigeria. In children from Nigeria, mean BLLs (107.5 – 153.3 μg/dL) were higher than mean BLLs in the current study (39 – 82.2 μg/dL). However, the maximum BLL of 445 μg/dL recorded in children from Nigeria was comparable to that of the current study (427.8 μg/dL). Although data on mortalities due to Pb poisoning in Kabwe are scarce, clinical signs consistent with Pb poisoning such as anemia, small stature and weakness were observed in children from the sampled areas during the current study. In Nigeria, over 400 children were reported to have died of Pb poisoning (Blacksmith Institute 2011, Dooyema et al. 2012; Lo et al. 2012). Findings in the current study were higher than BLLs in children from an urban population in Kinshasa, Democratic Republic of Congo, where mean BLLs of 9.9 μg/dL and maximum concentrations of 49.3 μg/dL were recorded (Tuakuila et al. 2013). Moreover, BLLs in the current study were higher than mean BLLs (16.38 μg/dL) in children in the vicinity of Pb mines and sheltering plants in China (Lin et al. 2011). When compared to most European countries where the median BLL in the general population is below 5 μg/dL (Taylor et al. 2007), it is evident from the current study that levels of Pb poisoning in Kabwe, Zambia are alarming.

When the severity of Pb poisoning among the townships was compared in the current study, the mean BLL in children from Kasanda (82.2 μg/dL) was higher ($p < 0.05$) than Makululu (57.1 μg/dL). Kasanda and Makululu were subjected to atmospheric Pb pollution emanating from the neighbouring mine as they are located on the western side of the mine, which is in the direction of the prevailing winds. However, the difference in BLLs in children from the two townships could be attributed to distance from the mines. Although all these townships were close to the mine, some households in Kasanda (even Chowa) were within 1 kilometre of the mine and the abandoned mine dumps hence most of the polluted dust settles in Kasanda Township. Despite being further away from the mine compared to Kasanda, Makululu Township, the largest shanty compound in Zambia equally poses a serious threat as roads, dwellings and house floors are dusty. Therefore, more children in Makululu Township could be at risk of Pb poisoning due to poverty and poor living conditions.

There was no gender difference in BLLs between boys and girls in Kasanda Township. This finding was in agreement with observations in the Democratic Republic of Congo (Tuakuila et al. 2013). However, trends in blood Pb accumulations between boys and girls were observed in the current study as boys in Makululu Township accumulated higher BLLs ($p < 0.05$) than girls in the same township. The same was observed when data of both Kasanda and Makululu were combined. Different behaviours between boys and girls could be one of the factors contributing to this difference as boys are likely to cover more distance away from home and play near the mine dumps than girls. When children in the current study were grouped according to age, it was observed that younger children between the ages of 0 – 3 years accumulated higher BLLs than their older counterparts (4 – 7 years). Significant negative correlation between age and BLL supported this finding. Similarly, younger children (1 – 2 years) in the Democratic Republic of Congo accumulated higher BLLs than older children (Tuakuila et al. 2013). Therefore, findings in the current study emphasized the increased susceptibility of younger children to the health risks of Pb pollution.

Earlier studies also observed that BLLs tend to peak at around 2 years of age (Koller et al. 2004). This observation is not unexpected as this period encompasses both the onset of independent ambulation and the time when a child's oral exploration of the environment including hand-to-mouth or object-to-mouth behaviour (pica) is greatest. This exposure pathway of children has been well documented in other studies (Lanphear and Roghmann

1997; Lanphear et al. 2002). It has been established that children typically ingest an average of 50 mg/day of soil (Stanek and Calabrese 1995). However, this amount can exceed 5 g a day in the case of pica (Mielke and Reagan 1998), with some children having been reported to ingest 25-60 g during a single day (Calabrese et al. 1997). Given that maximum Pb concentration in soils in the vicinity of the mine in Kabwe is about 50,000 µg/g or 50 mg/g (Nakayama et al. 2011), it means that children who ingest about 5 - 60 g of soil/day in the vicinity of the mine in Kabwe would ingest 250 - 3000 mg of Pb/day. Since the permissible tolerable weekly intake (PTWI) of Pb is 25 µg/Kg of body weight per week (WHO 1987), concentrations of Pb ingested by children through pica in Kabwe mining area could be high.

The current study has demonstrated that childhood Pb poisoning in Zambia's Kabwe mining town is among the highest in the world, especially in children under the age of 3 years. Lead exposure among children is associated with developmental abnormalities including impaired cognitive function, reduced intelligence, impaired hearing and reduced stature (Canfield et al. 2003; Jusko et al. 2008). Although reports of clinical cases and deaths due to Pb poisoning among children in Kabwe are rare, the findings of the current study indicate that more studies need to be done in order to clearly establish the health effects of Pb poisoning in children exposed to Pb pollution in the townships around the mine in Kabwe. This is important because BLLs in all of the sampled children in the current study exceeded 5 µg/dL. In children, it has been established that neurobehavioral effects such as decrease in IQ may occur at BLLs < 10 µg/dL (Canfield et al. 2003). Moreover, BLLs of 40 - 60 µg/dL are considered to be markedly elevated, resulting in distinct neurobehavioral effects (TNO 2005). Since 18 % of the sampled children from Chowa, 57 % (Kasanda) and 25 % (Makululu) in the current study had markedly elevated

BLLs exceeding 65 µg/dL, it would not be surprising to observe neurological effects of Pb poisoning in the exposed children. Although this is the first published study evaluating Pb poisoning in Kabwe, it was earlier reported that during the mining period between 1971 to 1973, cases of suspected Pb poisoning with encephalopathy occurred among children aged 10 to 30 months living in the township of Kasanda (Clark APL, unpublished data). Therefore, the children in Chowa, Kasanda and Makululu townships should be closely monitored to enable early detection of clinical signs related to Pb toxicity and medical intervention.

6. Conclusions

Given that Pb poisoning among children in Kabwe was extensive, it is recommended that chelation therapy be commenced in the children with BLL exceeding 45 µg/dL prior to the onset of symptoms to reduce morbidity and prevent mortality in the affected children. This can be achieved for each child by devising and implementing an individualized plan of follow-up, especially for those children with extremely high BLLs. Interrupting the process of Pb poisoning through early detection and intervention can prevent children from dying or suffering severe permanent effects of Pb toxicity such as persistent seizures and mental retardation. Moreover, urgent interventions are required to reduce Pb exposure in the affected townships. This can be done through community-based programs to educate the affected communities about the health effects of Pb, sources of Pb and practical ways of reducing Pb exposure in their homes and communities.

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Conflict of interest

The authors declare no conflicts of interest.

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Figures legends:

Fig. 1. A map of Kabwe showing different geographic areas and sampling sites

Fig. 2. Stacked histogram showing blood lead accumulation trends in children from Kasanda (46 boys and 54 girls) and Makululu (59 boys and 70 girls) townships of Kabwe, Zambia.

Fig. 3. Histogram showing blood lead accumulation trends in younger (0 – 3 years) and older (4 – 7 years) children from Kasanda and Makululu townships of Kabwe (Zambia).

Table 1.

Mean age (year) and BLLs (µg/dL) of children from Chowa, Kasanda and Makululu townships in vicinity of the Pb-Zn mine in Kabwe, Zambia

Township	Mean age	Sample size	Arithmetic mean BLL	Median	Minimum	Maximum
Chowa	5.76	n = 17	39.0	39.3	15.6	79.7
Kasanda	3.65	n = 100	82.2	74.9	5.40	427.8
Makululu	4.51	n = 129	57.1	51.1	9.40	388.7

n = Number of samples

Table 2.

Numbers of children (under the age of 7 years) with elevated BLLs from the sampled townships in Kabwe

Reference limits	Chowa (*n* = 17)	Kasanda (*n* = 100)	Makululu (*n* = 129)
< 5 µg/dL	0	0	0
5 - 44 µg/dL – elevated levels	8	27	50
45 - 64 µg/dL – initiate treatment	7	15	44
65 - 149 µg/dL – toxicity level	2	50	33
> 150 µg/dL – encephalopathy, death	0	8	2

n = Number of children sampled

Table 3.

Blood lead accumulation differences (age, sex and site) by stepwise multiple linear regression analyses in children from Kasanda and Makululu townships in Kabwe.

Kasanda and Makululu

Parameter	Estimate	nDF	SS	F Ratio	p value (Prob>F)
Intercept	1.898	1	0.00	0.00	1.0
Age	-0.035	1	1.05	15.84	**9.35E-05**
Sex{F-M}	-0.050	1	0.56	8.44	**0.004**
Area{Makululu-Kasanda}	-0.048	1	0.48	7.25	**0.008**

Kasanda

Parameter	Estimate	nDF	SS	F Ratio	p value (Prob>F)
Intercept	1.936	1	0.00	0.00	1.0
Age	-0.033	1	0.41	4.36	**0.039**
Sex{F-M}	-0.060	1	0.35	3.77	0.055

Makululu

Parameter	Estimate	nDF	SS	F Ratio	p value (Prob>F)
Intercept	1.861	1	0.00	0.00	1.0
Age	-0.038	1	0.66	14.3	**0.0002**
Sex{F-M}	-0.043	1	0.22	4.79	**0.030**

Bold indicate significant ($p < 0.05$), nDF: number of degrees of freedom for a term, SS: Sequential Sum of Squares

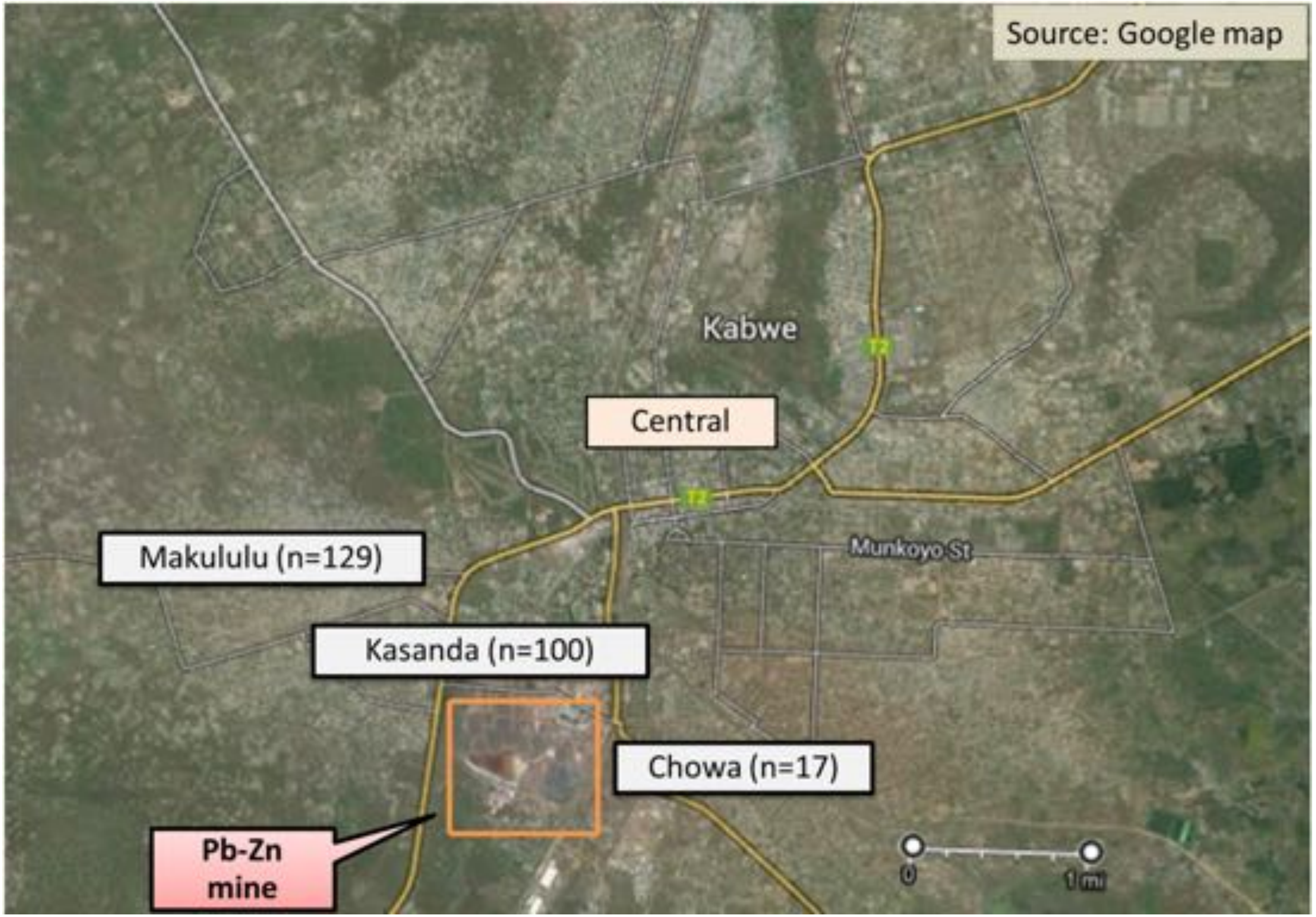
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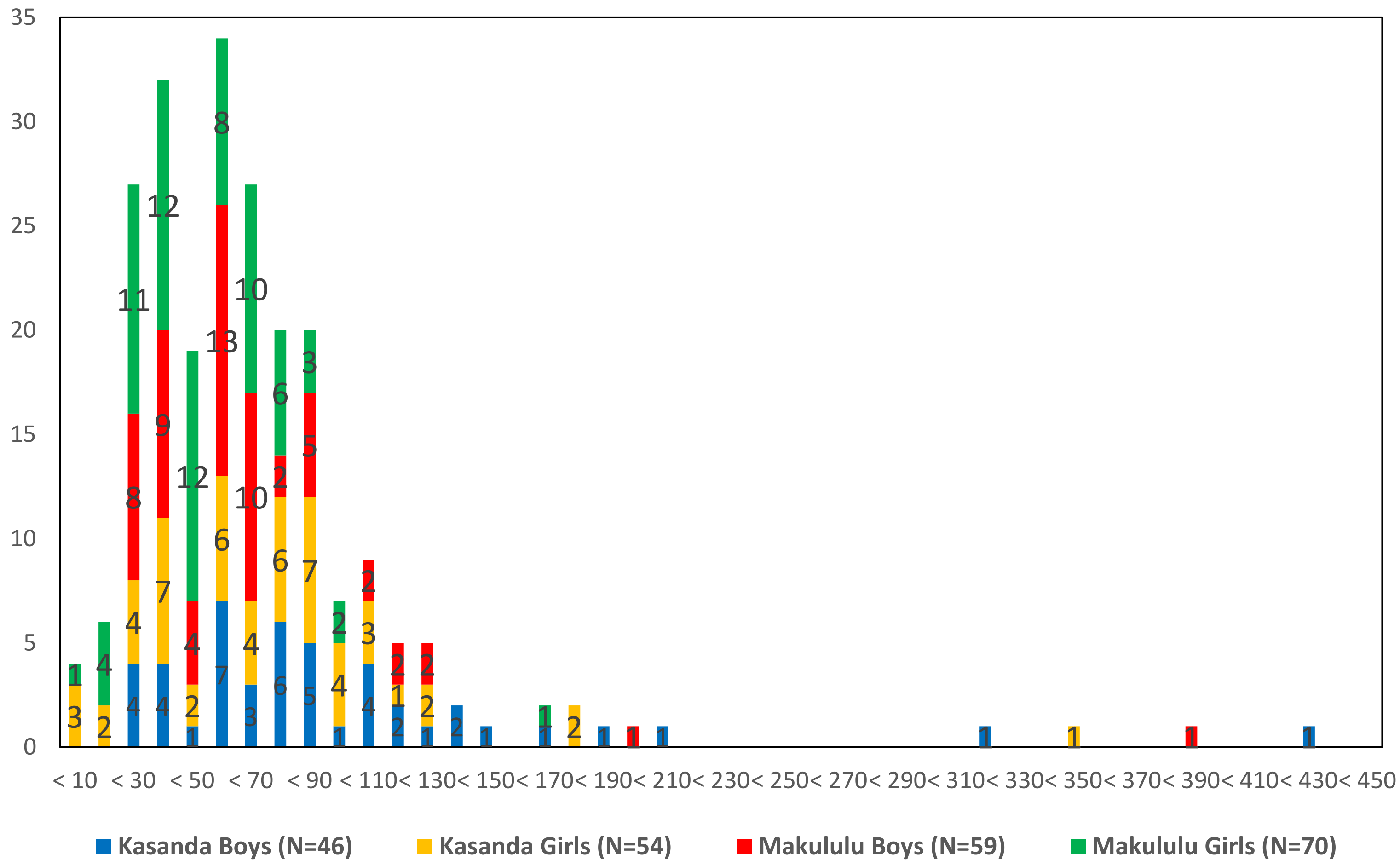
Fig. 1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Kasanda Boys (N=46)
Kasanda Girls (N=54)
Makululu Boys (N=59)
Makululu Girls (N=70)

Fig. 2

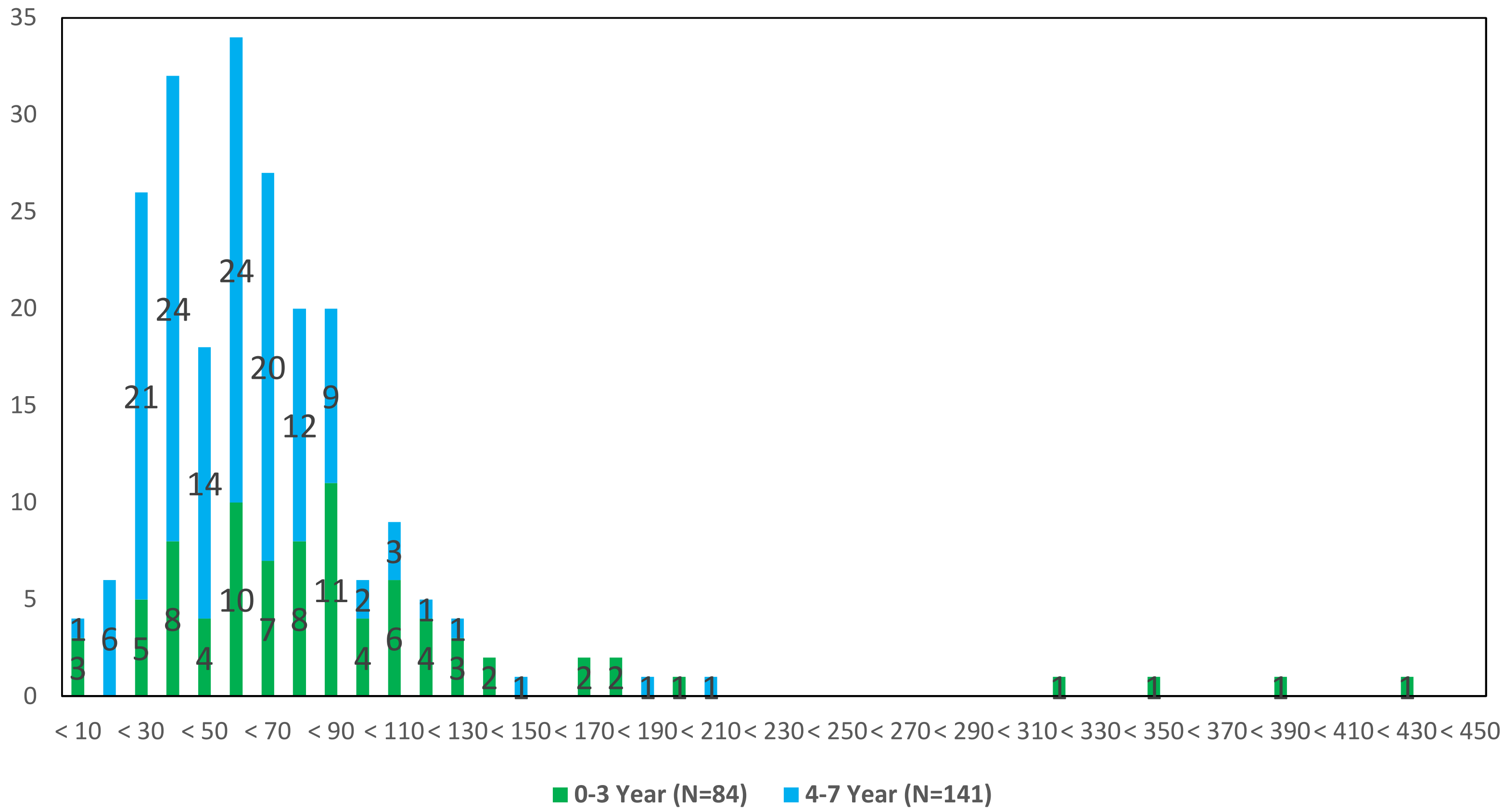
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Fig. 3

Figure legend: Fig. 2. Paediatric effects of lead at various blood lead levels

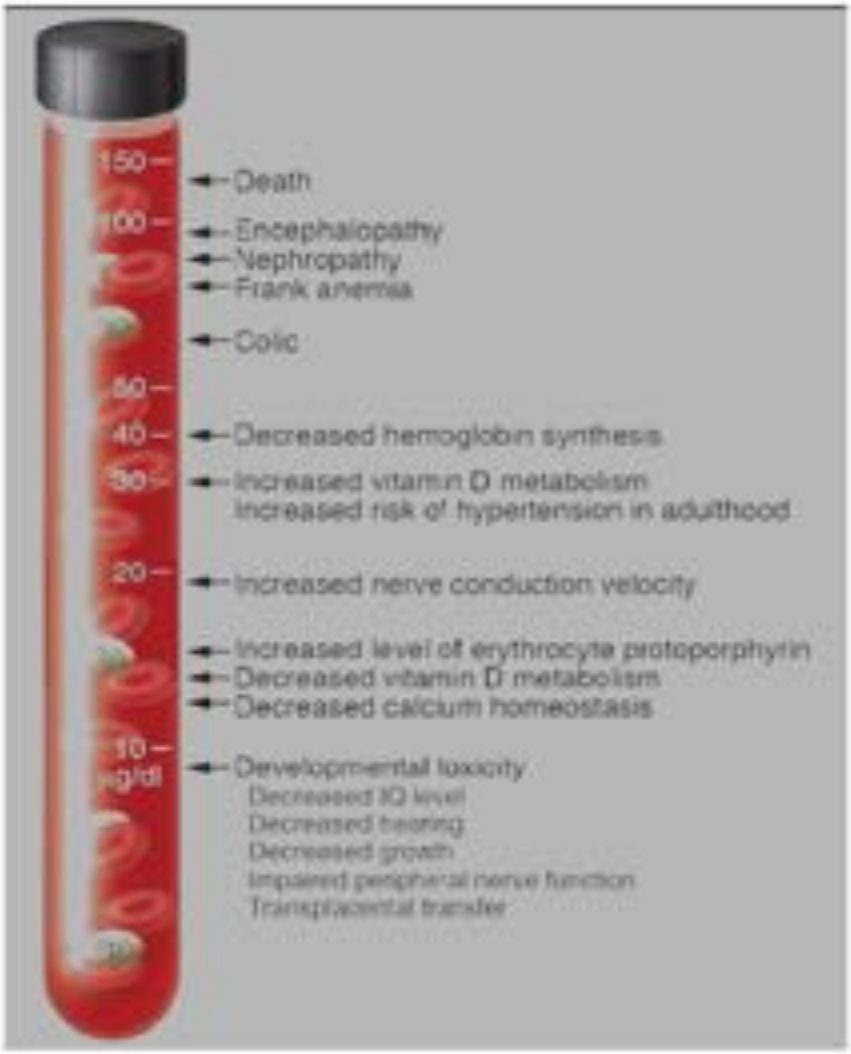
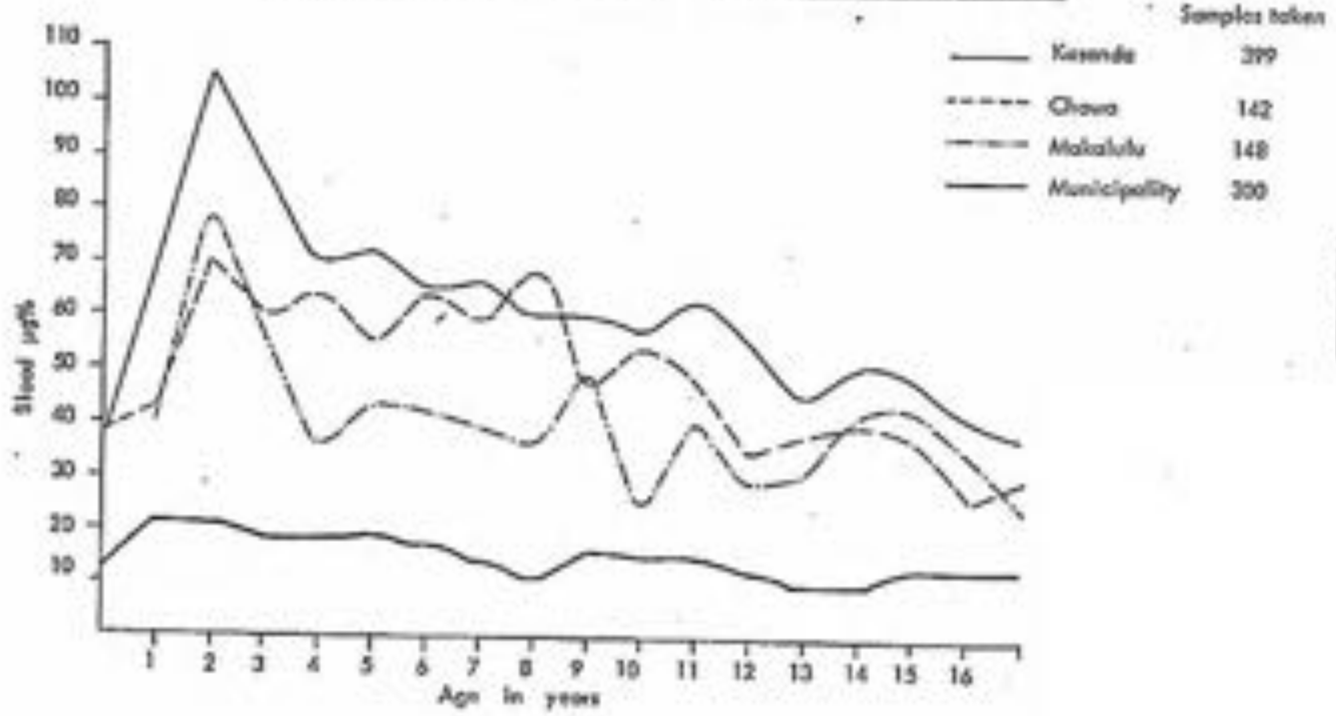


FIGURE 3[1]

BLOOD LEAD CONCENTRATIONS / YEAR OF AGE AS AT 31-1-'74



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Our commitment to human rights is further expressed through our being a signatory to the United Nations Global Compact and the Voluntary Principles on Security and Human Rights (VPSHR), and through being a supporter of the UN Guiding Principles on Business and Human Rights (Guiding Principles). Human rights principles are embedded in a number of our internal Policy documents, including those related to employment practices, exploration, environmental practices, social performance and security.

We accept and support the corporate responsibility to respect human rights and actively seek to avoid involvement with human rights abuses. We aim to identify, assess and minimise potential adverse human rights impacts that we may cause or contribute to, or that are linked to our business, through on-going due diligence and appropriate management, as stated in the Guiding Principles.

We also recognise that our host governments have a duty to protect the human rights of everyone within their jurisdiction. Where it is appropriate and within our power to do so, we also seek to promote the observance of human rights in the countries where we work and will work with states to build capacity in support of that objective.

DOES THIS APPLY TO ME?

This Policy applies to our relationships with our employees, contractors and other public and private sector business partners in what they do on our behalf. In those situations where Anglo American does not have full management control, we will exercise our available leverage to influence compliance with this Policy.

This is a Group Policy that applies to Anglo American globally, unless any aspect of the Policy is not permitted by local law or regulation.

Accountability for implementation of this Policy lies with the Group Chief Executive and with the Chief Executives of the business units.

WHAT DO I NEED TO KNOW?

Respected rights

Our commitment to respect human rights includes recognition of all internationally-recognised human rights, in particular: those contained in the International Bill of Human Rights (which includes the Universal Declaration of Human Rights, the International Covenant on Civil and Political Rights and the International Covenant on Economic, Social and Cultural Rights); the International Labour Organisation's

Declaration on Fundamental Principles and Rights at Work; and international humanitarian law, where applicable.

Our commitment to the International Labour Organisation's fundamental labour rights entails respect for the right to freedom of association and collective bargaining, the right to equal remuneration for equal work, and a zero tolerance approach to forced and bonded labour, child labour and unfair discrimination.

As a signatory to the Voluntary Principles on Security and Human Rights (VPSHR), we have made a commitment to maintaining the safety and security of our operations and staff within an operating framework that encourages respect for human rights via any necessary interactions with both public and private security providers.

We commit to address both adverse human rights risks and impacts and to contribute positively to an enabling environment for human rights to be respected. We are also committed to paying special attention to the rights of potentially vulnerable groups.

We recognise that the nature of mining operations, from the earliest stages in the life of our mines, creates the potential for a wide range of human rights risks and we seek to mitigate the risk of any breaches.

As part of our commitment to respect human rights and to a comprehensive approach, we will also undertake appropriate due diligence throughout the lifecycle of mining operations. Where we have caused or contributed to adverse human rights impacts we will contribute to their remediation as appropriate. We will inform and engage appropriately with affected and potentially affected persons on risks, impacts and management measures and keep them involved in monitoring performance.

We will make particular effort to ensure that we engage with those most vulnerable, in particular where they encounter challenges in voicing their opinions or having them heard, and to identify any additional specific measures to avoid, prevent or mitigate impacts on them.

DELIVERY AND IMPLEMENTATION

We commit to embed this Policy into our corporate culture and practices. Our efforts will be guided by the relevant sections of the Guiding Principles and will include:

- Incorporating ongoing human rights due diligence into relevant business processes as appropriate, such as impact assessments.
- Engaging with relevant, potentially affected stakeholders in assessing and addressing impacts.
- Including human rights-related requirements within contractual arrangements with business partners and host governments as appropriate.
- Collaborating with or providing access to remedy through effective complaints and grievances procedures.

We will continue to play an active and constructive role in relevant human rights-related multi-stakeholder initiatives, including the VPSHR, for which the continued implementation is an important pillar of the human rights approach set out in this Policy.

Anglo American will always comply with applicable laws and respect the rule of law. In situations where there is a conflict between domestic legal requirements and international human rights norms, we shall seek to uphold our company values. In doing so we will consider all options; this may include refraining from new, or exiting from existing, investments in the respective jurisdiction.

WHAT DO I NEED TO DO?

It is everyone's responsibility to uphold our commitment to show respect for human rights in every aspect of how we do business. This means we must demonstrate care and respect in our interactions with each other and with our stakeholders. It also means we must undertake risk-based due diligence of any new activity or business partner where there is a possibility of adverse human rights impacts arising as a result of that activity or relationship, and also on an ongoing basis in our existing activities. It also highlights the importance of having the courage to report any potential or suspected labour or human rights abuse you may observe in our operations or in those of a business partner.

Training and communication

Anglo American will communicate this Policy and its requirements to internal and external stakeholders, including general awareness raising and specific training on human rights-related issues where deemed necessary.

MONITORING AND REPORTING:

Monitoring and reporting

The adherence of Anglo American sites to this Policy and the on-going process of human rights due diligence it outlines will be monitored as a component part of wider assessment of social performance that is conducted on an annual basis under the Anglo American Social Way.

Suppliers' and contractors' human rights performance will likewise be monitored as stipulated in their contractual agreements with Anglo American as outlined in the Group's Responsible Sourcing framework.

Any incident identified through the Speak Up confidential reporting service or the Social Way reporting mechanism that may constitute a potential or actual infringement of human rights will be reported to the owner of the Human Rights Policy as well as to the Board Sustainability Committee.

Consequences of breach

Employees', contractors' and suppliers' performance contracts incorporate a commitment to Anglo American's Code of Conduct, and by extension an undertaking to maintain adherence to this Policy. We will all be held accountable for our behaviour while working on the company's behalf and action will be taken where the Code or this specific Policy has not been followed. Consequences will depend on how an individual has contravened the Policies in the Code and in what circumstances, and could range from a warning to dismissal.

Where a breach of legislation is proven in this regard, Anglo American also reserves the right to refer the matter to the relevant authorities for further action.

FURTHER INFORMATION:

Internal references

- Anglo American Safety, Health and Environment (SHE) Way
- Anglo American Social Way
- Group Equality and Inclusion Policy
- Group Business Integrity Policy
- Group Climate Change Policy
- Anglo American Human Rights framework
- Anglo American Responsible Sourcing framework

External references

United Nations Global Compact

United Nations Guiding Principles on Business and Human Rights

Voluntary Principles on Security and Human Rights

Universal Declaration of Human Rights

International Covenant on Civil and Political Rights

International Covenant on Economic, Social and Cultural Rights

International Labour Organization (ILO) Fundamental Conventions

If you need any further information or require guidance on reporting on suspected/alleged human rights-related incidents, email **humanrights@angloamerican.com** or contact the Government Relations team.

BUSINESS MAVERICK

Seeing the light: Anglo CEO says industry is seeking guidance from faith leaders on social issues

By Ed Stoddard • 7 October 2020

The mining industry was largely built on the well-documented exploitation of a mainly black and migrant labour force, and was regard...

Anglo American CEO Mark Cutifani made an intriguing reference to the guidance the mining industry has sought from leaders of faith to help navigate its social relations. He was delivering the keynote address at the online Joburg Mining Indaba organised by Resources 4 Africa.

South Africa's mining industry has had some fraught relations with its host and labour-sending communities over the decades, to say the least. The industry was largely built on the well-documented exploitation of a mainly black and migrant labour force, and was regarded as one of the economic pillars of the apartheid state. Its sordid legacies have included lungs ruined by silicosis, thousands of lives lost underground, broken communities and massive disparities of wealth that still disfigure South Africa's body politic.

In more recent years, even as the industry has strived on a range of fronts to make amends, it has frequently been the target of community wrath over land rights, lack of jobs, and other social and economic flashpoints.

"It has become commonplace for us as an industry to wake up to news about a mining operation that has been blockaded by a community, often over legitimate concerns such as jobs, procurement opportunities or the disruption that our operations sometimes bring to host communities," Cutifani said in prepared remarks.

"But there's a new paradigm of community engagement that is unfolding in front of our eyes. Our host communities frequently tell us that they want to be heard; that they want to determine their destinies."

And leaders of faith are among the sources of guidance the industry has turned to as it navigates turbulent social landscapes.

"Several years ago, we, as leaders in the mining industry, initiated a ground-breaking dialogue with the Vatican under the leadership of His Eminence Cardinal Peter Turkson. What we wanted to do was listen to Cardinal Turkson's view and what we were missing in our relationship with communities, NGOs and society at large, as mining companies," Cutifani said.

"I know some people still wonder why we turned to faith leaders for help as an industry. The reasoning is pretty simple: because they are literally in every community around the world – churches and other religious institutions are sometimes the only ones speaking for the neediest in society. Their voice matters and their moral standing is an important shaping force."

Cutifani has long been an articulate voice in the industry, and often, as in this case, a revealing one. In many of the resource-rich regions where major mining companies operate – notably Latin America and Africa, or the global South – rates of religiosity are far higher than in industrialised regions such as Europe. So, it makes sense to engage with faith leaders to understand the needs and aspirations of their flocks. And this goes beyond the revealed religions of the Abrahamic faiths.

As an example: if Rio Tinto had paid heed to the sacred importance of two 46,000-year-old rock shelter sites in Australia to the Aboriginal community, it might not have blundered ahead with its destruction of them to gain access to some high-grade iron ore. And its CEO would not be on his way out the door.

> *Investors and shareholders are driving ESG compliance (https://www.dailymaverick.co.za/article/2020-09-27-investors-and-shareholders-are-driving-esg-compliance/)*

A cynic might note how a tsunami of sex abuse scandals has swept away much of the Vatican's moral standing, and point to a host of other social ills perpetrated by religions across the board. But the broader point is that there are still lots of people of faith out there, and many are found in mining communities. And, as Cutifani noted, houses of faith are often the ones that speak for and lend a helping hand to the poor and the needy.

Cutifani also said "we are acutely aware of the deep and lasting effects of our history as an industry. I would even go as far as arguing that we are one of the very few industries that has had to reckon with the legacies of our past in a real and progressive way. While our progress is encouraging, we are still not where we need to be."

That almost sounds like a confession. **BM**

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Paddy Ross 7 October 2020 at 18:18 (https://www.dailymaverick.co.za/article/2020-10-07-seeing-the-light-anglo-ceo-says-industry-is-seeking-guidance-from-faith-leaders-on-social-issues/#comment-2387419)

Capitalism is essential for democracies to flourish but it should be ethical capitalism. Unfortunately, we see the blind pursuit of profit leaving those who helped to deliver that profit far behind in financial terms. Society needs to reequilibrate how capitalism operates so that society at large in its widest sense can benefit and not just a self-selecting few.

> **Sam Joubs** 7 October 2020 at 21:41 (https://www.dailymaverick.co.za/article/2020-10-07-seeing-the-light-anglo-ceo-says-industry-is-seeking-guidance-from-faith-leaders-on-social-issues/#comment-2387731)
>
> Unfortunately greed causes ethical capitalism to be a contradiction in terms.

Sam Joubs 7 October 2020 at 18:37 (https://www.dailymaverick.co.za/article/2020-10-07-seeing-the-light-anglo-ceo-says-industry-is-seeking-guidance-from-faith-leaders-on-social-issues/#comment-2387443)

Brilliant move Mark. Seek expert advice on how to control the masses from the people who invented faith and religion to control the masses.

Pieter Malan 8 October 2020 at 08:55 (https://www.dailymaverick.co.za/article/2020-10-07-seeing-the-light-anglo-ceo-says-industry-is-seeking-guidance-from-faith-leaders-on-social-issues/#comment-2388519)

A virgin can conceive. A dead body can walk again. Your leprosy can be cured. The blind can see. Nonsense. It’s not moral to lie to children. It’s not moral to lie to ignorant, uneducated people and tell them that if they only would believe nonsense, they can be saved. It’s immoral.
Christopher Hitchens

Antonette Rowland 8 October 2020 at 09:26 (https://www.dailymaverick.co.za/article/2020-10-07-seeing-the-light-anglo-ceo-says-industry-is-seeking-guidance-from-faith-leaders-on-social-issues/#comment-2388617)

Congratulations on this faith-based initiative. Yesterday I posted my own related reflection on http://www.marfam.org.za (http://www.marfam.org.za) on the subject of Hope and the need not to exclude God. With reference to the Vatican, the latest encyclical FRATELLI TUTTI issued just last week is an excellent and important reflection on current social issues that should be widely studied.

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By Ed Stoddard

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