KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

KUMASI, GHANA

COLLEGE OF ENGINEERING

GEOLOGICAL ENGINEERING DEPARTMENT

PROJECT REPORT

SOIL, WATER AND CROP QUALITY ASSESMENT ON RECLAIMED TAILINGS DAM SITES AT ABOSSO GOLDFIELDS

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DECLARATION

We hereby declare that except for references to others peoples works, which have been duly acknowledged, this project report submitted to the Geological Engineering Department, College of Engineering, Kwame Nkrumah University of Science and Technology, Kumasi, is the result of our own work.

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I hereby declare that I have supervised these students in the making of this project and confirm that the students have my permission to present it for assessment.

ABSTRACT

This study assesses heavy metal levels in water, soil, and vegetables and food crops (cabbage, okro, green pepper, tomatoes, hot pepper, orange, green beans, garden eggs, plantain and cassava) from reclaimed dam sites in Abosso, Ghana. The samples of soils, water and crops were randomly collected, processed and analysed for heavy metals. The obtained results show that the concentrations of Zn, Pb, Cr, Ni and Co were higher in the soils from reclaimed dam sites than the control sites. The soils are not contaminated in Arsenic in the STSF but are moderate contamination in the ATSF. The study also revealed that the pockets of waterbodies around the dam sites are not contaminated in As and Cd when compared with the WHO guideline value. However, it is suspected that the pockets of waterbodies may have high concentrations of the trace elements found in the soil, since water is a universal solvent. All 10 crop samples show EDI values higher than the RfD in at least 2 of the three trace elements tested for (Zn, Cr, Ni), except for hot pepper which shows high values for Cr only. The crop samples were analysed for carcinogenic and non-carcinogenic health risks. All the crops show high probability of adverse health effects due to both carcinogenic and non-carcinogenic risks.

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Contents

[redacted]INTRODUCTION

[redacted]BACKGROUND INFORMATION

To extract valuable metals and other minerals for industrial processes, fertilizers, cosmetics and other consumer products large quantities of rock are mined and processed. A fine grind is necessary to release the metals and minerals, so the mining industry process large quantities of fine rock particles which end up as waste and are known as tailings (U.S. Environmental Protection Agency, 1994). Due to the nature of the tailings, dams are built to contain them. The term "tailings dam" is used in its widest sense, to include both the retaining structure and the impounded material (Mining Journal Research Services, 1996). Reclamation of a tailings dam is an important process for the comprehensive management of mine tailings. Tailings reclamation is generally to cover the beach and slopes of the tailings pond after the dam area is closed, and planting crops to protect the tailings from erosion (Zhen & Hu, 2021).

Mine tailings contain high concentrations of heavy metals that are toxic like Fe, Mn, Pb, Cu, As, Cd, Cr, Zn, Ni, and Hg. Heavy metals generally refer to metals and metalloids having densities greater than 5 g/cm3 (Oves & Khan, 2012). Heavy metals are released from the mine tailings to the ground and surface water systems, as well as the geological environment due to their solubility and mobility. Total metal concentrations in soil are an indication of the geology and weathering, and sometimes anthropogenic inputs of metals from industrial activities (Kersten & Forstner, 1989).

Metals cannot be degraded and thus they remain persistent in the environment posing serious health problems by existing in soil, surface, and drinking water (Yang, et al., 2009). Toxic metals such as Cu, Zn, Co, Ni, Fe, Cr, Mn, I and Se also known as micronutrients play a crucial role in the metabolic and physiological activities of humans, plants as well as microorganisms depending on their concentrations. On the other hand, specific toxic metals such as As, Ag, Hg, Cd and Pb are of no biological relevance to plants and animals; rather, they are harmful. Contamination of the edible parts of plants, for example, roots, whole plants, or other plant products, obtained from metal-contaminated soil followed by their uptake by humans and other animals basically constitute an important route of metal exposure (Jackson and Alloway 1992; Wang et al. 2005). Many scientific studies have implicated heavy metals in the cause of dermatological diseases, skin cancer and internal cancers (liver, kidney, lung and bladder), cardiovascular disease, diabetes, and anemia, as well as reproductive, developmental, immunological and neurological disorder in the human body.

The bioavailable metal content in soil heavily influences soil quality and its use in food production. Therefore, the assessment of metal contamination is important in farming areas (Loska, et al., 2004). Generally, the factors that affect the bioavailability and accumulation of heavy metals in soil or plants include (a) soil type, which includes soil pH, organic matter content, clay mineral, and other soil chemical and biochemical properties; (b) crop species or cultivars; (c) soil–plant–microbes interaction, which plays an important role in regulating heavy metal movement from soil to the edible parts of crops; and (d) agronomic practices such as fertilizer application, water managements, and crop rotation system. Heavy metals at higher concentrations cause damage to the various metabolic activities leading consequently to the death of plants (Oves & Khan, 2012). The objective of this study was, therefore, to assess the effect of mine tailings reclamation on soil, water and crop quality at Abosso Goldfields using geochemical indices.

PROBLEM STATEMENT AND JUSTIFICATION

1.2.1 Problem Statement

The reclaimed damsites at Abosso may have a potential for agricultural activities. Release of heavy metals from mine tailings into the environment affects soil and water quality in these reclaimed areas. Food crops cultivated in these areas may assimilate these heavy metals in large quantities and this poses a serious health risk to both the plants and consumers.

1.2.2 Justification

This project will help create awareness about the geochemical state of the reclaimed damsites at Abosso Goldfields and to check if the area is suitable for agricultural purposes.

PURPOSE AND SPECIFIC OBJECTIVES

1.3.1 Purpose

The purpose of this project is to determine the level of contamination of soil and water by heavy metals and assess the health risk associated with the consumption of crops harvested from the reclaimed damsites at Abosso Goldfields.

1.3.2 Specific Objectives

- To evaluate the degree of heavy metal pollution of soil and water on the reclaimed damsite.
- To assess the health risks posed by the consumption of crops harvested from these contaminated soils.

[redacted] STRUCTURE OF THESIS.

This technical report consists of five chapters. Chapter one, the introduction, comprises of the brief background to introduce the project, the problem statement, the relevance, the purpose and specific objectives and the main methods used in the project. Chapter two focusses on Literature review. Chapter three presents the research methodology, explains how the study was carried out. Chapter four discusses the results and interpretations of the findings from the study. Chapter five presents' conclusions and recommendations based on findings from the study.

[redacted] LITERATURE REVIEW

[redacted] STUDY AREA

Abosso Goldfields Limited is located in the Prestea-Huni Valley District which is about 30km north-east of Tarkwa in South Western Ghana and can be found within latitude 5.30 and 5.60N and longitude 1.78 and 2.08W. Abosso has a tropical climate, with average monthly temperatures between 21°C and 32°C, and is characterized by two distinct rainy seasons from March-July and September-November. Average annual rainfall near the site is 2,030 mm.

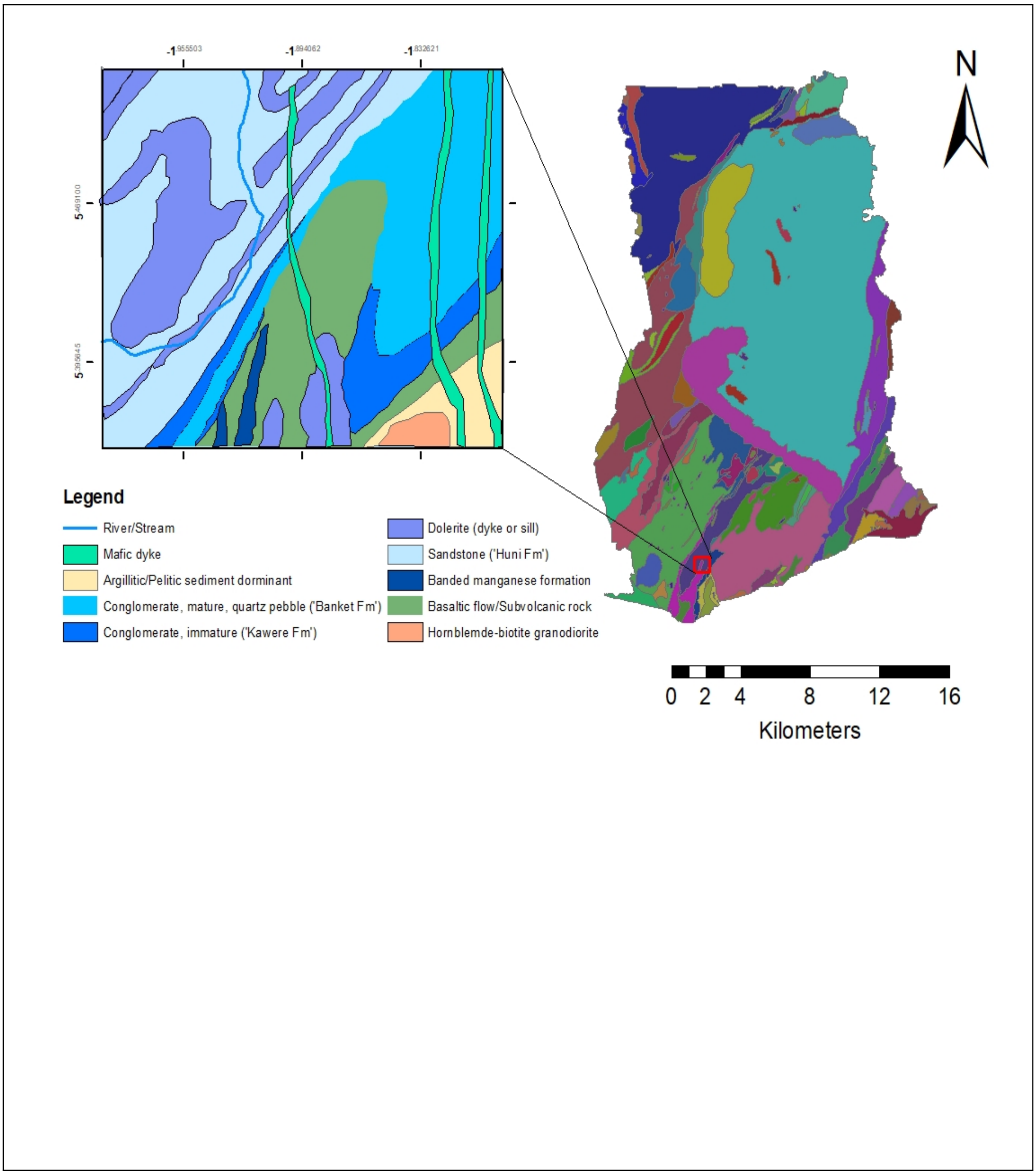

Figure 2.1: Geological map of Abosso.

2.1.1 Local Geology

The Damang ore bodies are located within the Tarkwaian Sediments, which form a significant portion of the stratigraphy of the Ashanti Belt in southwest Ghana. The Ashanti Belt is a north-easterly striking, broadly synclinal structure made up of Lower Proterozoic sediments and volcanics underlain by the metavolcanics and metasediments of the Birimian System. The Tarkwaian unconformably overlies the Birimian, and is characterized by lower intensity metamorphism and the predominance of coarse grained, immature sedimentary units.

The stratigraphy at Damang is primarily through the Tarkwaian Group and comprises a large-scale fining upwards sequence of clastic sediments interrupted by up to four major gold-bearing quartz pebble conglomerate horizons. This sequence unconformably overlies a mixed Birimian Supergroup basement comprising volcaniclastic deposits and minor fine-grained clastic sediments and black shales. The entire region is intruded by a number of igneous intrusions, the most common being dolerites that occur as narrow dykes and sill-like bodies along contacts on either side of the Tarkwa Phyllite, a particularly fine-grained pelitic unit in the upper Tarkwaian. A second intrusive body, the so-called `Diorite Porphyry' occurs sporadically along the boundary between the Birimian and the Tarkwaian.

2.1.2 Gold Mineralisation

Palaeoplacer mineralisation: There are three gold-bearing conglomerate horizons recognised on the western limb of the Damang Anticline. From footwall to hanging wall, these are known as, the Star/Composite, Malta/Breccia, and Gulder Reefs. There are also three gold-bearing conglomerate horizons recognised on the eastern limb, namely the Lima, Kwesie-K1, and Kwesie-K2 Reefs. These conglomerate horizons are separated by poorly mineralised sandstone units.

The reefs are usually characterised by a fining upwards sequence of poorly to moderately sorted, clast supported polymictic conglomerates. However, local variations are observed where the conglomerate domain is interbedded with fine to coarse grained, poorly sorted sandstones. The Star/Composite, Malta/Breccia, and Gulder Reefs on the west limb and the Lima, Kwesie-K1 and Kwesie-K2

Reefs on the east limb of the Damang Anticline, feature significantly higher gold grades than the poorly mineralised sandstone units, which separate the reefs. The conglomerate reefs may contain between 1.3 to 1.5 g/t Au, and the poorly mineralised sandstone units usually contain between 0.2 to 0.1 g/t Au.

Hydrothermal mineralisation: Hydrothermal gold mineralisation at Damang occurs in pyrite and pyrrhotite alteration selvages, which are usually less than 1 m wide and located immediately adjacent to en-echelon quartz veins. Gold is also associated with accessory vein minerals such as carbonate, muscovite, tourmaline, ilmenite, and apatite. These alteration zones are often linked, and may result in significant volumes, characterised by intense veining and gold mineralisation.

Damang is unique in Ghana by virtue of having hydrothermal mineralisation hosted in the quartzites of the Tarkwaian Banket Footwall as opposed to the Metavolcanics and Metasediments of the Birimian Basement as seen at Prestea, Bogoso, and Obuasi.

[redacted] MINE TAILINGS AND TAILINGS DAM

Tailings are defined as the processing waste from a mill, washery or concentrator that removed the economic metals, minerals, mineral fuels or coal from the mined resource (Lottermoser, 2010). A wide range of particle size fractions is discharged to the tailings. This includes coarse mine waste, fine clays, flotation tailings, chemical precipitates and slimes (Ritcey, 2005). These materials are very different from the usual mine overburden, which consists of rocks and soil that are removed to access the ore deposits in open pit mines (Ndlovu & Simate, 2017) and waste rocks, which are which are low grade rocks that are mined but are removed ahead of processing (Mining, Minerals, 2002). The chemical composition of tailings depends on the minerals mined and the extraction technique. For example, cyanide compounds are used in some gold (Au) operations (Rossner & Rons, 1992). By far the larger proportion of ore mined in most industry sectors eventually becomes tailings that must be disposed of. In the gold industry, for example, only a few hundredths of an ounce of gold may be produced for every ton of dry tailings generated (U.S. Environmental Protection Agency, 1994).

In mining, the steps taken for product extraction are not always efficient, thereby creating challenges in recovering reusable and expended processing reagents and chemicals. Most of the unrecoverable and uneconomic metals, chemicals and process water are disposed, largely as slurries, to a final storage area known as a Tailings dam. In most cases, tailings are pumped at very high pressure into ponds for sedimentation to occur. For cost efficiency, the water ejected from such mine tailings dam are often used in other processing cycles at the mines. The tailings dams, when poorly designed, constructed or managed, pose a significant risk to local communities and ecosystems. The construction of such retaining structures is exclusive and depends on the type of environment and mineral processing operation (Okereafor, et al., 2020).

[redacted] HEAVY METALS

Heavy metals refer to any metallic element that has a relatively high density and is toxic or poisonous at low concentrations. Examples of these heavy metals include Hg, Cd, Pb, As, Cd, Cr and Zn. Heavy metals are also considered as trace elements because of their presence in trace concentrations (ppb range to less than 10ppm) in various environmental matrices (Kabata-Pendias & Pendias, 2001). Heavy metals are natural components of the earth's crust. However, additional contributions come from anthropogenic activities such as agriculture, urbanization, industrialization, and mining (Facchinelli, et al., 2001). They cannot be degraded or destroyed. Their toxicity depends on several factors including the dose, route of exposure, and chemical species, as well as the age, gender, genetics, and nutritional status of exposed individuals.

Because of their high degree of toxicity, arsenic, cadmium, chromium, lead, and mercury rank among the priority metals that are of public health significance. These metallic elements are considered systemic toxicants that are known to induce multiple organ damage, even at lower levels of exposure. They are also classified as human carcinogens (known or probable) according to the U.S. Environmental Protection Agency, and the International Agency for Research on Cancer. The enter our bodies through food, drinking water and the air. As trace elements, some heavy metals are essential to maintain the metabolism of the human body. However, at higher concentrations they can lead to poisoning.

2.3.1 Heavy Metals in Soil and their Implications.

It is noted that metals cannot be degraded; however, some metals such as Cr, As and Hg can be transformed to other oxidation states in the soil, influencing their mobility and toxicity. Metals in the soil solution are prone to mass transfer out of the system by leaching to groundwater, plant uptake, or volatilization. Metals exist in the soil solution as either free metal ions (e.g., Cd^{2+}, Zn^{2+}, Cr^{3+}), in various soluble complexes with inorganic or organic ligands (e.g., $CdSO_4$, $ZnCl^+$, $CdCl_3^-$), or associated with mobile, inorganic and organic colloidal material (Wuana & Okieimen, 2011). The quality of a soil contributes to both enzymatic and microbial activities. The extent of soil pollution could be assessed using microbial biomass as an important index (Aceves, et al., 1999). There is a significant obstruction of microbial activity in soils with the problem of toxic metal contamination. In a study of soil contaminated by Cu, Zn, Hg and other toxic metals, a lower microbial biomass was observed within soil nearer to a mine compared with to those far away from the mine (Kandeler, et al., 1996). Studies have also shown that low levels of toxic metals support microbial growth while high concentrations inhibit microbial growth, thus decreasing soil microbial biomass (Chander, et al., 1995).

The presence of mine tailings in soil leads to acidification. This is because the toxic metal ions are normally contained in untreated mine tailings. Low pH tailings, i.e., acidic tailings contain higher amounts of toxic metals as compared to high pH tailings (Speira, et al., 1999). At high pH, most of the toxic metal ions form insoluble hydroxides and sulphides, which then precipitate to reduce the ion content of the tailings.

The absorption of soil toxic metals by plants is not always a problem in the short term, but becomes an issue in the long term. This is when the concentrations of these toxic metals become too high and exceed the thresholds, which result in plant poisoning and subsequent death. Researchers in Florida, USA, observed that citrus seedlings were affected by soil with Cu content of more than 50mg/kg, while an increase to 200mg/kg caused the withering of wheat (Zhijie & Quifang, 1989). Human health is also at risk when soils have excessive levels of toxic metals. This is attributed to the absorption of toxic metals via the skin, dust inhalation and the pollution of food, water and air. In a survey conducted in China, over 30% of children sampled had Pb levels that exceeded the standard home requirement (100g/L), which was linked with the soil dusts (Robert & Jones, 2009).

2.3.2 Heavy Metals in Water and their Implications.

Globally, water contamination from toxic metals has remained a serious problem following the increasing deaths of animals and humans alike as a result of diseases linked to impure drinking water. The presence of heavy metals in natural water is affected by both hydro-chemical factors, such as the mineral composition of the rocks and soil characteristics, as well as anthropogenic activities. Metals in the environment tend to persist in their in their localities because they cannot be biologically or chemically degraded. The pollutant metals are moved from water bodies to the food chain via assimilation and process of bioaccumulation. A cycle of heavy metal movement is established in which the geochemical processes in water occur by way of interfaces into the atmosphere and into the sediment. Toxic metals are distributed by the atmosphere as solids (dry deposition) and in dissolved form (precipitation) as wet deposition in water bodies (Graedel, et al., 1993). Heavy metals are deposited in water bodies via inflow in dissolved form or as insoluble solids. The cycle is completed by sedimentation at the sediment stage, which returns to water bodies as a result of mobility (Ebenebe, et al., 2017).

A study carried out in South Africa investigated the possible transportation of toxic metals due to ground erosion during heavy rainfall in the Rural Mhangweni (Tzaneen, Limpopo province) and reported disturbing toxic metal concentrations such as Al (6.141 ppm), Zn (0.431 ppm), Fe (5.072), Cu (1.506), Pb (2.041) and Mn (3.918 ppm), which surpassed the maximum acceptable level of water composition as stipulated by the United States Environmental Protection Agency (Okereafor, et al., 2017). Heavy metals such as Hg is harmful particularly to humans when present in water that is a part of the food chain. This is because it causes problems to the central nervous system, leading to a condition called Minamata disease (Gibb & O'Leary, 2014). Also, Lead poisoning from water has been linked to stunted growth in children, nervous system damage and learning disabilities as well as antisocial behaviors (Kumar, et al., 2013).

2.3.3 Heavy Metals in Plants and their Implications.

Just like humans and other living organisms, plants show some reactions towards the availability and quite rarely, lack of critical micronutrients due to the roles they play in metabolism. Some heavy metals such as Cu, Zn, Co, Ni, Fe, Cr, Mn, I and Se play a crucial role in the metabolic and physiological activities of humans, plants as well as microorganisms depending on their concentrations. On the other hand, specific toxic metals such as As, Ag, Hg, Cd and Pb are of no biological relevance to plants and animals; rather, they are harmful. Generally, the metal elements' composition of plants reflects the chemical composition of their growth media (i.e., soil, water, air and nutrient solution).

Metal accumulation depends on factors such as the growing environment, soil pH, temperature, soil aeration, competition between plant species, root system, availability of the elements in the soil, the type of leaves and soil moisture (Nagajyoti & Lee, 2010). Studies have shown that an increase in pH, i. e. the environment becoming more alkaline, abruptly reduce the quantity of toxic metals that are available to plants (Misra & and Mani, 1991). Plants absorb any element presented to them in nutrient media, however the distribution of these elements within the plants may be heterogeneous; certain elements such as lead, nickel, copper, zinc, iron, manganese, chromium, and vanadium are preferentially retained by the root system, whereas major elements like Calcium and Potassium are transported in major part to the shoot system (Robb, 1983). The transport of trace elements among plant organs also depends on the electrochemical variables of elements. In general, easily transported from roots to above-earth parts are Ag, B, Li, Mo, and Se; moderately mobile are Mn, Ni, Cd, and Zn; and strongly bound in root cells are Co, Cu, Cr, Pb, Hg, and Fe (Kabata-Pendias, 2011).

The damaging effects of excessive toxic metals has been widely documented. Mn, Pb, Cd, Cr and Co during a study were observed to be responsible for the poor growth of maize plants (Ghani, 2010). At extreme levels, toxic metals could result in oxidative stress in plants, mutilation of cell structure through the substitution of deficient elements with toxic metals and slow down photosynthetic processes in plant cells (Van & Clijsters, 1990). The phytotoxicity effect of Zn and Cd is seen by retarded growth and development, metabolism and an inductive oxidation damage in various plant species such as Brassica juncea (brown mustard) (Doncheva, et al., 2001)]. Zinc toxicity has been linked to restricted growth of both root and shoot in plants (Fontes & Cox, 1998) as well as chlorosis in newer leaves (Ebbs & Kochian, 1997). There are reported cases of reduced crop production due to Ni toxicity that impaired certain enzymatic activities (amylase, protease and ribonuclease), thus adversely affecting the germination of seeds. Also affected by Ni were activities such as membrane stability, nitrate reductase and carbonic anhydrase (Yusuf, et al., 2012).

As a micronutrient for plants, Cu is crucial in the synthesis of ATP and assimilation of CO2 (Thomas, et al., 2008). Cu constitutes a major part of proteins such as plastocyanin of photosynthetic system and cytochrome oxidase of respiratory electron transport chain (Demirevska-Kepova, et al., 2004). When in excess as a result of anthropogenic activities such as mining, Cu has a cytotoxic effect on soil which induces stress and causes growth retardation and leaf chlorosis in plants (Ebbs & Kochian, 1997). From previous studies, a combination of both Cu and Cd were responsible for the poor germination, seedling length and number of lateral roots in Solanum melongena (eggplant) (Neelima, 2002).

It is important to mention that there are plants known as accumulators that can withstand higher concentrations of heavy metals in their natural environment. These plants are able to tolerate high metal levels through diverse mechanisms such as (i) exclusion: restriction of metal transport and maintenance of a constant metal concentration in the shoot over a wide range of soil concentrations; (ii) inclusion: metal concentrations in the shoot reflecting those in the soil solution through a linear relationship; and (iii) bioaccumulation: the accumulation of metals in the shoot and roots of plants at both low and high soil concentrations (Baker, 1981).

[redacted] HEAVY METALS IN HUMAN HEALTH AND THEIR IMPLICATIONS.

Heavy metals are harmful when consumed not only beyond certain optimal concentrations, but can generally pose a serious health risk even at undetermined low concentrations. Human exposure to heavy metals has risen dramatically as a result of an exponential increase of their use in several industrial, agricultural, domestic and technological applications. It has been reported that metals Co, Cr, Cu, Mo, Fe, Mn, Ni and Zinc are essential nutrients that are required for various biochemical and physiological functions. Inadequate supply of these micro-nutrients results in a variety of deficiency diseases or syndromes (World Health Organization, 2000). Toxic metals such as Pb, Cd, Hg and Arsenic are of no use to the human system. Unfortunately, there is no established homeostasis for them (Vieira, et al., 2011). In addition to the toxicities of metals, the potential carcinogenicity of metal compounds had been of interest to society.

The movement of heavy metals in humans is quite complex. For instance, Pb ends up in the digestive and respiratory tract, before entering the bloodstream in the form of soluble salts, protein complexes or ions with over 95% of the insoluble phosphate lead accumulating in bones. As a highly organizational element, Pb affects and destroys several body organs and systems, such as kidney, liver, nervous system and the basic processes of cell and gene expression (Mahurpawar, 2015). Exposure to pregnant women may result in reduction in immunity and birth weight (Day, 1998).

Cu, Zn and Ni are vital trace metals in the human body but, when consumed in excess, are harmful to the body. Prolonged human exposure to copper results in accumulation in organs such as liver, kidney, brain and cornea which leads to cellular damage, respiratory tract irritation, hemolytic anemia, nausea, dizziness and death may occur (Martínez & Motto, 2000). A previous study indicated that individuals working closely with nickel powder are at risks of having respiratory cancer and that the content of Ni in the environment is absolutely associated with nasopharyngeal carcinoma (Barta & Powell, 2019).

Depending on the severity of the level of exposure, Cadmium (Cd) toxicity is mostly evident in organs such as liver, kidneys, placenta, brain, lungs and bones (Sobha, et al., 2007). Some of the symptoms include nausea, abdominal cramps, vomiting, dyspnea and muscular weakness. Extreme exposure has been linked to death and pulmonary odema with effects such as emphysema, bronchiolitis and alveolitis (Duruibe, et al., 2007). A variety of clinical conditions such as cardiac failure cancers, anosmia, osteoporosis, cerebrovascular infarction, proteinuria cataract formation in the eyes and emphysema are largely associated with cadmium.

Just like mercury and lead, the toxicity symptoms of arsenic are dependent on the form in which they are ingested. Arsenic aids the coagulation of protein, aid the formation of complexes with coenzymes and stops the production of adenosine triphosphate (ATP) during respiration. It is mostly carcinogenic in compounds of its oxidation states. which results in death when exposed to an extreme level. Cases of arsenic are responsible for disorders similar to and often likened to Guillain-Barre syndrome, an anti-immune disorder that arises when the body’s immune system erroneously attacks part of the PNS, leading to inflammation of the nerve that causes weakness of the muscle (Duruibe, et al., 2007).

[redacted] NON-CARCINOGENIC RISK

Non-carcinogenic risk is a measure of the likelihood that a receptor may develop non

-cancer health effects due to long term exposure to a given chemical or group of chemicals. It is calculated using the hazard quotient, which is the ratio of the estimated daily exposure (EDI) of each contaminant to the applicable chronic reference dose (RFD) for that contaminant. It can be expressed by the following equation; $HQ = {}^{EDI}/_{RfD}$.

Whether the THQ < 1, it is usually assumed to be secure for the risk of noncarcinogenic effects; if THQ > 1, it is assumed that there is a greater likelihood of noncarcinogenic effects as the value rises.

CARCINOGENIC RISK

Carcinogenic risk is the incremental probability of an individual to develop cancer over a lifetime as a result of exposure to a potential carcinogen. It is given by; $CR = EDI \times CSF$, where CR = cancer risk over a lifetime by individual heavy metal ingestion, EDI = estimated daily metal intake in mg/day/kg body weight, CSF = oral cancer slope factor in (mg/kg/day), and n is the number of heavy metals considered for cancer risk calculation. For single carcinogenic metals and multi carcinogenic metals, the permissible limits are 10^{-6} and < 10^{-4}, respectively (Tepanosyan, et al., 2017).

ESTIMATED DAILY INTAKE (EDI)

The estimated daily intake is an estimate of the amount of trace element ingested on a daily basis when the crop is consumed. The EDI is calculated using the equation described by (Gebeyehu & Bayissa, 2020) and is given by; **EDI =** $\frac{Ef \times Ed \times Fir \times Cm \times Cf \times 0.001}{Bw \times Ta}$, where E_f = exposure frequency (365 days/year); E_d = exposure period (for men 77 years, women 81 years), which is equivalent to the average life span; F_{ir} = average vegetable consumption, C_m = metal concentration (mg/kg dry weight); Cf = concentration conversion factor for fresh vegetable weight to dry weight, B_w = body weight; and T_a = average exposure period, and 0.001 stands for unit conversion factor.

CONTAMINATION FACTOR (CF)

The contribution of human activities to the addition of heavy metals in sediments is indicated by the contamination factor (CF) (Ahmed et al., 2016). The contamination factor was suggested be Hakanson (1980) and is given by; CF = $\frac{C_{0-1}}{C_n}$, where C_{0-1} is the mean content of each of the heavy metals from at least 5 sample sites which provide an even cover of the accumulation area and Cn is the reference or background value for the heavy metals. The following terminology is used in this risk index approach to get a uniform way of describing the contamination factor (Hakanson, 1980).

Table 2.1 Range of contamination factor values and their corresponding extent of contamination

CF value	Grade
CF < 1	Low contamination factor
1 ≤ CF < 3	Moderate contamination factor
3 ≤ CF < 6	Considerable contamination factor
CF ≥ 6	Very high contamination factor

[redacted]GEO-ACCUMULATION INDEX

The geo-accumulation index (Igeo) was introduced by Müller (Müller, 1969). It enables the assessment of environmental contamination by comparing differences between current and preindustrial concentrations (Li, et al., 2014). Originally used with river bottom sediments, it can also be applied to the assessment of soil contamination (Loska, et al., 2004). The Igeo for the soils of the reclaimed damsites is computed using the following equation, $Igeo=\log_2 (Cn/1.5Bn)$, where Cn is the measured concentration of the heavy metals found in the reclaimed soil, and Bn is the geochemical background value of the heavy metals found in soil. The constant 1.5 is used due to potential variations in the baseline data (Loska et al., 2004; Solgi et al., 2012). The geo-accumulation index consists of 7 classes. The concentration doubles with each step from one class to the next higher class (Förstner & Müller, 1981).

Table 2.2 Range of geo-accumulation index values and the corresponding soil quality

CLASS	VALUE	SOIL QUALITY
0	Igeo ≤ 0	Practically uncontaminated
1	Igeo 0–1	Uncontaminated to moderately contaminated

2	Igeo 1–2	Moderately contaminated
3	Igeo 2–3	Moderately to heavily contaminated
4	Igeo 3–4	Heavily contaminated
5	Igeo 4–5	Heavily to extremely contaminated
6	Igeo ≥ 5	Extremely contaminated

[redacted] BIO – ACCUMULATION COEFFICIENT

The bio - accumulation coefficient is quantified as; BAC = Cplant/Csoil , where Cplant is the concentration of metal in the plant; and Csoil is the metal concentration in soil. This coefficient is used to evaluate the metal-accumulating capacity of plants relative to the degree of soil contamination (Zu, et al., 2005).

[redacted] METHODOLOGY

The methodology consists of the pre-field, post field and field work.

[redacted] PRE-FIELD WORK

The pre-field work involves desk study which includes finding any relevant background information of the area and field of study and preparation of maps.

[redacted] FIELD WORK

The field work consists of soil, water and crop sampling.

3.2.1 Soil Sampling

Soil was sampled from 3 different sites, namely; Abosso Tailings Storage Facility, South Tailings Storage Facility and a virgin area nearby. Composite samples of top soil (0-20 cm) were collected from the same locations simultaneously with the crops. Nine representative soil samples were taken from each of these sites. About 1kg of each soil sample was collected using a stainless-steel spade. The collected soil samples were stored in zip locked polythene bags for transport and storage. The pH at each sampling site was measured and recorded. The coordinates of sampling locations were recorded with a GPS.

3.2.2 Water Sampling

Samples of water was taken from pockets of waterbodies around the tailings damsites. The samples were filtered in the field and stored in polyethylene bottles. The polyethylene bottles were washed with HNO3 for 12 h prior to sampling, and a trace metal clean procedure was always employed during sample collection.

3.2.3 Crop Sampling

Crops harvested from the reclaimed damsites were collected for sampling. In total, 10 species of vegetable and crops were sampled. Plant samples were placed loosely in a labeled cloth bag, and were transported to the lab as quickly as possible.

[redacted] POST-FIELD WORK

All soil samples were air-dried at room temperature (25°C), stones or other debris were removed, and then sieved to 2 mm sieve. Portions of soil samples (about 50 g) were finely ground manually using mortar and pestle and passed through a 0.149 mm sieve. The prepared soil samples were then stored in polyethylene bags for analysis.

The natural water samples were analyzed using ICP-MS for the heavy metals.

Prior to the analysis of the plant material, the edible portions of vegetable material were separated and carefully washed with tap and deionized water in order to remove any surface soil or dust deposits, and then oven-dried, then ground into fine powder sieved through 1 mm nylon sieve.

Dried vegetable, and soil samples were analyzed using AAS analysis.

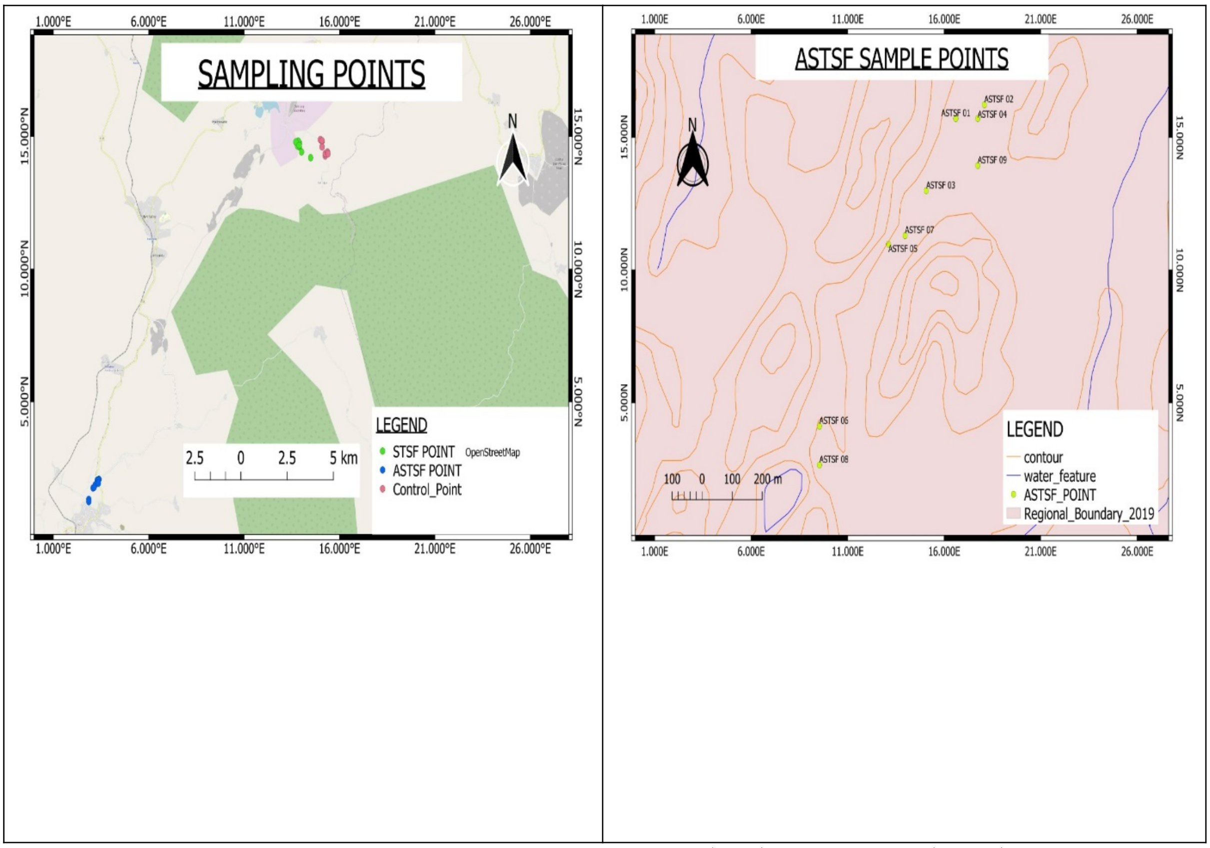

Figure 3.1 Map of sampling points (left) and ATSF (right)

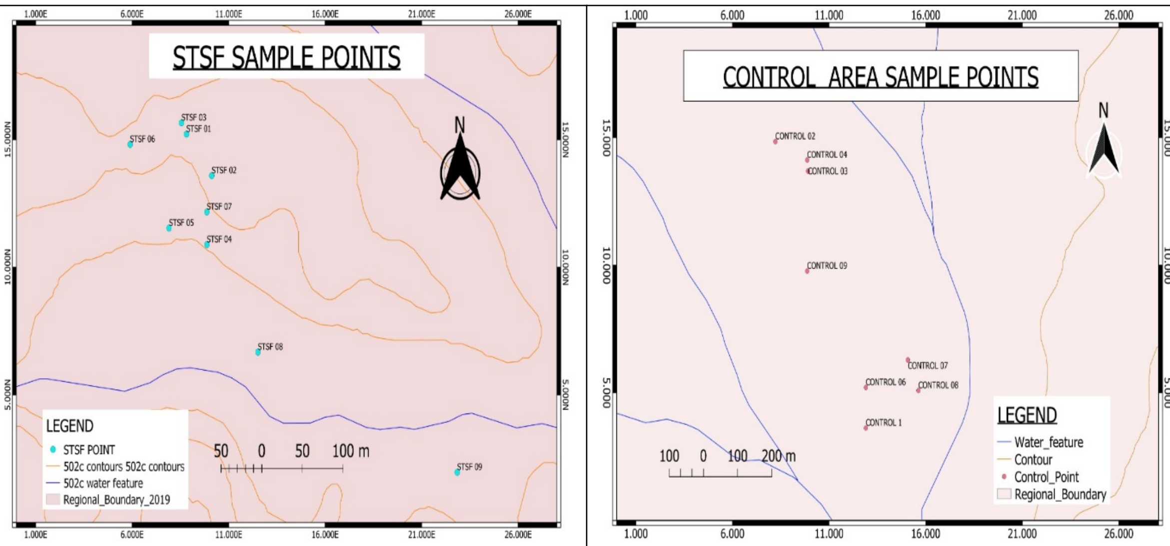

Figure 3.2 Map of STSF sample points (left) and control area sample points (right)

[redacted] RESULTS AND DISCUSSIONS

[redacted] CONCENTRATION OF TRACE METALS IN THE SOILS

The results from the lab contained pH values as well as selected trace element concentrations. The following tables and graphs show the results obtained from the lab for the soil sampling.

Table 4.1 pH and elemental concentrations for the STSF

Site	pH	Zn	Pb	As	Ni	Co	Cr
STSF 1	7.9	12	6	0.08	21.0	11.0	51.0
STSF 2	8.4	9.9	11	0.08	22.0	9.8	49.0
STSF 3	8.5	16	9	0.11	21.0	18.0	62.0
STSF 4	8.5	9.7	8	0.13	16.0	5.9	89.0
STSF 5	8.5	9.8	23	0.06	22.0	12.0	42.0
STSF 6	7.5	9.6	6	0.08	9.1	9.5	22.0
STSF 7	8.4	11.2	10	0.15	20.0	11.0	49.0
STSF 8	8.3	11.6	10.6	0.12	18.1	10.4	48.5
STSF 9	8.2	10.7	11	0.16	17.5	11.7	60.0

Table 4.2 pH and elemental concentrations for the ATSF

Site	pH	Zn	Pb	As	Ni	Co	Cr
ATSF 1	7.5	25	8	3	5.9	8.1	43
ATSF 2	8.5	84	32	5	8.6	13	12
ATSF 3	8.0	97	46	4	14	13	30
ATSF 4	8.5	68	38	3	12	12	33
ATSF 5	8.0	45	26	5	9.2	9.5	16
ATSF 6	8.5	82	42	2	8.2	13	27
ATSF 7	8.2	69	32	4	9	11	27
ATSF 8	8.3	67	33	3	9	12	27
ATSF 9	8.2	65	31	4	10	11	25

Table 4.3 pH and elemental concentrations for the control area

Site	pH	Zn	Pb	As	Ni	Co	Cr
Control 1	6.5	3.6	2	<2	<0.5	<0.3	5
Control 2	6	6.1	4	<2	<0.5	<0.3	5
Control 3	6.2	4.5	2	<2	<0.5	<0.3	3
Control 4	6.5	3.1	5	<2	<0.5	<0.3	4
Control 5	6	5.4	3	<2	<0.5	<0.3	5
Control 6	6.3	4.4	3	<2	<0.5	<0.3	5
Control 7	6.4	4.5	3	<2	<0.5	<0.3	4
Control 8	6.3	4.6	4	<2	<0.5	<0.3	5
Control 9	6.3	4.5	3	<2	<0.5	<0.3	5

The soils tested were slightly basic with a mean pH of 8.2 for both the South Tailings Facility and the Abosso Tailings Facility. The minimum and maximum pH for soil samples on both sites was 7.5 and 8.5 respectively. The investigation did not reveal the occurrence of acidic soils. Table 4.1.4 gives the contents of the metals in the soil. It shows, apart from the minimum and maximum values, the mean as well as the standard deviation and skewness because some of the distributions were not normal. The table also contained contents of metals from a virgin area close to the sites which served as background values.

Table 4.4 Metal content in soils at the STSF, ATSF and control sites

Site	pH	Zn	Pb	As	Ni	Co	Cr
STSF							
Min	7.5	9.6	6.0	0.1	9.1	5.9	22.0
Max	8.5	16.0	23.0	0.2	22.0	18.0	89.0
Mean	8.2	11.2	10.5	0.1	18.5	11.0	52.5
Median	8.4	10.7	10.0	0.1	20.0	11.0	49.0
SD	0.3	2.0	5.1	0.0	4.1	3.2	17.9
Skewness	-1.3	1.6	1.8	0.2	-1.4	0.8	0.5
ATSF							

Min	7.5	25.0	8.0	2.0	5.9	8.1	12.0
Max	8.5	97.0	46.0	5.0	14.0	13.0	43.0
Mean	8.2	66.9	32.0	3.6	9.7	11.4	26.6
Median	8.2	68.0	32.0	3.7	9.3	12.0	26.8
SD	0.3	21.4	10.9	1.0	2.3	1.7	9.0
Skewness	-1.2	-0.8	-1.3	0.0	0.5	-1.1	0.1
CONTROL							
Min	6	3.1	2	1	0.3	0.15	3
Max	6.5	6.1	5	1.9	0.45	0.25	5
Mean	6.3	4.5	3.2	1.8	0.4	0.2	4.5
Median	6.25	4.5	3	1.7	0.4	0.2	5

The mean zinc content in the soils at the STSF and ATSF were 11.2 and 66.9 mg/kg respectively, with the STSF having twice as much as its mean content in the non-contaminated soil and the ATSF having about 15 times the mean content of the non-contaminated soil.

The mean Pb content in the STSF soils was 10.5 mg/kg and was higher than the average lead content in the soils from the control area (3.2 mg/kg). The soils from the ATSF contained much higher amounts of lead, 32 mg/kg.

The average arsenic content in the tested soils from the STSF and ATSF were 0.1 mg/kg and 3.6 mg/kg respectively. The STSF had arsenic concentrations within the range of the concentrations from the control area (<2 mg/kg). However, the ATSF had higher arsenic concentration.

The mean Ni content in the STSF and ATSF reached 18.5 mg/kg and 9.7 mg/kg respectively, both values being higher than the Ni content from the control area (<0.5).

The average cobalt content in the soils from the virgin area was estimated to be <0.3 mg/kg. The content assayed in the STSF and ATSF were 11mg/kg and 11.4 mg/kg respectively.

Chromium content in the soils of both the STSF and ATSF was high. The STSF had an average Cr content of 52.5 mg/kg while the ATSF had a mean Cr content of 26.6 mg/kg. the background content for Cr was 4.5 mg/kg.

[redacted] CONCENTRATION OF TRACE METALS IN THE WATERBODIES

Results of concentration of heavy metals namely; Arsenic and Cadmium for pockets of waterbodies around the reclaimed damsites are presented in table 4.2.

Table 4.5 Trace metal concentrations in pockets of water bodies

	STSF		ATSF	
Date	As	Cd	As	Cd
	mg/kg	mg/kg	mg/kg	mg/kg
Aug-15	0.002	0.001	0.002	0.002
Sep-15	0.002	0.001	0.001	0.002
Oct-15	0.013	0.002	0.001	0.001
Nov-15	0.003	0.001	0.001	0.001
Dec-15	0.004	0.002	0.001	0.001

Table 4.6 Mean As and Cd content in pockets of waterbodies.

	As (mg/kg)	Cd (mg/kg)
STSF	0.0048	0.0014
ATSF	0.0012	0.0014
WHO guideline value	0.01	0.003

The mean content of As in the STSF and ATSF were 0.0048 and 0.0014 mg/kg respectively. These values are within the WHO guideline value of 0.01 mg/kg as shown in the table. The average concentration of Cd was 0.0014 in both the STSF and ATSF. This value is also within WHO guideline value of 0.003.

[redacted] CONCENTRATION OF TRACE METALS IN CROPS

Food crops are very crucial to human diet and therefore it is very important to maintain their quality. If grown in a contaminated environment, they can accumulate high metal concentrations that could affect human health after consumption (Alam, et al., 2003). Trace metals accumulate more quickly in leafy vegetables than in fruit grains and crops (Mapanda, et al., 2005). The levels of trace metals in crop samples (cabbage, okro, green pepper, garden eggs, hot pepper, tomatoes, orange, green beans, plantain and cassava) grown in the two reclaimed dam sites (South Tailings Storage Facility and Abosso Tailings Storage Facility) were examined and the findings are summarized in table 4.7.

Table 4.7 Trace element concentrations in vegetables and crop samples

Sample	Sites	Zn	Limits for Zn(mg/kg)	Ni	Limits for Ni (mg/kg)	Cr	Limits for Cr(mg/kg)
Brassica oleracea capitata (Cabbage)	STSF	58	24-31	11	0.6-3.3	1.4	0.05-0.21
	ATSF	62		18		2.1	
Abelmoschus esculentus (Okro)	STSF	54	24-31	1.9	0.43-0.48	0.2	0.02-0.24
	ATSF	48		3		0.7	
Capsicum annuum (Green pepper)	STSF	41	24-31	6.9	0.43-0.48	0.3	0.07-0.13
	ATSF	53		3.9		0.9	
Solanum melongena (Garden eggs)	STSF	25	24-31	0.8	0.43-0.48	3.1	0.07-0.13
	ATSF	15		1.6		1.1	
Capsicum annuum (Hot pepper)	STSF	4.8	24-31	0.4	0.43-0.48	0.4	0.07-0.13
	ATSF	3.6		1.2		0.7	
Lycopersicum esculentum (Tomatoes)	STSF	28	17-22	0.35	0.43-0.48	3.4	0.07-0.13
	ATSF	31		0.15		3.7	
Citrus sinensis (Orange)	STSF	17	0.4-0.3	0.25	0.39	0.25	0.03-0.05
	ATSF	22		0.12		0.6	
Phaseolus vulgaris (Green beans)	STSF	55	32-38	3.7	0.2-0.25	0.13	0.05-0.16
	ATSF	42		4.1		0.45	

Musa paradisiaca (Plantain)	STSF	6.9	2.8	0.2	-	0.23	-
	ATSF	8		0.42		0.55	
Manihot esculenta (Cassava)	STSF	12	10 - 2 6	0.15	0.29-1.0	0.33	0.02-0.05
	ATSF	15.4		1.05		0.8	

Limits for Zn and Cr were proposed by Kabata-Pendias(2011).

Limits with (-) not found

Generally, all the trace elements found in the food crops are higher than their corresponding limits. Few exceptions are hot pepper, garden eggs and cassava, which has lower Zn concentrations and tomatoes which has lower Cr content than the limits.

[redacted] EVALUATION OF CONTAMINATIONS

The degree of contamination was evaluated using pollution indices such as the contamination factor, geo-accumulation index and bio-accumulation factor.

4.4.1 Contamination Factor

The contamination factor was calculated to assess the soil contaminantion and is given by; CF = $\frac{C_{0-1}}{C_n}$, where C_{0-1} is the mean content of each of the heavy metals from at least 5 sample sites which provide an even cover of the accumulation area and Cn is the reference or background value for the heavy metals.

CF for Zinc at the STSF = $\frac{C_{0-1}}{C_n} = \frac{11.2}{4.5}$, = 2.5

CF for Lead at the STSF = $\frac{C_{0-1}}{C_n} = \frac{10.5}{3.2}$ = 3.3

The evaluated data for the contamination factor are presented in table 8.

Table 4.8 Contamination factors for both STSF and ATSF

Site	Zn	Pb	As	Ni	Co	Cr
STSF						
CF	2.5	3.3	0.1	46.3	55.2	11.7

ATSF						
CF	14.8	10.1	2	24.1	57.2	5.9

Figure 4.1 Contamination factors for STSF (left) and ATSF (right)

Table 4.9 Categories for contamination factor values (Hakanson, 1980)

CF value	Grade
CF < 1	Low contamination factor
1 ≤ CF < 3	Moderate contamination factor
3 ≤ CF < 6	Considerable contamination factor
CF ≥ 6	Very high contamination factor

4.4.2 Geo-Accumulation Index

The geo-accumulation index (Igeo) was introduced by Müller (Müller, 1969). The Igeo for the soils of the reclaimed damsites is computed using the following equation:

Igeo= $\log_2$ (Cn/1.5Bn), where Cn is the measured concentration of the heavy metals found in the reclaimed soil, and Bn is the geochemical background value of the heavy metals found in soil. The geo-accumulation index consists of 7 classes.

Igeo for Zinc at the STSF= $\log_2$ (Cn/1.5Bn) = $\log_2(11.2/1.5\times4.5) = 0.7$

Igeo for Zinc at the ATSF= $\log_2$ (Cn/1.5Bn) = $\log_2(10.5/1.5\times3.2) = 3.3$

Table 4.10 Geo-accumulation indices for the STSF and ATSF

Site	Zn	Pb	As	Ni	Co	Cr
STSF						
I_{geo}	0.7	1.1	-4.6	4.9	5.2	3.0
ATSF						
I_{geo}	3.3	2.8	0.4	4.0	5.3	2.0

Figure 4.2 Geo-accumulation indices for STSF (left) and ATSF (right)

Table 4.11 Classification of geo-accumulation values (Muller,1981)

CLASS	VALUE	SOIL QUALITY

0	Igeo ≤ 0	Practically uncontaminated
1	Igeo 0–1	Uncontaminated to moderately contaminated
2	Igeo 1–2	Moderately contaminated
3	Igeo 2–3	Moderately to heavily contaminated
4	Igeo 3–4	Heavily contaminated
5	Igeo 4–5	Heavily to extremely contaminated
6	Igeo ≥ 5	Extremely contaminated

4.4.3 Bio-Accumulation Coefficient

The bio - accumulation coefficient is quantified as; BAC = Cplant/Csoil , where Cplant is the concentration of metal in the plant; and Csoil is the metal concentration in soil. This coefficient is used to evaluate the metal-accumulating capacity of plants relative to the degree of soil contamination (Zu, et al., 2005)

Sample	BAC (Zn)		BAC (Ni)		BAC (Cr)	
	STSF	ATSF	STSF	ATSF	STSF	ATSF
Cabbage	5.2	5.5	0.6	1.0	0.03	0.04
Okro	4.8	4.3	0.1	0.2	0.004	0.01
Green pepper	3.7	4.7	0.4	0.2	0.01	0.02
Garden eggs	2.2	1.3	0.04	0.09	0.1	0.02
Hot pepper	0.4	0.3	0.02	0.06	0.01	0.01
Tomatoes	2.5	2.8	0.02	0.01	0.1	0.07
Orange	1.5	2.0	0.01	0.01	0.005	0.01
Green beans	4.9	3.8	0.2	0.2	0.003	0.01
Plantain	0.6	0.7	0.01	0.02	0.004	0.01
Cassava	1.1	1.4	0.01	0.05	0.01	0.02

Zn accumulation in the crops is very high, as BAC for all the crop samples are above 1. Cr and Ni are not readily absorbed by the plants since they show values less than 1.

[redacted]HEALTH RISK ASSESMENT

4.5.1 Estimated Daily Intake.

The mean metal concentrations of the crops as well as the estimated daily consumption of the crops (g), was used to calculate the element's estimated daily intake (EDI) using the equation described by (Gebeyehu & Bayissa, 2020), **EDI =** $\frac{Ef \times Ed \times Fir \times Cm \times Cf \times 0.001}{Bw \times Ta}$, where E_f = exposure frequency (365 days/year); E_d = exposure period (60 years for adults and 12 years for children), which is equivalent to the average life span; F_{ir} = average vegetable consumption (240 g/person/day for adults and 80kg for children), as defined by the World Health Organisation Report (WHO 2002)for low fruit and vegetable intake and 800g for plantain and cassava (Zango, et al., 2013). C_m = metal concentration (mg/kg dry weight); Cf = concentration conversion factor for fresh vegetable weight to dry weight (0.085) (Arora, et al., 2008); B_w = body weight (average of 70kg for adults and 30kg for children) ; and T_a = average exposure period (Ed 365 days/year), and 0.001 stands for unit conversion factor.

EDI for Zn from cabbage in the STSF **=** $\frac{Ef \times Ed \times Fir \times Cm \times Cf \times 0.001}{Bw \times Ta}$, = $\frac{365 \times 60 \times 240 \times 58 \times 0.085 \times 0.001}{70 \times 365}$ = 1.01mg/kg/day (Adults)

Table 4.12 Estimated Daily Intake for Adults

Sample	EDI (Zn)		EDI (Ni)		EDI (Cr)	
	STSF	ATSF	STSF	ATSF	STSF	ATSF
Cabbage	1.01	1.08	0.192	0.315	0.024	0.04
Okro	0.94	0.84	0.033	0.052	0.003	0.012
Green pepper	0.72	0.93	0.121	0.068	0.005	0.015
Garden eggs	0.44	0.26	0.014	0.028	0.054	0.02
Hot pepper	0.08	0.06	0.007	0.021	0.007	0.01
Tomatoes	0.49	0.54	0.006	0.003	0.06	0.06
Orange	0.30	0.38	0.004	0.002	0.004	0.01
Green beans	0.96	0.73	0.065	0.072	0.002	0.007
Plantain	0.40	0.47	0.012	0.024	0.013	0.032
Cassava	0.70	0.90	0.009	0.061	0.019	0.047

The estimated daily intakes for Zn ranged from 0.08 - 1.01 for the STSF and 0.06 - 1.08 (mg/kg/day) for the ATSF. The EDIs for Zn were all greater than the reference dose (0.3mg/kg/day) except for hot pepper (both sites) and garden eggs (ATSF). For Ni, the EDIs ranged from 0.004 - 0.192 for the STSF and 0.002 - 0.315 (mg/kg/day) for the ATSF. Cabbage, okro and green pepper in the STSF had values greater than the reference dose (0.02 mg/kg/day), while all the crops in the ATSF except tomatoes and orange had values lesser than the reference dose. Cr had EDI values ranging from 0.002 – 0.054 for the STSF and 0.007 – 0.47 for the ATSF (mg/kg/day). All the crops from the STSF had higher values than the reference dose (0.003 mg/kg/day) except for green beans.

4.5.2 Non-Carcinogenic Risk

The target hazard quotient (THQ) values were calculated to evaluate non-carcinogenic human health risks from the consumption of the crops harvested from the tailings dam site. It is given by the equation; **THQ =** $\frac{\text{EDI}}{\text{RfD}}$, where EDI represents the estimated daily intake in mg/day/kg body weight and RfD is the oral reference dosage (mg/kg/day) values for each of metal of concern. The RfD values of Zn, Cr and Ni were 0.3,0.003 and 0.02 mg/kg/day, respectively (Gebeyehu & Bayissa, 2020). For THQ < 1, it is usually assumed to be secure for the risk of non-carcinogenic effects; if THQ > 1, it is assumed that there is a greater likelihood of non-carcinogenic effects as the value rises.

THQ for Zn from cabbage in the STSF = $\frac{\text{EDI}}{\text{RfD}} = \frac{1.01}{0.3} = 3.38$ (Adults)

Sample	THQ (Zn)		THQ (Ni)		THQ (Cr)	
	STSF	ATSF	STSF	ATSF	STSF	ATSF
Cabbage	3.38	3.61	9.62	15.74	8.16	12.24
Okro	3.15	2.80	1.66	2.62	1.17	4.08
Green pepper	2.39	3.09	6.03	3.41	1.75	5.24
Garden eggs	1.46	0.87	0.70	1.40	18.07	6.41
Hot pepper	0.28	0.21	0.35	1.05	2.33	4.08
Tomatoes	1.63	1.81	0.31	0.13	19.82	21.57
Orange	1.00	1.28	0.22	0.10	1.46	3.50

Green beans	3.21	2.45	3.23	3.58	0.77	2.62
Plantain	1.34	1.55	0.583	1.224	4.47	10.69
Cassava	2.33	2.33	0.437	3.060	6.41	15.54

THQs for Zn for all crops were higher than 1 except for hot pepper (STSF and ATSF) and garden eggs (ATSF). Cr also had THQ greater than 1 for the following crops in the STSF; garden eggs, hot pepper, tomato, orange, plantain and cassava, and for the ATSF, tomato and orange. Ni exhibited values greater than 1 in all the crops except green beans. In all, there is a high probability that health effects could be experienced. Some health effects associated with excessive zinc in the body includes nausea, vomiting, loss of appetite and headaches. For Cr, health effects include nasal irritation, nasal ulcer and asthma. For Ni, health effects are lung fibrosis, kidney and cardiovascular diseases.

4.5.3 Carcinogenic Risk

The cancer risk (CR) presented to human health by individual potential carcinogenic metals was calculated. Then, the cumulative cancer risk (TCR), which may promote carcinogenic effects depending on exposure dose, was then calculated from ingestion of the trace metals (Cr, Ni) using the formulas, **CR = EDI×CSF** and **TCR = CRn,** where CR = cancer risk over a lifetime by individual heavy metal ingestion, EDI = estimated daily metal intake of the population in mg/day/kg body weight, CSF = oral cancer slope factor in (mg/kg/day), and n is the number of heavy metals considered for cancer risk calculation. The CSF values of Cr and Ni were 0.5 and 1.7 mg/kg/day, respectively (Gebeyehu & Bayissa, 2020). For single carcinogenic metals and multi carcinogenic metals, the permissible limits are 10^{-6} and $< 10^{-4}$, respectively (Tepanosyan, et al., 2017).

CR for Ni from cabbage in the STSF **= EDI×CSF** = 0.19×1.7 = 0.33 (Adults)

Table 4.3.6 Carcinogenic health risk for adults

Sample	CR (Ni)		CR (Cr)	
	STSF	ATSF	STSF	ATSF
Cabbage	3.27E-01	5.35E-01	1.22E-02	1.84E-02
Okro	5.65E-02	8.92E-02	1.75E-03	6.12E-03
Green pepper	2.05E-01	1.16E-01	2.62E-03	7.87E-03

Garden eggs	2.38E-02	4.76E-02	2.71E-02	9.62E-03
Hot pepper	1.19E-02	3.57E-02	3.50E-03	6.12E-03
Tomatoes	1.04E-02	4.46E-03	2.97E-02	3.23E-02
Orange	7.43E-03	3.57E-03	2.19E-03	5.25E-03
Green beans	1.10E-01	1.22E-01	1.14E-03	3.93E-03
Plantain	1.98E-02	4.16E-02	6.70E-03	1.60E-02
Cassava	1.49E-02	1.04E-01	9.62E-03	2.33E-02

The CR values for Ni ranged from 7.43E-03 to 3.27E-01 for STSF and 3.23E-02 to 3.93E-03 for the STSF. The CR values for Cr also ranged from 1.14E-03 to 2.97E-02 for the STSF and 3.93E-03 to 3.23E-02 for the ATSF. All CR values are higher than 10^{-4}, therefore our results indicate that consumption of the crops poses a possible cancer risk to the population.

Table 4.3.7 Carcinogenic health risk for children

[redacted] CONCLUSION AND RECOMMENDATIONS

[redacted] CONCLUSION

This research highlighted the toxic repercussions of heavy metals in a polluted environment as a result of mining activities (tailings dam-site) on three important components of the ecosystem; soil, plants, and water in Abosso in the western region of Ghana. Heavy metals toxicity causes serious problems for children and adults by ingestion, inhalation, and dermal adsorption. The effects of heavy metals in high concentrations were comprehensively discussed in addition to their implications on human health. It was observed that Zn is extremely mobile in the soil and consequently accumulate relatively high in various parts of the plant. Soil concentrations of trace elements are generally high both in ATSF and STSF and thus make areas around the dam-site contaminated. Soil can be treated with following methods;

- Biological treatment/Bio-remediation; uses bacteria to break down substances in soil
- Chemical oxidation; converts contaminated soil into non-hazardous soil
- Soil stabilization; addition of immobilizing agents to reduce a contaminants leachability
- Phytoremediation; using plants to clean contaminated soil

Surface and pockets of water bodies sampled after laboratory results didn't show high levels of the trace elements tested (As and Cd). The toxic, cancerous nature of As and Cd and the detection limit influenced the choice of these elements for testing among other trace elements discussed in this project. Although levels of Cd and As were low and did not exceed the FAO/WHO guideline, water is a universal solvent and the soil is heavily polluted we can conclude that surface water in Abosso near the tailing dam-sites and sampled soil locations is not safe for drinking or agricultural purposes. Surface water around tailing dam-sites sampled soil locations should be treated if used for purposes such as drinking and agriculture.

Water pollution remediation techniques include;

- Distillation
- Filtration
- Chemical precipitation

- Membrane filtration
- Ion exchange

Certain elements are essential components of the human diet. However, because of their tendency of accumulating in the human body, their content in crops must be determined and assessed for potential health risks to human. Crops and vegetation that were sampled after laboratory results showed very high bio-accumulation factors for Zn. Most of the trace element concentrations also exceeded the limits proposed by Kabata-Pendias, 2011, which became a necessity to run a carcinogenic and non-carcinogenic risk assessment. Values and interpretation from health risk assessment shows that crops consumed will increase the risk of carcinogenic and non-carcinogenic health effects. Our findings support the need for close monitoring of the reclaimed damsites in Abosso Goldfields. Different body organs can be affected along with body systems. The harmful health implications of heavy metals can be concluded as neurodegenerative disorders, musculoskeletal diseases, and reproductive hormonal imbalance. We also suggest that further studies should be carried out on new approaches to the phytoremediation and bioremediation of environmental toxicants.

[redacted]RECOMMENDATIONS

- Data collected from Abosso Goldfields are from five (5) years ago and are not representative of the present-day state of the reclaimed dam-site. More studies are to be done to make a more comprehensive and realistic verdict on the state on the dam-site and its health implication on inhabitants.
- In this work, there is the possibility of uncertainties that may not be taken into account and could consider as a limitation for the validity of the risk estimation. For instance, (i) body weights and daily intake of drinking water were not estimated for the people who live in Abosso, (ii) most of the probability variables applied for estimation were derived from the US EPA guideline which may not apply to this population,, (iii) CSF was considered as a constant for all individuals, but in reality, CSF can change between individuals, and (v) the health risk was only assessed using the heavy metal toxicity, but the fact is that drinking water also contains other chemicals from possible exposure. Thus, the level of risk from drinking water in Abosso may be higher than that estimated values in this work. All parameters used in the calculation of carcinogenic and non-

carcinogenic risk were average and constant values and not representative of inhabitants of Abosso.

- The water samples should have been tested for other trace elements present in the soil for more accurate and comprehensive results since surface water will readily dissolve significant amount of trace elements.
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