Research Article

Mitigating the Concentration of Arsenic in Drinking Water in Mining Areas Using Ferric Hydroxide Soil Samples in Response to the Incidence of Cancer Diseases: A CASE STUDY IN KITWE, COPPERBELT PROVINCE

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Abstract

The aim of this study was to analyze the concentrations of arsenic in drinking water for Kitwe residents and mitigate arsenic in water samples using the adsorption process of ferric hydroxide in response to the incidences of cancer diseases. The concentrations of arsenic before the adsorption process in the water samples from Mindolo stream were 22.2μg/L, Kafue River were 7.5μg/L whereas those from tap water were 4.6μg/L, respectively. After the adsorption process using two soil samples, clay soil and ferric hydroxide containing soil samples (SS1 and SS2), whose iron compositions were 24.46% and 38.22%, respectively, the concentrations of the water samples were as follows; Mindolo stream 5.4μg/L, Kafue river 5.4μg/L and tap water 0.9μg/L for clay soil sample one (SS1), whereas for in situ soil sample (SS2) after the adsorption process, the concentrations for water samples from Mindolo stream, Kafue river and tap water were 4.3μg/L, 2.5μg/L and 0.3μg/L, respectively. Therefore, making it possible for government to come up with sensitization programs about arsenic and make deliberate policies.

ABBREVIATIONS

ATP: Adenosine Triphosphate; BCC: Basal Cell Carcinoma; BFD: Black Foot Disease; CGH: Comparative Genomic Hybridization; CTS: Cancer Tissue Sites; DNA: Deoxyribonucleic acid; EPA: Environmental Protection Agency; HPV: Human Papiloma Virus; ICP-OES: Inductively Coupled Plasma- Optical Emission Spectroscopy; NCD: Non Communicable Disease; ROS: Reactive Oxygen Species; WHO: World Health Organization

INTRODUCTION

Background of the Study

In recent decades, there has been a rise in health problems that are Cancer-related. Globally, cancer is now the second leading cause of death, after cardiovascular diseases, in persons before the age of 70 years; an important barrier to increasing life expectancy worldwide. In the year 2020 alone, estimated 19.3 million new cancer cases and almost 10.0 million cancer deaths were recorded by the World Health Organization [1]. The magnitude of the statistics poses grave threat to human life. However, this increase in cancer-related cases is not distributed evenly in all countries across the world population. There are countries with escalating figures of cancer cases, and Zambia is one of the countries predominantly affected, with a record of over 12000 cancer cases annually [2].

Out of 19.3 million cancer cases reported worldwide by the World Health Organization in 2020, approximately 13831 (0.072%) were recorded in Zambia [2]. Worse still, over 60% of the 13,831 cancer-related problems, are prevalent in areas with mining activities, such as Kitwe and Chingola districts on the Copperbelt Province [3,2]. Moreover, given the country's population, which is hardly 20 million, the percentage scale of the disease is quite alarming and necessarily raises the question about the cause. What is causing the prevalence of cancer in these areas and are the mining activities contributing to this problem?

Cancer diseases and other non-communicable diseases such as cardiovascular diseases, chronic respiratory diseases, and diabetes which are by far the leading cause of death worldwide, are attributed to many factors, among them, human exposure to heavy metal elements and anions. These heavy metal elements and anions are arsenic, lead, cadmium, mercury, copper, phosphate, sulphates, among others. Human exposure to these

health hazardous heavy metal elements and anions is a result of human activities like agricultural activities, mining activities, manufacturing industrial activities and natural sources through food, air, water and soil [4]. Cancer arises from the transformation of normal cells into tumors in a multi- stage process that generally progresses from a pre-cancerous lesion to a malignant tumor. These changes are a result of the interaction between a person's genetic factors and chemical carcinogens such as arsenic: a drinking water contaminant, among other interactions, especially arsenic from groundwater; the greatest threat to public health. Scientifically, therefore, there seems to be a correlation between cancer-related cases and exposure to arsenic [5,1].

It has been determined that exposure to arsenic and inorganic arsenic compounds increases the risk of cancer based on epidemiological studies and case studies of individuals who were exposed to arsenic or arsenic compounds while working or obtaining medical care [6]. Tissues that can acquire cancer include the skin, lungs, digestive tract, liver, urinary bladder, kidney, lymphatic, and haematological systems. Angiosarcoma of the liver, intestinal lining, urinary bladder, and meningioma have all been recorded in conjunction with skin cancer in people who were exposed to arsenic for medicinal purposes; tumors of the membranes covering the central nervous system [7].

Of the mentioned heavy metal elements, arsenic, one of the toxic elements associated to incidences of cancer diseases globally, was the element of interest in doing this research because of its carcinogenicity properties. This was because a large number of people are exposed to arsenic chronically throughout the world through the mentioned media, diet or food stuffs, air, water and soil. The concentrations of arsenic naturally in air in remote locations, away from human activities, ranges from 1 to 3 ng/m3, whereas concentrations in cities where mining and industrial economic activities are actively conducted, the concentrations may range from 20 to 100ng/m3 [8].

It can be found in the water, air, plants, animals, rocks, and soil in nature. As a result, it is widely dispersed in the environment, including the air, water, and land. Although it is sometimes found in its pure form as a steel grey metal. The element belongs to the most toxic element in nature which must be reduced or removed from drinking water if the concentration is higher than 10µg/L as per WHO standards.

Arsenic compounds exist in two forms, inorganic and organic arsenic compounds. Pentavalent arsenic (As (V)), one of the two forms of arsenic, is reported to be far less poisonous than its inorganic counterparts and is not known to be associated with cancer. Certain foods, like fish and shellfish, contain organic substances. Trivalent arsenic, As (III)" is an inorganic chemical that can be found in water (especially underground water from underground and open mining pits) that has been contaminated with arsenic, building materials, and some "pressure-treated" timbers. This tends to be the more toxic form of arsenic and has been linked to a variety of health problems such as heart disease, diabetes, and cancer of the bladder, lung, and skin, kidney, liver and prostate, among other cancer-related diseases, due to

long-term exposure [8]. The concentrations of arsenic in water are usually less than 10µg/L, although higher concentrations can occur near natural mineral deposits or man-made sources such as mining activities, pharmaceutical industries, pesticides and herbicides industries, among other chemical production industries that disposes off effluents into water bodies nearby [8]. Therefore, chronic exposure to these media in areas of arsenic contamination may become significant to cancer related diseases due to high incidences reported world over annually.

Diet is also one of the largest source of arsenic exposure for individuals, with an average intake of about $50\mu g$ per day from food [8]. The accumulation of arsenic in food is mainly based on the soil composition on which they are grown "for plants and vegetables", fertilizer composition, herbicides, pesticides preservatives, water used for irrigation and drinking for livestocks, especially in cities where mining and industrial economic activities are conducted on daily basis. The natural levels of arsenic in soil usually range from 1 to 40mg/kg, but due to fertilizer, pesticides, herbicides applications or waste disposal produce higher values [8]. Humans, especially children get exposed directly to these concentrations of arsenic through soil ingestion, which happens when children are left alone playing in the soil. However, plants and animals although not affected directly, are another source of food that when grown on the soil with high concentrations of arsenic and through the usage of fertilizer and pesticides for their growth and disease control absorb arsenic from the soil.

It makes sense that the mining process has a negative influence on the environment [9,10]. A considerable region of surface or groundwater may end up with an abnormally high concentration of particular substances, such as arsenic, sulfuric acid, and mercury [6]. Due to the numerous chemicals employed in the mining process as well as the potentially harmful substance and the metal recovered from the ore, there is a risk of significant pollution of the region around mines [11]. The likelihood that these chemicals will contaminate ground and surface water is increased by the vast amounts of water that are used during mining processes such as aqueous extraction, mine cooling, and mine drainage [5].

As a result, human activity-related localized increases in arsenic levels in water are caused by human mobility and the redistribution of naturally occurring arsenic. As a result, the arsenic levels that have been found in a given area may be the result of a mix of natural processes, ancient, widely distributed human sources, and modern human activity, particularly mining activities. There is evidence from numerous research linking drinking water arsenic exposure to skin cancer. Studies on the epidemiology of arsenic exposure in Taiwan, where Blackfoot disease (a disorder of the peripheral blood vessels caused by arsenic) is common, revealed an increased risk of bladder, kidney, skin, lung, liver, and colon cancer in people who drank water with arsenic levels ranging from 0.35 to 1.14 mg/L. Arsenic exposure has also been linked to a higher incidence of cancers of the kidney, digestive tract, lymphatic, and haematological

systems among smelter workers. Studies on the prevalence of arsenic exposure and case studies of individuals exposed include glass workers, hat manufacturers, and pesticide workers [12].

The connection among the cancer-causing variables is shown in [Figure 1], illustrating how mining activities contribute to the exposure of arsenic compounds that may contaminate drinking water, and when ingested, may cause the prevalence of cancer-related diseases like skin cancer, among others.

Several techniques are used in the removal of arsenic in drinking water, such as removal by oxidation techniques, coagulation and flocculation, membrane technologies, adsorption and ion exchange, respectively [10]. Arsenic removal methods also include chemical precipitation, reverse osmosis and electro-dialysis. All these methods have their advantages and challenges in terms of efficiency and cost effectiveness. For instance, when arsenic is being removed by precipitation, it is removed as ferric arsenate, calcium arsenate or arsenic sulphide because arsenic precipitation with ferric salts is believed to more efficient than aluminium salts. Several steps are used in converting soluble arsenite when using the oxidation process used to remove arsenic (arsenic III) to arsenate (arsenic V) using different oxidants such as atmospheric oxygen, hypochlorite and permanganate, but this technique cannot be used in isolation of others in that it does not remove arsenic from the solution. This therefore, means that other removal techniques such as adsorption, coagulation or ion exchange should be incorporated to remove arsenic from water. This method is less competent for arsenic removal with an average oxidation conversion ranging from 54% to 86% efficiency, depending on the oxidants and due to other interfering substances that may be present in water [10].

Thus, this research aimed at firstly determining the concentrations of arsenic in different sources of water in Mindolo Township in Kitwe on the Copperbelt Province Zambia. Secondly, the mitigation of arsenic from contaminated water was conducted by using two soil samples of ferric hydroxide that are abundant and cheap. These soil samples were obtained from Chinsali because of their ability to form precipitates such as ferric hydroxides when mixed with contaminated water. Two sample
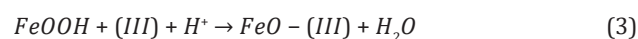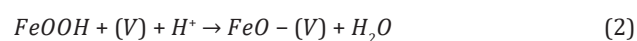
Figure 1 Correlation between arsenic-related variables and cancer diseases

soils were obtained from the stream banks and away from the banks because of their distinct in silicon and iron compositions.

Effect of temperature

It is very important to study the effect of temperature on the adsorption capacity of the adsorbent composites for designing a sustainable adsorption system [13]. This was demonstrated by the results that maintaining the temperature at 25℃, the adsorption capacities of the ferric hydroxide soil sample adsorbent were efficient. Although the adsorption process is proven to be an endothermic and is controlled by the intraparticle and pore diffusion, the mobility of adsorbent ions increases with the increase of the aqueous temperature, thus increasing the adsorptive capacity of the ferric hydroxide soil samples, the results which were yield even when the temperature was maintained were very good.

Effect of pH on arsenic adsorption

Arsenic adsorption is understood as a pH-dependent method due to the vulnerability of the surface groups of the adsorbent which undergo the protonation and deprotonation, in whichever state arsenic occurs, as either As (III) or As (V) [13]. Thus the removal efficiency of arsenic using ferric hydroxide soil samples would either decrease with the increase in the initial pH or increase with decrease in the initial pH. Higher adsorption of arsenic at lower pH has been attributed to the electrostatic attraction of the positively charge adsorbent sites and the negatively charged H_2AsO- species [13]. This therefore means that at low pH, the adsorbent composites behave as weak acid and form positive surface site for anionic arsenic adsorption by forming inner-sphere surface complexes. This is mainly attributed to what happens in aqueous medium, where iron silicate (Fe2SiO4) forms a highly reactive iron species (=FeOOH) which bounds to As (V) and As (III) by ligand exchanges (Baig et al, 2014). Therefore, the occurrence of ligand exchange between As(V) and As(III) with adsorbent effective site (= FeOOH) plays a critical role for the completion of sorption process by forming inner-sphere surface complexes at the solid-water interface, as written in Equations (1), (2) and (3).

$$Fe_2SO_4 + \tfrac{1}{2}O_2 + 3H_2O \rightarrow 2[FeOOH] + 4H^+ + SiO_4^{4-} \qquad (1)$$

$$FeOOH + (V) + H^+ \rightarrow FeO - (V) + H_2O \qquad (2)$$

$$FeOOH + (III) + H^+ \rightarrow FeO - (III) + H_2O \qquad (3)$$

Problem Statement

One of the environmental problems which arise due to mining activities is surface and underground water pollution. The mining sector uses large quantities of water during the extraction and processing of minerals from their ores containing inorganic arsenic as one of the impurities, which causes health complications to humans such as heart disease, cancer, and chronic diseases, among others. This contamination happens both to the surface and underground water pollution due to erosion of waste materials containing arsenic at mining sites such as open-
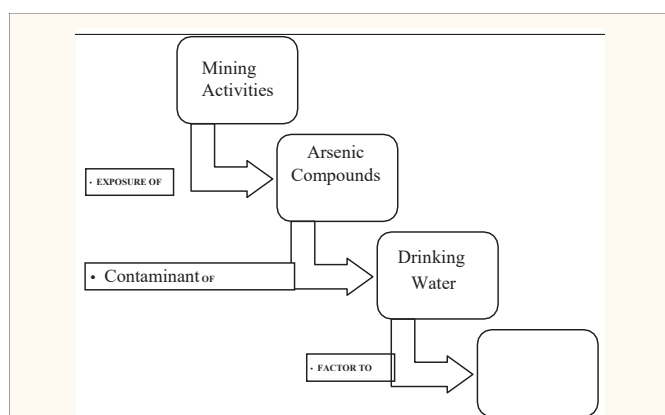
pit areas, heap and dumps leaches, waste rock overburden piles, ore stockpiles, tailings piles and dams, and others. Secondly, when pumping and discharging mine water which is deposited into nearby streams and rivers like Mindolo streams and Kafue River, through the mining drainages.

According to the Ministry of Health and Globocan, estimates showed the distributional growth of cancer cases in Zambia by province, based on the routine screening conducted at the Cancer Disease Hospital (CDH). The data indicated that the prevalent areas in Lusaka and the Copperbelt provinces with approximately 31% and 35%, respectively. The approximate distribution of the 13,831 cancer cases that were recorded and reported by The Global Cancer Observatory is presented in [Figure 2], based on the observations which were made by the Cancer Disease Hospital [14,15].

On the Copperbelt province, Kitwe district was an ideal research area because of industries and mining activities, and due to escalating numbers of cancer related-diseases and in any age group as well as lack of cancer screening awareness. For instance, the prevalence and incidence of all types of cancer-related diseases in Kitwe district were 52 males and 113 females which were recorded from 2007 to 2014 [16]. According to [17], most women interviewed are aware of cancer in women but were found to have very low interest in cancer screening especial in remote areas.

It was however important to emplore the adsorption process in mitigation of arsenic in drinking water using ferric hydroxide soil samples from Chinsali district, so as to help reduce on the incidences of cancer-related diseases. This method was chosen because of the availability, cost effectiveness and efficiency of soil samples.

Research Objectives

The main objectives for this project were;

i. To determine the concentration of arsenic in drinking water using the Inductively Coupled Plasma-Optical Emission Spectroscopy (ICP-OES) method.

ii. To use the adsorption method based on abundant clay
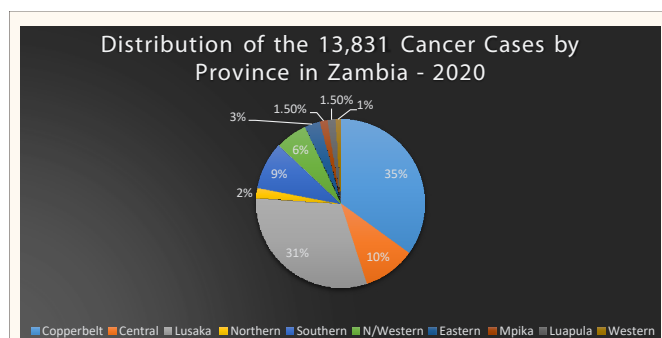
Figure 2 Approximate percentage distribution of cancer cases by province in Zambia-2020 [14,15].

in mitigating presence of arsenic in portable water in Zambia.

Research Questions

The research questions were;

i. What is the concentration of arsenic in drinking water?

ii. How effective is ferric hydroxide-containing soil samples in adsorbing arsenic in the water samples?

Significance of the Study

This study would contribute to finding solutions in mitigating the incidence and prevalence of cancer diseases caused by high concentrations of arsenic in drinking water through the adsorption method using ferric hydroxide-containing soil samples. The study would also assist the government to extend the gesture to domestic water supplying companies to take a keen interest in determining the concentrations of arsenic sensitize the community about the dangers of arsenic to their health and adopt the adsorption method in purifying water before its distributions to their clients. The study would further contribute to policy makers and government to work on health measures which would benefit communities which host mines through Corporate Social Responsibility provided by the government and the mine owners.

Scope of the Study

The study was mainly based on investigating the concentration of arsenic in the Mindolo stream, Kafue river and other sources of water used in communities for drinking and domestic purposes on the Copperbelt in Kitwe district, using ICP-OES method, and using clay soil samples and ferric hydroxide-containing soil samples to mitigate arsenic concentrations.

LITERATURE REVIEW

Introduction

In this section, related research works that have been carried out both internationally and locally were reviewed, and analyzed to the under study: Mitigating arsenic in drinking water in mining areas using ferric hydroxide soil containing samples in response to the incidence and prevalence of cancer, a case study in Kitwe, Copperbelt Province.

Sources of Arsenic

Arsenic is a metalloid element that appears in nature in its sulphide form in complex minerals that also contain other metal elements including cobalt (Co), lead (Pb), copper (Cu), nickel (Ni), and silver (Ag). The main anthropogenic sources of arsenic pollution of drinking water include mining, the smelting of non-ferrous metals, and the combustion of fossil fuels. It is also released into the environment as a result of volcanic activity.

Due to mining, smelting, and other industrial activities that

have contributed to elevated concentration of arsenic in local water, exposure to high concentrations of arsenic in drinking water has been recognized for many decades in some regions of the world, including the People's Republic of China (Taiwan), Chile, and Argentina, India (West Bengal), among others. The strongest evidence for the connection between human cancer diseases and arsenic in drinking water comes from studies in these five areas: south-western and north-eastern Taiwan (China), northern Chile, Cordoba Province in Argentina, Bangladesh, West Bengal (India), and other regions in the Ganga plain [18].

Mining itself (the removal of the ore from the earth), mineral processing or beneficiation (the creation of the mineral concentrate out of the ore), and metallurgical processing are the three main processes for the generation of mining wastes (the generation of a refined metal out of the mineral concentrate). The heavy metals discharged in the form of solid, liquid, or gaseous mining effluents, such as arsenic and its compounds, are thought to have no immediate economic value and build up at mine sites. Tailings, sludge, acid water effluents, and noxious gases are some of the mining effluents that are produced. Following mineral beneficiation, the mineral concentrate is further processed using extractive metallurgy, which uses solvents to dissolve the ore's crystallographic bonds and release the desired element. All these effluents are mainly deposited into streams and rivers nearby the processing plants, some of which are tributaries to the main water source for domestic purposes to the residents nearby the mining area [19].

Therefore, the entire population of a region with noncommunicable diseases (NCD), including cancer diseases, may be affected by heavy metal, arsenic, and arsenic compound contamination of the drinking water supply. The impact of even a small increase in contamination can be quite strong in terms of the total number of excess cases when large populations are affected.

Effects of Arsenic (Arsenic Poisoning)

Arsenic may easily enter cells and can harm or kill cells through a variety of processes. Arsenic is a known human carcinogen that is thought to induce cancer by attaching to a particular protein, changing the protein's shape, impairing its ability to recruit and interact with other proteins and DNA, and ultimately causing the protein to lose its function. The primary explanation for this is the strong binding affinity of trivalent arsenicals for DNA and tissue cells that include proteins or peptides with sulfhydryl groups, as well as their disruption of enzymes that contain sulfhydryl groups. When this occurs, trivalent arsenic (As III) is powerful, inhibiting the tricarboxylic acid cycle and the pyruvate oxidation pathway, impairing gluconeogenesis, and reducing oxidative phosphorylation. [Figure 3] shows the effect of arsenic exposure on human health.

In numerous biological reactions, pentavalent arsenic As (V) is substituted for phosphorous. This is one way. This simply states that the rapid hydrolysis of high-energy bonds in compounds like adenosine triphosphate (ATP), a process that results in the

Figure 3 Arsenic Exposure and Health Effects [8].
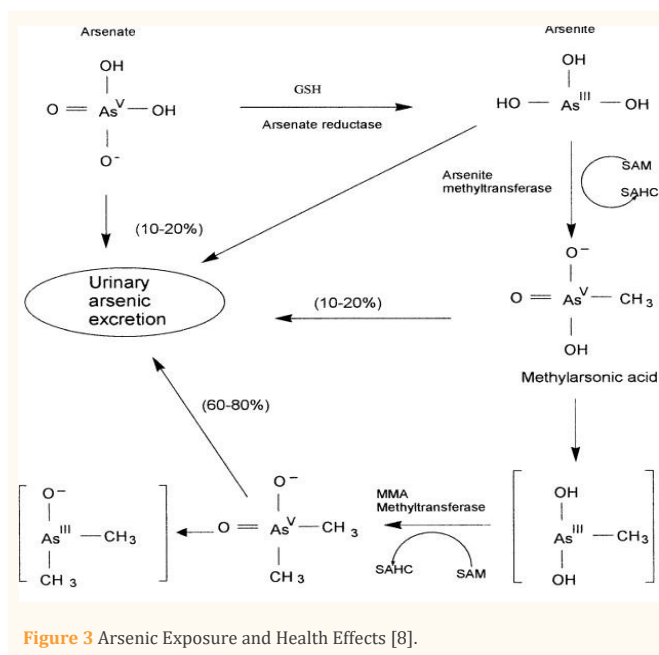
loss of high-energy phosphate bonds and effectively "uncouples" mitochondrial respiration, is caused by replacing the stable phosphorous anion in phosphate with the less stable pentavalent arsenic As (V) anion [20].

The direct ingestion of inorganic arsenic and arsenical compounds by humans has an approximation of 95% of absorption through the gastrointestinal tract. As a result, the renal system quickly removes inorganic arsenic and arsenical compounds from the blood when they enter it within two hours of ingestion. Two stages are involved in the metabolism of pentavalent and trivalent arsenic compounds in both humans and many other animal species. As seen in [Figure 1], above, the pentavalent forms of arsenic are mostly or rather typically reduced to trivalent forms, which are then methylated to create monomethylated and dimethylated arsenic compounds.

When compared to the comparable pentavalent arsenic compounds, these trivalent arsenic compounds are three to four times more hazardous [21]. Arsenic poisoning typically causes vomiting, diarrhea, and abdominal pain, which are then followed by paresthesia in the limbs, cramps, and in the most serious cases, death. Humans who have been exposed to arsenic and its compounds over an extended period of time develop skin lesions, changes in skin colour, and hard patches on their palms and soles. In addition to peripheral neuropathy, renal system effects, gastrointestinal issues, diabetes, high blood pressure, conjunctivitis, an enlarged liver, bone marrow suppression, erythrocyte destruction, and cardiovascular diseases, this condition known as "chronic arsenic exposure" also results in other health issues [22].

However, one of the difficulties that causes the detection of arsenic in human bodies to be delayed is the metabolic conversion and utilization of harmful inorganic arsenic and arsenical compounds into organic form. Specifically, they are deposited in

the hair, nails, and skin of those who are afflicted by them and are mostly removed from the human body through metabolic wastes like urine [23]. In light of this, it may be concluded that arsenic, in the forms of arsenic trioxide, arsenic pentoxide, arsenous acids, arsenic acid, and related salts (arsenites and arsenates), is a known carcinogen (Carcinogen category 1) [24].

Humans' neurological, circulatory, and epidermal systems are all known to be impacted by arsenic. Humans are exposed to high quantities of inorganic arsenic mostly through the disposal of mining effluents and the usage of fertilizers that contain arsenicals, as well as through drinking water that has been contaminated with arsenic in surface and groundwater. One of the main causes of the issue is food cooked with this polluted water and food crops irrigated with high-arsenic water resources. Cancers of the skin, bladder, lungs, kidney, liver, and prostate are also brought on by arsenic [20].

Arsenic and its compounds are group I human carcinogens, according to the International Agency for Research on Cancer, which means there is enough scientific evidence to support their ability to cause cancer in people. It is hypothesized that the majority of reproductive abnormalities, including spontaneous abortion, stillbirth, and preterm birth, are linked to pregnant women who are repeatedly exposed to drinking water contaminated with arsenic, making their placenta more permeable to arsenic. Arsenic exposure during pregnancy and infancy has been related to a later risk of developing lung cancer and bronchiectasis. Therefore, the epidemiological data on humans point to a connection between drinking water arsenic exposure and its detrimental effects on the reproductive system as well as outcomes [25].

Arsenic may impact the developing brain through a variety of potential processes, according to numerous researches done on rats and school-age children. This is because arsenic is pro-oxidant element which has a direct effect on the developing brain in that it causes oxidative stress to it [26]. The second way arsenic might function is by disrupting the dopaminergic system and causing hormonal imbalance, particularly in the oestrogen and thyroid hormones, which are both essential for brain development. Additionally, arsenic lowers dopamine levels, which alters brain function and results in inattention, impulsivity, lack of concentration, and alertness [27].

According to a study done on Mexican children, there was an inverse relationship between urine arsenic content, verbal IQ and long-term memory. Additionally, it was discovered that chronic malnutrition and exposure to arsenic in children impaired their long-term memory, attentiveness, and speech understanding [28]. These similar studies have however been observed in animal models as well [29].

The most reliable indicator of exposure is the detection of arsenic in urine, hair, and nails. Because inorganic arsenic and dimethylarsinic acid are deposited in the hair root, which provides a reflection of previous exposure, hair samples are employed as a biomarker for arsenic exposure [30]. An elevated arsenic levels

in hair is an indication of the pastexposure of 6- 12 months. This suggestion is based on research showing that, in populations not exposed to arsenic, the average concentration of arsenic in hair is between 0.02-0.2 mg/kg. While the people reported having high levels of arsenic contamination in their hair after consuming water with high arsenic content. This was attributed to two studies: one in Alaska, where an average of 400 g/L in drinking water corresponded to 3.3 g/g arsenic contamination in hair, and the other in West Bengal, India, where arsenic concentrations ranging from 3 to 10 mg/kg in hair were observed in the people drinking high arsenic contaminated water. Children's hair samples from another investigation that was conducted in Bangladesh found extremely high levels of arsenic contamination [31]. They were drinking water that was extremely tainted with arsenic from three hand pumps. Their impaired intelligence and memory are symptomatic of the impact of arsenic exposure even though they had no symptoms of arsenicosis. The children also showed impulsivity, an inability to concentrate, and a lack of attentiveness. The early reporting of cases of mental disability in the community is another major problem in this area.

One conclusion drawn from the research on people in Bangladesh who were exposed to arsenic through their drinking water was that the signs and symptoms of arsenic toxicity typically appear first in the skin through various cellular processes in organ systems. This is due to the skin's symptoms, which include hypermelanosis, hyperkeratosis, and hyperpigmentation of the palms and soles [32]. Other cancer diseases that were observed are Bowen's disease, squamous cell carcinoma and basal cell carcinoma [33]. Because of other health issues like gastrointestinal issues like gastritis and flatulence, constipation, anaemia, loss of appetite, breathlessness, mental disability, and others, these arsenic-exposed humans of all age groups who drank arsenic-contaminated water displayed arsenicosis symptoms like hyperkeratosis and hyperpigmentation in the palms and soles. The advent of skin cancer and breast cancer in the community was the most regrettable development.

Arsenic is also responsible for causing various types other health problems such as hypertension, diabetes, hormonal disorders, neuropathies, severe arteriosclerosis, skin manifestations, among others, other than many significant types of cancer diseases in the population from acute exposure to chronic exposure effects [34]. The daily consumption of 1.6 litres of contaminated arsenic (especially inorganic arsenic, with about 50µg/L) has been associated with an estimate of 21/1000 cancer death risk, based on various studies which have been conducted in recent decades. The classic symptoms of arsenicosis, such as hyperkeratosis in the soles and palms, legs, and raindrop coloration across their entire bodies, were reported to the cancer centre by persons from severely arsenic-contaminated areas. Squamous cell carcinoma of the skin was identified in these people's hands as malignant lesions. The arsenic concentration in these individuals' drinking water was determined to be 244.6 g/L, whereas it was 48.02 g/L in their blood samples and 323.32 g/L in their hair samples. Through medical intervention and amputation of their injured bodily parts, their lives were saved [35].

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The most glaring long-term effect of persistent exposure to inorganic arsenic appears to be cancer disorders. This is because epidemiological studies have shown a clear causal link between exposure to inorganic arsenic in the environment, at work, and in medical settings and cancers of the skin and lungs. There is a definite link between human exposure to water-soluble inorganic arsenic through drinking water with either high natural arsenic content or through contamination from mining activities and precancerous cutaneous keratosis, epidermoid carcinoma of the skin, and to some extent, lung cancer. Therefore, epidemiological research from Taiwan, Canada, Chile, Argentina, and other countries suggests links between drinking water contaminated with arsenic and skin cancer, Bowen's disease, and Blackfoot disease. Workers exposed to inorganic arsenic in the manufacturing and usage of pesticides (spray), gold mining, and the smelting of nonferrous metals, particularly copper, have been seen to experience an increase in fatalities from respiratory cancer [1].

Further evidence that exposure to arsenic and inorganic arsenic compounds increases the risk of cancer diseases through protein-containing tissue sites, also known as Cancer Tissue Sites, was provided by epidemiological studies and case reports of humans exposed to these substances for medical treatment, in drinking water, or at work (CTS). The skin, lung, digestive tract, liver, urinary bladder, kidney, lymphatic and haematological systems are some of the cancer tissue locations. People who were exposed to arsenic for medicinal purposes have reported developing skin cancer, sometimes in conjunction with cancers at other tissue sites like meningioma, intestinal and urinary bladder cancer, and blood vessel cancer (Angiosarcoma) of the liver (tumors of the membranes covering the central nervous system). However, epidemiological studies have only found a link between medical arsenic use and skin cancer [7].

There some suggestions that arsenic has long been a concern to man because small amounts can be toxic to humans in that it is thought, as a carcinogenic priority pollutant - especially if ingested by oral route - to cause the incidence of tumors of the liver, blood and lungs, among other tissue organelles. A pattern of skin changes is one of the most recognizable side effects of prolonged oral exposure to "inorganic arsenic" from drinking water contaminated with arsenic. Particles of darkened skin and the appearance of tiny "corns" or "warts" on the palms, soles, and torso are examples of these; they are linked to alterations in the skin's blood vessels that may progress to skin cancer [35,36].

Ingestion of arsenic through drinking arsenic-contaminated water has also been reported to increase the risk of cancer in the liver, bladder, prostate, lungs, and nasal cavity [35,36]. This is mainly attributed to chronic exposure which results in the accumulation of the metalloid to toxic levels, thereby compromising the detoxification role of the liver and placing it together with other body tissue cells at considerable risk. This is because, though methylation and excretion are the two ways that arsenic has been considered a detoxification mechanism in humans, when the concentration ingested, through drinking arsenic- contaminated water, is above $10 \mu g/L$ tends to remain in the body and become hazardous because of the connection to cancer diseases.

There are numerous molecular mechanisms that contribute to arsenic-related skin carcinogenesis, such as arsenic exposure resulting in mutations in healthy human epidermal keratinocytes that cause aberrant gene expression. Increased transcriptional levels of keratinocyte growth factors, oxidative stress, and lastly regulation of the MAPK and 54d NF-B pathways may all contribute to this. Arsenic-induced skin BCC and SqCC are frequently seen of as precursors to the early skin symptoms or premalignant skin lesions caused by exposure to arsenic [12]. These lesions include melanosis, hyperpigmentation, rain drop pigmentation, hyperkeratosis, and hyperpigmentation, which are frequently seen in people who have been exposed to arsenic [37]. Given that this does not happen in every exposed person, there is a chance that genetic susceptibilities and arsenic- associated skin lesions are related in some way. In a very short amount of time, hyperkeratosis and lesions are produced by exposure to arsenic, and the majority of these lesions develop into arsenic- induced skin cancer [38].

Other investigations suggest that lesions resulting from hyperkeratosis, melanosis, or other skin characteristics predominated in skin cancer cases caused by exposure to arsenic [39]. Therefore, together with other environmental carcinogens including fertilizers, pesticides, herbicides, and mining effluents, among others, arsenic poisoning directly stimulates the carcinogenic process. Additionally, exposure to arsenic combined with ultraviolet radiation exposure can contribute to the development of skin conditions including hyperkeratosis and ultimately skin cancer [40].

Due to economic activities like mining, pharmaceutical, pesticide, and fertilizer industries, among others, undertaken in these locations, the majority of cancer cases reported globally are from the cities or towns that are located near rivers and streams for the disposal of arsenic- containing effluents. It's conceivable that the population's use of surface and groundwater contaminated with arsenic has contributed to health problems, ultimately resulting in cancer disorders. In 2016, as per World Health Organization's mortality statistics, approximately 9.1 million cancer related deaths were recorded, representing a total of 16 per cent of the 57 million deaths which were recorded for non-communicable diseases (NCD). According to epidemiological data on cancer, urban areas with frequent commercial activity and those close to river basins experienced higher occurrences of the disease than non-river areas and rural areas. There were many different types of cancers present, including skin cancer, skin melanoma, lung cancer, bladder cancer, hepatobiliary cancer, renal cell carcinoma, breast cancer, ovarian cancer, and endometrial cancer. Indicated that there might be some connection between the arsenic and the typical symptoms of arsenicosis.

Bangladesh, east of Asia, represents the largest population

exposed to arsenic in the history with a total mortality of about 10500 cancer related diseases recorded in 2016, due to the groundwater used for drinking is contaminated with inorganic arsenic [41]. Lung Squamous cell carcinoma occurrences in males with lung cancer are linked to arsenic poisoning in drinking water from tube wells in the exposed population of Bangladesh.

These cancer diseases were reported to be very common in locations where arsenic levels are greater than 100 g/L [42]. However, it is noted that the lifetime mortality rates for lung cancer are 23.1 for women and 159.1 for men (per 100 000 population). People who are exposed to arsenic in Southwest Taiwan develop black foot illness (BFD). The primary symptoms of peripheral artery disease are severe systemic arteriosclerosis and spontaneous gangrene that can result in amputation [34]. Lung cancer incidence and mortality rates in the BFD- affected areas have been well-documented, particularly in those who have consumed arsenic- contaminated water for more than 40 years. Smokers in these areas have a 4.1-fold increased risk of developing lung cancer, suggesting a probable link between cigarette use and lung carcinogenesis caused by arsenic exposure. Several studies have also linked a five-year increase in lung cancer risk to drinking water containing arsenic [35].

For the purpose of examining the long-term dangers of arsenic-caused cancer, several significant advantages were supplied by an uncommon arsenic exposure scenario in northern Chile. When river water from the adjacent Andes Mountains was discovered to have significant levels of naturally occurring arsenic in the late 1950s, it was transferred to Antofagasta, the area's major city, for drinking. From 1958 to 1970, the city's water supply had an average arsenic concentration of 860 g/L. After a treatment facility was installed, these concentrations were brought down to 10 g/L [43]. The exposure scenario, which is unusual in environmental epidemiology and provides a unique opportunity to study the long-term latency patterns of a widespread carcinogen like arsenic, has a well-documented high exposure to a well- known and potent carcinogen, large numbers of people exposed, and a distinct end to the high exposure period.

The fact that northern Chile is the driest populated region on earth and has a dearth of water resources means that practically everyone who lives there, whether in a city or a village, relies on one of the region's few sizable public water supplies. The World Health Organization's estimated 28600 cancer-related deaths from 2016, which are substantiated by historical records of arsenic concentrations available for each of these significant suppliers that stretch back at least 40 years. However, one of the most prevalent malignancies in Chile is lung cancer. Globocan figures predict that there will be 53,365 new cases of cancer and 28,443 fatalities in Chile in 2018. Lung cancer is the leading cause of cancer death, accounting for about 3581 of those deaths, while its reported yearly incidence was 3873 in the same year for both sexes. It is clear enough from the combination of these criteria that a person's lifetime exposure to arsenic in Chile may be accurately predicted by knowing the cities or towns they have lived in or currently reside in [43].

Putila and Guo [31], despite the relative lower quantity of arsenic compared to other nations, environmental exposure to arsenic may have a substantially bigger impact on lung cancer incidence than previously anticipated in the United States of America (USA). As a result, the levels that are typically found in the research locations still constitute a serious risk that can be quantified at the population level. On a national population level, there was evident interaction between smoking habits and arsenic contamination exposure. Furthermore, it was shown that regions with greater rates of smoking and arsenic exposure had more lung cancer cases than could be attributable to each factor alone. However, these estimates may be affected by other unmeasured factors. Compared to Centre, Mifflin, Perry, and Juniata counties in the state's centre, which have arsenic levels that vary from 4.374mg to 5.141mg, Beaver, Greene, and Washington counties on Pennsylvania's western border have increased levels of arsenic ranging from 6.426mg to 7.497mg. In 2016, there were around 1.7 million new cases of cancer in the United States, and there were approximately 616440 cancer-related deaths.

In Zambia, the onset of cancer and other NCDs is frequently covert, with patients frequently presenting or, more accurately, tending to become aware of the issue in middle life, when the disease is advanced. Cancer disorders account for more than 80% of NCD-related mortality and significantly increase the expense of healthcare. Because of this, cancer diseases-particularly those that affect women, such cervical and breast cancer-have had a substantial impact on morbidity and death among NCDs in Zambia. Prostate cancer and Kaposi's sarcoma are two other cancers with a high incidence [44].

The Zambia National Cancer Registry made an estimation of 12,000 new cancer cases countrywide were going to be recorded in 2018, and that about 7380 deaths of all new cases were going to be recorded. According to the recent studies which were conducted, the statistical data for cancer diseases indicated that cervical cancer accounted for 3,000 new instances of cancer in Zambia in 2018, followed by Kaposi's sarcoma (1,700), prostate cancer (1230), and breast cancer (900). Leukemia (blood cancer), Kaposi's sarcoma, nephroblastoma, and retinoblastoma are among the children's cancers that are frequently diagnosed. Since its opening in 2006, the Cancer Diseases Hospital has provided care for more than 43,000 cancer patients. 2,734 new cancer patients were admitted to the hospital for cancer disorders in 2018. Cervical cancer was the most common, followed in order by breast cancer, prostate cancer, lymphomas, and Kaposi's sarcoma. 3967 patients were admitted to the hospital overall in 2017, and 570 of them died. In 2018, mortality decreased to 424 from a total of 3718 admissions [44,2]. However, based on studies conducted in Zambia, cancer diseases have been suspected to be mainly caused by the HPV.

Ngoma [45], Suggested that the rise in the prevalence of all cancer illnesses in developing nations like Zambia can be attributed to risk factors and lifestyle changes such poor diets, reduced activity, crowded living circumstances, and increased

tobacco use. Cancer diseases are attributable to infections in these countries and the oncogenic infections that have been linked to cancer is the Human Papilloma Virus (HPV) [39].It was therefore evident that in Zambia, arsenic in drinking water had not been regarded as also one of the major contributors to the incidence and prevalence of cancer diseases, especially in mining areas like on the Copperbelt province. It indicated that there was a research gap on the causes of cancer diseases in Zambia because the research took and explore.

Methods of Arsenic removal

The chemistry and composition of arsenic-contaminated water are the major factors to determining the removal of arsenic. Most of the available removal technologies are more efficient for arsenate given that arsenite is predominantly non-charged at pH below 9.2. The metalloid element can be removed in areas where the drinking water contains unsafe concentrations through various methods such as oxidation, ion exchange, membrane techniques and adsorption using ferric hydroxide granules [46,47].

The ion exchange method has a maximum removal of 95% of pentavalent arsenic (arsenate) in drinking water, using commercially produced synthetic resins such as zeolites. This makes the trivalent form of arsenic less available for ion exchange. This therefore means that the treatment technologies become more effective by using a two-step approach, with an initial oxidation conversion of arsenite to arsenate, then followed by a technique for the removal of arsenate [46,47].

Whereas oxidation/filtration method has a maximum removal of 80% of arsenic in water, with the iron to arsenic ratio of at least 20:1. Oxidation involves the conversion of soluble arsenite to arsenate. This method does not remove arsenic from the solution alone, it involves other removal techniques such as adsorption, coagulation, or ion exchange, must follow. For anoxic groundwater, oxidation is an important step since arsenite is the prevalent form of arsenic at near neutral pH when atmospheric oxygen, many chemicals and bacteria, have been used to directly oxidize arsenite in water. However, oxidation of arsenite with oxygen is a very slow process in that it can take hours or weeks to complete whereas chemicals, such as chlorine, ozone, and permanganate, can rapidly oxidize arsenite [As(III)] to arsenate [As(V)] [48,46].

Reverse osmosis looks to be one of the most cost-effective methods for removing arsenic from water supplies when using membrane techniques. RO can be considered to be molecular filtration. It operates by pushing water through a distinct membrane. The membrane features small pores that are specifically designed to catch bigger inorganic compounds like lead, iron, chromium, and arsenic while letting water molecules pass through. According to studies, RO can remove arsenic up to 95% of the time [46]. The disadvantages of this method are that it can only be mainly recommended for private people with wells and boreholes in that it requires replacing the media on regular basis and the presence of iron, manganese, sulfate, silica or organic carbon reduces its effectiveness [46].

Coagulation and flocculation are among the most used and recommended techniques for arsenic removal from water [46,47]. Coagulation's positively charged coagulants such as aluminum sulphate and ferric chloride reduce negatively charge of colloids, thereby making the particles collide and get larger. Flocculation, on the other hand involves the addition of an anionic flocculants that causes bridging or charge neutralization between the formed larger particles which lead to the formation of flocs. These processes transforms dissolved arsenic by the chemicals into an insoluble solid through precipitation. Sometimes soluble arsenic species can be incorporated into a metal hydroxide phase and be co-precipitated and later removed as solids through sedimentation or filtration [46].

Adsorption is a process that uses solids as medium for the removal of substances from gaseous or liquid solutions. Mainly this process is driven by the van der Waals forces and electrostatic forces between the adsorbate molecules and the adsorbent surface atoms, where substances such as heavy metals are separated from one phase followed by their accumulation at the surface of another [46]. This makes it important to characterize first the adsorbent surface properties such as surface area and polarity before being used for adsorption. A wide variety of sorbents has already been studied in several researches, which includes activated carbon, coal, red mud, fly ash, chicken feathers, kaolinite, montmorillonite, goethite, zeolites, activated alumina, titanium dioxide, iron hydroxide, zero-valent iron, chitosan, and cation-exchange resins. The adsorbing phase is the adsorbent, and the material concentrated or adsorbed at the surface of that phase is the adsorbate. Adsorption on solid matrices such as clay, zeolites and granular ferric hydroxides has been shown to be one of the most efficient treatment methods for heavy metals removals [49].

Adsorption method using Granular Ferric Hydroxide, (a modified product of ferric hydroxide granules), has a maximum removal of 99% of arsenic in drinking water. This method proved to be effective in the treatment or rather the removal of arsenic and heavy metals such as antimony, lead, and copper, among others, and exhibits high operating capacity across a wide range of potential hydrogen (pH), influent arsenic concentrations and flow rates [49,46]. This method has been reported as the most widely used technique for arsenic removal due to its several advantages, including relatively high arsenic removal efficiencies, easy operation, and handling, cost-effectiveness, and no sludge production. It was in this vain that the research involved the utilization of naturally occurring ferric hydroxide in soil samples and observe whether these substances could meet the required qualities needed to be used by many as they are readily available in many parts of the country, especially the fact that Zambia is endowed with iron ores in almost all regions of her corners.

Effect of contact time and adsorption kinetics

The adsorption of arsenic onto the adsorbent from aqueous solution involves steps such as transport into the exterior surface (film diffusion), transport into the pore and surface diffusion (intraparticle diffusion) and adsorption onto the adsorbent

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surface from the bulk phase. However, the overall adsorption rate was determined by the slowest adsorption step in arsenic removal through the adsorbent composites of ferric hydroxide soil samples along with contact times of 48 hours, which was also attributed to the phenomenon of higher concentration gradient and more adsorptive sites. However, adsorption kinetics is determined by the interaction of adsorbate adsorbent, and plays an important role in the purification meaures of water through the reaction rate and adsorption mechanism during the adsorption process.

METHODOLOGY

Introduction

The research study involved the analysis of arsenic contamination in drinking water through mining activities in Kitwe district of the Copperbelt Province. The study was designed to analyze the concentration of arsenic in water samples from Mindolo stream, Kafue River and tap water distributed in homes for the residents in Kitwe, and conduct an adsorption process using ferric hydroxide soil samples in mitigating it.

Sample Collection

The research was conducted in Kitwe district, on the Copperbelt. The research was aimed at mitigating the concentrations of arsenic in drinking water in response to the incidence and prevalence of cancer diseases in Kitwe district, a mining area. The major research materials which were used are two iron (III) hydroxide (ferric hydroxide) soil-containing samples, different in iron and silicon percentage compositions, from Chinsali district for the adsorption method. The two soil samples were collected from two different places, soil sample one (SS1) was collected from the banks of the stream, whereas soil sample two (SS2) was collected one kilometer away from the stream where soil sample one was collected. These two soil samples were very different in both appearance and iron composition. Soil sample one (SS1) was whitish in appearance whereas SS2 was brown in appearance.

Three water samples were collected from Mindolo stream, Kafue River and tap water. The Mindolo stream and Kafue River were purposely selected since they are the recipients of wastewater from the mines, and are the major sources of drinking and domestic water supplied to the residents of Kitwe. The Figure 4 shows the summary of how the research was designed.

Data Collection Procedures

The water samples were collected in polythene bottles, which were cleaned before the day of collection of the samples. These bottles were cleaned with metal-free detergent and rinsed with distilled water. After the collection of the samples, they were transported in a cool box to the laboratory and analyzed them using an ICP-OES, Model number Agilent 5900, and 100ml of each water sample was analyzed for arsenic composition. The research was done at the Copperbelt University Chemistry Laboratory, on the Copperbelt, while the analyses of samples were done at Alfred H. Knight laboratories in Kitwe district.
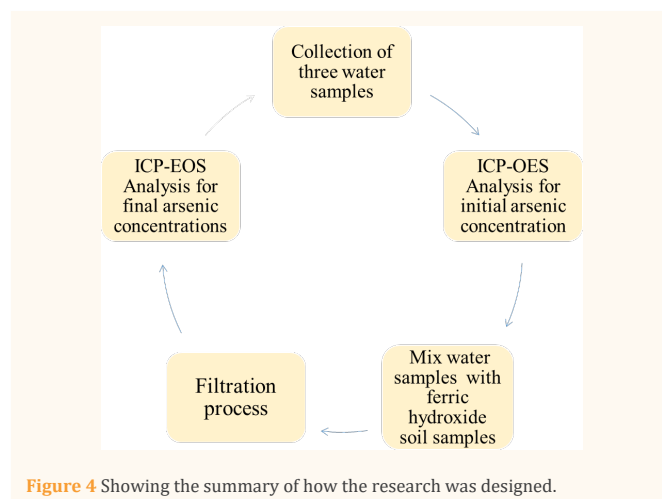

Figure 4 Showing the summary of how the research was designed.

The study aimed at determining the concentrations of arsenic in the water samples and remove arsenic from the water samples using soil samples containing ferric hydroxide. The jaw crusher was first used to reduce the sizes of the soil samples before using the pulveriser to crush soil samples in powder form. Further, the sieve shaker was used to sieve soil samples with the required sieve size of 355μm. the two soil sample compositions were analyzed using ICP-OES, just like water samples and 100grams of each soil sample were analyzed for their composition. The two soil samples were used (ferric hydroxide-containing soil samples) for the adsorption process of arsenic in water samples and took the collected water samples for analysis to determine the percentages of arsenic that was mitigated were the soil samples.

After analyzing the compositions of both water and soil samples, the experiments were set up by mixing the water and soil samples to allow the adsorption process of arsenic in water to take place. The process was observed for forty eight hours before the water samples were filtered from the mixture. Six sample mixtures of water and soil samples (clay and in situ soil samples) were set up by splitting the three water samples with two ferric hydroxide-containing soil samples different in composition and texture, and used 100grams of each soil sample to mix with 100mls of water samples.

Principle of ICP-OES

An Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) is an analytical technique used to determine how much of certain elements (selected elements) are in a sample. The principle of an ICP-OES uses is dependent on the fact that atoms and ions absorb energy to move electrons from the ground state to an excited state. Its source of energy is heat from an argon plasma that operates at 10,000kelvin, and its principle relies on the excited atoms releasing light at specific wavelengths as they transition to a lower energy level, where the amount of light released at each wavelength is proportional to the number of atoms or ions making the transition as shown in [Figure 5].
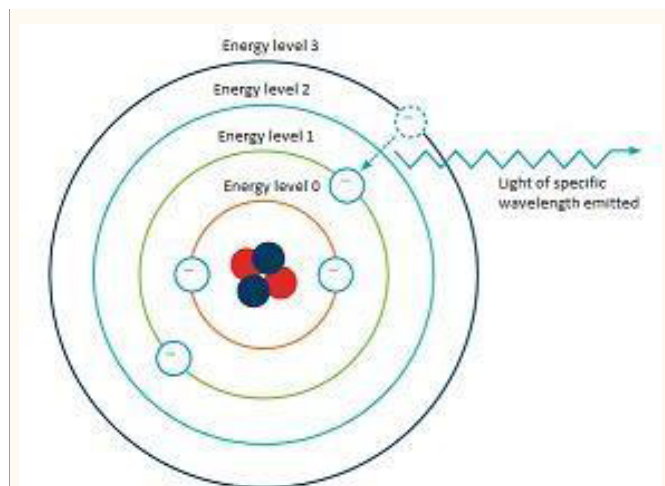
Figure 5 Showing the principle of ICP-OES during the absorption and emission of light with specific wavelength by atoms and ions of selected elements [50].

As an electron returns from a higher energy level to a lower energy level, usually the ground state, it emits light of a very specific wavelength, either an atom or an ion, and the energy levels the electron is moving between, determines the wavelength of the emitted light. The concentrations of the elements in each sample solution are determined from the calibration graphs. The concentrations in the original sample are calculated from the measured concentrations of the elements in the sample solution and the known dilution factor. ICP-OES analysis delivers results that list the concentration of the selected elements typically in µg/L or mg/L.3.8 Validity of Instruments. The ICP-OES instrument is one of the analytical instruments widely used for the determination of total concentrations of arsenic in water. This is because ICP-OES is highly sensitive and can measure arsenic at concentrations below the guideline concentrations.

Reliability of Instruments

The ICP-OES is an analytical technique based on the principle of optical spectroscopy for the determination of more than 70 elements with detection limits in parts per million (ppm) ranges, with samples prepared in either liquids, solids or gas. Thus, the water samples were used for the analysis of arsenic using ICP-OES and soil samples in solid state were analyzed. The ICP-OES, therefore, provided the capability of simultaneous multi-element analysis for arsenic and other elements present in water and soil samples in 1 to 2 minutes.

Adsorption efficiency of ferric hydroxide containing soil samples

In order to investigate the efficiency of the adsorption process of arsenic which was found in the water samples, two ferric hydroxide containing soil samples were split into three parts of 100g each, making a total of six bottles, and mixed with 100mls water samples from Kafue River, Mindolo stream and tap water. The mixtures were regularly shook and observed

for not less than 48 hours. This was allowed in order to allow the adsorption process take place effectively. After 48 hours of shaking and observations, the water samples were filtered and taken to laboratory so the final analyses could be conducted. The following formula was used for determining the efficiencies of the two soil samples; initial arsenic concentrations-final arsenic

$$\frac{\text{initial arsenic concentrations} - \text{final arsenic concentrations}}{\text{initial concentrations}} \times 100\% = \text{efficiency}$$

$$\text{or} \quad \frac{\text{concentrations of adsorbed arsenic}}{\text{initial arsenic concentrations}} \times 100\% = \text{efficiency of clay soil sample}$$

RESULTS

Introduction: The main aim of this research thesis was to determine the concentration of arsenic in water before and after adsorption process. However, the results and discussions of the analyses in form of tables and figures are presented in elemental composition using ICP-OES (Inductively Coupled Plasma Optical Emission Spectroscopy).

Composition of the Soil Samples: The results for elemental analysis of the adsorbents using ICP-OES are shown in [Table 1]. The major constituents of Chinsali soil samples one and two are silicon and iron, although other elements such as aluminium, sodium and calcium were also detected at various compositions. On the other hand, iron oxide had predominately a high percentage of iron in relation to silicon and aluminum. [Tables 1,2] shows the elemental and oxide percentage compositions of silicon, iron and aluminium, respectively.

In order to express the elemental composition as oxide based results, the results from [Table 2] were multiplied by the stoichiometric oxide conversion factors for SiO2 (2.1392), Al2O3 (1.8895), and Fe2O3 (1.4297) [51]. It is evident that in the two Chinsali soil samples, iron has the highest oxide sites with 34.97% and 54.63% compared with aluminum sites having 0.05% and 0.08% oxygen sites, respectively.

Adsorption of Arsenic on the Soil Samples: The adsorption of arsenic on ferric hydroxide sites involves interactions between the adsorbate and the hydroxyl group of the ferric hydroxide. This is because ferric hydroxide nanoparticles possess magnetic properties, which allow them to be conveniently separated from aqueous solutions. On the other hand, in other studies it has been investigated that ferric hydroxide particles form monodentate species and bidentate binuclear complexes at low surface coverage and higher surface coverage, respectively. The use of ferric hydroxide soil samples as adsorbents constitutes a very attractive alternative for removing arsenic from contaminated water because they are quite abundant in nature, relatively inexpensive as well as shows high adsorption affinity for both arsenate and arsenite. [Table 3] and [Figure 5] constitutes the initial and final arsenic concentrations after adsorption for the three water samples, as well as the efficiencies for the two soil samples, SS1 and SS2 respectively [Figure 6].

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DISCUSSIONS

From the data presented above, water samples from Mindolo stream contained the highest concentration with 22.2μg/L of arsenic, followed by water samples from Kafue River with 7.5μg/L, and tap water were the least with 4.6μg/L. This evidently indicates that the water samples which were collected contained

Table 1: Results analysis of the elemental composition for the two soil samples from Chinsali.

Elemental composition	Silicon (Si) in %	Iron (Fe) in %	Aluminium (Al) in %
SS1 from Chinsali	45.74	24.46	7.10
SS2 from Chinsali	45.10	38.22	2.38

Table 2: Results analysis of the oxide based composition for the two soil samples from Chinsali in percentages.

Elemental composition	Silicon (SiO_2) in %	Iron (Fe_2O_3) in %	Aluminium (Al_2O_3) in %
SS1 from Chinsali	97.84	34.97	13.42
SS2 from Chinsali	96.48	54.64	4.50

Table 3: Results analysis for Arscenic in the water samples in μg/L before and after the adsorption process using ICP-OES

	Water Sample	Initial[As] pre-adsorption in μg/L	Final [As] post-adsorption with SS1 in μg/L	Final [As] post-adsorption SS2 in μg/L	% As removed by soil sample one (SS1)	% As removed by Soil sample two (SS2)
1	Mindolo stream water	22.2	5.4	4.3	75.68	80.63
2	Tap water	4.6	0.9	0.3	80.43	93.48
3	Kafue river water	7.5	3.4	2.5	54.67	66.67
4	WHO	10μg/L				
5	EPA	10μg/L				

NB: SS1 = soil sample one from Chinsali (riverbed) and SS2 = soil sample two from Chinsali 1 Km from river
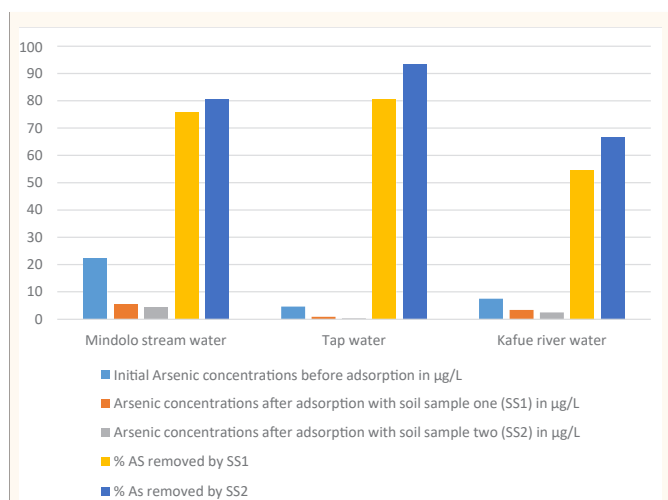

Figure 6 The arsenic concentrations before and after adsorption process in μg/L.

Figure 7 Shows the picture site where SS1 was collected.

arsenic and clearly show how residents get exposed to arsenic in drinking water due to mining activities in the region.

The arsenic concentrations for water samples for Mindolo stream as shown in [Table 3], were beyond the threshold which the World Health Organization (WHO) and (EPA) recommends of 10μg/L. Residents who live nearby this stream use this water for irrigation and domestic purposes, especially during shortages of water supply by water utility companies. This, therefore, means that the residents are at risk of having cancer through direct ingestion of arsenic (through drinking water from Mindolo stream) and the crops they grow near the stream if they continuously use this water on a daily basis, although the results may not be imminent. Thus, years may pass for symptoms and signs of cancer diseases to show or rather notice that indeed there is an accumulation of arsenic in their body, which lead to many numerous health complications such as heart failure, blood pressure, among other diseases apart from cancer diseases.

Most of the water in this stream (Mindolo stream) comes from one of the biggest tailings dams for the mines and deposits its waters into the Kafue River. The Kafue River is mainly contaminated with arsenic by discharges of effluents from mining companies not only in Kitwe but also from Chambishi, Chingola and Mufulira mining towns through its tributaries (rivers and streams). The Chambishi and Kitwe mining effluents from tailings dams are deposited into the Kafue River through the Mwambashi River and Mindolo stream, while the Chingola and Mufulira mining effluents from tailings dams are deposited first into the Mwambashi River through Muntimpa and Lwela streams respectively, and proceeds into the Kafue River. It is therefore evident enough that indeed the water samples from Kafue river were found to contain arsenic concentrations, which were not above the threshold for drinking water, and that residents who live nearby the river take less arsenic than the required amount (the required concentrations of not more than 10μg/L) as per WHO standards, but this does not entirely exempt them from developing health complications that are cancer related and NCDs.

Nevertheless, the Kafue River is the major source of water for domestic and commercial use supplied by water utility companies on the Copper belt to the residents, especially Kitwe residents. This meant that the arsenic concentrations which were in tap water were as a result of Kafue River, the main source of water supply in the region. This means that indeed arsenic may be considered to be one of the contributing factors to the prevalence and incidences of cancer diseases in Kitwe district due long term exposure through drinking water from water sources, contaminated by mining activities in this region. Non-communicable diseases were as well cited because of the damage caused to the central nervous system, kidney, skin, liver and lungs in humans by continuous exposure to arsenic and other heavy metal elements found in the water as pollutants through mining and other industrial economic activities, as well as agricultural activities.

However, these concentrations might be better than those which were found in water samples from Taiwan, India, China, Argentina, Chile and Bangladesh, where arsenic concentrations ranges from 300µg/L to 934µg/L, respectively, as pointed earlier in Chapter two. These countries records high prevalence's and incidences of cancer diseases due to arsenic exposure in drinking water due to mining and other economic activities conducted, which does not require an enormous timeframe to establish or conclude that cancer cases recorded are a result of arsenic in water. Thus, people from these countries show early signs of arsenic exposure, as early as five years for those whose immune systems are strong, whereas those whose immune systems are very weak, signs and symptoms can be detected as early as two years, due to chronic exposure. This therefore means that the prevalence and incidence of cancer diseases due to arsenic exposure in drinking water in Kitwe district might be there, especially residents using water from Mindolo stream but it may or rather take time to realize that some of cancer cases are a result of arsenic in the water they drink due to low concentrations of the element in water.

Nevertheless, it must be mentioned that the water purification methods adopted by the water utility company in the district are so far helping reducing the concentrations of arsenic before they could supply to their clients.

However, the adsorption method was favoured as the cost-effective process of removing arsenic in drinking water among other methods, in response to the prevalence and incidences of cancer diseases, a solution that would be used by water utility companies providing services to the residents whose water bodies are contaminated with arsenic and other heavy metals due to mining activities like in Kitwe district and everybody at the household level, whose drinking water is contaminated with arsenic. Of the several, if not many methods of arsenic removal in water, this method (the adsorption method) was preferred, using two different soil samples (in terms of iron composition) containing ferric hydroxide. The method was chosen because of its high efficiency in arsenic removal in that arsenic has a high affinity for iron (high interactions between arsenic and

iron hydroxides, leading to strong adsorption on the surface sites of iron hydroxides through the formation of inner-sphere complexes).

The two soil samples were mixed separately with all three water samples from Kafue River, Mindolo stream and tap water, effectively assessing their efficiency in adsorbing arsenic from these water samples. Clay soil sample one "SS1"had less iron composition, whereas the other soil sample two "SS2" had more iron composition.

The concentrations of arsenic for three water samples (Mindolo, tap water and Kafue water samples, respectively) that remained after the adsorption process with ferric hydroxide soil sample two in terms of efficiency, soil sample one's (SS1) efficiencies of arsenic adsorption on all the three water samples were less than those of SS2. This was because the two soil samples have very low organic substances, which made them to effectively remove arsenic in water samples. Figure 7 shows a picture which was captured from the site where soil sample one (SS1) was collected.

The initial arsenic concentrations which were used were the concentrations of the water samples before they were subjected to the adsorption process, and the final arsenic concentrations were concentrations after the adsorption process. Thus, the difference between the initial arsenic concentrations and final arsenic concentrations is the concentrations of adsorbed arsenic. However, the adsorption efficiencies or rather removal of arsenic from the Kafue and Mindolo water samples by the two soil samples were very much affected (arsenic removal from these two water samples was not very good enough) by the phosphate and sulphate anions which were present and in excess compared to those which were detected in tap water samples. This would be because of the interactions between these two anions and iron hydroxides which could have decreased the arsenic adsorption in that they bring about competition when they coexist with arsenic in the suspension of iron hydroxides.

Similarly, the arsenic removal from Bangladesh water by adsorption process using ferric hydroxide with arsenic concentrations ranging from 280µg/L to 587µg/L and 5.5 to 7.8µg/L, had 51-75% arsenic removed from water samples, not as the predicted 99% efficiency respectively.

According to Tang et al. [52], synthesiszed iron oxide nanoparticles were able to remove around 74% of arsenic from water samples within the first 30 minutes of contact from an initial of 111µg/L to 40µg/L arsenic concentrations whereas the solution which had 95µg/L arsenic concentrations recorded 100% removal.

CONCLUSION AND RECOMMENDATIONS

Conclusion

Following the analytical results for three water samples from Mindolo stream, tap water and Kafue River, which were analyzed

using an Induced Couple Plasma Optical Emission Spectrometry (ICP-OES), the results showed that the water samples contained arsenic in them. Human activities such as mining and agriculture are one of the major contributors to polluting these water bodies, especially the Kafue River which is a main source of water for water utility companies supplied in the region, receives all the mining effluents containing arsenic from as far as Chingola and Mufulira mining districts, respectively. This point was made because it is understood that the effects or rather impact of arsenic on the health of human beings take longer periods to be detected, especially if the concentrations been exposed to, were minimum or slightly above the accepted threshold of 10μg/L, as was the case with Mindolo stream water samples tested.

However, an alternative solution to this problem which may have endangered human species for decades now, was looked at, by putting these water samples to test through adsorption process of arsenic using two ferric hydroxide-containing soil samples with different iron compositions with 80.43% and 93.48% arsenic removal efficiency, proved to be viable and very cost-effective in that the concentrations of arsenic in all three water samples were lowered, and that there were no other substances were added to these two soil samples. The performance of these two soil samples was a result of their richness in low molecular weight organic compounds. Therefore, this method proved to be very effective in mitigating arsenic and can to a certain level help reduce the incidences and prevalence of cancer cases.

Recommendations

Based on the findings, the following are the recommendations;

i. Further research studies to be conducted on the soil samples from Chinsali district so they can be modified into a more lighter and efficient adsorbent, so they can be used by mining companies and industrial companies that contaminate water bodies with arsenic such as Kafue River.

ii. Water utility company adopt the adsorption process of ferric hydroxides for the removal of arsenic in water before being supplied to their clients in Kitwe and other surrounding districts. This will help reduce the concentrations of arsenic and other heavy metal elements in water which in turn would help reduce the prevalence and incidences of cancer diseases in the region.

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