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Appropriate Technology for Water Purification in the Tropic and Subtropic Areas Focusing on the Copperbelt Province of Zambia

Bachelor Thesis

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DECLARATION

I declare that I have written my bachelor thesis titled "Appropriate Technology for Water Purification in the Tropic and Subtropic Areas Focusing on the Copperbelt Province of Zambia," by myself with the help of literature listed in References.

In Prague, …………………………………..

....
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ABSTRACT

The work is a literary review, which first provides a general insight into the African country of Zambia, its geography, soil, climate, economy, and political and socio-economic relations. It next focuses on one of its provinces, the Copperbelt, which for decades carried out a large copper mining operation that has left the environment in very poor condition. The overview describes the basic pollution of the environment and those facts are shown in the figures in the form of specially drawn maps by the Czech Geological Survey. This information is presented for a better understanding of the area and the importance of using quality technologies for water purification. In the next section the technologies for cleaning industrial wastewater and subsequent filtration that can positively change the situation are described in detail. For example in Kabwe, which lies close to the Copperbelt Province, a study of people tested for exposure to lead pollution showed concentrations in children five to ten times higher then the United States standard for environmental safety. This high incidence of lead in the body can lead to death (Walsh, 2014). Adverse impacts on the environment, the people's health, and the health of the animals are excessively prevelent.

KEY WORDS:

copper, mining, industrial polluted water, contaminated water, heavy metals

ABSTRAKT

Práce je literární přehled, který nejprve nabízí obecný náhled na africkou zemi Zambii, na její geografii, půdu, klima, ekonomii a politicko socio-ekonomické vztahy. Po té se zaměřuje na jednu z jejích provincií, provincii Copperbelt, kde již desetiletí probíhá ve velkém těžba mědi, která zanechala tuto oblast ve velice špatném stavu. Přehled popisuje základní oblasti znečištění životního prostředí a tyto skutečnosti znázorňuje v přílohách v podobě speciálně vypracovaných map České geologické služby. Tyto informace jsou předloženy pro lepší porozumění dané oblasti a důležitosti využití kvalitních technologií pro purifikaci vody, ke kterým se dostáváte v následují části. Jsou popsány, jak technologie pro čistění industriální odpadní vody, tak následná filtrace. Tato opatření mohou celou situaci příznivě změnit. Například ve městě Kabwe, které leží v těsné blízkosti provincie Copperbelt, bylo znečištění olovem v tělech testovaných tak silné, že testy prokázaly jeho koncentraci u dětí pět až desekrát vyšší, než jsou normy Spojených států pro environmentální bezpečnost. Takto vysoký výskyt olova v těla může vést až ke smrti (Walsh, 2014). Nepříznivých dopadů na prostředí a zdraví jak obyvatel, tak zvířat, je celá řada.

KLÍČOVÁ SLOVA:

měď, těžba, industriálně znečištěná voda, kontaminovaná voda, těžké kovy

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LIST OF ABBREVIATIONS

As - arsenic

°C - degree Celsius

Cd - cadmium

cm - centimetres

Co – cobalt

Cr - chromium

Cu – copper

D.A.F. - Dissolved Air Flotation

D.E. - Diatomaceous Earth

DR Congo – Democratic Republic of the Congo

E. coli - Escherichia coli

GDP - Gross Domestic Product

Hg - mercury

KCM - Konkola Copper Mines

km^2 - square kilometres

mg/kg – milligrams per kilogram

mm - milimetres

MWCO - Molecular Weight Cut Off

NCCM - Nchanga Consolidated Copper Mines Limited

Ni - nickel

Pb – lead

pH – potential of hydrogen

POE - Point of Entry

POU - Point of Use

ppm – parts per million

RCM - Roan Copper Mines Limited

Se - selenium

TD2 - tailings dam number 2

TLP - Tailings Leach Plant

t/y – metric tons per year

UK – United Kingdom

US$ - American dollar

VR – Vedanta Resources

WHO – World Health Organization

ZCCM - Zambia Consolidated Copper Mines Limited

Zn - zinc

1. INTRODUCTION

Together with the Earth's atmosphere, water is an essential condition for the existence of life on Earth. Its quality and availability are key aspects of human welfare, socio-economic development, and maintaining a peaceful state in the world.

The average human adult is composed of about 55, 19, 19 and 7 % respectively of water, protein, fat and inorganic material (Montgomery et al., 1977). With that in mind, it is evident that water is one of the most important factors in human health. Without drinking water, a person will not survive for any extended period of time. Due to its often limited or contaminated sources, combined with the ever-increasing consumption rate, water's availability is becoming an increasingly urgent and life threatening issue.

However, these issues are not being ignored. Millennium Development Goals began a program in 1990 to achieve set targets for drinking water by 2015. Due to their efforts, the goals were met in 2010, five years ahead of schedule. In 1990 76 % of the world's population had access to drinking water. The goal was to provide this option to 88 %. In 2015, this figure climbed to 91 %, which means that 2.6 billion people gained access to drinking water from 1990 to 2015. These improvements are ground-breaking, but in 2015 a staggering 663 million people were still without access to improved drinking water sources. Statistics show that 8 out of 10 of those affected are living in rural areas.

The data is significantly different in developing countries where although noticeable improvements are being made, a large part of the population suffers from a lack of quality drinking water. For example, the sub-Saharan Africa Development Goal was not achieved, despite an improvement of 20 %. Likewise, in Caucasus, Oceania and Central Asia the situation has improved by only 2 % and 5 % in the same 25-year period (UNICEF and WHO, 2015).

The threat of polluted water is therefore still valid and threatens the human population, especially in the least developed countries. Drinking contaminated water results in a yearly death toll of around eight hundred forty thousand people, which is approximately two thousand three hundred people a day (PRUSS-Üstün et al., 2014).

Development of new technologies in water purification is, therefore, an important sector in which to pay attention, and we should not underestimate their potential for growth. Recycling and conscientious waste disposal is not only the most effective and sustainable way to deal with increasing water consumption, but in many disadvantaged areas, it remains the only viable solution. For a change to take place and last, the technologies we use must be of high quality while remaining sustainable and accessible so they can be adopted by the least developed countries.

2. AIMS OF THE THESIS

This bachelor thesis intended to survey and illuminate the pollution sources of the Copperbelt Province in Zambia. Utilizing statistical resources, scientific articles, and data from information centers the thesis sought to find the biggest source of pollution and to suggest technologies and procedures for preventing said pollution. The main aim was the protection of the water in the Copperbelt Province through the utilization of appropriate technologies in accordance with the local environmental conditions. A brief summary of the water purification technologies suitable for this region and nearby localities was also provided. All technologies and procedures were selected primarily for their benefits to the population and the wildlife of the area.

3. METHODS

The information contained in this thesis is based on the careful study and analysis of appropriate literature related to problems in the Copperbelt Province concerning mining-related contamination, and the technologies used to correct them. The information used came from various sources, including scientific articles and researches conducted over the last 30 years.

General information about Zambia was derived from various resources like Lonely Planet, the CIA, and many others. The thesis is based upon the studies conducted by Kříbek, Majer, and Nyambe found in: "Environmental-geochemical Atlas of the Central-northern Part of the Copperbelt Province of Zambia" published in 2007, which scientifically describes the current environmental situation. Here can be found detailed information on the contamination of the water, the soil (surface and subsurface), and various details of the agricultural industry. The book contains about 30 maps based on the studies and also provides a description for every one of them.

The water treatment technologies information was derived from many resources that are in the business of industrial water treatment. Wastewater polluted from mining processes create very unique situations. The Alar company and its products proved to be very helpful because they described through video exactly how the technologies work. Also, a Dissertation Thesis from Hassan "Assessment of Water Quality and Proposal of Appropriate Water Purification Unit for Agricultural Area of Province Lattakia, Syria" (2015), was very informative on the topic of filtration.

4. LITERATURE REVIEW

4.1 REPUBLIC OF ZAMBIA

4.1.1 BASIC INFORMATION

The Republic of Zambia is an inland state located in South Africa. Its capital city is Lusaka, located at 14 degrees south latitude and 30 degrees east longitude. Zambia‘s neighbouring states include Tanzania, Malawi, Mozambique, Zimbabwe, Botswana, Namibia, Angola and the Democratic Republic of Congo. Formerly the territory of Northern Rhodesia, Zambia was administered by the British South Africa Company until it was taken over by the UK in 1923. During the 20’s and 30’s, advances in mining caused an increase in immigration and development. Zambia is now a presidential republic and changed their official name when they declared their independence from the UK on October 24, 1964. The current president of Zambia is Edgar Lungu. The country is divided into 10 provinces: Central Province, Copperbelt Province, Eastern Province, The Province of Luapula, Lusaka Province, Northern Province, North West Province, Southern Province, Western Province and Muchinga. In the 80’s and 90’s the economy suffered due to many factors including economic mismanagement, declining copper prices, and a prolonged drought (CIA, 2017).

The official language of Zambia is English. They use it for both teaching in schools and conducting business. Like many African states Zambia has local languages that differ from the official tongue. The main local language in Lusaka is Nyanja, followed closely by Bemba. Conversely, in the Copperbelt, Bemba is the main language and Nyanja is second. Bemba and Nyanja are both spoken in all of the urban areas alongside various other indigenous languages and dialects local to Zambia (US Department of State, 2010).

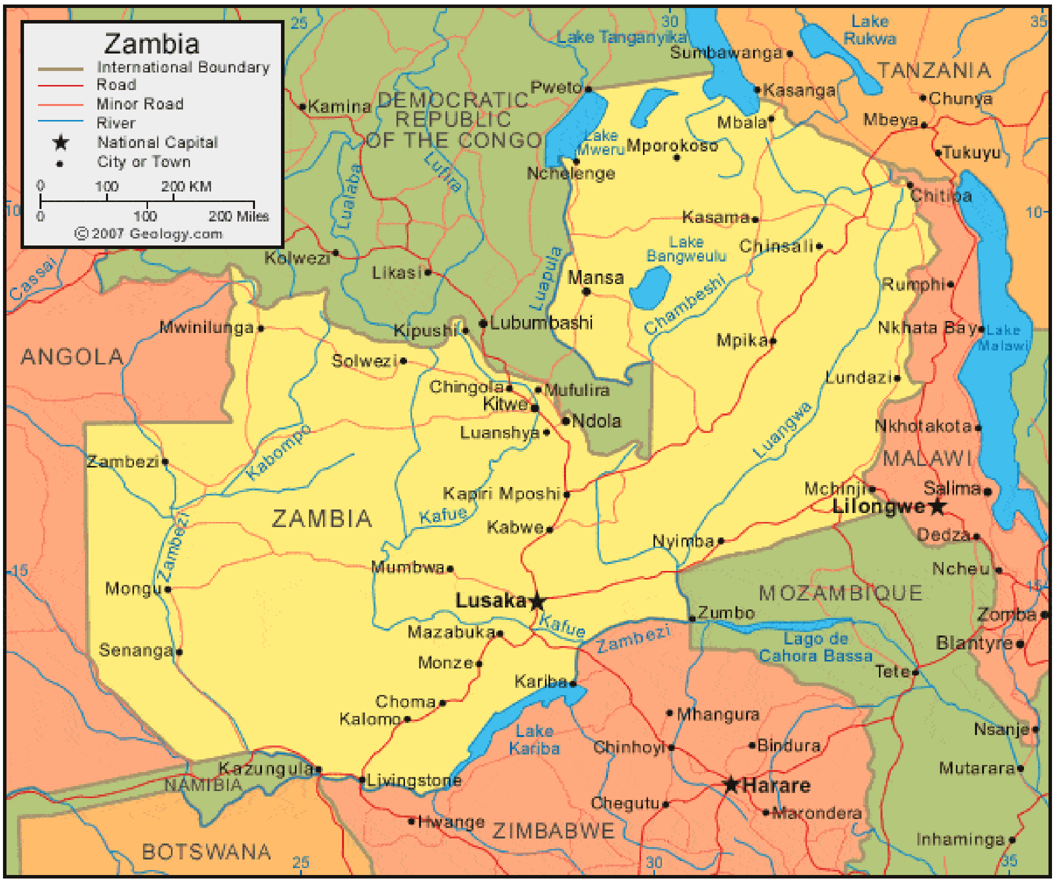

FIGURE 1: POLITICAL MAP OF ZAMBIA SHOWING THE INTERNATIONAL BOUNDARIES.

Source: (Geology, 2007)

4.1.2 GEOGRAPHY

Zambia has a total area of 752,618 square kilometres, of which 743,398 km^2 is occupied by land and 9,220 km^2 is covered by water. Zambia covers an area that is almost 10 times larger than the Czech Republic. It consists mainly of undulating plateaus with a height of around 900-1,500 metres above sea level (CIA, 2017). The Zambian territory has an extensive number of large lakes, including Lake Mweru and Lake Tanganyika. The main river system is made up of the Kafue and Luangwa rivers which flow into the Zambezi River. This famous river is located on the border of Zimbabwe and is well known for the beautiful Victoria falls. The Zambezi is the fourth longest African river, and the longest tributary river that enters the Indian Ocean (Worldatlas, 2016).

4.1.3 SOIL

The primary soil types found in Zambia are loamy-sand or sand Alfisols, interspersed with clay. This is due, in part, to the fact that Zambia's plateau and some hilly areas have been degraded, a result of geomorphological processes. Presently, Zambia has four agro-ecological regions that are comprised of different soil types. Upland soils have low inherent fertility and consist of moderately leached sandveldts, loams, and clays. Their structure, texture, and physical properties vary (Aregheore, 2009).

The dambo areas are classified as shallow wetlands, typically found in higher rainfall plateaus that contain small river like formations that branch through them. Soils in most dambo areas are characterized by a dark color in the top 30 cm of the profile. This dark color is attributed to the soils high organic matter content. In many cases this layer is covered by silt loams, underlain by silt clay loam with clay developing in lower layers. Clay migrates to lower horizons and formes within the water tables (Chidumayo, 1992).

Dambo soils are very beneficial and have been shown to support crop production on a sustainable basis and remove the need to apply external inorganic fertilizers. This is because of their organic matter and high nutrient pool. There is currently an increasing popularity in dambo cultivation due to their high moisture and high fertility status. The variation in fertility of both upland and lowland dambo soils must be viewed and approached cautiously with different land management practices if production is to be sustainable (Aregheore, 2009).

4.1.4 CLIMATE

The seasons of Zambia fall broadly into three periods. The rainy season takes place from December to April and constitutes the majority of the year. This contributes to the waterways that run throughout the dambo areas. May through August bring about a cool dry season followed by the hot “summer” season from September to November.

During the rainy season months, it is warm and wet with temperatures in Lusaka generally in the low 20 °C. Most yearly rainfall occurs at this time. But sunshine is still frequent – Lusaka sees around five hours per day in January.

The cool dry season in the middle months of the year bring lower temperatures, averaging around 16 °C in Lusaka. July is usually the coldest month, with clear skies at night giving the occasional ground frost, even in the valleys.

Just two months separate the coldest month of the year (July), from the hottest (October) as temperatures rise rapidly and reach into the 30 °C. High humidity can make this one of the least comfortable times of the year. The first rains clear the air and wash away the dust (Our Africa, 2017).

4.1.5 ECONOMY

Within the labour force of 7.116 million (CIA, 2016) a vast majority, 85 %, work as subsistence farmers. This means they farm and produce only enough to feed their family and have little left to sell. Commercial agriculture is confined to a limited number of large farms. Industry constitues 6 % of the workforce and the remaining 9 % are in services. Agriculture is the main source of income for the rural population, including women in particular, who constitute a high proportion of the rural population and agricultural labour force (DFID, 2004).

In the past ten years, Zambia has had one of the world’s fastest growing economies. Zambia’s Gross Domestic Product (GDP) has shown a 6.7 % annual growth. However, because of falling copper prices in 2015 growth slowed to a staggering 3 %. Other contributing factors included a depreciation of the currency kwacha and reduced power generation. Zambia’s dependency on copper as its only major export and overall lack of economic diversification has made it extremely vulnerable to any fluctuations in the world commodities market. In 2015 a decline in demand for copper in China caused prices to plummet. This resulted in the Democratic Republic of Congo taking Zambia's place as Africa's largest producer of copper (IMF, 2016).

High levels of unemployment and extreme rural poverty are continual concerns in Zambia, despite strong economic growth and a recent status change to a low-middle income country. High reports of HIV/AIDS, high birth rates, unconventional energy, and agricultural policies are contributing factors. The weakness that has developed in the kwacha was caused by continually inconsistent economic policies and poor budget execution. In 2015 it was listed as Africa's worst performing currency. In July 2015, April 2014, and September 2012 Zambia issued sovereign bonds to international investors and collectively raised US$7 billion, significantly raising the country's public debt as a share of the GDP.

In 2015 the kwacha depreciated against the dollar leading to the central bank restricting lending. Annual inflation has increased to 23 % by March 2016. This was caused by weakened industrial productivity, likely the result of poorly managed water resources and a shortage in power generation (CIA, 2017).

4.1.5.1 INDUSTRY

Despite drawing the maximum GDP from the service sector, Zambia also hosts a well developed industrial sector. Employing just 6 % of the work force, Zambia's industry sectors contribute 31.3 % of the GDP of the country. Some of the major industries of Zambia include copper mining and processing, construction, food, beverages, chemicals, textiles, fertilizer, and horticulture.

Zambia has traditionally relied on the copper mining industry. The copper output fell grossly in 1998 to 228,000 metric tons. Following a 30-year constant decline and due to insufficient investment, low copper prices and lack of proper decision regarding privatization led to a serious economic crisis. It was only in 2001 that the country recorded increased productivity for the first time since 1973. This was the consequence of a complete year of privatized industry. The copper industry's future was threatened in January 2002 when investors in the largest copper mine decided to withdraw their investment. However, the surging rates of copper that started in 2004 heightened international interest in the country's copper sector. China has invested heavily in the Zambian copper industry and in February 2007, China and Zambia announced the forming of the Chinese-Zambian economic partnership zone around the Chambishi copper mine (Economy watch, 2010).

4.1.5.2 AGRICULTURE

Zambian territory encompasses 75 million hectares (752,000 km^2), of which 58 % (42 million hectares) is classified as medium to high potential for agricultural production. Roughly 15 % of this land is currently under cultivation. Overall, the climate is favorable for agricultural development and production. Zambia's climate is classified as mostly tropical, with some smaller sections classified as semi-arid. Average temperatures are comprised between 17.5 and 25.5 °C, and average rainfalls are between 0 and 200 mm of precipitation per month. Zambia is a landlocked country, but thanks to its numerous rivers, lakes, and underground water resources, it is home to 40 % of Southern and Central Africa's water resources (Zambia Invest, 2016).

The Zambian agriculture sector comprises crops, livestock, and fisheries. The country's staple and most commonly cultivated crop is maize. Other major crops include sorghum, rice, peanuts, sunflower seeds, vegetables, flowers, tobacco, cotton, sugarcane, cassava (manioc, tapioca), and coffee (CIA, 2017). Zambia is also known for being one of the largest seed exporters in Africa, exporting a recorded total of 17,891 tons of certified seeds to other African countries in 2011. The livestock sector produces everything derived from cattle, as well as dairy products, chicken, eggs, pigs, hides and skins. Fisheries produce 70,000 metric tons of fish per year, accounting for about 3.2 % of Zambia's GDP, 87 % of the production comes from capture fisheries and 13 % from the newly implemented aquaculture. The Zambian fisheries sector currently produces less than half of its fully exploited potential (Zambia Invest, 2016).

4.1.6 POLITICAL AND SOCIO-ECONOMIC SITUATION

After the establishment of the National Independence Party in 1958, and the growing popularity of African Nationalism, elections were eventually held. In 1964, Zambia became an independent country with Kenneth Kaunda as president. President Kaunda struggled with severe economic problems throughout the 27 years that he held office. Despite his difficulties he was celebrated for encouraging local industry and introducing mass education.

Modern Zambia has a multi-party democracy. The most recent elections took place in September 2011, and Michael Sata was voted president. President Sata died while in office in 2014. Acting president Edgar Lungu led celebrations marking the 50th anniversary of Zambia's independence (Hill, 2015).

Zambia is officially a Christian nation according to the 1996 constitution, but a wide variety of religious traditions still exist. Traditional religious thoughts blend easily with Christian beliefs in many of the country's syncretic churches giving the people ease with assimilation. The 2014 CIA estimated the average life expectancy in Zambia was 51.83 years, with 60.5 % of the population living below the poverty line as of 2010 (CIA, 2017).

4.2 COPPERBELT PROVINCE

4.2.1 BASIC INFORMATION

The Copperbelt province in Zambia is rarely chosen as a tourist destination unless the visitors are members of the mining industry. The area covers the bush and farming areas of the south and the mineral-rich Copperbelt. It is known as the industrial heart of Zambia. On average, the Copperbelt Province is home to as much as 15 % of the Zambian population, making it a major population center like Lusaka. During the British colonial rule, the Copperbelt Province was the backbone of the Northern Rhodesian economy. It was an optimistic cornerstone for the post-independence period. However, in 1973, it’s economic importance was severely threatened by a drop in world copper prices. The Copperbelt Province borders the Katanga province, located in the Democratic Republic of the Congo (DR Congo), which is also a mineral rich area. The Copperbelt province consists of ten districts where the population is growing rapidly. There was an increase to 2,420,678 inhabitants shown by a census in 2016, almost doubling the 1990 census reading of 1,458,459 (Brinkhoff, 2016).

Kitwe, Mufalira, Ndola, Luanshya, Chililabombwe, and Chingola are the Copperbelt's main cities. Thanks to the mining industry the transport paths are relatively well developed, roads and railways even extend north into the DR Congo and Lubumbashi. However, the Second Congo War suspended economic relationships between the two countries. They are now recovering politically.

The capital city of the Copperbelt province is Ndola. It offers a relatively peaceful and clean atmosphere. It is quite small in comparison to Lusaka, the capital of Zambia. The population was recorded in 2010 at 444,194 inhabitants.

Chililabombwe was formerly named Bancroft, which translates to “place of the croaking frog”. Mining copper is the principal economic activity. It has a population of 90,530 as seen in a census taken in 2010.

In 2008, Chingola’s population was listed at 157,340 residents. The Nchanga Copper mine, a high-grade deep shaft copper mining operation, is located in Chingola. In the 1960’s it led to the development of two open pit operations, the Chingola open pit, and the second biggest open pit mine in the world the Nchanga Open Pit.

Kalulushi, in North-central Zambia, is another town in the Copperbelt Province. A 2000 census showed a population of 75,806 inhabitants. In 1958 it became a public town after five years as a “company town” for the workers of the nearby copper and cobalt mine Chibuluma.

Kitwe is the second biggest city in Zambia and the core of the country’s mining industry. A census in 2010 put the population at 504,194 inhabitants. Like Ndola and

Lusaka, Kitwe is one of the most commercially and industrially developed areas in the nation. On its western and north-western borders are a vast array of mines.

Early in the 20th century, a prospector and explorer named William Collier was hunting a Roan Antelope along the banks of the Luanshya River in Northwestern Zambia, near the border of the DR Congo. Collier felled the antelope and upon retrieving the body discovered an exposed vein of copper ore. The town of Luanshya was founded soon thereafter and the mining company Roan Antelope Copper Mines Ltd. was formed to investigate Collier's discovery. The town is in the Lufwanyama District of the Copperbelt Province (Fitzpatrick et al., 2013; MLGH, 2017).

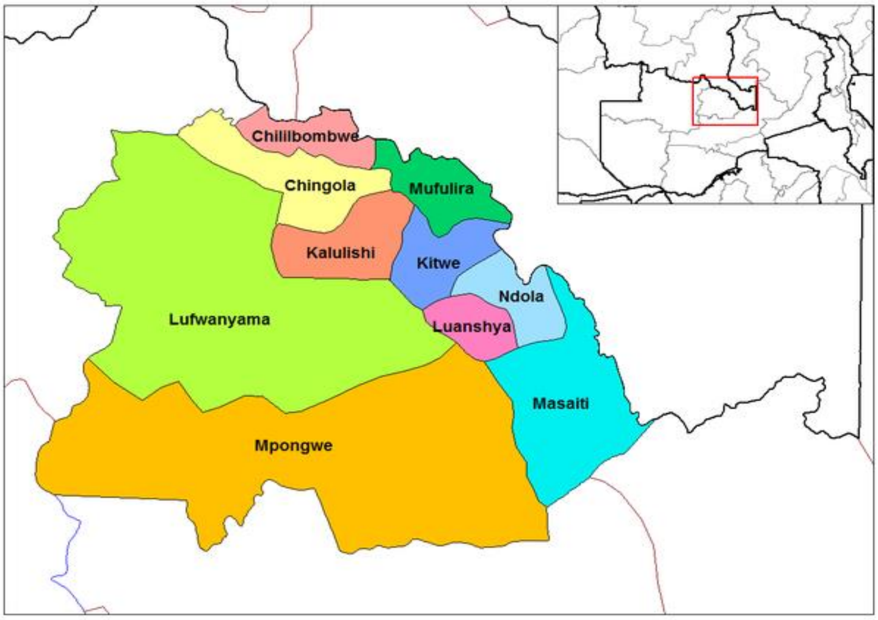

FIGURE 2: MAP OF THE DISTRICTS OF THE COPPERBELT PROVINCE IN ZAMBIA.

Source: (Rarelibra, 2006)

4.2.2 HISTORY OF MINING AND QUARRYING

Mining and refinery shaped the growth and development of Zambia. It contributed to the formation of its economy, caused an interest for investors, and encouraged immigration as the opening of mines created work opportunities for people from all walks of life. This growth was sparked when geological exploration lead to mining in Zambia during the 1920s.

When the British South African Company found the area to be rich in copper, containing one of the highest-grade copper seams of the world, they began to offer prospecting rights to large multinational companies. This resulted in the discovery and development of various mines such as Luanshya and Nkana Mines (1931), Mufulira (1933) and Nchanga (1936), Konkola and Nchanga (1957), Chibuluma Mine (1964) Chambeshi Open pit (1965), Bwana Mkubwa (1971) and Chambeshi underground mine (1972) under the main companies of Roan Selection Trust and Anglo American Corporation. Annual Zambian copper production peaked at over 755,000 t/y in 1969. In the same year, the Zambian government nationalized the industry by acquiring a 51 % stake in all mining utilities and reorganised them into Nchanga Consolidated Copper Mines Limited (NCCM) and Roan Copper Mines Limited (RCM). In 1979, this stake was further increased to 60.3 % (Mwansa, 2007).

The governments support of their profitable mining and exportation proved to be an economically dangerous decision and Zambia fell into poverty in the 1970's after international copper prices declined. In an attempt to redress falling production trends, NCCM and RCM were merged into Zambia Consolidated Copper Mines Limited (ZCCM) in 1982 (Mwansa, 2007). Unfortunately, nationalization did not have the desired affect that the newly independent country and government had envisioned and by the 1990's the mining industry was producing a meager 200,000 t/y (GBR, 2014).

Zambia turned into a multi-party state in 1991 and the government endeavored to privatize the parastatal companies, this included the mining industry. By March 2000, the privatization of the largest mining assets was finished. A 51 % stake in Konkola Copper Mines (KCM) was acquired by Anglo American. KCM, at this time, had mining operations in Konkola and Chingola, and refining/smelting operations in Nkana. In 2002 Anglo American withdrew as KCM shareholders, making the two government entities ZCCM and Zambia Cargo & Logistics Limited the main shareholders. This changed again in November 2004 when Vedanta Resources (VR) acquired a 51 % share in KCM. In 2008 VR increased its share to 79.4 %. Since its initial acquisition, KCM has invested over 2.9

billion U.S. dollars to expand capacity, build new facilities, and upgrade equipment. These investments added 25 years to the life of the mines (KCM, 2017).

The privatization of mining companies, started to draw much needed foreign direct investment and was the lifeline that saved the Zambian economy from total collapse. Thus, Zambia's privatization efforts are continuing to pay off with the country's copper output, rising to an estimated 800,000 t/y in 2012, accounting for 4.8 % of global copper production (Mining Indaba, 2016).

TABLE 1: TRENDS IN COPPER PRODUCTION 1973 - 2014 (IN METRIC TONS).

1973	750,000
1980	550,000
1991	400,000
1992	441,531
1993	402,950
1994	360,347
1995	275,000
1997	263,000
2000	200,000
2004	398,000
2005	467,000
2006	600,000
2011	675,000
2012	800,000
2014	700,000

Source: (Bank of Zambia, 2014)

4.2.3 ENVIRONMENTAL IMPACT OF MINING

The term pollution has many interpretations. One simplified version is "Pollutants are substances and levels of energy present at the 'wrong' time, in the 'wrong' place and in the 'wrong' quantities." A more comprehensive alternative is: "Environmental pollution is the unfavorable alteration of our surroundings, wholly or largely as a by-product of man's action, through direct or indirect effects of changes in energy patterns, radiation levels, chemical and physical constitution and abundance of organisms" (Nicoll, 1988).

Large-scale mining has several impacts on local communities, including dislocations and displacements, effects on employment, health and safety, a reduction in corporate social responsibility, and an increase in environmental degradation. Contestations and arguments over access to mineral wealth can cause implications for human security. The way in which these issues are handled can affect the relationship between local communities and mining companies on one side, and the people and their government, on the opposing side (Simutanyi, 2008). The business side of mining has always been centered on profit making. Keeping this in mind it is no surprise that the huge tons of copper and cobalt produced over a span of 75 years of mining on the Copperbelt produced enormous amounts of waste as a result of the mining and processing (Mwansa, 2007).

Human endeavors that lead to pollution are a danger to the environment because they contaminate the environment with materials that interfere with human health, the quality of life or the natural functioning of the living organisms and their surroundings (Connect, 2016). The cost of mining to the Zambian and Ghanaian economies goes far beyond the loss of profit from taxation or export fees. The real price of copper includes the pollution of water and air caused by mining and transportation, the negative health effects and diminished quality of life for the local populations, the cost of decommissioning mines and smelters, and the depletion of the finite resources that will not be available to future generations. These are known as 'externalities', which means real costs that will be borne by people and governments at present and in the future, but which are not included in the market price of a resource. Ecological economist Maarten De Wit values the real cost of copper (including externalities) at US$ 33,000 per ton, four to five times the current market price. The price is high because copper is one of the most material intense metals to produce - creating 500 tons of waste and using 260 tons of water for each ton of primary copper yielded (Das and Rose, 2014).

The effects of mining impact thousands of kilometres of streams and rivers, contaminating the environment with copper, zinc, lead, cobalt, arsenic, and mercury.

The most toxic form mercury is found in organic compounds (methylmercury). This is the form it takes when it is found in fish. Mercury by itself is not extremely poisonous. However, its compounds can cause neurological disorders, vision disorders, muscle weakness, fatigue, decreasing reproductive ability, and it can also pass through the placenta and cause fetal psychomotor harm (Maršák et al., 2008).

Lead can be highly toxic. It is more harmful in children than in adults. Low levels of exposure in children can cause peripheral and central nervous system damage, shortened stature, learning disabilities, impaired function and formation of blood cells, and impaired hearing. Lead stores in the bone alongside calcium and accumulates in the body over time. This is very dangerous during pregnancy because it is released from the bones as maternal calcium and will help form the fetus's bones. If the mother is deficient in dietary calcium there will be more lead in the fetus's bones. Lead also easily passes through the placental barrier. Negative side effects can be seen in the fetus and the mother potentially leading to premature birth, decreased kidney function, and reduced fetal growth (EPA, 2017).

4.2.3.1 HYDROLOGY AND WATER SITUATION

In October 2015 Foil Vedanta journeyed for the second time to Vedanta's subordinate company Zambian Konkola Copper Mines (KCM) to research the legacy of pollution that has detrimentally impacted livelihoods and the environment around Chingola since 2004. (Controlling shares in KCM were bought by Vedanta in 2004.) KCM is Africa's biggest copper mine and the biggest mining company in the copper dependant economy in Zambia. Their report from 2014 "Copper Colonialism: Vedanta KCM and the copper-based economy of Zambia" describes gross contamination that constantly pollutes the Kafue river, and continually causes sickness and the loss of livelihood for tens of thousands of residents (Foil Vedanta, 2016).

"We visited communities living around Vedanta-KCM's mines and refineries in the Copperbelt. Helen and Shimulala communities are located near KCM's Nchanga mine in Chingola. They are home to 400 people. Pollution from KCM's tailings dam number 2 (known as TD2) has contaminated their water supply as well as the Mushishima stream which runs nearby. Local residents told us that KCM drilled them a borehole after the stream became contaminated but when they took samples it was also polluted with copper sulphate. They allege that a water tank subsequently delivered by the company also contained contaminated water. With no clean water source in their village residents now walk to a shallow well they have dug in marsh to fetch dirty water. They fear this may also be polluted" (Das and Rose, 2014).

The second visit proved no better. A video was made documenting acidic material overflowing from the raffinate tanks and running straight into the Chingola stream, after it had been used to leach out copper in the Tailings Leach Plant (TLP). After flowing into the stream the spillage reaches the Mushishima stream and then the river Kafue. The Kafue river provides drinking water for 40 % of Zambians. It also demonstrates KCM's inability to maintain important pollution control devices that were specifically manufactured to stop acid wastes from entering the environment (Foil Vedanta, 2016).

After years of research, Development Cooperation Programme of the Czech Republic in cooperation with Czech Geological Survey and many others, published a document mapping the track of water pollution. In their research an extent of contamination of stream sediments with metals was evaluated using the Coefficient of Industrial Pollution, which is an average of concentrations of selected metals in stream sediments at individual sampling points, divided by the median values of the same metals in stream sediments of the whole region (Kříbek and Nyambe, 2002).

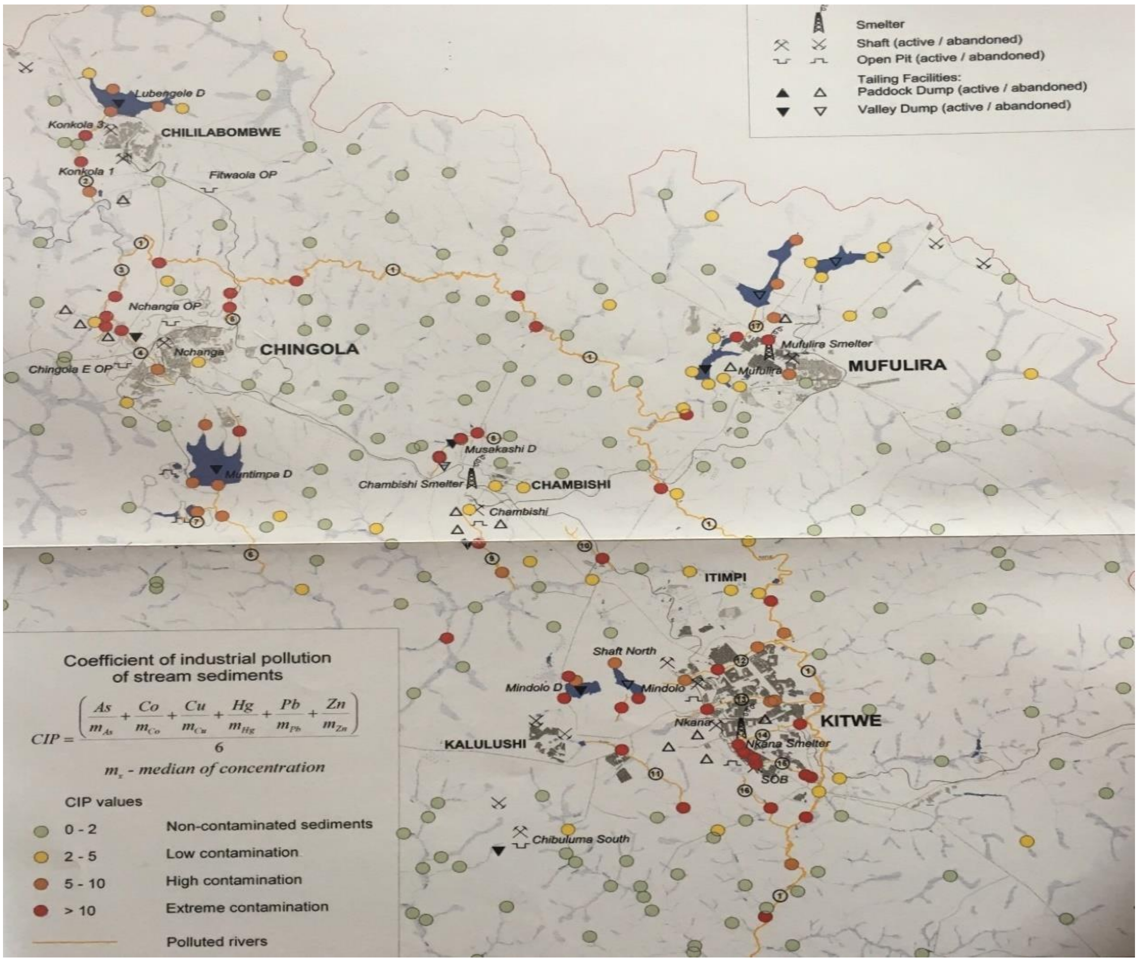

FIGURE 3: THE COEFFICIENT OF INDUSTRIAL POLLUTION FOR STREAM SEDIMENTS.

Source: (Kříbek et al., 2007)

"*Classed post map of the Coefficient of Industial Pollution (CIP) for stream sediments in the Central-Northern part of the Copperbelt in Zambia. The CIP scale is based on statistical characteristics of data set. Abbreviations: D – DAM, OP – Open Pit, E OP – 'E' Open Pit, SOB – South ore body*" (Kříbek et al., 2007).

In figure 3 we see the contamination of many test sites. The contamination sources rapidly decrease downstream due to the rapid sedimentation of mineralised suspensions and rapid precipitation of dissolved metals. Therefore, the source of Kafue River contamination represents only the Lubengele, Mushishima and Changa rivers in the area of Chililambwe and Chingola, and the Mindolo, Kitwe, Uchi, Busakile, and Lwanshimba rivers in the Kitwe region. It is important to note that low CIP values for the stream sediments indicate either low industrial contamination or primarily increased amounts of metals in the soils (Kříbek et al., 2007).

4.2.3.2 Soil

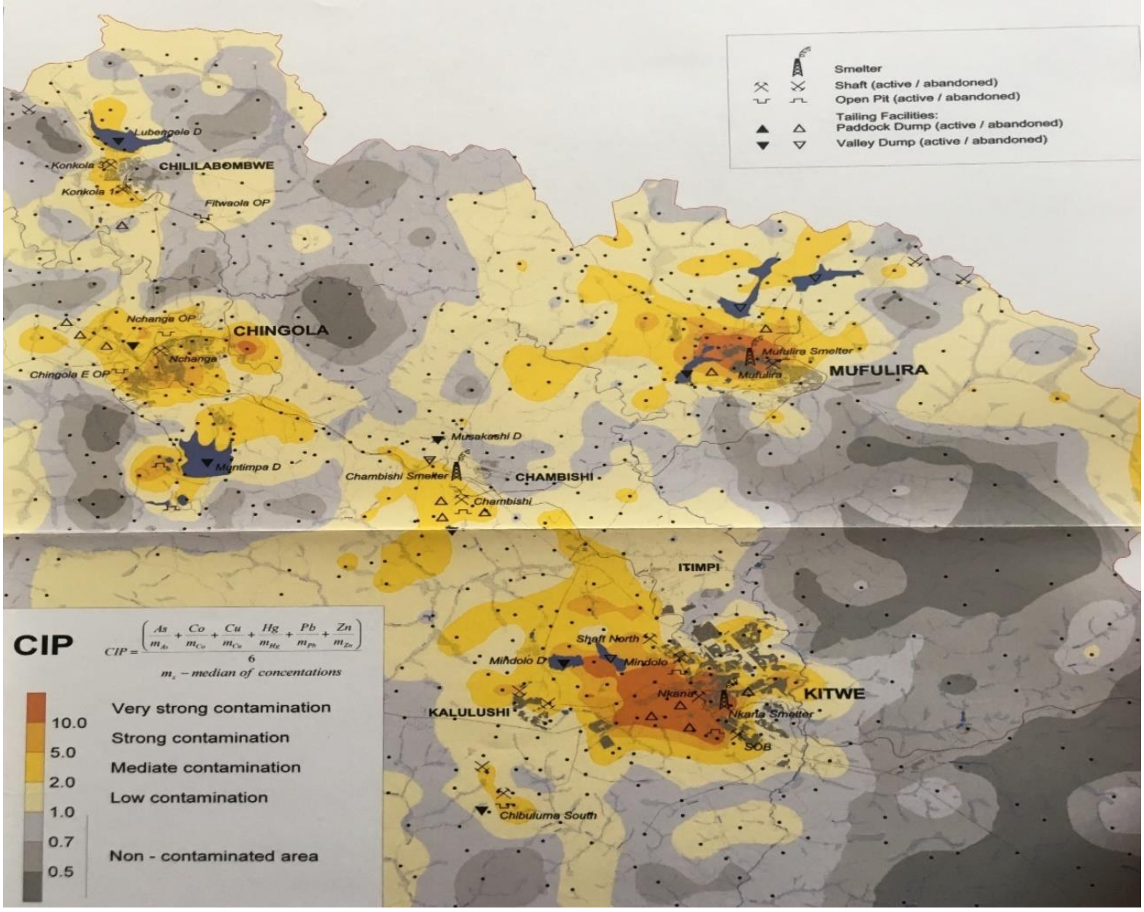

FIGURE 4: CONTOUR MAP OF THE COEFFICIENT OF INDUSTRIAL POLLUTION IN SURFACE SOILS.

Source: (Křibek et al., 2007)

"Contour map of the Coefficient of Industrial Pollution (CIP) in surface soils in the Central-northern part of the Copperbelt Province Zambia. The CIP scale is based on statistical characteristics of data set. Sampling points are shown as black dots. Abbreviations: D - Dam, OP - Open Pit, E OP – 'E' Open pit, SOB – South Ore Body" (Křibek et al., 2007).

Copper content is always higher in surface soils than subsurface soils. This indicates an anthropogenic contamination in the survey area. The surface soil copper concentrations were noted to be the highest (greater than 1800 ppm) around smelters and downwind in the northwest direction. Areas around tailing impoundments showed heavy top-soil contamination as well due to dust fall-out from the dry "beaches" of the impoundment. The copper content of the subsurface soil did not match the local geological data and was indicative of the introduction of a dissolved copper species, or some form of copper rich dust, into the soil profile to a depth of at least 70 to 90 cm. The copper infiltration was likely facilitated by the low pH of the soil (Kříbek et al., 2007).

4.2.3.3 AGRICULTURE

Contaminated water can cause serious problems when used in crop irrigation and farming. It can reduce yields, stunt growth and accumulate contaminants in the crops. If it makes its way to fisheries it will also accumulate in the fish (Foil Vedanta, 2016). The Czech Geological Survey performed a study in 2007 which showed that cassava and sweet potatoes build up substantial amounts of contaminants in their roots and leaves. Maize is not as susceptible. Heavy metal content in plants is based on many things like the plant's age, the metal speciation, the chemical properties of the soil, the degree of contamination, and other variables. For example, studies showed that sweet potatoes that were in less contaminated areas only had increased metal content in their leaves, but sweet potatoes in more heavily contaminated areas had increased metal content in the roots as well as the leaves. This is exceptionally evident with arsenic, lead, and copper. Sweet potatoes growing around Mufalira and Nkana smelters and the area between Chingola and Kitwe showed heavy contamination in the leaves. The eastern portion of the surveyed area was less contaminated (Kříbek et al., 2007).

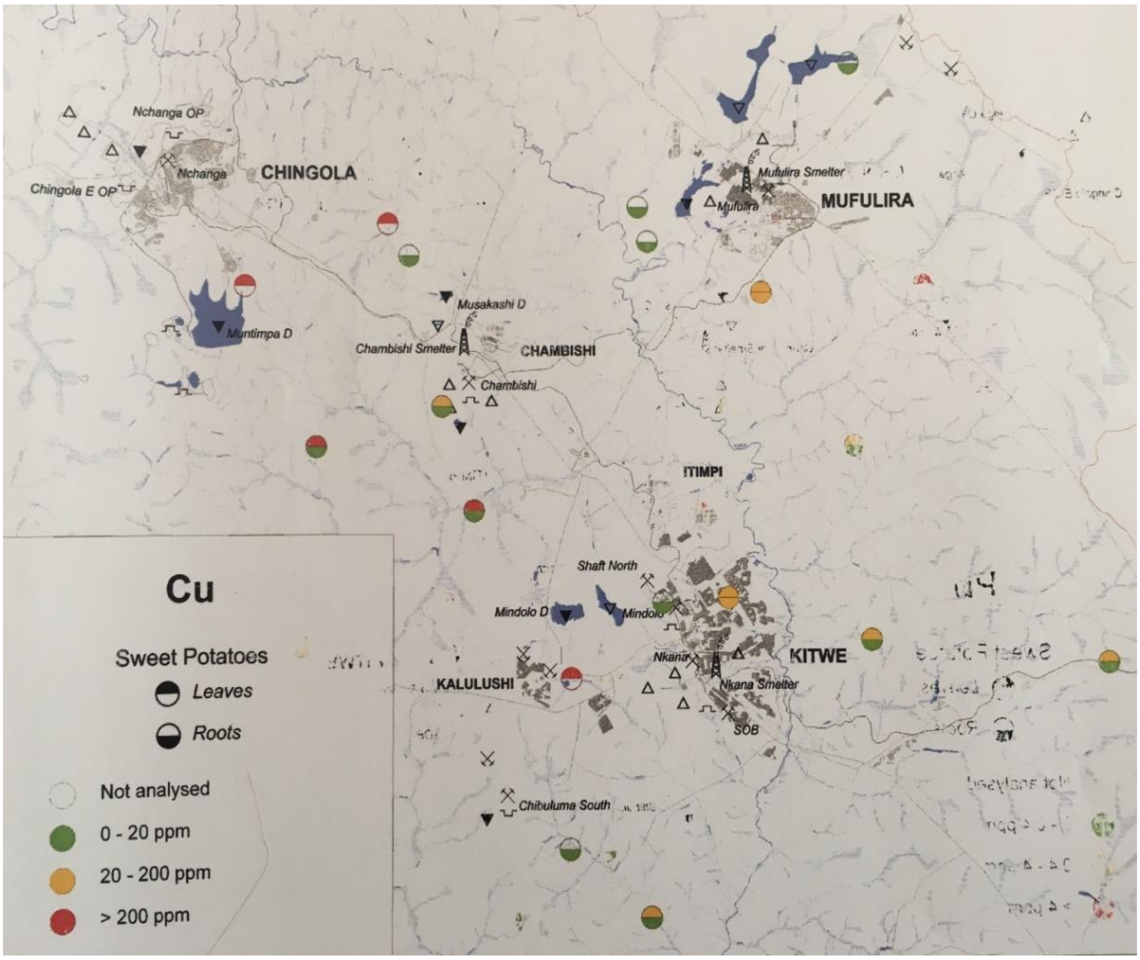

FIGURE 5: THE CONTENT OF COPPER IN FRESH SAMPLES OF SWEET POTATO.

Source: (Křìbek et al., 2007)

"The content of copper in fresh samples of sweet potato leaves (upper semi-circle) and roots (lower semi-circle) in the Central-northern part of the Copperbelt Province of Zambia. Empty semi-circle indicates that leaves or roots were not available. ABbreviations: D – Dam, op – open pit, e op - 'E' Open pit, SOB – South Ore Body" (Křìbek et al., 2007).

4.3 Industrial Wastewater Treatment Technologies

4.3.1 Mining, Heavy Metals, and Water

There are various different mining processes currently in use throughout the world. All of which result in one form or another of wastewater. Excessive levels of toxic heavy metals present in the wastewater are a key factor in the continued destruction of local environments and ecosystems. Toxic heavy metals are defined as having a specific gravity of 5.0 or more and being poisonous in nature. They include zinc (Zn), nickel (Ni), chromium (Cr), and copper (Cu). The term is used broadly, however, and can also reference the presence of cadmium (Cd), lead (Pb), arsenic (As), selenium (Se), and mercury (Hg). Also present in the wastewater can be various acids, oils, and hydraulic fluids from the mining process and various machinery used.

There are a plethora of different filtration processes available for the removal of the aforementioned contaminants. The following paragraphs will investigate two processes based on equipment available from the American company ALAR Waste Pollution Control Systems. Both processes are designed to produce water that will be clear and safe to discharge into a sewage system and maintain the contaminants in a solid state. The solid state waste will need to be disposed of appropriately in a government regulated landfill. The two processes boast the ability to reduce solid contaminants by 95 % when the filtration process is complete. The filtered water can also be recycled back into the filtration process or reused in the mining process reducing the need for constant fresh water.

The two systems of filtration explained are the rotary vacuum precoat drum filter system and the plate and frame filter press system. Both systems require at least one of two mechanical pretreatments if not both. Depending on whether or not various oils are present or what stage of the mining process the wastewater being filtered was derived from will determine which of the two available mechanical pretreatment processes are necessary. The Dissolved Air Flotation System (D.A.F.) is a mechanical pretreatment device used to remove various oils and contaminants that are less dense than water. It will also allow for the removal of fine solids. The alternative mechanical pretreatment device is a gravity settling tank also known as a baffled decant system and is used prior to the use of either of the two filtration systems as it is designed for removing large solids. After one or both of the mechanical pretreatment phases are complete, a chemical pretreatment phase must occur to solidify the contaminants and or adjust the pH for optimal filtration (ALAR, 2017).

4.3.2 Mechanical Pretreatments

4.3.2.1 DISSOLVED AIR FLOTATION MECHANICAL PRETREATMENT

ALAR offers a mechanical pretreatment device called the D.A.F. A slurry or wastewater mixture is pumped into the D.A.F. system where dissolved air is utilized to induce the flotation of fine solids, oils, and grease. The floating contaminates are then skimmed off the surface with a mechanically operated wiper blade and discharged into a sludge trough. The sludge can then be pumped to a tank for chemical pretreatment before being transferred to a dewatering filter such as the rotary vacuum precoat drum system or the plate and frame filter press system (ALAR, 2017).

4.3.2.2 GRAVITY SETTLING TANK OR BAFFLED DECANT SYSTEM

ALAR also offers the more commonly used gravity settling tank that they have aptly named the Clarifier. "The Clarifier produces a clear effluent through the separation of liquids from settleable solids and free floating suspended solids. The concentrated sludge 'sinks' to the bottom of the clarifier" where it can be pumped to a tank for chemical pretreatment before being transferred to one of the above-mentioned dewatering filtration systems (ALAR, 2017).

4.3.3 DEWATERING FILTRATION SYSTEMS

4.3.3.1 PLATE AND FRAME FILTER PRESS SYSTEM

Waste is transferred to a treatment tank where it is tested to determine the amount and type of chemicals needed to solidify the contaminates and adjust the pH of the mixture for optimal filtration. The chemically treated wastewater is then pumped through the machine where it is pressurized and passes through a series of filter cloths. The type of contaminate that is desired to be removed will determine the type of filter cloth used. After the water passes through the filter cloths, the frames that the filtration cloths are built into are compressed through a hydraulic process to remove any additional water. The fresh water can now enter any sewer system or be reused in the filtration or mining process. At this point, an air purge valve is opened, further drying the solid wastes. The pressure is then taken off of the filtration cloths allowing the captured contaminants to fall free in the form of solid cakes. These “waste cakes” can then be disposed of properly in government regulated landfills (ALAR, 2017).

FIGURE 6: EXAMPLE OF THE PLATE AND FRAME PRESS SYSTEM IN USE.

Source: (Alibaba, 2016)

4.3.3.2 Rotary Vacuum Precoated Drum Filter System

As before, waste is transferred to a treatment tank where it is tested to determine the amount and type of chemicals needed to ready the mixture for optimum filtration. Chemical pretreaters can include pH adjusters, polymers to bond to the contaminates, and clays which serve the same purpose.

While the chemical pretreatment phase is taking place the filter operator mixes water and Diatomaceous Earth (D.E.), a filtration medium. He then runs it through the machine where a vacuum draws the slurry onto a filtration cloth that is wrapped around a rotating drum. The D.E. cakes onto the drum forming a filtration medium that reaches a thickness of three inches. This process turns the drum into an ideal filter capable of filtering particles as small as 0.5 of a micron.

Prior to filtration the chemically pretreated waste, now referred to as suspended contaminant solids, are kept under agitation to create a homogeneous mixture, ensuring optimum filtration. The homogenous waste mixture is then pumped into the filter pan where the same vacuum draws the liquid through the filter media. The solid wastes accumulate on the surface of the D.E. As filtration continues a variable speed knife advances against the surface of the D.E. and removes the solid waste into a containment pan. The solids can then be collected and disposed of properly at a government regulated landfill. The filtered water is then safe to discharge and can be pumped into any sewage system or as mentioned before reused in the various filtration and mining processes (ALAR, 2017).

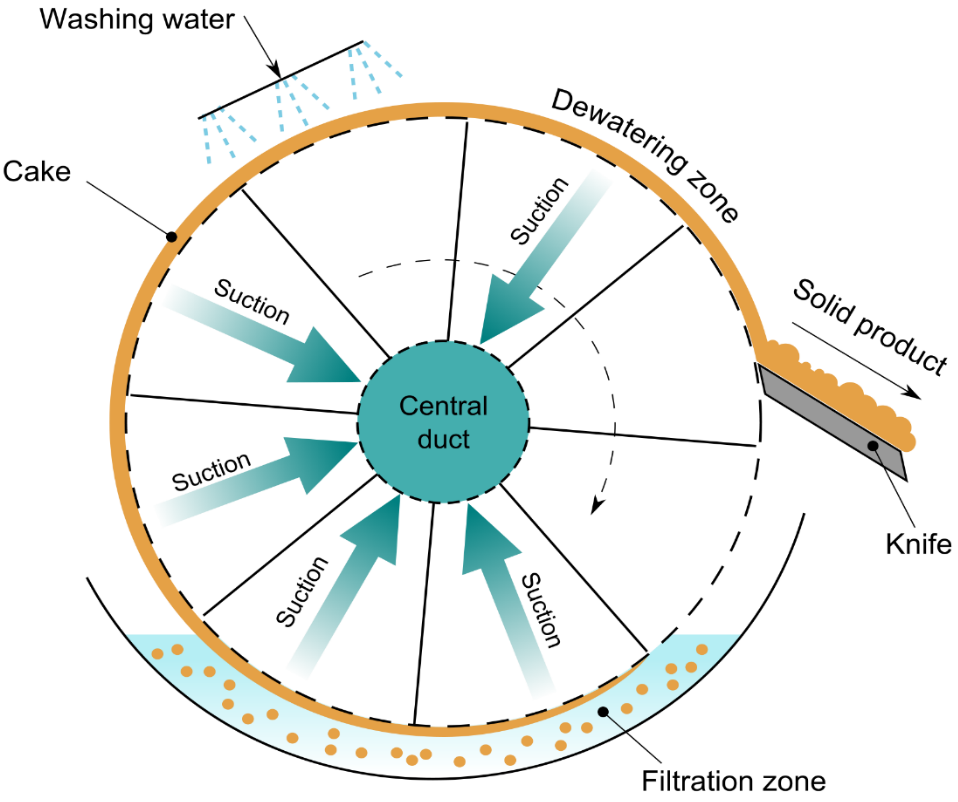

FIGURE 7: SCHEME OF THE ROTARY VACUUM PRECOATED DRUM FILTER SYSTEM.

Source: (Aushulz, 2009)

4.4 DRINKING WATER TREATMENT TECHNOLOGIES

Two important forms of water treatment are Point of Use (POU) and Point of Entry or “whole-house systems” (POE). Their processes include the addition of components or chemicals, and filtration. The components added can include aluminum, carbon, coagulants (to aid in filtration), and iron salts. POE systems usually treat the majority of water entering a dwelling, and are plumbed in after the water meter. Point of use systems usually treat water in specific quantities or “batches” and provide the treated water to one tap, like a kitchen sink or drinking fountain (CDC,2008).

4.4.1 Filtration

Filtration occurs in all states of matter, be it solid, gaseous, or liquid. It is the act of a solid being held within the pores of, or affixed to the surface of a filtration medium that allows the liquid or gas being filtered to pass through. Typically filtration is used to remove contaminants, however it can also be used to maintain or yield a desired component. The process depends entirely on what is being filtered, how much of it there is, the charge, and the size. In water filtration a membrane is often used, along with various additives to aid in filtering and protect the membrane (Fuller et al., 1997).

4.4.1.1 MICRO FILTRATION

Microfiltration is commonly used in water filtering and highly effective. It’s membrane has a pore size of approximately 0.1 micron (pore size ranges vary by filter from 0.05 micron to 5 micron). Based on this fact it is typically ineffective in removing chemicals or viruses. However, it is highly effective in removing protozoa like Giardia and Cryptosporidium. It is also moderately successful in removing bacterium like Salmonella, E. coli, Campylobacter, and Shigella (Hassan, 2015).

4.4.1.2 ULTRA FILTRATION

Ultra filtration is a highly effective process that filters based on a particles weight, size and charge. It’s filters have a pore size of roughly 0.01 micron (pore size ranges vary by filter from 0.001 micron to 0.05 micron, Molecular Weight Cut Off [MWCO] of 13,000 to 200,000 Daltons). As with micro filtration it can filter protozoa and bacteria. Its also has a very moderate success rate for filtering viruses, such as Hepatitus A, Nor Virus, Enteric, Rotavirus etc. It is not very effective in removing chemicals (Hassan, 2015).

4.4.1.3 Nano Filtration

Nano filtration takes it one step further. Nano filters have a pore size of 0.001 microns (pore size ranges vary by filter from 0.008 micron to 0.01 micron, Molecular Weight Cut Off [MWCO] of 200 to 2000 Daltons) and are highly effective in the removal of protozoa, bacteria and viruses. Nano filtration is also moderately effective in removing chemicals (Hassan, 2015).

4.4.1.4 Osmotic Reversion

Currently, reverse osmosis is the best practical filtering technology in use. It is also the most widely used technology for cleaning and bottling water. It is highly effective in eliminating and reducing a large array of contaminants, more than any other technology currently in use for water filtration. It has the ability to remove particles as small as ions. The membranes pores are 0.0005 microns. This is sufficient for filtering bacteria, typically 0.2 to 1 micron, and viruses, typically 0.02 to 0.4 microns (DMA, 2013). It is capable of removing common chemicals such as metal ions and aqueous salts including sodium, chromium, chloride, copper, and lead. It may also reduce arsenic, fluoride, radium, sulfate, calcium, magnesium, potassium, nitrate, and phosphorous (CDC, 2008).

FIGURE 8: REVERSE OSMOSIS IN USE.

Source: (Water Softener Guide, 2017)

The United States has been using this technology in households for cooking and drinking water ever since the nineties, but reverse osmosis has very large range of uses including laboratories, as a substitute for distillation, gastronomy, hydroponics, aquaria, engineering, laser cutting, machining etc (DMA, 2013).

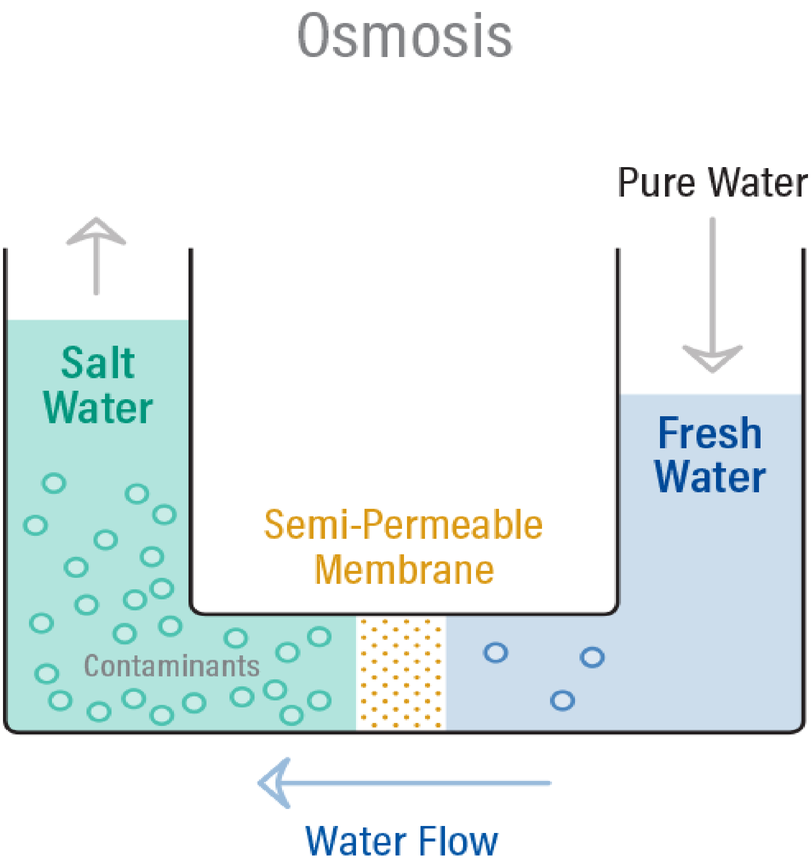

FIGURE 9: PRINCIPLE OF THE REVERSION OSMOSIS.

Source: (Puretec Industrial Water, 2017)

5. CONCLUSIONS

As mentioned, the Copperbelt province is an important water source for Southern and Central Africa. However, mining such massive amounts of copper since the 1920s has created detrimental consequences. The region has serious issues with water, air, and soil pollution as well as with the products of local agriculture. After reading the studies conducted in the Copperbelt province, it goes without saying that food safety and public health is threatened, due to the mining companies and institutions desire for profit generation. These entities have far greater powers than the local affected population. The growing population of nearby towns increases the need for drinkable and quality water every day. If we want to ensure a good quality of life for locals and later generations, it is necessary to start using sufficiently functioning and protective technologies.

In the thesis, markedly polluted places were shown in accordance with research performed by the Czech Geological Survey. Water pollution is the worst in Kitwe and its surroundings, followed by the cities of Chingola, Mufulira and Chambishi. Of course, we must take into account that this pollution continues to the next streams, polluting the Kafue River, which is a significant sized river and the largest tributary to the Zambezi.

Regarding the soil, significant amounts of contamination, classified as very strong, are present in Kitwe and Mufulira. There are other less contaminated areas, which still suffer from strong and medium contamination. In the agriculture sector, studies recommend reducing cultivation and consumption of cassava and sweet potato in areas where arsenic (As) exceeds 5 mg/kg, copper (Cu) 200 mg/kg and lead (Pb) 4 mg/kg. This applies to much of the Copperbelt area.

It is necessary for mining companies to use technologies that are sufficient in ridding water of toxic substances. The waste must then be removed and disposed of properly in a landfill so that the leakage of dangerous substances into streams and rivers will be prevented. Classic filtration may assist in solving the problem of contaminated water being used in family households.

It is interesting to compare how much more readily available informational resources are in regards to mining and investing in copper as opposed to the more limited availability of information regarding the effects of mining on the environment and its corresponding health consequences. I find it essential to inform local residents about the status of the environment, propose appropriate solutions, and prevent consumption of highly polluted water immediately.

Preventing additional pollution is of the utmost importance. This is because it is more expensive and difficult to treat and remove dangerous substances than it is to eliminate its sources. Stopping pollution at its source is the best chance to get ahead of the current situation.

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7. APPENDIX

FIGURE 10: NCHANGA SOUTH RESIDENTS SHOW WHAT COMES OUT OF THEIR TAPS.

Source: (Foil Vedanta, 2016)

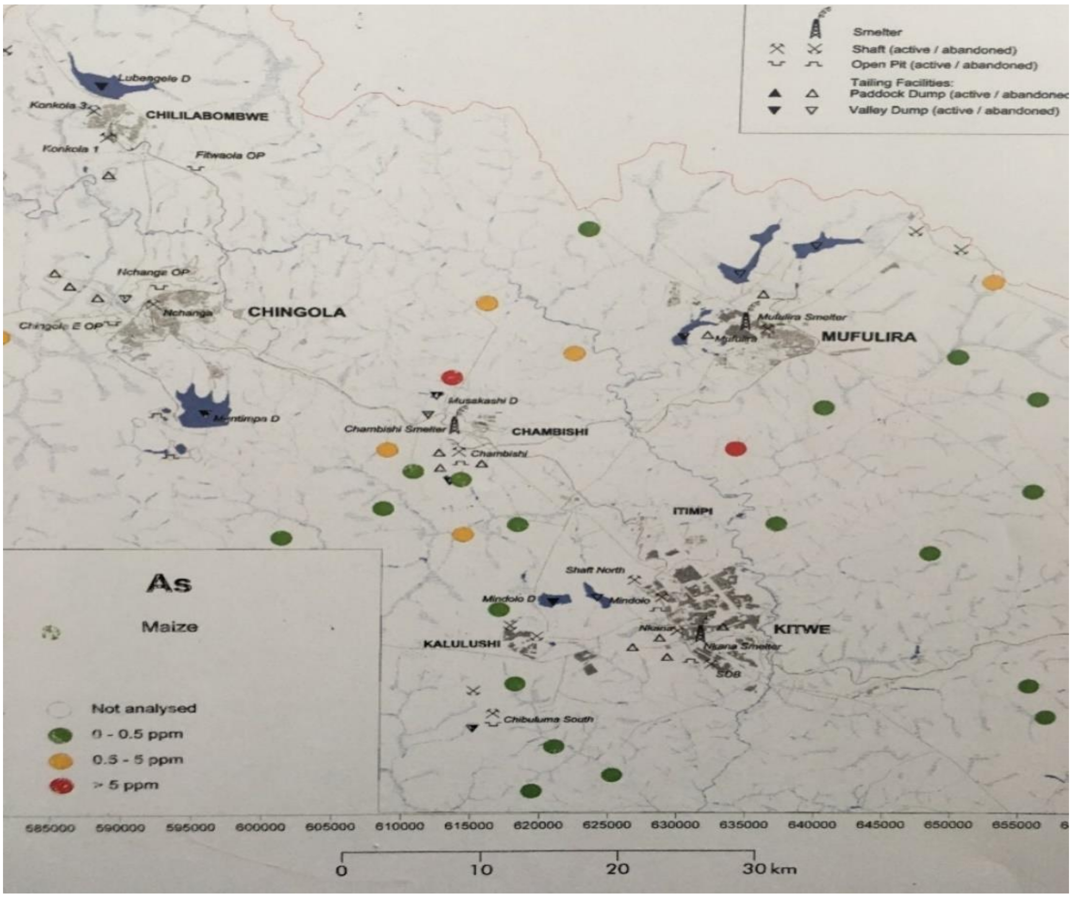

FIGURE 11: THE CONTENT OF ARSENIC IN FRESH MAIZE GRAINS.

Source: (Kříbek et al., 2007)

"The content of arsenic in fresh maize grains in the Central-northern part of the Copperbelt Province of Zambia. Abbreviations: D - Dam, OP- Open Pit, E OP – 'E' Open pit, SOB – South Ore Body" (Kříbek et al., 2007).

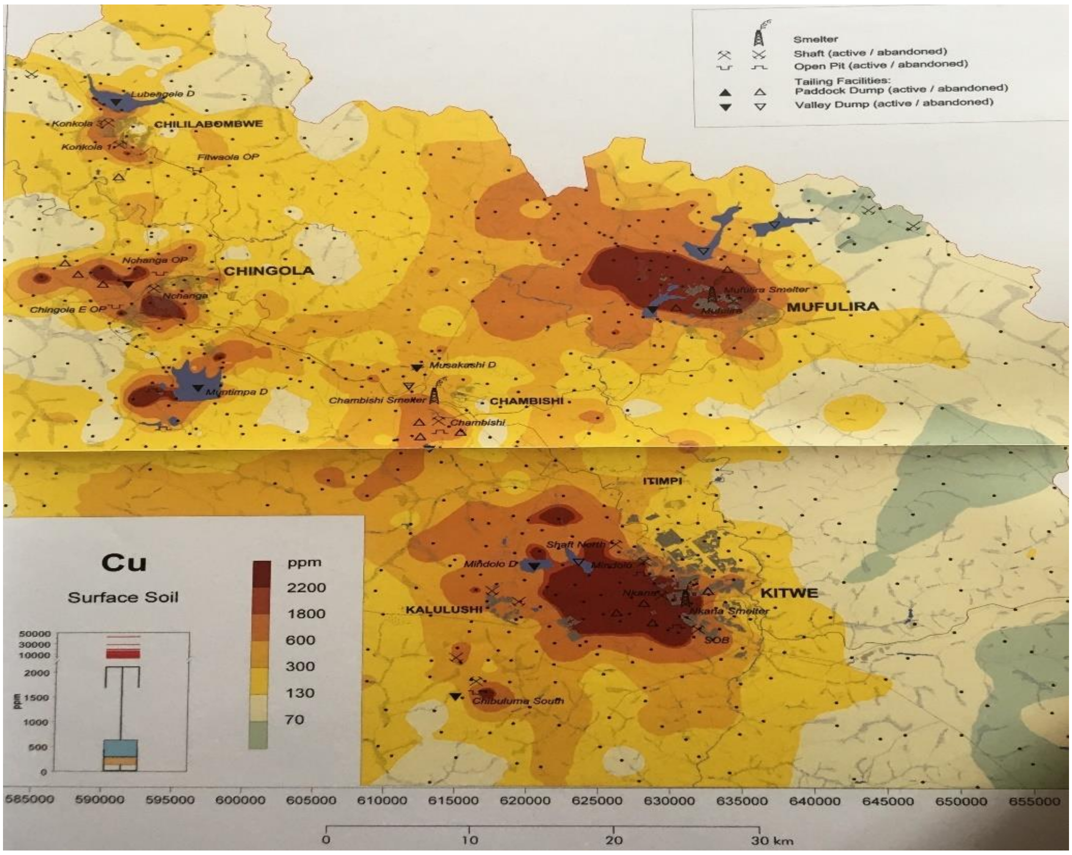

FIGURE 12: CONTOUR MAP OF COPPER VALUES IN SURFACE SOIL.

Source: (Kříbek et al., 2007)

“Contour map of copper values in surface soil in the Central-northern part of the Copperbelt Province Zambia. Distribution of data is given in boxplot. Sampling points are marked by black dots. Abbreviations: D-Dam, OP-Open Pit, E OP – ‘E’ Open pit, SOB – South Ore Body” (Kříbek et al., 2007).