2.0 Material and methods

A total of 24 dust samples were collected randomly including control samples from four different Quarries with a plastic scoop to collect the settled dust into polyethylene bags in each of the study areas. Analysis of pH and EC of dust samples was achieved using standard methods at Activation Laboratory, Canada. Analysis of metals was carried out on the samples, using the Inductively Coupled Plasma – Mass Spectrometry (ICP-MS) technique in Actlabs, Canada. Furthermore, the degree of a linear association between the physical parameters and both heavy and trace metals were measured by Pearson's correlation at $p<0.01$ and $p<0.05$ to observe their relationships.

3.0 Results and Discussion

Results of the analysed pH, EC and selected metals are shown in table 1 below:

Table 1: Analysed parameters in the dust of the quarry sites

Sample Location (s)	GPS Coordinates (Longitude/Latitude)	pH	EC (µS/cm)	Zn(ppm)	Cu(ppm)	Cr(ppm)	Pb(ppm)
FW SAN QUARRY	7⁰14′ 51.6360′ ′ N 3⁰29′ 34.2540′ ′ E	8.50±0.34[B]	271±77.30[a]	98.8±15.5[b]	20±5.54[b]	24±7.81[b]	5.57±1.92[a]
DE CROWN QUARRY	7⁰15′ 32.6580′ ′ N 3⁰32′ 15.1260′ ′ E	8.50±0.34[B]	388.17±91.75[b]	5.57±1.92[a]	15.2±0.40[a]	35±5.57[a]	5.57±1.92[a]
EMPTECH QUARRY	7⁰15′ 28.1940′ ′ N 3⁰31′ 57.6840′ ′ E	8.38±0.18[b]	220.83±72.28[a]	90.1±7.71[b]	17.1±0.89[a]	25.7±13.31[a]	5.70±0.40[a]
DLK QUARRY	7⁰15′ 17.6820′ ′ N 3⁰31′ 29.9220′ ′ E	8.54±0.07[B]	277.50±12.74[a]	109.3±9.35[b]	15.5±7.58[b]	26.3±3.79[b]	6.03±0.92[a]
USEPA Limit (1992)				500	100	5	5
Dosage of elemental Inhalable dust				2.65 x10 $^{-8}$ m ^{3} day $^{-1}$	4.80 x10 $^{-9}$ m ^{3} day $^{-1}$	8.608 x10 $^{-9}$ m ^{3} day $^{-1}$	1.46 x10 $^{-9}$ m ^{3} day $^{-1}$

The result of the physical parameters of sampled quarry dusts indicates that, the values of pH and electrical conductivity ranged from 8.38 to 8.70 and 388 to 220 respectively). The results reflect a medium acid to a slightly alkaline soil pH condition. The mean concentration of heavy metals that were analysed showed that highest elemental concentration was observed in Mn giving 549ppm followed by Zn, Cr, Cu, Ni, Co, Pb, Fe, Mo, Al and Cd. In trace element concentration Barium (Ba) has the highest concentration in all the sampling locations with an average value ranging from 158.3ppm. All the elemental concentrations were above USEPA detention limit. The dosage of elemental dust inhalable by an adult from the quarry site were in the order of Zn < Cr < Cu<Pb with values calculated as 2.65 x10 $^{-8}$, 8.608 x10 $^{-9}$, 4.80 x10 $^{-9}$ and 1.46 x10 $^{-9}$ m ^{3} day $^{-1}$ respectively.

4.0 Conclusions

The dusts of the analysed quarry sites are generally acidic in nature and relatively rich in carcinogenic metals which presently pose minimal health risk.

References

Divya, C.M., Divya, S., Ratheesh, K. & Volga, R. (2012). Environmental issues in stone crushers.

Reddy, M.V. and Reddy, C.N.V.S. (2007). "An experimental study of rock flour and insulator ceramic scrap in concrete", *Journal of Institute of Engineer (India), Vol-88*, August, pp 4750.

United States Environmental Protection Agency (USEPA). Method 1311 Toxicity Characteristics Leaching Procedure (TCLP). United States Environmental Protection Agency (USEPA), United States; 1992 Jul. p. 1–35

ASSESSMENT OF THE QUALITY OF SOILS AROUND ARTISANAL GOLD MINE PITS IN OSU AND ITAGUNMODI AREAS, SOUTHWESTERN NIGERIA

[1,] Mustapha, S. O., [2]Olajide-Kayode, J. O. and [3]Olatunji, A. S.

[1]*Department of Geology, Kwara State University, Malete, Nigeria*

[2]*Department of Geosciences, Pan African University Life and Earth Sciences Institute, University of Ibadan, Ibadan, Nigeria*

[3]*Department of Geology, University of Ibadan, Ibadan, Nigeria*

Abstract. Osu and Itagunmodi areas of southwestern Nigeria have a long history of artisanal gold mining. The mining activities are done with crude tools and equipment with no safety regulations or precautions, and can adversely affect not only environmental media but also the health of miners and residents around mining sites. An evaluation of the quality of soils around Artisanal Gold Mine (AGM) pits within Osu and Itagunmodi areas, and the potential impact on the health of artisanal miners and residents is presented in this study. Forty-eight soil samples obtained around AGM pits at Orogo, Amuta and Itagunmodi areas were analysed for Potentially Harmful Elements (PHEs) such as Mo, Cu, Pb, Zn, Ni, Co, As, Cd and Hg, using Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) technique sequel to aqua regia digestion. Calculated Enrichment Factor and Geo-accumulation Index revealed that the soils around the AGM pits are moderately contaminated with Cu, Co, Pb Zn, Cd and Hg; while strong As contamination was detected in soils at Orogo area. Prolonged contact with these soils therefore poses significant health risks to the artisanal miners and residents of the areas investigated. Long term effects of exposure to these PHEs include damage to the liver, kidney,

heart, blood vessels, thyroid; and cancer of the skin, lung and bladder.

Keywords. Artisanal Mining, Potentially Harmful Elements (PHEs), Enrichment Factor, Geo-accumulation Index

1.0 Introduction

Primary and placer gold deposits are hosted within the north-south trending, Proterozoic Ilesa Schist Belt in Southwestern Nigeria. The primary gold is hosted within metabasic and metasedimentary units, especially east of the Ifewara Zungeru Fault (IZF). Placer deposits in alluvium and eluvium, which occurs in areas west of the IZF (Oyinloye and Steed, 1993), are mainly exploited by small-scale artisanal mining. The mining, processing operations (milling, panning and sluicing) and disposal of mine waste water are all potential sources of environmental pollutants. The mining activities are done with crude tools and equipment with no safety regulations/precautions (Fig. 1), and often adversely affect not only environmental media (such as soil, air and water) but also the health of miners and residents around mining sites. It is therefore a serious potential source of risk to the environment and human health. Land degradation and loss of vegetation are other resultant adverse effects of artisanal mining. Numerous health problems have been associated with artisanal gold mining processes (Adriano, 1986). The processes of exploitation, ore transport, processing and disposal of mine waste (tailings and water) has been linked directly to metal contamination around gold mines (Taiwo and Awomeso, 2017). Artisanal gold mining has been revealed as the primary source of exposure to mercury; as it is believed to release 1000t of mercury (30-40% of global emissions) into the environment annually (Basu et al., 2015). According to Obiri et al. (2016), gold miners are at the risk of exposure to mercury, arsenic, cadmium and chromium. Toxicity of these metals lead to neurological disorders, cardiovascular diseases, high blood pressure, renal dysfunction and cancer (Rajaee et al., 2015; Choi et al., 2009; Goodrich et al., 2012; International Agency for Research on Cancer (IARC), 2012).

In Osu and Itagunmodi areas of Southwestern Nigeria, artisanal gold mining from eluvial deposits is prevalent. The gold is mined from near-surface and underground pits. Being rural/semi-urban areas, agriculture and animal husbandry practices are prevalent, surface water sources are also often used for domestic purposes. Quantitative data on the concentration of Potentially Harmful Elements (PHEs) in soils around the Artisanal Gold Mine (AGM) pits within the study areas has not been obtained, and their contamination levels have also not been determined. This study therefore evaluated the quality of soils around artisanal gold mine pits within Osu and Itagunmodi areas, and the potential risk posed to the health of artisanal miners and residents.



Figure 1. Artisanal gold mining process at Osu, Southwestern Nigeria

2.0 Material and Methods

Forty-eight soil samples were obtained from vertical (down-pit; n=9) and horizontal profiles (n=39) at three active AGM pits: Orogo (Osu area), Amuta and Itagunmodi (Itagunmodi area). Vertical profile samples were collected at intervals from the top of the mine pit to the gold-bearing saprolite at pit base, while samples were obtained at depths 0-30cm from the horizontal profiles at defined intervals of 50m and 100m from the AGM pits. At Orogo, soil samples were collected, at 100m sample spacing, from lateral profiles in the northern, eastern and southern directions away from the mine pit (Fig. 2). Down-pit soil samples were obtained at depths 0m (top of mine pit), 1m and 2m. Horizontal profile samples were obtained at 50m intervals away from the AGM pits at both Amuta and Itagunmodi in the eastern and northwestern directions (Figs. 3 and 4). Vertical profile samples obtained at Itagunmodi pit were collected at the top of the pit, 1m and 2m depths while samples were collected at the top, 1.5m and 3.5m at Amuta. The sampling was done within a 700m radius around the AGM pit at Orogo, and 250m radius around AGM pits at Amuta and Itagunmodi

The soil samples were air-dried, disaggregated with an agate mortar and sieved to extract the <75-micron fractions at the Geochemistry Laboratory, University of Ibadan. The concentrations of PHEs such as Mo, Cu, Pb, Zn, Ni, Co, As, Cd and Hg in the sieved fractions were analysed using ICP-MS sequel to aqua regia digestion at Bureau Veritas Minerals Pty. Ltd, Vancouver, Canada. The data generated were analysed using contamination indices and descriptive statistics.

© IMGA NIGERIA

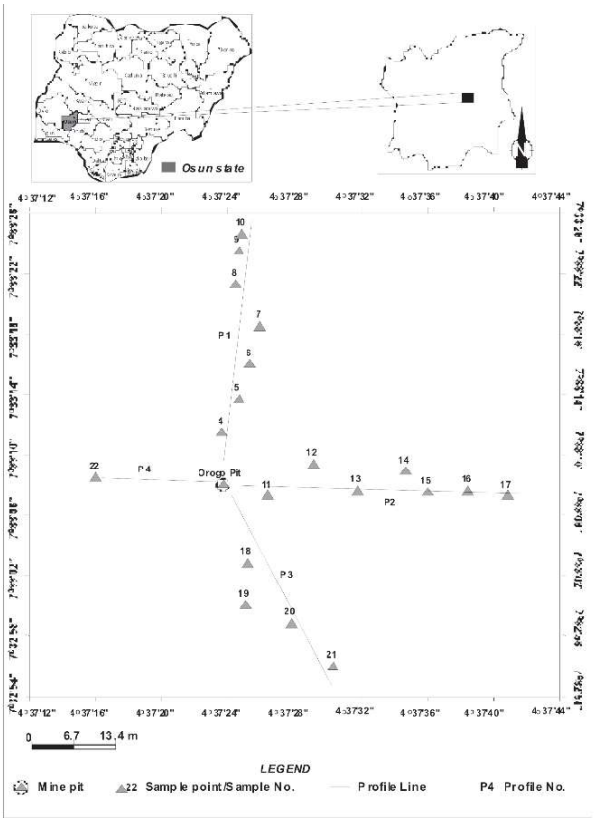


Figure 2. Soil sampling sites map for Orogo Area.

3.0 Results and Discussion

Concentration of PHEs detected in soils sampled from Orogo, Amuta and Itagunmodi areas respectively were: Mo (0.3-1.77; 0.63-1.25; 0.34-0.96), Cu (20.21-279.19; 42.05-108; 45.91-225.46), Pb (12.82-16.67; 13.25-21.25; 12.81-21.87), Zn (22.1-85; 54.1-85.9; 63.9-106.3), Ni (11.9-49.9; 32.2-56.4;31.6-71.7), Co (5.8-92.7; 30.1-92.6; 44.1-86), As (BDL-39.8; 1.1-2.7; 0.5-2.8), Cd (BDL-0.23; 0.02-0.21;0.03-0.22) and Hg (0.04-0.15; 0.04-0.15; 0.03-0.11).

The assessment of the degree of enrichment/contamination of the PHEs in the soils of the study areas was calculated using Enrichment Factor (EF) (Simex and Helz, 1981) and Index of Geoaccumulation (Igeo) (Muller, 1969), respectively using the relations:

$$\mathbf{EF = (C_x / C_{Rx})_{Sample} / (C_x / C_{Rx})_{Reference\ sample}}$$

$$\mathbf{Igeo = Log_2 (Cn / 1.5Bn)}$$

where:

- C_x is the concentration of element in the sample of interest and reference sample, while C_{Rx} is the concentration of reference (immobile) element (i.e. Al).

- Cn indicates the measured concentration of element *n* in the media of interest, Bn is the background concentration of element *n* in the media of interest, while 1.5 is a factor compensating for variation due to lithologic effects and minor anthropogenic influences. Background concentrations used for the contamination assessment are Average Crustal Values (ACV) of Alloway (1990) and Taylor (1964), and calculated background values for the study areas.

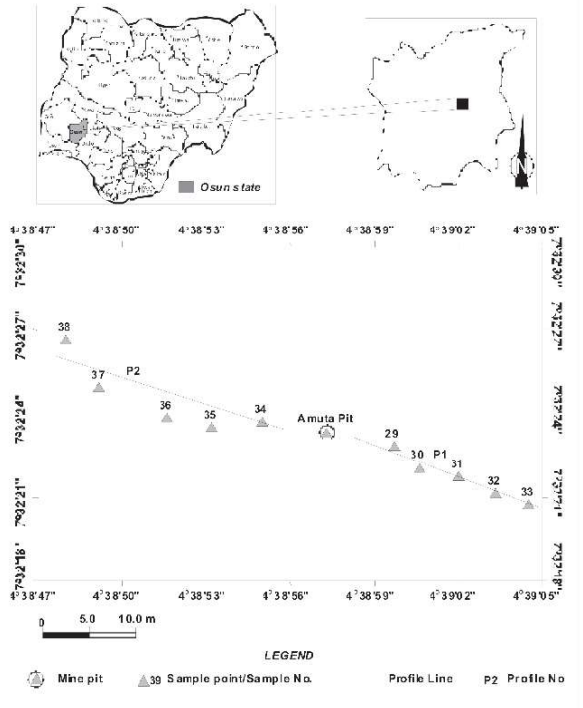


Figure 3. Soil sampling sites map for Amuta Area

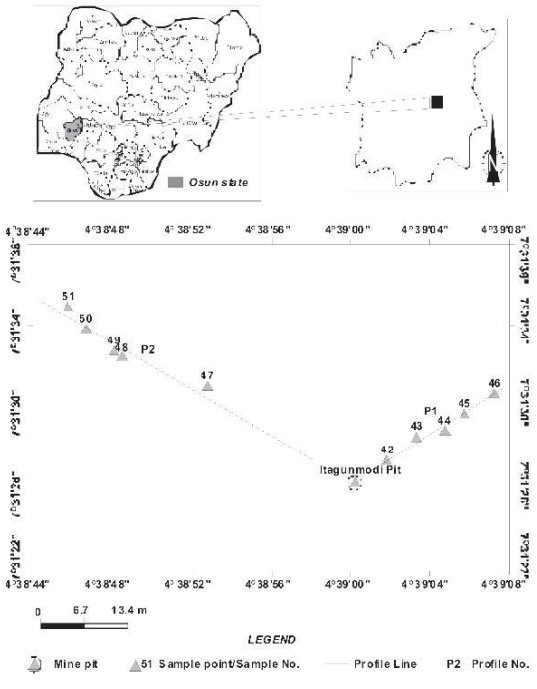


Figure 4. Soil sampling sites map for Itagunmodi Area

Calculated Enrichment Factors using the ACV of Taylor (1964) as reference value and Al as the reference element

for the PHEs revealed that the soils of Orogo area displayed depletion to minimal enrichment of Ni; and a preponderance of depletion to minimal enrichment of Mo. The soil samples analysed were moderately enriched with Mo (S05, S06, S12, S16-S18 and S22), Cu (S01, S04-S14, S19, S20 and S22), Pb (S02, S03, S08-S10, S12, S15-S17, S21 and S22), Zn (S01, S04-S07, S10, S13, S14, and S19-S22), Co (S06, S11, S13 and S22), As (S02, S0, S06, S11, S12, S14, S17, S18 and S22), Cd (S01, S04-S07, S10, S11, S13, S14 and S18-S21) and Hg (S02, S08-S13, S20-S22). Significant enrichments of Cu (S18 and S21) Pb (S01, S04-S07, S11, S13, S14 and S18-S20), Co (S01, S04, S05, S07-S10, S14 and S18-S20), As (S04, S07, S09 and S10) and Hg (S01, S04-S07, S14, S18 and S19) were also detected, while As displayed extremely high enrichment (S08) in soils of the area. Soils in Amuta area were depleted to minimally enriched in Mo and Ni; preponderantly moderately enriched in Zn and Hg; and moderately enriched in Cu, Pb and As. Moderate Co (S23 and S26), Cd (S27, S29-S32, S34 and S35) and Hg (S27, S28 and S30-S35) enrichment; with significant enrichment of Co (S24, S25 and S27-S35) and Hg (S29) were detected in some of the soils. Itagunmodi soil samples displayed depletion to minimal enrichment of Mo; preponderance of moderate enrichment of Cu, Pb and Hg; and moderate enrichment of Zn, Ni (S36, S39, S43 and S46-S48), Co (S37 and S38), As (S37, S43 and S47-S48), Cd (S39, S44-S48) and Hg (S36, S39-S41 and S43-S48). Furthermore, the soils were significantly enriched in Cu (S39, S42, and S46-S48), Pb (S44 and S47-S48) and Co.

Using calculated background values, soils from Orogo area were depleted to minimally enriched in Mo, Cu, Pb, Zn and Ni; preponderantly depleted to minimally enriched in As and Hg; and preponderantly moderately enriched in Co. Moderate enrichment of As (S04-S07 and S12), Cd (S07-S10, S12, S15 and S22) and Hg (S01, S04-S06, S14, S18 and S19) were detected in soils of the area; with significant enrichment of As (S09 and S10) and Cd (S01, S04-S06, S14, S18 and S19). The soils also displayed very high enrichment of As (S08). Amuta soils were depleted to minimally enriched in Mo, Cu, Pb, Zn, Ni and Co; and preponderantly depleted to minimally enriched in As, Cd and Hg. Moderate enrichment were only detected for S35 (As) and S29 (Cd and Hg). At Itagunmodi, concentrations of Mo, Pb, Zn, Ni, Co and Hg fell within the depleted to minimally enriched class; while Cu, As and Cd were preponderantly in the depleted to minimally enriched class. Moderate enrichment was detected for Cu (S48), As (S37, S43 and S47-S48) and Cd (S44) in the soils sampled.

Calculated Igeo for soils in Orogo area using ACV of Alloway (1990) revealed that the soils are uncontaminated with Mo, Zn and Ni; and preponderantly uncontaminated with Cu, Pb and Cd. They were uncontaminated to moderately contaminated with Cu (SS09, S11, S12 and S18), Pb (S04, S05, S08, S09, S13, S18 and S19), Co (S04-S07, S11, S14, S18-S20 and S22), As (S04, S06, S07 and S12), Cd (S04-S06, S13, S14 and S21) and Hg (S02, SO4, S07-S14 and S18-21). Moderate contamination of Cu (S21), Co (S08-S10) and Hg (S05 and S06) were also detected, while As displayed moderate to strong contamination (S09 and S10) and strong to extreme contamination (S08) in soils of the area. Soils sampled from Amuta were also uncontaminated with Mo, Zn and Ni; and preponderantly uncontaminated with Pb and Cd. They were uncontaminated to moderately contaminated with Cu (S23-S27 and S31-S33), Pb (S29), Co (S23-S26 and S35), As (S23, S24, S26, S27 and S32-S35) and Hg (S27, S28 and S30-S35). Moderate Co (SS27-S34) and Hg (S29) contamination were also detected in soils of Amuta area. Itagunmodi soil samples were uncontaminated with Mo, Zn and Ni; and preponderantly uncontaminated with Pb and As. The soils were uncontaminated to moderately contaminated with Cu (S36, S37, S39, S42, S43, S46 and S47), Pb (S48), Co (S37, S38, S41 and S42), Cd (S46-S48) and Hg (S39-S41, S43-S48). Moderate Co contamination was detected in samples S36, S39, S40 and S43-S48; while S48 displayed moderate Cu contamination.

Igeo values were also obtained using calculated elemental background values for PHEs in soils from Orogo, Amuta and Itagunmodi areas. Soils from Orogo area were preponderantly uncontaminated with Pb. They were uncontaminated to moderately contaminated with Mo (S03 and S15-S21), Cu (S06-S10, S16, S17, S21 and S22), Pb (S10, S16, S20 and S21), Zn (S07-S10 and S20-S22), Ni (S03-S07, S17, S21 and S22), Co (S04, S15 and S18-S21), As (S03, S13-S14, S16 and S20-S21), Cd (S02) and Hg (S02-S08 and S14-S22). The soils also showed moderate contamination of Mo (S22), Cu (S20), Ni (S08-S10), Co (S05-S09, S16, S17 and S22), As (S05-S07, S17 and S22), Cd (S03, S04 and S13) and Hg (S09 and S10); moderate to strong contamination of Cu (S21), Co (S10) and Cd (S05-S10, S14, S18, S19 and S22); and strong contamination of As (S08 and S09) and Cd (S15-S17, S20 and S21). Extreme contamination of As was also detected in S10. The soil samples obtained from Amuta were uncontaminated with Pb and Zn, and preponderantly uncontaminated with Mo, Ni and Hg. They were uncontaminated to moderately contaminated with Mo (S25 and S35), Cu (S23-S25, S29, S30, S34 and S35), Ni (S25), Co (S24, S25, S29, S30 and S33-S35), As (S24, S25, S29, S30 and S32-S35), Cd (S28-S30 and S35) and Hg (S29 and S30). Itagunmodi soils were uncontaminated with Pb, Zn, Co and Hg; and preponderantly uncontaminated with Mo, Cu, Ni and Cd. The soils were uncontaminated to moderately contaminated with Mo (S37, S38 and S48), Cu (S43, S46 and S47), Ni (S38, S43 and S46), As (S36, S37, S42 and S46-S48) and Cd (S45-S48). Moderate contamination of Cu (S48) and As (S38 and S43) was also detected in the Itagunmodi area. Summary of elemental enrichment/contamination in the soils analysed is presented in Tables 1 and 2.

Table 1 (a and b): Summary of Enrichment (EF) in soils of the study areas

	Using ACV (Taylor, 1964)		
PHE	Orogo	Amuta	Itagunmodi
Mo	Moderate	Depleted - Minimal	
Cu	Moderate - Significant	Moderate	Moderate - Significant
Pb	Moderate - Significant		
Zn	Moderate		Moderate
Cd	Moderate		
Co	Moderate - Significant		
Hg	Moderate - Significant		Moderate
As	Moderate - Extremely High	Moderate	

(b)

	Using Calculated background values		
PHE	Orogo	Amuta	Itagunmodi
Cd	Moderate - Strong	Moderate	
Co	Moderate	Depleted - Minimal	
Hg	Moderate		Depleted - Minimal
As	Moderate - Very High	Moderate	

Table 2 (a and b): Summary of Contamination (Igeo) in soils of the study areas

(a)

	Using ACV (Alloway, 1990)		
PHE	Orogo	Amuta	Itagunmodi
Cu	Moderate		
Co			
Hg			
As	Strong - Extreme	None - Moderate	None

(b)

	Using Calculated Background values		
PHE	Orogo	Amuta	Itagunmodi
Mo	Moderate	None - Moderate	
Ni			None - Moderate
Hg			None
Cu	Moderate - Strong		Moderate
Co			None
Cd	Strong		None - Moderate
As	Strong - Extreme		Moderate

3.1 Health Risk Assessment

Human exposure to PHEs occurs through skin contact, breathing in metal-contaminated dust, and ingestion of contaminated water and soil; or plants cultivated over contaminated soil. The artisanal miners, and by extension people living within the vicinity of the areas investigated, are at risk of exposure to Cu, Pb, Zn, Cd, Co, Hg and As, especially through dermal contact and ingestion.

Even though Cu is not classified as a carcinogen, continuous or prolonged exposure to dust containing Cu can cause nose, mouth and eye irritation, while high intake can lead to liver and kidney damage (Agency for Toxic Substances and Disease Research [ATSDR], 2004). Pb, a cumulative toxicant, adversely affects the brain, liver, kidney and bones. No level of Pb exposure is considered safe (WHO, 2018). Though an essential trace element, toxicity of Zn causes damage to the pancreas, arteriosclerosis and disturbs protein metabolism. Cd is classified as a human carcinogen, and adversely affects the kidney, skeletal and respiratory systems. Bone fracture and damage to the Central Nervous System are other adverse effects of Cd toxicity (WHO, 2018b). Adverse effects of Co in humans include vomiting, and damage to the heart, blood vessels, vision and thyroid. Co toxicity also affects the respiratory system. Plants cultivated on Co-contaminated soils will accumulate small quantities especially in the fruit and seeds, which are often consumed by humans. Co is anticipated to be carcinogenic to humans by the National Toxicology Program (NTP) of the United States Department of Health and Human Services and World Health Organization's (WHO) International Agency for Research on Cancer (IARC) (ATSDR, 2004). Hg, an element classified as possibly carcinogenic to humans, is one of the most dangerous elements to human health (Ghrefat and Yussuf, 2006). Hg toxicity causes disruptions to the nervous system; damages to DNA, chromosomal and brain functions; and reproductive effects such as sperm damage, birth defects and miscarriages (WHO, 2017; ATSDR, 2004). As is a proven human carcinogen (WHO, 2018; IARC, 2012; Thomilson et al., 1980), the toxicity of which causes skin pigmentation and lesions, which lead to skin cancer in the long term. Other resultant effects of long-term exposure to As include cancer of the bladder and lungs, developmental defects, diabetes, pulmonary disease and cardiovascular disease (ATSDR, 2007; WHO, 2018).

The artisanal miners in the study area are at the risk of health hazards associated with Cu, Pb, Zn, Cd, Co, Hg and As toxicity; resulting from direct contact (dermal exposure) with the soils during the exploitation and processing operation. Ingestion of these metals can also occur as the miners consume their food on-site, without covering them or washing their hands before doing so. These metals can also enter the human system through ingestion of food cultivated on soils around the mining sites, thus the areas sampled can be deemed unsuitable for agricultural activities. Ingestion of soil (by children or through the act of geophagy) and leaching of the metals from the soils into surface and ground water sources are other potential sources of health hazard.

4.0 Conclusions

An assessment of the quality of soils around AGM pits in Osu and Itagunmodi areas revealed moderate contamination of Cu, Co, Pb, Zn, Cd and Hg in soils of the areas; and strong As contamination in soils around Orogo AGM pit in Osu area. Continuous exposure of the artisanal miners to the contaminated soils put them at risk of health hazards such as liver, kidney, cardiovascular, brain and nervous system damage; skin, lung and bladder cancer. The study also indicates the unsuitability of the areas investigated for agricultural activities. This is because the PHEs can bio-accumulate in the food chain, leading to cumulative and long-term health effects. A comparison of the quality of soils from locations remote from the gold mining areas is recommended in order to assess the impact

of the gold mining activities on the level of soil contamination in the areas investigated. More geo-environmental and health assessment studies should also be conducted at artisanal gold mining areas in others parts of the Nigerian Schist Belt.

Acknowledgments

This study is part of the first author's Masters Degree research at the Pan African University Life and Earth Sciences Institute, University of Ibadan, Ibadan. The help rendered by Dr. Olusegun Olisa during the fieldwork exercise is acknowledged and appreciated.

References

Adriano, D.C. (1986): Trace Elements in the Terrestrial Environment. Spring-Verlag, New York.

Agency for Toxic Substances and Disease Registry (2004): Toxicology Profile for Copper (Accessed at www.atsdr.cdc.gov, 5/11/18)

Agency for Toxic Substances and Disease Registry (2004): Toxicology Profile for Cobalt (Accessed at www.atsdr.cdc.gov, 5/11/18)

Agency for Toxic Substances and Disease Registry (2007): Toxicology Profile for Arsenic (Accessed at www.atsdr.cdc.gov, 5/11/18)

Alloway, B.J. (1990): Heavy Metals in Soils. John Wiley and Sons, New York. 339pp.

Basu, N., Clarke, E., Green, A., Calys-Tagoe, B., Chan, L., Dzodzomenyo, M., Fobil, J., Long, R.N., Neitzel, R.L., Obiri, S., Ode, E. (2015): Integrated assessment of artisanal and small-scale gold mining in Ghana—Part 1: Human health review. Int. J. Environ. Res. Public Health 12, 5143–5176.

Choi, A.L., Weihe, P., Budtz-jørgensen, E., Jørgensen, P.J., Jukka, T., Tuomainen, T., Murata, K., Nielsen, H.P., Skaalum, M., Askham, J., Grandjean, P. (2009): Methylmercury exposure in Faroese Whaling men and adverse cardiovascular effects. Environ. Health Perspect. 117, 367–372.

Gao S, Luo T-C, Zhang B-R, Zhang H-F, Han YW, Zhao Z-D, Hu Y-K (1998a) Chemical composition of the continental crust as revealed by studies in East China. Geochim Cosmochim Acta 62:1959–1975

Ghrefat, H. and Yusuf, N. (2006): Assessing Mn, Fe, Cu, Zn and Cd Pollution in Bottom Sediments of Wadi Al-Arab Dam, Jordan. *Chemosphere*, 65 (11),2114-2121. doi:10.1016/j.chemosphere.2006.06.043

Goodrich, J.M., Wang, Y., Gillespie, B.,Werner, R., Franzblau, A., Basu, N. (2012): Methylmercury and elemental mercury differentially associate with blood pressure among dental professionals. Int. J. Hyg. Environ. Health 216, 195–201.

International Agency for Research on Cancer (2012): A review of human carcinogens: arsenic, metals, fibres, and dusts: chromium (VI) compounds. IARC Monographs vol. 100C-9. International Agency for Research on Cancer (IARC) . http://monographs.iarc.fr/ENG/Monographs/vol100C/mono100C-9.pdf (Accessed: 25/05/2016).

Muller, G. (1969): Index of geoaccumulation in sediments of the Rhine river. J. Geol., 2: 108-118.

Obiri, S., Yeboah, P.O., Osae, S., Adu-kumi, S., Cobbina, S.J., Armah, F.A., Ason, B., Antwi, E., Quansah, R. (2016): Human health risk assessment of artisanal miners exposed to toxic chemicals in water and sediments in the PresteaHuni Valley District of Ghana. Int. J. Environ. Res. Public Health 12, 139.

Oyinloye, O.A. and Steed, G.M. (1993): Geology and geochemistry of Iperindo primary gold deposits, Ilesa Schist Belt, Southwestern Nigeria. *Trans. Instu Min. Metall.* 105: 74-81.

Rajaee, M., Sánchez, B.N., Renne, E.P., Basu, N. (2015): An investigation of organic and inorganic mercury exposure and blood pressure in a small-scale gold mining community in Ghana, I. Int. J. Environ. Res. Public Health 12, 10020–10038.

Simex, S.A. and Helz, G.R. 1981. Regional geochemistry of trace elements in Chesapeake Bay. Environ. Geo. 3: 315-323.

Taylor, S.R. 1964. Abundance of chemical elements in the Continental Crust: a new table. Geochimica et Cosmochimica Acta, 28: 1273-1285.

Taiwo, A.M and Awosemo, J.A. (2017): Assessment of trace metal concentration and health risk of artisanal gold mining activities in Ijeshaland, Osun State. Journal of Geochemical Exploration 177: 1-10.

Thomilson, D. C. , Wilson, D. J., Harris, C. R. and Jeffrey, D. W. (1980): Problem in Heavy Metals in Estuaries and the Formation of Pollution Index. *Helgol. Wiss. Meere-sunlter,* 33 (1-4), 566-575.

World Health Organization (2017): Fact Sheets: Mercury and Health (Accessed at www.who.int, 5/11/18)

World Health Organization (2018): Fact Sheets: Arsenic (Accessed at www.who.int, 5/11/18).