Mercury Pollution from Small – Gold Mining in the Waste of Al Salam Gold Mine, Northern Sudan

Gobran N. Ali [1,2]. , Siddig T. Kafi[1], Hago A[3]., and Abdullah T. Naji[4]

[1]*Department of physics, Faculty of Science & Technology, Neelain University, Khartoum,Sudan.*

[2] *Physics Department , Faculty of Science, Sana'a University, Yemen*

[3]*Department of Hydrogeology, Faculty of Petroleum & Minerals, Neelain University, Khartoum, Sudan.*

[4]*Biomedical Engineering Department, Faculty of Engineering, University of Science and Technology, Yemen.*

. ***Correspondent Author:*** ***JNS_030@yahoo.com***

DOI: https://doi.org/10.56807/buj.v2i2.54

Abstract

This study aimed to assess the trace of mercury in the tailings of Al Salam Mine in Al Abiydia city, Sudan. Sixteen soil samples were collected from mine waste and studied using Direct Mercury Analyzer-80 (DMA-80). The analyzed results showed that the total concentration of Hg in soil samples ranged from 2.144 to 47.635 mg.kg^{-1}, with a mean of 19.696 mg. kg^{-1}. These values exceeded the background values according to international standards such as (IAEA, 0.04 mg.kg^{-1}; VIRM, 4.8 mg.kg^{-1}; ASTRD, 0.063 mg.kg^{-1}). Also, the pollution and toxicity degree were assessed using the Contamination Factor (CF), potential ecological risk(Er) and risk index degree (RI). The results showed that, the Contamination Factor (CF) is ranged from 492.4 to 1190.88, with the average value of 53.6 which indicated a very high contamination (CF>6). While the Risk Index (RI) was found above 600 which indicated high toxicity, these results of high level of mercury pollution can cause an environmental hazard to the surrounding area due to the possibility of mercury seepage to the Nile River with rains and wind.

Key Words**:** *Mercury, Contamination factor, Potential ecological risk, Potential risk.***

تلوث الزئبق من تعدين الذهب – المصغر في مخلفات منجم السلام لتعدين الذهب – شمالي السودان

الملخص

هدف البحث لتحديد أثر الزئبق في مخلفات منجم السلام في مدينة العبيدية، السودان. 16 عينة جُمعت من مخلفات المنجم ، تم تحديد الاثر باستخدام تقنية *Direct Mercury Analyzer-80 (DMA-80).* نتائج التحليل اظهرت ان تركيز الزئبق في عينات التربة تدرج من

(2.144 to 47.635 mg.kg^{-1}) بمتوسط (*19.696 mg. kg^{-1}*). هذه القيم تجاوزت القيم المرجعية العالمية كـ *(IAEA, 0.04 mg.kg^{-1}; VIRM, 4.8 mg.kg^{-1}; ASTRD, 0.063 mg.kg^{-1})* ايضاً التلوث ودرجة السمية حُددت باستخدام معامل التلوث Contamination Factor (CF) وامكانية الخطر البيئي potential ecological risk(Er) و درجة مؤشر الخطر (risk index degree (RI)). النتائج بينت ان معامل التلوث(CF) تراوح من (492.4 to 1190.88) بقيمة متوسطة 53.6 التي اشارة الى تلوث عالي *(CF>6)* . بينما مؤشر الخطر (RI) وُجد اعلى من 600 وأشار الى السمية العالية، هذه النتائج لمستوى تلوث الزئبق المرتفع من الممكن ان ينتج عنه ضرر للمنطقة المحيطة نتيجة الى امكانية تسرب الزئبق الى نهر النيل بسبب الامطار والرياح .

Introduction

Gold metal is one of the most precious, and it has been become an important source of income for communities, particularly in rural regions where economic alternatives to agriculture are limited, also, it provides a basic livelihood for a large number of small enterprises which support the mining activities all around the world (Schutzmeier et al., 2016, Veiga et al., 2014, Eisler and Wiemeyer, 2004).). That is the cause of effort required to more extract it from nature and its scarcity relative to other metals by an industrial scale and manual labour (Artisanal Small-Scale Gold Mining, ASGM) using amalgamation process "*the process by which mercury forms a metal alloy with gold*". For this reason, ASGM has expanded in many regions in the world, it is a poverty-driven activity practiced by 10 to 20 million gold miners in 70 countries at worldwide including 4-5 million women and children (Esdaile and Chalker, 2018, Langeland et al., 2017, Schutzmeier et al., 2016, Eisler and Wiemeyer, 2004), due to it is cheaper than most alternative methods, quick and easy process, can be used by person independently (e.g. at home).

Globally, approximately one million ton (1 M ton) of metallic Hg has been extracted from cinnabar and other ores during the past five centuries, roughly half amount is used for mining of gold, and the Hg deposition from anthropogenic emission about (0.1 to 0.2 M tons) (Hylander and Meili, 2005). So, the amalgamation process is considered the major source for emission and release of the Hg into the environment refer to excessive using, and practiced illegally for mercury metal through the process of mining in many countries as documented by (Güiza and Aristizabal, 2013, Mudyazhezha and Kanhukamwe, 2014).

During the last two decades, artisanal gold mine (ASM) has been growing drastically and widely spread in Sudan. It is estimated that 40,000 locations of AGM existed all over the country , more than 173 companies involved in small gold mining which was extracted from the ore, 142 companies large- scales mining and 52 (Karta) companies extracting gold from the waste of AGM using chemical methods (i.e. NaCN in open – pit and closed system (*Elhashmi, 2015*). So that, Sudan became the third gold producing country in Africa (*Al Karam, 2015*). The rate of gold production had grown from 6.67 tons in 2004 to 93 tons in 2017 (*Al Karam, 2015, Sudanese Economy, 2017, Yager, 2013*). About, more than 1.5 million person practice this work (*Mohamed et al, 2015, Ibrahim, 2015, Elhashmi, 2015*) and it is considered the most source of subsistence for about 5 million person (*Ibrahim, 2015, Wadi and Alredaisy, 2015* . Artisanal miners consumption about 50 – 100 tons of mercury (*Esdaile and Chalker, 2018*) to produce more than 80 % (*Al Karam, 2015, Sudanese Economy, 2017*) from the total extracted gold (90 tons in 2017) (*Sudanese Economy, 2017*). So that, the estimation of Hg pollution due to the activities of artisanal miners is of a vital importance.

By Increasing of formal and indigenous mining activities in large parts of the Sudanese States, there is a lack of awareness, absence of clear information, and a limited research on the environmental impacts. This study might show the general knowledge of what kind of impacts anticipated to affect mining districts. Also, could provide a consolidated source of information about the contaminants which result from the gold mining activities, and may become a useful base to protect the environment in the areas surrounding gold mines.

1. Area of Study

AlSalam Mine is a part of Rida Mining Company which was established in 1999 The mine area lies at the northeastern part of River Nile State. This area is about twenty-two kilometers east of Al Abiydia township and is approximately 470 kilometers north of Khartoum. The map of Gold Concession area of Rida Mining Company is bounded by latitudes 18° 10' 0'' N to 18° 20' 0'' N and longitudes 33° 55' 0'' E to 34° 0' 0'' E, as shown in the below map. According to the map, the area of Al Salam Mine is characterized by low lying to moderately elevation isolated hills, and contains a number of waterways which flow from east to west towards the River Nile.

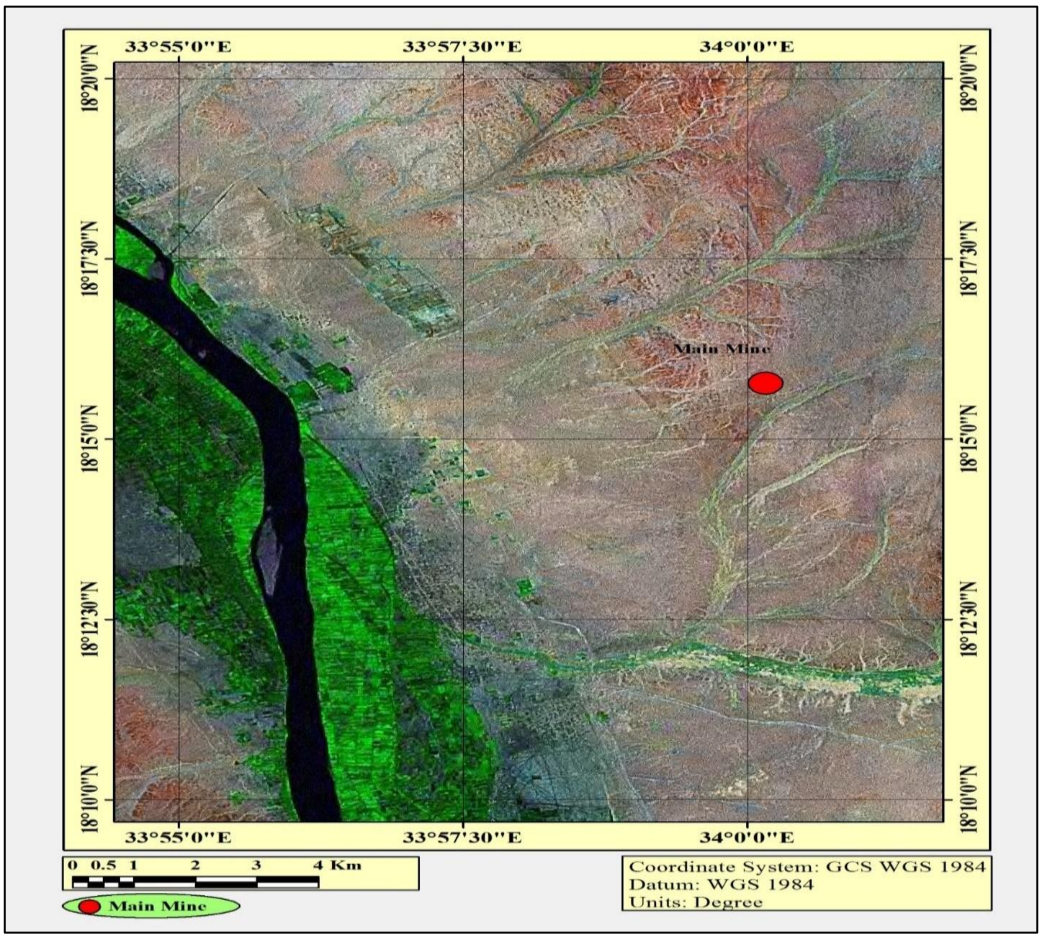

*Fig (1). Al Salam Mine, **Al** Abiydia Area, Berber Province.*

2. Material and Methods

2.a Samples Collection and Preparation

16 surficial samples (OB 01 – OB 16) were collected at depth of (0 -10 cm) approximately using hand auger. These samples were collected from various tailings inside the mining. Samples were dried at room temperature in open air and grinded manually into a fine powder, which passed through a 2 mm sieve to remove large debris, stone and stubbles.

2.b Mercury Analyzer DMA-80 Technique

Soil samples were analyzed by Milestone's DMA-80 in Petroleum Laboratories Research and Studies (PLRS), Khartoum, Sudan. Samples solution with a weight of 1 g for each one were introduced into the direct mercury analyzer. Thermal Decomposition, Catalyst Conversion, Amalgamation, and Atomic Absorption Spectrophotometer are detected by an optical spectrometer. The intensity of spectral line of an element is proportional to the concentration. The Method for solid sample analysis is summarized in fig. (2).

2.c Contamination Assessment by tracing mercury in soil samples -

Contamination and toxicity of soil samples were assessed using contamination factor (CF), potential ecological risk index (E_r), and risk index (RI). CF calculated from the ratio between the concentration of Hg metal in the samples C_n and the reference value of concentration IAEA C_{ref} ($CF = C_n / C_{ref.}$) is, 2000. The levels of contamination factors are shown in table (1-a,b), according to (*Hakanson, 1980*)

Table (1-a): CF index of heavy metal classes

CF index	Degree of Contamination
$CF < 1$	Low Contamination
$1 \leq CF < 3$	Moderate Contamination
$3 \leq CF < 6$	Considerable Concentration
$CF \geq 6$	Very high contamination

2.d The degree of pollution in soil samples calculated using formula of potential ecological risk factor (E_r) and risk index (RI) *(Hakanson, 1980)***,**

$E_r^i = T_i * \frac{C_n(\text{Sample concentration})}{C_B(\text{background value})} = T_i * CF$ and $RI = \sum_{i=1}^{n} E_r^i$, where E_r is the monomial potential ecological risk factor, C_n is the metal content in the sediments, C_B is the background values, and T_i is the toxic-response factor of Hg metal equal 40 *(Hakanson, 1980, Yu et al., 2017).* The standard evaluation of the risk index are shown in table (1-b).

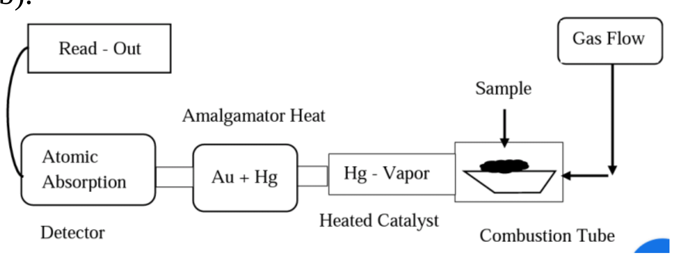

Fig. (2). Schematic diagram of a DMA-80 Sample Processing

3- Results and Discussion

Hg concentration of 16 soil samples under test was computed as a sum of mercury concentration in individual fractions, by DMA-80 and tabulated in the table (2).

The results showed that the total range of mercury concentration varied between 2.144 and 47.635 mg/kg with a mean of 19.696 mg/kg. The founded mercury content in soil exceeds the standard background values, *IAEA*, *2000*, *0.04* mg/kg; *VIRM*, 4.8 mg/kg; (Kabata-Pendias, 2010), 0.05 mg/kg; ATSDR, 1999 (0.02 - 0.063 mg/kg) and *SEAP*, *2001*, 1 mg/kg.

The Comparison between this study findings and some previous studies findings for some sites in the world are listed in table (3).

The comparison shows that, the concentration range of mercury concentration in the soil samples of this study is more than those for other sites of the previous studies except the values of mercury concentration for Bolgatanga in Ghana (54.6 mg .kg^{-1}) (*Rajaee et al., 2015*), Tongguan, in China (0.9 -76 mg .kg^{-1})(*Feng et al., 2006, Drace et al., 2012*), Cuyuni River Basin in Venezuela (0.16-542 mg .kg^{-1})(*Santos-Francés et al., 2011*), Wuchuan in Chain (3.3 - 810 mg .kg^{-1})(Li et al., 2012), and Nambija Mineral Distract in Ecuador (89 - 1555 mg .kg^{-1})(*Requelme et al., 2003*).

Contamination and toxicity of Hg for the soil samples were assessed through using contamination factor (CF), and risk index (RI). At mean, minimum and maximum Hg concentration, the CF was 492.4, 53.6 and 1190.88, and indicated very high contamination CF>6 respectively (*Hakanson,*

Table (2): Concentration of mercury in many wastes inside the Al Salam Mine area

Sample No.	**Con. mg/kg**	**Sample No.**	**Conc. mg/kg**	**Sample No.**	**Con. mg/kg**	**Sample No.**	**Conc. mg/kg**
OB 01	2.144	OB 05	36.906	OB 09	15.67	OB 13	15.400
OB 02	31.572	OB 06	11.264	OB 10	10.202	OB 14	11.441
OB 03	36.491	OB 07	11.103	OB 11	5.42	OB 15	14.975
OB 04	34.156	OB 08	11.065	OB 12	19.694	OB 16	47.635
Minimum : 2.144 mg. kg^{-1}							
Maximum : 47.635 mg. kg^{-1}							
Average : 19.696 mg. kg^{-1}							

1980). Also, Risk index (RI) at mean, minimum and maximum values was 19,696, 2,144 and 47,635.2 respectively(*Hakanson, 1980*). The toxicity degree was more than the level (RI > 600) and appeared to very high risk.

According to the analysis, the results revealed that the soil samples under test are highly contaminated with Hg. Elevated toxicity degree of soil samples with mercury can spread to the surrounding areas and River and may be cause hazard on plants, animals, and on aquatic life due to forming a very highly toxic organic methylmercury (MeHg) by biological process (*Qiu et al., 2005; Hunerlach et al., 1999; Genchi et al., 2017)*. So, negative impacts pose to serious threat to both humans and ecosystem (Nabaasa 2016; DU et al., 2016).

Table (3). Comparison of Hg concentration in soil (mg/kg) in AL Salam mining with some contaminated sites in the world

Comparison between this study results and Studies for some sites in the world			
Area	**Location**	**Hg con.**	**References**
ALSalam mine	**Al Abiydia, Sudan**	**2.14 - 47.64**	Our Results
Andacollo	**[a]Coquimbo, Chile**	**13.6 ∓1.6**	[a] *Morales, 2013.*
Rwamagasa	**[b]Northwest Tanzania**	**0.05–9.2**	[b] *Taylor et al., 2005.*
Kejetia	**[c]Bolgatanga, Ghana**	**54.6**	[c] *Rajaee et al., 2015*
Serra de Santa	**[d]Bahia, Brazil**	**10**	[d] *de Andrade Lima at el., 2008.*
Dutch Flat Mining	**[e]California**	**2.4 - 21**	[e] *Hunerlach, et al., 1999*
Ngwabalozi River	**[f]Zimbabwe**	**0.01 - 0.31**	[f] *(Mudyazhezha and Kanhukamwe, 2014)*
Cuyuni River Basin	**[g]Venezuela**	**0.16 - 542**	[g] *Santos-Francés et al., 2011*
Tongguan,	**[h]Shaanxi, China**	**0.9 - 76**	[h] *Feng et al., 2006; Drace et al., 2012*
Mwakitolyo	**[i]Tanzania**	**2.50**	[i] *Van Straaten, 2000;* [h] *Drace et al., 2012*
Kedougou,	**[j]Senegal**	**up to 9.9**	[j] *Niane et al., 2014.*
Pra River	**[k]Ghana**	**0.018 - 2.917**	[k] *Niane et al., 2014; Donkor et al., 2006; Van Straaten, 2000.*
Wuchuan	**[l]Guizhou, China**	**3.3 to 810**	[l] *Li et al., 2012*
Nambija Mineral	**[m]Ecuador**	**89 - 1555**	[m] *Requelme et al., 2003*
Migori–Transmara	**[n]Kenya**	**8.90**	[n] *Okang'Okang et al., 2014*
	[o]Guyana	**0.029– 1.2**	[o] *Howard et al., 2011.*

Conclusion

Sixteen soil samples from Al Salam Hg mine-wastes in Al Abiydia city were analyzed by DMA-80 technique. The results showed that the concentration of Hg ranged from 2.144 to 47.635 mg.kg^{-1}, with an average of 19.969 mg.kg^{-1}. These values exceeded the background values (IAEA, 0.04 mg.kg^{-1}; VIRM, 4.8 mg.kg^{-1}; ASTRD, 0.063 mg.kg^{-1}). Also, the Pollution and toxicity degree were calculated and presented high values of pollution and toxicity. During this analysis, the results showed that the soil samples are highly contaminated with Hg. The elevated Hg level can seepage to Nile River by environmental conditions such as rains and wind and cause environmental hazard to the surrounding area.

References

[1]. DRACE, K., KIEFER, A. M., VEIGA, M. M., WILLIAMS, M. K., ASCARI, B., KNAPPER, K. A., LOGAN, K. M., BRESLIN, V. M., SKIDMORE, A. & BOLT, D. A. (2012). Mercury-free, small-scale artisanal gold mining in Mozambique: utilization of magnets to isolate gold at clean tech mine. *Journal of Cleaner Production*, 32, 88-95.

[2]. FENG, X., DAI, Q., QIU, G., LI, G., HE, L. & WANG, D. (2006). Gold mining related mercury contamination in Tongguan, Shaanxi Province, PR China. *Applied Geochemistry*, 21, 1955-1968.

[3]. HAKANSON, L. (1980). An ecological risk index for aquatic pollution control. A sedimentological approach. *Water research*, 14, 975-1001.

[4]. KABATA-PENDIAS, A. (2010). *Trace elements in soils and plants*, CRC press.

[5]. LI, P., FENG, X., QIU, G., SHANG, L. & WANG, S. (2012). Mercury pollution in Wuchuan mercury mining area, Guizhou, Southwestern China: The impacts from large scale and artisanal mercury mining. *Environment international*, 42, 59-66.

[6]. MUDYAZHEZHA, S. & KANHUKAMWE, R. (2014). Environmental Monitoring of the Effects of Conventional and Artisanal Gold Mining on Water Quality in Ngwabalozi River, Southern Zimbabwe. *International Journal of Engineering*, 4, 8269.

[7]. NIANE, B., MORITZ, R., GUEDRON, S., NGOM, P. M., PFEIFER, H. R., MALL, I. & POTE, J. (2014). Effect of recent artisanal small-scale gold mining on the contamination of surface river sediment: Case of Gambia River, Kedougou region, southeastern Senegal. *Journal of Geochemical Exploration*, 144, 517-527.

[8]. RAJAEE, M., LONG, R. N., RENNE, E. P. & BASU, N. (2015). Mercury exposure assessment and spatial distribution in a Ghanaian small-scale gold mining community. *International journal of environmental research and public health*, 12, 10755-10782.

[9]. REQUELME, M. R., RAMOS, J., ANGELICA, R. & BRABO, E. (2003). Assessment of Hg-contamination in soils and stream sediments in the mineral district of Nambija, Ecuadorian Amazon (example of an impacted area affected by artisanal gold mining). *Applied Geochemistry*, 18, 371-381.

[10]. SANTOS-FRANCES, F., GARCíA-SáNCHEZ, A., ALONSO-ROJO, P., CONTRERAS, F. & ADAMS, M. (2011). Distribution and mobility of mercury in soils of a gold mining region, Cuyuni river basin, Venezuela. Journal of environmental management, 92, 1268-1276.

[11]. YU, R., HU, G., LIN, C., YANG, Q., ZHANG, C. & WANG, X. (2017). Contamination of heavy metals and isotopic tracing of Pb in intertidal surface sediments of Jinjiang River Estuary, SE China. Applied Geochemistry, 83, 41-49.

[12]. ELHASHMI, ELFADIL. (2015). The polities of Mining and Trading of gold in Sudan: *Challenges of corruption and Lack of Transparency*, Sudan Democracy First Group (SDFG).

[13]. Al Karam, 2015. Effect of Gold Mining on the Sudanese Economy, *Journal of Red Sea University*, ISSN: 1858 – 7674, pp. 25 – 42.

[14]. SUDANESE ECONMOY (2017). Interview with Minister of Minerals in Sudan, *Newspaper*, Issue 8083.

[15]. MOHAMED, F. A., KOVEKE,E. P., OHIRA, SHIN-ICHI, TODA, K., 2015. *Mercury Pollution from Artisanal Gold Mining Activities in Sudan*, BRCORP, 4th World Conference on Applied Science, Engineering & Technology , Kumamoto University, Japan,PP: 1-3.

[16]. IBRAHIM, M. S., (2015). *Artisanal Mining in Sudan - Opportunities, Challenges and Impacts*, 17th Africa OILGASMINE,

Khartoum, 23-26, Extractive Industries and Sustainable Job Creation, UNCTAD.

[17]. WADI,E.I. A.,& ALREDAISY,S.M.A. H., (2015). Socioeconomic and Environmental Implications of Traditional Gold Mining in Sudan: The caseof BarberLocality, RiverNiles State, *American Based Research Journal*, vol.4, Issue 7: 1-12.

[18]. ESDAILE, L. J. & CHALKER, J. M. (2018). The Mercury Problem in Artisanal and Small-Scale Gold Mining. *Chemistry–A European Journal*, 24, 6905-6916.

[19]. IAEA. (2000). *Soil-7*. International Atomic Energy Agency, Vienna, Austria, January: 1- 4.

[20]. VIRM, Rijkswaterstaat, Ministry of Infrastructure and the Environment Dutch list.

[21]. SEPA.(2001). *State of the environment soil quality report*, Scottish Environment Protection Agency.

[22]. ATSDR, U. (1999). *Toxicological profile for mercury*. Atlanta: Agency for Toxic Substances and Disease Registry, US Department of Health and Human Services.

[23]. MORALES, S. (2013). Environmental assessment of mercury pollution in urban tailings from gold mining. *Ecotoxicology and environmental safety*, 90, 167-173.

[24]. TAYLOR, H., APPLETON, J., LISTER, R., SMITH, B., CHITAMWEBA, D., MKUMBO, O., MACHIWA, J., TESHA, A. & BEINHOFF, C. (2005). Environmental assessment of mercury contamination from the Rwamagasa artisanal gold mining centre, Geita District, Tanzania. *Science of the Total Environment*, 343, 111-133.

[25]. RAJAEE, M., LONG, R. N., RENNE, E. P. & BASU, N. (2015). Mercury exposure assessment and spatial distribution in a Ghanaian small-scale gold mining community. *International journal of environmental research and public health*, 12, 10755-10782.

[26]. DE ANDRADE LIMA, L., BERNARDEZ, L. & BARBOSA, L. A. D. (2008). Characterization and treatment of artisanal gold mine tailings. *Journal of hazardous materials*, 150, 747-753.

[27]. HUNERLACH, M. P., RYTUBA, J. J. & ALPERS, C. N. (1999). *Mercury contamination from hydraulic placer-gold mining in the Dutch Flat mining district*, California.

[28]. MUDYAZHEZHA, S. & KANHUKAMWE, R. (2014). Environmental Monitoring of the Effects of Conventional and Artisanal Gold Mining on Water Quality in Ngwabalozi River, Southern Zimbabwe. *International Journal of Engineering*, 4, 8269.

[29]. DRACE, K., KIEFER, A. M., VEIGA, M. M., WILLIAMS, M. K., ASCARI, B., KNAPPER, K. A., LOGAN, K. M., BRESLIN, V. M., SKIDMORE, A. & BOLT, D. A. (2012). Mercury-free, small-scale artisanal gold mining in Mozambique: utilization of magnets to isolate gold at clean tech mine. *Journal of Cleaner Production*, 32, 88-95.

[30]. VAN STRAATEN, P. (2000). Mercury contamination associated with small-scale gold mining in Tanzania and Zimbabwe. *Science of the Total Environment*, 259, 105-113.

[31]. DONKOR, A., BONZONGO, J., NARTEY, V. & ADOTEY, D. (2006). Mercury in different environmental compartments of the Pra River Basin, Ghana. *Science of the Total Environment*, 368, 164-176.

[32]. LI, P., FENG, X., QIU, G., SHANG, L. & WANG, S. (2012). Mercury pollution in Wuchuan mercury mining area, Guizhou, Southwestern China: The impacts from large scale and artisanal mercury mining. *Environment international*, 42, 59-66.

[33]. REQUELME, M. R., RAMOS, J., ANGELICA, R. & BRABO, E. (2003). Assessment of Hg-contamination in soils and stream sediments in the mineral district of Nambija, Ecuadorian Amazon (example of an impacted area affected by artisanal gold mining). *Applied Geochemistry*, 18, 371-381.

[34]. OKANG'ODUMO, B., CARBONELL, G., ANGEYO, H. K., PATEL, J. P., TORRIJOS, M. & MARTíN, J. A. R. (2014). Impact of gold mining associated with mercury contamination in soil, biota sediments and tailings in Kenya. *Environmental Science and Pollution Research*, 21, 12426-12435.

[35]. HOWARD, J., TROTZ, M. A., THOMAS, K., OMISCA, E., CHIU, H. T., HALFHIDE, T., AKIWUMI, F., MICHAEL, R. & STUART, A. L. 2011. Total mercury loadings in sediment from gold mining and conservation areas in Guyana. *Environmental monitoring and assessment*, 179, 555-573.

[36]. QIU, G., FENG, X., WANG, S. & SHANG, L. (2005). Mercury and methylmercury in riparian soil, sediments, mine-waste calcines, and moss from abandoned Hg mines in east Guizhou province, southwestern China. *Applied Geochemistry*, 20, 627-638.

[37]. GENCHI, G., SINICROPI, M. S., CAROCCI, A., LAURIA, G. & CATALANO, A. (2017). Mercury exposure and heart diseases. *International journal of environmental research and public health*, 14, 74.

[38]. NABAASA, H. (2016). Artisanal and small-scale gold mining and food security: An ecological perspective. *African Journal of Public Affairs*, 9 (4): 144 – 155.

[39]. DU, B., LI, P., FENG, X., QIU, G., ZHOU, J. & MAURICE, L. (2016). Mercury exposure in children of the Wanshan mercury mining area, Guizhou, China. *International journal of environmental research and public health*, 13, 1107.

[40]. YU, R., HU, G., LIN, C., YANG, Q., ZHANG, C. & WANG, X. (2017). Contamination of heavy metals and isotopic tracing of Pb in intertidal surface sediments of Jinjiang River Estuary, SE China. *Applied Geochemistry*, 83, 41-49.

[41]. SCHUTZMEIER, PAUL; BERGER, URSULA; AND BOSE-O'REILLY, STEPHAN. (2016). Gold Mining in Ecuador: A Cross-Sectional Assessment of Mercury in Urine and Medical Symptoms in Miners from Portovelo/Zaruma. *International Journal of Environmental Research and Public Health*, 14(1):34.

[42]. VEIGA, MARCELLO M.; ANGELOCI-SANTOS, GUSTAVO; AND MEECH, JOHN A. (2014). Review of barriers to reduce mercury use in artisanal gold mining. *The Extractive Industries and Society*, 1, (2).

[43]. EISLER, RONALD; AND WIEMEYER, STANLEY N. (2004). Cyanide Hazards to Plants and Animals from Gold Mining and Related Water Issues. *Reviews of environmental contamination and toxicology* , 183:21-54.

[44]. ESDAILE LJ, CHALKER JM. (2018). The mercury problem in artisanal and small-scale gold mining. *Chem Eur J*. 24(27):6905–6916.

[45]. LANGELAND, A.L.; HARDIN, R.D.; NEITZEL, R.L.(2017). Mercury Levels in Human Hair and Farmed Fish near Artisanal and Small-Scale Gold Mining Communities in the Madre de Dios River Basin, Peru. *Int. J. Environ. Res. Public Health*. 14, 302.

[46]. HYLANDER, LARS; MEILI, MARKUS. (2005). The Rise and Fall of Mercury: Converting a Resource to Refuse After 500 Years of Mining and Pollution. *Critical Reviews in Environmental Science and Technology*, 35(1):1-36.

[47]. GÜIZA, L., & ARISTIZÁBAL, J. D. (2013). Mercury and gold mining in colombia: A failed state. *Universitas Scientiarum*, 33-49.

[48]. MUDYAZHEZHA, SIMBARASHE; KANHUKAMWE, REGINALD. (2014). Environmental Monitoring of the Effects of Conventional and Artisanal Gold Mining on Water Quality in Ngwabalozi River, Southern Zimbabwe. *International Journal of Environmental Monitoring and Analysis.* Vol. 2, No. 2, 2014, pp. 123-127.