



ENVIRONMENTAL HEALTH IMPACT ASSESSMENT OF ARTISAN GOLD MINING ACTIVITIES: A CASE STUDY OF GOLD MINING SITES IN OSUN STATE, SOUTH-WEST, NIGERIA.

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ABSTRACT

Mining activities have been identified as one of the major anthropogenic activities that release heavy metals into the ecosystem. Mining activity becomes even more harmful when it is done in an unregulated manner as in the case of artisanal mining. In this study, we assessed the effects of artisanal gold mining on the pH, dissolved oxygen concentration (DO), and biochemical oxygen demand (BOD) in drinking water nearest to the mining sites using appropriate methods. We also measured the concentrations of (Cu), lead (Pb), chromium (Cr), cadmium (Cd), and arsenic (As) in the drinking water and soil samples obtained from the artisanal gold mining sites with atomic absorption spectrophotometer (AAS). The results revealed that 59% of the water samples have acidic pH. Similarly, 73% of the water samples have DO that does not fall within the stipulated standard range. The BOD of only 3 water samples (14%) has values that are above the permissible limit. The heavy metal concentrations of water samples revealed that apart from Cu, the levels of other metals were above the permissible limits. Contrarily, the concentration of all the metals tested in all the soil samples falls within the standard permissible limit.

Keywords: Heavy metals, artisanal mining, water, soil, pollution.

INTRODUCTION

Mining is an essential activity of great economic importance through which important raw materials vital for industrial and technological advancement are obtained (Adewuyi and Laniyan 2023). Meanwhile, illegal mining mainly through artisanal or small-scale mining, has become one of the major routes of heavy metals exposure to the topsoil and water bodies with attendant negative impacts on the health status of humans and the ecosystem (Fatoki and Badmus 2022). The debilitating human health status and unsettling ecosystem occasioned by heavy metal exposure is a drawback to achieving sustainable development goals 3 and 15.

Although heavy metals are ubiquitous in the environment, anthropogenic activities, such as illegal mining further escalate the release of these heavy metals into the environment in a magnitude that is hazardous to the environment (Fatoki et al. 2022).

In many developing countries such as Nigeria, gold is one of the mineral resources mined actively by various artisans. In Nigeria, this illegal gold mining is common in places like Zamfara State in the northern part of Nigeria, and the Ife/Ijesa axis of Osun State in the southern part of the country. Meanwhile, previous studies have shown that metals such as cadmium (Cd), copper (Cu), lead (Pb), and zinc (Zn) are associated with gold mines and are therefore dispersed downstream as a result of the weathering process of tailings, enhancing the accumulation of these dangerous metals in the water bodies, soils, air, and food crops (Wani et al. 2021).

High levels of heavy metals in the soil have been shown to result in bioaccumulation in the crops grown on such soil, and they can therefore be transferred to other media via the food chain. Meanwhile, the bioconcentration factor (BCF) of heavy metals in the crop–soil interface has been well documented. Similarly, heavy metal contamination of water is expected to have a

myriad of negative effects on local consumption by residents. In addition, it may also result in ecological imbalance and potential disruption of food chains (Belle et al. 2021). Furthermore, exposure of humans to heavy metals has been linked with plethoral health challenges such as cancer of multiple origins, cardiovascular diseases, neurological disorders, etc. (Fatoki et al. 2019a). In many cases, it has been shown from previous studies that heavy metals induced toxicities via the induction of oxidative stress due to heavy metal-induced enhancement of free radical generation (Fatoki et al. 2019b).

Several countries of the world have had their share of heavy metal poisoning arising from illegal mining activities. These include Fetal Minamata Disease in Japan, mercury-contaminated grains in Iraq, heavy metal contamination of groundwater in Bangladesh, and heavy metal-contaminated drinking water in Hong Kong, Bolivia, and Berlin. In Nigeria, the incidence of Zamfara lead poisoning is one of the well-reported cases of heavy metal poisoning (Thurtle et al. 2024).

Continuous assessment and monitoring of the heavy metal concentration and its impact on the environment and water bodies in places where small-scale mining is actively taking place is essential to ensure an ambient environmental condition is sustained. This study for the first time, therefore aimed at determining the level of soil and drinking water heavy metal contaminations across various illegal mining sites in the Ife/Ijesa axis of Osun State, Nigeria.

MATERIAL AND METHODS

Description of Study Areas

The study was conducted in the Ife – Ijesa axis covering Ilesa East, Ilesa West, Atakunmosa East, Atakunmosa West, Ife Central, Obokun, and Osogbo Local Government Areas of Osun State, Southwest Nigeria. The study area is known for heavy artisanal mining activities. The Geographic Positioning System (GPS) of the sampling areas is detailed in Table 1. Samples were also taken from the Osun Osogbo River because most of the river water studied flows directly to the Osun Osogbo River.

Table 1: Description of the Study Areas

S/N	Location Name	Location Code	GPS Location
1	Ileki Mining Site	001M	N7°34'58''E4°47'37''
2	Ileki (Drinking Water)	001D	N7°34'58''E4°47'37''
3	Isireyun Village Mining Site	002M	N7°34'52''E4°41'35''
4	Isireyun Village (Drinking Water)	002D	N7°34'52''E4°41'35''
5	Ibodi Mining Site	003M	N7°34'52''E4°40'351''
6	Ibodi (Drinking Water)	003D	N7°35'34''E4°40'43''
7	Arowaji Mining Site 1	004M	N7°35'24''E4°38'48''
8	Arowaji (Drinking Water)	004D	N7°35'24''E4°38'48''
9	Arowaji Mining Site 2	004S	N7°35'24''E4°38'48''
10	Igila Mining Site	005M	N7°35'13''E4°39'58''
11	Igila (Drinking Water)	005D	N7°35'13''E4°39'58''
12	Ajangila Itamerin Mining Site	006M	N7°36'7''E4°41'39''
13	Ajangila Itamerin (Drinking Water)	006D	N7°36'7''E4°41'39''
14	Idominasi Mining Site	007M	N7°41'14''E4°42'10''
15	Idominasi (Drinking Water)	007D	N7°41'25''E4°42'22''
16	Oora Mining Site 1	008M	N7°42'29''E4°40'7''
17	Zion City – 100 meters from Oora 1 mining site. (Drinking Water)	008D	N7°42'32''E4°40'4''
18	Oora Mining Site 2	009M	N7°42'39''E4°39'49''
19	Ikamu Village – 90 metres from Oora 2 mining site. (Drinking Water)	009D	N7°43'2''E4°38'49''
20	Osun Osogbo River Water	010	N7°45'20''E4°33'6''
21	Ilesa Township Borehole Water	011B	N7°37'40''E4°29'80''
22	Ilesa Township Well Water	011W	N7°37'40''E4°29'80''

A total of twenty-two (22) water samples, comprising eleven (11) each from the mining sites and sources of drinking water closest to the mining site were collected into sterilized plastic bottles from various locations as described in the study areas detailed above. Soil samples were also collected from each of these sampling sites. The soil samples were also collected into sterilized sample bottles. All samples were transported immediately to the laboratory on ice packs for further laboratory analysis.

Determination of Physical Characteristics of Water Samples

pH

The pH of the water samples was determined using a standardized digital pH meter with a glass electrode (Rex model pHs 25) at the collection point.

Dissolved Oxygen (DO)

The dissolved oxygen of all the water samples was measured using a standardized digital dissolved oxygen (DO9100) at the collection point.

Biochemical Oxygen Demand (BOD)

BOD was determined by incubating all the water samples in the dark for five (5) days at 20°C, enhancing various conditions for the decomposition of organic matter by the microorganisms. The difference between DO levels before and after the five (5) days incubation period measures the total amount of oxygen consumed by the microbes for the decomposition processes provided in the BOD data (Neetia and Jawalkar 2024).

Determination of Total Cu, Pb, Cr, Cd, and As in the Water Samples

A small quantity of each water sample (100 ml) was digested in concentrated HNO₃ at 80° in a fume cupboard. Concentrated HNO₃ at a high temperature (≥ 60°C) is a potent oxidizing agent capable of liberating metals from materials in the form of soluble nitrate salt (Hu and Qi 2014). Total Cu, Pb, Cr, Cu, and As concentrations (in ppm) of

the water samples were determined using atomic absorption spectrometry

Determination of Total Cu, Pb, Cr, Cd, and As in the Soil Samples

A portion of the dried soil samples (1 g) were digested in aqua regia (mixture of concentrated HCl and HNO₃ in a ratio of 3:1 v/v) at 80°C in a fume cupboard. Aqua regia has stronger dissolving and oxidizing power than the 2 constituting acids (Balaram and Subramanyam 2022). The soil samples' total Cu, Pb, Cr, Cu, and As concentrations (in ppm) were determined using atomic absorption spectrometry.

Statistical Analysis

Statistical analysis was conducted with GraphPad® Prism 5 and data are expressed as mean ± SD of five independent evaluations.

Results

The pH, DO (mg/L), and BOD (mg/L) of all the 22 water samples studied are presented in Table 2. As shown, the pH of the water samples ranges from 4.9 (Ilesa Township Borehole Water) to 7.4 (Oora Mining Site), with 13 out of the 22 water samples representing 59% having acidic pH. The pH of the remaining 9 (41%) water samples falls within the basic range of the pH scale. Similarly, the DO of the 22 water samples ranges between 1.30 mg/L (Arowaji Mining Site 2) and 14.20 mg/L (Ileki Mining Site). As shown in the Table, only 5 (23%) water samples have DO values that are within the normal range of 6.5 – 80 mg/L as stipulated by the World Health Organization (WHO). 16 water samples representing 27% and 11 water samples representing 50% have DO values that are above and below the WHO values respectively. Furthermore, as also presented in Table 2, the Ileki Mining Site has the highest BOD of 8.10 mg/L, while Arowaji Mining Site 2 has no BOD value. Meanwhile, 3 water samples representing 14% have BOD values that are above the permissible limit of 6.0 mg/L as stipulated by the National Environmental Standard and Regulation Enforcement Agency (NESREA)

Table 2: Physical Characteristics of Water Samples

S/N	Location Code	pH	Dissolved Oxygen (mg/L)	Biochemical Oxygen Demand (mg/L)
1	001M	7.1	14.20	8.10
2	001D	6.4	7.90	2.20
3	002M	7.1	8.90	3.50
4	002D	7.0	7.60	4.30
5	003M	7.4	8.60	3.00
6	003D	6.6	6.10	0.63
7	004M	6.3	2.06	0.10
8	004D	6.3	4.16	0.43
9	004S	6.7	1.30	0.00
10	005M	7.3	8.60	3.90
11	005D	7.2	6.40	2.70
12	006M	5.8	5.40	0.30
13	006D	6.6	4.90	2.10
14	007M	6.5	5.60	2.97
15	007D	6.3	6.70	0.53
16	008M	7.2	9.00	6.67
17	008D	5.7	4.40	0.90
18	009M	7.4	12.40	9.00
19	009D	5.4	7.20	2.00
20	010	7.4	7.50	2.81
21	011B	4.9	4.30	2.00
22	011W	5.5	7.43	2.10

The concentration (ppm) of Cu, Pb, Cr, Cd, and As in the water samples tested in the present study are shown in Table 3 as mean \pm SD. The water samples with the highest concentration for each of the metals are Isiregun Village Drinking

Water (0.138 ± 0.0012), Isiregun Village Drinking Water (0.61 ± 0.009), Arowaji Mining Site 1 (601 ± 0.03), Ibodi Mining Site (0.015 ± 0.004) and Ikamu Village Drinking Water (0.014 ± 0.0003) for Cu, Pb, Cr, Cd, and As respectively.

Table 3: The levels of heavy metals (Cu, Pb, Cr, Cu, and As) in Water Samples

S/N	Location Code	Cu (ppm)	Pb (ppm)	Cr (ppm)	Cd (ppm)	As (ppm)
1	001M	0.058 ± 0.0007	0.07 ± 0.001	0.289 ± 0.01	0.013 ± 0.003	0.008 ± 0.0002
2	001D	0.067 ± 0.0003	0.04 ± 0.006	0.266 ± 0.07	0.010 ± 0.002	0.008 ± 0.0001
3	002M	0.041 ± 0.0009	0.10 ± 0.003	0.382 ± 0.06	0.010 ± 0.001	0.007 ± 0.0003
4	002D	0.138 ± 0.0012	0.61 ± 0.009	0.295 ± 0.18	0.011 ± 0.002	0.010 ± 0.0007
5	003M	0.054 ± 0.0006	0.22 ± 0.006	0.463 ± 0.03	0.015 ± 0.004	0.009 ± 0.0001
6	003D	0.076 ± 0.0001	0.28 ± 0.007	0.377 ± 0.09	0.012 ± 0.001	0.009 ± 0.0003
7	004M	0.258 ± 0.0018	0.14 ± 0.008	0.601 ± 0.03	0.012 ± 0.002	0.007 ± 0.0004
8	004D	0.021 ± 0.0004	0.09 ± 0.0001	0.292 ± 0.05	0.013 ± 0.001	0.007 ± 0.0005
9	004S	0.041 ± 0.0002	0.14 ± 0.001	0.387 ± 0.09	0.011 ± 0.002	0.007 ± 0.0001
10	005M	0.024 ± 0.0007	0.25 ± 0.003	0.290 ± 0.11	0.012 ± 0.003	0.012 ± 0.0003
11	005D	0.001 ± 0.0003	0.23 ± 0.002	0.175 ± 0.02	0.013 ± 0.004	0.007 ± 0.0002
12	006M	0.005 ± 0.0005	0.20 ± 0.001	0.398 ± 0.07	0.011 ± 0.003	0.008 ± 0.0001
13	006D	0.009 ± 0.0004	0.12 ± 0.001	0.445 ± 0.03	0.011 ± 0.001	0.006 ± 0.0005
14	007M	0.093 ± 0.0004	0.29 ± 0.003	0.470 ± 0.04	0.011 ± 0.001	0.010 ± 0.0002
15	007D	0.058 ± 0.0007	0.12 ± 0.002	0.340 ± 0.05	0.014 ± 0.002	0.010 ± 0.0004
16	008M	0.032 ± 0.0006	0.14 ± 0.001	0.507 ± 0.08	0.011 ± 0.003	0.006 ± 0.0001
17	008D	0.015 ± 0.0009	0.14 ± 0.003	0.436 ± 0.02	0.012 ± 0.002	0.010 ± 0.0003
18	009M	0.010 ± 0.0003	0.17 ± 0.004	0.556 ± 0.04	0.012 ± 0.003	0.013 ± 0.0003
19	009D	0.006 ± 0.0001	0.13 ± 0.001	0.427 ± 0.08	0.012 ± 0.002	0.014 ± 0.0001
20	010	0.008 ± 0.0002	0.18 ± 0.004	0.506 ± 0.06	0.011 ± 0.001	0.009 ± 0.0002
21	011B	0.015 ± 0.0001	0.25 ± 0.003	0.428 ± 0.07	0.011 ± 0.002	0.009 ± 0.0001
22	011W	0.010 ± 0.0003	0.12 ± 0.006	0.470 ± 0.04	0.013 ± 0.001	0.004 ± 0.003

Table 4 shows the concentrations (ppm) of all the 5 metals tested in the 22 soil samples considered in this study. As shown, the locations with the highest concentration of Cu, Pb, Cr, Cd,

and As are Ibodi Mining Site (22.83 ± 0.79), Ibodi Mining Site (22.25 ± 1.73), Idominasi Drinking Water (72.83 ± 1.39), Osun Osogbo River Water (0.73 ± 0.01), Ilesa Township Well Water (0.55 ± 0.01) respectively.

Table 4: The level of heavy metals (Cu, Pb, Cr, Cu, and As) in Soil Samples

S/N	Location Code	Cu (ppm)	Pb (ppm)	Cr (ppm)	Cd (ppm)	As (ppm)
1	001M	7.23 ± 0.91	13.50 ± 1.07	15.95 ± 0.99	0.38 ± 0.01	0.43 ± 0.03
2	001D	17.40 ± 0.68	18.75 ± 0.99	10.33 ± 1.01	0.25 ± 0.01	0.40 ± 0.02
3	002M	5.00 ± 0.17	3.25 ± 0.12	15.05 ± 0.89	0.28 ± 0.09	0.48 ± 0.02
4	002D	9.43 ± 0.36	11.25 ± 0.89	7.55 ± 0.71	0.40 ± 0.02	0.40 ± 0.01
5	003M	22.83 ± 0.79	22.25 ± 1.73	30.78 ± 1.48	0.38 ± 0.01	0.45 ± 0.04
6	003D	9.05 ± 0.09	17.50 ± 1.01	59.83 ± 2.11	0.43 ± 0.03	0.45 ± 0.03
7	004M	6.85 ± 0.06	4.00 ± 0.09	7.63 ± 0.16	0.55 ± 0.05	0.35 ± 0.02
8	004D	7.85 ± 0.82	13.25 ± 1.73	19.71 ± 0.78	0.45 ± 0.02	0.40 ± 0.02
9	004S	3.58 ± 0.05	2.50 ± 0.09	1.35 ± 0.07	0.35 ± 0.10	0.55 ± 0.04
10	005M	13.30 ± 1.10	11.50 ± 1.03	6.10 ± 0.12	0.50 ± 0.09	0.37 ± 0.02
11	005D	8.90 ± 0.89	8.25 ± 0.89	37.75 ± 1.79	0.45 ± 0.10	0.35 ± 0.02
12	006M	2.70 ± 0.02	9.75 ± 1.03	8.85 ± 0.73	0.50 ± 0.04	0.33 ± 0.07
13	006D	4.33 ± 0.43	4.00 ± 0.17	8.33 ± 0.96	0.50 ± 0.06	0.45 ± 0.02
14	007M	8.03 ± 0.19	2.25 ± 0.09	4.05 ± 0.09	0.48 ± 0.02	0.38 ± 0.02
15	007D	7.15 ± 0.08	5.00 ± 0.17	72.83 ± 1.39	0.45 ± 0.07	0.48 ± 0.03
16	008M	4.08 ± 0.02	6.25 ± 0.89	9.65 ± 0.91	0.53 ± 0.06	0.50 ± 0.02
17	008D	4.45 ± 0.13	3.50 ± 0.16	20.58 ± 1.06	0.48 ± 0.04	0.30 ± 0.03
18	009M	7.60 ± 0.18	14.25 ± 1.03	4.00 ± 0.19	0.55 ± 0.07	0.40 ± 0.04
19	009D	3.63 ± 0.04	4.75 ± 0.78	11.75 ± 0.48	0.58 ± 0.03	0.43 ± 0.02
20	010	2.35 ± 0.08	4.50 ± 0.05	7.68 ± 0.66	0.73 ± 0.10	0.48 ± 0.02
21	011B	3.30 ± 0.07	18.00 ± 0.93	6.60 ± 0.08	0.70 ± 0.03	0.45 ± 0.03
22	011W	2.59 ± 0.01	16.72 ± 0.79	6.71 ± 0.12	0.68 ± 0.05	0.55 ± 0.01

DISCUSSION

Heavy metal contamination is part of the contemporary serious public health challenges (Angon et al. 2024). The World Health Organization (WHO) has previously noted with caution the ecological degradation due to the substantial level of Pb, Cd, Cr, As, and Cu as contaminants in the drinking water of many developing countries. Additionally, Ni, Cd, Hg, Cu, Cr, As, Pb, and Zn are the common metals that contaminate various components of the

environment such as water, soil, and air (Rashid et al. 2023). Lead (Pb), Cd, Hg, Cr, and As have been classified as potent toxicants (Rai et al. 2019). Meanwhile, the Agency for Harmful Substances and Disease Registry (ATSDR) has identified Pb, Cd, and Cr as extremely dangerous to *fauna* and *flora*. This is due to the ability of these heavy metals to bioaccumulate and bio-magnify in human cells. The effects of heavy metals have been linked to the etiology of many human disorders such as cancer of multiple origins, renal dysfunction, immunodeficiency, and death

(Angon et al. 2024).

This study determines Pb, Cd, Cr, As, and Cu levels in soil and water samples as a possible consequence of artisanal gold mining activities. In addition, the pH, concentration of DO, and BOD of the various water samples were obtained from the study area. Chemical and microbial portable water is one of the necessities for the sustenance of human life (Yuan et al. 2024). DO, pH, and BOD are important markers widely used for assessing the level of contamination in any given water sample. A measure of the degree of the solution's alkalinity or acidity is pH, which determines water quality. Meanwhile, it has been reported that human activities such as mining can influence the pH of water bodies. Solubility and bioavailability of minerals and nutrients in the water are subject to the pH of the water. Low pH enhances toxic metals released from the sediment into the water while high pH reduces oxygen bioavailability in the water body. Water with a neutral pH has therefore been adjudged as the water that is safe for the entire ecosystem. Similarly, alkaline water with a pH higher than 8.5 has been linked to various health challenges such as skin irritation, and gastrointestinal disorders among others (Yuan et al. 2024). In this study, the pH of most of the water samples used for drinking in the study sites falls within the acidic and neutral region of the pH scale. The WHO standard range for drinkable water is between 6.5 and 8.5. The water samples of nine study sites fell below the pH of 6.5 WHO standard for drinking water. The artisanal mining activity could have been responsible for the low pH levels of the drinking water, a recipe for several non-communicable diseases for the exposed humans in the studied sites.

DO is a biochemical and physicochemical water quality index that reflects the balance between the quantity of oxygen produced and consumed (Yuan et al. 2024). Meanwhile, water quality primarily indicates the health status of the ecosystem in an aquatic community. DO plays a vital role in the reproduction and growth of marine animals and, the metabolic transformation of nutrients in the water space. DO is one of the most important parameters for determining the degree of eutrophication and water quality. Reduced DO concentration has been reported to cause asphyxiation, eutrophication, and death of animals

among other challenges within the aquatic space (Rodríguez-Gómez et al. 2021). Furthermore, biodegradation of organic matter, microbial growth and metabolism, and oxidation of inorganic substances in the marine ecosystem is impeded by low DO. Similarly, low DO concentration in water indicates enhanced environmental pollution as one of the direct consequences of global climate change. In this study, about 50% of water samples fell below the WHO standard range between 6.5 and 8.0 mg/L. Maintenance of the water DO level at an optimum value is a crucial aquaculture and wastewater treatment (Li et al. 2022). The mining activities in the studied area have distorted the site ecosystem making the water unsuitable for humans and microbes.

Biochemical Oxygen Demand (BOD) also known as biological Oxygen Demand is the quantity of dissolved oxygen (mg/L) that an aerobic biological organism requires to fully oxidize organic matter that is present in a particular water sample at a specific temperature and time. It is the oxygen equivalent of the sample's organic portion with susceptibility to oxidation by a potent chemical oxidant. It is a vital environmental marker for oxygen requirements assessment in a water body. It is also a measure of the amount of organic matter available as a substrate to support the growth and development of aquatic organisms (Alewi et al. 2021). In Nigeria, the permissible water BOD level stipulated by the National Environmental Standards and Regulation Enforcement Agency (NESREA) is 6.0 mg/L (NESREA 2011). Although, in the present study, only 3 of the 22 water samples tested have BOD values above the NESREA value, others have values that range from 0.1 to 4.3 mg/L which shows varying degrees of pollution that is most likely due to the artisanal mining activities at various locations in the vicinity of the water bodies.

The contamination of drinking water by Cu has been identified as a serious public health concern (Manne et al. 2022). Although Cu is an essential micronutrient, the United States Environmental Protection Agency (USEPA) has stipulated 1.3 ppm as the tolerable limit of Cu in drinking water (USEPA 1991). At a concentration, higher than this, acute health challenges such as

central nervous disorder, gastrointestinal problems, muscular irritation, and renal, hepatic, and blood capillary damage are some of the consequences of consumption of drinking water with Cu concentration above the set limit. Araya et al (Araya et al. 2001) however noted that drinking water with a low Cu concentration (below the permissible limit) is beneficial to human health. The Cu contents of all the water samples tested in this study were below the 1.3 ppm benchmark and, this suggests that the activities of the artisanal miners may not have any significant effects on the Cu concentration in the water bodies. Cu tends to accumulate in the topsoil as a result of the limited mobility of Cu in the soil and its adsorption onto the soil's organic and mineral materials (Poggere et al. 2023). The contamination and accumulation of Cu in the soil have been reported to be majorly from mining and other human activities. Contamination of soil by excessive copper contents has been shown to possess myriads of ecological risks and compromise the functions of the ecosystem. Other studies have indicated a high tendency for Cu to accumulate in plant tissues (Penteado et al. 2021). In the present study, the Cu concentration in all the soil tested ranges between 2.3 and 22.83 ppm which falls below the 36 ppm permissible limit of Cu in the soil (WHO 1996). It is therefore not out of place to propose that artisanal gold mining posed no significant effects on the Cu contents of the soil and water samples in the mining areas.

Pb-contaminated drinking water constitutes a man-made global human health risk of major concern (Jarvis and Fawell, 2021). There is a strong relationship between human exposure to lead and several negative consequences on human health. The World Health Organization (WHO) has highlighted Pb as one of the most potent environmental poison. It has been revealed by a recent study that an estimated 400,000 people die of cardiovascular disease in the United States of America (USA) alone as a result of exposure to minimal levels of Pb level (Jarvis and Fawell, 2021). Regulatory standards have become more stringent in setting the permissible limit for Pb in drinking water because of the potent harmful impacts of lead. The WHO and European Commission (EC) guidelines set a value of 10 µg/L as a provisional value (EC 2019). Meanwhile, the

USEPA in its case, sets an aspirational permissible target limit of 0 µg/L (USEPA 2018). The major source of Pb contamination in the soil is the mining of gold and other mineral resources. Ingestion of soil or dust contaminated with Pb is the major route of exposure and, other heavy metals. The permissible limit of soil Pb has been set at 85 mg/kg (WHO 1996). The high concentration of Pb in both the water and soil samples tested in the present study could be safely attributed to the activities of the artisanal miners in the sampling area (Raj and Das 2023), and this is expected to lead to the myriads of health risk associated with Pb exposure.

Chromium is a toxic heavy metal naturally found in the environment. Industrial and manufacturing activities are the major environmental sources of Cr exposure. Mining activities have also been reported as another major source of environmental Cr contamination that is fast becoming a major global health concern constituting a severe health risk. Most Cr compounds are water soluble enhancing their entrance into the food chain (Prasad et al. 2021). The permissible limit of Cr as recommended by WHO in the soil and drinking water is 100 ppm and 50 µg/L respectively (WHO 1996). As observed in the present research, the quantity of Cr detected in the water samples is higher than the permissible limit indicating a potential health hazard for people drinking such water. The levels of Cr in the soil samples tested are below the limit stipulated by WHO. This result indicates that mining activity in the studied areas might have affected the release of the metal from the soil into the water bodies. Although Cr plays a major role in the metabolism of biomolecules in human cells, it poses severe human health hazards such as respiratory tract disorder, lung cancer, and gastric cancer, as well as DNA, hepatic, and renal damage in fish. Similarly, it has been reported that Cr from contaminated soil and water could be translocated and accumulated in the various parts of plants grown in the affected area causing a reduction in shoot and root ground biomass, poor flowering and fruit setting, and ultimately crop yield loss and reduced quality of the eventual produce (Pinto et al. 2020).

Cadmium (Cd) is a non-essential ubiquitously present environmental trace element and one of the most toxic heavy metals. Mining

activity, application of Cd-containing fertilizers, and atmospheric deposition of combustion emissions are ways by which Cd contaminates soil and groundwater. As a result of its toxicity and ability to accumulate in human tissues, Cd-induced cellular oxidative stress results in organelle damage, leading to the pathogenesis of a myriad of oxidative stress-induced pathological conditions (Sevak and Pushkar 2024). For safety purposes, the permissible limit for Cd in the soil and drinking water has been put at 0.8 mg/kg (WHO 1996) and 0.5 µg/L (UNEP 2010) respectively. The low levels of Cd in this study may be because the studied area has low Cd contents and artisanal mining has little effect on Cd contents.

Arsenic (As) pollution and its eventual health risks are widely studied and reported (Fatoki and Badmus 2022). Anthropogenic activities (such as mining), weathering, natural biochemical reactions, and mineral dissolution are some processes that release As into the environment and contaminate it (Sevak and Pushkar 2024). Thus, the release and distribution of arsenic in the environment are largely influenced by human activities (Zohra et al. 2024). Arsenic is ubiquitous in the environment been the 20th most frequent metal in the earth's crust (Fatoki and Badmus 2022) and has been classified among the top 10 chemicals that constitute a major threat to human health. The concentration of As in the soil and water samples obtained from the areas where artisanal mining is taking place showed moderately low arsenic contamination below the WHO allowable 24 mg/kg (soil) and 10 ppb (drinking water) (WHO 2020). This might indicate that the As content of the soil is below the limit which can lead to the release of a substantial amount of As into the environment due to mining activity.

CONCLUSION

This study reveals an increase of some heavy metals in the gold mining area's drinking water and topsoil. This is a potential human health risk and ecosystem unsettling that can arise from the pollution of drinking water and soil samples. Therefore, the authors recommend alternative provision of safe water and strict government policies to address the identified artisanal gold mining-induced environmental pollution.

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Conflict of interest

The authors have no relevant financial or non-financial interests to disclose.

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