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Understanding and Mitigating Lead Exposure In Kabwe: A One Health Approach

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LIST OF ACRONYMS

Arsenic (As)
Blood lead levels (BLLs)
Cadmium (Cd)
Copper (Cu)
Copperbelt Environment Project (CEP)
Council of Churches in Zambia (CCZ)
Country Assistance Strategy (CAS)
Disability-Adjusted Life Year (DALY)
Dry weight (dry-wt)
Environment Africa (EA)
Environmental Management Facility (EMF)
Geographical Information System (GIS)
Institute for Health Metrics and Evaluation (IHME)
Intelligence quotient (IQ)
Kabwe Mining Amelioration Initiative Project (KAMPAI)
Kabwe Municipal Council (KMC)
Lead (Pb)
Lead-Zinc (Pb-Zn)
Memorandum of Understanding (MOU)
Ministry of Mines and Minerals Developmen(MMMD)
Micrograms per deciliter (μg/dL, μg dL^{-1})
Million tonnes (Mt)
Parts per million (ppm)
Southern African Institute for Policy and Research (SAIPAR)
Sustainable Development Goals (SDG)
The Center for Disease Control and Prevention (CDC)
The World Health Organization (WHO)
United Nations (UN)
United States Environmental Protection Agency (EPA)
University of Zambia (UNZA)
Zambia Consolidated Copper Mines (ZCCM)
Zambia Environmental Management Agency (ZEMA)
Zinc (Zn)

ABSTRACT

Kabwe is a city in the Republic of Zambia that is heavily polluted with heavy metals, specifically with lead (Pb) and cadmium (Cd). For over 25 years since the closure of the mining area in 1994, Kabwe residents remain to feel the environmental, social, and biological effects of lead contamination. Several studies have been conducted—flora, fauna, soil, and blood—yet there is a lack of a systematic review summarizing such studies. This study conducted a systematic review of published quantitative research in Kabwe and investigates interventions conducted by different entities. The aim of this paper is to describe recommendations for future interventions conducted in Kabwe using a One Health approach informed by relevant Zambian development objectives.

KEY WORDS: Kabwe; lead; environment; heavy metals; One Health; 7ND

1. INTRODUCTION

1.1. Kabwe

Kabwe, the capital city of Zambia's Central Province, is located 140 kilometers north of Lusaka and has an approximate population of 220,000 residents (Carrington, 2017). It is the second largest city in Zambia has one of the largest lead and copper deposits in Africa and was once Zambia's main producer of lead and zinc. During its 90 years of operation—between 1904 and 1994—the Kabwe mine and smelter roughly produced 1.8 million tonnes of zinc (Zn) and 0.8 Mt of lead (Pb) (Nakayama et al., 2011). The deposits were discovered in 1902, and extractive operations began two years after. Upon the closure of mining operations in Kabwe, the city experienced a serious economic depression with job losses and limited economic opportunities. Diversification of the local economy rapidly declined. Subsequently, the mining site was placed under the responsibility of the Zambian government-ran mining company, The Zambian Consolidated Copper Mines known as ZCCM ("The Kabwe Mine," n.d.).

Not only did the closure of Kabwe mining operations result in an economic depression, but it also caused extensive heavy metal contamination that poisoned the environment. Anthropogenic emissions of Pb, Zn, Cd, and Cu were emitted from smelters during the 90 years of operation without proper surveillance or mitigation efforts. Mining tailing, slags, and waste were left untreated in the open vicinity, which have been tested to have a high level of heavy metals. It is estimated that during its active years, the Pb-Zn mine cumulatively affected 300,000 people (Mwandira et al., 2017). These pollutants precipitated to the ground and, as a result of lead's non-biodegradable nature, permanently contaminated the ground surface (Tembo et al., 2006). Consequently, the current source of heavy metal exposure is in the dust and impacts the daily lives of Kabwe children and adults.

1.2. Lead[1]

The identified heavy metal pollutants in Kabwe are lead, cadmium, zinc, copper, and arsenic. Of these pollutants, lead is considered among the most harmful due to its ability to sequester in the human body. Lead is a cumulative toxicant that affects multiple body systems. Lead is capable of mimicking or inhibiting the actions of calcium, which affects calcium-dependent or related processes. Lead induces the activation of protein kinase C

[1] Adapted from "Lead Toxicity: What are Possible Health Effects from Lead Exposure?" published by Agency for Toxic Substances & Disease Registry, 2019

(PKC) and binds to PKC more avidly than calcium, which is the activating chemical of PKC. Lead binding to PKC forms problems with neurotransmitter release and consequently, altes impact second-messenger systems within the cell. This may lead to changes in the gene expression and protein synthesis.

Upon entering the body, lead is distributed to the brain, liver, and kidneys. It is stored in the teeth and bones, where it accumulates over time. The lead in the bone is released into the blood during pregnancy and becomes a source of exposure to the developing fetus ("Lead poisoning and health," n.d.). In pregnant women, maternal blood lead levels (BLLs) greater than 5 micrograms per deciliter ($\mu g\ dL^{-1}$) are associated with reduced fetal growth or lower birth weight. BLLs greater than 10 $\mu g\ dL^{-1}$ are associated with decreased postnatal growth, reduced head circumference, height, or other pointers of growth. Maternal BLLs are also predictors of the risk of developing eclampsia and pre-eclampsia.

Young children under the age of 7 years old are especially vulnerable to lead poisoning because they absorb more lead in their gastrointestinal tract compared to adults (roughly four to five more times). Moreover, children are more prone to hand-to-mouth behavior that leads to the increased swallowing of lead-containing or -coated objects known as pica ("Lead poisoning and health," n.d.). Lead is also known to inhibit the growing bodies of children from properly absorbing iron, calcium, and zinc, all of which are minerals important for brain and nerve development. There is no established threshold that's considered "safe" below which there is no risk of poor developmental or intellectual function expected. Children are often asymptomatic of lead toxicity until they are in school—usually not until before secondary school as standards for academic achievement increase. Elevated bone or blood lead levels have been linked with aggression, destructive and delinquent behavior, and attention deficit hyperactivity disorder. Later on in life, effects may include ADHD, delayed learning, lower IQ, hypertension, reproductive problems, and developmental problems with their offspring (Canfield et al., 2003).

As for adults, those exposed to lead will experience the same neurological symptoms that children experience, but the effects are shown at higher blood levels. The less severe neurological and behavioral effects shown in lead-exposed workers with BLLs from 40 to 120 $\mu g\ dL^{-1}$ include mood changes, diminished cognitive performance, hand dexterity, reaction time, and visual motor performance.

There are five components that must be present in the environment to have a "completed exposure pathway." The five components are the following: (1) a source of contamination, (2) an environmental medium and transport mechanism, (3) a point of exposure, (4) route of exposure, and (5) a receptor population.

Kabwe has a complete exposure pathway since all five components are present. The abandoned Pb-Zn mine along anthropogenic emissions are the (1) source of lead contamination. The transport medium (2) are the prevailing winds that move the lead-contaminated dust from the mining tailings into neighboring townships. This lead-contaminated dust is the main point of exposure (3). The primary routes of exposure (4) in Kabwe are inhalation, consumption, or absorption. The receptive population are the local residents in Kabwe near the former mining area in Kabwe (5).

1.3. Zambian Human Development and One Health Approach

Although the lead contamination in Kabwe is more so associated with the detrimental neurodevelopment effects on children, it is also critical to address lead's effect on human development. Human development is about improving the freedoms and opportunities of a population that ultimately influences their well-being ("About Human Development," n.d.). This paper explores how lead is hindering human development in Kabwe, and how this will impact the future of Zambian prosperity. By using the objectives outlined in Zambia's Seventh National Development Plan (7NDP) and the United Nations Sustainable Development Goals (SDGs), the heavy metal pollution in Kabwe is contextualized and analyzed.

Another helpful approach for understanding the heavy metal pollution in Kabwe is by using the One Health approach. The One Health approach is an inclusive strategy that links human health, animal health, and environmental health. Due to the extensive heavy metal pollution in Kabwe, it is critical to analyze this issue using the One Health to have a comprehensive understanding.

1.4. Study Purpose

Prior to this research, there were several questions that were left unanswered:

1. After 25 years since the mine in Kabwe's closure, why is the city still extensively contaminated with heavy metals?
2. Given the extensive heavy metal pollution in Kabwe, what are essential

intervention components that must be incorporated for an effective, long-term solution?

The aim of this study was to investigate the gaps between interventions and outcomes in Kabwe with the purpose of forming a series of recommendations for future interventions. These interventions used the One Health approach informed by relevant Zambian development objectives.

2. METHODOLOGY

Our research process was threefold: (1) a systematic review on relevant studies from 2000 to 2019, (2) an assessment of past and present interventions, and (3) a set of interviews with relevant stakeholders.

2.1. Systematic review

A systematic review of a total 15 studies were assessed. Studies were chosen based on their publication year (2000-), region of study (Kabwe, Zambia), and abundance of relevant information. These studies were separated into three different study sets: soil (n=6), children (n=5), and fauna (n=4). A summary of each set of studies was produced.

2.2. Intervention assessment

Interventions were reviewed and analyzed. Interventions had to fulfill the following three criteria: (1) public health-related project, (2) initiated after 1994, the year the mining operations closed in Kabwe, and (3) a minimum of two informative sources. A total of 6 interventions were analyzed. The interventions were separated into past (n=3) and current (n=3) interventions.

2.3. Stakeholder interviews

Interviews were conducted with relevant stakeholders. Relevant stakeholders were determined based either on expertise (i.e., environmental justice, researcher, or lawyer) or previous professional involvement in Kabwe (i.e., intervention stakeholder). Interviewee participation was voluntary and anonymity was granted upon request. Stakeholders were contacted either via telephone call or email. A draft of interview questions and a consent form were made available to each confirmed interviewee. Each interviewee either signed a consent form or gave verbal consent. Interviews were conducted either in-person or over the phone and lasted approximately 45 minutes. Interviews were used as a supplement to understand the interventions in Kabwe.

3. FINDINGS

The findings in this section are twofold: the systematic review (*3.1., 3.2., 3.3.*) and intervention findings (*3.4., 3.5.*).

3.1. Soil Studies

Extensive soil studies have been conducted by researchers in the past two decades. Soil studies are the most prominent types of studies available due to the quick sampling process and ability to collect numerous samples. A total of 6 soil studies are analyzed below.

3.1.1. UNZA, Department of Chemistry (Tembo et al., 2006)

The study was published in 2006 by the University of Zambia (UNZA). The main objective of the study was to investigate the spatial distribution of four heavy metals (Cd, Cu, Pb, and Zn) in the northern, southern, eastern, and western wind directions of the closed Kabwe mine. Soil samples were collected from random locations up to 20 km in the four wind directions. A series of control samples were used as reference.

The main finding of the study was that the western direction of the mine had the most lead contaminated soil (*Appendix Table 1*). There were also significant differences in relation to the distance from the mine, specifically 0 to 5 km from the mine. The distribution of lead and zinc in the eastern and northern directions differed greatly. The average concentration of lead in the northern soil at 5 km distance from the mine was 30.3 mg Pb kg^{-1} while for the eastern direction it was 110.0 mg Pb kg^{-1}. The study concluded that the source of heavy metal contamination is the mine, and that the pollutant precipitate to the ground.

3.1.2. Hokkaido University-UNZA (Ikenaka et al., 2010)

The study was conducted primarily by the Japanese institution, Hokkaido University, in collaboration with UNZA. The study investigated heavy metal distribution throughout Zambia by analyzing road soil and sediments. A total of 47 samples were collected; 3 samples were from Kabwe. Cluster analyses were conducted in which three clusters were produced: Cluster 1, Cluster 2, and Cluster 3. Kabwe samples were all in Cluster 1.

The study found that Cluster 1 had high ratios of Zn (57%) and Pb (32%). It was also determined Cluster 1 had significantly higher concentrations of Zn, As, Cd, and Pb than other clusters. The max values of Cd and As in Kabwe were 18.7 and 51.5 mg kg^{-1} dry-wt, respectively, which were both above their "trigger" values of 3.0 (Cd) and 10 mg kg^{-1} (As). The study concluded that heavy metal pollution in Zambia has great regional differences, and identifying Kabwe's heavy metal pollution as a public health risk

3.1.3. Hokkaido University-UNZA (Nakayama et al., 2011)

The study was conducted by the Hokkaido University in collaboration with UNZA. The objective of the study was to investigate the relationship between Pb accumulation in Kabwe wild rats (*Rattus sp.*) and the heavy metal soil contamination. The study used a Geographical Information System (GIS) to determine the source of soil contamination in Kabwe. Three different sites were used to collected soil samples: Kabwe (n=101), Mwangule (n=3), and Lusaka (n=7).

The results demonstrated that Kabwe had the highest average of the three sampled sites. The average Pb in Kabwe soil was found to be 282 mg Pb kg^{-1}, which was 10 times the average Pb found in Lusaka soil (26 mg Pb kg^{-1}) and above the U.S. benchmark of 120 mg Pb kg^{-1}. The max Pb concentration in the soil was 51,188 mg Pb kg^{-1}. In Kabwe, there was a positive correlation between soil organic matter and heavy metals in the soil (*Appendix, Table 1*).The study also concluded that the area south of the Pb-Zn mine had the highest heavy metal concentrations in Kabwe, which differed from the findings in Tembo et al. (2016).

3.1.4. Czech Geological Survey-UNZA (Majer et al., 2011)

The study was conducted by the Czech Geological Survey with UNZA School of Mines to determine the extent and intensity of the soil contamination in Kabwe, as well as the gastric availability of heavy metals and plant-available metals in the topsoil.

Majer et al. (2011) concluded that topsoil lead contamination was as high as 4%, while copper was 0.7% and zinc was 6.7%. The high level of heavy metals in the topsoil were predominantly found in the industrial zone near the former smelter. The results for gastric availability of metals in the dust revealed that Pb and Cd posed the greatest environmental hazard when dust particles are swallowed as a result of consuming unwashed foods. The results for the availability of metals in the soil for plant metabolism showed that lead and cadmium were very bioavailable for plants, which is an unfavorable result for agricultural practices.

The counter map (*Appendix, Image 2)* illustrates of lead contamination in the Kabwe area reference to the Pb-Zn smelter. It is visible that as the distance from the mine increases, lead levels in the topsoil decreases.

3.1.5. Pure Earth/BlackSmith Institute (Caravanos et al., 2014)

The first study that was analyzed was the Pure Earth/BlackSmith Institute study published by Dr. Jack Caravanos (New York University) in the CDC's Mortality and Morbidity Weekly Report (MMWR). The study was conducted as part of Pure Earth/BlackSmith Institute's continuous efforts to reduce lead exposure in Kabwe (reference *3.4. Past Interventions*). Caravanos investigated the soil contamination. The study sampled 339 locations in Kabwe residential areas.

The extent of lead soil contamination ranged from 139 mg Pb kg^{-1} to 62,142 mg Pb kg^{-1}, with a GM of 1,470 mg Pb kg^{-1}. Of the sampled soils, 98% were above the Zambian benchmark of 200 mg Pb kg^{-1}.

3.1.1.6. Czech Geological Survey-UNZA (Kříbek et al., 2019)

The study was headed by the Czech Geological Survey in collaboration with UNZA. The objective of the study was to analyze and determine the content of heavy metals in the topsoil (0-3 cm depth, n =116) and subsurface soil (70-90 cm depth, n = 40).

The study found that the median percentile of Pb in the topsoil (199 mg Pb kg^{-1}) was 7 times that of the subsurface soil (28 mg Pb kg^{-1}). The highest Pb and Zn concentrations were found in the topsoil near the former Pb-Zn mine, which may be due to dust fallout or tailing ponds.

3.2. Children Studies

As previously stated, children are the most vulnerable population in regards to lead exposure. This is due to their hand-to-mouth behaviors, readily absorption of lead by the gastrointestinal tract, and short height. Not to mention, children are actively developing physically, mentally, and emotionally; thus, lead exposure leads to directly impacts each of these developmental components. Due to the abundance of studies on children's blood lead levels, we analyzed five published studies and produced key conclusions.

3.2.1. PureEarth/BlackSmith Institute (Caravanos et al., 2014)

Pure Earth/BlackSmith Institute, under the guidance of Dr. Jack Caravanos (New York University), investigated the soil contamination. This was part of Pure Earth/Blacksmith Institute's continuous efforts in Kabwe (reference *3.4.3.*). The study sampled 339 locations in Kabwe residential areas. Caravanos sampled children ages 2 to 8 years old in six communities near the Kabwe mines and smelters, which have been previously established to have the highest concentrations of heavy metals (Sim 2014).

Caravanos et al. (2014) revealed that all of the children sampled were above the CDC's reference level of 5 μg Pb dL^{-1}. Moreover, the study revealed that over 98 children had BLLs at or above the reference level for medical intervention, 45 μg Pb dL^{-1} (*Appendix, Table 2*). 26.5% of the children sampled in this study were also over 65 μg Pb dL^{-1}.

3.2.2. UNZA-Hokkaido University (Yabe et al., 2015)

In a joint partnership study between UNZA and Hokkaido University, researchers analyzed the BLLs of 246 children from three different townships in Kabwe: Chowa (17), Kasanda (100), and Makululu (129). The objectives of the study was to determine the BLLs of children under the age of 7 near the former Pb-Zn mine and to identify children who required medical intervention (≥ 45 μg Pb dL^{-1}).

The study concluded that of the 246 children sampled, all had above the 5 μg Pb dL^{-1} reference level. More than 50% (161 out of 246) of the children sampled required medical attention (*Appendix, Table 2*). The study also revealed that younger children (0 to 3 years old) had higher BLLs than older children (4 to 7 years old) in both Kasanda and Makululu townships. BLLs in the Kasanda township were higher than those in Makululu. It is also important to note that one child in Kasanda had a significantly high BLL of 427.8 μg Pb dL^{-1} which was 5 times the average BLL sampled in the township. Similarly, a child in Makululu had a BLL of 388.7 μg Pb dL^{-1}, 6 times the average BLL sampled in Makululu.

3.2.3. UNZA-METS Study (Mbewe et al., 2015)

This study was a cross-sectional study by the University of Zambia (UNZA) using the 2015 data produced by the Misenge Environmental and Technical Services Ltd (METS). METS analyzed the BLLs of children in the Makululu township within four zones: Zambezi, Moomba, Makululu, and Chililalila. Makululu township was the area of interest due to its impact by the prevailing westerly winds that blow from the lead mine to the township. The study investigated 1,166 children under the age of 8 years old. This study used a reference level of 10 μg Pb dL^{-1} to determine "at-risk" children, and a BLL of 25 μg Pb dL^{-1} to determine the need of chelation therapy.

One of the main findings in this study was that with every 1 year decrease in age, there was a BLL increase by 0.45%. The studied revealed that 99% (1,159 of 1,166) of sampled children were “at-risk” and 73% (853 of 1,166) needed to begin chelation therapy (*Appendix, Table 3*). According to Mbewe et al., their findings were similar to that of a 2006 study by the Pure Earth/Blacksmith Institute. Thus, they concluded there have been no improvements in the BLLs of Kabwe children during those nine years.

3.2.4. UNZA-Hokkaido University (Yabe et al., 2018)
The study is a follow-up to the 2015 study by UNZA and Hokkaido University (reference *3.2.2.*). Using the known BLLs of children determined by the previous study, this study investigated lead concentrations in the urine (Pb-U) and fecal (Pb-F) of the same sampled children (*Appendix, Table 4*). The study sampled children who were 7 years old or younger and lived in the community for at least one year. There were a total of 190 children sampled from three different townships: Chowa (8), Kasanda (88), and Makululu (94).

The study revealed that lead in the blood, urine, and feces of children were positively correlated with all children presenting alarming concentrations of lead. The Kasanda township had children with higher fecal (GM = 90.6 mg Pb kg^{-1}) and urinary Pb (GM = 207 μg Pb L^{-1}) than those in Makululu. Cadmium levels were also analyzed and were highly concentrated in children. The study proved that urine and fecal samples are alternative to examine lead exposure in Kabwe children as opposed to blood testing which is more invasive.

3.2.5. Kabwe Scoping and Design Study (KSDS) - Copperbelt Environment Project (CEP)
The Kabwe Scoping and Design Study was the research component of the Copperbelt Environment Project (reference *3.4.1.*). This study sampled 2,500 Kabwe residents, including both children and adults (Bose-O’Reilly et al., 2018). The objective of the study was to investigate the BLLs of residents and determine ZCCM Investment Holdings PLC’s liability (Lacey 2016).

The results of the study showed that almost all children were above the 5 μg Pb dL^{-1} reference level. Children ages 0 to 7 years old had elevated BLLs (*Appendix, Table 5*). Children’s BLLs were higher if their residence was close to the mine. It was also concluded that Investment Holdings was liable for the impact of lead on Kabwe residents.

3.3. Fauna Studies

Apart from studies on Kabwe residents and soil, researchers have also studied the region’s fauna, or animals. By analyzing the health of animals, there is a more comprehensive understanding of the heavy metal contamination in Kabwe. Animal health is one of the three main components of the One Health concept that allows a more nuanced understanding of a region's health status. A summary of the fauna studies can be found in Table 6 (*Appendix*).

3.3.1. Hokkaido University-UNZA (Nakayama et al., 2011)
This study was headed by Hokkaido University with UNZA to determine the relationship between heavy metal contamination in the Kabwe soil and wild rats (*Rattus* sp.). There were 32 Kabwe wild rats sampled and compared to 20 Lusaka rats.

The main results of the study were that Kabwe rats had, on average, more Pb in their tissues than Lusaka wild rats. The average Kabwe rat's kidney had 2.2 mg Pb kg^{-1} which was 11x that found in the average Lusaka rat's kidney. The study also determined that Kabwe rats had a lower body rate than Lusaka rats, yet it was unclear if lead contamination was the cause. The study also found data on soil contamination (reference *3.1.3.*).

3.3.2. UNZA-Hokkaido University (Yabe et al., 2011)
The study was conducted by the Department of Veterinary Medicine at UNZA and Hokkaido University with the objective of investigating the level of heavy metals in the offal of cattle. Cattle samples were collected from different slaughterhouses in Zambia: Kapiri Mposhi, Chibombo, Mazabuka, and Siavonga. A total of 51 samples (e.g., livers, kidneys) were collected.

The main result of the study was that cattle near the Pb-Zn mine in Kabwe accumulate more heavy metals than cattle relative to other Zambian towns, specifically Pb and Cd. Mean level of Pb in the liver of Kabwe cattle was determined to be 0.42 mg Pb kg^{-1} (dry-wt). Cd was elevelated in the kidneys of Kabwe cattle with an average of 5.05 mg Cd kg^{-1} (dry-wt), which exceeded the 4.65 mg Cd kg^{-1} benchmark. There were no signs of metal toxicity in the cattle; however, Kabwe residents are at-risk of heavy metal exposure via cattle consumption.

3.3.3. Hokkaido University (Ikenaka et al., 2012)
The study was headed by Hokkaido University in collaboration with Dr. John Yabe (UNZA). The purpose of the study was to investigate the accumulated levels of toxic metals and their effects on metal-responsive proteins and cytokines (cellular-level effects) in cattle. The study sampled the peripheral blood (30-50 mL) of 12 female cows living around the Pb-Zn mine in Kabwe.

The main result of this study was the determination of more Pb and Cd in the peripheral blood of Kabwe cattle than in that of Lusaka cattle. There was also a strong correlation between Pb and Cd accumulation in cattle blood. Due to the average Pb in Kabwe cattle blood (90.6+/-67.6 μg Pb kg^{-1} dry-wt), the cattle may have toxicological effects. The study also revealed that Pb caused several alterations in the cellular-level of cattle: induction of mRNA expression (MT-2, iNOS, TNF-alpha, and IL-1 beta) and suppression of INF-gamma. All of these cellular-level components play a role in a cattle's immune response, specifically inflammatory responses.

3.3.4. UNZA-Hokkaido University (Yabe et al., 2013)
The study was conducted by UNZA with Hokkaido University. The study investigated the heavy metal contamination in the free-range chicken ("village chicken") of Kabwe. The total sample size were 17 free-range chickens and 32 liver samples from broiler chickens that were kept indoors and commercially fed.

The results of the study showed that the edible organs of free-range chickens had higher levels of Pb and Cd than the broiler chickens. The following are the average Pb found in free-range chicken organs: 4.15 mg kg^{-1} in the liver, 7.62 mg kg^{-1} in the kidneys, and 3.34 mg kg^{-1} in the lungs. All of these averages exceed the benchmark for consumption of lead in chicken offal, 0.5 mg Pb kg^{-1}. Similarly, the average levels of Cd in liver and kidneys exceeded the max value of 1.0 mg Cd kg^{-1}.

3.4. Past Interventions

3.4.1. Copperbelt Environment Project (CEP)[2]
The Copperbelt Environment Project (CEP) was financed by the World Bank for 53.1 million USD and implemented by the Republic of Zambia from 2003 to 2011. The project's main objectives were the following:

1. Address environmental liabilities and obligations associated with the mining sector, following the privatization of the mining assets of ZCCM; and
2. Strengthen the capacity of its environmental regulatory institutions to improve future-compliance of the mining sector with environmental and social regulations.

These objectives were extremely relevant at its appraisal because the project's design was the first of its kind in the African continent. The theme in the World Bank's 2000-

[2] Adapted from "IMPLEMENTATION COMPLETION AND RESULTS REPORT" published by (WHO, 2011)

2003 Country Assistance Strategy (CAS) for Zambia was to aid in the country's diversified and sustainable growth. CAS selected the Copperbelt Environment Project to address the environmental liabilities that was associated with the privatization of ZCCM assets. Along with attempting to mitigate ZCCM's adverse environmental past, CEP was designed to support the government's efforts in preventing new environmental liabilities as a result of new mining activities or mine closures in the case of unprecedented events.

The objectives were supported by two components:

i. The establishment of an Environmental Management Facility (EMF) for addressing historical environmental liabilities; and
ii. Strengthening of the environmental regulatory and institutional frameworks for preventing future liabilities related to mining.

The first component was estimated at 37.5 million USD. The EMF was expected to support the first object by financing and administering the implementation of priority measures to remedy environmental and social problems that came from ZCCM's pre-privatization mining operations, on behalf of ZCCM-IH and the government. The EMF was structured to finance subprojects in Kabwe (i.e., treatment of lead-exposed children and lead remediation in several environments). A Consolidated Environmental Management Plan (CEMP) was planned for preparation to identify funding priorities and provide criteria for selecting priority subprojects in Kabwe as well as the Copperbelt. The Kabwe Scoping and Design Study (KSDS) had the intention of providing the analytical basis for prioritizing subprojects, based on the severity of the public health and ecological impacts of the problems that were planned to be addressed. Component two was the strengthening of the environmental regulatory framework which used 4.2 million USD. This component was to support part (ii) of the objectives, strengthening the environmental regulatory and institutional frameworks, as a way to assist the government in addressing mining companies' compliance with national environmental and social safeguards. This was planned to be achieved by assigning more resources to the Environmental Council of Zambia's (known now as ZEMA) regulatory mandate, strengthening ECZ capacity, agency review of the Environmental Impact Assessments (EIAs), and more.

When this initiative was appraised, the government was apprehensive because the possibility of environmental liabilities from historic mining operations would discourage private mining companies from investing in the country. The Bank was a primary force behind the privatization of ZCCM's copper mines, so it would be sensible for the Bank to support the government in addressing the accumulated negative consequences of the past's mining and poor environmental practices on the environment, future investments, and public health.

The prime beneficiaries of this project were expected to be the people living in the mining communities within the five Copperbelt towns and Kabwe. The citizens of Zambia were also beneficiaries on account of there being a more robust economic position that would follow the removal of burdens to new private investments in the mining sector. The next set of predicted beneficiaries would be the Environmental Council of Zambia (currently ZEMA) and the Mines Services Department (MDS) in the Ministry of Mines and Minerals Development (MMMD). This prediction was based on improved regulatory capacity. The last set of beneficiaries would be NGOs, University of Zambia, Copperbelt University, and others. They would play a part in the contribution of strengthening national environmental management capacity through their role in consultancies, studies, and training.

In regards to outcomes, the project's objectives were met; however, there were shortcomings in timeliness and the scope of its outcomes. The most significant achievement was that the project led the government to adopt a long-term, systematic, and risk-based approach to environmental management planning. Concerning the first objective, 15 investor and 12 Counterpart Environmental Management Plans (EMPs) were created and defined the government's, ZCCM's, and private investors' responsibilities for each mining operation. This was the starting point for attacking the adverse environmental legacy and provided a baseline for the management and regulation of environmental and social issues. The approval of the CEMP was a critical milestone in the mitigation and prevention of mining related adverse environmental impacts. Despite the planning of the objectives, the remediation efforts were greatly underestimated. The project did manage to reduce exposure to health hazards.

Exposure was greatly reduced through the removal and proper disposal of hazardous materials from the mine sites, which includes 56,000 m^3 of lead contaminated soils in Copperbelt and Kabwe. There was also large-scale demolition, cleanup, and revegetation efforts. Lastly, there were four tailing dams and two overburden dumps that have been repaired, reducing the possibility of health and environmental risks. Part of the plan was to close 13 tailing dams, but that did not occur. Another outcome was a large number of children getting healthier as a result of lead treatment. Through KSDS's data, the project was able to finance a comprehensive set of activities to reduce the high BLLs in children living in close proximity to the smelter. The project assisted the Integrated Case

Management (ICM) program, which provided specialized care through a multifaceted team encompassing of a physician, sociologist, nurse, community volunteers, environmental technical specialist and caregivers. 2,822 out of the 5,000 children tested had a reduction of roughly 20 to 25 percent due to treatment with nutritional supplements (BLLs 20 to 64 μg Pb dL^{-1}) and by up to 74 percent for chelation treatment (BLLs beyond 65 μg Pb dL^{-1}).

There were efforts to prevent recontamination of treated children and the contamination of newly born children. The project did this by providing access to safe drinking water in 2005 to 2006 to about 99,000 Kabwe residents, or more than half of the Kabwe population. The lowered exposure of lead-containing dust through adequate hygiene included vegetable and hand washing. This also led to a drastic decrease in the number of cholera cases in Kabwe. The risk of exposure due to flood for 40 families living along the Kabwe Canal to lead-contaminated water was reduced because of the dredging, removal, and disposal of 56,000 m^3 of lead-contaminated material. The risk returned due to the lack of proper canal maintenance by the Kabwe Municipal Council. The removal of topsoil and greening of 3,100 household yards and 30 schools, and creating 11 play parks has reduced the exposure to lead-containing dust. Although 9 out of the 11 play parks have been vandalized, these green spaces still provide a space for children to play instead of in lead contaminated areas. There was also community outreach that consisted of lead risk awareness campaigns, the creation of two Environmental Public Information Centers (EPICs) and the rehabilitation of the Kabwe Public Library. Activities ran through the EPICs stopped at the end of the program due to lack of funding.

Through the project's prioritization of the second component, ECZ (ZEMA) became stronger, which is seen through the use of litigation to enforce compliance and its ability to temporarily shut down polluting mining facilities. There also was a strengthened relationship and revised Memorandum of Understanding between ECZ and the Mines Safety Department (MSD). ECZ also has a monitoring system in order to monitor the EMP's compliance with statutory limits. Due to the lack of funding from the Nordic Development Fund, the monitoring program was not fully implemented, and the collection of monitoring data is limited.

Overall, the outcome of the project was moderately satisfactory. There were three main downfalls to the project and one being the lack of funding:

1. Activities were unable to continue due to lack of funding;
2. The privatization of 13 tailing dams led to lack of regular inspection and monitoring of the sites; and
3. There was a need for the mining communities to become more involved in the decision-making.

The government's performance was unsatisfactory because of its inability to keep individual mining companies accountable for their lack of full compliance with environmental standards.

3.4.2. Pure Earth - Kabwe Environmental and Rehabilitation Foundation (KERF)[3]

The Kabwe Environmental and Rehabilitation Foundation (KERF) was an NGO founded by Pure Earth/Blacksmith Institute. KERF conducted mitigation efforts from 2003 to 2011. The objective of the NGO was to create enough leverage that would encourage the government to adopt an efficient environmental remediation plan in Kabwe. This goal was to relevant research in Kabwe assessing the lead contamination, as well as improving public awareness in order to end future contamination.

After receiving grants from the Global Greengrants Fund in 2002 and 2003, their efforts were noticed in April 2003 by the World Bank. The World Bank approved of a 40 million USD loan to ZCCM that provided the majority of funding for the Copperbelt Environment Project (CEP). Roughly 15 million USD of this loan was used in Kabwe. KERF's role in CEP was to research lead poisoning and educate the residents about exposure pathways. In 2003, KERF began educational outreach to inform the public about behavioral and hygiene practices to reduce their risk of lead exposure (Environmental Rehabilitation Foundation, n.d.). A cleanup of the highest threat level contaminated soil, including a contaminated canal and a number of toxic hotspots in neighborhoods, was also carried out throughout the city. For example, the township of Katondo, which is adjacent to a canal that previously carried toxic waste from the lead mine pits, was cleaned. During the rainy season in 2002, the canal flooded and years of toxic waste, silt, and rubbish polluted the neighborhoods. They also planned to cover Kabwe's mine dumps with vegetation or capping areas with concrete in order to prevent lead dust from blowing around. Despite KERF's efforts, the site still posed an acute health risk that requires further work.

[3] Adapted from "Zambia (Kabwe) – Environmental Rehabilitation Foundation" published by (Pure Earth, n.d.)

3.4.3. Pure Earth – Pilot Lead Remediation Project (Phase 1)[4]

The Pilot Lead Remediation Project led by Pure Earth/Blacksmith Institute was divided into two phases. The first phase began in August 2015 and was concluded on December 2015. The cost of this project was 115,000 USD, and the funding entities were terre des hommes, Marilyn S. Broad, Foundation Beyond Belief, International Foundation, and private donors. The main project partners were Environment Africa (EA) and the Kabwe Municipal Council (KMC).

The project had six main components:

i. Detailed environmental assessment;
ii. Community health education;
iii. Improvement of drainage;
iv. Yard remediation and lead encapsulation;
v. Home cleaning; and
vi. Quality control and follow-up.

The project started off with an environmental assessment of 250 homes to identify residential areas with high lead levels in the soil (Eriscon and Dowling, 2016). This group of homes was chosen due to its close proximity to the mine, as well as previous investigation testing results in the soil and BLLs. The environmental assessment revealed severely elevated lead contamination in the town of Chowa. The soil lead concentrations were highest along the northern border of the neighborhood adjacent to a large drainage canal. This canal is known to flood during heavy rains when it has not been properly maintained. The lowest concentrations were in the southeast direction of the neighborhood and that section was the furthest from the canal and mine. In addition to soil testing, three municipal water samples were collected. Lead was not detectable in all the water samples, therefore water was not a significant pathway.

Staff from EA and KMC were trained by Pure Earth on how to inform residents on the health effects of lead and lead exposure reduction methods. A total of 180 homes (within the overall project area and surrounding regions) were selected to attend one of three full day health workshops. Along with the workshops, a door-to-door campaign was conducted to allow residents to feel more comfortable with asking questions.

Project components three and four were grouped together in the planning process. The first work step was to improve the drainage system. It was necessary to ensure

[4] Adapted from “Project Completion Report” published by (Pure Earth, 2016)

remediation measures were sustainable in order to prevent erosion and recontamination of remediated areas caused by flooding. The KMC Engineering team worked through September and October to clean drainage canals in the roads while laborers hired by the Kabwe Municipal Council performed all drainage clearance activities. The drainage canal abutting the project area was cleared to ensure that storm runoff would flow and flooding of neighborhoods would be prevented.

78 of the 180 homes (that attended health workshops) were selected for Phase 1 of remediation efforts, which consisted of encapsulation and cleaning in late 2015. These homes were located in a rectangle area that comprised of four roads: Sturgeon, Moskwa, Kasaba, and the adjoining section of Chowa Road. The remainder of the homes were proposed for the same in Phase II in 2016. Distinctive remediation plans were established for yards of each home based on the layout of the yard, the location of outbuildings (chicken coops for example), future gardens, and mature shrubs and trees. Each yard was encapsulated using an amalgamation of barrier cloth and clean soil, freshly planted grass, gravel, and/or stone with the homeowner's input and consent. The planning process ended with the construction of adequate drainage ditches, cement pads, and vegetable gardens. The plan was put to action at the end of October of 2015, after bordering canals were cleared.

The fifth component was the cleanup of the 78 homes. Homes were cleaned with a vacuum that contained a high-efficiency particulate air (HEPA) filter, soap, and water. HEPA is an air filter that removes at least 99.97% of particles whose diameter is greater than or equal to 0.3 micrometer. Cleaning was done after the yard remediation to prevent the re-introduction of lead dust in homes.

The last component was monitoring and evaluation to see if the soil lead concentrations would drop. A follow-up team would spot check each yard to ensure quality control after all remediation and cleaning efforts were done. Prior to the project, levels measured in the 78 homes were as high as 24,000 parts per million (ppm) but were generally between 2,000 and 4,000 ppm. The lead levels greatly exceeded the USEPA standard for lead in residential soil, which is 400 ppm. At the end of the project, all 78 homes had soil concentration below the USEPA standard.

3.5. Current Interventions

This section explores the current interventions in Kabwe, Zambia. The interventions below may not be reflective of all the current interventions being carried out in Kabwe;

however, they were selected either due to (1) sufficient online publications and/or (2) relevance to the environmental pollution in Kabwe.

3.5.1. Kabwe Mine Amelioration Initiative Project (KAMAIP)
The Kabwe Mine Amelioration Initiative Project (KAMAIP) began in May 2016 and is expected to end in May 2021. KAMAIP is a collaborative project between Zambia's Ministry of Higher Education, the School of Veterinary Medicine at UNZA, the Japanese International Cooperation Agency (JICA), and other Japanese entities ("SATREPS KAMPAI Project - JICA," n.d.). KAMAIP is currently using a "multidisciplinary approach" that generally can be summarized into two parts: qualitative research and sustainable development ("Visualization of Impact of Chronic," n.d.).

KAMAIP's objectives are to reduce the impacts of Pb contamination in Kabwe by achieving the following:

- Identify the contamination pathways (ecosystems, humans, and animals);
- Quantitatively assess the Pb contamination in animals and humans;
- Establish and apply environmental remediation technology; and
- Create a sustainable monitoring system through capacity-building.

The project aims to fulfill its objectives by carrying out surveys, analyzing satellite data, and conducting trials. According to Mr. Hidenobu Sobashum, Japanese Ambassador to the Republic of Zambia, Japan is striving to remediate the environmental issues in Kabwe and continue with sustainable development, as Japan has. There are a variety of subprojects under KAMPAI that are reported via photo albums under the KAMPAI webpage.

3.5.2. Urban Sanitation and Hygiene for Health and Development (USHHD)
The Urban Sanitation and Hygiene for Health and Development (USHHD) is a project headed by the Dutch non-governmental organization, SNV Netherlands Development, funded by the Dutch Government. The project began in July 2017 with the closing date of September 2022. It is estimated to cost $4.5 million USD ("Zambia: Kabwe get a €4 Million boost for Sanitation and Hygiene," n.d.). The objective of the project is to improve the overall usage of sanitation facilities, while simultaneously addressing social factors like gender dynamics ("Urban Sanitation & Hygiene for Health and Development," n.d.). Mbala, Mpulungu, Kasama, and Nakonde are the specific residential areas where the implemented project is being carried out. There are a series of components USHHD approaches this project; however, the most important is the method of building and strengthening capacities to influence sanitation behavior

change.

3.5.3. Zambia Mining and Environmental Remediation and Improvement Project (ZMERIP)[5]

The project with the most predicted funds is the Zambia Mining and Environmental Remediation and Improvement Project (ZMERIP) with $65.6 million USD financed by the World Bank. The project was initiated in 2016 and is expected to be completed in 2022. The objective of ZMERIP is to reduce the environmental health risks of the local populations in mining areas of Zambia, specifically in Chingola, Kitwe, Mufulira, and Kabwe. Several studies—a few of which have been reviewed in this paper—have influenced the government's decision to pursue cost-heavy and elaborate projects in Kabwe. Due to a 2015 study, it was revealed that interventions in Kabwe have not been successful in the past 5 years.

There are four (4) detailed components of ZMERIP and their corresponding funding are shown below:

- Component 1: Remediation and environmental governance strengthening of the mining sector (25 million USD);
- Component 2: Enhancing institutional capacity to strengthen environmental governance and compliance (10 million USD);
- Component 3: Reducing environmental health risks through localized interventions (12 million); and
- Component 4: Project management, monitoring, and evaluation (3 million USD).

Moreover, since ZMERIP is not only implemented in Kabwe, there is a need to highlight Kabwe-specific initiatives. According to Zambia's Ministry of Mines and Mineral Development, the exclusive Kabwe initiatives include the following: remediation of lead-polluted areas, improvement of lead-screening, intervention and treatment of residents, assessment studies, and the construction of a canal. Note: this does not imply that other initiatives are not planned.

A project objective is to enhance the environmental governance of Zambian institutions, specifically the Ministry of Mines, Mines Safety Department (MSD), Zambia Environmental Management Agency (ZEMA), the Radiation Protection Authority (RPA) and Municipal Councils (including the Kabwe Municipal Council). Per ZEMA's Term of Reference, the institution will "develop a robust information management system" to

[5] Adapted from "Zambia Mining and Environmental Remediation and Improvement Project (ZMERIP) published by (Ministry of Mines and Minerals Development, n.d.)

improve efficiency, revenue, and store information ("Expression of Interest," n.d.). One of the modules of the Continuous Environmental Monitoring System is regarding public concerns and an environmental emergencies registrar that will be used as an information database.

Per a recent budgeting document released by the World Bank, there was a total of $565,872.21 USD approved that included soil programs in Kankoyo, consultancy services for environmental frameworks, vehicle purchases, and rehabilitation of offices.

4. DISCUSSION

4.1. QUALITATIVE STUDIES

Each set of studies (soil, fauna, children studies) provided sufficient qualitative evidence that should be used to primarily inform (1) the Zambian public, specifically the Kabwe population, and (2) relevant governmental Zambian agencies (ZEMA, Ministry of Health, Ministry of Mines and Minerals Department). Such studies have prompted the Zambian Government to carry out two major interventions known as CEP (reference *3.4.1.*) and ZMERIP (reference *3.5.3.*).

The main findings of the studies reviewed in this paper are the following:

- The source of heavy metal contamination in Kabwe is the former Pb-Zn mine and smelters;
- Lead-contaminated dust precipitates to different areas in Kabwe;
- There is a negative correlation between lead concentration and the distance from the Pb-Zn mine;
- The west and south of the Pb-Zn mine have the highest Pb concentrations due to the prevailing winds;
- Kabwe's topsoil (0-3 cm) is more contaminated with Pb;
- Lead and cadmium are readily accessible in the soil which are absorbed by plants for metabolism;
- Younger children (below 4 years old) have higher BLLs than older children;
- Children with elevated BLLs are commonly asymptomatic;
- On average, Kabwe children are above the 5 μg Pb dL^{-1} reference level;
- Children who live closer to the Pb-Zn mine have a higher BLL;
- Wild rats, free-range chickens, and cattle near the mine are contaminated with lead; and
- Lead produces cellular-level alteration to cattle.

Kabwe's environmental health is the current source of lead contamination, specifically the lead-contaminated soil in the mine tailings that are blown by wind onto nearby townships. Consequently, this contaminated dust is in all areas of the community: homes, school grounds, unpaved roads, and markets. Due to pica, stature, and intestinal absorption, young children are the most vulnerable population. While interacting with lead-contaminated dust, children intake lead and cadmium either through inhalation or ingestion. It is important to note that young children with high BLLs are typically asymptomatic, or they do not demonstrate symptoms of lead poisoning. However, one study noted anemia, small stature, and weakness in some sampled children from Kabwe (Yabe et al., 2015). Although children are the most vulnerable population in Kabwe, adults are similarly being exposed to high levels of lead. Since lead and cadmium are found in dust particles, adults may be directly ingesting dust on unwashed foods like fruits or vegetables. Thus, the human health system is being impacted by the environmental health system. Free-range chickens ("village chickens") are left to scavenge in open areas where they ingest dirt that is heavily contaminated with lead. Since such chickens are a cost-effective source of protein for residents in Kabwe, humans are exposed to high levels of lead via consuming chicken offal. Cattle offal are also contaminated with lead and are a lead exposure pathway. Thus, the animal health system is impacted by the environmental system and influences the human health system.

4.2. INTERVENTIONS

The series of interventions, both past and present, allows us to conclude that the studies conducted on Kabwe are promoting action among the Zambian government and relevant independent organizations. The interventions investigated in this paper (reference *3.4* and *3.5*), were carried out by both public and private entities; however, there remains a need to critically analyze the effectiveness, sustainability, and community engagement of such interventions.

4.2.1. Collaborations and holistic approaches

Different stakeholders have the responsibility to not produce a burden—whether environmental, social, or economic—on local residents. Thus, collaborations between different organizations prevents such burdens. Collaborations also allow different stakeholders to use a multidisciplinary approach when implementing interventions. The Pure Earth/Blacksmith Institute Pilot Lead Remediation Project (2015) exemplifies how collaborations between different organizations allows a multidisciplinary approach in addressing the issue in Kabwe. Environment Africa (EA) and the Kabwe Municipal Council (KCM) had clear and defined roles that allowed for the completion of different subprojects under the Pilot Lead Remediation Project. Due to EA's expertise in environment, health, and nutritional education, the EA was responsible for educating Kabwe communities. KMC was responsible for urban planning and the engineering of clearing drainage canals. Although EA and KMC were specialized in different sectors, this collaboration allowed Pure Earth/Blacksmith Institute to address distinct issues that ultimately impacted the same population.

Currently, the KAMPAI and ZMERIP are collaborating to share information, identify BLLs in children, and assess treatment. According to J. Yabe, "[KAMPAI and ZMERIP] have signed an MOU between the two projects to collaborate and share information such that we don't over-stress the community."[6] This collaboration also exemplifies how the University of Zambia, the World Bank, and JICA attempt to implement interventions without producing more burdens on local residents.

4.2.2. Systems strengthening and capacity building

A progressive part of the Copperbelt Environment Project (CEP) was that a main target in their design was to improve future compliance of the mining sector with environmental and social regulations. CEP's objective showed that there was concern for future environmental liabilities that derive from mining. Many of the interventions lacked this pertinent objective, and only concentrated on dealing with the Kabwe mine. Leaving regulations for current and future liabilities out of the plan may lead to future complications. The absence of attention to the mining compliance to safeguards will perpetuate the cycle of failed attempts to treat the problems that arise instead of prevention measures.

4.2.3. Lack of budget and progress reports

Most interventions analyzed did not have available reports online. The few interventions that had available budget reports were those financed by the World Bank (CEP and ZMERIP). Public interventions—those headed by the Zambian Government—should be publishing detailed and updated budget reports to inform the citizens where public funds are being invested in. The publication of such reports would also give insight into which components are being heavily funded and prioritized. Similarly, progress reports detailing the accomplishments of subprojects are needed. Reports should include the project's objectives and elaborate whether these objectives are being fulfilled with sufficient reasoning.

[6] J. Yabe, Research Manager at KAMPAI, Senior Lecturer at the School of Veterinary Medicine (UNZA); taken from an interview conducted on July 22, 2019

4.2.4. Lack of community participation

A common flaw in past and current interventions is the lack of community participation. By implementing or planning projects that do not actively involve the community, the project becomes is likely to be less impactful and ineffective. Those directly affected the heavy metal pollution in Kabwe need to be incorporated in the planning and implementation process. CEP was particularly criticized for its lack of community engagement. According to a third party reviewer, CEP did have community consultation services yet there should have been a "greater involvement of mining communities in the project decision-making processes" (Zambia Copperbelt Environment Project Review, 2012). The third party reviewer explains how this lack of community engagement led to unsustainability. Consultation services are also a component in ZMERIP; however, the most recent budget publication revealed that this component has not yet been funded (Ndalama, G., 2019). It remains unclear of other community engagement efforts by ZMERIP.

4.2.5. Lack of remediation efforts

The source of lead contamination continues to be the dust fallout in Kabwe which is brought from the tailing dams to surrounding areas. Several interventions do not address how to remediate the soil rather their is a focus on lead treatment or surveillance. Although these components are also essential in interventions, there is a dire need to implement interventions that prevent further lead exposure in Kabwe. For example, the Kabwe Environmental and Rehabilitation Foundation cleaned up the toxic hotspots in neighborhoods throughout the city by removing the topsoil. According to Dr. Pamela Towela Sambo, "[Zambians commonly] fight problems without addressing the root causes of those problems."[7] Removing soil is not addressing the root of the problem, it is just relocating the issue. It also raises the question of where the contaminated soil is moved, and if the appropriate surveillance is present to ensure citizens will not be exposed to the source once again. It has also been noted that the removal of soil is expensive.

4.2.6. Intervention-specific flaws

There are certain flaws that are not generalizable. These flaws are particularly relevant to public interventions due to their focus on capacity building and systems strengthening.

CEP was criticized by a third-party reviewer for lacking diversity in employed

[7] P. Sambo, Head of Private Law (UNZA), Environmental Justice Lawyer; taken from an interview conducted on July 10, 2019

specialists and personpower. Another point of criticism was the lack of effective leadership by both the Zambian Government and the World Bank. The project was unsuccessful in improving access to environmental data and compliance monitoring reports. Providing public access to such reports is necessary for social accountability, as it is known to be one of the four pillars of social accountability ("What is social accountability," n.d.). Without access to monitoring reports and evaluations, the public can not make credible claims based on reliable evidence about whether the government is performing up to par with expectations nor can they be a force that pressures the government to perform in a better manner. Another flaw of the project was lack of enforcing environmental regulations and increasing the mining companies' contributions to the Environmental Protection Fund. The government not being strict on their imposition presents a threat to the long-term benefits of all project interventions. Moreover, the privatization of 13 tailing dams allows for a lack of regular inspection and monitoring of the sites. This creates greater risk of the dams failing and widespread damage that includes the loss of human life. Lastly, having the sites privatized inhibits ZCCM-IH from implementing rehabilitation works.

Although ZMERIP does not have a website like CEP previously had, there are budge documents published by the World Bank. The recent budget document reveals that necessary equipment and the communication and citizen engagement consultancy were cancelled yet project vehicles were purchased. The reasoning behind these cancellations is not specified within the document. Moreover, ZMERIP is fulfilling its objective of capacity-building of environmental governance institutions by implementing an automated system for ZEMA. The main purpose of this new system is to increase revenue and implement a data-keeping system. Out of the total modules, only one component addresses a benefit to the public while the rest cater to the clients (mining entities). It is unclear if the new program will allow the public access to the permits granted as well as if the public will have access to the environmental emergencies and complaints, which was a flaw in the CEP.

4.3. FUTURE INTERVENTIONS

Given the findings from the qualitative studies and intervention analysis, there are a series of recommendations that can be addressed. The public health crisis in Kabwe is one that cannot be readily solved with a "magic bullet approach," in which a complex issue is tackled from one perspective. Synonymous with the situation in Kabwe, complex and holistic approaches are needed when planning future interventions. The recommendations below should be addressed by future interventions in Kabwe.

4.3.1. Healthcare

Health systems strengthening is a required component of future interventions in the region. The current health systems in Kabwe, including the Kabwe Mine Hospital and the Kasnada Clinic, must be assessed and addressed when carrying out an intervention that focus on lead exposure in Kabwe. The importance of systems strengthening in the healthcare field is a means of sustainability. Although BLL surveillance and treatment has been assessed by past researchers and different interventions, there is a lack of capacity and strengthening of the present health systems in Kabwe. Strengthening the health systems in Kabwe is essential when planning an intervention that aims to have a long-term impact on residents. In order for Kabwe residents to be able to seek constant care, clinics and hospitals must be able to deliver quality healthcare.

The strengthening of health systems can be achieved by equipment supplies (lead testing equipment), improving information resources, and medication supplies (nutritional supplements). According to J. Yabe, "[blood lead testing] should be one of the routine tests done in Kabwe. They should adopt [Lead Care machines] in the hospitals."[8] Yabe explains that by adopting machines that are bought by ZMERIP, this allows for sustainability after the completion of the project. He comments "the government can...continue supporting reagents," as a method to involve the government. Treatment, specifically chelation therapy, is also needed in Kabwe health clinics. However, it is noted that such treatment is unsustainable due to lead re-exposure. Moreover, nutritional supplements, specifically iron and calcium supplements, are needed to reduce the absorption of lead. Iron deficiency is known to cause an increase in lead uptake, specifically in children (Kordas et al., 2007). Health systems can also be enhanced by improving the infrastructure of facilities with the goal of maximizing patient turnout, specifically assessing the health of children under 7 years old.

4.3.2. Economic (Livelihoods)

For most illegal miners, scavenging the slags is their main source of income. Interventions that do not propose alternative livelihoods exemplify a lack of contextualizing the lead pollution issue in Kabwe. According to J. Yabe, "The ZMERIP is trying to change [scavengers'] livelihood and look at other sources of income-generating activities."[9] This is necessary to do so since discouraging scavenging needs to be prioritized. However, this cannot be achieved without providing alternative income

[8] J. Yabe, Research Manager at KAMPAI, Senior Lecturer at the School of Veterinary Medicine (UNZA); taken from an interview conducted on July 22, 2019

[9] J. Yabe, Research Manager at KAMPAI, Senior Lecturer at the School of Veterinary Medicine (UNZA); taken from an interview conducted on July 22, 2019

activities. Economic activities can be promoted by also building infrastructure, like markets and commercial facilities. Vocational training programs, specifically for illegal miners should be enacted in the area.

4.3.3. Infrastructure

The roads of Kabwe do not tend to have sidewalks, meaning people walk on dusty walkways. Road soils and river and lake sediments are a convenient for environmental pollution to spread. Wildlife and humans in Kabwe are exposed to heavy metals mainly through inhaling and/or ingesting air or soil that is contaminated by mining activities. The first intervention regarding infrastructure would be to pave dusty roads. By wetting imported laterite that is blended with a bit a cement and then rolling it on the dusty roads, the amount of contaminated dust in the air will be minimized (Kříbek et al., 2019). The addition of calcium chloride to this cement solution should be considered as it is a hygroscopic substance. As a hygroscopic substance, the calcium chloride will readily attract the water from its surroundings and therefore, there would be less water required to create the concrete and significantly reduce the setting time. It will also cause the dust particles to collect, settle in the cement, and prevent them from being dispersed by turbulence. For roads that are unable to be cemented or while waiting to be cemented, they should be sprayed. This is especially important during the dry season; wetting the roads and public areas will significantly reduce the amount of dust in the air.

The next recommendation for infrastructure would be to lay school grounds with grass. Children are known to be a vulnerable population in this situation because of their height and hand-to-mouth practices. More likely than not, children will fall on the dusty ground, get their hands covered by the dirt, and then accidentally absorb the lead because they failed to wash their hands after playing. By providing school grounds with grass, there will be less dust fallout and children will be less likely to inhale or ingest dust particles. Grass will also structure the playgrounds to be more aesthetically appealing, attracting children to play there instead of areas close to the mine.

Another recommendation would be to build healthcare facilities. There are a limited number of clinics where Kabwe residents can seek help. Residents may feel the need to go outside of their township to get medical attention, which may cost money that they necessarily do not have. Creating more clinics that are well equipped and knowledgeable about the symptoms of lead poisoning will prevent irreversible biological effects from occurring. This recommendation also provides the Kabwe community with more occupational opportunities.

4.3.4. Legal sector and rights

According to Dr. Kennedy Choongo, "in Zambia the laws could be good, but it's the problem of implementation...If you put regulations to prevent all the effects [of mining], then you prevent mining and money. That's the way they look at it."[10] The first step in legal interventions would be to enforcing environmental laws via the Municipal Council. When it comes to the mining sector, the laws are less likely to be sanctioned because of the profit that comes from the activities. Mining is a prominent way Zambia supports it economy, so it makes sense why they would not want to be strict on this sector. What the enforcers fail to see is what it would cost Zambia in the future. Profits from mining allows for instant gratification, but the country will lose money as the level of debt increases because they continuously have to pay back loans to institutions (like the World Bank) as they struggle to mitigate the effects of heavy metal contamination. By more enforcement on the law, and ensuring that companies comply with environmental and social regulations.

Mines also need to be required to have air scrubbers. It is known that the main reason why the soil is contamination is because of industrial emissions. An air scrubber is a device that removes particles, chemicals, or gases from the air in the mine. This will protect industrial workers from being exposed to harmful substances and also inhibit toxic metals from settling onto the soil.

The last recommendation for legal intervention is to educate citizens on their constitutional rights to a clean environment. Citizens need to know that: (1) whoever is pursuing environmental justice, they cannot be sued back by the opposing party and (2) the court is restrained from disposing the case with costs (i.e., cannot put the costs on the person who is suing).

4.3.5. Partnerships

Community engagement is an integral part of projects because without perspectives from the people directly affected, decision makers may not make the best decisions for the community. Morgan Katati accentuated the importance of community engagement by stating, "the project by design or by default, should allow collection of views from the people, because they are the primary stakeholders. They are the ones who know what should be done to create long-lasting impacts."[11] The very surface level benefit of having

[10] K. Choongo, Senior Lecturer at the School of Veterinary Medicine (UNZA), Researcher at KAMPAI; taken from an interview conducted on July 9, 2019

[11] M. Katati, CEO of Zambia Institute of Environmental Management; taken from an interview conducted on July 11, 2019

additional perspectives is that the end goal would be more likely to meet the needs and address the concerns of the vulnerable populations concerned. Other underlying benefits include empowering communities. A frequent problem of having outsiders solve a community's problem is that the community is ignored. Having community participation enables communities to feel influential in efforts as they gained a greater control over their lives. The second underlying benefit is that engagement of vulnerable populations creates a network of community members. The larger the group of people who know and understand what is going on, the more willing they are to work towards a goal and leads to a more successful outcome. The last underlying benefit is the increased level of trust citizens have in community organizations and governance.

For future interventions, there needs to be multiple disciplinary fields involved. This includes scientists at UNZA, local and foreign NGOs, educational organizations, the Kabwe Municipal Council, Ministry of Mines, ZEMA, Ministry of Health, the World Bank, and most importantly, the community.

4.3.6 Agriculture

The agriculture intervention would start with education programs. These education programs would differ from past ones, because it would include more than information on the effects of lead and how to reduce exposure. Residents will also be informed about the absorption of lead in chicken muscle and leafy greens. Consumers in Kabwe are exposed to high concentrations of toxic metals in the muscle and offal of scavenging chickens. Free-range chicken may be cheaper, but they pose a much greater risk to the health of human consumers than commercial chickens. The education programs would emphasize that free range chickens in the vicinity of the mine must be avoided because it could harm consumers' health. Residents will also learn about the detrimental effects of growing leafy greens in their backyards. J. Yabe explained how "recently we did some studies in Kabwe with the locally consumed vegetables, and [the] contamination was high. We know that could be a source of exposure to the families."[12] Leafy greens are known to absorb substantial amounts of lead compared to other vegetables and fruits. This is yet another pathway of contamination and residents could protect their health by not eating the leafy greens grown in their yards. If individuals want to grow their own leafy greens, it is suggested that elevated garden sets are built. The garden sets would contain non-contaminated soil taken outside of Kabwe and being elevated would position beds away from the ground, making it unlikely for the vegetables of absorbing heavy metals from the soil.

[12] J. Yabe, Research Manager at KAMPAI, Senior Lecturer at the School of Veterinary Medicine (UNZA); taken from an interview conducted on July 22, 2019

4.3.7 Bioremediation

The next suggestion for agricultural practices would be bioremediation of the soil. This addresses the problem head on, instead of relocating it by simply removing the topsoil. A salient suggestion for intervention would be microbiologically induced calcium carbonate precipitation (MICP) using ureolytic bacteria. This technique prevents metallic dust from becoming airborne in-situ. Calcium carbonate is a major biomineralization product and calcite ($CaCO_3$) precipitation is a common microbial process in the biosphere. Carbonates are readily available because they are often found as limestones on the Earth's surface. The MICP process starts with urease hydrolyzing urea into ammonia and carbamate and that causes an increase in pH that shifts the bicarbonate equilibrium to form carbonate ions. The carbonates precipitate around the toxic metals in the soil, causing the once mobile lead to be immboile and insoluble. In other words, MICP has the ability to trap heavy metals and subsequently makes the soil less contaminated with lead. The aggregation of the sandy material via MICP, immobilizes the sand and makes it less susceptible to being blown by the wind. This impedes the contamination pathway to humans and animals in and around the mine. The reason why MICP is suggested as the top bioremediation process is because it requires materials that are readily available. The materials required are sand, indigenous bacteria, nutrients, calcium source, and urea. This bioremediation process is inexpensive, sustainable, and less likely to change the integrity of the local biodiversity. Other methods would include vegetation cover and synthetic covers. Vegetation covers may be desired because it reduces surface erosion, but it is difficult to implement in Kabwe because vegetation growth is not possible at site due to high heavy metal concentrations and lack of nutrients. The use of synthetic covers is uneconomical and expensive.

4.4. Zambian Human Development

Zambia's human development is currently a prioritization by the government. The goals and plans the government has committed itself to are related to the situation in Kabwe due to the lack of effective human development in the city. Although there have been attempts to address the issue of development in Kabwe, like CEP, these attempts have proven to be insufficient. Thus, it is important to illustrate the connection between the government's outlined objectives and the heavy metal contamination in Kabwe.

4.4.1. Zambia's Seventh National Development Plan (7NDP)[13]

[13] Adopted from "Zambia's 7th National Development Plan (7NDP)" published by (SDG Philanthropy Platform, 2019)

The Sustainable Development Goals Philanthropy Platform (SDGPP) is a global and national facilitator with the objective of ending poverty, protecting the planet, and ensuring prosperity for all. SDGPP has determined Zambia as one of their eight target countries in which SDGPP has established and implemented their planning. The SDGPP aids Zambia with its national plans that are outlined in the Seventh National Development Plan (7NDP). The objectives in the 7NDP are aimed to be achieved by 2021. The goals of the 7NDP are in support of the objectives in the Vision of 2030, Zambia's first long-term national plan, with the aim to remodel Zambia into a "prosperous middle-income industrial nation."

The key outcomes that are desired from the 7NDP are the following:

i. Economic diversification and job creation;
ii. Poverty and vulnerability reductions;
iii. Enhanced human development;
iv. Reduced developmental inequalities; and
v. Enhanced governance environment for a diversified and inclusive economy.

Although the Zambian government aims at having a prosperous, diversified middle-income economy by 2030, past development plans have resulted in minimal economic diversification. This minimal development is reflected by the economic situation in Kabwe. A lack of economic diversification is one of the various social burdens faced by Kabwe residents, specifically unemployed men who turn to illegal mining. Women and children also result to illegal mining to earn a living while simultaneously exposing themselves to the highest levels of lead in Kabwe. This lack of economic diversification in Kabwe was a result of the closure of the mines in 1994. The need for economic diversification—not exclusively in Kabwe but all throughout Zambia—allows for economic opportunity. In Kabwe, a diversified economy would discourage the scavenging of stones for minerals.

Through the Environmental Protection Fund, a fund for environmental damages funded by operating mining companies, there will also be investments into profitable jobs for environmental restoration. Such funds can benefit Kabwe residents and similar cities with negative environmental conditions due to mining. Although there are general strategies to improve the Zambian economy, like the extraction of nontraditional industrial minerals, the government needs to prioritize public-private dialogue. Public-private dialogue allows the creation of partnerships with the ultimate result being job creation and employment in developing sectors (i.e., agriculture, tourism, construction). Such dialogue would specifically benefit Kabwe residents and the Zambian government.

Currently, there are different interventions in Kabwe—ZMERIP and KAMPAI—that are attempting to address the social burdens of lead contamination. If there is a facilitated dialogue between relevant stakeholders and the community, there can unprescendated benefit, like the creation of jobs and subprojects. Heavily-funded projects, like ZMERIP, should be employing local residents, specifically illegal miners, to aid in different subprojects when possible. Thus, this allows for the simultaneous discouragement of illegal mining while aiding effort of mitigating lead exposure. Another aspect of economic diversification would be improved transport systems and infrastructure. As mentioned in the suggestions for future recommendations, working paving the Kabwe dust roads will thwart large amounts of lead-contaminated dust flying in the atmosphere.

Improving the Zambian economy continues to be a challenge. According to the 7NDP, by the end of 2015, Zambia was one of the poorest countries in the world with a poverty rate of roughly 54.4 percent. There are several vulnerable households with limited access to basic human services including health, education, water, and sanitation. Poor nutrition is another detrimental influence that impairs human capital potential. In Kabwe, residents who suffer from malnutrition are a vulnerable population due to the increased intake of lead. As a result of inadequate diets, malnourished residents lack key brain and nerve development minerals. Improved nutrition among Zambian citizens is one of the objectives in the 7NDP. To tackle the issue of malnutrition, the 7NDP promotes the strengthening of social protection systems alongside improving education and human capital investments. Social cash transfer enhancement, food security pack enhancement, and public welfare assistance are examples of programs that can be implemented to enhance the livelihoods of the poor and vulnerable, which in turn would alleviate social burdens in Kabwe. The 7NDP also aims to protect vulnerable populations (i.e., pregnant women, the elderly, impoverished children) by addressing improper coverage of social protection that lead to inadequate augmentation to human capital accumulation. By filling these gaps, there will be improved nutrition, health, and education and improvements in productivity will follow. According to the Population and Demographic Projections 2011-2035, this is related to the work child dependency ratio of 87.4 that proves children are being burdened with work. However, if there continues to be insufficient social investment in children, there will not be any new economic opportunities for them thus hindering the prosperity of Zambia.

Lead poisoning has been proven to have a greater impact on children and women, specifically pregnant and breastfeeding women. Not only is there a dire need to mitigate the health effects of lead poisoning in Kabwe, but there is also the need to protect

Zambia's future in multiple aspects (i.e., educational, economical, social). The time to act is now. Due to an increasingly competitive global market, there is a need to invest in Zambian education as education investments are a determining factor of a country's future economic success. The country's economy becomes more productive as the number of educated workers increases considering that educated workers can more efficiently perform tasks that require literacy and critical thinking[5]. Economies that have a substantial amount of skilled labor brought through formal education are often able to capitalize on this through the development of more value-added industries.

4.4.2 Sustainable Development Goals (SDGs)[14]

The Sustainable Development Goals were formed by the United Nations in 2012. There are a total of 17 goals outlined by the UN which replaced the Millennium Development Goals (MDGs). The MDGs made considerable progress in addressing social issues, for example, reducing income poverty, providing access to water and sanitation, and combating HIV/AIDS. SDGs differ from MDGs due to its focus on sustainability. The 17 interconnected goals depend on one another's success. Out of the 17 SDGs, there are 7 goals that directly connect to the heavy metal contamination in Kabwe.

SDG 1 - Ending poverty.

The target of SDG 1 addresses resilience-building among the poor and vulnerable positions and a reduction of their exposure to injurious events (i.e., economic, social, and environmental). Due to a lack of economic means, impoverished townships in Kabwe are experiencing a heavier burden of lead contamination. Without considerable income, it is an obstacle to test and receive treatment for elevated BLLs. Per J. Yabe, "[lead testing] is quite expensive" and he does not "think the community can afford to get the tests done."[15]

SDG 3 - Good health and well-being.

An aspect of this goal is to end preventable deaths of newborns and children under the age of 5 by 2030. This category of deaths was classified by preventable risk factors including lead poisoning. An arresting statement was made by Morgan Katati: "Projects last for years, [then they] end, and the problem is still there. Stillbirths, brain damage for some of the kids, and lots of miscarriages."[16] Currently the extent of lead exposure is widespread; however, with effective and comprehensive planning there will be good

14 Adopted from "About the Sustainable Development Goals" published by (United Nations, n.d.)

15 J. Yabe, Research Manager at KAMPAI, Senior Lecturer at the School of Veterinary Medicine (UNZA), taken from an interview conducted on July 22, 2019

16 M. Katati, CEO of Zambia Institute of Environment Management, taken from an interview conducted on July 11, 2019

health and well-being across Kabwe. The people affected need immediate medical treatment and sustainable interventions for improved health.

SDG 8, 9 - Decent work and economic growth; Industry, innovation, and infrastructure.
As stated before, economic growth, infrastructure, and lead contamination are all related. There is a need for sustainable development in Kabwe's economy. Intervention efforts can simultaneously aid the economy while effectively reducing lead exposure. Creating decent work will reduce the prevalence of illegal miners by promoting alternative livelihoods. As previously stated, infrastructure is heavily lacking in Kabwe. Paved roads are needed in areas near the former Pb-Zn mine. This innovation permits the transport of goods and suppresses the spread of contaminated dust.

SDG 15 - Life on land.
SDG 15 is to protect and restore the sustainable use of terrestrial ecosystems, reverse land degradation, and put an end to biodiversity loss. Heavy metals are toxic to the soil, plants, and aquatic life. There is a need to address measures not only focused on reducing lead exposure to humans, but also to other health systems like flora and fauna. By addressing the root of the problem through remediation efforts, Zambia will be playing a part in making sure this goal is true across the world.

SDG 16, 17 - Peace, justice, and strong institutions; Partnership for goals.
There is a need for environmental justice for all the residents of Kabwe. Although there has been several interventions, residents are still unable to enjoy the environment without being exposed to elevated lead levels. SDG 17, collaboration and cohesive interventions, is associated with SDG 16 in that people living in Kabwe must be included in all intervention planning and implementation as it is their fight for environmental justice.

5. CONCLUSION

The systematic review explored a diversity of studies that support the conceptualization of the heavy metal pollution issue in Kabwe as a One Health issue. A series of recommendations were produced in this paper. These recommendations were informed by past and current interventions as well as the systematic review. These recommendations were diverse and used a holistic, One Health approach to address the lead contamination in Kabwe. As stated previously, the concept behind One Health is used when analyzing or planning health interventions.

There are certain challenges that are anticipated due to the practicality of such recommendations. The biggest constraint would be a lack in funding or insufficient funds. Without the necessary funding, none of the aforementioned recommendations will be possible. A strategy to prevent this issue is through the strict division of funds while in the planning process to ensure the money is used methodically. There are also social challenges that may arise. Community members may not be willing to participate in intervention planning due to past experience that prevented such participation. There is also the possibility of community members being unwilling to allow project members into their residential areas. To combat these challenges, the community will need to receive consistent reassurance of their value as partners, specifically how it aids intervention prosperity. This builds a symbiotic relationship that is supported by trust.

The last limitation would be obstructions in the remediation process due to privatization of area. This challenge can be disputed by having governmental agencies like ZEMA persuade the private entities to support remediation projects.

As for the next steps, a conference or formal meeting should be the first action. This conference needs to include stakeholders from diverse fields: environmental lawyers, researchers and physicians, investors, and the citizens of Kabwe. This meeting will allow the opportunity for members from different disciplines to speak on and comprehend the current status of lead contamination in Kabwe. The next step would be to create a council/panel to form a cohesive body of members who will collaborate for the projects in Kabwe. The following step would consist of a series of assessments of the Kabwe population, specifically socioeconomic and biological factors. This would include interviews families in Kasanda and Makululu townships to gain perspective on the contamination issue, testing BLLs, and testing water supplies for contamination. Bioremediation and treatment of those affected will come next. This solves the root of the problem since relocating the problem is not a solution. The last step would be the enforcement laws and regulations that require the maintenance of environmental health.

Our findings illustrate the extensive nature of lead contamination in Kabwe. Intervention findings allows for hind-sight benefits that should be addressed in future interventions. Without essential intervention components, as detailed in this paper, there will continue to be ineffective interventions in Kabwe. A complex issue, like the one at-hand, requires complex solutions using a One Health approach.

LIMITATIONS

There were several limitations to this study. The main limitation was time constraint; we only had seven weeks to schedule and conduct interviews with relevant stakeholders. With more time, it is possible that we would have been able to interview more experts. Our unfamiliarity with Zambia also hindered our research. Another limitation was the long bureaucratic process of obtaining an interview with a government official. We intended to speak with the Ministry of Mines and Minerals Development to gain insight from their perspective, but failed to do so because of the administrative process. We were also not permitted to travel to Kabwe or interview Kabwe community members. This limitation prevented us from speaking to individuals who would speak on their first-hand experience with the effects they have witnessed in regards to heavy metal contamination. The last limitation would be the lack of online publications, specifically by past and current interventions, that made them difficult to analyze.

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APPENDIX

Table 1. Summary of lead-contaminated soil studies in Kabwe, Zambia.[1]

Study	Objective	Findings	Conclusions
Tembo et al. (2006)[2]	Analyze the soil content of Cd, Cu, Pb, and Zn in the four wind directions of the closed Kabwe mine.	More lead was distributed in the southern direction compared to the eastern and northern directions, but less than in the western direction. A strong correlation (r = -0.95) between lead soil contamination and the western direction.	The most lead soil pollution is west of the mine. Metal concentration decreases with an increase of mine distance The mining in Kabwe is the source of heavy metal contamination. Polluted precipitation is the main source of soil contamination.
Ikenaka et al. (2010)[3]	Analyze soil samples to determine the contents of contaminants.	High ratios of Zn (57%) and Pb (32%) in Kabwe samples, Cluster 1. Average soil sample: 7076 ± 8644 mg Pb kg^{-1}. Maximum values of Cd and As were 18.7 and 51.5 mg kg^{-1}, respectively.	The main source of heavy metals are in the mining areas and are consequently transported by rivers. Kabwe soil is a risk to human health due to high Pb, Cd, and As levels.
Nakayama et al. (2011)[4]	Identify the relationship between Pb accumulation in wild rats (*Rattus sp.*) and the soil contamination in Kabwe.	Strong positive correlation among Pb and soil organic matter. Range of 9 to 51,188 mg Pb kg^{-1} with a median of 282 mg Pb kg^{-1}. Median Pb content in Kabwe is 10.8x the median Pb content in Lusaka soil.	Lead concentration and distance from the mine were negatively correlated. Humans and animals living south of the Pb-Zn mine are more at-risk.
Majer et al. (2011)[5]	Determine the extent of soil contamination and gastric availability of metals in the topsoil in Kabwe.	High contamination of heavy metals: lead 4%, zinc 6.7%, copper 0.7%, and arsenic 0.06%. Highest concentration of metals found in the industrial zone.	Heavy metal contamination exceeded the permissible concentrations by Canadian standards. Lead and cadmium in the soil were very bioavailable, thus, unfavorable for agricultural practices.
Caravanos et al. (2014)[6]	Examine the Pb soil contamination in Kabwe.	Range from 138 mg Pb kg^{-1} to 62,142 mg Pb kg^{-1} with a GM of 1,470 mg Pb kg^{-1}. Maximum Pb soil content in Kabwe was 941x the maximum Pb soil content in Lusaka (66 mg Pb kg^{-1}).	There is significant lead contamination in Kabwe, specifically in the residential neighborhoods near the former mines and smelters.
Kříbek et al. (2019)[7]	Compare Pb content of the topsoil (0-3 cm) and subsurface (70-90 cm) soil in Kabwe.	Topsoil has a higher concentration of Pb (median = 199 mg Pb kg^{-1}) relative to the subsurface soil (median = 28 mg Pb kg^{-1}).	The topsoil accumulates more Pb due to dust fallouts or tailing ponds.

1. Exclusively analyzed lead-soil components of each study.
2. Tembo, B. D., Sichilongo, K., & Cernak, J. (2006). Distribution of copper, lead, cadmium and zinc concentrations in soils around Kabwe town in Zambia. *Chemosphere*, *63*(3), 497-501.
3. Ikenaka, Y., Nakayama, S. M., Muzandu, K., Choongo, K., Teraoka, H., Mizuno, N., & Ishizuka, M. (2010). Heavy metal contamination of soil and sediment in Zambia. African Journal of Environmental Science and Technology, 4(11), 729-739.
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Table 2. Blood lead levels (BLLs) in children of Kabwe, Zambia.

Study	Sample Size (N)	Ages (y/o)	Average BLL (µg Pb dL^{-1})	≥ 5 µg Pb dL^{-1}	≥ 45 µg Pb dL^{-1}	≥ 150 µg Pb dL^{-1}
Caravanos et al. (2014)[1]	196	2 - 8	43.8	-	> 98	-
Yabe et al. (2015)[2]	246	7	39-82.2	246	161	10

1. Caravanos, J., Fuller, R., & Robinson, S. (2014). Notes from the field: severe environmental contamination and elevated blood lead levels among children-Zambia, 2014. *MMWR. Morbidity and Mortality Weekly Report*, *63*(44),1013-1013.
2. Yabe, J., Nakayama, S. M., Ikenaka, Y., Yohannes, Y. B., Bortey-Sam, N., Oroszlany, B., ... & Mweene, A. (2015). Lead poisoning in children from townships in the vicinity of a lead–zinc mine in Kabwe, Zambia. *Chemosphere*, *119*, 941-947.

Table 3. Summary of the findings in Mbewe et al. (2015).[1]

Sample Size (N)	Ages (y/o)	Average BLL (µg Pb dL^{-1})	≤ 10 µg Pb dL^{-1}	> 10 µg Pb dL^{-1}	< 25 µg Pb dL^{-1}	≥ 25 µg Pb dL^{-1}
1,166	1 - 8	36.9	7	1,159	313	853

1. Mbewe, A., Munekub, E., Michelo, C., & Siulapwa, Y. (2015). Blood lead levels and likely adverse health outcomes in under five children in Kabwe, Zambia. *International Journal of Sciences: Basic and Applied Research*, *24*(5), 171-183.

Table 4. Summary of the findings in Yabe et al. (2018).[1]

Sample Size (N)	Ages (y/o)	Highest Avg. Pb Urine[2] (µg Pb L^{-1})	Max Pb Urine[2] (µg Pb L^{-1})	Highest Avg. Pb Fecal[2] (mg Pb kg^{-1})	Max Pb Fecal[3] (mg Pb kg^{-1})
190	0 - 7	207	2914	90.6	225

1. Yabe, J., Nakayama, S. M., Ikenaka, Y., Yohannes, Y. B., Bortey-Sam, N., Kabalo, A. N., ... & Ishizuka, M. (2018). Lead and cadmium excretion in feces and urine of children from polluted townships near a lead-zinc mine in Kabwe, Zambia. *Chemosphere*, *202*, 48-55.
2. Found in the Kasanda township.
3. Found in the Makululu township.

Table 5.
Summary of the findings in Kabwe Scoping and Design Study (KSDS) under the Copperbelt Environment Project.[1]

Sample Size (N)	Objective[4]	Conclusion
2,500	Collect data to examine the extent impact of lead contamination at the household level in Kabwe.	Almost all children were above the 5 μg Pb dL^{-1} level. BLLs were particularly elevated for children 0-7 years old.

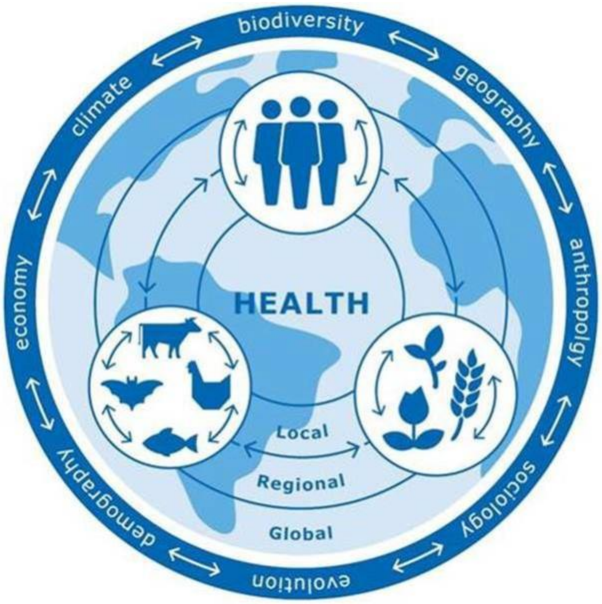
1. Bose-O'Reilly, S., Yabe, J., Makumba, J., Schutzmeier, P., Ericson, B., & Caravanos, J. (2018). Lead intoxicated children in Kabwe, Zambia. *Environmental research*, *165*, 420-424
2. Lacey, R. M. (2016, September 22). Zambia - Copperbelt Environment Project (cep). Retrieved from http://documents.worldbank.org/curated/en/759211474589929467/Zambia-Copperbelt-Environment-Project-cep

Table 6. Summary of lead-contaminated animal studies in Kabwe, Zambia.

Study	Objective	Findings	Conclusions
Nakayama et al. (2011)[1]	Identify the relationship between Pb accumulation in wild rats (*Rattus sp.*) and the soil contamination in Kabwe.	Average body weight of a rat in Kabwe was 86 grams versus in Lusaka it was 136 grams. Average Pb in the kidney of a Kabwe rat is 2.2 mg Pb kg^{-1} and of a Lusaka rat is 0.2 mg Pb kg^{-1}	Lusaka rats weighed on average 1.5x Kabwe rats. The amount of Pb in the kidney of a Kabwe rat is 11x that of a Lusaka rat. This increase in Pb in kidneys is due to the high concentrations of Pb in the soil.
Yabe et al. (2011)[2]	Investigate the metal pollution levels in the liver and kidneys of cattle from Kabwe.	Maximum levels of Cd was 19.4 mg kg^{-1} and Pb was 1.8 mg kg^{-1}. Average level of Pb in the livers of Kabwe cattle was 0.42 mg kg^{-1}. Average level of Pb in the kidneys were 0.58 mg kg^{-1}.	Cattle from Kbawe had high levels of Pb in the liver than the other cattle in the towns studied, except for Chibombo. There could be significant health risks associated with the consumption of cattle offal near the mine
Ikenaka et al. (2012)[3]	Explore the effects of heavy metals in Kabwe on the metal-responsive proteins and cytokines in cattle.	Greater concentration of Pb (90.6 ± 67.6 μg kg^{-1}) and Cd (114.9 ± 74.6 ng kg^{-1}) in the cattle peripheral blood were observed in Kabwe cattle as opposed to Lusaka cattle. Higher expression levels of MT-2 and iNOS in cattle white blood cells from Kabwe.	Pb exposure is one of the key agents modifying transcription factors in cattle. In Kabwe, cattle immune system function may be comprised as a result of lead exposure.
Yabe et al. (2013)[4]	Investigate metal contamination in the tissues of free-range chickens near the Pb-Zn mine in Kabwe.	In pectoral muscle, 59% of chickens exceeded 0.1 mg kg^{-1} max level for chicken muscle for Pb. Average Pb in livers of chickens is 4.15 mg kg^{-1}, in kidneys is 7.62 mg kg^{-1}, and lungs is 3.34 mg kg^{-1}.	Large quantities of Pb and Cd found in edible organs of free-range chickens. Livers, kidneys, and lungs of chickens were in excess allowed for human consumption.

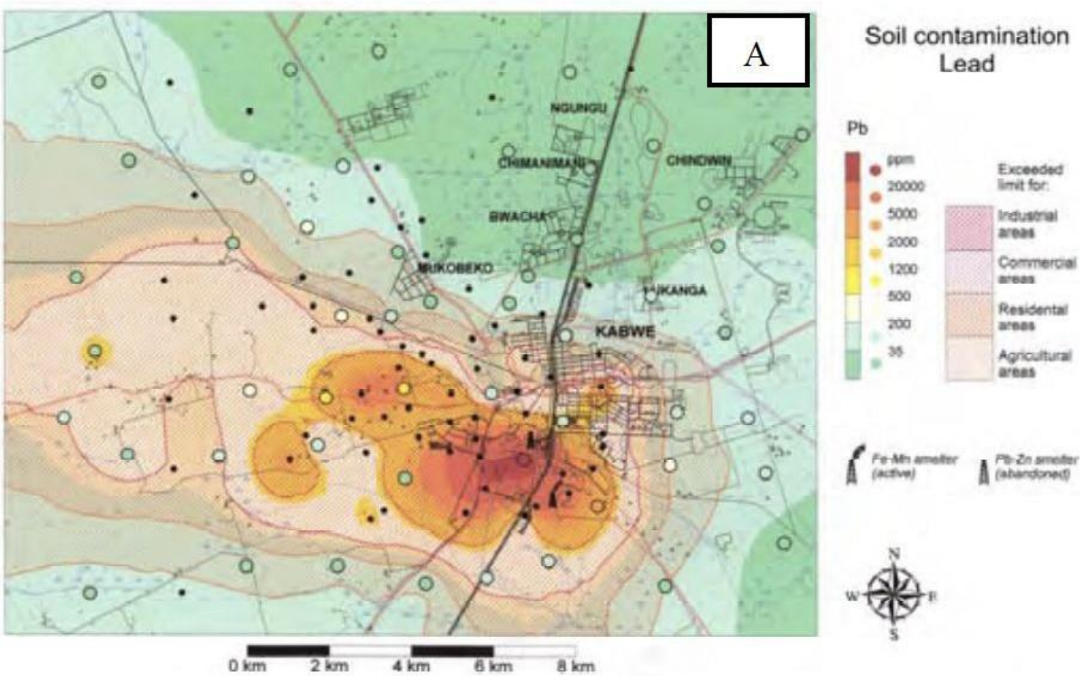
1. Nakayama, S. M., Ikenaka, Y., Hamada, K., Muzandu, K., Choongo, K., Teraoka, H., ... & Ishizuka, M. (2011). Metal and metalloid contamination in roadside soil and wild rats around a Pb–Zn mine in Kabwe, Zambia. *Environmental pollution*, *159*(1), 175-181
2. Yabe, J., Nakayama, S. M., Ikenaka, Y., Muzandu, K., Ishizuka, M., & Umemura, T. (2011). Uptake of lead, cadmium, and other metals in the liver and kidneys of cattle near a lead-zinc mine in Kabwe, Zambia. Environmental toxicology and chemistry, 30(8), 1892-1897.
3. Ikenaka, Y., Nakayama, S. M., Muroya, T., Yabe, J., Konnai, S., Darwish, W. S., ... & Umemura, T. (2012). Effects of environmental lead contamination on cattle in a lead/zinc mining area: changes in cattle immune systems on exposure to lead in vivo and in vitro. Environmental toxicology and chemistry, 31(10), 2300-2305.
4. Yabe, J., Nakayama, S. M., Ikenaka, Y., Muzandu, K., Choongo, K., Mainda, G., ... & Umemura, T. (2013). Metal distribution in tissues of free-range chickens near a lead–zinc mine in Kabwe, Zambia. *Environmental toxicology and chemistry*, *32*(1), 189-192

Image 1. One Health diagram.[1]



1. Global One Health. (n.d.). Retrieved from https://www.wur.nl/en/About-Wageningen/Strategic-Plan/Strategic-plan-2015-2018/Global-One-Health.htm

Image 2. Soil contamination contour map for lead in Kabwe.



2. Majer, V., Knésl, I., Křībek, B., Nyambe, I. A., Ziwa, G., Mihaljevič, M., ... & Sracek, O. (2011). Soil contamination and health risks associated with former Pb and Zn ore smelting in Kabwe, Zambia. *MINING AND THE ENVIRONMENT IN AFRICA*, 43.