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Impact of Different Illegal Small-Scale Gold Mining Operations on the Heavy Metal Concentrations of Soil and Water Bodies: A Case Study of Ghana

F. Owusu-Nimo[1], J. Mantey[2] and K. B. Nyarko[3]

[1]Dr, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana email: frednimo@gmail.com

[2]Dr, Gold Fields Ghana Limited, Tarkwa, Ghana, email: mybryanjones@yahoo.co.uk

[3]Prof, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana email: nyarko.k.b@gmail.com

ABSTRACT

In Ghana, most small-scale gold mining operations do not have licenses making their operations illegal. Such illegal mining operations are characterized by an untrained labour force and inappropriate techniques, polluting surrounding soil and water bodies. This study sought to determine the relative impacts of different operational forms of illegal mining in three districts in the Western North Region of Ghana on heavy metal concentrations of surrounding soil and water. The heavy metals concentration in soil and water samples obtained from the study sites were determined using Instrumental Neutron Activation Analysis and Atomic Absorption Spectrometry. The results from the study indicate that out of the eight heavy metals tested, only mercury recorded concentration levels higher than the recommended guideline values. The rest of the heavy metals had very low concentrations. The range of mercury was 0.001mg/kg -116mg/kg and 0.001 mg/L – 215 mg/L for soil and water, respectively. In terms of the mining operations, the mill house impacted soil and water bodies the most, with mercury ranging from 148mg/kg -230mg/kg and 149mg/L – 215mg/L, respectively, for soils and water samples, whiles the underground abandoned shaft and underground sample pit mining types was found to be the operations with the most negligible impact of mercury on the water bodies. The results from this study will enable the formulation of appropriate solutions and policies to curb this menace and restore affected sites. The results show that mercury contamination can be reduced significantly if proper means of processing and extracting the gold are established.

Keywords: Heavy metals, Galamsey, Illegal Mining, Mercury, Pollution

1 INTRODUCTION

In Ghana, a small-scale mining operation is defined as a mining operation over an area of land less than 21 hectares and under a small-scale mining license. However, most small-scale gold mining operations in Ghana have no license making their operations illegal. This illegal small-scale gold mining is popularly called “Galamsey” in Ghana. It is widespread with diverse operational forms and usually characterized by an untrained labour force and inappropriate extraction and processing techniques, resulting in the pollution of surrounding soil and water bodies (Mantey et al., 2016; Owusu-Nimo et al., 2018). Several studies have been carried out to assess the impact of Galamsey activities on the heavy metal concentration of soil and water bodies (Aryee et al.2003; Tschakert and Singha, 2007; Bempah et al., 2013). However, none of these studies has comprehensively measured or assessed the levels of heavy metals per the types of galamsey that exist within Ghana. These studies have failed to assess the relative impacts of the various galamsey operational types on the heavy metal concentrations of soil and water bodies. This study is, therefore, novel since it is aimed at assessing the relative impacts of different operational forms of small-scale illegal mining on the heavy metal concentrations of surrounding soil and water bodies. The results from this study will provide an understanding of how the various forms of illegal mining operations impact soils and water bodies. It will offer stakeholders the necessary

information required to formulate appropriate remedial solutions and effective policies to address this menace and restore the affected environment.

2 VARIOUS OPERATIONAL FORMS OF GALAMSEY

Various operational forms of galamsey have been identified through studies conducted by Mantey et al. (2016) at galamsey sites in the Western North region of Ghana. A summary of the nine galamsey types considered for this study and the equipment or resources used that have the potential to contaminate the soil and water bodies with heavy metals is provided in Table 1. Alluvial mining needs a constant water supply, so it can be found close to or along banks of water bodies, while underground mining is undertaken in tunnels or holes deep into the earth. Surface mining involves the digging and excavating rocky or sandy ore from a few meters into the earth and therefore takes place anywhere gold is found within the earth's material. Mill-house operations are usually on roadsides and close to water bodies or wetlands.

Table 1. *Summary of galamsey types and characteristics*

Broad category	Galamsey types	Equipment / Resources
Alluvial Mining	Washing Plant (WP)	Trommel, Excavator, Loader, Mercury, Water pumps, Generators, Coal Pot
	Washing Board (WB)	Washing/Sluice Board, Excavator, Loader, Mercury, Water pumps, Generators, Coal Pot
	Anwona (AN)	Suction Dredge/ "totototo", Mercury, Coal pot
	River Dredging (RD)	Suction Dredge, Mercury, Coal pot
	Dig and Wash (DW)	Pick axe, Spade/ Shovel, Head Pan, Sluice Board, Mercury, Coal Pot
Underground Mining	Underground Abandoned Shaft (UAS)	Blasting Agents, Hammers, Shovels, Batteries, Generators, Electric Motors
	Underground Sample Pit (USP)	Hammers, Shovels, Batteries, Generators, Electric Motors
Surface Mining	Chamfi (CH)	Chan-Fa Engine, Mercury, Shovels, Water pumps, Generator, Coal Pot
Mill-house Operation	Mill-house Operation (MH)	Chan Fa Engine, Crusher, Smoothing Machine, Mercury, Borax, Coal pot, Sluice Board, Hammers

These galamsey types have been grouped in Table 2 based on mining only, simultaneous mining and extraction, and extraction-only processes.

Table 2. *Summary of galamsey types and type of activity*

Activity Type	Galamsey types
Mining Only	Underground Abandoned Shaft (UAS); Underground Sample Pit (USP)
Simultaneous mining and extraction	Washing Board (WB); Anwona (AN); River Dredging (RD); Dig and Wash (DW); Underground Sample Pit (USP); Chamfi (CH)
Processing/extraction only	Mill-house Operation (MH)

3 SITE SELECTION, SAMPLING, AND LABORATORY ANALYSIS

The study was conducted in three districts in the Western North region of Ghana identified by Owusu-Nimo et al. (2018) as hotspot districts for Galamsey activities. These districts are Amenfi East, Prestea Huni-Valley, and Tarkwa-Nsuaem districts. For each established galamsey type, two sites were randomly selected from the three selected districts for soil and water sampling. Also, a location with no galamsey operation was selected as a reference/control (REF). For the soil, at each selected galamsey location and control, samples were taken at depths up to 50cm using hand augers. The samples were stored in Ziploc bags and properly labeled. At these same galamsey locations, water samples were taken from the following at the site: streams, ponds, lakes, and surface runoff, with preference given to the most impacted water (visually). The water samples were collected into preconditioned high-density polyethylene bottles. 19 soil and 19 water samples were obtained for laboratory analysis. The heavy metals analysed included Cadmium (Cd), Chromiun (Cr), Copper (Cu), Zinc (Zn), Nickel (Ni) Lead (Pb), Arsenic (As), and Mercury (Hg). The concentrations of these heavy metals in the samples were determined using Instrumental Neutron Activation Analysis and Atomic Absorption Spectrometry. These heavy metals were considered because they are priority heavy metals and are usually transferred from mining operations to the environment. Mining operations, which can lead to heavy metal contamination, include the disposal of metal waste, leaded gasoline, coal combustion residues, petrochemicals, and the mine tailings. Utilization of storage batteries and petroleum products during mining operations could also be potential sources of heavy metals.

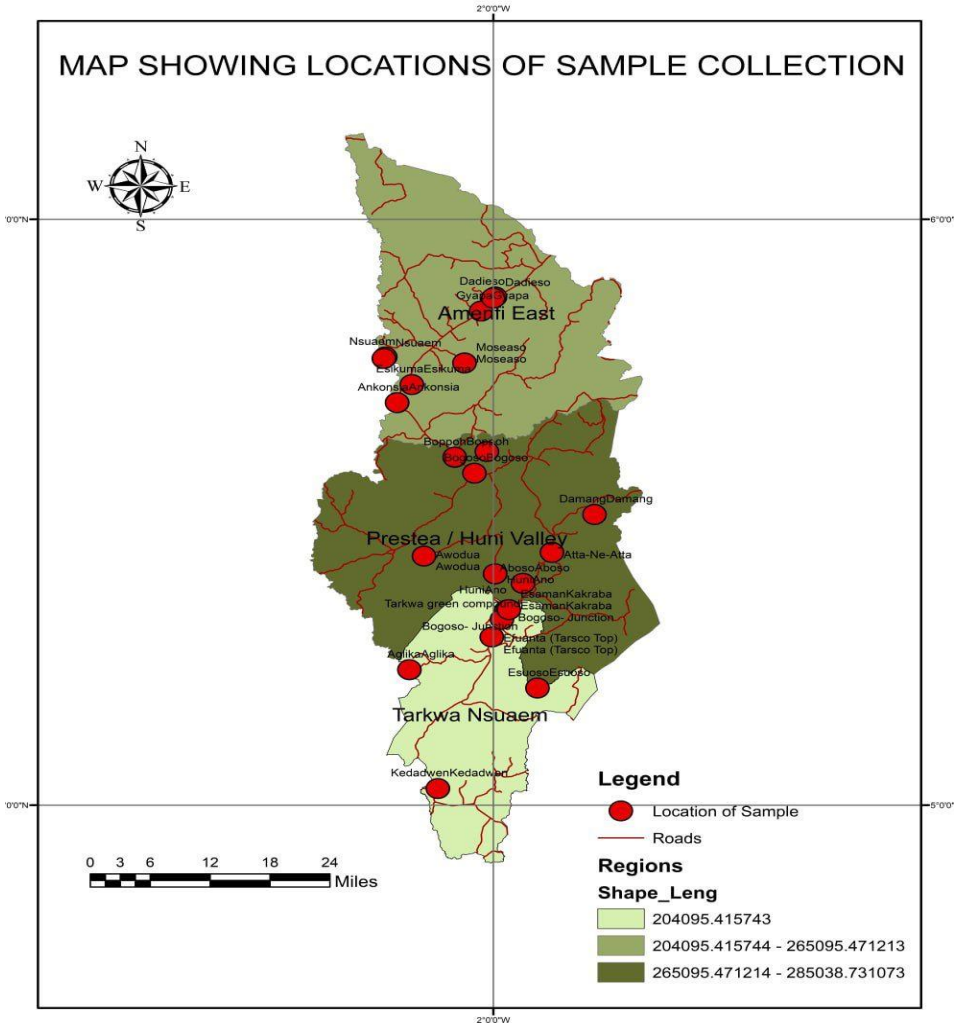

Figure 1. *Location of sample points within the three selected districts*

4 RESULTS AND DISCUSSION

The average concentrations of heavy metals obtained for the different galamsey types for the soil and water samples are provided in Table 3 and Table 4, respectively. For the soil samples, it was found that all the heavy metals analysed had very low concentration levels except Hg, which had an average contaminant level greater than the IAEA action level of 10mg/kg for some of the galamsey types. Heavy metal contamination of soils is usually through anthropogenic activities, including emissions from industrial waste, mine tailings, metal waste disposal, etc. After accumulating in the soil, the heavy metals do not undergo degradation, and their concentration in soils remains the same for a long time. High levels of heavy metals in soils can be toxic to humans if they find their way into the human body. Apart from Hg, the levels of the heavy metals were all below the IAEA action levels and, therefore, not harmful to the human body.

The very low levels of the other heavy metals recorded for the soil and water samples can be attributed to the fact that, unlike mercury, the miners do not directly use these heavy metals in mining or gold extraction. It was believed that resources or equipment the miners use, such as storage batteries, excavators, generators, water pumps, ashes from combustion, and petroleum products, could be potential sources of heavy metals. The results were, however, contrary to this belief. Similar results of low levels of heavy metals (excluding Hg) were recorded from other studies (Kpan et. al, 2014) at illegal gold mining locations. From the study, the towns with higher concentrations of heavy metals had extensive farming activities with abundant use of pesticides, herbicides, and fertilizers.

In terms of the mining operations, the underground abandoned shaft (UAS), underground sample pit (USP), river dredging (RD), and dig and wash (DW) contributed minimally to the mercury contamination of soils. The rest of the galamsey types contributed to mercury contamination of soils above the action levels, with the Mill House (MH) contributing the most to the Hg contamination of soils. The release of mercury to the soil from the other operational types in decreasing order of impact are as follows: Mill house, Chamfi, Washing Board, Anwona, Washing Plant, Dig and Wash, River Dredging, Underground Abandoned Shaft, and Underground Sample Pit.

Table 3. *Average contaminant levels in soil samples for different Galamsey types*

Heavy Metals	**Average Contaminant Levels (mg/kg)**										**Guideline Value (mg/kg)**
	WP	WB	AN	RD	DW	UAS	USP	CH	MH	REF	
Cr	0.44	1.18	9.73	0.85	2.23	1.54	3.69	2.07	0.66	0.57	12
Ni	1.62	2.21	8.38	3.38	2.79	3.53	4.80	2.86	5.19	2.55	380
Cu	2.06	1.49	6.59	2.62	3.89	4.52	8.44	2.24	4.50	8.69	190
Zn	1.16	1.10	2.04	1.02	1.12	2.58	1.79	2.36	2.04	1.55	720
Cd	0.30	0.17	0.00	0.08	0.20	0.00	0.10	0.57	0.00	0.12	210
Pb	0.00	0.74	0.00	1.25	0.00	4.23	2.84	4.12	4.26	0.52	55
As	2.13	2.68	3.16	2.32	1.30	2.42	3.41	2.40	3.42	1.74	530
Hg	17.78	46.54	29.34	0.69	1.88	0.06	0.45	65.4	196	0.09	10

For the water samples, the concentration levels of a few heavy metals were high for some operational types but generally lower than the recommended EPA guideline values. Mercury levels in the water were, however, high for all the operational types and exceeded the EPA guideline value of 0.005mg/L except for the underground abandoned shaft and underground sample pit galamsey.

Again, the mill house recorded the highest mercury level, averaging 196mg/L. Apart from the Mill house operation, the order in which the mining type negatively impacts the water bodies with mercury is the Chamfi, Washing Board, Washing Plant, Anwona, Dig and Wash, and River Dredging. The Underground Abandoned Shaft and Underground Sample Pit mining types were found to be the operations with the most negligible impact of mercury on the water bodies recording values below the detection limit (<0.001 mg/L).

Table 4. *Average contaminant levels in water samples for different Galamsey types*

Heavy Metals	Average Contaminant Levels (mg/l)										Guideline Value (mg/L)
	WP	WB	AN	RD	DW	UAS	USP	CH	MH	REF	
Cr	0.41	0.10	0.39	0.00	0.00	0.00	0.00	0.05	0.06	0.00	0.5
Ni	0.28	0.00	0.18	0.00	0.00	0.01	0.01	0.02	0.02	0.00	0.5
Cu	0.36	0.10	0.49	0.00	0.00	0.04	0.00	0.16	0.08	0.10	2.5
Zn	0.94	0.70	0.45	0.00	0.00	0.33	0.56	0.54	0.16	0.10	5.0
Cd	0.01	0.00	0.01	0.00	0.00	0.01	0.00	0.004	0.00	0.00	0.1
Pb	0.17	0.00	0.06	0.00	0.00	0.08	0.00	0.004	0.07	0.00	0.1
As	13.9	10.3	2.85	2.20	1.60	1.55	1.00	17.60	15.95	0.00	0.5
Hg	18.4	48.1	12.5	0.005	0.80	0.00	0.00	82.4	196	0.00	0.005

The high levels of mercury recorded for most of the galamsey operational types are not surprising because miners use a lot of mercury in gold processing and extraction. For instance, miners need about 1.5 – 2 g of mercury to extract 1g of gold. During the extraction of gold, the miners usually add mercury to the gold-bearing material to amalgamate the finest particles of gold. The amalgam is then isolated by hand and heated to distill the mercury and isolate the gold. The mercury vapour generated during amalgam processing affects miners and non-miners living there. Figures 2 and 3 show the density map of mercury contamination for the different galamsey types for the soil and water samples, respectively. Mill house operations had mercury levels ranging from 148mg/kg -230mg/kg and 149mg/L – 215mg/L, respectively, for soils and water samples.

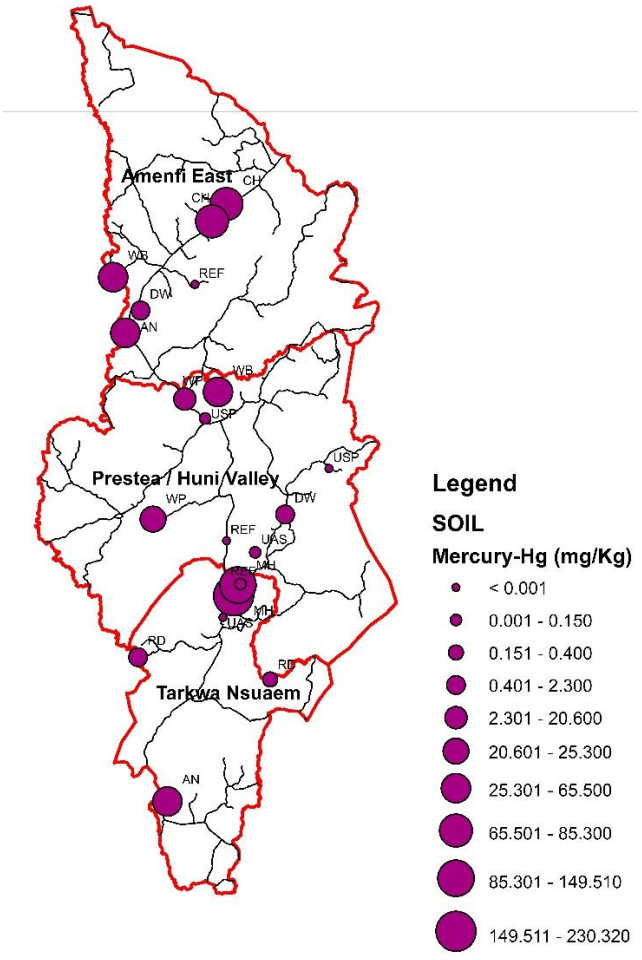

Figure 2. *Mercury levels in soil samples for different galamsey types*

The high levels of mercury recorded in both the soil and water samples are alarming and may pose serious health effects on the miners (Khan et al, 2008). The accumulated mercury in the soil may be absorbed by plants and make its way to the fruits and seeds consumed by humans and herbivorous species. The mercury in the water can also bioaccumulate along the food chain and eventually be consumed by humans.

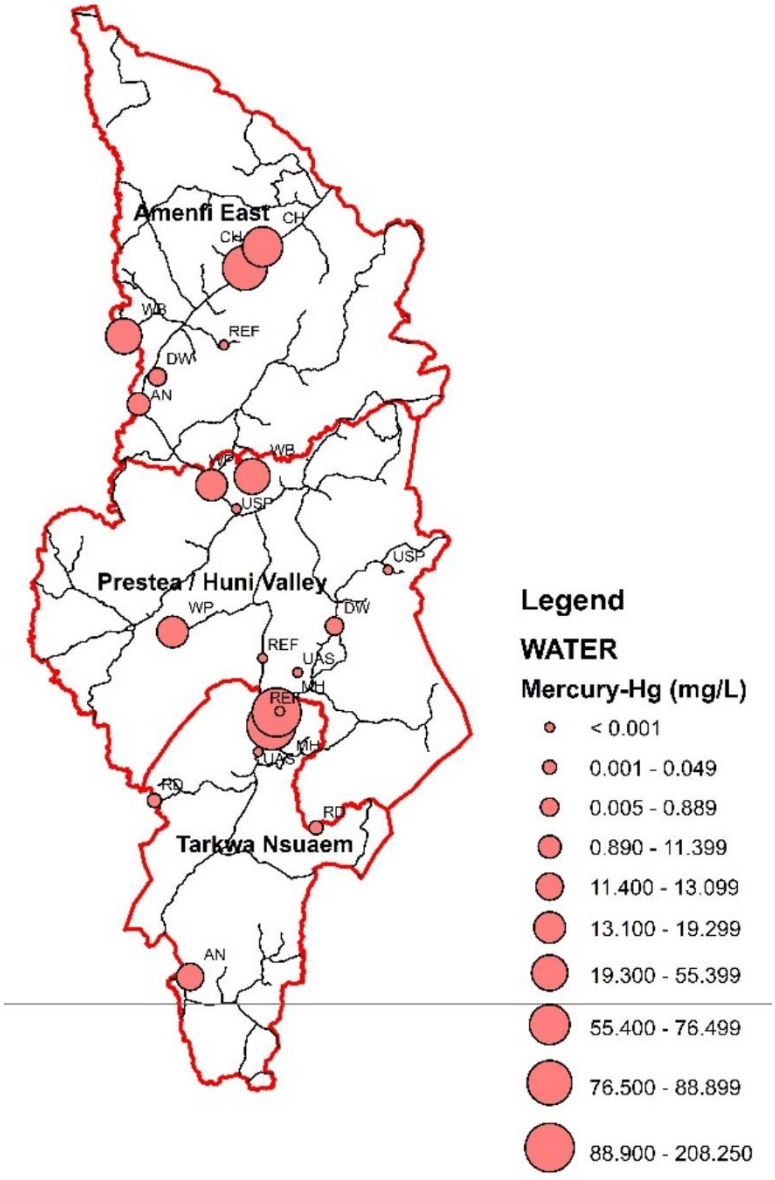

Figure 3. *Mercury levels in water samples for different galamsey types*

Due to the high levels of Hg recorded, there is a need for policies from regulating agencies to help reduce the contamination of soil and water bodies with mercury by regulating its use. As a solution, the government can set up gold processing factories or units ('Bigger Mill house with good environmental practices) to extract the gold from the ores since the gold extraction process leads to high Hg contamination of soil and water bodies. Also, policies that are developed should take into consideration the different galamsey types and their relative impacts.

5 CONCLUSIONS

Studies have been carried out within three galamsey hotspot districts to ascertain the impact of different galamsey type on the heavy metal contamination of soil and water bodies. The results indicated that, out of the eight heavy metals considered, only mercury had levels higher than the recommended guideline values and may pose serious health threats to the miners and non-miners nearby. In terms of the galamsey types, the Mill house operation contaminates the soil and water with mercury the most, whiles the least contributors to mercury contamination are the underground abandoned shaft and underground sample pit. Due to the high levels of Hg recorded, policies should be developed to regulate its use. The Mill house galamsey can also be improved to ensure that gold extraction or processing is carried out with good environmental practices to reduce Hg contamination.

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