

**AKENTEN APPIAH-MENKA UNIVERSITY OF SKILLS TRAINING AND
ENTREPRENEURIAL DEVELOPMENT (AAMUSTED)**

FACULTY OF ENVIRONMENT AND HEALTH EDUCATION

DEPARTMENT OF PUBLIC HEALTH EDUCATION

**ENVIRONMENTAL AND HUMAN HEALTH RISK ASSESSMENT OF TOXIC
METALS IN WATER AND SEDIMENTS FROM SOME ARTISANAL AND
SMALL-SCALE MINING COMMUNITIES IN THE AMANSIE SOUTH
DISTRICT OF GHANA**

SETH OPOKU

MASTER OF PHYLOSOPHY

SEPTEMBER, 2024

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**A THESIS IN THE DEPARTMENT OF PUBLIC HEALTH EDUCATION,
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PHILOSOPHY (ENVIRONMENTAL AND OCCUPATIONAL HEALTH
EDUCATION) IN THE UNIVERSITY OF EDUCATION, WINNEBA.**

SEPTEMBER, 2024

DECLARATION

STUDENT’S DECLARATION

I, Seth Opoku now declare that except for references to the works of other researchers duly cited, this work is the result of my original research and that this dissertation has neither in whole nor in part been presented for another degree elsewhere.

SIGNATURE:

DATE:

SUPERVISORS’ DECLARATION

We declare that the preparation and presentation of this work were supervised by the guidelines for the supervision of the thesis as laid down by the Akenten Appiah-Minkah University of Skills Training and Entrepreneurial Development

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DEDICATION

I dedicate this work to my father, Mr. Paul Wiredu Dankwah and my Late mother, Agnes Serwaa, and my lovely children for their unflinching love and pounding support throughout my education and career.

ABSTRACT

This study sought to examine the environmental and human risk assessment of small-scale and artisanal gold mining in the Amansie South district. A cross-sectional study design was used for the study. A total of Sixty-six (66) different samples of soil, sediments, and water were sampled from ten rivers in the Amansie South district from July to October 2023 for the study. Soil sediments, soil samples and water samples were collected and analyze using AAS. In addition, structured questionnaires were issued to ascertain from respondents the various mining activities and the possible effects of those activities on their health. The study found widespread water pollution by mercury, lead, and cadmium, significantly exceeding the WHO permissible limit (0.01 mg/L for Pb, 0.05 mg/L for Hg and 0.03 mg/L for Cd). While arsenic and copper were within the WHO permissible limits (0.01 mg/L and 2.0 mg/L respectively) for most water types. Residents reported water quality issues and believed mining caused them, with many experiencing health problems. Diseases associated with heavy metals according to the respondents were urinal diseases, hypertension, and arthritis. Urinal diseases was experienced by 18 (90%), hypertension 17 (85%) and arthritis 15 (75%). This study confirms extensive environmental damage from small-scale mining in the district. The analysis confirms widespread water and soil pollution by heavy metals exceeding safety limits, threatening both human health and environmental well-being. Government and stakeholders in the mining industry must strengthen enforcement of existing regulations or introduce new policies to control mining activities and mitigate environmental contamination.

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CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

Human-environment interaction, as posited by Ostergren and Le Bosse (2017), is an undeniable aspect of human existence with multifaceted implications. Individuals formulate crucial decisions based on technological advancements and cultural influences derived from a myriad of choices presented by the surrounding environment (Ostergren, 2011). Regrettably, certain choices such as mining and farming near water bodies or extraction of minerals near water bodies, whether deemed imperative or not, have played a significant role in instigating environmental alterations and harm. The exploitation of natural resources is far from being a recent occurrence. However, the progression from discovery to utilization has hitherto yielded adverse consequences on both society and the environment. Martinez-Alier (2018), unequivocally emphasized that irrespective of economic advancements, detrimental environmental practices will reverberate onto future generations.

Mining stands as a prevalent and profitable sector in numerous developing nations. For instance, Ghana is Africa's second-largest gold producer owing to its rich reservoirs of minerals like gold, diamonds, bauxite, and manganese (Martinez-Alier, 2018). The gold-endowed regions of Ghana boast a longstanding history of mining dating back to the colonial era when the country was known as the Gold Coast. The attractive price of gold in the global market, particularly in emerging economies, rendered mining highly lucrative, sparking a surge in mining activities.

Consequently, this scenario has led to instances where mining enterprises operate illicitly without due regard for the environmental and societal repercussions. According to Edwin and Gabriel

(2018), poverty serves as the primary motivator behind artisanal mining. In Ghana, over one million people are employed in the small-scale gold, diamond, sand-winning and quarry industries as compared to Large-Scale Mining (LSM) sector which employed just 33,109 people (Ghana Chamber of Mines, 2023). This comprised 10,087 direct employees of the Chamber's producing member companies and 22,022 employees of contractors (Ghana Chamber of Mines, 2023). Empirically, the mining sector's multiplier effect in employment generation is estimated to be 1:15, which implies that for every direct job created on the mine, 15 jobs are created indirectly through the relationships between a mine and its suppliers and between a mine's supplier and the mine supplier's supplier (Ghana Chamber of Mines, 2023). As highlighted by Hilson (2021), the practice of artisanal and small-scale gold mining has facilitated the employment of unskilled laborers in rural areas of Ghana, consequently leading to an increase in the nation's gold production.

However, it is essential to acknowledge that the considerable mercury pollution and land degradation in Ghana can be predominantly attributed to artisanal gold mining operations in the country. Currently, around 80 nations globally partake in artisanal and small-scale mining (ASM) activities (Hilson *et al.*, 2021). Artisanal and small-scale mining (ASM) encompasses a wide range of mining undertakings, spanning from small-scale, disorganized activities to large-scale, coordinated operations wherein individuals engage in gold or gemstone panning along riverbanks (Schudel *et al.*, 2019). The proliferation of ASM in numerous developing countries is primarily influenced by population pressure and the limited availability of alternative sources of income in rural settings (Boateng *et al.*, 2014). There is a growing recognition among international development entities that poverty plays a central role in driving ASM activities (Hilson *et al.*, 2021).

The absence of a universally acknowledged definition for ASM has led to debates, with some arguing that its adaptable nature is a defining characteristic that allows for broad application (Chaparro & Suchdev, 2019). Different nations utilize various criteria such as production volume, capital expenditure, claim size, and workforce size to define ASM within their regulatory frameworks, reflecting the diversity in approaches due to differing national preferences (Hilson *et al.*, 2021). The complexity arises from the varying values assigned to these criteria, making it challenging to establish a consensus on the defining features of ASM across different countries (Boateng *et al.*, 2014).

Numerous endeavors to precisely delineate ASM within the global arena have been unsuccessful, as have efforts to establish a clear differentiation between artisanal and small-scale miners (Schudel *et al.*, 2019). While certain countries have legal frameworks demarcating "artisanal mining" from "small-scale mining," others like Ghana lack such distinctions (Boateng *et al.*, 2014). The regulatory landscape in most countries today separates ASM from large-scale (or industrial) mining through distinct laws and regulations. ASM is characterized by relatively low production levels (though they can be substantial in certain regions like Brazil), limited mechanization and technological progress (as miners often utilize picks, chisels, sluices, and pans), high labour intensity, modest capital outlay, absence of long-term strategies, informal nature, and inadequate standards of environmental, occupational health, and safety (Schudel *et al.*, 2019; Miserendino *et al.*, 2013).

Furthermore, notable features of ASM encompass extensive geographical dispersion on a large scale, decentralized operations, generation of employment opportunities in remote rural areas, mitigation of rural-urban migration, provision for local markets, stimulation of local economies, establishment of local production networks, and advancement of geopolitical progress (Hilson *et*

al., 2021). This investigation categorizes both artisanal mining (employing rudimentary tools) and small-scale mining (utilizing relatively advanced machinery) as small-scale mining due to the absence of a clear differentiation between the two forms of mining (Obeng, 2015). Prior studies have adopted this terminology. Ghana possesses about 70% of the confirmed gold reserves in West Africa (Ayad & Bakkali, 2022).

The country's rich mineral resources can be attributed to its geographical positioning. The primary Precambrian rock formations in Ghana are associated with the Proterozoic Birimian rocks and these geological formations serve as the primary reservoir of the nation's key mineral resources, such as gold, bauxite, diamonds, and manganese (Fernandes Azevedo *et al.*, 2012). Roughly one-third of the eight main mineral resource belts in Ghana consist of Birimian rocks, which contribute significantly to the nation's gold output (Sherman *et al.*, 2015). Ghana's Akan majority historically gained cultural significance through the mining sector, however, with the arrival of European traders on the Gold Coast, the true value of gold was unveiled, leading to a lucrative gold mining industry emerging in the early 17th century (Aryee, 2003). The Ghana Statistical Services approximates that mining contributes around 40% of the nation's gross foreign exchange earnings and 5.6% of its GDP (GSS 2021).

Recent statistics indicate that in 2008, the industry yielded approximately \$700 million for the government subsequent to the Ashanti Goldfields' sale to the Anglo Gold Mining (AGM) Group of Companies (GSS 2021). Over an extended period, Ghana's Ashanti, Eastern, and Western regions have served as the primary mining zones within the country. Resources such as gold, manganese, and coal were discovered in the Upper East Region, previously identified as the North Eastern Corridor of the former Northern Territory of Ghana (Paruchuri *et al.*, 2010). The

initial mining exploration in the Upper East Region was carried out in 1934 by Russian miners in Nangodi, Talensi Nabdam District, although it was eventually abandoned (Hilson *et al.*, 2021).

Over the past few decades, there has been a notable rise in artisanal small-scale mining (ASM) activities in the region. The income generated from ASM mining operations nationally amounted to \$72,028 (Mensah *et al.*, 2016). Nevertheless, the increasing emphasis on mining to sustain livelihoods and the escalating worries regarding environmental degradation have led to a split in opinions. The swift damage inflicted by heavy metal contamination from AGM operations on soil, sediments, water, and plant ecosystems presents a pressing environmental issue in the southern part of Ghana. As highlighted by Gimmler *et al.* (2012), the toxic effects on plants and alterations in the plant community stem primarily from heavy metal pollution in soil, facilitating plant uptake and accumulation in plant tissues. While some heavy metals are essential for plant survival, crops cultivated in metal-contaminated soil may amass levels exceeding permissible limits, posing potential risks to public health (Sherman *et al.*, 2015). The accumulation of heavy metals in crops and soils is particularly worrisome as it could lead to the introduction of harmful substances into the human food chain.

The substantial water demand in gold mining activities diverts freshwater resources from other uses. The uncontrolled practices of both large-scale mining operations and small-scale mining contribute to a range of environmental issues, such as soil degradation, land subsidence, and air and water pollution (Emmanuel & Dzigbodi 2018), which in turn jeopardize human health. Currently, the methods employed for the disposal of AGM wastewater exhibit significant variation and largely hinge on local regulations. The cadmium (Cd), lead (Pb), mercury (Hg) and aluminum (Al) are considered non-essential for the growth of plants due to their lack of involvement in physiological processes within plants (Crawford & Botchwey, 2016).

Conversely, Iron (Fe), Copper (Cu), and Zinc (Zn) play vital roles in plant growth and metabolism; however, excessive levels of these metals can lead to environmental contamination issues (Antwi-Boateng & Akudugu, 2020).

Numerous studies have identified the presence and accumulation of heavy metals in surface water across significant mining sites in southern Ghana as well as in pristine environments (Hadzi *et al.*, 2015). At the ASM sites, the average concentrations of Hg varied from 0.001 to 0.45 mg/kg, while Fe was 1.75 mg/kg (Yen *et al.*, 2012). Similarly, research conducted by Akoto *et al.* (2017) in Kumasi, the capital city of the Ashanti region, documented heavy metal pollution in surface soils. Moderate to extreme levels of Zn, Cd, Hg, and Pb were identified through geo-accumulation indices. Recent findings by Gyamfi *et al.* (2019) highlighted significant soil pollution with Fe, Pb, Zn, As, Mn, and Cu in the Kokoteasua area of the Obuasi municipality in the Ashanti region of Ghana. Moreover, elevated levels of As and Zn in nearby mining areas rendered the drinking water unsafe for consumption (Gyamfi *et al.*, 2019).

Native plants in the ASM regions of Ghana were reported to exhibit substantial accumulation of metals, as noted by Nkansah *et al.* (2017). Various research studies have investigated the accumulation of heavy metals in the soil, sediments, water, and vegetation systems of southern Ghana (Belford & Nkansah, 2017). The assessment of soil, sediments, surface water, groundwater, and plants for contamination in the AGM regions of the Amansie South District in the Ashanti region of Ghana is crucial in light of these findings and their associated implications.

1.2 Problem statement

Ghana, a prominent gold mining region globally, harbours numerous underprivileged communities in West Africa, where artisanal and small-scale mining (ASM) contributes to 10% to 15% of the world's gold output (Islam *et al.*, 2016). Gold extraction has been a part of Ghana's

history for more than a millennium (Mensah *et al.*, 2016). Various mining disruptions, predominantly in rural zones, have occurred, with many being prohibited from continuing their operations. The activity of illegal mining, known as “Galamsey”, characterizes those engaging in unauthorized mining practices (Kumah, 2022). Nevertheless, due to the utilization of substandard equipment and a localized approach, it is referred to as "local mining." The majority of mining operations have adverse effects on the environment, primarily due to the frequent use of machinery, explosives (dynamites), and chemical leaks (Zhang *et al.*, 2011).

Moreover, ASM has been associated with numerous adverse impacts, such as the exposure of miners and communities downstream and adjacent to mining activities to pollutants (Miserendino *et al.*, 2013). Despite the positive economic contributions of these practices, they can lead to harmful social and environmental consequences, especially in low-income countries (Antwi-Boateng & Akudugu, 2020). The mining industry has negative effects on the environment, human health, agriculture, and society overall, despite its economic benefits. As noted by Adjei *et al.* (2012), mining has directly resulted in deforestation, water pollution, soil depletion, and land degradation in mining communities (Adjei *et al.*, 2023). Mining operations have polluted several major water bodies in the country, including the river Offin, which runs through the Upper Denkyira West District and is utilized for irrigation and other purposes. Additionally, due to the open pits left by illegal mining activities, the six clinics in the Upper Denkyira West District report that malaria is the most prevalent health issue in the region (Kuffour *et al.*, 2020a).

Mining activities in Prestea, a mining settlement in Ghana, have resulted in a disproportionate contamination of crucial water bodies (Eduful *et al.*, 2020). This has led to the loss of aquatic life, damage to biodiversity, removal of plants, depletion of soil resources, and impacts on agriculture (Eduful *et al.*, 2020). Research in Prestea, located in the Western Region of Ghana,

revealed elevated levels of antimony and arsenic in rivers, ranging from 0.09 to 0.75 mg/kg and 0.90 to 8.25 mg/kg, respectively, surpassing the WHO's recommended values of 0.005 and 0.01 mg/kg (Eduful *et al.*, 2020). Furthermore, mining activities have significantly affected most water bodies in the Amansie South district of the Ashanti region, leading to severe environmental and health challenges (Owusu-Sekyere, 2013). Mining negatively impacts traditional livelihoods, attracts newcomers to the area, strains social amenities, and contributes to social problems and environmental degradation (Owusu-Sekyere, 2013). Nevertheless, Antwi-Boateng & Akudugu (2020) suggested that the adverse effects of mining, like polluted water sources, air and noise pollution, and loss of arable land, lead to a notable reduction in poverty levels among the local population. Antwi and Akudugu (2020) further highlighted that environmental damage from mining activities, including tailings, can severely limit livelihood opportunities for those reliant on forestry, fishing, hunting, or agriculture.

1.3 Objectives of the Study

The general objective of the study is to examine the environmental and human health risk of toxic metals in water and sediments from some artisanal and small-scale mining communities in the Amansie South district.

1.3.1 Specific objectives of the Study

Specifically, the study seeks to;

1. Determine concentration of Fe, Cu, Zn, Pb, Cd, and Hg in the water
2. Assess the concentration of Fe, Cu, As, Pb, Cd, and Hg in the sediments at Amansie south district.
3. Asses the health risks of heavy metal contamination of small-scale and artisanal gold miners in the Amansie south district.

1.3 Research Questions

1. What is the concentration of Fe, Cu, As, Pb, Cd, and Hg in the water?
2. What is the concentration of Fe, Cu, As, Pb, Cd, and Hg in the sediment?
3. What are the health risks posed by heavy metal contamination and their health implications of heavy metal contamination of water bodies to small-scale and artisanal gold miners in the Amansie south district?

1.4 Justification of the study

The extent to which artisanal mining impacts the environment and community well-being is often contingent on the level of its expansion. Despite the dominance of the mining subsector in the district's economic activities, attracting miners from neighboring areas, Amansie South primarily functions as an agricultural region. With the exception of a few large and small mining enterprises, the majority of mining activities in the district are conducted by informal miners referred to as "galamseyers" (Osman *et al.*, 2022a). This research will analyze the presence of various heavy metals like Fe, Cu, As, Pb, Cd, and Hg in water, soil, sediments, and food to evaluate the extent of pollution from artisanal and small-scale mining in the Amansie South district. The objective of this study is to assess how artisanal and small-scale mining activities affect the district's water sources, soil quality, and food resources through a series of laboratory tests. Apart from recognizing the environmental challenges associated with artisanal and small-scale mining, this study will propose practical measures to alleviate these effects. The findings of this research will serve as a reference for mining companies, whether operating legally or illegally, urging them to consider the environmental concerns of local communities. Ultimately, this study seeks to establish a basis for future research initiatives and offer a comprehensive framework for the management of artisanal and small-scale mining.

1.5 Scope of the Study

Contextually, the study investigated how artisanal and small-scale gold mining affects the ecosystem. References would be specifically made to the concentration of heavy metals in water and sediments, Fe, Cu, As, Pb, Cd, and Hg. Mining practices that affect land, water, and food supplies were also be examined. The study's geographic focus was restricted to Ghana's Ashanti region, namely the Amansie South area. Every site owned by small-scale and artisanal miners would be considered.

1.6 Limitations of the Study

Limitations are constraints that are likely to hinder the continuation and effectiveness of the study. Considering the topic understudy, visitations and access to the various sources of water and soils from the various artisanal and small-scale mining sites within the district will be very difficult for the researcher. As such, the time within which the study should be completed will limit the success and accuracy of the information that will be gathered for the study. Also, financial difficulties as and when samples will be taken to the laboratory for experimentation and charges during the printing of materials.

1.7 Organization of the Study

There are six (6) chapters in the study. The study's Introduction, which comprises the study's background, problem statement, research aims, research questions, significance, scope, and delimitations, is covered in Chapter 1. The literature review is covered in Chapter 2. The study area's profile and the specifics of the research methodology are covered in Chapter 3, while results are covered in Chapter 4. Chapter five (5) of the study deals with discussion and Chapter 6 covering summary, conclusions and recommendation.

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

The critical review of literature is an essential and crucial component of any research project that aims to explore, identify, and analyze current theories and practices in the literature related to the research topic. The relevant literature on the subject is reviewed in this chapter. This chapter divided into many sections some of which are; regulations and laws pertaining to surface water quality, surface mining and its impacts, artisanal mining and its effects on vegetation, surface water pollution, degradation of land and vegetation, heavy metals' effects on surface water, and the effects of mining on the environment.

2.1 Overview of Artisanal and Small-Scale Mining

The process of illegally mining and/or extracting gold discovered in Ghana at or below the soil and water's surface is referred to as artisanal and small-scale mining, or "galamsey ". It is an illicit or uncontrolled type of artisanal small-scale gold mining (ASM) that can be done in three different ways: independently for gold extraction, independently for processing, or simultaneously for mining and processing (Donkor, 2015). Galamsey is illegal because the operators engage in activities that are restricted or sensitive(forest reserves, water bodies, sacred and culturally significant areas, residential zones, etc.), operate without regulatory approvals(from the Ghana Minerals Commission, Environmental Protection Agency, Water Resources Commission, Forestry Commission, or the host Municipal Assembly), and do not pay any taxes or statutory fees, and pays less or no attention to human rights(Morante-Carballo *et al.*, 2022).

These small-scale, artisanal gold mining activities have historical origins dating back to the colonial period, where they were initially established as rudimentary "pick and shovel" or "gather and sell" operations utilizing basic artisanal tools (Schwartz *et al.*, 2021). Nonetheless, contemporary "galamsey" mining and gold extraction involve a slightly more advanced chemical process (primarily utilizing liquid hydrocarbons and mercury), mechanical methods (employing excavators, dozers, and other heavy-duty machinery), and necessitate an extensive infrastructure that disrupts and contaminates the surrounding environment. The issue of Galamsey has emerged as a prominent topic of discussion in Ghana, representing arguably the most significant social challenge currently facing the nation. Various mineral-rich regions of Ghana have been infiltrated by illicit Artisanal and Small-Scale Mining (ASM), which operates through diverse means (Akoto *et al.*, 2017).

Notably, multiple operational forms of galamsey have been identified in the Ashanti and western regions of Ghana, classified into five main groups (Velásquez *et al.*, 2022). A summary and concise depiction of these operational forms is presented in the literature. Galamsey activities have been associated with different levels of health issues, accidents, and fatalities; this is attributed to the exposure of a considerable number of operators, local community members, and wildlife to highly hazardous environmental, safety, and health conditions (Obeng, 2015).

Galamsey is characterized by the aggressive conduct of specific unauthorized mining operators and a significantly heightened crime rate both within and beyond the host community. The illicit activities have resulted in numerous abandoned, waterlogged, and unclaimed wastelands (such as pits, garbage heaps, deforested areas, etc.), often endangering the safety of the local residents, especially women, children, and livestock (Ayad & Bakkali, 2022). Additionally, there have been documented instances of substantial harm to forests, agricultural lands (including cocoa and rubber plantations, food crops, etc.), and water contamination. One of the various consequences of galamsey is the pollution of water, soils, and land with hydrocarbons, along with human exposure to mercury. Addressing the menace posed by galamsey operations is now of utmost importance. There is a growing discourse on formalizing galamsey activities and rehabilitating the numerous deserted lands that have been identified.

Nevertheless, there remains a lack of comprehensive understanding regarding the various forms of galamsey, their operational attributes, and their geographical distribution across the regions of Ghana (Owusu-Nimo *et al.*, 2018). The categorizations and sites (host communities and villages) of galamsey, their prevalence and geographical scope, operational statuses of sites, and hotspots in Ghana are presently inadequately or nonexistantly mapped. Such data is crucial for combating the galamsey threat (Agariga and Appiah 2021). Many of the current strategies employed to

tackle galamsey challenges have been makeshift and have generated policies and remedies that do not account for the unique aspects of the issue at hand (Bryant & Mitchell, 2021).

2.2 Mining in Ghana

The resurgence of Ghana's mining sector post-1989 should not be perceived in isolation. The prevailing global paradigm, emphasizing development driven by the private sector to spur economic recovery in less developed countries, is the driving force behind it (Hinton, 2006). Within the framework of these economic initiatives, African nations reliant on mining were compelled to redirect their policy focus towards the overarching objective of optimizing tax revenue from mining in the long term (which remains predominantly positive), rather than pursuing alternative economic or political objectives such as resource domination or employment expansion (Akyeampong & Xu, 2023). The World Bank asserted the necessity of a revised division of labor to achieve this primary objective, whereby governments would emphasize industry promotion and regulation, while private enterprises would assume responsibility for managing, operating, and possessing mining ventures (GSS, 2021). Substantial institutional advancements and policy revisions were introduced during the period from 1984 to 1995 to align with this emerging paradigm. These initiatives encompassed the establishment of the Environmental Protection Agency in 1994, the Minerals Commission in 1984, the Minerals and Mining Code in 1986, the Small-Scale Mining Law in 1989, and the Minerals and Mining Commission in 1986 (Bryant & Mitchell, 2021).

The mining sector has historically played a pivotal and extensively documented role in Ghana's economic progress; indeed, the colonial name of the nation, Gold Coast, was chosen to reflect this reality. Gold predominates the mining industry, with Ghana ranking as the second-largest gold producer on the continent following South Africa. Additionally, the country holds the third

position in manganese and aluminum production, and represents a significant source of diamonds and bauxite (Bessah *et al.*, 2021b). Iron, limestone, kaolin, salt, and various other industrial mineral resources are included in the inventories, although their utilization remains limited. Following the initiation of policy adjustments for economic recovery in Ghana in 1983, there has been a notable surge in investment and production within the mining sector, particularly in gold mining (Mensah *et al.*, 2016). The quantity of new exploration and mining enterprises has risen substantially.

Additionally, a considerable number of auxiliary mining enterprises such as explosives manufacturers, transportation and catering services providers, as well as mineral assay laboratories, have been attracted to this sector. Over time, there seems to have been a significant influx of foreign direct investment into the industry, leading to an increase in its contribution to overall foreign exchange earnings (Islam *et al.*, 2016). Notwithstanding this advancement, concerns are mounting regarding the tangible benefits that ordinary Ghanaians in mining regions and the nation as a whole would accrue in light of the extensive tax incentives and other advantages granted to mining corporations following sectoral reforms (O’Faircheallaigh & Corbett, 2016). Other pressing issues include the environmental damage caused by illegal small-scale mining and the escalating job losses resulting from the privatization of state-owned mining enterprises.

Consequently, the escalating instances of conflicts between illicit small-scale mining operations and mining communities, as well as their leaders, reflect the increasing apprehension regarding the repercussions on the impoverished rural cocoa farmers (Osman *et al.*, 2022b). Some individuals in Ghana have voiced apprehensions that the nation's abundant natural resources could potentially be both a blessing and a curse due to illicit small-scale mining activities. Recent

attention has been devoted to Ghana's illicit small-scale mining sector and its detrimental effects on the local environment in mining enclaves. Nevertheless, given that other mineral-rich African countries have not encountered similar issues, this apparent adverse impact should not be viewed as inevitable (Roan, 2023).

2.3 Policies and Legislation on artisanal mining in the country/district

Prior to the 1980s, artisanal mining, also known as "galamsey" within the community, and the trade of extracted minerals, especially gold, were considered illegal. Similar to the situations in many developing countries, the industry was perceived as an unregulated and unsupervised sector with uncontrolled activities (Baddianaah & Adongo, 2022). Local chiefs, who predominantly own the regions where mining occurs, possess a traditional entitlement to one-third of the gold produced. Over a span of more than two decades, these chiefs have supervised and administered the gold mining operations (Aryee, 2003). The small-scale gold and manganese mining sector in Ghana has a history dating back over two thousand years. Given its highly unregulated nature, the industry requires governmental policies and regulations to place it within a national framework (International Council on Mining and Metal (Otamonga & Poté, 2020).

Consequently, from the 1980s onwards, the government enacted several laws to regulate business activities across the country. These legislative measures encompass The Ghana Minerals and Mining Act (1986 PNDCL 153), where section (1) stipulates that “All minerals in their natural state in, under, or on any land in Ghana, rivers, streams, waterways throughout Ghana, the exclusive economic zone, and any region covered by territorial waters or continental shelf are the property of the Republic of Ghana and shall be vested in the Provisional National Defence Council on behalf of the Ghanaian people” (Verbrugge & Thiers, 2021). Another statute, the

Small-Scale Gold Mining Law (1989 PNDCL 218), seeks to delineate the individuals eligible to partake in small-scale gold mining, among other provisions.

The Mercury Act of 1989 (PNDCL 217), which governs mercury management on a national scale, particularly within mining ventures, is an additional legislative instrument concerning minerals (Hilson & Maconachie, 2020). The state-owned Diamond Marketing Corporation (DMC), with an expanded responsibility for the buying and selling of gold and diamonds, was succeeded by the Precious Mineral Marketing Corporation (PMMC) under specific conditions (Clifford, 2022). Miners must register with the Minerals Commission in accordance with the statute governing small-scale mining in order to be given specific operating zones. However, many small-scale miners choose to operate illegally (without a mining license) because of the various challenges they face in attempting to obtain a mining license.

In Ghana, there are two groups of small-scale miners: those who are registered and licensed, who make up the majority (Kumah, 2022), and those who operate illegally (galamsey). Due to laws that restrict small-scale mining to local investors, the majority of small-scale miners in Ghana are nationals. Investigations revealed that this is not the case because illegal mining continues even at a higher rate. These guidelines were anticipated to be followed by artisanal miners across the country (Tschakert & Singha, 2007).

2.4 The Environment

The environment is made up of the surroundings. The physical environment, which includes the built environment and the natural environment, which include the air, water, land, and atmosphere, could be the subject or thing, or both (Huggins, 2016). The environment is constantly changing. It frequently serves as its main machinery with its surroundings and the entities within them acting as its main machinery. The environment is influenced by institutional, technological,

and socioeconomic factors, but natural phenomena also have a significant influence on what it will become (Lahiri-Dutt, 2018). Therefore, the impact of environmental degradation is never-ending. When natural resources are squandered or natural habitats are destroyed, the state of the environment (Debrah *et al.*, 2014). Deforestation, global warming, unsustainable farming and fishing practices, air and water pollution, and other immediate effects of environmental degradation are just a few examples. However, it also has a significant impact on rising poverty, starvation, extreme weather, the loss of species, acute and chronic medical conditions, war, and human rights violations (Debrah *et al.*, 2014).

The UN Environment Programme links poverty on the continent to the extent of the continent's extensive environmental degradation. According to the UN agency, fast population growth without commensurate economic growth, such as in Sub-Saharan Africa, causes excessive grazing and farmland erosion, sand and mineral mining-related pollution and degradation, deforestation, and water pollution and siltation (Bryant & Mitchell, 2021). The destruction of natural resources further puts the impoverished in danger. Because of their lower productivity and increased risk of adverse weather (Alhassan & Atindana, 2022),

Additionally, UN Professor Jeffrey Sachs came to the conclusion that "the environment is the golden thread, the red ribbon, running through and round all the Goals" (Hilson & McQuilken, 2014). Because rural areas lack opportunities for industrialization, people in developing nations are completely dependent on the environment. Only 15% of the logs are used by men to manually chop trees, drag the logs and harm them (Buss & Rutherford, 2022), grow trees in their path, and use chainsaws (Buss & Rutherford, 2022). Women use charcoal and wood to fuel the growing trees. Due to nomads' destruction of farmland by nomads, shifting agriculture, bush burning, and a recently-recognized practice of small-scale mining, which pollutes and erodes silting water

bodies (Zvarivadza, 2018), barren, and severely eroded farmland. Despite the troubling effects of human activity on the environment, organized laws and initiatives to protect it face frequently opposition. Opponents frequently make the case that they would not go hungry in the midst of God's abundant supply for the sake of environmental preservation. In order to have reasonable and sustainable environmental policies (Fritz *et al.*, 2022), it should be considered to include studies of traditional values, people's social and economic circumstances, and engineering (Cossa *et al.*, 2021).

2.5 Mining and the Environment

Mining operations have a well-documented negative environmental impact on the ecosystem (Talbert-Slagle *et al.*, 2023). The effects of both large- and small-scale gold mining operations on environmental contamination have received special attention. Although there is a noticeable degradation of the soil due to gold mining, the environmental impact of chemical contamination from the gold extraction process is doubled, with detrimental health effects on both the communities who depend on mining and the general public who live near these operations (Emmanuel & Ofosu-Mensah 2017). For example, most research focuses on mercury exposure and intoxication during the extraction and processing stage of mining because gold-mining in the South (Africa and Latin America) is informal (Meutia & Sakakibara, 2022). Study shows that throughout the gold amalgamation process, there are patterns of mercury toxicity (Mensah & Darku, 2021).

While most studies have limited sample sizes and are therefore biased, some try to use more rigorous designs. For instance, research was conducted at one location in the Philippines involving 102 individuals who were employed as mercury-exposed ball millers and amalgam smelters, 63 other residents who were exposed to the environment, 100 people who lived

downstream of the mine, and 42 residents of a different site who served as controls. Medical scores and biomarkers were collected for the surrounding populations and the workforce (Musa *et al.*, 2016). According to the authors, "Using this method, 71.6% of the workers were classified as Hg intoxicated" (Bose-O'Reilly *et al.* 2018), 0% of the controls, 38% downstream, and 27% from Mt. Diwata non-occupationally exposed (Adeleke *et al.*, 2021).

A comparable study conducted in Tanzania discovered lower levels of intoxication and a more complicated combination of ambient exposures to mercury through everyday goods like soap and mining-related exposures. Children engaging in "gold washing "have higher degrees of intoxication, according to a study conducted in Ecuador (Harari *et al.*, 2020). Despite exposure to mercury in the workplace and community, a Venezuelan study showed no mercury poisoning (Buss *et al.*, 2021). Numerous studies conducted in Ghana's mining towns have shown a connection between mining operations and environmental issues such food supply, water pollution, illness prevalence, and deforestation or land degradation (Donkor, 2015, Obeng, 2015, Ayad & Bakkali, 2022, Osman *et al.*, 2022a, 2022b, Akyeampong & Xu, 2023).

2.5.1 The Environment and ASM

The soil, which is a portion of the earth's surface used to grow food crops and other plants, is greatly impacted by mining operations. Particularly through their open mining pits, gangue mineral depots, and flotation tailing ponds, the mining and metallurgical industries degrade land (Mensah & Darku, 2021). A significant amount of fertile soil degradation has been caused by leaking flotation tailing ponds. Increased soil acidity, erosion, and vegetation damage have all been linked to sulfur dioxide emissions (UNEP, 2016). Growing ASSM activity poses a serious threat to the environment's ecosystem. Miners around the world have not spared mangroves or wetlands, tiny or substantial amounts of some minerals can be found. At least 54% of the

wetlands in the United States and up to 90% of the wetland ecosystems in European countries have been gone (Kumah, 2022b).

Only South America, Russia, and Asia discharge over 450 tons of mercury into the atmosphere each year and when it comes to ASM mining in Ghana, the majority of gold is recovered from alluvial deposits (Meutia *et al.*, 2022). Because these deposits are easier to handle manually through washing, miners are drawn to deposits near rivers, waterways, and little streams. The ore containing gold is crushed and ground in order to extract gold. Addition of mercury (Hg) and open-air roasting are the methods used to extract gold from the crushed or ground mixture (Otamonga & Poté, 2020). According to Basu *et al.*, (2015), the process releases ionic Hg (Hg^{2+}), a hazardous chemical component, into the atmosphere, where it subsequently condenses on land and in water (Basu *et al.*, 2015).



Plate 2. 1 Image depicting the impact of artisanal and small-scale mining on the environment in a community in the Amansie south district

Source: Field Survey (2023)

2.6 Water Quality

Policies that protect and conserve water are crucial for the ASGM industry as well as for individuals who are impacted by it. Miners with mineral rights who are licensed may "for purposes of or ancillary to the mineral operations, obtain, divert, impound, convey and use water from a river, stream, underground reservoir or watercourse within the land the subject of the mineral right" (Akuo-ko *et al.*, 2024). Ghana's National Water Policy aims to conserve water supplies in mining and other industrial areas while balancing the demands of the mining industry with those of the community. It also ensures that water is available for hydropower generation, transportation, recreation, and mining activities. Large-scale mines and other established enterprises must create and put into place environmental management systems, such as effluent discharge licenses, water use permits, and efficient water use practices that take into account their influence on water resources (Gorde & Jadhav, 2013).

However, the National Water Policy does not mention ASGM practices (Amengor, 2024). Mining operations must be situated close to water supplies since ASGM sites need water for a number of processes (such as sluicing/washing, panning, and amalgamation preparation). Alluvial mining required 49, 019, 000 L of water in the sluicing/washing step to yield one kilogram of concentrated gold ore (99.5% gold) from 23, 922 tonnes of ore, or 2049 L of water for 1 tonne of processed ore, according to a life cycle analysis of ASGM in Peru that looked at the implications of ASGM mining. Although there are no estimates available, it is safe to assume that the figures are comparable for ASGM water use in Ghana. Further research in this vital area is warranted (Lukhabi *et al.* 2024).

In addition to the amount of water used, ASGM operations have a significant impact on water quality. The processing of ore may cause unintended or planned chemicals and generated water to flow unevenly, cause excessive groundwater withdrawals or surface water withdrawals, and cause erosion as a result(Kazapoe *et al.*, 2024). In general, mining is associated with localized changes in water tables, increased river siltation, and increased flooding. There may be a lack of infrastructure for potable water and sanitation, including indoor plumbing, pit latrines, and even designated defecation areas, which adds to the concerns about biological contamination of drinking water sources (Adomako *et al.*, 2018). This may be because of the ASM communities 'transitional and brief histories (Adomako *et al.*, 2018).

2.6.1 Surface Water Quality Issues

Pollutant discharged into surface waters is one of the issues that mining operations may cause. Surface waterways can be contaminated with both dangerous and harmless compounds by a variety of mine-related operations and sources (Shaibu, 2024). Potentially large sources of toxic pollutants include waste rock dumps, heap and dump leach piles, tailings ponds, open pits, and stockpiles of ore and subore (Adu-Boahen *et al.*, 2023). The build-up of sediments that may be contaminated with heavy metals or other toxics, short- and long-term pH level reductions (especially for lakes and reservoirs), the devastation or degradation of aquatic habitat, the contamination of drinking water supplies, and other health problems for humans are some of the effects on surface waters(Kumi *et al.*, 2023).



Plate 2. 2 Polluted surface water as a result of artisanal and small-scale mining in Amansie south district

Source: Field Survey, (2022)

2.6.2 Ground Water Quality and Quantity

Because ground water flow is much slower than surface water, many affected aquifers have a more limited extent, and there is not as much oxygen available to continue the oxidation process, the effects of mining on ground water are not as broad as those on surface water (Akwo-ko *et al.*, 2024). Still, ground water pollution is a major worry since it is very hard to clean up once it happens (Kazapoe *et al.*, 2024). Ground water quality can be impacted by artisanal gold mining in a number of ways. The most noticeable is when mining takes place below the water table, either in open pits or underground workings, and thus gives aquifers a straight path (Ewusi *et al.*, 2024). The infiltration of surface items, such as wastes or other materials, into ground water can also have an impact on the quality of ground water, whether they are natural, processed, or wastewater waters.

A hydraulic connection between surface and ground water can also result in contamination. Elevated contaminant levels in ground water can result from any of these (Adu-Boahen *et al.*,

2023). Additionally, altering the ground water flow regime could have an impact on the amount of water accessible for other local purposes. Additionally, ground water could recharge surface water by contributing to base flow in a stream channel or springs, which would lower the gradient of the mine (Agodzo *et al.*, 2023). The constituent of concern, the type of material or waste, the management plan, the properties of the soil, and the local hydro-geology (depth, flows, and geochemistry of the underlying aquifers) all have a substantial impact on the pollutants' capacity to dissolve and migrate from materials or workings to ground water. The types and distance to local users influence the risks that contaminated ground water usage poses to human health and the environment. In addition, impacts on ground water can also indirectly affect surface water quality through recharge and/or seepage (Darko *et al.*, 2023).

2.6.3 Water Pollution

Water pollution occurs when a body of water is negatively impacted by the addition of significant amounts of materials, as defined by Mensah and Darku (2021), and when it is unsuitable for its intended use, it is deemed polluted. In order to produce food, find jobs along the river, enjoy leisure time, and preserve their culture, rural residents have historically built settlements around rivers and streams (Mensah & Darku, 2021). In a developing economy like ours, where income opportunities and access to drinkable water are unattainable, even in many urban areas, people in the community have a good reason to live close to natural resources. Water is also the main route via which pollution from mining can enter the environment (Mensah & Darku, 2021).

The protection of fresh water was greatly impacted by the advent of open cast gold mining in the 1980s. The topography of Ghana's Obuasi and Tarkwa regions is undulating, and it is thought that the establishment of large-scale mining operations in these environmentally sensitive locations would undoubtedly result in environmental issues (Lamb, 1985). Because there was no

incentive to conserve water, industries like mining saw fresh water as a free resource that could be used without any kind of effective regulatory framework. As a result, headwaters became deforested. Due to tailings leaks, mine waste disposal, cyanide spills, acid mine drainage, and mine pits, the growth of surface mining businesses has contaminated streams. These have tended to deprive communities of access to water, which is a basic need for human survival (Adusei-Gyamfi *et al.*, 2023).

2.6.4 Consequences of Water Pollution

Mining operations and the removal of vegetation for mining purposes can cause issues with siltation and sedimentation (Atampugre *et al.*, 2024). Water bodies' dissolved oxygen, pH, turbidity, conductivity, and other characteristics can all be altered by pollution runoff. According to Appiah-Boamah *et al.*, (2024), some mining villages in Ghana are suffering from water stress as a result of the pollution of their water bodies. The density of ASGM activities, the number and population of nearby communities, the rate of installations, the separation between mining activities and stream channels, as well as a combination of roads, pastures for agriculture, and other industrial operations (Tebbutt, 1997), are all likely to have an impact on receiving water streams and their biota (Tebbutt, 1997).

Small streams are especially vulnerable to the effects of water removal because the dilution rate of pollutants or solid loadings in the watershed may be lowered by reduced water flow from surface or groundwater withdrawals. Aquatic ecosystem may suffer from this elevated silt or pollutant concentration (Anang *et al.*, 2023). By decreasing photosynthetic activity and clouding the water, increased siltation might reduce the hospitability of aquatic habitats for biota. Furthermore, because they have a tendency to cling to sediments, toxins and nutrients can build up in the fluids and biota of aquatic systems affected by siltation (Anang *et al.*, 2023). A time of

water scarcity that would affect aquatic life, agricultural irrigation, and the availability of drinking water might also be caused by excessive surface and groundwater withdrawal (Ewusi *et al.*, 2024).

Reduced surface and water quality is crucial because ASGM populations may require a significant supply of drinking water. Desolute mine pits can fill with water, which could lead to mosquito breeding grounds, as it was discussed in the series 'Human Health Review. Additionally, they are a source of water for cooking and mining, which poses an additional risk to ASM community residents (Biney *et al.*, 2024). The following image encapsulates ASM's ecological effects on aquatic systems.

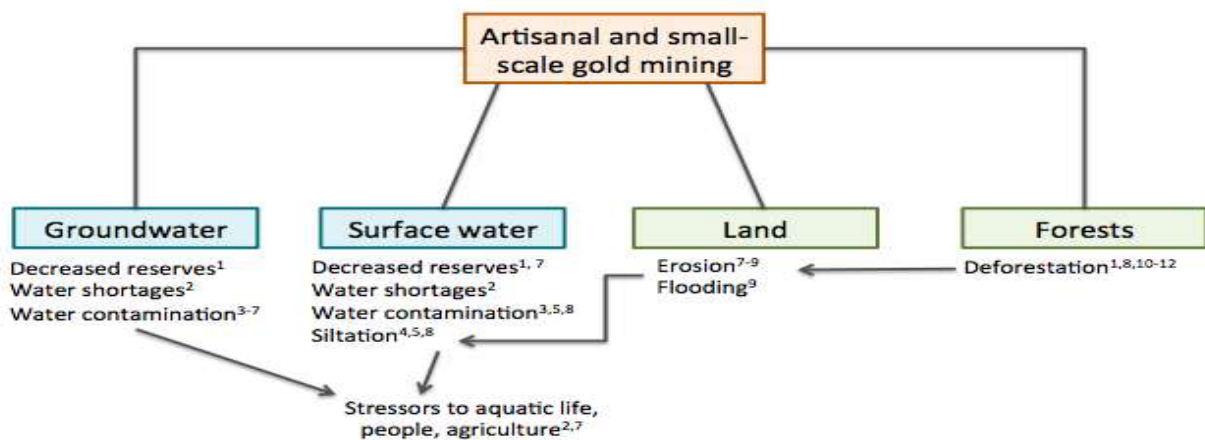


Figure 1: ASGM impacts on water systems
Source: Valdivia (2020)

2.6.5 Land Disturbances

Political frameworks and funding mechanisms may not always be in place to support environmental restoration or ensure that ASM operations are conducted in an environmentally friendly manner (Politicians and funding mechanisms) (Akuo-ko *et al.*, 2024). Because geologic

surveys of locations are occasionally not conducted prior to small-scale mines being registered, which can lead to further environmental degradation, miners can use a "trial and error" approach to find gold reserves. Despite the fact that the Minerals and Mining Act mandates that prospecting license holders "fill back or otherwise make safe to the satisfaction of the Commission a borehole or excavation made during the course of prospecting operations "and "remove within sixty days of the expiration of the prospecting license a camp, temporary building or machinery installed and make repairable for the Commission's damage to the surface of the ground caused by the removal" (Zango *et al.*, 2024). For sustainable mining techniques like exploration, reclamation, or tailings disposal or processing, it can be challenging for ASG miners to obtain financing or finance (Bessah *et al.*, 2021).

ASGM frequently calls for the removal of forests and other plants, which disturbs the land. Agricultural practices, building construction, ASGM, and other land disturbances raise the risk of soil erosion and stream sediment loading. It could be necessary to change the landscape grades to make room for ASGM operations (Miyittah *et al.*, 2020). Access roads may need to be made or built-in order to move equipment and materials. If erosion measures are not implemented, exposed surfaces will increase the amount of pollution and silt that runs off into neighboring streams, rivers, and lakes (Abanyie *et al.*, 2020).

All types of ASGM can cause terrestrial disturbances, but since there are less oversight mechanisms in place for illicit mining activities, it's possible that these incidents occur more frequently. In most cases, breaking the law and paying a fine for illicit mining is insufficient to stop unsustainable behavior (Karr & Dudley, 1981). Legalization may reduce harmful environmental acts by requiring more oversight through mining activity permits and monitoring, but funding methods (Tahiru *et al.*, 2020) remain a challenge.



a



b

Plate 2.3 (a) Cocoa farm before illegal mining activities and (b) Cocoa farmland after illegal mining activities

Source: Field Survey, 2022

2.6.6 Consequences of Land Disturbances

Numerous vegetation and soil layers that once covered ASGM landscapes are removed, leaving behind large piles of waste tailings, small dugouts, and deep pits. Although the risks that unclaimed and abandoned mines pose to the environment and the general public are known, there are n't many national assessments of the exact damage that ASGM causes (Tahiru *et al.*, 2020). In 1995, small-scale mining in Ghana destroyed 15, 000 hectares of land, according to the most popular estimate. There is probably a lot more land disturbance now than there was before the industry's explosive growth. Clearing topsoil for mining increases the area's risk of erosion and desertification in addition to lowering ecological and agricultural production. Mining in forested areas can threaten the remaining forests because of land degradation, loss of biodiversity, and fragmentation (Adusei-Gyamfi *et al.*, 2023). Only 54% of miners in the Denkyira region's survey said they would preserve the topsoil and subsoil for future recovery. If left unclaimed, the excavation pits can collect water and become mosquito breeding grounds. People and animals

are at risk from this in terms of physical health. In the vicinity of riparian zones, according to Manu and al., (2023), buruli ulcer cases are also thought to be related to land disturbances brought on by mining.

Wildlife is additionally stressed by ASGM. Depending on the species (e. g., migrating birds, amphibians, reptiles), noise, light, and habitat fragmentation from ASGM communities may have different effects on wildlife, even though we are unaware of any data to support this theory (Bessah *et al.*, 2021). Artificial lights, grinding machinery, pounding ore, and generators can all produce bright, noisy light pollution that has been found to have the ability to disturb wildlife in other environments. Roads, an increase in cars and pedestrians, and deforestation can lower the total amount of habitat area and split up already-existing wildlife habitats (Appiah-Boamah *et al.*, 2024).

2.7. Effects of Heavy Metals on Surface Water

When artisanal gold mining activities expose mined rocks to air and water, they leach into surface and ground waters in significant quantities (Darko *et al.*, 2023), and metals that have been mostly immobile in tightly bound subsoil are discovered. When they are present at extremely low dissolved levels or above a certain threshold, they can be harmful to people's health, the environment, and aquatic life in particular. Because these dumps lack a line, contaminating the waste rock is frequently a problem (Gbedzi *et al.*, 2022). The cyanide mismanagement by a number of artisanal gold mining companies has had a negative effect on local fish and wildlife populations, the health and livelihoods of rural people, and the contamination of freshwater resources and soils with cyanide. The environment and public health are both at risk from farming and indigenous communities. The cyanide-laced water and sediment are re-enter plastic-wrapped mass-retaining ponds (Tyagi *et al.*, 2013). However, these ponds eventually leak or the dams that

keep them in place collapse, contaminating the water table and nearby rivers and streams. Additionally, mercury is abundantly present in both the surface and the ground in mining towns and nearby mining towns (Tyagi *et al.*, 2013).

Acid Mine Drainage (AMD) is a major problem that arises from both active and abandoned mine sites. It is mostly dependent on the mineralogy of the rock material and the availability of water and oxygen (Kazapoe *et al.*, 2024). When metal sulphide minerals, which are frequent components in the host rock connected to metal mining activity, oxidize, AMD happens at mine sites. By removing sulfide rock material and exposing it to air and water, artisanal gold mining and beneficiation activities significantly accelerate these same chemical reactions (Shaibu, 2024). Acid drainage can also occur from mined materials (waste rock or tailings) that are removed from the mine site and used for building or other uses(such as road beds, rock drains, fill material, etc.). Operators and regulators need to know how to predict leaks because it is challenging and expensive to do so after acid drainage starts (Abanyie *et al.*, 2020). The water bodies in Obuasi's water bodies had higher levels of arsenic and iron than the streams in the study area, according to the hydrochemical analysis (Douti *et al.*, 2021).

2.8 Effects of Soil Erosion on Surface Water

Eroding can pose a serious risk at mining sites because of the vast areas of land that are disturbed by mining operations and the significant amounts of earthen materials exposed. Through erosion, especially during the months of heavy snowmelt and strong storms, significant amounts of sediments and any entrained chemical contaminants may be brought into close proximity to nearby water bodies. In stream valley flood plains or surface waters, the sediment's final deposition may be (Gyimah *et al.*, 2021). Some of the primary sources of erosion and sediment loadings at mining sites are heap and dump leaches, waste rock and overburden piles, tailings

pile and dams, haul roads and access roads, ore stockpiles, equipment maintenance areas, exploration areas, and reclamation areas (Miyittah *et al.*, 2020). Heavy metals can be released into the surrounding subsurface or adjacent surface waters as a result of the mineral deposits found in deposited sediments (Amuah *et al.*, 2022). Contaminated sediments in surface waters may be a persistent source of toxins that could endanger aquatic life and/or public health for the long term. Additionally, contaminated sediments have the potential to lower soil pH to the point where plants and appropriate habitat vanish (Tebbutt, 2017).

2.8.1 Dewatering Effects on Surface Water

Key environmental issues with surface mining include dewatering consequences. Large-scale land excavation by open-pit mines and the piling of earth along waterways alter the natural course of rivers and streams, ultimately reversing the direction of flow of ground water and depleting the ground water in some areas, leading to dewatering (Gbedzi *et al.*, 2022). These activities also consume large amounts of water for the heap-leach process, to clean and maintain equipment, and for the miners' families and community members. The majority of artisanal mining enterprises actively work to dewater areas by purposefully diverting major rivers and streams away from the mines or by lowering the water table, since the mines must be maintained dry (Lukhabi *et al.*, 2024). As a result, a number of boreholes, hand-dug wells and streams in mining areas have either become unproductive or now provide less water (Amuah *et al.*, 2022).

2.9 Effects of Artisanal Mining on Vegetation

In disturbed sites, there can be significant modifications to the soil texture and water content, which can alter the local plant life. The majority of plants can tolerate low concentrations of metals in the soil, yet species-specific susceptibility varies. Compared to forbs and shrubs, grass diversity and total coverage are less impacted by high pollutant concentrations (Gyimah *et al.*,

2021). Rejects or traces of mine waste resulting from mining operations can be found close to the mine, sometimes even distant from the source. Established plants are unable to escape disturbances and will eventually perish if heavy metals or metalloids are present in their environment at levels too high for their physiological needs (Owusu-Prempeh *et al.*, 2022).

Certain non-native species that can withstand these soil concentrations will relocate to the mine's surrounding areas to fill the ecological niche, other species that are more resilient will endure these levels (Lawer *et al.*, 2021). Direct poisoning of plants is possible; for instance, soil containing high levels of arsenic decreases the diversity of bryophytes. Reduced species richness can also result from soil acidification caused by chemical contamination that lowers pH levels (Karikari *et al.*, 2021). By altering or upsetting microorganisms, contaminants can change the availability of nutrients and lead to a decrease in the amount of vegetation in the area. In order to avoid the contaminated zone, some tree roots diverge from deeper soil layers. As a result, they lack anchorage inside the deep soil layers and may be uprooted by the wind when their height and shoot weight rise (Amoakwah *et al.*, 2020). When compared to unpolluted areas, root exploration is typically lower in contaminated areas. The variety of plant species in restored ecosystems will continue to be lower than in unaltered regions (Asare *et al.*, 2024).

There could be an issue with farmed crops close to artisanal mining sites. Weakly contaminated areas can support the growth of most crops, but the yield is often lower than under normal growing circumstances (Opoku *et al.*, 2020). Additionally, plants frequently house heavy metals in their aerenchyma organs, which may eventually be absorbed by people through fruits and vegetables. Long-term health issues may be brought on by consuming contaminated crops frequently. The tobacco industry may have a negative impact on the population because it has a tendency to have zinc and cadmium in its leaves (Kuffour *et al.*, 2020).

2.9.1 Degradation of Land and Vegetation

Apparently, large tracts of land and vegetation were razed to make way for surface mining operations in Tarkwa. Open pit mining concessions currently cover more than 70% of Tarkwa's total land area (Akabzaa & Darimani, 2001). A mining company could have used 40 to 60% of its concession area for things like mine silos, heap leach facilities, tailings dumps and open pits, mine camps, roads, and community resettlement (Akabzaa & Darimani, 2016). This severely harms the land and plants that make up the majority of the inhabitants' means of subsistence. Already there is a land grab in Atuabo and Dumasi. Most of Tarkwa's environment is rapidly deteriorating, and its enormous economic potential is declining annually (Barenblitt *et al.*, 202). This is primarily due to the region's high mining activity concentration. A decrease in agricultural areas' fallow time has been observed from 10-15 years to 2-3 years as a result of the loss of land for agricultural production (Takyi *et al.*, 2021).

Due to lack of land, the traditional bush fallow system, which effectively increased the productivity of the following cycle and recycled significant amounts of nutrients, is no longer practicable (Akabaa & Darimani, 2016). Large-scale mining operations typically continue to reduce the area's vegetation to levels that are detrimental to biological diversity. The deforestation brought on by surface mining has long-term effects (Lawer *et al.*, 2021). Even after the soil is replenished and new trees are planted following decommissioning (Lawer *et al.*, 2021). The composition of the topsoil may change as a result of the potential introduction of new species, which could affect crop length and fallow-ability. The loss of animal and bird habitat and the decline in the land's suitability for agriculture are caused by the degradation of the surface vegetation. Water sources, cultural sites, biodiversity, and lush plant life have all been destroyed as a result (Akabzaa & Darimani, 2016). By the time the four companies GAG, TGL, GGL, and

AGL have exhausted all of their concessions, sixteen ridges, measuring in height from 120 to 340 meters, will have been twisted into massive craters (Akabzaa & Darimani, 2016).

2.10 Scientific Research on Use of Hg in Artisanal Gold Mining in Ghana

High levels of mercury (Hg) contamination were found in the results of the survey study on the assessment of Hg levels in water, sediment, soil, and human hair that was tested from the main tributaries of the rivers Pra and Offin (Yen *et al.*, 2012). Even water samples taken from places far from active gold mining operations had high quantities of mercury, up to 148 ng/L. Hg values in samples along the Offin ranged from 41.6 to 420 ng/L (Ofei-Aboagye *et al.*, 2004). Ranges for Lower Pra were found to be 24–294 ng/L, while Upper Pra revealed ranges of 28.7–403 ng/L. These mercury levels unquestionably surpass the permissible limits set by international organizations (Bannerman *et al.*, 2016; Adomako & Baah, 2019). In addition, in the case of River Offin, the mean readings for sediment and soil exceeded the US-EPA's 200 ppb (Osman *et al.*, 2022) threshold. The WHO recommended 50 parts per million (ppm) in 2016 but the Hg concentrations in the hair samples from the study location were below that level. The results are very worrying because the majority of the impacted areas 'rivers drain into the Gulf of Guinea, where mercury may be found. Any mercury that enters these waters ways will likely increase human exposure through food consumption (Dwomoh *et al.*, 2023).

2.11 An Assessment of the Ecological Health Issues

By looking at the causes, current circumstances, emerging patterns, and the results of significant hazards, we examine and evaluate the natural science concerns raised by ASGM in Ghana. The best scientific data is compiled for this assessment in order to facilitate agreement and direct decision-making when choosing a course of action (Ayamba *et al.*, 2017). The information is intended to give an impartial view of the current state of affairs. The main effects of ASGM on

the health of natural systems are listed below in detail. These implications serve as a ranking, compiling, and condensing tool for the most important ideas (Roan, 2023). The figure below illustrates the causes and effects that are highlighted in this study.

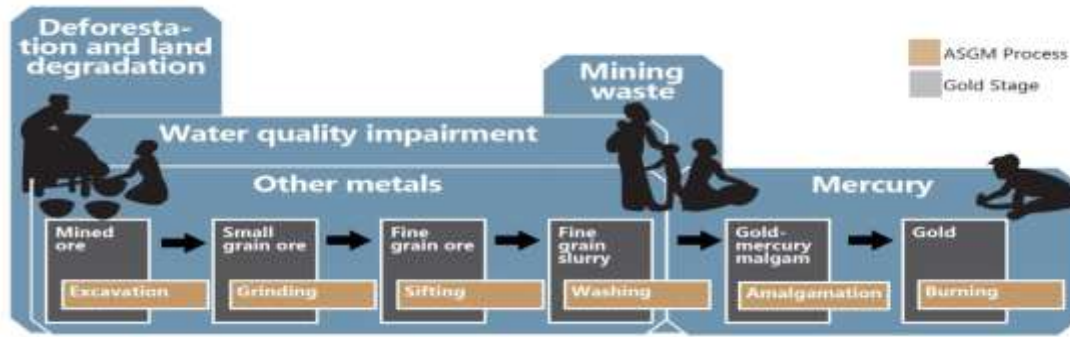


Figure 2: Key ecological hazards in the Ghanaian artisanal and small-scale gold mining (ASM) sector.

Silhouettes adapted from UNEP Mercury: Time to Act (2013).

2.11.1 Mercury Contamination

Mercury is a metal that occurs naturally. It can be found in nature in three main forms: elemental (Hg), inorganic (HgS, HgCl₂, Hg⁺, Hg²⁺), and organic (CH₃Hg, or methylmercury) (Donkor, 2015). Because elemental mercury can separate gold from other non-target minerals, it is employed in ASGM. Gold and mercury combine to form an amalgam. Burning the gold-mercury amalgam releases the valuable metal since mercury has a low vapor pressure. When mercury vapor from burning amalgam is released into the atmosphere and travels great distances before returning to the earth as inorganic mercury, it can have a substantial effect both locally, in villages and towns where the vapor is released, and globally (Obeng, 2015). Microorganisms primarily found in aquatic environments have the ability to methylate (bind) inorganic mercury to carbon. Because methylmercury can bioaccumulate and biomagnify in organisms, it is frequently

detected in fish at increasing amounts (Konadu-Amoah *et al.*, 2018). An estimated 37% of annual global anthropogenic mercury emissions are attributed to ASGM, which can lead to direct releases into soil and water in addition to air emissions (Gilbert & Albert, 2016).

The United Nations Environment Programme (UNEP) estimates that ASGM is currently the leading cause of anthropogenic mercury in the atmosphere worldwide, surpassing even the burning of fossil fuels (Gilbert & Albert, 2016). The largest regional consumers of mercury for ASGM are East and Southeast Asia, South America, and Sub-Saharan Africa (Adeleke *et al.*, 2021b). Mercury was used, but it was outlawed in Ghana from 1932 to 1989. Mercury can be lawfully purchased and traded by licensed traders and registered ASGM operators from approved dealers, including the Precious Minerals Marketing Corporation (PMMC) (Hassen *et al.*, 2016a). However, the Ghana Minerals Commission and the PMMC claim that the amount of mercury used looks to be more than what is publicly accessible, indicating a sizable "black market" for the metal. Given that ASGM activity has increased due to both the rising price of gold and the declining demand for diamonds, recent increases in the demand for mercury may be a reaction to current market conditions (Hilson, 2002, Hassen *et al.*, 2016a, Mamodu *et al.*, 2018, Ramesh *et al.*, 2018).

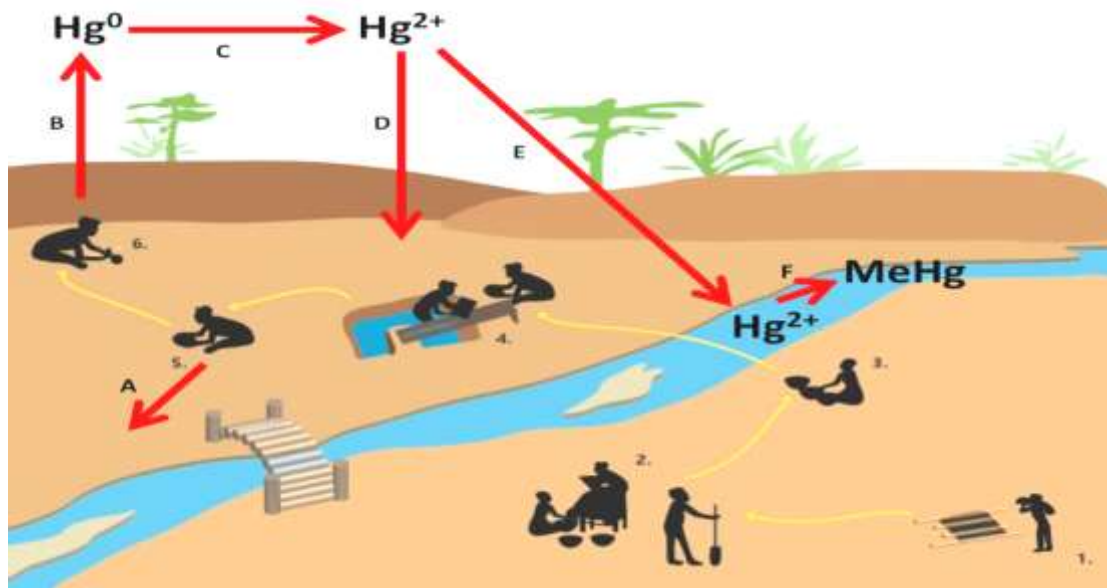


Figure 3: Mercury (Hg) cycle in a typical artisanal and small-scale gold mining (ASGM) process

Numbers represent key steps in the ASGM process: 1—excavation, 2—crushing and grinding, 3—sifting/shanking, 4—washing/slucing, 5—amalgamation, and 6—burning. Letters represent key steps in the mercury cycle: A—residual mercury from amalgamation may be discarded in local soil and water, B—volatilization of elemental mercury into the atmosphere, C—oxidation of elemental mercury, D—deposition onto local terrestrial systems, E—deposition onto local aquatic systems, F—methylation of inorganic mercury to methyl mercury.

Without any kind of capture technology to lessen chemical leaks into the environment, mercury is typically employed in ASGM. Retorts have been met with rejection by many miners who lament a slower procedure and their inability to see the gold. Because of their fragility and low capacity, even transparent retorts, like the ThermEx® retort endorsed by the Ghanaian government, have not been used to their full potential (Thomas *et al.*, 2019). In Denkyira, for

instance, just 27% of respondents utilized a retort, whereas 68% used an open flame in a survey of 44 licensed and 77 unlicensed miners (Miranda *et al.*, 2005).

The effects of ASGM mining and the usage of mercury from gold ore were studied in a life cycle analysis of ASGM in Peru. They calculated that 2 kilograms of mercury is needed to create 1 kg of concentrated gold ore (99.5% gold), using an alluvial mining example that most closely mimics ASGM in Ghana (Yen *et al.*, 2012). The researchers' visits to two ASGM sites in Tarkwa, Ghana, were to determine the amount of mercury used in the ASGM process. After being processed and suited, the concentrate ore at one small-scale mine was supplemented with about 210 grams of elemental mercury (Mensah *et al.*, 2016). The miners then burned the amalgam ball, releasing 211.3 g of sponge gold. Borax was then used to melt this substance and remove any remaining impurities. The final kilogram of gold produced would be 200 grams, assuming impurities between 2 and 5% (Gump *et al.*, 2017).

2.11.2 Effects of Mercury

Mercury exposure has been linked to health problems in fish, wildlife, and human populations all over the world. Relevant exposures have been demonstrated in certain instances to disrupt normal biological function in fish and wildlife, affecting both individuals and populations (Mensah *et al.*, 2016). Key systems affected include the neurological and reproductive systems. According to a recent review by Bose-O'Reilly *et al.* (2010), fish with muscle mercury concentrations ranging from 0.5 to 1.2 $\mu\text{g/g}$ (w. w.) and in the whole body from 0.3 to 0.7 $\mu\text{g/g}$ (w. w.) experience sub-clinical changes such as gene expression alterations, oxidative stress, and effects upon reproductive hormones and behavior (Bose-O'Reilly *et al.*, 2010). While few cases of excessive exposures exist, the majority of fish (individuals and species) tested in Ghana have levels below 0.3 $\mu\text{g/g}$. Although fish from Ghana may contain similar to other parts of Africa,

where there are high levels of mercury, but for unknown reasons, they are lower. According to an analysis of mercury levels in fish from 12 Sub-Saharan African countries, only fish samples taken close to ASGM operations had mean mercury levels above the FAO/WHO recommendation. We are not aware of any studies conducted in Ghana on this subject (Sherman *et al.*, 2015), despite findings from numerous other regions of the world that suggest that fish-eating wildlife is susceptible to exposure.

2.11.3 Contamination from Other Heavy Metals

The land disturbance that occurs at ASGM may lead to increased metal contamination. Tailings waste can be extracted, ground, and leaked, all of which can cause otherwise secluded heavy metals to be released into the environment. In addition to contaminating water supplies, sediments, and soils, several of these heavy metals have the potential to bioaccumulate in the local biota (Owusu-Prempeh *et al.*, 2022).

2.11.4 Consequences of Contamination from other Heavy Metals

The land disturbance that occurs at ASGM may lead to increased metal contamination. Tailings waste can be extracted, ground, and leaked, all of which can cause otherwise secluded heavy metals to be released into the environment. In addition to contaminating local biota, several of these heavy metals have the potential to bioaccumulate (Odipe *et al.*, 2019). Depending on the area, these metals can be found elsewhere, and ASGM is not always to blame for contamination. Although both cadmium and arsenic are naturally occurring metals, they are also related to ore that contains gold, and they are frequently found in higher amounts close to gold-mining sites. Cadmium is another byproduct of lead and zinc ores smelting (Lawer *et al.*, 2021). The Tarkwa area's elevated cadmium content may be a result of the mining and processing of zinc and other chalcophilic metals. In some geologic formations, such as the Tarkwanian and Birimain rock

systems in the mining region of Tarkwa, high concentrations of lead, cobalt, and chromium are present (Takyi *et al.*, 2021). My industrial emissions and drainage system also contribute to the lead. Mining tailings can cause heavy metals to be deposited into water, soil, and sediment. Arsenic and lead contamination of the soil was a symptom of the mining industry's proximity. The concentration of arsenic in irrigated crops increased when contaminated water was used for irrigation (Mokarram *et al.*, 2020).

Another study discovered no correlation between the amounts of lead, cadmium, or arsenic in the soil and the location of nearby mining operations. There were no discernible variations in the levels of arsenic in urine between Tarkwa and Accra residents, and both regions' water levels of arsenic remained low, indicating that there may be more ways for people to be exposed to arsenic, such as through tainted food (Adimalla, 2020a). This extra exposure pathway worry is supported by our review, which found significantly higher levels of arsenic contamination in food plants (Dhaliwal *et al.*, 2020). Toxic metals including lead, cadmium, and arsenic are all widely recognized. The majority of studies on these metals' effects on human health have overlooked their recognized effects on other species, ecosystem services, and creatures (Hanfi *et al.*, 2020). All forms of arsenic considerably decreased the overall biomass of fungi and microorganisms as well as the enzymatic activity in soils contaminated with arsenic in Chhattisgarh, India (Rahman, 2020). Even though the mean concentrations of the majority of the soil samples examined in Ghana were lower than those in Chhattisgarh, one-third of the sites have important arsenic concentrations. Lead, cadmium, and arsenic were found to have a negative effect on the growth of soybean roots and shoots in acute toxicity experiments (Long *et al.*, 2021). However, only about half of the Ghanaian regions have relevant amounts of these metals when soil samples were taken to assess the levels of arsenic and cadmium concentrations. In birds and aquatic species

'tissues, admium can buildup and become toxic. Asare *et al.*, (2024) suggested that soil cadmium poisoning may have negative effects on both animal and human health because soil quality is influenced by complex interactions between soil, plant, and invertebrate species (Asare *et al.*, 2024).

The International Agency for Research on Cancer has determined that arsenic and cadmium are carcinogenic to people (Group 1, adequate evidence of carcinogenicity in humans) and are linked to an elevated risk of cancer. Arsenic exposure is linked to serious negative effects on skin lesions, anemia during pregnancy, behavioral abnormalities, cardiovascular and respiratory conditions, and neurodevelopment (Adimalla, 2020b). Many of the endemic villages in Ghana affected by buruli ulcer are found in mining zones, including Amansie West, WassaAmenfi, Dunkwa, and Tarkwa Nsuaem (Opoku *et al.*, 2020). There has been evidence linking the occurrence of buruli ulcer in these areas to proximity to drainage canals, farms with arsenic levels over 15 ppm, and gold-mining locations. Ingesting cadmium is linked to cardiovascular illness, bone toxicity, and kidney damage (itai-itai disease) (Takyi *et al.*, 2021). The non-cancerous health risk from exposure to arsenic and cadmium in water in Nangodi, a historic ASGM town in the Upper East Region, surpassed the US EPA's tolerable risk due to the possibility of developing keratosis, skin hyper-pigmentation, tremors, low IQ, and renal failure. Adult brain reductions in grey matter are linked to childhood lead exposure, especially in the prefrontal cortex and anterior cingulate cortex, which are in charge of executive functioning, mood regulation, and decision-making (Hilson, 2002).

CHAPTER THREE

MATERIAL AND METHODS

3.1. Study Area and Sites

The Amansie South District was carved out of the Amansie West District 2018 with Legislative Instrument 2325. It shares common boundaries with Amansie West to the North, Atwima Nwabiagya and Atwima Mponua to the east, Amansie Central and Obuasi Municipal to the west, and Upper Denkyira to the south (figure 4). The district also shares boundaries with the Central Region. It is located within latitudes 6.05° West: 6.35 ° North: 1.40 ° South and 2.05 ° East. The district spans an area of about 765.06 km² and constitutes nearly 3.4% of the total land area of the Region. The Capital Manso Adubia, is about 65 km from Kumasi. The district's population is estimated to be 77,382, made up of 39,224 males and 38,191 females in 2018, representing 51%) and 49%, respectively with a growth rate of 2.6% (Ghana Statistical Service (GSS), 2022). A more significant proportion of the population falls within the active labour force bracket between 19 and 45 years.



Figure 4: A map of Manso Adubia showing the various communities.

3.1.1 Relief and Drainage

The topography of the district is generally undulating, with an elevation of 300 m above sea level. The most prominent feature is the range of hills stretching across the district's northwestern part. The district is drained in the north by the Offin and Oda rivers. This can be harnessed for vegetable and rice farming.

3.1.2 Vegetation

The district's vegetation primarily resembles a rainforest and has semi-dried, moist characteristics. The land is therefore extremely fertile and suitable for agriculture-related investments. The natural environment has been gradually destroyed by illegal mining and logging activities. Odaho Reserve, Apanprama, and Aboaboso Forest Reserves are the district's three main forest reserves.

3.1.3 Mineral Deposits

Among the resources identified in the district are potentially rich mineral (gold) deposits. Areas with such deposits include Tontokrom, Datano, Manso Nkran, Adubia and Aponapong. A large area of the district has been acquired by concessionaires, with some companies licensed for prospecting.

3.1.4 Agriculture Activities in the study area

The district's economy is viewed as agrarian, largely due to the sector's contribution to Gross Domestic Product (GDP). However, as the majority of young people who work in mining are now actively engaged, the sector is gradually losing its worth. In consequence, the majority of agricultural products are imported from nearby towns. Poor roads, inadequate marketing support, inadequate extension staff, and high prices for agricultural inputs are among the issues in the sector.

3.1.5 Industries

Mining dominates the industrial activities in the district. Illegal miners dominate the mining activities. However, a few agro-processing industrial activities such as cassava processing (Gari making), oil extraction, and alcohol production are found in the district. The others are wood

processing into lumber, furniture production, and wood carving; a few people are into metal fabrication.

3.2 Study Design

This study employed a cross-sectional design to assess the environmental impact of small-scale and artisanal gold mining. According to Sedgwick (2015), cross-sectional survey research collects data from participants across a defined period. As a result, this research employs a certain time frame to collect pertinent information from the Amansie South district within the Ashanti Region. The Amansie South district was selected because it allows researchers to collect data from towns like Adubia, Keniago, Datano, Odaho, and Tontokrom in the Amansie South district where small-scale mining is ongoing.

3.3 Sample population and sample size

The population for the study was personnel of some identified small scale mining firms in the study areas

3.4 Sample size

A total of 50 participants were sampled for the study. Slovin's technique was deployed to calculate for the sample size. Slovin's formula is written as: $n = N \div (1 + Ne^2)$ Where n = Number of samples,

N = Total population and e = Error tolerance

3.5 Sampling technique

Data was collected using both primary and secondary data collection techniques. A multistage sampling technique was used for sampling. Samples were collected using purposive and convenience techniques. Soil, sediments and water samples were collected at mining sites, rivers and boreholes in the areas of the study.

3.6 Primary data collection

Primary data was collected by the usage of questionnaire and laboratory analysis for heavy metals in water, sediments and soil.

3.7 Test for heavy metals

3.7.1 Sample collection

The sample size is estimated based on the simple random sampling method that will be adopted for the selection of ten river bodies within the study area. These towns and their rivers include Datano Stream Water (DSW), Keniago Stream Water (KSW), Keniago Well Water (KWW), Keniago Borehole Water (KBW), Tontokrom Stream Water (TSW), Adubia Steam Water (ASW), Nipankyeremia Stream Water (NSW), Odaho Stream Water (OSW), Odaho Borehole Water (OBW), Odaho Stream Water (OSW), Nipankyeremia Well Water (NWW) and Nipankyeremia Borehole Stream Water (NBW) The areas under study were Adubia (River Kyekyewere and River Adubia), Keniago, (River Offin and River Adubiam), Datano, (River Ameyaw and River Ahensu), Odaho, (River Oda and River Nwene), and Tontokrom (River Tweaa and River Komkomu). Ten (10) sediments and ten (10) soil samples from the tailing sites were collected from the five sample locations of tailing sites for analysis. One (1) soil sample and one (1) sediment were collected from an isolated environment and used as a control.

Five boreholes (5), Ten (10) rivers, and five 5 wells were identified in each town in the study location. 10 samples of bore-hole water, 20 samples of river water, and 10 samples of the wells were analyzed. Two (2) water samples from the river were collected 100 m apart from upstream to downstream from each community. One (1) sample of bore-hole, well water, and river from an isolated community that has not been affected by mining activities was collected and used as a control. A total of 60 samples were used.

3.7.2 Procedure for collection of Sediment/Soil

Soil and sediment samples were collected in clusters within the study locality of each sampling site. The samples were homogenized by mixing three (3) samples collected 5m apart to form a representative sample for each site. Two (2) different samples were collected from each study site for analysis. The samples were taken from the top 10 cm of the stream sediment bed and were stored in airtight polyethylene bags after sampling the soils at the study site were very shallow, about 110 cm deep. The soils were moderately well drained, and the color varies from pale brown to dark greyish brown and brown. They were sandy loam, with gravels and small fragments of rocks in almost all horizons of the profiles. The soils were derived from the same parent material, weathered quartzes. Each sample was collected using the mixing method to obtain two (2) representative samples for each location. Soil and sediment samples were collected at Manso as a controlled sample. The tools used for the collection of soil samples were a spade or shove and a cutlass.

3.7.3 Procedure for collection of water samples

There are numerous sources of water in the study location. Notable among them are pipe-borne water, public tap or standpipe, bore-hole/pump/tube wells, unprotected wells, rivers or streams, ponds, etc. River water samples were collected at the galamsey sites in the area of study and 500 ml water bottle containers. Water samples were also collected from the various water bodies in the controlled location in the study.

3.7.4 Laboratory Method for Sediments/Soil

Metal digestion was done using the Milestone Acid digestion method (USEPA, 2001). A 5 ml volume of each water sample was pipetted into a 20ml teflon tube. Following oven drying, soil samples were broken down and then crushed using a pestle and mortar into a fine earth (<2.00

mm) fraction. After weighing two grams of the sample into a digestion flask, 30 mL of a 1:1.5 concentrated HNO₃ and concentrated HClO₄ mixture was added. The mixture was heated slowly on a digestion rack in a fume chamber for approximately thirty minutes, or until no charred organic materials remained in the digest. After allowing it to cool, it was poured into a 100 ml volumetric flask and brought to volume using distilled water. Using GBC Avanta PM. Ver. 2.02, the concentrations of Hg, Cd, As, Cu, Pb and Fe were measured on the AAS. The device was configured to do metal detection by presenting three absorbance values, of which the average was presented in order to verify the process.

3.7.5 Laboratory method for water samples

Water samples were examined in the lab after being delivered in a cool box filled with ice on the same day. Samples intended for heavy metal analysis were kept at 4°C in a refrigerator. The 1.5 L plastic bottles were used to collect the samples, which were rinsed with distilled water after being prewashed with detergent and a 1:1 concentrated nitric acid/distilled water solution. A portable water analyzer (D-55, Horiba, Japan) was used to measure the temperature, pH, and dissolved oxygen in the water on-site. Prior to being sent to the lab, the samples intended for metal analysis were acidified using strong nitric acid to a pH of 2.

At the Asanko Gold Mine Limited in Manso Nkran in the Amansie South District, heavy metals were examined using Inductively Coupled Plasma Optical Emission spectrometry (ICP-OES: Varian vista MPC, California, USA) from hot water extracted, soil and sediments. The measurements were carried out in three replications to obtain greater precision. Heavy metals such as Fe, Cu, Pb, Cd, Hg and As were analyzed in soil, sediments and water. A Quality Control/Quality Assurance (QC/QA) sample was created from a certified standard solution and tested after every ten samples to ensure analytical quality. The relative standard deviation of

QA/QC samples ranged from 1 to 4.5%. Analyzing recognized reference material National Institute Standard and Technology (NIST) 1944 (waterway sediment) allowed for the maintenance of analytical quality control (Taylor, 1995). The recovery of $95 \pm 17\%$ was seen in the replicated study of this reference material. Reagent blanks, internal standards, and QA/QC protocols all showed that the analytical precision was better than $\pm 10\%$.

3.8 Data Analysis

The data was analysed using SPSS version 20.0. The study employed One-way analysis of variance (ANOVA) to examine the variations in metal concentrations between the communities. The statistical technique of least significant difference was employed at the p-value of 0.05.

3.8.1 Human health risk assessment

The human health risk assessments were carried out using the Spatial Analysis and Decision Assistance (SADA) software, whose risk models follow the risk assessment guidelines (USEPA, 2001). For a deterministic approach, the 95% upper confidence limit (UCL) of the data mean was calculated with SPSS. This study considered two kinds of receptors, adults and children, and two kinds of exposure routes: water incidental ingestion and water dermal contact during swimming activities. Each exposure pathway's received dose (ADD: $\text{mg}\cdot\text{kg}^{-1}\cdot\text{day}^{-1}$) was calculated using the equations below according to USEPA recommendations.

$$\text{ADD ingestion} = \frac{C \times \text{EF} \times \text{ET} \times \text{IR} \times \text{ED}}{\text{BW} \times \text{AT}} \quad \text{eq 1}$$

$$\text{ADD dermal contact} = \frac{C \times \text{EF} \times \text{ET} \times \text{SA} \times \text{Kp} \times \text{ED}}{\text{BW} \times \text{AT}} \quad \text{eq 2}$$

Where **C** value is the heavy metal concentration ($\mu\text{g}\cdot\text{L}^{-1}$);

Table 1: Parameters used in the models

Parameter	Reference
EF	is the exposure frequency ($\text{days}\cdot\text{year}^{-1}$);

ET	is the exposure time ($\text{hour}\cdot\text{day}^{-1}$); IR is the ingestion rate ($\text{L}\cdot\text{day}^{-1}$);
ED	is the life exposure duration (years); SA is the skin surface area exposed (cm^2);
AF	is the adherence factor ($\text{mg}\cdot\text{cm}^{-2}\cdot\text{day}^{-1}$);
KP	is the skin permeability constant ($\text{cm}\cdot\text{hour}^{-1}$);
AT	is the average time (days), and BW is the body weight (kg).

Source: USEPA (2001)

CHAPTER FOUR

4.0 RESULTS

4.1 Heavy Metals Concentration in Water

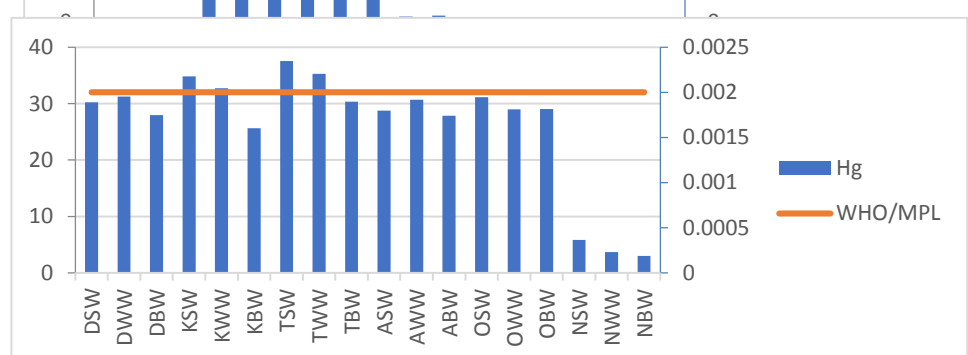
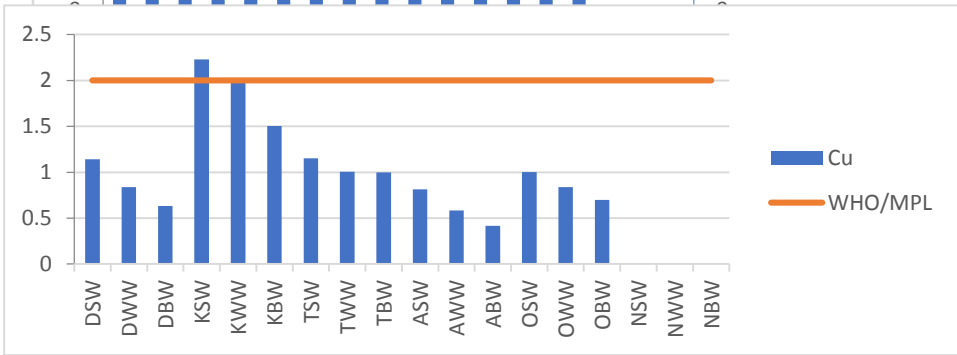
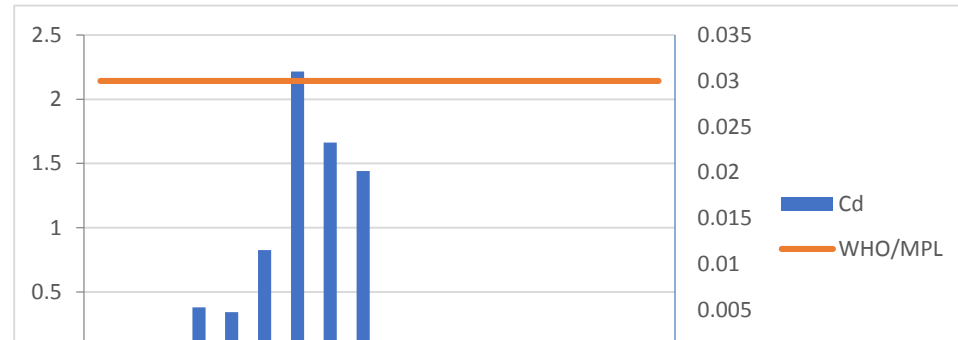
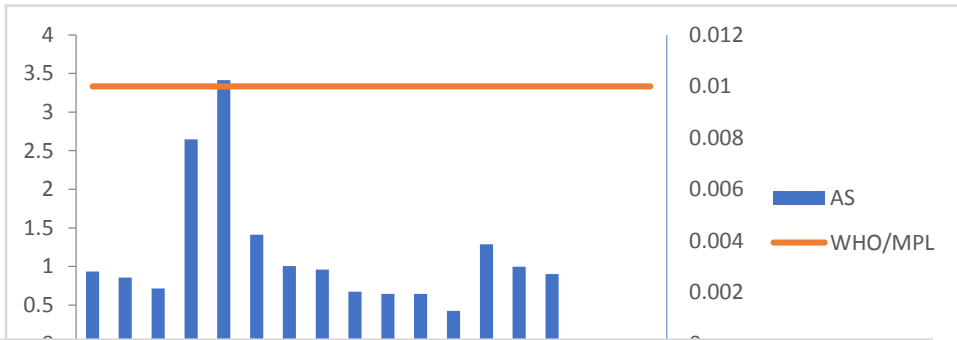
The result from the table below shows that the concentration of Mercury (Hg) in all water samples except those classified under Nipankyeremia sources of water (NSW, NWW, NBW) significantly exceeds the World Health Organization/Maximum Permissible Limit (WHO/MPL) guideline of 0.002 mg/L, suggesting a widespread pollution issue. The highest concentration is

observed in TSW (37.563 mg/L), which is alarmingly high. Lead (Pb) and Cadmium (Cd) concentrations in many samples exceed the WHO/MPL standards (0.01 mg/L for Pb and 0.03 mg/L for Cd), indicating potential health risks. Notably, TSW, TWW, and TBW samples have high levels of Cd, significantly surpassing the safety limit. Arsenic concentrations are generally below the WHO/MPL standard of 0.01 mg/L, except for KSW, KWW, KBW, and TSW samples. This indicates localized contamination that could be related to specific sources of pollution. Copper (Cu) levels are within safe limits for all water types, as the WHO/MPL standard is 2 mg/L. However, attention should still be given to KSW and KWW, where concentrations are notably higher but still below the threshold. Iron (Fe) concentrations vary widely across samples, with several instances exceeding the WHO/MPL standard of 0.01 mg/L. This is particularly evident in samples DSW, KSW, KWW, KBW, TSW, and ASW.

Table 2: Concentration of heavy metals in water

LABELS	As	Cd	Cu	Hg	Pb	Fe
DSW	0.934±0.0163	0.006±0.0014	1.141±0.128	30.203±1.698	0.2195±0.005	3.117±0.631
DWW	0.857±0.033	0.0035±0.0007	0.838±0.077	31.254±1.772	0.167±0.113	2.076±0.0057
DBW	0.713±0.0304	0.0015±0.0007	0.632±0.057	27.95±0.128	0.074±0.023	1.974±0.0381
KSW	2.649±0.278	0.381±0.413	2.227±0.316	34.807±0.339	1.882±0.0707	3.1705±0.213
KWW	3.416±0.560	0.344±0.1803	2.0035±0.0035	32.743±0.439	1.054±0.046	2.252±0.226
KBW	1.412±0.255	0.826±0.1173	1.503±0.606	25.621±0.873	0.305±0.294	1.776±0.361
TSW	1.006±0.0056	2.2155±0.306	1.15±0.199	37.563±0.793	2.325±0.157	2.996±0.091
TWW	0.9595±0.050	1.662±0.168	1.0055±0.021	35.2895±0.875	1.934±0.082	2.052±0.069
TBW	0.6745±0.066	1.4405±0.524	0.999±0.0056	30.3625±1.103	1.0015±0.0007	1.082±0.045
ASW	0.644±0.1245	0.0455±0.032	0.8125±0.057	28.764±1.075	0.6015±0.117	1.975±0.027
AWW	0.646±0.066	0.053±0.055	0.5825±0.059	30.6975±0.745	0.569±0.117	1.7165±0.041
ABW	0.423±0.078	0.0375±0.006	0.417±0.054	27.8285±0.702	0.332±0.075	0.964±0.039
OSW	1.2855±0.091	0.0085±0.0007	1.0005±0.028	31.131±1.865	0.33±0.0167	1.885±0.206
OWW	0.997±0.0056	0.004±0.003	0.8375±0.062	28.9705±1.993	0.3155±0.046	1.003±0.002
OBW	0.9015±0.069	0.0035±0.0007	0.7±0.098	29.0395±0.234	0.194±0.051	0.539±0.118
NSW	0.0045±0.0007	0.0035±0.0007	0.0085±0.0007	5.834±1.001	0.027±0.0056	0.041±0.0134
NWW	0.003±0	0.0035±0.0021	0.006±0.0014	3.653±0.590	0.074±0.0091	0.013±0.0021
NBW	0.0015±0.0007	0.002±0.0014	0.003±0.0014	2.9805±0.5098	0.019±0.0014	0.017±0.0056
WHO/MPL	0.01	0.03	2	0.002	0.01	0.01

Source: Field Work (2023)



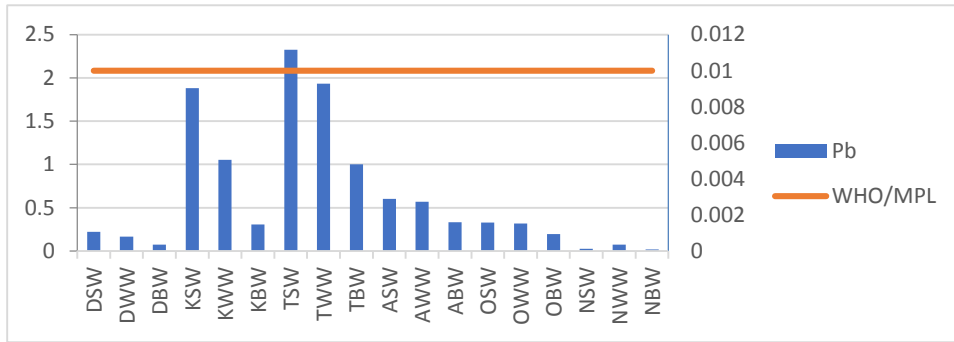
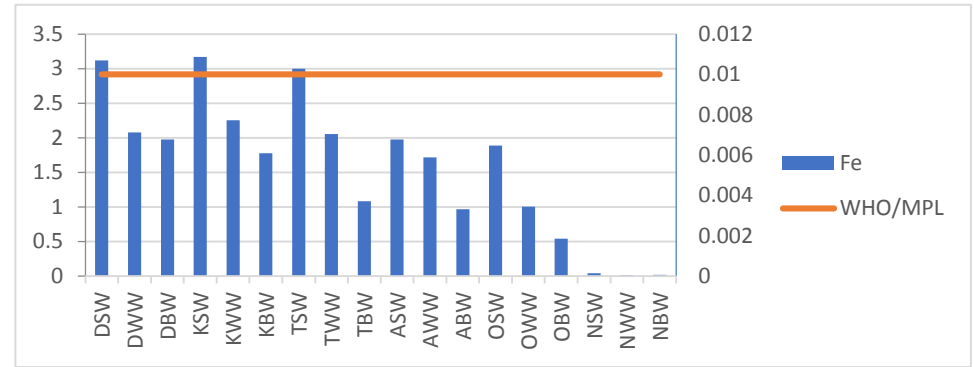


Figure 5: Level of heavy metals in water as compared to WHO/MPL limits



From the figures 5 above the result shows that KSW has an arsenic concentration of 2.6485 mg/L, which is significantly above the guideline, indicating severe contamination reports the highest arsenic level among the water samples at 3.416 mg/L, suggesting that the source water or the processes it undergoes significantly elevate arsenic levels. SW and OWW also show elevated levels of arsenic (1.2855 mg/L and 0.997 mg/L, respectively), which are close to or exceed the WHO/MPL, indicating potential contamination from external environmental sources or plumbing. Most other samples, including Drinking Water Supply (DSW) and natural surface waters, have arsenic levels at or below the guideline, suggesting that, for arsenic at least, they may be considered safe for consumption or contact based on this criterion alone. (NSW and NWW) shows significantly lower levels of arsenic (0.0045 mg/L and 0.003 mg/L, respectively), indicating minimal arsenic contamination in these sources, which could be due to their natural environments being less impacted by human activities.

Notably, TSW (2.2155 mg/L), TWW (1.662 mg/L), and TBW (1.4405 mg/L) have cadmium levels far exceeding the safe limit. Cadmium is toxic, particularly to the kidney, and can lead to bone demineralization. Other samples show lower levels of cadmium, with some like DBW (0.0015 mg/L) and NBW (0.002 mg/L) having significantly lower concentrations. All samples are below the WHO/MPL for copper (2 mg/L), suggesting that copper, despite its necessity for human health, is not at a toxic level in these water sources. All samples, except (NSW, NWW, and NBW), have mercury levels that vastly exceed the WHO/MPL (0.002 mg/L). This is particularly concerning for human health, given mercury's neurotoxic effects. Several samples, such as KSW (1.882 mg/L) and TSW (2.325 mg/L), significantly exceed the lead limit, posing risks of neurological and developmental disorders. Most samples were below the limit for iron, which is set relatively low and is more of an aesthetic and taste concern at the levels observed

rather than a health hazard. Iron is essential for human health, but excessive iron can be problematic, especially in areas for individuals with certain health conditions.

Table 3: Heavy metal concentration in sediment

Samples	As	Cd	Cu	Hg	Pb	Fe
DSS	2.162±0.225	1.04±1.236	2.076±2.368	39.126±38.241	1.476±1.533	4.32±4.486
DSDS	3.636±0.105	1.6725±0.155	3.272±0.376	40.766±0.437	1.995±0.017	5.5945±0.391
KSS	2.508±0.385	0.827±0.085	4.18±0.075	40.351±0.321	2.546±0.148	3.5155±0.573
KSDS	3.0755±0.050	1.2875±0.060	5.685±0.106	43.794±0.503	2.398±0.472	4.1955±0.203
TSS	2.916±0.105	1.546±0.617	3.258±0.214	44.245±0.515	1.6555±0.163	2.3275±0.301
TSDS	3.8115±0.098	1.464±0.355	4.296±0.058	46.9045±0.919	2.281±0.068	3.501±0.439
ASS	2.135±0.169	1.474±0.34	1.378±0.286	41.435±1.851	0.533±0.080	3.1555±0.121
ASDS	3.0545±0.064	1.67±0.339	2.05±0.057	46.7675±0.771	0.984±0.001	3.5685±0.354
OSS	2.5685±0.051	0.698±0.095	1.932±0.079	39.358±0.513	1.352±0.194	1.907±0.035
OSDS	2.9±0.144	0.917±0.038	2.0935±0.054	43.853±0.758	2.0185±0.018	2.481±0.191
NSS	0.002±0.0007	0.004±0.0007	0.004±0.001	7.716±0.918	0.009±0.0007	0.065±0.007
NSDS	0.005±0.0007	0.0025±0.0007	0.007±0.0007	9.0375±0.023	0.025±0.007	0.085±0.007
WHO/MPL	1-40	0.8	1.66	0.50	2.0	0.03

Source: Field Work, (2023)

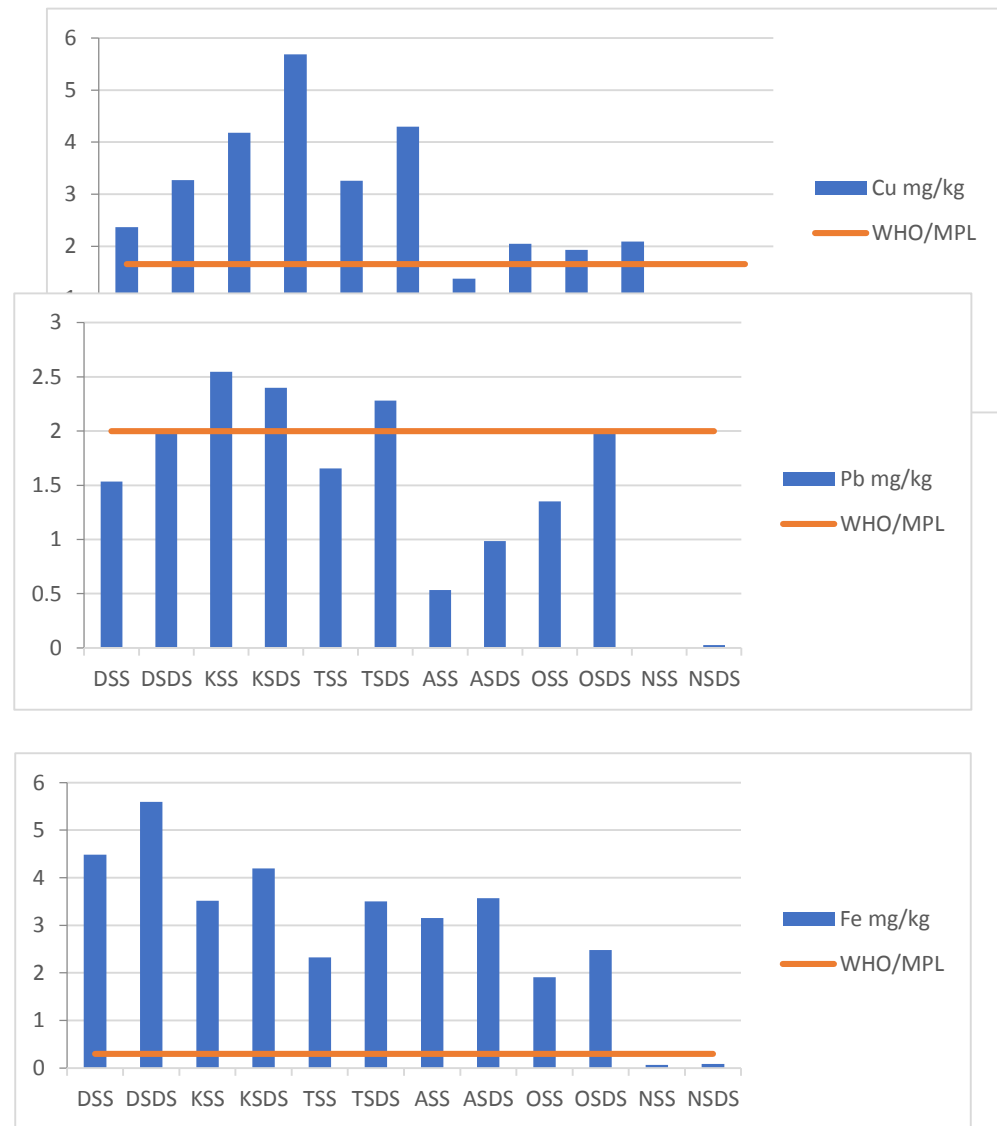
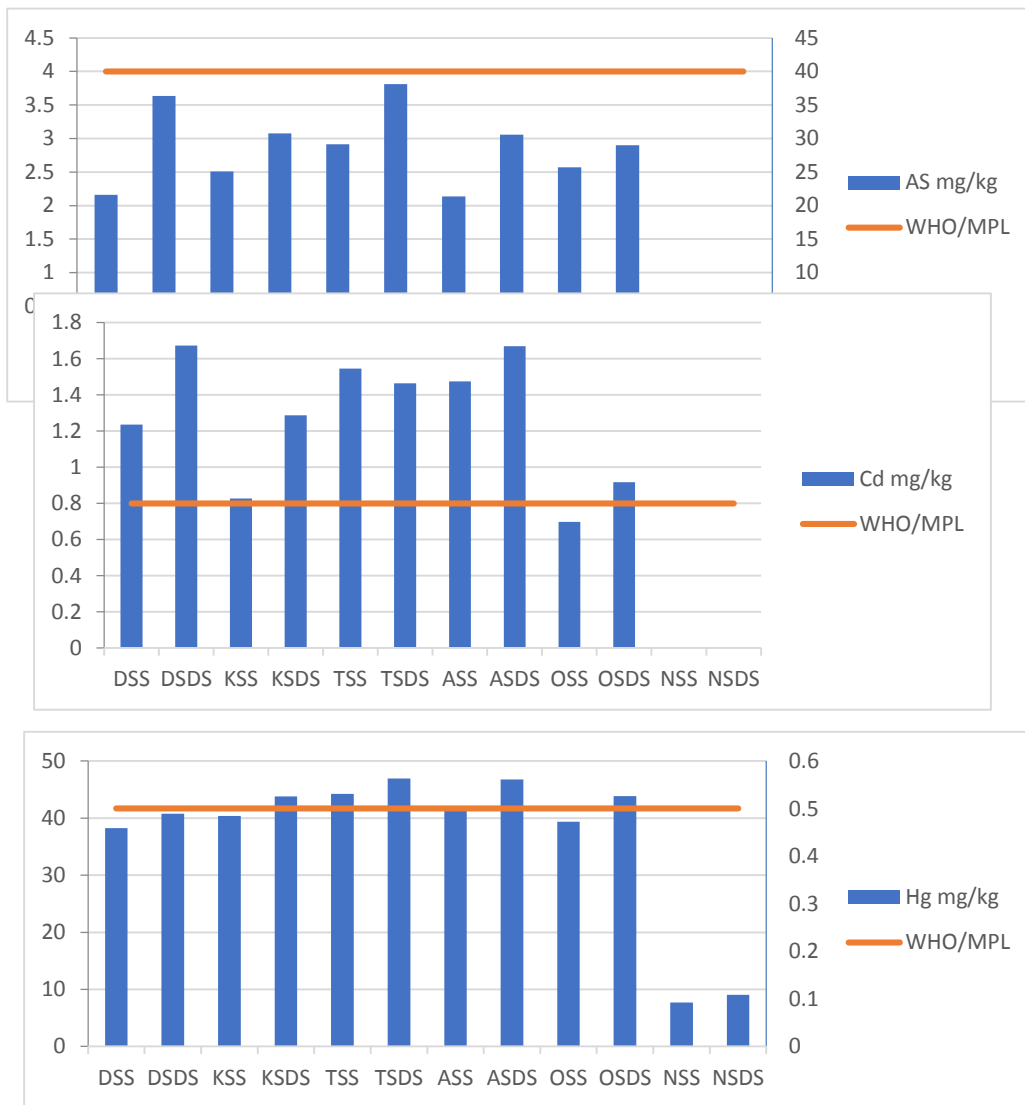


Figure 6: Heavy Metals Concentration Soil and Sediment

The arsenic levels in the NSS (0.002 mg/kg and NSDS (0.005 mg/kg) samples are significantly lower than in other samples, suggesting these might be from areas with minimal anthropogenic (human) impact. These low values could serve as background levels for comparison. Arsenic is a well-known carcinogen, with long-term exposure being linked to increased risks of skin, lung, and bladder cancers, among other health issues. The fact that all samples are significantly below the WHO/MPL is reassuring from a public health perspective, particularly for those in direct contact with the soil or consuming crops grown in it. The concentrations of cadmium in all samples are relatively low, further affirming their safety for various uses, including agriculture and residential purposes. Such low concentrations pose minimal risk to human health and the environment. Most of the given samples, including ASS (1.378 mg/kg), OSDS (2.0935 mg/kg), OSS (1.932 mg/kg), ASDS (2.05 mg/kg), DSS (2.3675 mg/kg), and NSS (0.004 mg/kg), fall below the WHO/MPL of 1.66 mg/kg. These concentrations indicate that, in terms of copper content, these soils and sediments are generally considered safe for use according to WHO standards. However, some samples, namely DSDS (3.272 mg/kg), KSS (4.18 mg/kg), KSDS (5.685 mg/kg), TSS (3.258 mg/kg), and TSDS (4.296 mg/kg), exceed the WHO/MPL (figure 6).

This suggests potential concerns regarding copper contamination in these specific samples, indicating a need for further investigation and possibly remediation measures. All of the given samples exceed the WHO/MPL for mercury in soil. This indicates that there are elevated levels of mercury present in these sediment and soil samples, posing potential risks to human health and the environment. The concentrations of mercury vary widely across the samples, ranging from 38.241 mg/kg in DSS to 9.0375 mg/kg in NSDS. This variation may be attributed to differences in local geology, anthropogenic activities, or historical sources of contamination in the respective areas. Mercury is a highly toxic heavy metal that can cause serious health issues, including neurological disorders, kidney

damage, and developmental problems, particularly in children and fetuses. Elevated levels of mercury in soil can also contaminate water bodies through runoff, posing risks to aquatic ecosystems and wildlife. The sources of mercury contamination in soil can be diverse and include industrial activities (e.g., mining, smelting), agricultural practices (e.g., the use of mercury-containing pesticides), and atmospheric deposition from natural and anthropogenic sources. Understanding the specific sources of contamination is crucial for effective remediation efforts. Only two samples, namely OSDS (2.0185 mg/kg) and KSS (2.546 mg/kg) exceed the WHO/MPL for lead. While these concentrations are slightly above the permissible limit, they may warrant further investigation and monitoring to assess potential health and environmental impacts, especially in areas where human exposure to lead is more likely.

Lead is a toxic heavy metal that can cause serious health issues, particularly in children and pregnant women. Chronic exposure to lead can lead to neurological disorders, developmental delays, and cardiovascular problems. Therefore, even low levels of lead in soil should be carefully managed to minimize risks to public health. All of the given samples fall below the WHO/MPL for iron in soil. This indicates that, in terms of iron content, these sediment and soil samples meet the international standards for soil quality and pose minimal risks to human health and the environment. The concentrations of iron vary across the samples, ranging from 0.065 mg/kg in NSS to 5.5945 mg/kg in DSDS. This variation may be attributed to differences in soil composition, geological factors, and anthropogenic activities in the respective.

Table 4: Demographic characteristics of the respondents in the Amansie South District

Variable	Frequency	Percentage
Age		
18-25	15	30.0
26-35	20	40.0
36-45	11	22.0
45+	4	8.0
Gender		
Male	36	72.0
Female	14	28.0
Occupation		
Miner	23	46.0
Farmer	8	16.0
Business owner	10	20.0
Student	9	18.0
Duration of stay/ worked in the district		
Less than 1 year	10	20.0
1-5 years	12	24.0
6-10 years	17	34.0
More than 10 years	11	22.0
Directly/ indirectly involved in mining activities		
Yes	36	72.0
No	14	28.0
Type of mining activities are you involved in		
Surface mining	16	32.0
Underground mining	18	28.0
Small-scale mining (galamsey)	5	10.0
Large-scale mining	11	22.0
Type of scale of mining activities		
Small-scale (artisanal)	15	30.0
Medium-scale	20	40.0
Large-scale	11	22.0
Mixed scale (combination of different scales)	4	8.0
Observe changes in water quality in the area		
Yes		
No		
Describe the changes you have observed		
Odor	28	56.0
Colored	15	30.0
Turbidity	7	14.0
Mining activities contribute to water contamination		
Yes	36	72.0
No	14	28.0
Ever experienced health issues due to water contamination		
Yes	32	64.0
No	18	36.0
Regulations/ policies to control water contamination?		
Yes	21	42.0
No	22	44.0
Not sure	7	14.0

The majority of respondents are between 26 and 35 years old (40%), followed by the 18-25 age group (30%). This suggests a relatively young population, with those under 45 making up 92% of respondents. There's a significant gender disparity, with males comprising 72% of respondents, indicating that males may be more involved in activities surveyed, particularly mining. Almost half of the respondents (46%) are miners, indicating mining as a predominant occupation. Business owners and students together make up 38%, showing a mix of economic activities besides mining. A majority (78%) have lived or worked in the district for more than a year, suggesting a stable, not transient, population. A significant 72% of respondents are directly or indirectly involved in mining, underscoring mining's centrality to the district's livelihoods. Underground mining is slightly more common (28%) than surface or large-scale mining (32% and 22%, respectively), with small-scale mining (galamsey) being the least reported (10%).

Medium-scale mining is perceived to be the most common (40%), though there's a significant acknowledgment of both small-scale (30%) and large-scale operations (22%). A majority have noticed changes in water quality, specifically odor (56%), coloration (30%), and turbidity (14%), indicating widespread awareness of water contamination issues.: A large majority (72%) believe that mining activities contribute to water contamination, reflecting a clear consensus on the source of the problem.64% have experienced or know someone who has experienced health issues related to water contamination, highlighting the significant impact on community health. Opinions are divided on the existence of regulations or policies to control mining-related water contamination, with a slight majority (44%) stating no such regulations exist, 42% saying yes, and 14% unsure.

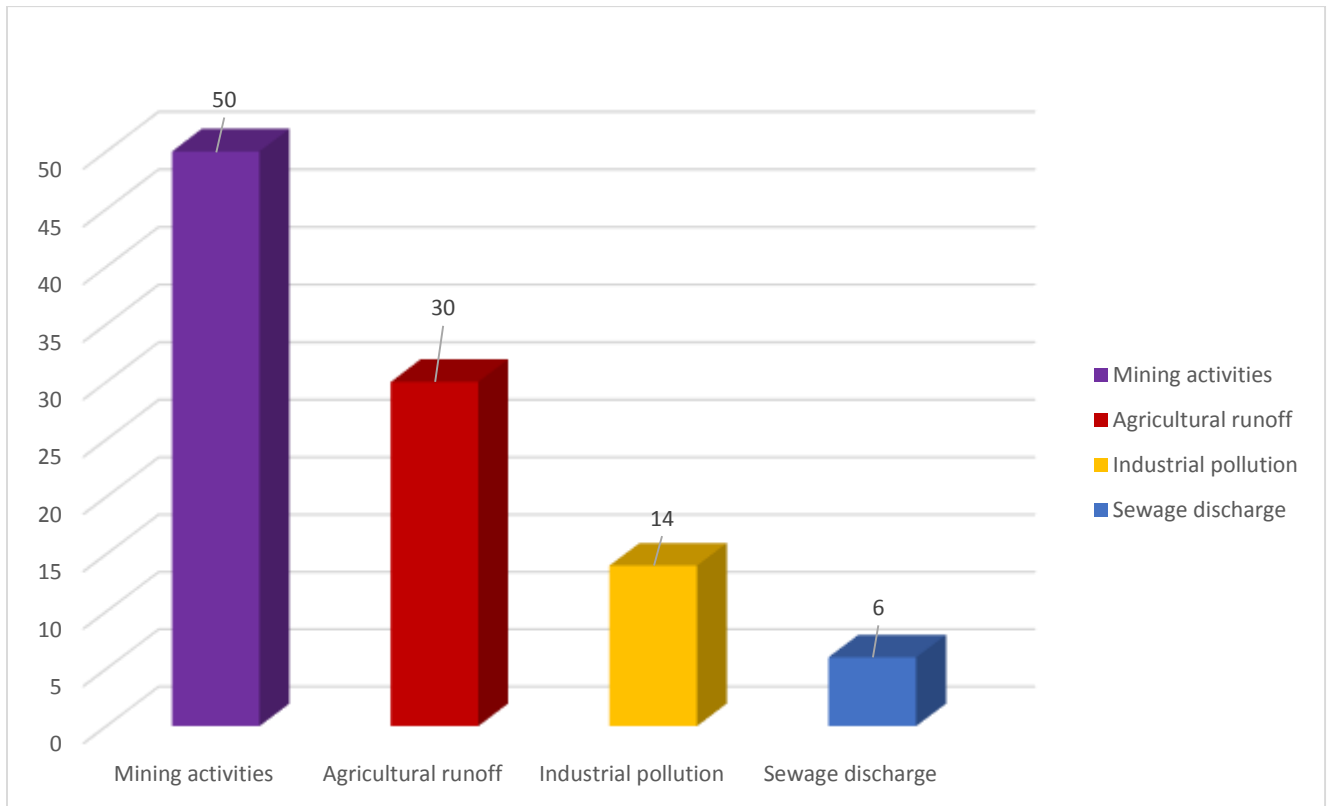


Figure 7: Sources of water contamination in the district

Mining activities being responsible for 50% of water contamination is significant. This high percentage suggests that mining operations are likely a major economic activity in the district but come with substantial environmental costs. The pollutants from mining (heavy metals, sediments, and acid mine drainage) can drastically alter the chemical composition of water bodies, making them inhospitable for aquatic life and unsafe for human consumption. Agricultural runoff contributing 30% to water contamination indicates a substantial impact from farming practices, including the use of fertilizers and pesticides and livestock waste management. This type of pollution often results in nutrient overload in water bodies, leading to algal blooms and subsequent ecological imbalances. The 14% attributed to industrial pollution, while smaller relative to mining and agriculture, still represents a significant source of contaminants such as toxic chemicals and heavy metals. Industrial facilities may need to adopt cleaner production technologies and better wastewater treatment processes to

reduce their environmental footprint. Although, only accounting for 6% of the contamination, sewage discharge remains a critical issue, particularly because it directly impacts human health. Even at this relatively low percentage, the potential for spreading waterborne diseases and introducing pharmaceuticals and personal care products into the ecosystem is significant

4.2 Health Risks (objective 3)

Table 4.3 shows the health effects of heavy metals. Diseases associated with heavy metals according to the respondents were urinal diseases, hypertension, and arthritis. Urinal diseases was experienced by 18(90%), hypertension 17(85%) and arthritis 15(75%). Symptoms experienced were back pain, problems with hearing, pain in the chest area, and skin problems. Back pain was 15(75%), problems with hearing 18(90%), pain in the chest area 17(85%) and skin problems 16(80%).

Table 5: Health effects of heavy metals Non-carcinogenic health risks of metals by ingestion and dermal pathways

Element	RfDing (mg/kg/day)	(GIABS)	HQing		HQderm		HI= ΣHQs	
			Adult	Child	Adult	Child	Adult	Child
Hg	0.00E-03	1.00E+00	1.46E-01	3.41E-01	7.63E-05	2.25E-04	1.46E-01	3.41E-01
AS	3.00E-04	1.00E+00	1.32E-01	3.09E-01	6.91E-04	2.04E-03	1.33E-01	3.11E-01
Pb	3.50E-03	1.00E+00	1.46E-01	3.41E-01	7.63E-05	2.25E-04	1.46E-01	3.41E-01
Cu	4.00E-02	1.00E+00	6.14E3	1.43E-02	3.21E-05	9.46E-05	6.17E-03	1.44E-02
Cd	2.00E-03	1.00E+00	1.12E-01	2.08E-01	7.91E-06	2.46E-03	1.34E-01	3.45E-01
Fe	2.30E-03	1.00E+00	1.11E-01	2.21E-01	3.43E-05	2.21E-04	1.26E-01	2.11E-01

Keys:HQ = hazard quotient, HI = hazard index, ELCR = excess lifetime cancer risk, GIABS = gastro-intestinal absorptivity, RFD = reference dose

The metal concentrations in water samples were used to assess human exposure through ingestion and dermal absorption pathways. Two population groups were considered: children and adults. Table 8 presents the HQ and HI values calculated for Residents based on the ingestion and dermal absorption of groundwater. Table 4.8 analyzed an assessment of non-carcinogenic health risks associated with the ingestion and dermal exposure to mercury, arsenic, lead, and copper. For both

adults and children, the HQ_{ing} for mercury through ingestion is 0.146, indicating that the exposure is below the reference dose. The HQ_{derm} for dermal exposure is also below the reference dose. The Hazard Index (HI) for mercury is 0.146 for both adults and children, suggesting a low non-carcinogenic health risk from both ingestion and dermal exposure. The HQ_{ing} for arsenic through ingestion is 0.132 for both adults and children, and the HQ_{derm} for dermal exposure is also below the reference dose. The Hazard Index (HI) for arsenic is 0.133 for both adults and children, indicating a relatively low non-carcinogenic health risk from both pathways.

The HQ_{ing} for lead through ingestion is 0.146 for both adults and children, and the HQ_{derm} for dermal exposure is below the reference dose. The Hazard Index (HI) for lead is 0.146 for both adults and children, suggesting a low non-carcinogenic health risk from both ingestion and dermal exposure. The HQ_{ing} for copper through ingestion is relatively high ($6.14E+03$) for adults and children, indicating a potential concern. However, the HQ_{derm} for dermal exposure is much lower. The Hazard Index (HI) for copper is 0.00617 for adults and 0.0144 for children. While the HQ_{ing} for ingestion is high, the overall risk is mitigated by low dermal exposure

The RfD for cadmium is set at $2.00E-03$ mg/kg/day. For adults, the HQ by ingestion is $1.12E-01$, and for children, it is $2.08E-01$. These values are relatively moderate, indicating a potential non-carcinogenic risk through ingestion. The HQ for dermal exposure is minimal, with values of $7.91E-06$ for adults and $2.46E-03$ for children. The combined hazard index (HI) for cadmium is $1.34E-01$ for adults and $3.45E-01$ for children, suggesting that children are at a higher non-carcinogenic risk due to both ingestion and dermal exposure.

The RfD for iron (Fe) is $2.30E-03$ mg/kg/day. The HQ by ingestion for adults is $1.11E-01$ and for children, it is $2.21E-01$. Like cadmium, these values suggest a moderate non-carcinogenic risk through ingestion. The HQ for dermal exposure is also minimal, with values of $3.43E-05$ for adults

and 2.21E-04 for children. The HI for iron is 1.26E-01 for adults and 2.11E-01 for children, indicating that children again face a higher risk compared to adults, though overall, the risks from iron are less concerning than those from cadmium. In conclusion, both cadmium and iron present non-carcinogenic health risks, particularly through ingestion. Children are more vulnerable to these risks than adults, with cadmium posing a slightly higher concern compared to iron

Table 6: Total hazard index and excess lifetime cancer risk due to ingestion and dermal pathways

Sample Location	Adult			Child			Excess lifetime cancer risk		
	HIing	HIderm	HItotal	HIing	HIderm	HItotal	ELCRing	ELCRderm	ELCRtotal
DSW	8.63E-01	2.08E-02	8.84E-01	2.01E+00	6.12E-02	2.07E+00	7.89E-05	3.98E-07	7.93E-05
DWW	2.04E+00	7.65E-02	2.12E+00	4.77E+00	2.26E-01	5.00E+00	9.61E-05	4.07E-07	9.65E-05
DBW	1.60E+00	1.99E-02	1.62E+00	3.73E+00	5.85E-02	3.79E+00	2.47E-04	1.30E-06	2.48E-04
KSW	1.37E+00	3.93E-02	1.41E+00	3.21E+00	1.16E-01	3.33E+00	6.12E-05	2.82E-07	6.15E-05
KWW	2.04E+00	3.92E-02	2.08E+00	4.76E+00	1.15E-01	4.88E+00	1.27E-04	6.32E-07	1.28E-04
KBW	1.15E+00	2.61E-02	1.18E+00	2.67E+00	7.69E-02	2.75E+00	5.63E-05	2.84E-07	5.66E-05
TSW	1.15E+00	2.61E-02	1.18E+00	2.67E+00	7.69E-02	2.75E+00	5.63E-05	2.84E-07	5.66E-05
TWW	3.90E-01	1.09E-02	4.01E-01	9.11E-01	3.21E-02	9.43E-01	3.98E-05	2.07E-07	4.00E-05
TBW	9.49E-01	7.10E-03	3.72E-01	8.53E-01	2.08E-02	8.74E-01	5.41E-05	2.76E-07	5.44E-05
ASW	1.93E+00	6.81E-02	2.00E+00	4.51E+00	2.01E-01	4.71E+00	4.77E-05	1.93E-07	4.79E-05

Sources: Field Work (2023)

The hazard index (HI) is a measure used to assess the potential health risks associated with exposure to multiple contaminants through ingestion and dermal pathways. It represents the sum of individual hazard quotients (HQs) for each contaminant, where the HQ is the ratio of the exposure dose to a reference dose. An HI greater than 1 indicates that there may be potential adverse health risk effects due to exposure. The hazard index (HI) and excess lifetime cancer risk (ELCR) values provided in the table indicate the potential health risks associated with the ingestion and dermal exposure to contaminants present in various water samples. The HI combines the potential health risk effects of multiple contaminants by summing their hazard quotients (HQs). An HI value greater than 1 indicates that cumulative exposure to contaminants may pose a risk to human health, particularly for sensitive populations such as children. Looking at the HI values for both adults and children across different sample locations, we observe that several samples exhibit HI values exceeding 1, suggesting potential health risks associated with exposure to contaminants through ingestion and dermal pathways. For instance, DWW, KWW, and ASW samples have HI values greater than 2 for adults, indicating a significant risk of adverse health risk effects from exposure to contaminants in these water sources.

Similarly, HI values for children exceed 2 in DWW, KWW, and ASW samples, indicating a potentially higher susceptibility to health risks among children. The ELCR estimates the additional lifetime risk of developing cancer as a result of exposure to contaminants in water sources. ELCR values below 1 in a million (10^{-6}) are generally considered acceptable for protecting public health. In the provided data, ELCR values for both ingestion and dermal pathways are generally below 10^{-5} , indicating a relatively low risk of cancer associated with exposure to contaminants in most water samples. However, it's crucial to note that ELCR values exceeding 10^{-5} are observed in several samples, particularly for adults, suggesting a potential increased risk of cancer associated with long-term exposure to contaminants in these water sources.

The findings suggest that while some water samples may pose a low risk of cancer and adverse health risk effects, others exhibit HI and ELCR values that exceed acceptable thresholds, indicating a potential health hazard for individuals exposed to these contaminants. This highlights the importance of regular monitoring and assessment of water quality to identify and mitigate potential risks to public health. Further investigation into the sources of contamination and implementation of appropriate remediation measures are warranted to ensure the safety of water sources and protect human health. Additionally, strategies to minimize exposure to contaminants, especially among vulnerable populations such as children, should be prioritized to mitigate potential health risks associated with water consumption and recreational activities.

CHAPTER FIVE

5.0 DISCUSSION

5.1 Heavy Metals Concentration in Water

The findings of the study regarding the contamination of water samples with heavy metals such as Mercury (Hg), Lead (Pb), Cadmium (Cd), Arsenic (As), Copper (Cu), and Iron (Fe) align with existing literature on water pollution and its associated health risks. The elevated levels of mercury in water samples, particularly in TSW, are indeed alarming and suggest a significant pollution issue. Mercury contamination in water bodies is a well-documented concern, often originating from industrial activities such as mining, coal combustion, and waste incineration (Wang, 2024). These findings highlight the urgent need for remediation efforts to mitigate mercury pollution in affected water sources. The study's identification of lead and cadmium concentrations exceeding WHO/MPL standards is consistent with previous research highlighting the adverse health effects of these heavy metals. Lead exposure, even at low levels, is associated with neurological and developmental impairments, particularly in children (Gyimah *et al.*, 2021).

Similarly, cadmium exposure is linked to kidney damage and various adverse health outcomes (Adeleke *et al.*, 2020). The detection of high levels of these metals in water samples emphasizes the importance of monitoring and regulating industrial activities to prevent further contamination. The localized contamination of arsenic in specific water samples corresponds with known sources of arsenic pollution, such as mining activities, industrial discharge, and the use of arsenic-containing pesticides (Bose-O'Reilly *et al.*, 2010). Arsenic exposure through contaminated water positions significant health risks, including skin abrasions, cancer, and cardiovascular diseases (Lipińska, 2016). The study's findings underline the importance of targeted interventions to address arsenic

contamination in affected areas. While copper levels in the studied water samples remain within safe limits, the elevated concentrations in certain samples warrant attention. Copper contamination in water sources can result from various anthropogenic activities, including mining, agricultural runoff, and corrosion of copper pipes (Patel *et al.*, 2016). Although below the safety threshold, the elevated copper levels highlight the need for continued monitoring and preventive measures to avoid potential health impacts.

The wide variation in iron concentrations across samples, with some exceeding WHO/MPL standards, indicates the presence of iron contamination in certain water sources. Iron pollution in water bodies can arise from natural sources, such as geological formations, as well as anthropogenic activities, including industrial discharge and agricultural runoff (Karakuş, 2019). While iron is an essential nutrient, excessive intake through contaminated water can have adverse health effects, particularly on individuals with certain health conditions (Madhav *et al.*, 2018a). Efforts to mitigate iron contamination should consider both natural and human-induced sources.

5.2 The Level of Heavy Metals Concentration in Water as Compared with WHO/MPL

The study's findings regarding the contamination levels of arsenic, cadmium, copper, mercury, lead, and iron in various water samples provide valuable insights into the potential health risks associated with these heavy metals. These results align with existing literature on the toxicity and health impacts of these contaminants in water sources (Hassen *et al.*, 2016b). The significantly elevated arsenic concentration in KSW, as well as in SW and OWW, indicates severe contamination, likely originating from either the source water or kitchen processes. Arsenic contamination in drinking water is a major global concern due to its carcinogenic properties and adverse health effects on various organ systems (Lee *et al.*, 2017). The study underscores the importance of identifying and mitigating sources of arsenic contamination to safeguard public health. The exceptionally high cadmium levels in TSW,

TWW, and TBW samples pose serious health risks, particularly to the kidneys and skeletal system. Chronic exposure to cadmium through contaminated water sources can lead to renal dysfunction, osteoporosis, and other adverse health outcomes (Patel *et al.*, 2016).

The findings highlight the urgent need for remediation efforts to reduce cadmium pollution in affected water bodies. Although all samples remain below the WHO/MPL for copper, elevated concentrations in certain samples warrant attention. While copper is an essential micronutrient, excessive intake can lead to adverse health effects, including gastrointestinal disturbances and liver toxicity (Karakuş, 2019). Continued monitoring of copper levels in water sources is crucial to prevent potential health risks associated with long-term exposure. The widespread exceedance of mercury levels in all samples, except for NSW, NWW, and NBW, raises significant concerns for human health. Mercury is a potent neurotoxin, with adverse effects on cognitive development, particularly in children (Madhav *et al.*, 2018b). The findings underscore the importance of mitigating mercury pollution to protect vulnerable populations from its harmful effects. The elevated lead levels in several samples, including KSW and TSW, pose risks of neurological and developmental disorders, particularly in children. Lead exposure through contaminated water sources can result in cognitive impairments, behavioural problems, and cardiovascular effects (Hassen *et al.*, 2016b).

Efforts to reduce lead contamination in water supplies are essential to safeguard public health. While most samples exceed the limit for iron, it is primarily an appealing and taste concern rather than a significant health hazard at the observed levels. However, individuals with certain health conditions or living in areas with specific water chemistry may be more susceptible to adverse effects from excessive iron intake (Li *et al.*, 2016)

5.3 Heavy Metals Concentration in Sediments/soil

The study's findings regarding the concentrations of arsenic (As), cadmium (Cd), copper (Cu), mercury (Hg), lead (Pb), and iron (Fe) in sediment and soil samples highlight potential risks to water quality, food safety, and environmental health (Scaini *et al.*, 2015). These results align with existing literature on the impact of heavy metal contamination on ecosystems and human health. Elevated concentrations of arsenic in sediment and soil samples from DSS and DS DS indicate potential leaching into water sources, posing risks to water quality and human health. Arsenic-contaminated water can have significant adverse effects on human health, including carcinogenic and non-carcinogenic health effects (Cobbina *et al.*, 2015).

The findings underscore the importance of monitoring and mitigating arsenic contamination to protect both aquatic ecosystems and public health. The high concentrations of cadmium in sediment and soil samples raise concerns about potential risks to food safety if crops are grown in contaminated soil (Loubet *et al.*, 2014). Chronic exposure to cadmium through contaminated food can lead to adverse health effects, including kidney damage and bone disorders (Huff *et al.*, 2014a). Efforts to reduce cadmium contamination in agricultural soils are essential to minimize health risks associated with food consumption.

While concentrations of copper in sediment and soil samples may exceed water quality guidelines, typical background levels in soil are higher, and phytotoxic levels are usually considered much higher. However, elevated copper levels in soil can still pose risks to plant growth and environmental health (O'Faircheallaigh & Corbett, 2016b). Monitoring and management practices are necessary to prevent adverse effects on soil ecosystems. Severe contamination of sediment and soil samples with mercury poses risks to both human health and wildlife through bioaccumulation in the food chain. Mercury

exposure can lead to neurological and developmental effects in humans and adverse impacts on aquatic ecosystems (Salati *et al.*, 2014).

Effective remediation strategies are crucial to mitigate mercury contamination and protect environmental and public health. Elevated lead levels in sediment and soil samples suggest potential harm to human health, particularly for children through incidental ingestion and the risk of developmental effects. Lead exposure is associated with neurological and developmental impairments, making soil lead contamination a significant public health concern (Bhatti *et al.*, 2018). Measures to reduce lead exposure, such as soil remediation and prevention of soil ingestion, are essential to safeguard human health. While high iron concentrations in sediment and soil samples may not pose significant health risks, they can affect soil quality, plant growth, and water quality. Management strategies to address excessive iron levels in soil should consider potential impacts on environmental health and ecosystem functioning (Santos *et al.*, 2019).

5.4 Heavy Metals Concentration in the soil of various Metals as against WHO/MPL

The study's analysis of arsenic, cadmium, copper, mercury, lead, and iron levels in soil and sediment samples provides valuable insights into potential environmental and human health risks associated with heavy metal contamination. These findings are in line with existing literature on the toxic effects of heavy metals and their impact on ecosystems and public health (Pellegrini *et al.*, 2016). The relatively low levels of arsenic in NSS and NSDS samples suggest minimal anthropogenic impact, serving as background levels for comparison. While all samples are below WHO/MPL standards, long-term exposure to arsenic can still pose health risks, including increased cancer risks (Lado *et al.*, 2020). However, the overall low concentrations are reassuring from a public health perspective, particularly for individuals in direct contact with soil or consuming crops grown in it. The relatively low concentrations of cadmium in all samples indicate minimal risk to human health and the

environment (Kuroda *et al.*, 2015). These findings support the safety of various land uses, including agriculture and residential purposes. While most samples meet WHO/MPL standards for copper content, elevated levels in specific samples such as DSDS, KSS, KSDS, TSS, and TSDS warrant further investigation and possibly remediation measures. Copper contamination in soil can have adverse effects on ecosystems and human health, especially if concentrations exceed permissible limits.

The widespread exceedance of WHO/MPL standards for mercury in all samples indicates elevated levels of mercury contamination, posing potential risks to human health and the environment (Li *et al.*, 2018). Mercury is highly toxic and can cause serious health issues, particularly neurological disorders and kidney damage. Understanding the sources of contamination is crucial for effective remediation efforts. While only two samples exceed WHO/MPL standards for lead, even low levels of lead in soil can pose health risks, especially to children and pregnant women. Therefore, further investigation and monitoring are necessary to assess potential health and environmental impacts, particularly in areas with higher human exposure to lead (Ronchi *et al.*, 2019). All samples fall below WHO/MPL standards for iron, indicating minimal risks to human health and the environment. However, the wide variation in iron concentrations across samples suggests differences in soil composition and anthropogenic activities (Adler Miserendino *et al.*, 2013).

5.5 The mining processes that contaminate water

The findings of this study with other research can provide a broader perspective on the issues related to mining activities and their impacts on communities. Here's a discussion comparing the key points from this study with findings from other studies: While this study indicates a relatively young population, other studies might reveal variations in age demographics depending on the region and socio-economic factors. Some communities might have older populations due to outmigration of

younger individuals for employment opportunities (Wang & Li, 2017). The predominance of mining occupations found in this study aligns with research in many mining-dependent regions. However, in areas where mining is not the primary economic activity, other studies might highlight different occupational distributions. The stability of the population observed in this study might contrast with findings from areas experiencing rapid population turnover due to transient employment opportunities in the mining sector (Adeleke *et al.*, 2020).

The distribution of mining activities observed in this study (e.g., underground, surface, large-scale, small-scale) may vary depending on the geological characteristics and regulatory frameworks of different regions. Perception of the scale of mining activities can vary widely depending on local definitions and interpretations. In some studies, the distinction between small-scale and large-scale mining might be less clear due to informal or artisanal mining practices (Patel *et al.*, 2016). Concerns about water contamination from mining activities are commonly reported in mining-affected communities worldwide. Studies from different regions often highlight similar issues, including changes in odor, coloration, and turbidity. Health impacts associated with mining-related water contamination are well-documented in various studies, with reported cases ranging from respiratory illnesses to skin conditions and gastrointestinal problems (Tarras-Wahlber *et al.*, 2000). The presence and effectiveness of regulations and policies to address mining-related environmental and health concerns can vary significantly between regions. Some studies might highlight successful regulatory frameworks, while others may identify gaps in enforcement and compliance.

5.6 Sources of water contamination in the district

The assertion that mining is responsible for 50% of water contamination is remarkably high compared to many global averages, where mining is indeed a significant source but not always to this extent. For instance, studies from regions with extensive mining operations, like parts of South America and

Africa, do show high levels of water contamination from mining but also emphasize the role of inadequate regulatory frameworks and enforcement in exacerbating these impacts. Mining contributes to heavy metals, acid mine drainage, and sedimentation, as you mentioned, which can be mitigated with modern technologies and stricter regulations (Karakuş, 2019).

The 30% contribution from agricultural runoff is consistent with global trends, where nonpoint source pollution from agriculture is a leading cause of water quality degradation. The use of fertilizers and pesticides, coupled with improper livestock waste management, leads to nutrient overload, which causes eutrophication and hypoxic zones in aquatic ecosystems. Compared to other studies, the emphasis on agriculture's role is a critical reminder of the need for sustainable farming practices, integrated pest management, and effective runoff control measures (Madhav *et al.*, 2018b). The 14% figure for industrial pollution may vary widely by region, depending on the industrial base and the effectiveness of pollution control measures in place. In some areas, particularly where regulations are less stringent or poorly enforced, industrial pollution can account for a higher percentage of water contamination (Madhav *et al.*, 2018b; Hassen *et al.*, 2016b). The pollutants mentioned, such as toxic chemicals and heavy metals, are of particular concern due to their persistence in the environment and bioaccumulative properties. Cleaner production technologies and improved wastewater treatment are widely recommended in the literature as essential strategies for reducing industrial water pollution (Karakuş, 2019).

While sewage discharge accounts for only 6% of the contamination in your summary, other studies have shown that in areas with inadequate wastewater treatment infrastructure, sewage can be a primary source of water contamination. This discrepancy highlights the importance of infrastructure development and maintenance in preventing waterborne diseases and the spread of pharmaceuticals and personal care products into the environment. The impact of sewage discharge is also a significant

concern for public health, emphasizing the need for investment in sewage treatment facilities (Madhav *et al.*, 2018b). The disparities and similarities between the figures you provided and other studies suggest that the impact of various sectors on water contamination can vary significantly based on geographic, economic, and regulatory contexts. For instance, in industrialized countries, stricter regulations might lead to a lower relative impact of industrial pollution and a higher emphasis on nonpoint sources like agriculture (Baddianaah, 2022). In contrast, in developing economies, lack of infrastructure, enforcement, and technology might result in higher contributions from all sectors, especially mining and industrial activities

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The findings of this study underscore the significant environmental impact of small-scale and artisanal gold mining in the district. The data reveals a young population heavily involved in mining activities, particularly males, indicating the centrality of mining to the local economy. The majority of respondents perceive mining-related water contamination as a pressing issue, with notable impacts on community health. Moreover, the study highlights widespread contamination of water and soil samples with heavy metals such as mercury, lead, cadmium, and arsenic, surpassing WHO/MPL guidelines in many cases. Water quality assessment highlights widespread awareness of contamination issues, with mining activities being identified as a major contributor. Health issues related to water contamination are prevalent among respondents, further emphasizing the significant impact on community well-being.

Analysis of water and soil samples reveals alarming levels of heavy metal contamination, particularly mercury, lead, and cadmium, exceeding WHO guidelines in many instances. These pollutants pose serious risks to human health and environmental integrity, with potential implications for both aquatic ecosystems and agricultural productivity. The alarming levels of heavy metals in water pose immediate risks to human health, including neurological disorders, developmental delays, kidney damage, and various cancers. Similarly, soil contamination raises concern for agricultural productivity and food safety, with potential long-term consequences for human health and environmental sustainability.

6.2 Recommendations

1. Strengthen enforcement of existing regulations or introduce new policies to control mining activities and mitigate environmental contamination. This includes measures to monitor and reduce the discharge of pollutants into water bodies and soil.
2. Launch community education campaigns to raise awareness about the health risks associated with mining-related contamination. Empower residents with knowledge about safe water and soil practices to minimize exposure to heavy metals.
3. Invest in environmentally sustainable mining practices and technologies to minimize the release of toxic substances into the environment. Promote the adoption of cleaner production methods and efficient wastewater treatment systems within mining operations.
4. **Monitoring and Remediation:** Implement comprehensive monitoring programs to regularly assess water and soil quality in affected areas. Develop targeted remediation strategies to address contamination hotspots and mitigate the spread of heavy metals in the environment.
5. Foster collaboration between government agencies, mining companies, local communities, and environmental organizations to tackle the complex challenges of mining-related environmental degradation. Encourage dialogue and cooperation to develop holistic solutions that prioritize both economic development and environmental protection.
6. Provide training and capacity-building initiatives for local stakeholders, including miners, farmers, and government officials, to enhance their ability to monitor, manage, and respond to environmental challenges effectively.

REFERENCES

- Abanyie, S. K., Sunkari, E. D., Apea, O. B., Abagale, S., & Korboe, H. M. (2020). Assessment of the quality of water resources in the Upper East Region, Ghana: A review. *Sustainable Water Resources Management*, 6(4), 52. <https://doi.org/10.1007/s40899-020-00409-4>
- Adeleke, B., Robertson-Andersson, D., Moodley, G., & Taylor, S. (2020). Aquaculture in Africa: A Comparative Review of Egypt, Nigeria, and Uganda Vis-À-Vis South Africa. *Reviews in Fisheries Science and Aquaculture*, 29(2), 167–197. <https://doi.org/10.1080/23308249.2020.1795615>
- Adimalla, N. (2020a). Heavy metals contamination in urban surface soils of Medak province, India, and its risk assessment and spatial distribution. *Environmental Geochemistry and Health*, 42(1), 59–75. <https://doi.org/10.1007/s10653-019-00270-1>
- Adimalla, N. (2020b). Heavy metals contamination in urban surface soils of Medak province, India, and its risk assessment and spatial distribution. *Environmental Geochemistry and Health*, 42(1), 59–75. <https://doi.org/10.1007/s10653-019-00270-1>
- Adjei, P. O.-W., Dakurah, G. B., Forkuor, D., & Adjei, J. O. (2023). Forest Security Appraisal of Community Management Interventions against Threats of Forest Commons at Offinso North District in Ghana. *Ghana Journal of Geography*, 15(1), 35–61.
- Adler Miserendino, R., Bergquist, B. A., Adler, S. E., Guimarães, J. R. D., Lees, P. S. J., Niquen, W., Velasquez-López, P. C., & Veiga, M. M. (2013). Challenges to measuring, monitoring, and addressing the cumulative impacts of artisanal and small-scale gold mining in Ecuador. *Resources Policy*, 38(4), 713–722. <https://doi.org/10.1016/j.resourpol.2013.03.007>
- Adomako, B.-Y., Baiden, F., Sackey, S., Ameme, D. K., Wurapa, F., Nyarko, K. M., Kenu, E., & Afari, E. (2018). Dog bites and rabies in the eastern region of Ghana in 2013–2015: A call for a one-health approach. *Journal of Tropical Medicine*, 2018. <https://www.hindawi.com/journals/jtm/2018/6139013/abs/>
- Adu-Boahen, K., Boateng, I., Okyere, E. Y., & Kyeremeh, S. (2023). An assessment of water quality and the locals' perception of coastal lagoon pollution in Ghana: A case study of Chemu lagoon in Tema. *Asian Review of Environmental and Earth Sciences*, 10(1), 28–39.
- Adusei-Gyamfi, J., Gyebi, A. S. A., Amponsah, A. K., Atampugre, G., Tilahun, S., & Cofie, O. (2023). *Fostering community-based water quality and quantity monitoring through citizen*

- science in the Ashanti Region of Ghana: A citizen science training report.*
<https://cgspace.cgiar.org/items/3f3d7f75-a4c3-43b1-a608-74577aacddb3>
- Agariga, F., Abugre, S., & Appiah, M. (2021). Spatio-temporal changes in land use and forest cover in the Asutifi North District of Ahafo Region of Ghana,(1986–2020). *Environmental Challenges*, 5, 100209.
- Agodzo, S. K., Bessah, E., & Nyatuame, M. (2023). A review of the water resources of Ghana in a changing climate and anthropogenic stresses. *Frontiers in Water*, 4, 973825.
- Akabzaa, T., & Darimani, A. (2001). Impact of mining sector investment in Ghana: A study of the Tarkwa mining region. *Third World Network*, 11(2), 47–61.
- Akoto, O., Bortey-Sam, N., Ikenaka, Y., Nakayama, S. M., Baidoo, E., Yohannes, Y. B., & Ishizuka, M. (2017). Contamination levels and sources of heavy metals and a metalloid in surface soils in the Kumasi Metropolis, Ghana. *Journal of Health and Pollution*, 7(15), 28–39.
- Akuo-ko, E. O., Otoo, F., Glover, E. T., Amponsem, E., Tettey-Larbi, L., Csordás, A., Kovács, T., & Shahrokhi, A. (2024a). A comprehensive radiological survey of groundwater resources in artisanal mining communities in the eastern region of Ghana: Water quality vs. Mining activities. *Water*, 16(1), 62.
- Akuo-ko, E. O., Otoo, F., Glover, E. T., Amponsem, E., Tettey-Larbi, L., Csordás, A., Kovács, T., & Shahrokhi, A. (2024b). A comprehensive radiological survey of groundwater resources in artisanal mining communities in the eastern region of Ghana: Water quality vs. Mining activities. *Water*, 16(1), 62.
- Akyeampong, E., & Xu, L. (2023). Chinese technology and the transformation of the rural economy in Ghana: Evidence from Galamsey in the Ashanti and Savannah regions. *African Affairs*, adad023. <https://doi.org/10.1093/afraf/adad023>
- Alhassan, E. H., Dandi, S. O., & Atindana, S. A. (2022). Effects of Small-Scale Mining Activities on Fisheries and Livelihoods in the Birim River in Atiwa District, Eastern Region of Ghana. *Tanzania Journal of Science*, 48(3), 703–717.
- Amengor, J. K. (2024). *An Investigation of Heavy Metal Pollution Impact on Drinking Water Quality in the Birim River Sub-Basin of Ghana.*
<https://prism.ucalgary.ca/bitstreams/5a6108ed-c2b2-45dc-8431-b83cbe7ca7c7/download>
- Amoakwah, E., Ahsan, S., Rahman, M. A., Asamoah, E., Essumang, D. K., Ali, M., & Islam, K. R. (2020). Assessment of Heavy Metal Pollution of Soil-water-vegetative Ecosystems

- Associated with Artisanal Gold Mining. *Soil and Sediment Contamination: An International Journal*, 29(7), 788–803. <https://doi.org/10.1080/15320383.2020.1777936>
- Amuah, E. E. Y., Amanin-Ennin, P., & Antwi, K. (2022). Irrigation water quality in Ghana and associated implications on vegetables and public health. A systematic review. *Journal of Hydrology*, 604, 127211.
- Anang, E., Lawson, B. W., Ankrah Aduboffour, V. K., Tei, M., & Antwi, A. B. (2023). Mercury and lead pollution in rivers in Ghana: Geo-accumulation index, contamination factor, and water quality index. *Water Practice & Technology*, 18(5), 1273–1283.
- Andrew, J. S. (2003). Potential application of mediation to land use conflicts in small-scale mining. *Journal of Cleaner Production*, 11(2), 117–130.
- Antwi-Boateng, O., & Akudugu, M. A. (2020). Golden Migrants: The Rise and Impact of Illegal Chinese Small-Scale Mining in Ghana. *Politics & Policy*, 48(1), 135–167. <https://doi.org/10.1111/polp.12342>
- Appiah Boamah, L., Nyamekye, C., Gyamfi, C., Ballard, J. Q., & Anornu, G. K. (2024). Mapping and estimating water quality parameters in the Volta Lake's Kpong Headpond of Ghana using regression model and Landsat 8. *Cogent Engineering*, 11(1), 2307165. <https://doi.org/10.1080/23311916.2024.2307165>
- Aryee, B. N. (2003). Small-scale mining in Ghana as a sustainable development activity: Its development and a review of the contemporary issues and challenges. *The Socioeconomic Impacts of Artisanal and Small-Scale Mining in Developing Countries*, 379–418.
- Asare, D., Ansong, M., Kyereh, B., Dampfey, F. G., & Asante, W. A. (2024). Contribution of early succession regeneration plants to heavy metal remediation in abandoned Artisanal Small-Scale Mining sites in Ghana. *Scientific African*, e02249.
- Atampugre, G., Igbadun, H. E., Tilahun, S., Oke, A., Mabhaudhi, T., Olaleye, O. A., & Cofie, O. (2024). *Social-Ecological Landscape Sustainability in Ghana and Nigeria: Applying the DPSIR-SEL Framework*. <https://www.researchsquare.com/article/rs-3866457/latest>
- Ayad, A., & Bakkali, S. (2022). Economic impact of derangements on mining process—Case study: Sidi Chennane. *Journal of Mining and Environment*, 13(4), 989–996.
- Ayamba, H. A., Dramani, A., & Agbenyega, O. (2017). Legalizing small scale gold mining in Gbane in the Upper East Region, Ghana. *Journal of African Political Economy and Development*, 2(1), 78–95.

- Baddianaah, I. (2022). Integrated Analysis of the Dynamics of Artisanal and Small-Scale Gold Mining Operations in the Upper West Region, Ghana. *Www.Udsspace.Uds.Edu.Gh*.
- Baddianaah, I., Baatuuwie, B. N., & Adongo, R. (2022). Socio-demographic factors affecting artisanal and small-scale mining (galamsey) operations in Ghana. *Heliyon*, 8(3). [https://www.cell.com/heliyon/pdf/S2405-8440\(22\)00327-9.pdf](https://www.cell.com/heliyon/pdf/S2405-8440(22)00327-9.pdf)
- Barenblitt, A., Payton, A., Lagomasino, D., Fatoyinbo, L., Asare, K., Aidoo, K., Pigott, H., Som, C. K., Smeets, L., & Seidu, O. (2021). The large footprint of small-scale artisanal gold mining in Ghana. *Science of the Total Environment*, 781, 146644.
- Basu, N., Clarke, E., Green, A., Calys-Tagoe, B., Chan, L., Dzodzomenyo, M., Fobil, J., Long, R. N., Neitzel, R. L., & Obiri, S. (2015). Integrated assessment of artisanal and small-scale gold mining in Ghana—Part 1: Human health review. *International Journal of Environmental Research and Public Health*, 12(5), 5143–5176.
- Belford, F. K. N. E. J., & NKANSAH, F. (2017). Heavy metals accumulation by indigenous plants growing in contaminated soil in a gold mining Area in Ghana. *J. of Nat. Sci. Research*, 7(24), 2224–3186.
- Bessah, E., Raji, A. O., Taiwo, O. J., Agodzo, S. K., Ololade, O. O., Strapasson, A., & Donkor, E. (2021a). Assessment of surface waters and pollution impacts in Southern Ghana. *Hydrology Research*, 52(6), 1423–1435.
- Bessah, E., Raji, A. O., Taiwo, O. J., Agodzo, S. K., Ololade, O. O., Strapasson, A., & Donkor, E. (2021b). Gender-based variations in the perception of climate change impact, vulnerability and adaptation strategies in the Pra River Basin of Ghana. *International Journal of Climate Change Strategies and Management*, 13(4/5), 435–462.
- Bhatti, S. S., Kumar, V., Sambyal, V., Singh, J., & Nagpal, A. K. (2018). Comparative analysis of tissue compartmentalized heavy metal uptake by common forage crop: A field experiment. *Catena*, 160(November 2016), 185–193. <https://doi.org/10.1016/j.catena.2017.09.015>
- Biney, E., Mintah, B. A., Ankomah, E., Agbenorhevi, A. E., Yankey, D. B., & Annan, E. (2024). Sustainability assessment of groundwater in south-eastern parts of the western region of Ghana for water supply. *Cleaner Water*, 1, 100007.
- Boateng, D. O., Nana, F., Codjoe, Y., & Ofori, J. (2014). Impact of illegal small scale mining (Galamsey) on cocoa production in Atiwa district of Ghana. *Int J Adv Agric Res*, 2, 89–99.

- Bose-O'Reilly, S., McCarty, K. M., Steckling, N., & Lettmeier, B. (2010). Mercury exposure and children's health. *Current Problems in Pediatric and Adolescent Health Care*, 40(8), 186–215.
- Bryant, C., & Mitchell, M. I. (2021). The political ecology of cocoa in GHANA: Past, present and future challenges. *Natural Resources Forum*, 45(4), 350–365. <https://doi.org/10.1111/1477-8947.12232>
- Buss, D., & Rutherford, B. (2022). Gendering women's livelihoods in artisanal and small-scale mining: An introduction. In *The (In) Visibility of Women and Mining* (pp. 1–16). Routledge. <https://www.taylorfrancis.com/chapters/edit/10.4324/9781003245414-1/gendering-women-livelihoods-artisanal-small-scale-mining-introduction-doris-buss-blair-rutherford>
- Buss, D., Rutherford, B., Kumah, C., & Spear, M. (2021). Beyond the rituals of inclusion: The environment for women and resource governance in Africa's artisanal and small-scale mining sector. *Environmental Science & Policy*, 116, 30–37.
- Chaparro, C. M., & Suchdev, P. S. (2019). Anemia epidemiology, pathophysiology, and etiology in low- and middle- income countries. *Annals of the New York Academy of Sciences*, 1450(1), 15–31. <https://doi.org/10.1111/nyas.14092>
- Clifford, M. J. (2022). Artisanal and small-scale mining and the sustainable development goals: Why nobody cares. *Environmental Science & Policy*, 137, 164–173.
- Ghana Chamber of Mines (2023). Performance of the mining industry in 2023. Accessed <https://ghanachamberofmines.org/wp-content/uploads/2024/06/Performance-of-the-Mining-Industry-in-2023.pdf>
- Cobbina, S. J., Duwiejuah, A. B., Quansah, R., Obiri, S., & Bakobie, N. (2015). Comparative assessment of heavy metals in drinking water sources in two small-scale mining communities in Northern Ghana. *International Journal of Environmental Research and Public Health*, 12(9), 10620–10634. <https://doi.org/10.3390/ijerph120910620>
- Cossa, H., Scheidegger, R., Leuenberger, A., Ammann, P., Munguambe, K., Utzinger, J., Macete, E., & Winkler, M. S. (2021). Health studies in the context of artisanal and small-scale mining: A scoping review. *International Journal of Environmental Research and Public Health*, 18(4), 1555.
- Crawford, G., & Botchwey, G. (2016). Foreign involvement in small-scale gold mining in Ghana and its impact on resource fairness. In *Fairness and justice in natural resource politics* (pp. 193–

- 211). Routledge. <https://library.oapen.org/bitstream/handle/20.500.12657/46735/oa-9781317269885.pdf#page=194>
- Darko, H. F., Karikari, A. Y., Duah, A. A., Akurugu, B. A., Mante, V., & Teye, F. O. (2023). Effect of small-scale illegal mining on surface water and sediment quality in Ghana. *International Journal of River Basin Management*, 21(3), 375–386. <https://doi.org/10.1080/15715124.2021.2002345>
- Debrah, A. A., Watson, I., & Quansah, D. P. O. (2014). Comparison between artisanal and small-scale mining in Ghana and South Africa: Lessons learnt and ways forward. *Journal of the Southern African Institute of Mining and Metallurgy*, 114(11), 913–921.
- Dhaliwal, S. S., Singh, J., Taneja, P. K., & Mandal, A. (2020). Remediation techniques for removal of heavy metals from the soil contaminated through different sources: A review. *Environmental Science and Pollution Research*, 27(2), 1319–1333. <https://doi.org/10.1007/s11356-019-06967-1>
- Donkor, L. A. (2015). *Assessing the environmental and health impact of small-scale mining in the Amansie West District of Ashanti region, Ghana* [PhD Thesis]. <https://dspace.knust.edu.gh/bitstreams/54ee6d20-c73a-4599-aadf-8cfb1e4a0716/download>
- Douti, N. B., Amuah, E. E. Y., Abanyie, S. K., & Amanin-Ennin, P. (2021). Irrigation water quality and its impact on the physicochemical and microbiological contamination of vegetables produced from market gardening: A case of the Veia Irrigation Dam, UER, Ghana. *Journal of Water and Health*, 19(2), 203–215.
- Dwomoh, J., Ofori, S. A., Frimpong, D. K., Osei, C. N., Adongo, E., & Appiah, S. (2023). Invasive Plant Species in Ghana: Route of Spread, Socio-Economic and Environmental Impact. *Asian Journal of Environment & Ecology*, 20(4), 19–28.
- Eduful, M., Alsharif, K., Eduful, A., Acheampong, M., Eduful, J., & Mazumder, L. (2020). The illegal artisanal and small-scale mining (galamsey) ‘menace’ in Ghana: Is military-style approach the answer? *Resources Policy*, 68, 101732.
- Emmanuel, A. Y., Jerry, C. S., & Dzigbodi, D. A. (2018). Review of environmental and health impacts of mining in Ghana. *Journal of Health and Pollution*, 8(17), 43–52.
- Emmanuel Ababio Ofosu-Mensah. (2017). Historical and Modern Artisanal Small-Scale Mining in Akyem Abuakwa, Ghana. *Africa Today*, 64(2), 69. <https://doi.org/10.2979/africatoday.64.2.04>

- Ewusi, A., Tetteh, S. E. K., Seidu, J., & Ahenkorah, I. (2024). Hydrogeological risk assessment for mineral exploration in Ghana: A brief overview. *Scientific African*, e02218.
- Fernandes Azevedo, B., Barros Furieri, L., Peçanha, F. M., Wiggers, G. A., Frizera Vassallo, P., Ronacher Simões, M., Fiorim, J., Rossi de Batista, P., Fioresi, M., & Rossoni, L. (2012). Toxic effects of mercury on the cardiovascular and central nervous systems. *BioMed Research International*, 2012. <https://www.hindawi.com/journals/bmri/2012/949048/abs/>
- Fritz, M., McQuilken, J., Collins, N., & Weldegiorgis, F. (2022). *Global Trends in Artisanal and Small-Scale Mining (ASM): A review of key numbers and issues*. International Institute for Sustainable Development (IISD). <https://www.researchgate.net/profile/Fitsum-Semere-Weldegiorgis/amp>
- Gbedzi, D. D., Oforu, E. A., Mortey, E. M., Obiri-Yeboah, A., Nyantakyi, E. K., Siabi, E. K., Abdallah, F., Domfeh, M. K., & Amankwah-Minkah, A. (2022). Impact of mining on land use land cover change and water quality in the Asutifi North District of Ghana, West Africa. *Environmental Challenges*, 6, 100441.
- Gilbert, D., & Albert, O.-B. (2016). Illegal small-scale gold mining in Ghana: A threat to food security. *Journal of Food Security*, 4(5), 112–119.
- Gimmler, H., Carandang, J., Boots, A., Reisberg, E., & Woiatke, M. (2002). *Heavy metal content and distribution within a woody plant during and after seven years continuous growth on municipal solid waste (MSW) bottom slag rich in heavy metals*. <https://www.cabidigitallibrary.org/doi/full/10.5555/20033007991>
- Gorde, S. P., & Jadhav, M. V. (2013). Assessment of water quality parameters: A review. *J Eng Res Appl*, 3(6), 2029–2035.
- Gump, B. B., Dykas, M. J., MacKenzie, J. A., Dumas, A. K., Hruska, B., Ewart, C. K., Parsons, P. J., Palmer, C. D., & Bendinskas, K. (2017). Background lead and mercury exposures: Psychological and behavioral problems in children. *Environmental Research*, 158, 576–582.
- Gyamfi, E., Appiah-Adjei, E. K., & Adjei, K. A. (2019). Potential heavy metal pollution of soil and water resources from artisanal mining in Kokoteasua, Ghana. *Groundwater for Sustainable Development*, 8, 450–456.
- Gyimah, R. A. A., Gyamfi, C., Anornu, G. K., Karikari, A. Y., & Tsyawo, F. W. (2021). Multivariate statistical analysis of water quality of the Densu River, Ghana. *International Journal of River Basin Management*, 19(2), 189–199. <https://doi.org/10.1080/15715124.2020.1803337>

- Hadzi, G. Y., Essumang, D. K., & Adjei, J. K. (2015). Distribution and risk assessment of heavy metals in surface water from pristine environments and major mining areas in Ghana. *Journal of Health and Pollution*, 5(9), 86–99.
- Hanfi, M. Y., Mostafa, M. Y. A., & Zhukovsky, M. V. (2020). Heavy metal contamination in urban surface sediments: Sources, distribution, contamination control, and remediation. *Environmental Monitoring and Assessment*, 192(1), 32. <https://doi.org/10.1007/s10661-019-7947-5>
- Harari, A., Frenkel, A. L., Barshack, I., Sagee, A., Cohen, H., Kamari, Y., Harats, D., Kfir, M. K., & Shaish, A. (2020). Addition of fish oil to atherogenic high fat diet inhibited atherogenesis while olive oil did not, in LDL receptor KO mice. *Nutrition, Metabolism and Cardiovascular Diseases*, 30(4), 709–716.
- Hassen, I., Hamzaoui-Azaza, F., & Bouhlila, R. (2016a). Application of multivariate statistical analysis and hydrochemical and isotopic investigations for evaluation of groundwater quality and its suitability for drinking and agriculture purposes: Case of Oum Ali-Thelepte aquifer, central Tunisia. *Environmental Monitoring and Assessment*, 188(3), 135. <https://doi.org/10.1007/s10661-016-5124-7>
- Hassen, I., Hamzaoui-Azaza, F., & Bouhlila, R. (2016b). Application of multivariate statistical analysis and hydrochemical and isotopic investigations for evaluation of groundwater quality and its suitability for drinking and agriculture purposes: Case of Oum Ali-Thelepte aquifer, central Tunisia. *Environmental Monitoring and Assessment*, 188(3), 1–20. <https://doi.org/10.1007/s10661-016-5124-7>
- Hilson, G. (2002). An overview of land use conflicts in mining communities. *Land Use Policy*, 19(1), 65–73.
- Hilson, G., & Maconachie, R. (2020). Artisanal and small-scale mining and the Sustainable Development Goals: Opportunities and new directions for sub-Saharan Africa. *Geoforum*, 111, 125–141.
- Hilson, G., & McQuilken, J. (2014). Four decades of support for artisanal and small-scale mining in sub-Saharan Africa: A critical review. *The Extractive Industries and Society*, 1(1), 104–118.
- Hilson, G., Mondlane, S., Hilson, A., Arnall, A., & Laing, T. (2021). Formalizing artisanal and small-scale mining in Mozambique: Concerns, priorities and challenges. *Resources Policy*, 71, 102001.

- Hinton, J. (2006). *Communities and Small Scale Mining: An Integrated Review for Development Planning*, Report to the World Bank, 213 p. *Washington DC: Communities and Small-Scale Mining (CASM) Initiative*.
- Huff, M. D., Kumar, S., & Lee, J. W. (2014a). Comparative analysis of pinewood, peanut shell, and bamboo biomass derived biochars produced via hydrothermal conversion and pyrolysis. *Journal of Environmental Management*, *146*, 303–308.
- Huff, M. D., Kumar, S., & Lee, J. W. (2014b). Comparative analysis of pinewood, peanut shell, and bamboo biomass derived biochars produced via hydrothermal conversion and pyrolysis. *Journal of Environmental Management*, *146*, 303–308. <https://doi.org/10.1016/j.jenvman.2014.05.015>
- Huggins, C. (2016). Artisanal and small-scale mining: Critical approaches to property rights and governance. *Third World Thematics: A TWQ Journal*, *1*(2), 151–164. <https://doi.org/10.1080/23802014.2016.1233043>
- Islam, M. Z., Van Dao, C., Shiraishi, M., & Miyamoto, A. (2016). Methylmercury affects cerebrovascular reactivity to angiotensin II and acetylcholine via Rho-kinase and nitric oxide pathways in mice. *Life Sciences*, *147*, 30–38.
- Karakuş, C. B. (2019). Evaluation of groundwater quality in Sivas province (Turkey) using water quality index and GIS-based analytic hierarchy process. *International Journal of Environmental Health Research*, *29*(5), 500–519. <https://doi.org/10.1080/09603085.2019.1648888>
- Karikari, A. Y., Duah, A. A., Akurugu, B. A., & Darko, H. F. (2021). Assessing the impacts of artisanal mining on the quality of South-western Rivers System in Ghana. *Environmental Monitoring and Assessment*, *193*(11), 715. <https://doi.org/10.1007/s10661-021-09515-y>
- Karr, J. R., & Dudley, D. R. (1981). Ecological perspective on water quality goals. *Environmental Management*, *5*(1), 55–68. <https://doi.org/10.1007/BF01866609>
- Kazapoe, R. W., Addai, M. O., Amuah, E. E. Y., & Dankwa, P. (2024). Characterization of groundwater in southwest Ghana: Implications for sustainable agriculture and safe water supply in a mining-dominated zone. *Environmental and Sustainability Indicators*, *22*, 100341. <https://doi.org/10.1016/j.esi.2024.100341>
- Konadu Amoah, B., Dadzie, I., & Takyi-Kyeremeh, K. (2018). Integrating gravity and magnetic field data to delineate structurally controlled gold mineralization in the Sefwi Belt of Ghana. *Journal of Geophysics and Engineering*, *15*(4), 1197–1203.

- Kuffour, R. A., Tiimub, B. B. M., Manu, I., & Owusu, W. (2020a). *The effect of illegal mining activities on vegetation: A case study of Bontefufuo Area in the Amansie West District of Ghana*. <https://www.researchsquare.com/article/rs-29641/latest>
- Kuffour, R. A., Tiimub, B. B. M., Manu, I., & Owusu, W. (2020b). *The effect of illegal mining activities on vegetation: A case study of Bontefufuo Area in the Amansie West District of Ghana*. <https://www.researchsquare.com/article/rs-29641/latest>
- Kumah, R. (2022a). Artisanal and small-scale mining formalization challenges in Ghana: Explaining grassroots perspectives. *Resources Policy*, 79, 102978.
- Kumah, R. (2022b). Artisanal and small-scale mining formalization challenges in Ghana: Explaining grassroots perspectives. *Resources Policy*, 79, 102978.
- Kumi, S., Adu-Poku, D., & Attiogbe, F. (2023). Dynamics of land cover changes and condition of soil and surface water quality in a Mining–Altered landscape, Ghana. *Heliyon*, 9(7). [https://www.cell.com/heliyon/pdf/S2405-8440\(23\)05067-3.pdf](https://www.cell.com/heliyon/pdf/S2405-8440(23)05067-3.pdf)
- Kuroda, K., Nakada, N., Hanamoto, S., Inaba, M., Katayama, H., Do, A. T., Nga, T. T. V., Oguma, K., Hayashi, T., & Takizawa, S. (2015). Pepper mild mottle virus as an indicator and a tracer of fecal pollution in water environments: Comparative evaluation with wastewater-tracer pharmaceuticals in Hanoi, Vietnam. *Science of the Total Environment*, 506–507, 287–298. <https://doi.org/10.1016/j.scitotenv.2014.11.021>
- Lado, K., Sube, L., Daniel, J., Lako, W., Stephen, C., Lumori, G., Yengkopiong, J. P., Augustino, J., Utong, M., Binyason, S. A., Samuel, Y., Ngerja, L., Kalisto Moilinga, M., Lado, T. F., & Kheiralla, A. H. (2020). Diversity and distribution of medicinal plants in the republic of South Sudan. *World Journal of Advanced Research and Reviews*, 2020(01), 2581–9615. <https://doi.org/10.30574/wjarr>
- Lahiri-Dutt, K. (2018). *Between the plough and the pick: Informal, artisanal and small-scale mining in the contemporary world*. ANU Press. <https://books.google.com/bo>
- Lamb, J. C. (1985). *Water quality and its control*. Wiley New York. <https://www.academia.edu/d8>
- Lawer, E. A., Mupepele, A.-C., & Klein, A.-M. (2021). Artisanal mining impacts small mammals while chainsaw milling is a more sustainable practice in Ghana. *Biodiversity and Conservation*, 30(2), 295–310. <https://doi.org/10.1007/s10531-020-02089-0>
- Lee, M., Keller, A. A., Chiang, P. C., Den, W., Wang, H., Hou, C. H., Wu, J., Wang, X., & Yan, J. (2017). Water-energy nexus for urban water systems: A comparative review on energy

- intensity and environmental impacts in relation to global water risks. *Applied Energy*, 205, 589–601. <https://doi.org/10.1016/j.apenergy.2017.08.002>
- Li, P., He, S., Yang, N., & Xiang, G. (2018). Groundwater quality assessment for domestic and agricultural purposes in Yan'an City, northwest China: Implications to sustainable groundwater quality management on the Loess Plateau. *Environmental Earth Sciences*, 77(23), 1–16. <https://doi.org/10.1007/s12665-018-7968-3>
- Li, P., Wu, J., & Qian, H. (2016). Hydrochemical appraisal of groundwater quality for drinking and irrigation purposes and the major influencing factors: A case study in and around Hua County, China. *Arabian Journal of Geosciences*, 9(1), 1–17. <https://doi.org/10.1007/s12517-015-2059-1>
- Lipińska, D. (2016). Resource-efficient growth in the EU's sustainable development: A comparative analysis based on selected indicators. *Comparative Economic Research. Central and Eastern Europe*, 19(1), 101–117.
- Long, Z., Zhu, H., Bing, H., Tian, X., Wang, Z., Wang, X., & Wu, Y. (2021). Contamination, sources and health risk of heavy metals in soil and dust from different functional areas in an industrial city of Panzhihua City, Southwest China. *Journal of Hazardous Materials*, 420, 126638.
- Loubet, P., Roux, P., Loiseau, E., & Bellon-Maurel, V. (2014). Life cycle assessments of urban water systems: A comparative analysis of selected peer-reviewed literature. *Water Research*, 67(June), 187–202. <https://doi.org/10.1016/j.watres.2014.08.048>
- Lukhabi, D. K., Mensah, P. K., Asare, N. K., Akwetey, M. F. A., & Faseyi, C. A. (2024). Benthic macroinvertebrates as indicators of water quality: A case study of estuarine ecosystems along the coast of Ghana. *Heliyon*, 10(7). [https://www.cell.com/heliyon/fulltext/S2405-8440\(24\)04049-0](https://www.cell.com/heliyon/fulltext/S2405-8440(24)04049-0)
- Madhav, S., Ahamad, A., Kumar, A., Kushawaha, J., Singh, P., & Mishra, P. K. (2018a). Geochemical assessment of groundwater quality for its suitability for drinking and irrigation purpose in rural areas of Sant Ravidas Nagar (Bhadohi), Uttar Pradesh. *Geology, Ecology, and Landscapes*, 2(2), 127–136. <https://doi.org/10.1080/24749508.2018.14524>
- Madhav, S., Ahamad, A., Kumar, A., Kushawaha, J., Singh, P., & Mishra, P. K. (2018b). Geochemical assessment of groundwater quality for its suitability for drinking and irrigation purpose in rural areas of Sant Ravidas Nagar (Bhadohi), Uttar Pradesh. *Geology, Ecology, and Landscapes*, 2(2), 127–136. <https://doi.org/10.1080/24749508.2018.145248>

- Mamodu, A., Ojonimi, I. T., Apollos, S. S., Jacinta, O.-C. N., Salome, W. H., & Enesi, A. A. (2018). Analyzing the environmental impacts and potential health challenges resulting from artisanal gold mining in Shango area of Minna, North-Central, Nigeria. *Journal of Degraded and Mining Lands Management*, 5(2), 1055.
- Manu, E., De Lucia, M., & Kühn, M. (2023). Hydrochemical Characterization of Surface Water and Groundwater in the Crystalline Basement Aquifer System in the Pra Basin (Ghana). *Water*, 15(7), 1325.
- Martinez-Alier, J. (2003). *The Environmentalism of the poor: A study of ecological conflicts and valuation*. Edward Elgar Publishing. <https://books.google.com/books?hl=en&>
- Mensah, E. O., & Darku, E. D. (2021). The Impact of Illegal Mining on Public Health: A Case Study in Kenyasi, the Ahafo Region in Ghana. *Technium Soc. Sci. J.*, 23, 1.
- Meutia, A. A., Lumowa, R., & Sakakibara, M. (2022). Indonesian artisanal and small-scale gold mining—A narrative literature review. *International Journal of Environmental Research and Public Health*, 19(7), 3955.
- Miranda, M., Chambers, D., & Coumans, C. (2005). *Framework for responsible mining: A guide to evolving standards*. MiningWatch Canada. <https://ceaa-acee.gc.ca/B4777C6B-docs/WP-1785-034.pdf>
- Miserendino, R. A., Bergquist, B. A., Adler, S. E., Guimarães, J. R. D., Lees, P. S., Niquen, W., Velasquez-López, P. C., & Veiga, M. M. (2013). Challenges to measuring, monitoring, and addressing the cumulative impacts of artisanal and small-scale gold mining in Ecuador. *Resources Policy*, 38(4), 713–722.
- Miyittah, M. K., Tulashie, S. K., Tsyawo, F. W., Sarfo, J. K., & Darko, A. A. (2020). Assessment of surface water quality status of the Aby Lagoon System in the Western Region of Ghana. *Heliyon*, 6(7). [https://www.cell.com/heliyon/pdf/S2405-8440\(20\)31310-4.pdf](https://www.cell.com/heliyon/pdf/S2405-8440(20)31310-4.pdf)
- Mokarram, M., Saber, A., & Sheykhi, V. (2020). Effects of heavy metal contamination on river water quality due to release of industrial effluents. *Journal of Cleaner Production*, 277, 123380.
- Morante-Carballo, F., Montalván-Burbano, N., Aguilar-Aguilar, M., & Carrión-Mero, P. (2022). A bibliometric analysis of the scientific research on artisanal and small-scale mining. *International Journal of Environmental Research and Public Health*, 19(13), 8156.

- Musa, J. J., Mustapha, I. H., Kuti, I. A., Yerima, I. Y., Shaaba, U. M., & Manta, I. H. (2016). *Assessment of selected heavy metal presence in some dumpsites in Nigeria: A review*. <http://repository.futminna.edu.ng:8080/jspui/handle/123456789/16624>
- Obeng, S. (2015). *Effects of Illegal Small Scale Gold Mining Activities on the Environment: Case Study of Selected Communities in the Amansie West District*. [PhD Thesis, KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI]. https://www.academia.edu/download/38540256/S._Obeng_et_al_COMPLETE_PROJECT.pdf
- Odipe, O. E., Raimi, M. O., Deinkuro, N. S., Funmilayo, A. A., innocent Edewor, O.-P., Lateefat, H. M., & Fadeyibi, M. (2019). Assessment of environmental sanitation, food safety knowledge, handling practice among food handlers of Bukateria Complexes in Iju Town, Akure north of Ondo-State, Nigeria. *Acta Scientific Nutritional Health*, 3(6). https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3422457
- O’Faircheallaigh, C., & Corbett, T. (2016a). Understanding and improving policy and regulatory responses to artisanal and small scale mining. *The Extractive Industries and Society*, 3(4), 961–971.
- O’Faircheallaigh, C., & Corbett, T. (2016b). Understanding and improving policy and regulatory responses to artisanal and small scale mining. *Extractive Industries and Society*, 3(4), 961–971. <https://doi.org/10.1016/j.exis.2016.11.002>
- Ofei-Aboagye, E., Thompson, N. M., Al-Hassan, A., Akabzaa, T., & Ayamdoo, C. (2004). Putting miners first: Understanding the livelihoods context of small-scale and artisanal mining in Ghana. *A Report for the Centre for Development Studies*. Swansea: Swansea University. https://delvedatabase.org/uploads/resources/Putting-Miners-First-Understanding-the-Livelihoods-Context-of-Small-Scale-and-Artisanal-Mining-in-Ghana_190924_075712.pdf
- Opoku, P., Gikunoo, E., Arthur, E. K., & Foli, G. (2020). Removal of selected heavy metals and metalloids from an artisanal gold mining site in Ghana using indigenous plant species. *Cogent Environmental Science*, 6(1), 1840863. <https://doi.org/10.1080/2331184>
- Osman, N., Afele, J. T., Nimo, E., Gorleku, D. O., Ofori, L. A., & Abunyewa, A. A. (2022a). Assessing the Impact of Illegal Small-Scale Mining (Galamsey) on Cocoa Farming and Farmer Livelihood: A Case Study in the Amansie West District of Ghana. *Pelita Perkebunan (a Coffee and Cocoa Research Journal)*, 38(1), 70–82.

- Osman, N., Afele, J. T., Nimo, E., Gorleku, D. O., Ofori, L. A., & Abunyewa, A. A. (2022b). Assessing the Impact of Illegal Small-Scale Mining (Galamsey) on Cocoa Farming and Farmer Livelihood: A Case Study in the Amansie West District of Ghana. *Pelita Perkebunan (a Coffee and Cocoa Research Journal)*, 38(1), 70–82.
- Ostergren, R. C. (2011). *The Europeans: A geography of people, culture, and environment*. Guilford Press. <https://books.google.com/books?hl=en&lr=&id=y-1fwi>
- Otamonga, J.-P., & Poté, J. W. (2020). Abandoned mines and artisanal and small-scale mining in Democratic Republic of the Congo (DRC): Survey and agenda for future research. *Journal of Geochemical Exploration*, 208, 106394.
- Owusu-Nimo, F., Mantey, J., Nyarko, K. B., Appiah-Effah, E., & Aubynn, A. (2018). Spatial distribution patterns of illegal artisanal small scale gold mining (Galamsey) operations in Ghana: A focus on the Western Region. *Heliyon*, 4(2). [https://www.cell.com/heliyon/pdf/S2405-8440\(17\)32596-3.pdf](https://www.cell.com/heliyon/pdf/S2405-8440(17)32596-3.pdf)
- Owusu-Prempeh, N., Awuah, K. O., Abebrese, I. K., & Amaning, E. N. (2022). Analysis of the status and ecological risks of heavy metals contamination in artisanal and small-scale gold mine-spoils at the Atewa Forest Landscape, Ghana. *Scientific African*, 16, e01235.
- Owusu-Sekyere, E. (2013). *The buruli ulcer morbidity in the amansie West District of Ghana: A myth or a reality?* <http://www.udsspace.uds.edu.gh/handle/123456789/187>
- Paruchuri, Y., Siuniak, A., Johnson, N., Levin, E., Mitchell, K., Goodrich, J. M., Renne, E. P., & Basu, N. (2010). Occupational and environmental mercury exposure among small-scale gold miners in the Talensi–Nabdam District of Ghana’s Upper East region. *Science of the Total Environment*, 408(24), 6079–6085.
- Patel, P., Raju, N. J., Reddy, B. C. S. R., Suresh, U., Gossel, W., & Wycisk, P. (2016). Geochemical processes and multivariate statistical analysis for the assessment of groundwater quality in the Swarnamukhi River basin, Andhra Pradesh, India. *Environmental Earth Sciences*, 75(7), 1–24. <https://doi.org/10.1007/s12665-015-5108-x>
- Pellegrini, G., Ingrao, C., Camposeo, S., Tricase, C., Contò, F., & Huisingh, D. (2016). Application of water footprint to olive growing systems in the Apulia region: A comparative assessment. *Journal of Cleaner Production*, 112, 2407–2418. <https://doi.org/10.>

- Rahman, Z. (2020). An overview on heavy metal resistant microorganisms for simultaneous treatment of multiple chemical pollutants at co-contaminated sites, and their multipurpose application. *Journal of Hazardous Materials*, 396, 122682.
- Ramesh Kumar, K., & Anbazhagan, V. (2018). Analysis and assessment of heavy metals in soils around the industrial areas in Mettur, Tamilnadu, India. *Environmental Monitoring and Assessment*, 190(9), 519. <https://doi.org/10.1007/s10661-018-6899-5>
- Roan, P. (2023). *Muddy State Development in Ghana's Upper East Region: One Village, One Dam, and Its Effects on Smallholder Farmers in a Study Community* [PhD Thesis, Colorado State University]. <https://search.proquest.com/openview/652417e59813a>
- Ronchi, S., Salata, S., Arcidiacono, A., Piroli, E., & Montanarella, L. (2019). Policy instruments for soil protection among the EU member states: A comparative analysis. *Land Use Policy*, 82, 763–780. <https://doi.org/10.1016/j.landusepol.2019.01.017>
- Salati, L. K., Mireku-Gyimah, D., & Eshun, P. A. (2014). Evaluation of stakeholders' roles in the management of artisanal and small-scale gold mining in Anka, Zamfara state, Nigeria. *Developing Country Studies*, 4(19), 150-161–161.
- Santos, R. E. dos, Santos, I. F. S. dos, Barros, R. M., Bernal, A. P., Tiago Filho, G. L., & Silva, F. das G. B. da. (2019). Generating electrical energy through urban solid waste in Brazil: An economic and energy comparative analysis. *Journal of Environmental Management*, 231(October 2018), 198–206. <https://doi.org/10.1016/j.jenvman.2018.10.015>
- Scaini, A., Sánchez, N., Vicente-Serrano, S. M., & Martínez-Fernández, J. (2015). SMOS-derived soil moisture anomalies and drought indices: A comparative analysis using in situ measurements. *Hydrological Processes*, 29(3), 373–383. <https://doi.org/10.1002/hyp.10150>
- Schudel, G., Kaplan, R., Miserendino, R. A., Veiga, M. M., Velasquez-López, P. C., Guimarães, J. R. D., & Bergquist, B. A. (2019). Mercury isotopic signatures of tailings from artisanal and small-scale gold mining (ASGM) in southwestern Ecuador. *Science of the Total Environment*, 686, 301–310.
- Schwartz, F. W., Lee, S., & Darrah, T. H. (2021). A Review of Health Issues Related to Child Labor and Violence Within Artisanal and Small- Scale Mining. *GeoHealth*, 5(2), e2020GH000326. <https://doi.org/10.1029/2020GH000326>
- Ghana Statistical Service (GSS) (2021). *Population and Housing Census. District Report*. Accra-Ghana.

- Shaibu, A.-G. (2024). *Assessing the Challenges of Crop Water Requirements on Agricultural Productivity and Food Security in Ghana: An Empirical Review*.
<http://publish.sub7journal.com/id/eprint/1969>
- Sherman, L. S., Blum, J. D., Basu, N., Rajaei, M., Evers, D. C., Buck, D. G., Petrlik, J., & DiGangi, J. (2015). Assessment of mercury exposure among small-scale gold miners using mercury stable isotopes. *Environmental Research*, *137*, 226–234.
- Tahiru, A. A., Doke, D. A., & Baatuuwie, B. N. (2020). Effect of land use and land cover changes on water quality in the Nawuni Catchment of the White Volta Basin, Northern Region, Ghana. *Applied Water Science*, *10*(8), 198. <https://doi.org/10.1007/s13201-020-01272-6>
- Takyi, R., Hassan, R., El Mahradi, B., & Adade, R. (2021). Socio-ecological analysis of artisanal gold mining in west Africa: A case study of Ghana. *Journal of Sustainable Mining*, *20*(3), 206–219.
- Talbert-Slagle, K., Ajami, I., Currey, B., Galvao, R., Hadush, J., Li, S. S., Flowers, J. T., Ziah, M., Amuh, D., & Rabb, M. (2023). Transforming medical education in Liberia through an international community of inquiry. *PLOS Global Public Health*, *3*(3), e0001610.
- Tarras-Wahlber, N. H., Flachier, A., Fredriksson, G., Lane, S., Lundberg, B., & Sangfors, O. (2000). Environmental impact of small-scale and artisanal gold mining in southern Ecuador: Implications for the setting of environmental standards and for the management of small-scale mining operations. *Ambio*, *29*(8), 484–491. <https://doi.org/10.1579/0044-7447-29.8.484>
- Taylor, B.N. (1995). *Guide for the use of the International System of Units (SI)*. NIST Special Publication 811, 1995 Edition. Washington, DC, America
- Tebbutt, T. H. Y. (1997). *Principles of water quality control*. Elsevier.
https://books.google.com/books?hl=en&lr=&id=J25QfcD5eF8C&oi=fnd&pg=PP1&dq=Water+Quality+&ots=xzjH8LB1gf&sig=_G0n06ciCyE8vz15Wc95C_FDOoE
- Thomas, M. J., Veiga, M. M., Marshall, B. G., & Dunbar, W. S. (2019). Artisanal gold supply chain: Measures from the Ecuadorian Government. *Resources Policy*, *64*, 101505.
- Tschakert, P., & Singha, K. (2007). Contaminated identities: Mercury and marginalization in Ghana's artisanal mining sector. *Geoforum*, *38*(6), 1304–1321.
- Tyagi, S., Sharma, B., Singh, P., & Dobhal, R. (2013). Water quality assessment in terms of water quality index. *American Journal of Water Resources*, *1*(3), 34–38.

- Velásquez, J. R., Schwartz, M., Phipps, L. M., Restrepo-Baena, O. J., Lucena, J., & Smits, K. M. (2022). A review of the environmental and health implications of recycling mine tailings for construction purposes in artisanal and small-scale mining communities. *The Extractive Industries and Society*, 9, 101019.
- Verbrugge, B., & Thiers, R. (2021). Artisanal and small-scale mining. In *Handbook of Critical Agrarian Studies* (pp. 401–409). Edward Elgar Publishing.
<https://www.elgaronline.com/abstract/edcoll/9781788972451/9781788972451.00055.xml>
- Wang, P. Q. (2024). Personalizing guest experience with generative AI in the hotel industry: There's more to it than meets a Kiwi's eye. *Current Issues in Tourism*, 1–18.
<https://doi.org/10.1080/13683500.2023.2300030>
- Wang, Q., & Li, W. (2017). A GIS-based comparative evaluation of analytical hierarchy process and frequency ratio models for landslide susceptibility mapping. *Physical Geography*, 38(4), 318–337. <https://doi.org/10.1080/02723646.2017.1294522>
- Yen, Y.-P., Tsai, K.-S., Chen, Y.-W., Huang, C.-F., Yang, R.-S., & Liu, S.-H. (2012). Arsenic induces apoptosis in myoblasts through a reactive oxygen species-induced endoplasmic reticulum stress and mitochondrial dysfunction pathway. *Archives of Toxicology*, 86(6), 923–933.
<https://doi.org/10.1007/s00204-012-0864-9>
- Zango, M. S., Pelig-Ba, K. B., Anim-Gyampo, M., Gibrilla, A., & Abu, M. (2024). Quality and health risk assessment of trace elements in groundwater within the Veia catchment of the Upper East Region, Ghana. *International Journal of Energy and Water Resources*.
<https://doi.org/10.1007/s42108-023-00274-9>
- Zhang, Z., Wang, X., Cheng, S., Sun, L., Son, Y.-O., Yao, H., Li, W., Budhraj, A., Li, L., & Shelton, B. J. (2011). Reactive oxygen species mediate arsenic induced cell transformation and tumorigenesis through Wnt/ β -catenin pathway in human colorectal adenocarcinoma DLD1 cells. *Toxicology and Applied Pharmacology*, 256(2), 114–121.
- Zvarivadza, T. (2018). Artisanal and Small-Scale Mining as a challenge and possible contributor to Sustainable Development. *Resources Policy*, 56, 49–58.

APPENDICES

Results on heavy metal concentration in Datano water source

LABELS	As mg/kg	Cd mg/kg	Cu mg/kg	Hg mg/kg	Pb mg/kg	Fe mg/kg
DSW1	0.945	0.005	1.231	29.002	0.223	2.671
DSW2	0.922	0.007	1.050	31.404	0.216	3.563

DWW1	0.834	0.003	0.783	32.506	0.247	2.080
DWW2	0.881	0.004	0.893	30.001	0.087	2.072
DBW1	0.691	0.002	0.591	27.860	0.058	1.947
DBW2	0.734	0.001	0.672	28.041	0.090	2.001
WHO/MPL	0.01	0.03	2.00	0.002	0.01	0.01

Results on heavy metal concentration in Datano soil and sediments samples

LABLES	As mg/kg	Cd mg/kg	Cu mg/kg	Hg mg/kg	Pb mg/kg	Fe mg/kg
DSS1	2.321	1.431	2.659	37.356	1.590	4.651
DSS2	2.003	1.040	2.076	39.126	1.476	4.320
DSDS1	3.710	1.563	3.006	40.457	1.983	5.871
DSDS2	3.562	1.782	3.538	41.075	2.007	5.318
WHO/MPL	1-40	0.8	36	0.50	85	0.30

Results on heavy metal concentration in Keniogo water source

LABLES	As mg/kg	Cd mg/kg	Cu mg/kg	Hg mg/kg	Pb mg/kg	Fe mg/kg
KSW1	2.452	0.089	2.003	35.046	1.932	3.020
KSW2	2.845	0.673	2.450	34.567	1.832	3.321
KWW1	3.812	0.216	2.001	33.053	1.021	2.412
KWW2	3.020	0.471	2.006	32.432	1.087	2.092
KBW1	1.592	0.909	1.932	26.238	0.097	2.031
KBW2	1.231	0.743	1.074	25.003	0.513	1.521
WHO/MPL	0.01	0.03	2.00	0.002	0.01	0.01

Results on heavy metal concentration in Keniogo soil and sediments samples

LABLES	As mg/kg	Cd mg/kg	Cu mg/kg	Hg mg/kg	Pb mg/kg	Fe mg/kg
KSS1	2.780	0.887	4.233	40.124	2.441	3.110
KSS2	2.236	0.767	4.127	40.578	2.651	3.921

KSDS1	3.040	1.330	5.610	44.150	2.064	4.052
KSDS2	3.111	1.245	5.760	43.438	2.732	4.339
WHO/MPL	1-40	0.8	1.66	0.50	2.0	0.30

Results on heavy metal concentration in Tontokrom water source

LABLES	As mg/kg	Cd mg/kg	Cu mg/kg	Hg mg/kg	Pb mg/kg	Fe mg/kg
TSW1	1.002	2.432	1.291	38.124	2.214	3.060
TSW2	1.010	1.999	1.009	37.002	2.436	2.932
TWW1	0.924	1.781	1.020	34.671	1.876	2.101
TWW2	0.995	1.543	0.991	35.908	1.992	2.003
TBW1	0.721	1.070	1.003	31.142	1.002	1.113
TBW2	0.628	1.811	0.995	29.583	1.001	1.050
WHO/MPL	0.01	0.03	2.00	0.002	0.01	0.01

Results on heavy metal concentration in Tontokrom soil and sediments samples

LABLES	As mg/kg	Cd mg/kg	Cu mg/kg	Hg mg/kg	Pb mg/kg	Fe mg/kg
TSS1	2.990	1.110	3.107	43.881	1.771	2.115
TSS2	2.842	1.982	3.409	44.609	1.540	2.540

TSDS1	3.881	1.213	4.337	47.555	2.329	3.190
TSDS2	3.742	1.715	4.255	46.254	2.233	3.812
WHO/MPL	1-40	0.8	1.6	0.50	2.0	0.30

Results on heavy metal concentration in Adubia water source

LABLES	As mg/kg	Cd mg/kg	Cu mg/kg	Hg mg/kg	Pb mg/kg	Fe mg/kg
ASW1	0.556	0.023	0.853	28.004	0.684	1.994
ASW2	0.732	0.068	0.772	29.524	0.519	1.956
AWW1	0.693	0.014	0.541	30.171	0.652	1.688
AWW2	0.599	0.092	0.624	31.224	0.486	1.745
ABW1	0.478	0.033	0.379	28.325	0.279	0.992
ABW2	0.368	0.042	0.455	27.332	0.385	0.936
WHO/MPL	0.01	0.03	2.00	0.002	0.01	0.01

Results on heavy metal concentration in Adubia soil and sediments samples

LABLES	As mg/kg	Cd mg/kg	Cu mg/kg	Hg mg/kg	Pb mg/kg	Fe mg/kg
ASS1	2.255	1.715	1.580	42.744	0.590	3.070
ASS2	2.015	1.233	1.176	40.126	0.476	3.241

ASDS1	3.009	1.910	2.010	46.222	0.983	3.819
ASDS2	3.100	1.430	2.090	47.313	0.985	3.318
WHO/MPL	1-40	0.8	1.6	0.50	2.0	0.30

Results on heavy metal concentration in Odaho water source

LABLES	As mg/kg	Cd mg/kg	Cu mg/kg	Hg mg/kg	Pb mg/kg	Fe mg/kg
OSW1	1.350	0.009	0.981	29.812	0.342	2.030
OSW2	1.221	0.008	1.020	32.450	0.318	1.739
OWW1	1.001	0.002	0.881	27.561	0.348	1.001
OWW2	0.993	0.006	0.794	30.380	0.283	1.004
OBW1	0.853	0.004	0.630	28.874	0.158	0.456
OBW2	0.950	0.003	0.770	29.205	0.230	0.623
WHO/MPL	0.01	0.03	2.00	0.002	0.01	0.01

Results on heavy metal concentration in Odaho soil and sediments samples

LABLES	As mg/kg	Cd mg/kg	Cu mg/kg	Hg mg/kg	Pb mg/kg	Fe mg/kg
OSS1	2.532	0.765	1.988	39.721	1.489	1.932
OSS2	2.605	0.631	1.876	38.995	1.215	1.882
OSDS1	2.798	0.890	2.055	44.389	2.006	2.345
OSDS2	3.002	0.944	2.132	43.317	2.031	2.616
WHO/MPL	1-40	0.8	1.6	0.50	2.0	0.30

Results on heavy metal concentration in Nipankeremia water source as a control experiment

LABLES	As mg/kg	Cd mg/kg	Cu mg/kg	Hg mg/kg	Pb mg/kg	Fe mg/kg
NSW1	0.005	0.004	0.009	6.542	0.023	0.050

NSW2	0.004	0.003	0.008	5.126	0.031	0.031
NWW1	0.003	0.002	0.007	4.070	0.067	0.011
NWW2	0.003	0.005	0.005	3.235	0.080	0.014
NBW1	0.002	0.001	0.004	2.620	0.018	0.021
NBW2	0.001	0.003	0.002	3.341	0.020	0.013
WHO/MPL	0.01	0.03	2.00	0.002	0.01	0.01

Results on heavy metal concentration in Nipankeremia soil and sediments samples as a control experiment

LABLES	As mg/kg	Cd mg/kg	Cu mg/kg	Hg mg/kg	Pb mg/kg	Fe mg/kg
OSS1	0.002	0.004	0.005	7.067	0.008	0.070
OSS2	0.001	0.003	0.003	8.365	0.009	0.060
OSDS1	0.004	0.002	0.006	9.054	0.020	0.080
OSDS2	0.005	0.003	0.007	9.021	0.030	0.090
WHO/MPL	1-40	0.8	1.6	0.50	2.0	0.30

