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A ecological study of galamsey activities in Ghana and their physiological toxicity

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ABSTRACT

Background: Small-Scale Small-Scale Gold Mining (ASGM), locally known as "galamsey," has emerged as a pervasive issue in Ghana characterized with environmental degradation, land and water resource depletion, health hazards for miners, social and economic impacts. This comprehensive review explores the ecological and health effects of galamsey operations across different regions of the country. **Methods:** The study employs a systematic analysis method to examine the available literature from 2000 to 2023. Various academic databases, including PubMed, Google Scholar, JSTOR, and relevant government publications, were searched to gather relevant information. **Findings:** The review reveals that galamsey has had significant ecological consequences, including deforestation, habitat destruction, water pollution, and soil degradation, which have adversely affected Ghana's natural beauty. Moreover, the study highlights the physiological health issues faced by galamsey miners, such as accidents, physical strain, mental strain, kidney problems, respiratory disorders, and metabolic diseases. The presence of elevated levels of mercury, cyanide, arsenic, and cadmium in both the environment and the human body are directly linked to ASGM in Ghana. About seventy percent (70%) of the houses in ASGM community relied on surface water, and all of the homes utilized the fields or bush as their main toilet. **Conclusion:** Implementing remote sensing, geospatial technologies, promoting clean mining technologies, integrating environmental conservation, occupational safety and public health awareness are key technical and innovative measures to mitigate galamsey in Ghana. **Novelty/Originality of this article:** This study proposes an integrated approach to address the impacts of galamsey, combining remote sensing and geospatial technologies with public health and environmental conservation programs. The model can provide a comprehensive understanding of the spatial and temporal impacts of ASGM and enable more targeted interventions.

KEYWORDS: galamsey; illegal mining; physiological health and ghana; small scale gold mining.

1. Introduction

Galamsey, a phrase derived from Ghana's Akan language that combines "gather" and "sell," has emerged as a prominent feature of the country's economic and environmental

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landscape (Osman et al., 2022). In recent years, the environmental impact of illegal small-scale gold mining, commonly known as "galamsey," has become a growing concern worldwide. Galamsey activities involve the extraction of gold from deposits using rudimentary methods that often result in significant ecological degradation and the release of toxic substances into the environment. Across the globe, numerous countries face comparable challenges associated with unregulated artisanal and small-scale mining operations. For instance, countries such as Brazil (Bruno et al., 2020; Lobo et al., 2016), Colombia, Indonesia (Bruno et al., 2020), and the Democratic Republic of Congo (Geenen, 2012; Hayes & Perks, 2012; Otamonga & Poté, 2020) have grappled with the adverse environmental consequences of informal mining activities. These regions share common characteristics with Ghana, including the prevalence of galamsey-like practices, limited government oversight, and inadequate enforcement of environmental regulations.

These small-scale mining operations, which are usually carried out without legal authorization, provide a living for many Ghanaians, particularly in rural regions where official employment opportunities are limited (Kumah, 2022). Despite its informal character, the galamsey industry contributes significantly to Ghana's gold output, elevating the country to the world's top gold producer (Crawford & Botchwey, 2016). The revenue generated from this sector, although unregulated, has tangible implications for the national economy (Gilbert & Albert, 2016).

Galamsey's history may be traced back to pre-colonial and colonial eras, when artisanal mining was popular. It was an important component of the local economy and culture (Mabe et al., 2021). However, galamsey has seen considerable changes in recent decades. This surge can be attributed to a range of factors, including economic pressures, fluctuations in global gold prices, and a lack of alternative employment opportunities (O'Faircheallaigh & Corbett, 2016).

These operations are prevalent throughout the country, with concentrated activity in mineral-rich regions like Western, Ashanti and Eastern Ghana. However, galamsey has serious environmental and health effects underneath the economic surface (Bansah et al., 2018). It causes deforestation, habitat destruction, water pollution, soil degradation, and biodiversity loss, all of which have a negative influence on Ghana's natural resources (Dwomoh et al., 2023). Miners suffer considerable occupational health risks, including exposure to hazardous compounds such as mercury and cyanide used in gold extraction, which can lead to a variety of health problems (Baddianaah et al., 2022). Mental health concerns among miners, stemming from harsh working conditions and job uncertainty, are also prevalent (Ofei-Aboagye et al., 2004). Local populations around galamsey sites face health risks as a result of water pollution from mining activities, which affects drinking water supplies and agriculture (Ayamba et al., 2017). These groups also face socioeconomic and psychological challenges. The Ghanaian government has put measures in place to address these problems, although their efficiency and implementation remain debatable (Nyame & Grant, 2014). The purpose of this review is to provide comprehensive information on the ecological destruction and physiological health effect as a result of galamsey activities in Ghana.

2. Methods

Extensive research was conducted to gather relevant publications and articles on the ecological and health implications of galamsey activities in Ghana. The search was carried out between 2000 and 2023 and several electronic databases were selected to cover a wide range of disciplines and research areas, including PubMed, Scopus, Web of Science, and Google Scholar. These databases were chosen for their extensive coverage of scientific literature in the fields of environmental science, public health, toxicology, mining, and related disciplines.

A combination of keywords and controlled vocabulary was used to construct search queries. The keywords and phrases encompassed various aspects of the topic, including "galamsey," "illegal mining," "Ghana," "ecological impact," "physiological toxicity," and "physiological Health". The search queries were adapted to the specific syntax and requirements of each database. Truncation and Boolean operators (e.g., and, or) were utilized to expand or narrow down the search results, as appropriate.

Inclusion criteria were established to ensure the selection of articles and studies that directly addressed the ecological impact of galamsey activities in Ghana and their physiological toxicity. Relevant criteria included studies published in peer-reviewed journals, research articles, review articles, and reports from reputable organizations. Articles and studies that focused on other forms of mining activities or were not specific to the Ghanaian context were excluded from consideration. Similarly, studies that did not investigate the ecological impact or physiological toxicity associated with galamsey were excluded. The literature selection prioritized studies with methodologies, including field surveys, laboratory analysis, and empirical data collection.

The initial literature search was conducted using the defined search queries and filters to retrieve relevant articles and studies. The search was conducted independently by different researchers to ensure consistency and minimize bias. Duplicate records were removed using reference management software, and the remaining records were screened based on titles and abstracts. The selected articles proceeded to the full-text review stage. The full-text review involved a careful assessment of the selected articles to determine their relevance to the research objectives. Articles that met the inclusion criteria were retained for data extraction and synthesis. The final selection of literature was made based on consensus between the researchers after discussing any discrepancies or disagreements during the review process. To ensure completeness, a supplementary search was conducted by reviewing the reference lists of the selected articles and performing a citation search on key papers. This process aimed to identify additional relevant studies that may have been missed in the initial search. The supplementary search helped uncover older or seminal studies that might have been missed in the initial search, ensuring the inclusion of comprehensive and foundational literature on the topic. A total of 81 studies were found and 16 met the inclusion criteria and were selected for data extraction and synthesis. These papers encompassed a range of study designs, including empirical research, case studies, and review articles.

The review encompasses studies conducted across multiple regions of Ghana to capture the health effects of galamsey operations across the country. Specifically, studies from various regions, including but not limited to Ashanti, Eastern, Western, Central, Ahafo, Bono, Northern and upper East Region were included in the analysis. The selection aimed to provide a comprehensive understanding of the health impacts associated with galamsey operations in different regions of Ghana.

3. Results and Discussion

3.1 Environmental impact of galamsey activities in Ghana

On a worldwide basis, artisanal and small-scale gold mining (ASGM) operations provide around 350 metric tons of gold each year, accounting for nearly 15% of total global gold output (Mensah & Darku, 2021). ASGM is practiced directly by up to 15 million people globally, with an additional 80 to 100 million people relying on ASGM for at least a portion of their income (Bondah et al., 2020). Many of these artisanal gold miners come from economically and socially disadvantaged families (Mensah & Tuokuu, 2023). ASGM operations often include small groups of people, frequently from rural and immigrant populations, who process a limited amount of ore in a narrow geographic region (Bondah et al., 2020). In some instances, these operations may be conducted illegally (Fisher et al., 2015) . Although ASGM has traditionally been associated with low-impact techniques such as gold panning, it now frequently involves more modern methods (Bondah et al., 2020). Galamsey activities in Ghana are not limited to a particular region; they have spread throughout a large percentage of the country, impacting both regions and individual districts within them. These illicit mining activities have left an unmistakable imprint on Ghana's biological ecosystem, with each area and district facing its own set of issues.

Galamsey activities in the Ashanti Region, particularly in districts like Obuasi, Amansie West, and Atwima Mponua, have led to extensive deforestation, soil degradation, and water pollution (Donkor, 2015; Kuffour et al., 2020). The region has been significantly impacted ecologically, as documented in numerous field studies (Akyeampong & Xu, 2023; Donkor, 2015; Osman et al., 2022). In the Western Region, districts such as Tarkwa-Nsuaem, Prestea-Huni Valley, and Wassa Amenfi East, which are rich in mineral resources, have witnessed extensive galamsey operations. This has resulted in profound deforestation, water contamination, and disruption of local ecosystems (Owusu-Nimo et al., 2018). The prevalence of galamsey in Ghana's Central Region, particularly in Assin North, Mfantseman, and Gomoa West, has jeopardized the cocoa and wood sectors. Water pollution and habitat devastation have grown widespread, threatening vital natural resources (Donkor et al., 2023). Mining activities in districts like Kwahu West, Birim Central, and Atiwa have led to a loss of biodiversity in the Eastern Region's forests and wildlife habitats, while soil degradation poses significant challenges to local agriculture. This regional ecological impact has been documented in studies (Boateng et al., 2014; Nyantakyi-Frimpong et al., 2023). The Upper East Region, with districts such as Bawku West, Bongo, and Builsa North, has experienced soil degradation and the loss of fertile land (Ayamba et al., 2017). The distribution of illegal mining at the district level in Ghana can be seen in Figure 1.

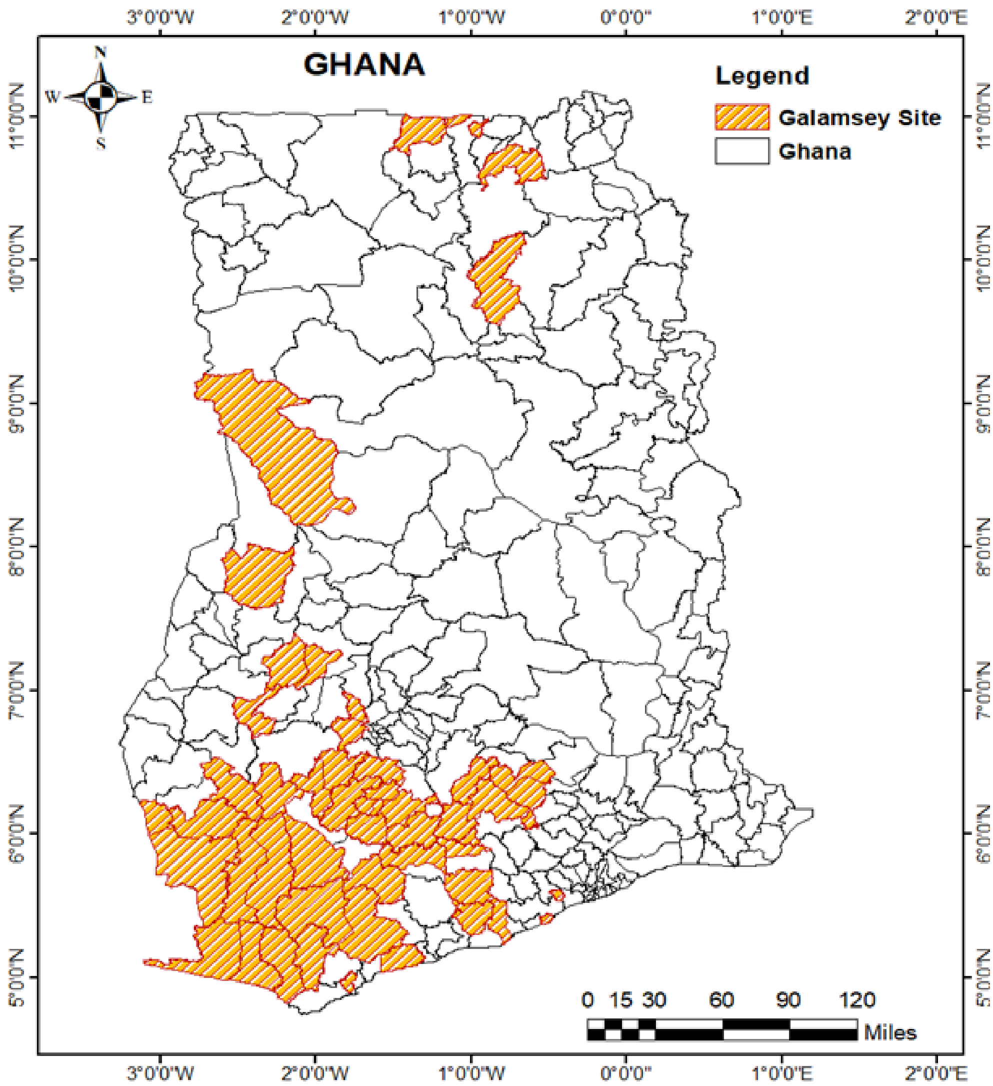

Fig. 1. District level distribution of illegal mining in Ghana

Contamination of water bodies from mining is a pressing issue in districts like Bibiani-Anhwiaso-Bekwai, Bodi, and Juabeso. The effects are felt by local communities and the region's ecosystems, necessitating urgent environmental protection efforts (Eduful et al., 2020; Owusu-Nimo et al., 2018). The Ahafo Region, rich in gold deposits, has become a hub for galamsey operations, causing deforestation and habitat destruction. This has far-reaching effects on natural resources and local economies, especially in districts like Asutifi North, Tano South, and Sunyani West (Arah, 2015). Emerging galamsey activities in districts like West Gonja, Central Gonja, and Sawla-Tuna-Kalba in the Savannah Region are already resulting in consequences for local ecosystems and natural resources (Agariga et al., 2021; Alhassan et al., 2022; Alhassan, 2014; Gilbert & Albert, 2016; Owusu-Nimo et al., 2018). Findings of the Ecological Distribution and Toxicity of Galamsey Activity in Various Regions of Ghana can be seen in Table 1.

Table 1. Ecological Distribution and Toxicity Findings of Galamsey Activities in Different Regions of Ghana

Author(s)	Geographical Area	Ecological Distribution Effect	Summary of toxicity findings
Owusu-Nimo et al., 2018	Western Region	- Extensive deforestation and loss of habitat near mining sites - Impact on specific ecosystems (e.g., riverine habitats).	- High mercury levels in water bodies. - Health risks for miners.
Kuffour et al., 2020	Ashanti Region	- Soil degradation leading to localized ecological changes. - Impact on biodiversity within the region.	- Decline in agricultural productivity. - Respiratory issues among locals.
Nyantakyi-Frimpong et al., 2023	Eastern Region	- Habitat loss in specific forests and wildlife habitats. - Impact on flora and fauna distribution.	- NA
Donkor et al., 2023	Central Region	- Impact on Ghana's cocoa and timber industries within the region.	- Health effects among local cocoa farmers due to water contamination.
Ayamba et al., 2017	Upper East Region	- Spatial analysis of mining areas and their effects on the local ecology.	- Respiratory health issues among galamsey miners. - Mental health challenges.
Alhassan, 2014	Nationwide	- Summarizes the ecological distribution effects across various regions in Ghana.	- Aggregated health findings from multiple regions.

3.2 Deforestation and habitat destruction

The enormous deforestation and habitat damage caused by galamsey is one of the most visible repercussions in Ghana. Forests that were previously teeming with wildlife are being destroyed ceaselessly to make space for mining activities (Boateng et al., 2014). The removal of trees and vegetation causes the extinction of many plant and animal species, some of which are unique or endangered. As mining operations increase, these places become barren, degraded landscapes, affecting the composition and function of local ecosystems (Bryant & Mitchell, 2021). Mensah & Darku, 2021 and Owusu-Nimo et al., 2018 have found extensive deforestation in Ghana's Western and Ashanti regions. These studies also show how ecological disruptions have resulted in diminishing biodiversity in these areas (E. O. Mensah & Darku, 2021; Owusu-Nimo et al., 2018). The consequences of habitat destruction go beyond immediate environmental impacts; they extend to the disruption of ecosystems that many local communities depend on for their livelihoods, such as farming and traditional agriculture (Ayad & Bakkali, 2022). This loss of biodiversity can lead to a reduction in ecosystem services, which can have an impact on the well-being and resilience of these communities (Konadu Amoah et al., 2018).

3.3 Soil degradation and loss of biodiversity

Large amounts of land are frequently excavated and altered in galamsey operations. The disturbance created by these mining activities has the potential to significantly degrade soil. Topsoil removal, contamination with pollutants such as mercury and cyanide, and physical disturbance of the ground all lead to soil erosion and decreased fertility (Wireko-Gyebi et al., 2020). These challenges not only have an impact on agricultural output, but they also alter the equilibrium of local ecosystems. Konadu Amoah et al., (2018) has emphasized the impacts of soil degradation and biodiversity loss in Ghana's Ashanti region.

The findings demonstrate how the region's natural fabric is unraveling as a result of galamsey's damaging consequences (Konadu Amoah et al., 2018). Soil deterioration has a direct influence on local agriculture, making it impossible for people to survive on conventional farming. Furthermore, the loss of rich soil owing to mining activities has an impact on agriculture's long-term viability, providing food security concerns for the people (Baddianaah et al., 2022). In tandem with soil degradation, loss of biodiversity further compounds the ecological crisis caused by galamsey. Many native plant and animal species are on the verge of extinction or are already endangered as a result of habitat loss. According to a study conducted by Nyantakyi-Frimpong et al. in 2023, the decrease in biodiversity in the Eastern area has wide-ranging consequences that impact ecosystem services and disrupt the natural balance (Nyantakyi-Frimpong et al., 2023).

3.4 Water pollution

Water pollution resulting from illegal mining activities, known as galamsey, has led to severe contamination of major rivers such as Pra, Ankobra, and Birim. A considerable percentage of individuals residing in mining communities, approximately 4.8% of respondents, express grave concerns about water pollution (Bessah et al., 2021; Kuffour et al., 2020; Boateng et al., 2014). The use of hazardous substances like mercury and cyanide in artisanal and small-scale gold mining (ASGM) has gained notoriety. These chemicals are essential for separating gold from ore but have detrimental effects on water quality. Toxic substances from mining sites, referred to as "tailings," infiltrate rivers and groundwater, posing a significant threat (Gilbert & Albert, 2016).

Mercury, a heavy metal utilized to bind gold particles together, presents a particularly insidious problem. When released into water bodies, it undergoes a transformation into methylmercury, an extremely toxic form that accumulates in fish and other aquatic organisms. The consumption of contaminated fish can lead to mercury poisoning in humans, resulting in neurological and developmental issues, particularly in children (Mensah & Tuokuu, 2023). Cyanide, employed to dissolve gold, also carries its own risks.

Poor containment and management of cyanide waste can lead to disastrous spills, as witnessed in various mining accidents. Water contaminated with cyanide affects not only aquatic life but also the individuals who depend on these water sources (Owusu-Nimo et al., 2018). The increase in water pollution has contributed to the spread of water-borne diseases such as typhoid and hepatitis (Issahaku et al., 2017). Additionally, mercury exposure has been linked to neurological and kidney damage in affected populations. A significant factor contributing to this problem is the lack of regulation and oversight. Many small-scale mining operations operate informally, circumventing environmental standards.

Even when regulations are in place, they are often poorly enforced due to limited resources and corruption (Boahen & Owusu, 2023).

3.5 Loss of livelihoods

Illegal mining activities, known as galamsey, have resulted in the displacement of farmers and the destruction of cocoa farms, which are Ghana's most important cash crop. This has led to a decline in food crop production, posing a threat to food security. The depletion of forests due to mining has dramatically reduced the harvesting of non-timber forest products such as snails, honey, and firewood (Gilbert & Albert, 2016). Cocoa is a crucial source of income and a significant contributor to Ghana's economy, generating a substantial portion of its export revenue. However, galamsey has displaced cocoa farmers in many regions (Yen et al., 1995). The unregulated mining activities often result in the degradation of fertile farmland, rendering it unsuitable for cocoa cultivation. This further exacerbates the loss of livelihoods for cocoa farmers (Donkor et al., 2023). Displaced farmers not only experience a significant reduction in income but also face economic instability as they are compelled to seek alternative means of livelihood (Mensah & Darku, 2021).

Gallamsey not only impacts cocoa production but also disrupts the cultivation of food crops such as cassava, plantains, and yam. Mining activities pollute water bodies and contaminate the soil, leading to reduced crop yields and poor crop quality (Bessah et al., 2021). As food crop production declines, Ghana's food security is compromised. This poses a risk to the country's ability to adequately feed its population, potentially resulting in food shortages, higher prices, and increased food insecurity for vulnerable communities (Owusu-Nimo et al., 2018). Furthermore, galamsey contributes to widespread deforestation and the destruction of habItats, causing a significant decline in the availability of non-timber forest products (Roan, 2023). Local communities that traditionally depend on resources such as snails, honey, and firewood for income and sustenance are adversely affected. The scarcity of these resources limits their options for making a living. Additionally, the loss of forest resources erodes the traditional ecological knowledge of communities that have relied on these resources for generations (Akyeampong & Xu, 2023).

3.6 Physiological toxicity of mercury exposure

Many small-scale miners regularly use mercury to extract gold from ore, a method known as amalgamation. This method is preferred due to its simplicity, cost-effectiveness, wide availability, and a long-standing history of utilization in the region (Boamponsem et al., 2010). ASGM's expansion worldwide and the extensive utilization of mercury within this industry are expected to result in ASGM accounting for 37 percent of mercury emissions into the atmosphere on a global scale. This corresponds to the release of 727 tons of mercury into the atmosphere in 2023 (Doamekpor et al., 2019). In terms of overall world emissions, Sub-Saharan Africa is second only to East Asia. Mercury exists in both inorganic and organic forms (Dorleku et al., 2018). Inorganic mercury encompasses elemental metallic mercury (Hg0 or gaseous mercury) and oxidized mercury salts (Hg+ or Hg2+). In ASGM communities, exposure to elemental mercury primarily occurs during the burning of amalgam. The kidneys play an important role in the elimination of mercury in the human body, with mercury levels in urine being a generally acknowledged indicator of recent exposure (Li et al., 2014). Recent study using stable isotopes of mercury in ASGM miners supports the use of urine mercury as a biomarker for inorganic mercury exposure (Paruchuri et al., 2010). Organic mercury, on the other hand, is commonly found as methylmercury (MeHg). MeHg exposure is mostly connected to the eating of fish (Sherman et al., 2015), with the hepatobiliary system helping in mercury clearance. Mercury levels in hair or blood are recognized indicators of organic mercury exposure (Emmanuel et al., 2018).

ASGM miners may be exposed to mercury by both inhalation of burnt mercury and eating of contaminated seafood (Bempah & Ewusi, 2016). However, in the case of Ghana, mercury inhalation appears to be of greater relevance, as mercury content in Ghanaian fish, in ASGM communities, remains relatively low, as does the consumption of fish. Studies reported biomarker values in urine and hair in Ghana exceed guideline limits, with urinary mercury levels (indicative of elemental exposures) closely mirroring those observed in ASGM locations throughout the world (Emmanuel et al., 2018; Esdaile & Chalker, 2018; Nyantakyi-Frimpong et al., 2023). Children and fetuses are more vulnerable to the harmful effects of mercury and experience more serious symptoms. The main way they are exposed to mercury is by eating contaminated fish. Due to the increased sensitivity of the fetal brain to mercury, the FDA advises pregnant or breastfeeding women and children to avoid fish that have high levels of mercury, such as shark, king mackerel, tilefish, swordfish, and tuna (Park & Zheng, 2012).

Pathophysiological, Mercury attaches itself to sulfhydryl groups, and to a lesser extent, amide, carboxyl, and phosphoryl groups. This interaction disrupts the normal functioning of cellular enzymes and protein systems in the body. As a result, mercury can substantially impair the activity of enzymes, hinder membrane function, disrupt transport mechanisms, and affect structural proteins. Inhibition of choline acetyltransferase and catechol O-methyltransferase leads to hypertension (Mahaffey, 2005) and tachycardia as the results of deficiency of acetylcholine (Fernandes Azevedo et al., 2012). Following exposure, mercury salts induce early damage to the mucosa of the gastrointestinal tract and the proximal renal tubules. This damage occurs as a result of the direct oxidative impact of mercuric ions. Inorganic salts have limited ability to dissolve in lipids, which makes it difficult for them to pass through the blood-brain barrier. However, due to their slow elimination from the body, some degree of accumulation can still occur (Fernandes Azevedo et al., 2012). Organic mercury, specifically methylmercury, has an affinity for lipids and can distribute throughout various tissues, including the central nervous system (CNS). Studies have shown that the organic mercury deposits in the CNS undergo a conversion to inorganic mercury, which contributes to its toxic effects (Ratcliffe et al., 1996).

3.7 Physiological toxicity of cyanide exposure

The use of cyanide to dissolve gold from ore is a dangerous practice in artisanal and small-scale gold mining (ASGM). Miners commonly come into touch with this dangerous material, due to improper handling and disposal (Sherman et al., 2015). Cyanide exposure has significant health concerns ranging from minor symptoms to life-threatening outcomes (Doamekpor et al., 2019). Initial cyanide exposure is frequently followed by headaches and dizziness. These early warning indicators, while seemingly innocuous, are suggestive of more serious problems to come (Afriyie et al., 2023). Individuals may develop nausea and vomiting as their exposure continues. This stage is distinguished by an increasing sensation of discomfort and misery (Wiafe et al., 2022). The toxicity of cyanide can rapidly develop, causing respiratory distress marked by laborious breathing and a rising sensation of bewilderment and disorientation. Cyanide exposure can cause loss of consciousness in severe situations, and if left untreated, this can lead to death. Cyanide disrupts the body's ability to generate adenosine triphosphate (ATP), a vital molecule for cellular energy, leading to a rapid energy crisis within vital organs (Asare-Donkor et al., 2015; Fortin et al., 2010; O'Brien et al., 2011; Purser et al., 1984).

Immediate administration of cyanide antidotes, such as sodium thiosulfate or hydroxocobalamin, can counteract the toxic effects of cyanide. However, time is a critical factor, and any delay in treatment may reduce the likelihood of a successful outcome (Asare-Donkor et al., 2015). Regrettably, in the remote and often informal settings of galamsey operations, access to medical resources and knowledge is severely constrained. Miners who fall victim to cyanide poisoning in these regions frequently face a dearth of immediate medical assistance, amplifying the severity of their predicament (Asare-Donkor et al., 2015). Cyanide exposure in the context of galamsey activities is an urgent demand for safer and more controlled mining techniques. Its toxicity poses a severe danger to miners' health and well-being, emphasizing the necessity for quick action and the availability of suitable healthcare services (Adusei-Mensah et al., 2019).

3.8 Physiological toxicity of arsenic (As) exposure

Exposure to arsenic in galamsey (artisanal small-scale mining) sites can pose significant health risks. Arsenic is a toxic heavy metal that can enter the body through inhalation of dust or fumes, ingestion of contaminated water or food, or dermal contact. A study assessed urine samples from ASGM miners in different categories in southwest Ghana, including permanent large-scale miners, casual large-scale miners, and large-scale miners residing at various distances from the mine (Banunle et al., 2018). The results suggest a significant difference in As levels, with miners in closer proximity to the mine site exhibiting higher As concentrations in their urine. This pattern is consistent with the well-established understanding that proximity to mining activities is associated with increased exposure to environmental contaminants (Abrefah et al., 2011). It's important to note that the study didn't include a control group of non-miners from this region, making it challenging to draw definitive conclusions regarding the comparative risks of As exposure. In Tarkwa, urine samples were collected from Galamsey workers and non-Galamsey workers. The data indicates that Galamsey workers had higher urinary As levels compared to non-Galamsey workers, corroborating the notion that occupational exposure in Galamsey environments elevates the risk of As contamination (Boamponsem et al., 2010).

The study in Accra provides a control group for urinary As levels. Although the sample size for the control group was small, it serves as a reference point for evaluating the difference in As levels between the capital city and Galamsey areas (Arah, 2015). The research in Talensi District, Upper East Region of Ghana focused on small-scale artisanal miners from various locations. The findings reflect the impact of ASGM activities on As exposure in areas where these activities are prevalent (Paruchuri et al., 2010).

Prolonged exposure to inorganic arsenic leads to various cardiovascular disorders, including hypertension, ventricular arrhythmias, heart diseases and atherosclerosis. Arsenite, a form of arsenic, stimulates the production of reactive oxygen species (ROS) such as superoxides and hydrogen peroxide by activating nicotinamide adenine dinucleotide phosphate (NADPH) oxidase in the plasma membrane of vascular endothelial cells (Hu et al., 2020). ROS produced during arsenite exposure increase the expression of genes associated with atherosclerosis, such as heme oxygenase-1 (HO-1), monocyte chemo-attractant protein (MCP-1), and interleukin-6 (IL-6), which promote the attachment, penetration and migration of monocytes in vascular smooth muscle cells (VSMC) (Hu et al., 2020). Chronic arsenic exposure is associated with skin lesions, peripheral neuropathy, and cardiovascular diseases. It can also have detrimental impacts on the respiratory system, leading to chronic obstructive pulmonary disease (COPD) and bronchiectasis (Yen et al., 2012).

Moreover, arsenic interferes with multiple metabolic pathways, including those related to glucose metabolism, which can contribute to diabetes. It may also disrupt the endocrine system, impacting thyroid function. Arsenic exposure during pregnancy is linked to adverse birth outcomes, including low birth weight and developmental issues in children (Hu et al., 2020; Wang et al., 1996; Yen et al., 2012). Long-term exposure to arsenic leads to a decrease in the expression of PPAR-γ, which can result in reduced sensitivity to insulin. This reduced sensitivity to insulin is responsible for the development of type II diabetes in response to arsenic exposure. Arsenite replaces a phosphate group from adenosine triphosphate (ATP), forming ADP-arsenate. This alteration slows down glucose metabolism, disrupts energy production, and interferes with ATP-dependent insulin secretion (Ofori et al., 2023). Study on Heavy Metal Contamination in Samples from Different Regions in Ghana can be seen in table 2

Table 2. Studies on Heavy Metal Contamination in Samples from Various Regions in Ghana

Authors	Location	Type of Sample	Identify	Heavy Metal	
Abrefah et al., (2011)	Southwest Ghana	Urine	Mercury	Arsenic	
Adimado & Baah (2002)	Ankobra & Tano	Urine	Mercury	Arsenic	
Asante et al., (2007)	Tarkwa	Urine	Mercury	Arsenic	Cadmium
Asante et al., (2007)	Accra	Urine	Mercury		
Kwaansa-Ansah et al., (2010)	Dunkwa-on-Offin,	Urine	Mercury		
Paruchuri et al., 2010	Talensi-Nabdam District	Urine	Mercury	Arsenic	Cadmium
Anim et al., 2011	Pra River Basin	Hair	Mercury		
Donkor et al., 2006	Central and Ashanti Regions	Hair	Mercury		
Kwaansa-Ansah et al., 2010	Dunkwa-on-Offin	Hair	Mercury		Cadmium

3.9 Physiological toxicity of cadmium (Cd) exposure

A study highlighted higher Cd levels among small scale mine workers, reinforcing the potential occupational hazards associated with mining, including increased Cd exposure. The study in Accra provides a control group for Cd levels, offering a reference point for assessing the difference in Cd levels between the capital city and small scale mining areas (Asare-Donkor et al., 2015). The investigation into Cd exposure in this Talensi District, Upper East Region, involving small-scale artisanal miners from various locations, again demonstrates the potential health risks faced by ASGM miners (Paruchuri et al., 2010). Cadmium (Cd) is a heavy metal found in various environmental settings, with mining activities being one potential source of exposure. These metals have well-documented physiological effects on human health.

Cadmium exposure can lead to various physiological effects, primarily affecting the kidneys and bones. Long-term exposure to cadmium, often through inhalation or ingestion of contaminated water and food, can result in kidney damage and renal dysfunction (Islam et al., 2016). The accumulation of cadmium in the kidneys can lead to conditions like Itai-Itai disease, which is characterized by severe pain and deformities of the skeleton (Adusei-Mensah et al., 2019). Cadmium also has detrimental effects on the cardiovascular system, increasing the risk of hypertension, atherosclerosis, and cardiovascular disease. Furthermore, cadmium can interfere with calcium metabolism, potentially leading to osteoporosis and fractures. It has also been associated with adverse effects on lung function (McGinnis et al., 2013).

3.10 Respiratory diseases and lung conditions

Engaging in galamsey activities often exposes miners to fine airborne particles, dust, and toxic fumes, which can have adverse effects on their respiratory health. Silica dust, commonly found in gold-bearing rocks, can cause silicosis, a progressive and irreversible lung disease (Fortin et al., 2010). Living in inadequate conditions and constant exposure to dust increase the risk of respiratory infections, particularly in areas with limited access to healthcare. Silicosis is a prevalent and serious respiratory disease among galamsey miners, primarily caused by inhaling fine airborne particles containing crystalline silica, a common component of gold-bearing rocks (Banunle et al., 2018). Miners involved in crushing and grinding ore are at a higher risk of inhaling silica dust, which can lead to lung inflammation and scarring when deposited in the lungs (Wiafe et al., 2022). Silicosis is characterized by progressive and irreversible damage to lung tissue, reducing its elasticity and impairing its function (Sebiawu et al., 2020). Common symptoms include chronic cough, shortness of breath, chest pain, and in advanced cases, respiratory failure. Silicosis weakens the immune system, making miners more vulnerable to tuberculosis (TB), a dangerous co-infection (Afriyie et al., 2023; Esdaile & Chalker, 2018)

Living conditions that are inadequate and continuous exposure to dust and air pollution in galamsey work environments increase the risk of respiratory infections among miners. These infections pose numerous challenges (Esdaile & Chalker, 2018). Galamsey workers often reside in overcrowded and unhygienic settlements with poor ventilation, facilitating the transmission of respiratory pathogens (Esdaile & Chalker, 2018). Miners working in damp and poorly ventilated tunnels may encounter fungi and bacteria that can cause lung infections, especially if they already have lung damage from silicosis. Access to healthcare services is often limited or nonexistent in remote galamsey areas, exacerbating the severity of respiratory infections and leading to delayed or inadequate treatment (Yen et al., 2012).

4. Conclusions

In terms of the ecological impact on the environment, the study finds that Ghana's natural beauty has suffered significantly. Deforestation, habitat destruction, water pollution, and soil degradation have left lasting scars on the landscape. Environmental challenges are threatening local ecosystems and significant resources in regions such as Ashanti, Western, and Central.

The health of galamsey miners is a major concern on the human front. Accidents, physical strain, and the mental toll of their employment are all risks they confront. A number of health issues have been linked to ASGM in Ghana. Empirical evidence suggests elevated mercury and cyanide which leads to respiratory problems and other health issues. Exposures in employees and ASGM community members, as well as surrounding biotic and abiotic environmental factors. There is additional evidence that ASGM miners and community members are exposed to other heavy metals mobilized during the mining process, such as arsenic and cadmium. Studies revealed that in one ASGM community, 100% of households used bush or fields as their primary toilet facility, compared to only 18% in the broader Ghanaian population, 70% relied on surface water, 30% on sachet water, and alternative water sources were scarcely used.

These findings highlight the critical need for safer working conditions and improved miner protection. The effect of ecological and health issues resulting from galamsey calls for a swift and quick response. Implementing remote sensing, geospatial technologies, promoting clean mining technologies, integrating environmental conservation, occupational safety and public health awareness are key technical and innovative measures to mitigate galamsey in Ghana.

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The authors declare no conflict of interest.

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References

Adusei-Mensah, F., Essumang, D. K., Agjei, R. O., Kauhanen, J., Tikkanen-Kaukanen, C., & Ekor, M. (2019). Heavy metal content and health risk assessment of commonly patronized herbal medicinal preparations from the Kumasi metropolis of Ghana. *Journal of Environmental Health Science and Engineering, 17*(2), 609–618. https://doi.org/10.1007/s40201-019-00373-y

Afriyie, R. Z., Arthur, E. K., Gikunoo, E., Baah, D. S., & Dziafa, E. (2023). Potential health risk of heavy metals in some selected vegetable crops at an artisanal gold mining site: A case study at moseaso in the wassa amenfi west district of Ghana. *Journal of Trace Elements and Minerals*, 100075. https://doi.org/10.1016/j.jtemin.2023.100075

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. https://doi.org/10.1016/j.envc.2021.100209

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, 122*(448), 329-351. 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. https://doi.org/10.4314/tjs.v48i3.17

Alhassan, I. A. (2014). Galamsey and the making of a deep state in Ghana: Implications for national security and development. *Research on Humanities and Social Sciences, 4*(16), 47–56. https://www.academia.edu/download/87130929/234674063.pdf

Arah, I. K. (2015*). The impact of small-scale gold mining on mining communities in Ghana.* African Studies Asociation of Australasia and the Pacific (AFSAAP) 37th, Annual Conference-Dunedin-New Zealand-25-26 November 2014 Conference Proceedings. https://afsaap.org.au/assets/final-abstracts-for-Conference_30-october.pdf

Asare-Donkor, N. K., Kwaansa-Ansah, E. E., Opoku, F., & Adimado, A. A. (2015). Concentrations, hydrochemistry and risk evaluation of selected heavy metals along the Jimi River and its tributaries at Obuasi a mining enclave in Ghana. *Environmental Systems Research, 4*(1), 12. https://doi.org/10.1186/s40068-015-0037-y

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. https://doi.org/10.22044/jme.2022.12326.2236

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. https://journals.co.za/doi/abs/10.10520/EJC-c3d16e031

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

Bansah, K. J., Dumakor-Dupey, N. K., Kansake, B. A., Assan, E., & Bekui, P. (2018). Socioeconomic and environmental assessment of informal artisanal and small-scale mining in Ghana. *Journal of Cleaner Production, 202,* 465–475. https://doi.org/10.1016/j.jclepro.2018.08.150

Banunle, A., Fei-Baffoe, B., & Otchere, K. G. (2018). Determination of the physico-chemical properties and heavy metal status of the Tano river along the catchment of the Ahafo mine in the BrongAhafo region of Ghana. *Journal of Environmental & Analytical Toxicology, 8*(3), 2161–0525. https://www.hilarispublisher.com/environmental-analytical-toxicology.html

Bempah, C. K., & Ewusi, A. (2016). Heavy metals contamination and human health risk assessment around Obuasi gold mine in Ghana. *Environmental Monitoring and Assessment, 188(5)*, 261. https://doi.org/10.1007/s10661-016-5241-3

Bessah, E., Raji, A. O., Taiwo, O. J., Agodzo, S. K., Ololade, O. O., Strapasson, A., & Donkor, E. (2021). 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. https://www.emerald.com/insight/content/doi/10.1108/IJCCSM-02-2020-0018/full/html

Boahen, E., & Owusu, L. (2023). Water quality issues in Ghana: A Review of Greater Accra Region. https://osf.io/preprints/23avu/

Boamponsem, L. K., Adam, J. I., Dampare, S. B., Nyarko, B. J. B., & Essumang, D. K. (2010). Assessment of atmospheric heavy metal deposition in the Tarkwa gold mining area of Ghana using epiphytic lichens. *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms, 268*(9), 1492–1501. https://doi.org/10.1016/j.nimb.2010.01.007

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. https://www.academia.edu/download/77743706/Boateng_et_al.pdf

Bondah, D. A., Command, U. A., & College, G. S. (2020). *Natural resource exploitation and national security: A case study of illegal mining in Ghana* [PhD Thesis, Fort Leavenworth, KS: US Army Command and General Staff College]. https://apps.dtic.mil/sti/citations/AD1124575

Bruno, D. E., Ruban, D. A., Tiess, G., Pirrone, N., Perrotta, P., Mikhailenko, A. V., Ermolaev, V. A., & Yashalova, N. N. (2020). Artisanal and small-scale gold mining, meandering tropical rivers, and geological heritage: Evidence from Brazil and Indonesia. *Science of the Total Environment, 715,* 136907. https://doi.org/10.1016/j.scitotenv.2020.136907

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

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://www.hilarispublisher.com/environmental-analytical-toxicology.html

Doamekpor, L. K., Abusa, Y., Acheampong, C., Klarke, R. K., Nartey, V. K., & Aoamekpor, M. (2019). Assessment of some heavy metals and polycyclic aromatic hydrocarbons in soot from the exhaust of standby generators. *International Journal of Applied and Natural Sciences, 8*(3), 81–94. https://www.iaset.us/journals/international-journals/international-journal-of-applied-and-natural-sciences

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

Donkor, P., Siabi, E. K., Frimpong, K., Mensah, S. K., Siabi, E. S., & Vuu, C. (2023). Socio-demographic effects on role assignment and associated occupational health and safety issues in artisanal and small-scale gold mining in Amansie Central District, Ghana. *Heliyon, 9*(3). https://www.cell.com/heliyon/pdf/S2405-8440(23)00948-9.pdf

Dorleku, M. K., Nukpezah, D., & Carboo, D. (2018). Effects of small-scale gold mining on heavy metal levels in groundwater in the Lower Pra Basin of Ghana. *Applied Water Science, 8*, 1–11. https://doi.org/10.1007/s13201-018-0773-z

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. https://doi.org/10.9734/ajee/2023/v20i4445

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. https://www.sciencedirect.com/science/article/pii/S0301420719305823

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. https://meridian.allenpress.com/jhp/article/8/17/43/67530

Esdaile, L. J., & Chalker, J. M. (2018). The Mercury Problem in Artisanal and Small-Scale Gold Mining. *Chemistry – A European Journal, 24*(27), 6905–6916. https://doi.org/10.1002/chem.201704840

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/

Fisher, M. B., Williams, A. R., Jalloh, M. F., Saquee, G., Bain, R. E., & Bartram, J. K. (2015). Microbiological and chemical quality of packaged sachet water and household stored drinking water in Freetown, Sierra Leone. *PloS One, 10*(7), e0131772. https://doi.org/10.1371/journal.pone.0131772

Fortin, J.-L., Desmettre, T., Manzon, C., Judic-Peureux, V., Peugeot-Mortier, C., Giocanti, J.-P., Hachelaf, M., Grangeon, M., Hostalek, U., & Crouzet, J. (2010). Cyanide poisoning and cardiac disorders: 161 cases. *The Journal of Emergency Medicine, 38*(4), 467–476. https://doi.org/10.1016/j.jemermed.2009.09.028

Geenen, S. (2012). A dangerous bet: The challenges of formalizing artisanal mining in the Democratic Republic of Congo. *Resources Policy, 37*(3), 322–330. https://doi.org/10.1016/j.resourpol.2012.02.004

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. https://doi.org/10.12691/jfs-4-5-2

Hayes, K., & Perks, R. (2012). *Women in the artisanal and small-scale mining sector of the Democratic Republic of the Congo.* In *High-Value Natural Resources and Peacebuilding,* 529–544. Routledge.

Hu, Y., Li, J., Lou, B., Wu, R., Wang, G., Lu, C., Wang, H., Pi, J., & Xu, Y. (2020). The role of reactive oxygen species in arsenic toxicity. *Biomolecules, 10*(2), 240. https://doi.org/10.3390/biom10020240

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. https://doi.org/10.1016/j.lfs.2016.01.033

Issahaku, A., Ampadu, B., & Braimah, M. M. (2017). The causes, effects, and disease burden attributable to water quality and sanitation conditions in the Kassena Nankana Municipality, Ghana. *Environmental Quality Management, 26*(4), 17–29. https://doi.org/10.1002/tqem.21501

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. https://doi.org/10.1088/1742-2140/aaa7b2

Kuffour, R. A., Tiimub, B. B. M., Manu, I., & Owusu, W. (2020). The effect of illegal mining activities on vegetation: A case study of Bontefufuo Area in the Amansie West District of Ghana. *East African Scholars Journal of Agriculture and Life Sciences, 3*(11). https://doi.org/10.36349/easjals.2020.v03i11.002

Kumah, R. (2022). Artisanal and small-scale mining formalization challenges in Ghana: Explaining grassroots perspectives. *Resources Policy, 79*, 102978. https://doi.org/10.1088/1742-2140/aaa7b2

Li, Z., Ma, Z., van der Kuijp, T. J., Yuan, Z., & Huang, L. (2014). A review of soil heavy metal pollution from mines in China: Pollution and health risk assessment. *Science of the Total Environment, 468*, 843–853. https://doi.org/10.1016/j.scitotenv.2013.08.090

Lobo, F. de L., Costa, M., Novo, E. M. L. de M., & Telmer, K. (2016). Distribution of artisanal and small-scale gold mining in the Tapajós River Basin (Brazilian Amazon) over the past 40 years and relationship with water siltation. *Remote Sensing, 8*(7), 579. https://doi.org/10.3390/rs8070579

Mabe, F. N., Owusu-Sekyere, E., & Adeosun, O. T. (2021). Livelihood coping strategies among displaced small scale miners in Ghana. *Resources Policy, 74*, 102291. https://doi.org/10.1016/j.resourpol.2021.102291

Mahaffey K. R. (2005). Mercury exposure: medical and public health issues. *Transactions of the American Clinical and Climatological Association, 116*, 127–154. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1473138/

McGinnis, W. R., Audhya, T., & Edelson, S. M. (2013). Proposed toxic and hypoxic impairment of a brainstem locus in autism. *International Journal of Environmental Research and Public Health, 10*(12), 6955–7000. https://doi.org/10.3390/ijerph10126955

Mensah, A. K., & Tuokuu, F. X. D. (2023). Polluting our rivers in search of gold: How sustainable are reforms to stop informal miners from returning to mining sites in Ghana? Frontiers in *Environmental Science, 11*, 583. https://doi.org/10.3389/fenvs.2023.1154091

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. https://techniumscience.com/index.php/socialsciences/article/view/4503

Nyame, F. K., & Grant, J. A. (2014). The political economy of transitory mining in Ghana: Understanding the trajectories, triumphs, and tribulations of artisanal and small-scale operators. *The Extractive Industries and Society, 1*(1), 75–85. https://doi.org/10.1016/j.exis.2014.01.006

Nyantakyi-Frimpong, H., Christian, A. K., Ganle, J., & Aryeetey, R. (2023). Now we've all turned to eating processed foods: A photovoice study of the food and nutrition security implications of 'galamsey'in Ghana. *African Journal of Food, Agriculture, Nutrition and Development, 23*(1), 22200–22220. https://www.ajol.info/index.php/ajfand/article/view/244983

O'Brien, D. J., Walsh, D. W., Terriff, C. M., & Hall, A. H. (2011). Empiric management of cyanide toxicity associated with smoke inhalation. *Prehospital and Disaster Medicine, 26*(5), 374–382. https://doi.org/10.1017/s1049023x11006625

O'Faircheallaigh, C., & Corbett, T. (2016). Understanding and improving policy and regulatory responses to artisanal and small scale mining. *The 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.

Ofori, S. A., Yeboah, E. O., Amissah-Reynolds, P. K., Owusu, P., & Philip, A. (2023). An efficacy of anti-hyperglycemic agents (nigella sativa) in blood, body weight and glucose levels of diabetes mellitus rats: A comprehensive review. International Journal of Health Sciences and Research, 13(1). https://doi.org/10.52403/ijhsr.20230109

Osman, N., Afele, J. T., Nimo, E., Gorleku, D. O., Ofori, L. A., & Abunyewa, A. A. (2022). 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. https://doi.org/10.22302/iccri.jur.pelitaperkebunan.v38i1.496

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. https://doi.org/10.1016/j.gexplo.2019.106394

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

Park, J.-D., & Zheng, W. (2012). Human exposure and health effects of inorganic and elemental mercury. *Journal of Preventive Medicine and Public Health, 45*(6), 344. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3514464/

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. https://doi.org/10.1016/j.scitotenv.2010.08.022

Purser, D. A., Grimshaw, P., & Berrill, K. R. (1984). Intoxication by cyanide in fires: A study in monkeys using polyacrylonitrile. *Archives of Environmental Health: An International Journal, 39*(6), 394–400. https://doi.org/10.1080/00039896.1984.10545871

Ratcliffe, H. E., Swanson, G. M., & Fischer, L. J. (1996). Human exposure to mercury: A critical assessment of the evidence of adverse health effects. *Journal of Toxicology and Environmental Health, 49*(3), 221–270. https://doi.org/10.1080/00984108.1996.11667600

Sebiawu, G. E., Antwi-Akomeah, S., Mensah, N. J., & Abana, D. (2020). Heavy metal and bacteriological contamination of herbal medicines sold over the counter in the municipality of wa of the upper West Region-Ghana. *International Journal of Scientific Research in Multidisciplinary Studies, 6*(5), 15-23. https://www.isroset.org/journal/IJSRMS/full_paper_view.php?paper_id=1889#parentHorizontalTab3

Sherman, L. S., Blum, J. D., Basu, N., Rajaee, 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. https://doi.org/10.1016/j.envres.2014.12.021

Wang, T.-S., Kuo, C.-F., Jan, K.-Y., & Huang, H. (1996). Arsenite induces apoptosis in chinese hamster ovary cells by generation of reactive oxygen species. *Journal of Cellular Physiology, 169*(2), 256–268. https://doi.org/10.1002/(SICI)1097-4652(199611)169:2<256::AID-JCP5>3.0.CO;2-N

Wiafe, S., Awuah Yeboah, E., Boakye, E., & Ofosu, S. (2022). Environmental risk assessment of heavy metals contamination in the catchment of small-scale mining enclave in Prestea Huni-Valley District, Ghana. *Sustainable Environment, 8*(1), 2062825. https://doi.org/10.1080/27658511.2022.2062825

Wireko-Gyebi, R. S., Asibey, M. O., Amponsah, O., King, R. S., Braimah, I., Darko, G., & Lykke, A. M. (2020). Perception of Small-Scale Miners on Interventions to Eradicate Illegal Small-Scale Mining in Ghana. *SAGE Open, 10*(4), 215824402096366. https://doi.org/10.1177/2158244020963668

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 dysfunctio n pathway. *Archives of Toxicology, 86*(6), 923–933. https://doi.org/10.1007/s00204-012-0864-9

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