Health Sciences Investigations Journal

share

Send us an email: hsijournal@ug.edu.gh
Visit us: https://www.hsijournal.ug.edu.gh

ISSN Online 2704-4890 ISSN Print 2720-7609

Online first publication

Review

HSI Journal (2024) Volume 5 (Issue 2):726-734. https://doi.org/10.46829/hsijournal.2024.6.5.2.726-734

Open Access

A review of health hazards associated with exposure to galamsey-related pollutants

Jonathan AWEWOMOM [1,2*], Benyade K BENJAMIN [2], Fobi E OSEI [2], David AZANU [3], Francis OPOKU [2], Lyndon NA SACKEY [3], Osei AKOTO [2]

[1]Department of Earth and Environmental Sciences, College of Natural Sciences, Michigan State University, East Lansing, United States of America; [2]Department of Chemistry, College of Science Kwame Nkrumah University of Science and Technology, Kumasi, Ghana; [3]Department of Environmental Science, College of Science, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana

Special Edition on Galamsey

Received February 2024; Revised April 2024; Accepted May 2024

Abstract

Galamsey, the unregulated artisanal small-scale gold mining in Ghana, is emerging as a significant global concern. Galamsey operations typically involve numerous unlicensed and untrained people at a multiplicity of sites who engage in the uncontrolled excavation of soil and/or water bodies using rudimentary tools. Aside from haphazard destruction of land and vegetation, galamsey operations often release hazardous substances such as mercury and cyanide, recognised as mining pollutants. This review examines the far-reaching implications of galamsey-related pollutants, drawing particular attention to the context of Ghana and focusing on the toxicological impacts of pollutants such as hydrocarbons, cyanide, mercury, lead, arsenic, soot, silt, and nitrate, often released during galamsey activities. These contaminants have been linked to various adverse health effects, including neurological disorders, respiratory diseases, cardiovascular issues, and congenital defects. Special attention is given to the mechanism of action of these pollutants, emphasising how they disrupt biological systems and lead to chronic health conditions and birth defects. Finally, the review proposes comprehensive recommendations for mitigating the health and environmental consequences of galamsey.

Keywords: Illegal mining sites, pollutants, socioeconomic, and galamsey

Cite the publication as Awewomom J, Benjamin BK, Osei FE, Azanu D, Opoku F, Sackey LNA, Akoto O (2024) A review of health hazards associated with exposure to galamsey-related pollutants. HSI Journal 5(2):726-734. https://doi.org/10.46829/hsijournal.2024.6.5.2.726-734

INTRODUCTION

Galamsey, is an informal term used in Ghana for unregulated artesinal small-scale gold mining. This illicit activity involves untrained individuals excavating the earth and filtering soil and water with rudimentary tools to extract gold. This is usually done using inappropriate techniques, materials, and machines such as tractors, excavators, and grinding mills (known locally as Chamfi) to clear off the forest and vegetation, dig deep into the soil, and damage the soil structure. Other galamsey operators excavate riverbeds for alluvium. The obtained soil is washed to reveal nuggets of crude gold in a process that turns streams and rivers into muddy and high-turbidity water bodies unfit for aquatic life. Galamsey-mined gold is processed in the open by untrained and ill-equipped labourers using toxic substances like mercury and cyanide, regarded as mining pollutants. The consequences of these actions include wanton destruction of vegetation, which contributes to the factors leading to changes in the climate. Galamsey activities also lead to land degradation, soil erosion, conflicts between humans and wildlife, water pollution, improper disposal of waste and various types of harm [1]. Ghana is one of the few sub-Saharan countries with abundant deposits of gold. During pre-colonial periods, Ghana was rich in gold, allowing ordinary individuals to gather gold dust and nuggets by excavating a few meters below the surface with simple implements such as pickaxes, shovels, and pans. In some instances, they could even stumble upon gold lying freely on the ground. During Ghana's pre-colonial days, gold was used as a

* *Corresponding author*
Email: jonathankeinzie8a154@gmail.com

currency in barter transactions for goods and services. The arrival of Western explorers, astounded by the region's abundant gold, led to naming the area as the "Gold Coast." They subsequently established a colonial presence, building forts and castles and developing industries focused on gold and the slave trade. However, the post-colonial period saw a shift from manual extraction to using chemicals in mining. These substances, even in small quantities, pose serious health risks, including hypertension, birth defects, brain disorders, kidney issues, and anaemia [2-7]. In Ghana, galamsey is prevalent in areas such as Tarkwa Nsuaem, Amenfi East, Prestea Huni-valley district, and Aboabo in the Western and Ashanti regions of Ghana, respectively [2]. According to the Ghana Statistical Service, about 2.4% of the labour force has been employed in the mining industry for the past two decades [8]. However, the substantial rise in the country's unemployment rate often leads many young people to engage galamsey, as a swift and effective method to support themselves financially [9,10].

Statistics from the Ghana Health Service (GHS) indicate a continual rise in birth mortality rates, stillbirths, and other birth-related complications in regions impacted by illegal mining [8]. In China [11], heavy metal ingestion by pregnant women, through direct or indirect exposure, led to issues such as lower newborn birth weight, reduced length at birth, and increased chances of preterm delivery. Additionally, there have been reports of other acute and chronic conditions, including gastrointestinal and kidney dysfunction, nervous system disorders, skin lesions, vascular damage, and cancer [11,12]. The yearly increase in birth defects linked to the consumption of water and food contaminated with heavy metals like arsenic, mercury, and lead parallels the surge in per-infant medical costs. This includes higher government spending on drugs and medical equipment for newborns. As a result, survivors of these birth-related issues often grow up unhealthy and less productive, becoming a liability rather than an asset to the country [13].

The adverse environmental impacts of galamsey, are widely recognised. However, this review paper aims to shed light on a crucial but often overlooked aspect: the health risks and birth defects resulting from exposure to galamsey-related pollutants. Evidence from existing literature has highlighted the alarming health problems prevalent in communities residing near these mining sites. A cross-sectional study by Cooper et al. established associations between maternal proximity to mountain-top removal (MTR) mining and increased birth defects [14]. This study highlighted the prevalence ratios of gastrointestinal defects in infants with varying degrees of MTR exposure. Another epidemiological study [15] found that heavy metals, especially the interaction of mercury with lead, had a significant correlation with the risk for Congenital Heart Defects (CHDs) resulting from prenatal exposure to these pollutantsIn addition, findings from the Pediatric Society of Ghana revealed that exposure to the heavy metals generated by illegal mining operations leads to a higher occurrence of congenital deformities, child fatalities, and cognitive impairments that have a detrimental impact on their academic performance [16]. These heavy metals upon entering the human body, tend to disrupt enzymatic processes, compromise the body's antioxidant defence mechanisms, and stimulate the generation of reactive oxygen species (ROS) [17].

This study also addresses the magnitude of health risks posed by galamsey-related pollutants to elucidate the potential health effects and birth defects associated with exposure to these pollutants. One of the repercussions of galamsey activities is respiratory complications [18]. Airborne respiratory disease, known as pneumoconiosis (black lung disease), is the major lung disease acquired by miners and operators of galamsey through inhalation of dust generated from the mining process [19]. According to Ayaaba et al., 47.5%, 14.3%, 9.69%, and 5.1% of gold miners (both regulated and unregulated) have been diagnosed with asthma, pneumonia, bronchitis, and emphysema, respectively, with coughing being the most prevalent symptom [20].

Galamsey-related pollutants

Several studies have confirmed elevated levels of various environmental pollutants in regions impacted by galamsey, as summarised in Table 1. This table provides a comparative analysis of the prevalence and distribution of these contaminants, highlighting the significant presence of toxic substances from illegal small-scale mining both in Ghana and globally. Such pollutants, particularly heavy metals such as lead, mercury, and arsenic, are often released during the gold separation process using chemicals like cyanide, sulfuric acid, and nitric acid. Acid mine drainage, erosion of waste residues, and primarily mining tailings are key sources of these pollutants. Tailings significantly contaminate water bodies and ecosystems with high concentrations of mercury, acid, arsenic, lead, and nickel. These pollutants pose a direct threat to the health of local residents in rural galamsey areas, who rely on rivers and streams as their primary water source. In addition to heavy metals, mining pollutants include hydrocarbons, cyanide, and particulate matter such as soot and silt, all contributing to potential health risks and birth defects associated with prolonged exposure [21,22].

Illegal mining activities result in the release of toxic petroleum hydrocarbons (fuel oils and grease) due to spills and leaks. Hydrocarbons can also be found in tailings, effluents, and waste materials generated by mining operations. The most common hydrocarbons from illegal mining activities include methane and volatile organic carbons (VOCs) such as benzene, toluene, ethylbenzene, and xylene. Nitrate, a prevalent pollutant in galamsey operations, primarily enters the environment through the use of blasting agents such as ammonium nitrate. During these galamsey activities, nitrate compounds are released and can swiftly infiltrate nearby water bodies. This contamination poses significant risks to ecosystems and human health, as nitrates in water can lead to various environmental and health concerns, including water quality degradation and potential harm to aquatic life.

Case studies of galamsey activities in Ghana

Table 2 indicates the concentration of various pollutants found in different study areas in Ghana and other global regions, specifically focusing on the impact of galamsey activities. Based on the findings from Ghana: Studies conducted in River Tano [52], Tarkwa Nsuaem, Amenfi East, and Prestea Huni Valley [53] in Ghana revealed mercury concentrations in fish species and galamsey waste. Also, in the River Pra estuaries of Ghana, high concentrations of lead were reported in the water [58]. These significantly exceed the recommended health limits, indicating a serious health threat to both aquatic life and the local population. This could potentially lead to mercury and lead poisoning with associated neurological disorders and carcinogenicity [84]. In Kenyase in the Asante region of Ghana, the levels of cyanide found in yams were alarmingly high (43.47 mg/L), far exceeding the recommended limit of (10 mg/kg). This is particularly concerning as cyanide is highly toxic, leading to metabolic acidosis, cellular dysfunction, and organ failure at high exposures [85].

The Western region of Ghana, encompassing 22% of the country's drainage system, notably the Pra and Ankobra rivers [86,87], has faced the detrimental consequences of galamsey activities. The environmental impact is starkly evident through the presence of heavy metals like lead (Pb), arsenic (As), cadmium (Cd), and mercury (Hg) detected in fish samples collected from these rivers, as analysed by the Environmental Protection Agency (EPA) [88]. Levels of heavy metal contaminants (mg/L) detected in River Pra in the Ashante region of Ghana ranged from 0.12 - 0.26 for Cd, 8.65 - 8.48 for Pb, and 0.50 - 0.08 for Hg [119]. Consuming fish contaminated with these heavy metals has been linked to damage to the nervous system and the occurrence of birth-related disorders [58,89]. Additionally, a study conducted in areas such as Sanso, Anyinam, Anyimadokrom, Abombe, and Tutuka within the Obuasi municipality has reported a significant increase in cases of skin diseases, colds, catarrh, and respiratory illnesses, accounting for 27% [90,91].

These findings underscore the dire environmental and public health consequences of galamsey activities in the region. Among the reported sites, Anyimadokrom emerges as the most significantly affected by galamsey-related pollutants, owing to its close proximity to galamsey operations [92]. Instances of galamsey-related health issues, such as skin diseases, are particularly prevalent in Anyimadokrom, with 26.6% of respondents reporting these problems, as opposed to other areas like Sanso, where 24.3% of responses were recorded [91]. This data indicates the heightened impact of galamsey activities on the healthof the local population in Anyimadokrom compared to neighbouring areas.

Recommendations and future perspectives

This study unveils a pressing need for proactive measures to address the multifaceted challenges posed by galamsey activities in affected communities. The following recommendations and future perspectives are proposed to chart a path toward sustainable solutions.

a. Mitigating Political Influence on Galamsey: The persistent issue of political influence on galamsey must be tackled at its root. Authorities should institute stringent regulations and enforce them without compromise, irrespective of political interests. Government agencies, in collaboration with relevant stakeholders, should implement policies to prevent illegal mining operations and penalise those who facilitate or engage in these activities.
b. Advanced Research on Bioavailability: While extensive quantitative and analytical research has been conducted on galamsey-related pollutants, a deeper understanding of their bioavailability is essential. Comprehensive bioavailability assessments should be carried out to precisely determine the levels of these pollutants in the affected population. This information is critical for designing targeted intervention strategies and assessing the health risks accurately.
c. Enhancing Healthcare Infrastructure: Many health centres in galamsey-affected areas and Ghana as a whole lack the necessary technologies to detect and monitor chemical contaminants in affected individuals. To bridge this gap, toxicological divisions should be established within healthcare facilities. These divisions would be equipped with state-of-the-art equipment for diagnosing and monitoring the health effects ofgalamsey-related pollutants, ensuring timely and accurate healthcare provision.
d. Investment in toxicological assays and the availability of readily accessible assays for detecting galamsey-related pollutants is paramount. Investment in the development and widespread deployment of assays for quantifying pollutants, including but not limited to cyanide, is essential. Such assays should be made accessible to healthcare professionals, allowing for rapid, on-site testing of affected individuals.
e. Community Education and Awareness: Education and awareness campaigns should be intensified to inform individuals about the dire consequences of galamsey. These campaigns should encompass not only the health risks but also the environmental and socioeconomic impacts of illegal mining. Community engagement and awareness programs can deter participation in galamsey and encourage responsible practices.
f. Robust Water Treatment Systems: Galamsey-affected communities should have access to robust water treatment systems that can help remove contaminants from drinking water sources. Investing in these systems is vital for ensuring the availability of safe, clean water, which is a fundamental requirement for public health

Table 1 Overview of Galamsey-Related Pollutants, Adverse Health Effects, and Mechanisms of Action

Pollutant	Adverse Health Effects	Mechanism of Action
Hydrocarbons (PAHs,VOCs, methane, fuel oil and grease)	Central nervous system damage and Increased risk of leukemia, impairment of fetal growth [23,24]. Congenital health defects on offsprings (conotruncal heart defect) [25]	Hydrocarbons metabolize into toxic intermediates that damage (Deoxyribonucleic Acid) DNA and proteins, increase mutation risk, and induce oxidative stress, generating reactive oxygen species that cause cellular damage.
Cyanide	Metabolic acidosis, Cellular disfunction, organ failure and induce central nervous system dysfunction [26]	Cyanide's inhibits cytochrome c oxidase, a crucial enzyme in the electron transport chain of mitochondria, responsible for aerobic respiration. $Cyanide\ (CN-) + Cytochrome\ c\ oxidase \rightarrow CyanideCytochrome\ c\ oxidase\ complex$ [27-29]
Mercury	Organ dysfunction (brain, renal, endocrine glands), stillbirths and neurological disorders (tremors, impaired cognition, muscle weakness) and causes neural tube defects [30]	Galamsey activities release organic mercury, bonding with proteins, altering structures, causing organ dysfunction. Methyl mercuric-cysteinyl complex crosses placenta, leading to birth defects. $[MeHg]^{+} + RSH \rightarrow \mathrm{MeHg-SR} + H^{+}$ [31-33] . Where= RHS = Alkyl thiol or alkanethiol, MeHg−SR = methyl mercuric-cysteinyl complex
Lead	Reduced erythrocyte resilience, anemia, Impaired heme synthesis, disrupted hemoglobin production, shortened red blood cell lifespan, [34]. Damages the central nervous system, cognitive impairments, and an increased risk of hypertension and cardiovascular disease in adults [35].	When introduced as lead phosphate, lead undergoes precipitation in the blood, creating an acidic environment that weakens erythrocytes (red blood cells) and reduces their oxygen-carrying capacity. $Pb_3(PO_4)_{2(s)} + H_2O_l \rightarrow H_3PO_{4(aq)} + 3Pb^{2+}{}_{(aq)}$ [34].
Arsenic	Skin lesions, respiratory tract infections and increased risk of cancer	Once ingested, inorganic arsenic undergoes methylation to form organic arsenic compounds, but this does not mitigate its health risks. Both inorganic arsenic and its organic metabolites disrupt cellular processes, leading to severe health issues [36].
Soot	Respiratory problems (asthma, bronchitis), coronary heart diseases and Premature birth, low birth weight [37,38].	Combustion of fuels emits soot particles and droplets into the air which disperse into the surrounding environment. leading to significant health risks due to Inhalation of soot-laden air. [39].
Silt	Reduced water quality resulting in water borne diseases [40].	Galamsey activities disrupt water bodies through soil erosion and alluvial mining, leading to substantial accumulation of suspended sediments in the water, known as siltation. [41].
Iron	Neurotoxicity	A chemical interaction between iron and hydrogen peroxide (Fenton Reaction), produces hydroxyl radicals (OH•), which are extremely reactive and harmful to living cells. These OH• radicals interact with various biomolecules in the bloodstream, compromising enzymatic activities and causing damage to proteins, lipids, nucleic acids, and DNA strands. $Fe + H_2O_2 \rightarrow OH^{\bullet} + Fe^{2+}$ [42,43]
Vanadium (V)	Nausea, vomiting, abdominal pain and tongue discolouration	When in contact with blood plasma containing Nicotinamide adenine dinucleotide phosphate (NADPH) and ascorbic acid, V transforms into a reduced form. This reduced V then reacts with oxygen in the bloodstream to generate an oxygen radical. This radical further reacts with V, allowing its transportation to various parts of the body [44].
Carbon monoxide (CO).	Otitis media, asthma, autism spectrum disorder (ASD), small for gestational age. Reduced oxygen delivery impairs fetal growth and development	CO binds with haemoglobin to form carboxyhemoglobin (COHb) in the blood, reducing oxygen delivery to the foetus. This contributes to neurological disorders by affecting the delivery of oxygen to the brain during critical periods of foetal development and exacerbate respiratory conditions by impairing oxygen transport and causing inflammation in the respiratory system [45].
Nitrate (from blasting agent, ammonium nitrate)	Prenatal exposure to nitrates mostly through drinking water causes childhood cancer, preterm delivery and lower birth weight, Infant mortality, congenital cataract, neural tube defects including Spina Bifida and affects the heart of offsprings [46,47].	Nitrates, undergo conversion in the body to nitrites, which can then further react to form N-nitroso compounds. These compounds are of particular concern due to their potential carcinogenic and teratogenic effects. In the case of pregnant women, these N-nitroso compounds can cross the placenta, potentially interfering with foetal development and leading to birth defects, particularly affecting the central nervous system and possibly other organ systems [48].
SO_2 (Sulfur Dioxide)	Congenital limb defects and neural tube defects in offsprings [49, 50], respiratory problems, aggravation of existing cardiovascular diseases, irritation of the eyes, nose, and throat [51].	SO_2 generated from the combustion of oil in galamsey machines dissolve in water vapour in the air to form sulfurous acid (H_2SO_3), which is a respiratory irritant. When inhaled, it reacts with the water lining of the respiratory tract, forming acidic compounds that irritate the respiratory system. This leads to bronchoconstriction and increased asthma symptoms [51]

Table 2. Reported Levels of Galamsey-Related Pollutants in Different Study Areas

Pollutant	Study Area	Sample Type	Concentration	Recommended Limit
Mercury	River Tano, Ghana. [52] Tarkwa Nsuaem, Amenfi East and Prestea Huni Valley, Ghana. [53] Cispatá Bay, Colombia. [54]	M. rume fish species L.niloticus fish species galamsey waste Blood of birds	(1.01 ± 0.03) mg/Kg (1.1 ± 0.14) mg/Kg (0.0060 ± 0.0004) mg/Kg (0.23 ± 1.09) µg/L	≤ 0.5mg/Kg [55] ≤ 4mg/Kg [56]
Lead	Lake Badovci, Kosovo. [57] River Pra estuaries, Ghana. [58] Dagua River estuary, Colombia. [59]	Water Water Sediments and Tissues of A. tuberculosa	0.01 mg/kg (8.65 ± 8.48) µg/L (0.87 ± 0.68) mg/Kg	(0.01-0.015) mg/L [60]
Arsenic	Central Yinchuan basin, China. [61] Mojana region, Colombia. [62] Caracoto, Peru. [63]	Groundwater Blood of children and Adolescents Groundwater	(0.7-26) µg/L 1.96 ± 2.73) µg/L (31.9-113.1) µg/L	≤ 10 µg/L [64]
Cadmium	Fena River, Ghana. [65] Pawara, Eastern Cameroon. [66] La Oroya Antigua, Ecuador. [67]	Water Soil Soil	(0.14 ± 0.19) mg/L (12.2-25.0) mg/Kg 4,820ppm	≤ 0.005ppm [68] ≤ 0.6mg/Kg [69]
Hydrocarbons	Suixi County, China. [70] Henan Province, China. [71] Harare, Zimbabwe. [72]	Soil Groundwater Soil	(218-1548) ng/g (146.9-1220.6) ng/L 21,415 mg/Kg	≤ 100mg/Kg [73] ≤ 300g/L [74] ≤ 100mg/Kg
Soot (Particulate matter)	Bochnia, Poland. Kiruna, [75] Norrbotten County, Lapland, Sweden. [76] Kemi-Tornio region, Finland. [77]	Air Air Air	(21-79) $\mu g/m^3$ 94 µg EC m^{-3} and 1200 µg NO_2 m^{-3} (22-1100) µg m^{-3}	≤ 35mg/m^3
Silt	Central Gold Belt, Malaysia[78] Tapajós river basin, Brazil. [79] South-western Rivers system, Ghana. [80]	Soil Water water	78.23% sludge, 68.06% waste dump, 63.98% stockpile HG, 60.65% stockpile SLG and 53.21% sediment ~5.0 mgL^{-1} 382 mg/L	
Cyanide	Kenyase, Ghana. [81] Jilin, China. [82] Kelantan, Malaysia. [83]	Yam Water urine	43.47 mg/L 2.5 mg/Kg 0.56 mg/dL	≤ 10mg/Kg ≤ 0.2g/L

g. Sustainable Mining Practices: Promoting sustainable mining practices and encouraging small-scale miners to transition to legal and responsible mining activities should be a long-term objective. Government incentives and support can facilitate this transition, creating alternative livelihoods for those currently engaged in galamsey.

h. To safeguard pregnant women and mitigate the risk of birth defects, it is essential to enhance environmental monitoring and control in areas prone to pollution from sulfur dioxide, cyanide, carbon monoxide, and hydrocarbons. Healthcare providers should offer regular screenings and advice on avoiding exposure.

Conclusion

This review has extensively explored general pollutants generated and related to illegal gold mining operations and delivered parallels to the specific pollutants generated from galamsey operations in Ghana. The findings presented highlight the dire health implications and congenital defects associated with exposure to pollutants. Notably, mercury, lead, arsenic, and other heavy metals have been linked to severe neurological and developmental disorders, respiratory diseases, and cardiovascular problems. Pregnant women and their unborn children are especially vulnerable, with exposure leading to birth defects such as neural tube defects, congenital heart defects, and low birth weights. Also, sulfur dioxide, cyanide, carbon monoxide, and hydrocarbons have all been associated with significant birth defects and developmental problems. Exposure to these pollutants can lead to congenital heart defects, neurological issues, and impaired foetal growth, highlighting the critical need for protective measures for pregnant women.

The health risks and birth defects associated with exposure to galamsey-related pollutants are a public health emergency that requires immediate attention. This review serves as a call to action for policymakers, healthcare providers, and the community to work together to eradicate the scourge of illegal mining and its devastating health consequences. A united and comprehensive approach can protect current and future generations from the harmful effects of galamsey.

DECLARATIONS

Ethical considerations
None

Consent to publish
All authors agreed on the content of the final paper.

Funding
None

Competing Interest
None

Author contributions
JA conceived the project topic. JA, FO, DA, LNAS, and OA participated in writing the original draft, reviewing, and editing the manuscript.

Acknowledgement
None

Availability of data
None

REFERENCES

1. Baddianaah I, Baatuuwie BN, Adongo R (2022) Socio-demographic factors affecting artisanal and small-scale mining (galamsey) operations in Ghana. Heliyon 8:e09039.
2. Owusu-Nimo F, Mantey J, Nyarko KB, 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:e00534.
3. Nova Scotia Museum (2019) Early Gold Mining Techniques. https://museumofindustry.novascotia.ca/nova - scotia-industry/gold-mining/early-gold-mining techniques. Accessed 5th October 2023.
4. Convention WH (1979) Forts and Castles, Volta, Greater Accra, Central and Western Regions. https://whc.unesco. org/en /list/34/. Accessed 18th October 2023 2023.
5. Hilson G (2002) Harvesting mineral riches: 1000 years of gold mining in Ghana. Resources Policy. 28:13-26.
6. Metwally AA, Khalafallah MM, Dawood MAO (2023) Water quality, human health risk, and pesticides accumulation in African catfish and Nile tilapia from the Kitchener Drain-Egypt. Sci Rep 13:18482.
7. Koomson JA, Koomson B, Owusu C, Agyemang FO (2023) Detoxification of lead and arsenic from galamsey polluted water using nano synthesised iron oxide from cupola furnace slag. Mater Chem Phys 308:128301.
8. Mines GCo (2020) Mining industry statistics and data. https://ghanachamberofmines.org/wp-content/uploads/ 2021/09/2020-Mining-Industry-Statistics-and-Data.pdf (2020). Accessed 5th October 2023.
9. Hilson G, Amankwah R, Ofori-Sarpong G (2013) Going for gold: transitional livelihoods in Northern Ghana. J Mod Afr Stud 51:109–137.
10. Ndetei C (2022) Causes and effects of galamsey in Ghana. https://yen.com.gh/104844-causes-effects-galamsey-ghana.html (2022). Accessed 5th October 2023.
11. Lin Z, Chen X, Xi Z, Lin S, Sun X, Jiang X, Tian H (2018) Individual heavy metal exposure and birth outcomes in Shenqiu county along the Huai River Basin in China. Toxicol Res (Camb) 7:444–453.
12. Bonney GE, Walker M, Gbedemah K, Konotey-Ahulu FI (1978) Multiple births and visible birth defects in 13,000 consecutive deliveries in one Ghanaian hospital. Progress in clinical and biological research. 24 Pt B:105-8
13. Paudel P, Sunny AK, Gurung R, Gurung A, Malla H, Rana NB, KC N, Chaudhary RN, KC A (2021) Burden and consequence of birth defects in Nepal-evidence from prospective cohort study. BMC Pediatr 21:81.
14. Cooper DB, Walker CJ, Christian WJ (2022) Maternal proximity to mountain-top removal mining and birth defects in Appalachian Kentucky, 1997–2003. PLoS One 17:e0272998.
15. Wang C, Pi X, Yin S, Liu M, Tian T, Jin L, Liu J, Li Z, Wang L, Yuan Z, Wang Y, Ren A (2022) Maternal exposure to heavy metals and risk for severe congenital heart defects in offspring. Environ Res 212:113432.
16. Ghana Pso: Galamsey increasing the risk of child morbidity, mortality in affected communities. https://pedsgh.com/2023/02/11/galamsey-increasing-the-risk-of-child-morbidity-mortality-in-affected-communities -paediatricsociety/#:~:text=%E2%80%9CExposure%20 to%20chemicals%20such%20as,suspected%20to%20cause %20congenital%20malformations.%E2%80%9D (2021). Accessed 10th September 2023.
17. Engwa GA, Ferdinand PU, Nwalo FN, et al. Mechanism and health effects of heavy metal toxicity in humans. Poisoning in the Modern World – New Tricks for an Old Dog? 2019;1–23.
18. Future CE (2023) Causes and Effects of Mining on Human Health and the Environment. https://www.conserve-energy-future.com/causes-effects-mining-human-health-environment.php. Accessed 16th September 2023.
19. Services USDoHH (2019) Mining Topic: Respiratory Diseases. https://www.cdc.gov/niosh/mining/topics/respira torydise ases.html (2019). Accessed 16th September 2023.
20. Ayaaba E, Li Y, Yuan J, Ni C (2017) Occupational Respiratory Diseases of Miners from Two Gold Mines in Ghana. Int J Environ Res Public Health 14:337.
21. Guides HH: HealthWiki > A Community Guide to Environmental Health > Chapter 21: Mining and Health > Chemicals Used in Mining. https://en.hesperian.org/hhg/ A_Community_Guide_to_Environmental_Health:Chemical s_Used_in_Mining#:~:text=Toxic%20chemicals%20used% 20in%20mining,ANFO%E2%80%9D)%20used%20in%20 blasting%20tunnels (2020). Accessed 10th September 2023.
22. Salomons W (1995) Environmental impact of metals derived from mining activities: Processes, predictions, prevention. J Geochem Explor 52:5–23.
23. Agarwal P, Anand M, Chakraborty P, Singh L, Masih J, Taneja A (2022) Placental levels of polycyclic aromatic hydrocarbons (PAHs) and their association with birth weight of infants. Drug Chem Toxicol 45:868–877.
24. Kuppusamy S, Maddela NR, Megharaj M, Venkateswarlu K (2020) Impact of Total Petroleum Hydrocarbons on Human Health. In: Total Petroleum Hydrocarbons. Springer International Publishing, Cham, :139–165

25. Patel J, Nembhard WN, Politis MD, Rocheleau CM, Langlois PH, Shaw GM, Romitti PA, Gilboa SM, Desrosiers TA, Insaf T, Lupo PJ (2020) Maternal occupational exposure to polycyclic aromatic hydrocarbons and the risk of isolated congenital heart defects among offspring. Environ Res 186:109550.

26. Downey JD, Basi KA, DeFreytas MR, Rockwood GA (2015) Chronic cyanide exposure. Toxicology of Cyanides and Cyanogens: Experimental, applied and clinical aspects. 2015:21-40.

27. Pauluhn J (2016) Risk assessment in combustion toxicology: Should carbon dioxide be recognised as a modifier of toxicity or separate toxicological entity? Toxicol Lett 262:142–152.

28. Huzar TF, George T, Cross JM (2013) Carbon monoxide and cyanide toxicity: etiology, pathophysiology and treatment in inhalation injury. Expert Rev Respir Med 7:159–170.

29. Graham J TJ (2023) Cyanide Toxicity. https://www.ncbi.nlm.nih.gov/books/NBK507796/#:~:text=The%20toxicity%20of%20cyanide%20is,reduction%20of%20oxygen%20to%20water. Accessed 18th October, 2023 2023.

30. Tong M, Yu J, Liu M, Li Z, Wang L, Yin C, Ren A, Chen L, Jin L (2021) Total mercury concentration in placental tissue, a good biomarker of prenatal mercury exposure, is associated with risk for neural tube defects in offspring. Environ Int 150:106425.

31. Kerper LE, Ballatori N, Clarkson TW (1992) Methylmercury transport across the blood-brain barrier by an amino acid carrier. American Journal of Physiology-Regulatory, Integrative and Comparative Physiology 262:R761–R765.

32. Carrier G, Brunet RC, Caza M, Bouchard M (2001) A Toxicokinetic Model for Predicting the Tissue Distribution and Elimination of Organic and Inorganic Mercury Following Exposure to Methyl Mercury in Animals and Humans. I. Development and Validation of the Model Using Experimental Data in Rats. Toxicol Appl Pharmacol 171:38–49.

33. Wikipedia: Methylmercury. https://en.wikipedia.org/wiki/Methylmercury#cite_note-24 (2023). Accessed 18th October, 2023.

34. Flora G, Gupta D, Tiwari A (2012) Toxicity of lead: a review with recent updates. Interdiscip Toxicol 5:47–58.

35. Olufemi AC, Mji A, Mukhola MS (2022) Potential Health Risks of Lead Exposure from Early Life through Later Life: Implications for Public Health Education. Int J Environ Res Public Health 19:16006.

36. Stýblo M, Venkatratnam A, Fry RC, Thomas DJ (2021) Origins, fate, and actions of methylated trivalent metabolites of inorganic arsenic: progress and prospects. Arch Toxicol 95:1547–1572.

37. Khazin ML (2020) International Emission Standards for Mining Machinery and Equipment. personnel. 9:12.

38. PuroClean (2019) The Dangers of Soot Exposure and How to Clean Soot Up. https://puroclean.ca/blog/the-dangers-of-soot-exposure-and-how-to-clean-soot-up/#:~:text=Soot%20can%20enter%20the%20body,heart%20disease%2C%20and%20even%20cancer. Accessed 16th October, 2023 2023.

39. Jackie Weidman SM (2012) Soot Pollution 101. https://www.americanprogress.org/article/soot-pollution-101/#:~:text=How%20is%20soot%20produced%3F,small%20particles%20or%20liquid%20droplets.. Accessed 16th October, 2023 2023.

40. Dutta S (2016) Soil erosion, sediment yield and sedimentation of reservoir: a review. Modeling Earth Systems and Environment. 2:1-18.

41. Koç C (2012) A study on sediment accumulation and environmental pollution of Fethiye Gulf in Turkey. Clean Technologies and Environmental Policy. 14:97-106.

42. Lloyd R V., Hanna PM, Mason RP (1997) The Origin of the Hydroxyl Radical Oxygen in the Fenton Reaction. Free Radic Biol Med 22:885–888.

43. Azeh Engwa G, Udoka Ferdinand P, Nweke Nwalo F, N. Unachukwu M (2019) Mechanism and Health Effects of Heavy Metal Toxicity in Humans. In: Poisoning in the Modern World - New Tricks for an Old Dog? IntechOpen

44. Crans DC, Smee JJ, Gaidamauskas E, Yang L (2004) The Chemistry and Biochemistry of Vanadium and the Biological Activities Exerted by Vanadium Compounds. Chem Rev 104:849–902.

45. Organisation WH (2019) Ambient air pollution: training for health care providers. World Health Organization.

46. Stayner LT, Jensen AS, Schullehner J, Coffman VR, Trabjerg BB, Olsen J, Hansen B, Pedersen M, Pedersen CB, Sigsgaard T (2022) Nitrate in drinking water and risk of birth defects: Findings from a cohort study of over one million births in Denmark. The Lancet Regional Health - Europe 14:100286.

47. Clemmensen PJ, Schullehner J, Brix N, Sigsgaard T, Stayner LT, Kolstad HA, Ramlau-Hansen CH (2023) Prenatal Exposure to Nitrate in Drinking Water and Adverse Health Outcomes in the Offspring: A Review of Current Epidemiological Research. Curr Environ Health Rep 10:250–263

48. Shi J (2022) Nitrite Toxicity: Chemical Analysis, Metabolism, and Health Effects. Highlights in Science, Engineering and Technology 19:210–215.

49. Jiang W, Liu Z, Ni B, Xie W, Zhou H, Li X (2021) Modification of the effects of nitrogen dioxide and sulfur dioxide on congenital limb defects by meteorological conditions. Human Reproduction 36:2962–2974.

50. Zhang J-Y, Dai H-X, Wu Q-J, Li J, Huang Y-H, Chen Z-J, Li L-L, Chen Y-L, Liu S, Jiang C-Z (2021) Maternal exposure to ambient levels of sulfur dioxide and risk of neural tube defects in 14 cities in Liaoning province, China: a population-based case–control study. J Expo Sci Environ Epidemiol 31:266–275.

51. Khalaf EM, Mohammadi MJ, Sulistiyani S, Ramírez-Coronel AA, Kiani F, Jalil AT, Almulla AF, Asban P, Farhadi M, Derikondi M (2022) Effects of sulfur dioxide inhalation on human health: a review. Rev Environ Health.

52. Nyantakyi AJ, Wiafe S, Akoto O, Fei-Baffoe B (2021) Heavy Metal Concentrations in Fish from River Tano in Ghana and the Health Risks Posed to Consumers. J Environ Public Health 2021:1–11.

53. Mantey J, Nyarko KB, Owusu-Nimo F, Awua KA, Bempah CK, Amankwah RK, Akatu WE, Appiah-Effah E (2020) Mercury contamination of soil and water media from

different illegal artisanal small-scale gold mining operations (galamsey). Heliyon 6:e04312.

54. Hernando Campos N, Luis Marrugo-Negrete J (2023) Mercury in the Colombian Caribbean: The Bay of Cartagena, A Model in Resilience
55. Curtis J ME, Sergent SR: Hydrocarbon Toxicity. https://www.ncbi.nlm.nih.gov/books/NBK499883/ (2023). Accessed 15th October, 2023 2023.
56. Ye B-J, Kim B-G, Jeon M-J, Kim S-Y, Kim H-C, Jang T-W, Chae H-J, Choi W-J, Ha M-N, Hong Y-S (2016) Evaluation of mercury exposure level, clinical diagnosis and treatment for mercury intoxication. Ann Occup Environ Med 28:5.
57. Malsiu A, Shehu I, Stafilov T, Faiku F (2020) Assessment of Heavy Metal Concentrations with Fractionation Method in Sediments and Waters of the Badovci Lake (Kosovo). J Environ Public Health 2020:1–14.
58. Faseyi CA, Miyittah MK, Sowunmi AA, Yafetto L (2022) Water quality and health risk assessments of illegal gold mining-impacted estuaries in Ghana. Mar Pollut Bull 185:114277.
59. Lucero Rincón CH, Peña Salamanca EJ, Cantera Kintz JR, Lizcano OV, Cruz-Quintana Y, Neira R (2023) Assessment of mercury and lead contamination using the bivalve Anadara tuberculosa (Arcidae) in an estuary of the Colombian Pacific. Mar Pollut Bull 187:114519.
60. Ebrahimi SJ, Eslami A, Ebrahimzadeh L. Evaluation of heavy metals concentration in the drinking water distribution network in Kurdistan villages in the year 2012. Research Journal of Pharmaceutical, Biological and Chemical Sciences. 2015;6:55-61.
61. Zhu Y, Yang Q, Wang H, Yang J, Zhang X, Li Z, Martín JD (2023) A hydrochemical and isotopic approach for source identification and health risk assessment of groundwater arsenic pollution in the central Yinchuan basin. Environ Res 231:116153.
62. De la Ossa CA, Ramírez-Giraldo AF, Arroyo-Alvis K, Marrugo-Negrete J, Díez S (2023) Neuropsychological effects and cognitive deficits associated with exposure to mercury and arsenic in children and adolescents of the Mojana region, Colombia. Environ Res 216:114467.
63. George CM, Sima L, Arias MHJ, Mihalic J, Cabrera LZ, Danz D, Checkley W, Gilman RH (2014) Arsenic exposure in drinking water: an unrecognised health threat in Peru. Bull World Health Organ 92:565–572.
64. Frisbie SH, Mitchell EJ (2022) Arsenic in drinking water: An analysis of global drinking water regulations and recommendations for updates to protect public health. PLoS One 17:e0263505.
65. Duncan AE (2020) The Dangerous Couple: Illegal Mining and Water Pollution—A Case Study in Fena River in the Ashanti Region of Ghana. J Chem 2020:1–9.
66. Fodoué Y, Ismaila A, Yannah M, Wirmvem MJ, Mana CB (2022) Heavy Metal Contamination and Ecological Risk Assessment in Soils of the Pawara Gold Mining Area, Eastern Cameroon. Earth 3:907–924.
67. Reuer MK, Bower NW, Koball JH, Hinostroza E, De la Torre Marcas ME, Surichaqui JAH, Echevarria S (2012) Lead, Arsenic, and Cadmium Contamination and Its Impact on Children's Health in La Oroya, Peru. ISRN Public Health 2012:1–12.
68. Gupta S, George N, Yadav M, Dwibedi V (2024) Optical detection of heavy metal contaminants: advancements with bio-functionalised gold nanoparticles in environmental monitoring. Chemical Papers 78:699–714.
69. Samlafo B (2006) Levels of cadmium in soil, sediment and water samples from Tarkwa and its environs. African Journal of Educational Studies in Mathematics and Sciences. 4:53-9.
70. Ren M, Zheng L, Hu J, Chen X, Zhang Y, Dong X, Wei X, Cheng H (2022) Characterisation of polycyclic aromatic hydrocarbons in soil in a coal mining area, East China: Spatial distribution, sources, and carcinogenic risk assessment. Front Earth Sci (Lausanne) 10:.
71. Wang XW, Zhong NN, Hu DM, Liu ZZ, Zhang ZH (2009) Polycyclic aromatic hydrocarbon (PAHs) pollutants in groundwater from coal gangue stack area: characteristics and origin. Water Science and Technology 59:1043–1051.
72. Makombe N, Gwisai RD (2018) Soil Remediation Practices for Hydrocarbon and Heavy Metal Reclamation in Mining Polluted Soils. The Scientific World Journal. 2018:5130430
73. Anderson GK, McCarthy JE (1994) Use of risk-based standards for clean-up of petroleum contaminated soil. Air force center for environmental excellence brooks afb tx. 1994.
74. Inyang SE, Aliyu AB, Oyewale AO (2019) Total petroleum hydrocarbon content in surface water and sediment of Qua-Iboe River, Ibeno, Akwa-Ibom State, Nigeria. Journal of Applied Sciences and Environmental Management 22:1953.
75. Puławska A, Manecki M, Flasza M, Styszko K (2021) Origin, distribution, and perspective health benefits of particulate matter in the air of underground salt mine: a case study from Bochnia, Poland. Environ Geochem Health 43:3533–3556.
76. Gren L, Krais AM, Assarsson E, Broberg K, Engfeldt M, Lindh C, Strandberg B, Pagels J, Hedmer M (2022) Underground emissions and miners' personal exposure to diesel and renewable diesel exhaust in a Swedish iron ore mine. Int Arch Occup Environ Health 95:1369–1388.
77. Saarikoski S, Salo L, Bloss M, Alanen J, Teinilä K, Reyes F, Vázquezuez Y, Keskinen J, Oyola P, Rönkkö T, Timonen H (2019) Sources and Characteristics of Particulate Matter at Five Locations in an Underground Mine. Aerosol Air Qual Res 9:2613–2624.
78. Syed Hasan S, Mohd Kusin F, Jusop S, Mohamat Yusuff F (2018) Potential of Soil, Sludge and Sediment for Mineral Carbonation Process in Selinsing Gold Mine, Malaysia. Minerals 8:257.
79. de Lucia Lobo F, Márcia Leão de Moraes Novo E, Clemente Faria Barbosa C, Hugo Fernandes de Vasconcelos V (2019) Monitoring Water Siltation Caused by Small-Scale Gold Mining in Amazonian Rivers Using Multi-Satellite Images. In: Limnology - Some New Aspects of Inland Water Ecology. IntechOpen
80. Karikari AY, Duah AA, Akurugu BA, Darko HF (2021) Assessing the impacts of artisanal mining on the quality of South-western Rivers System in Ghana. Environ Monit Assess 193:715.
81. Kwaansa-Ansah EE, Amenorfe LP, Armah EK, Opoku F (2017) Human health risk assessment of cyanide levels in

water and tuber crops from Kenyasi, a mining community in the Brong Ahafo Region of Ghana. Int J Food Contam 4:16.

82. Li Z, Zhao Q, Yang H, Liu Q, Zhang Y, Wang Y, Tong L (2022) Vertical Distribution of Cyanide and Heavy Metals in a Tailings Pond in Jilin, China. Minerals 12:1394.

83. Hassan NA, Sahani M, Hod R, Yahya NA (2015) A Study on Exposure to Cyanide Among a Community Living Near a Gold Mine in Malaysia. Journal of Environmental Health. 77:42-49.

84. Asare EA (2021) Impact of the illegal gold mining activities on Pra River of Ghana on the distribution of potentially toxic metals and naturally occurring radioactive elements in agricultural land soils. Chemistry Africa. 4:1051-68.

85. McAllister J, Kunsman GW, Levine BS (2020) Carbon Monoxide/Cyanide. In: Principles of Forensic Toxicology. Springer International Publishing, Cham, 545–560

86. Mantey J, Owusu-Nimo F, Nyarko K, Aubynn A (2017) Operational dynamics of "Galamsey" within eleven selected districts of western region of Ghana. Journal of Mining and Environment. 8:11-34.

87. Yeleliere E, Cobbina SJ, Duwiejuah AB (2018) Review of Ghana's water resources: the quality and management with particular focus on freshwater resources. Appl Water Sci 8:93.

88. Division EMSLCR (1991) Methods for the determination of metals in environmental samples. Chemistry Research Division, Environmental Monitoring Systems Laboratory.

89. Asuquo Isangedighi I, Samuel David G (2019) Heavy Metals Contamination in Fish: Effects on Human Health. Journal of Aquatic Science and Marine Biology 2:7–12

90. Raghunathan PL, Whitney EAS, Asamoa K, Stienstra Y, Taylor TH, Amofah GK, Ofori-Adjei D, Dobos K, Guarner J, Martin S, Pathak S, Klutse E, Etuaful S, van der Graaf WTA, van der Werf TS, King CH, Tappero JW, Ashford DA (2005) Risk Factors for Buruli Ulcer Disease (Mycobacterium ulcerans Infection): Results from a Case-Control Study in Ghana. Clinical Infectious Diseases 40:1445–1453.

91. Emmanuel AY, Jerry CS, Dzigbodi DA (2018) Review of Environmental and Health Impacts of Mining in Ghana. J Health Pollut 8:43–52

92. Yeboah JY (2008) Environmental and health impact of mining on surrounding communities: a case study of Anglogold Ashanti in Obuasi