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Health risk assessment model for lead contaminated soil in Bagega Community, Nigeria

***[1]ALABA, OC; [2]OPAFUNSO, ZO; [3]AGYEI, G**

[1]Department of Mining Engineering, Federal University of Technology, Akure, Nigeria
[2,3]Department of Mining Engineering, University of Mines & Technology, Tarkwa Ghana
Corresponding Author e-mail: ocalaba@futa.edu.ng; zoopafunso@umat.edu.gh

ABSTRACT: The study developed health risk assessment model for lead contaminated soil in Bagega community using United States Environmental Protection Agency (US EPA) and Canadian Standards Association (CAS) standard procedures. Questionnaires were used to investigate the background causes and exposure pathways of lead contaminated soil. Soil samples were collected at five different sites and cancer health risk values were estimated using equations proposed by US EPA. The results show that 84.0 % of the respondents agreed that the causes of lead poisoning in the study area were due to the activities of artisanal gold miners. The major exposure pathways to lead contaminated soil are ingestion, dermal contact and inhalation while the soil ingestion generates high cancer risk, dermal contact generates low cancer risk and that of inhalation was insignificant when compared with 1.00E-06 (mg/kg/day) WHO cancer risk standard. The mean cancer health risk value for combined exposure pathway is ranged from 1.49E-03 mg/kg/day to 5.99E-03 mg/kg/day. The study established that lead contaminated soil posed cancer health risk to the people of the study area.

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The prevalent news of lead poisoning through the activities of artisanal gold mining in some states in Nigeria has become a worrisome to the stakeholders across the mining sector. According to Alaba and Opafunso (2016), the first lead poison was reported in Zanfara State in 2010 while another one was reported in Niger State in 2013. The released of lead during the gold processing into the environment has resulted to potential danger to the people, which requires urgent attention to protect public health and the environment (USEPA, 1991). The first action that expert needs to execute is to develop health risk assessment model that will facilitate the selection and effectiveness of remedial options (Alaba and Adesida, 2017). The risk assessment model provides the necessary information for decision makers and ensures the allocation of the available resources in order of importance during the remediation (Taiwo and Awomeso, 2017). The risk assessment model involves estimation of the type and magnitude of the exposure compared to the chemical elements present in the soil (WHO, 1994). According to USEPA (1989), the risk assessment is multi-step procedures that comprise: data collection, exposure assessment, toxicity assessment and risk characterization.

In Bagega community, more than 200 children under the age of 5years have been reported death due to the gold processing carried out by artisanal gold miners (MSF, 2012; Greig *et al.,* 2014). The local methods adopted by the miners in processing gold enhanced the release of substantial amounts of lead dust which was spread across the community. The ingestion, inhalation and dermal contact of lead contaminated soil, water and food crops were responsible for the monumental death of the children (CDC, 2010; Bello *et al.,* 2016). The environmentalists tagged the Zamfara State incident as the worst outbreak of lead poison in modern history (HRW, 2011). The study therefore developed a health risk assessment model (HRAM) that facilitates the selection and effectiveness of remedial options of the contaminated soil.

MATERIAL AND METHODS

Description of the Study Area: The study area is Bagega Community which situated in Anka Local Government Areas of Zamfara State. The location of the study area is within the coordinates 5.999E and 6.049E; 11.873N and 11.861N. The main occupation of the people in the study area is farming until recent time when artisanal gold mining becomes important socio-economic activities of the people due to rise in worldwide gold prices (JUNEP/OCHA, 2010). The major agricultural produce includes carrot, sweet potatoes, millet, guinea-corn, maize, rice, groundnuts, cotton, vegetables, tobacco and beans.

Corresponding Author e-mail: ocalaba@futa.edu.ng; zoopafunso@umat.edu.gh

Methodology: Questionnaire was designed for the study in order to determine the background causes of lead contaminated soil and their exposure pathways in the study area. Two hundred and fourteen (214) questionnaires were distributed to the farmers, artisanal gold miners, government agencies/NGOs and health workers. The judgment sampling procedure was used in selecting the respondents, while simple random sampling technique was used to distribute the questionnaires to the respondents. The analyses of the questionnaire were carried out using descriptive and inferential statistical analyses. The sampling of soil samples was carried out in five different areas based on their land use of which health risk assessment was carried out. The area includes: Bagega Residential Compound (BRC), Bagega Residential Garden (BRG), Bagega Village Common (BVC) Areas, Bagega Industrial Area (BIA) and Bagega Farmland Area (BFA) with their nothing and easting coordinates given in Table 1. Soil samples were collected using stratified random sampling methods in accordance with ASTM D6907 standard procedures while the concentration of lead was determined using Atomic Absorption Spectrophotometer (AAS) in accordance with ASTM D 3559 standard methods.

Table 1: Location of Soil Sample

Site	BRC		BRG		BVC		BPA		BFA	
ID	East	North	East	North	East	North	East	North	East	North
01	173712	1313334	173201	1313415	173416	1313554	173209	1313368	173143	1313894
02	173429	1313395	173462	1313344	173733	1313334	173589	1313359	173372	1313935
03	173209	1313138	173289	1313189	173431	1313383	173569	1313116	173654	1313721
04	173342	1313214	173359	1313343	173281	1313620	173130	1313782	173641	1313558
05	173655	1313335	173521	1313105	173224	1313274	173198	1313629	173746	1313497
06	173456	1313327	-	-	173442	1313604	173347	1313551	173073	1313247
07	173392	1313523	-	-	173823	1313412	173230	1313808	173010	1313683
08	173270	1313449	-	-	173249	1313507	173486	1313272	173766	1313162
09	173116	1313728	-	-	173512	1313216	173162	1313446	-	-
10	173528	1313344	-	-	173390	1313693	173319	1313141	-	-
11	173283	1313418	-	-	173320	1313218	173141	1313641	-	-
12	173283	1313640	-	-	173013	1313561	-	-	-	-
13	173459	1313166	-	-	-	-	-	-	-	-
15	173215	1313571	-	-	-	-	-	-	-	-
15	173292	1313548	-	-	-	-	-	-	-	-

The cancer health risks of lead contamination in soil were estimated using equation (1) to (3) as proposed by USEPA (1991).

(a) Soil ingestion:

$$\text{Cancer risk } (CR_{ingest}) = \frac{IR_s * C_s * EF * CF * ED}{BW * AT * 365 \text{ days/yr}} * CSF_{oral} \quad 1$$

(b) Dermal Absorption

$$\text{Cancer risk } (CR_{dermal}) = \frac{C_s * CF * SA * EF * ABS * AF * ED}{BW * AT * 365 \text{ days/yr}} * CSF_{dermal} \quad 2$$

(c) Particulate Inhalation

$$\text{Cancer risk } (CR_{inh}) = \frac{C_s * {}^{1}/_{PEF} * IR_a * ET * EF * ED}{BW * AT * 365 \text{ days/yr}} * CSF_{inh} \quad 3$$

Where, CR = cancer risk for daily intake of metal (ingestion, dermal, inhalation) [mg/kg/day]; CSF is cancer slope factor (oral, dermal, inhalation) $(mg/kg\text{-}day)^{-1}$; IR_s is soil ingestion rate [mg/day]; CF is conversion factor [1E-06, kg/mg]; C_{soil} is concentration of pollutant in soil [mg/kg]; SA is skin surface area available for exposure (cm^2/event); AF is soil to skin adherence factor (mg/cm^2); ABS is absorption factor (unitless); IR_a is inhalation rate (m^3/hr); PEF is soil-to-air particulate emission factor (kg/m^3); ET is exposure time (hrs/day); EF is exposure frequency [days/year]; ED is exposure duration [years]; BW is body weight [kg]; AT is average time (years); and RfD is reference dose (oral, dermal, inhalation) (mg/kg-day).

The health risk assessment model (HRAM) was developed by adopting USEPA (1991) and CAS (2001) standard procedures. The was carried out by developing conceptual health risk model during the first stage of site assessment and updated as more detailed information on the site and the nature of contamination becomes available. The development of HRAM involved technical data from various sources that: support selection of sampling locations to establish background concentrations of identified contaminants; describe the processes that determine contaminant release, migration and receptor exposure; and evaluate the risk to human or ecological receptors. This was achieved by pulling together results obtained from questionnaire analyses, laboratory analyses and health risk analyses to form a flowsheet.

RESULTS AND DISCUSSION

The result of the questionnaire shows that 84.0 % of the respondents agreed that the causes of lead poisoning in the study area were due to the activities of artisanal gold miners, while 7.0 % agreed that it was due to the geology of the mineral deposit and 9.0 % agreed that it was caused by the materials used for processing gold as shown in Table 2. Therefore, it can be deduced from the result that the activities of artisanal gold miners were responsible for lead poisoning across the study area. As a result of physical observation carried out with the support of the questionnaire, the lead release mechanism of contaminated soil was established through the methods of gold processing in the study area which include breaking and grinding, pulverization, sluicing and washing, amalgamation as shown in Figure 1. Also, Figure 2 illustrates the exposure point to lead contaminated soil in the study area. The identified exposure points are: Bagega residential compound (BRC), Bagega residential garden (BRG), Bagega village common (BVC) area, Bagega industrial area (BIA) and Bagega farmland area (BFA). Figure 3 shows the exposure pathways and the receptors of lead contaminant across the study area. The identified exposure pathways are ingestion, dermal contact and inhalation of lead dust while the major receptors of lead contamination are human being, animal and their environment.

Table 2: Causes of Lead Poisoning in Bagega Community

Description of the activities	Frequency	Percent
AGM Activities	180	84.0
Geology of the areas	14	7.0
Use of lead materials	20	9.0
Total	**214**	**100.0**

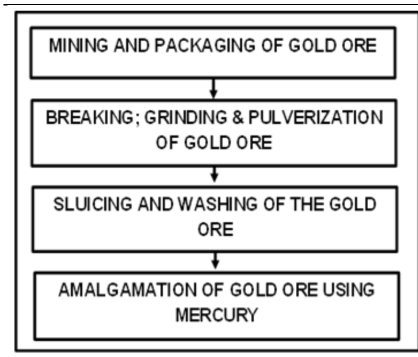

Fig. 1: Gold Processing Flowsheet as Reported by Miners

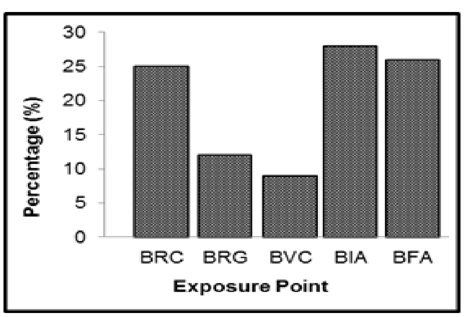

Fig. 2: Exposure Point to Lead Contaminated Soil in the Study Area

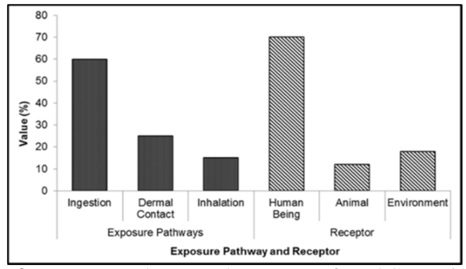

Fig. 3: Exposure Pathways and Receptors of Lead Contaminant

Table 3 shows the exposure pathways for cancer risk of lead metal in residential compounds. All the sampled residential compounds generates high carcinogenic lifetime risk for soil ingestion while dermal contact generates very low carcinogenic lifetime risk and that of inhalation is insignificant when compared with 1.00E – 06 WHO standard of cancer risk. It means that the lead pollution at residents of the study area posed a major cancer risk to the people and their environment through soil ingestion while sites BRC/06; BRC/07; BRC/08; BRC/09; BRC/10 and BRC/11 posed a minor cancer risk to the people and their environment through dermal contact and none of the sites posed risks to the people and their environment through inhalation. Therefore, those sites that posed cancer health risk to the people and their environment need to be monitored for further action. Table 4 establishes that only soil ingestion generates major high carcinogenic lifetime risk as their values above the WHO standard for cancer risk in the sampled residential garden. Meanwhile, sites BRG/02 and BRG/03 generate minor carcinogenic lifetime risk through dermal contact. Therefore, the people who work in the residential gardens were liable to be exposed to cancer risk through ingestion and dermal contact of lead contaminated soil. Table 5 illustrates that the sampled village common areas generates high carcinogenic lifetime risk for soil ingestion only as their values above the WHO standard for cancer risk. This justifies that people playing at village common areas were likely to be exposed to cancer risk through ingestion of lead contaminated soil at BVC. Table 6 shows that the only soil ingestion generates high carcinogenic lifetime risk in the sampled industrial areas as their values above the WHO standard for cancer risk. This established that the workers will be exposed to cancer risk through ingestion of lead contaminated soil and dust in industrial areas. It was discovered (Table 7) that all the sampled farmlands generates high carcinogenic lifetime risks of soil ingestion when compared with the WHO standard of acceptable risk. This established that the farmers will be exposed to cancer risk posed by lead pollution through ingestion of lead contaminated soil and dust at their farmlands.

Table 3: Cancer Health Risk for Exposure Pathways at BRC

ID	Soil Ingestion (mg/kg/day)	Dermal Contact (mg/kg/day)	Inhalation (mg/kg/day)	Total (mg/kg/day)
BRC/01	9.11E-03	2.87E-05	5.40E-08	9.14E-03
BRC/02	1.30E-02	4.10E-05	7.71E-08	1.30E-02
BRC/03	1.29E-03	4.07E-06	7.65E-09	1.29E-03
BRC/04	2.28E-03	7.19E-06	1.32E-08	2.29E-03
BRC/05	1.93E-03	6.08E-06	1.14E-08	1.94E-03
BRC/06	3.45E-03	1.08E-05	2.05E-08	3.46E-03
BRC/07	3.63E-03	1.14E-05	2.16E-08	3.64E-03
BRC/08	5.53E-03	1.75E-05	3.28E-08	5.55E-03
BRC/09	3.71E-03	1.17E-05	2.20E-08	3.72E-03
BRC/10	2.84E-02	8.96E-05	1.69E-07	2.85E-02
BRC/11	3.38E-03	1.06E-05	2.01E-08	3.39E-03
BRC/12	9.29E-03	2.93E-06	5.51E-09	9.29E-03
BRC/13	1.92E-03	6.08E-06	1.14E-08	1.93E-03
BRC/14	1.61E-03	5.09E-06	9.56E-09	1.62E-03
BRC/15	1.10E-03	3.48E-06	6.54E-09	1.10E-03
MEAN	**5.98E-03**	**1.71E-05**	**3.22E-08**	**5.99E-03**

Table 4: Cancer Health Risk for Exposure Pathways at BRG

ID	Soil Ingestion (mg/kg/day)	Dermal Contact (mg/kg/day)	Inhalation (mg/kg/day)	Total (mg/kg/day)
BRG/01	1.95E-03	1.29E-05	1.06E-07	1.96E-03
BRG/02	7.95E-04	5.24E-06	4.32E-08	8.00E-04
BRG/03	2.69E-03	1.78E-05	1.47E-07	2.71E-03
BRG/04	9.91E-04	6.54E-06	5.39E-08	9.98E-04
BRG/05	1.17E-03	7.72E-06	6.36E-08	1.18E-03
MEAN	**1.52E-03**	**1.00E-05**	**8.27E-08**	**1.53E-03**

Table 5: Cancer Health Risk for Exposure Pathways at BVC

ID	Soil Ingestion (mg/kg/day)	Dermal Contact (mg/kg/day)	Inhalation (mg/kg/day)	Total (mg/kg/day)
BVC/01	4.70E-04	1.61E-06	2.56E-08	4.72E-04
BVC/02	9.60E-04	6.38E-06	5.25E-08	9.66E-04
BVC/03	1.92E-03	1.26E-05	1.04E-07	1.93E-03
BVC/04	8.00E-04	5.30E-06	4.37E-08	8.05E-04
BVC/05	2.19E-03	1.45E-05	1.19E-07	2.20E-03
BVC/06	1.56E-03	1.03E-05	8.52E-08	1.57E-03
BVC/07	4.30E-04	2.86E-06	2.35E-08	4.33E-04
BVC/08	6.80E-04	4.48E-06	3.96E-08	6.85E-04
BVC/09	2.60E-03	1.72E-05	1.41E-07	2.62E-03
BVC/10	7.70E-04	5.10E-06	4.21E-08	7.75E-04
BVC/11	3.71E-03	2.45E-05	2.02E-07	3.73E-03
BVC/12	1.72E-03	1.14E-05	9.35E-08	1.73E-03
MEAN	**1.48E-03**	**9.69E-06**	**8.10E-08**	**1.49E-03**

Table 6: Cancer Health Risk for Exposure Pathways at BIA

ID	Soil Ingestion (mg/kg/day)	Dermal Contact (mg/kg/day)	Inhalation (mg/kg/day)	Total (mg/kg/day)
BIA/01	3.64E-03	2.40E-05	1.98E-07	3.66E-03
BIA/02	1.12E-03	7.39E-06	6.08E-08	1.13E-03
BIA/03	5.26E-03	3.47E-05	2.86E-07	5.29E-03
BIA/04	1.99E-03	1.32E-05	1.08E-07	2.00E-03
BIA/05	5.53E-03	3.66E-06	3.02E-08	5.53E-03
BIA/06	1.79E-03	1.18E-05	9.72E-08	1.80E-03
BIA/07	7.85E-03	5.18E-05	4.26E-07	7.90E-03
BIA/08	6.84E-03	4.52E-05	3.72E-07	6.89E-03
BIA/09	5.41E-03	3.57E-05	2.94E-07	5.45E-03
BIA/10	1.39E-03	9.18E-06	7.56E-08	1.40E-03
BIA/11	5.72E-03	3.77E-05	3.11E-07	5.76E-03
MEAN	**4.23E-03**	**2.49E-05**	**2.05E-07**	**4.26E-03**

The significance of health risk posed by the ingestion of lead contaminated soil as the major contributor to cancer health risk was tested with one sample t-test statistic in order to determine their levels of significance as shown in Table 8.

The respective p-values statistic for each site is less than 0.05. The study therefore established that the mean value of soil ingested in each site posed a significant cancer health risk to the people of the study area. Also, the average mean difference of cancer health risk for each site when compared with 1.00E-06 WHO standard are in descending order of BIA< BRC < BFA< BRG< BVC.

The health risk assessment model (HRAM) for the lead contaminated sites from the source of lead contaminant to the types of health risks posed to the people is presented in Figure 5. This was achieved by pulling together data obtained from questionnaire analyses; laboratory analyses and health risk analyses.

The source of lead contaminant was identified as artisanal gold mining as established in Table 2. Also, the lead released mechanism into the study area was given as breaking and grinding of gold ore, pulverization of gold, sluicing and washing of gold and amalgamation of gold as identified in Figure 1.

The potential environmental lead transport medium and their exposure points are: BRC, BRG, BVC, BIA and BFA as established in Figure 2.

Consequently, the major identified exposure pathways were given as ingestion, dermal contact and inhalation as identified in Figure 3. Meanwhile the receptor of lead exposure were human being, animal and environment and exposures risk is cancer risk as identified in Tables 2 – 8.

Table 7: Cancer Health Risk for Exposure Pathways at BFA

ID	Soil Ingestion (mg/kg/day)	Dermal Contact (mg/kg/day)	Inhalation (mg/kg/day)	Total (mg/kg/day)
BFA/01	5.90E-04	3.93E-06	3.24E-08	5.94E-04
BFA/02	3.95E-03	2.61E-05	2.15E-07	3.98E-03
BFA/03	4.50E-04	2.99E-05	2.47E-08	4.80E-04
BFA/04	3.09E-03	2.01E-05	1.66E-07	3.11E-03
BFA/05	1.67E-03	1.10E-05	9.08E-08	1.68E-03
BFA/06	2.21E-03	1.46E-05	1.20E-07	2.22E-03
BFA/07	5.67E-03	3.74E-05	3.08E-07	5.71E-03
BFA/08	6.72E-03	4.43E-05	3.66E-07	6.76E-03
MEAN	**3.04E-03**	**2.34E-05**	**1.65E-07**	**3.07E-03**

Table 8: One Sample t-test Statistic for Soil Ingestion

Test Value = 0.000001						
					95% Confidence Interval of the Difference	
Site ID	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
BRC	4.919	10	0.001	2.44864	1.3394	3.5579
BRG	4.294	4	0.013	0.98700	0.3489	1.6251
BVC	5.147	11	0.000	0.96450	0.5521	1.3769
BIA	2.930	14	0.011	3.51027	0.9410	6.0795
BFA	3.763	7	0.007	1.97000	0.7319	3.2081

Significance at 5%

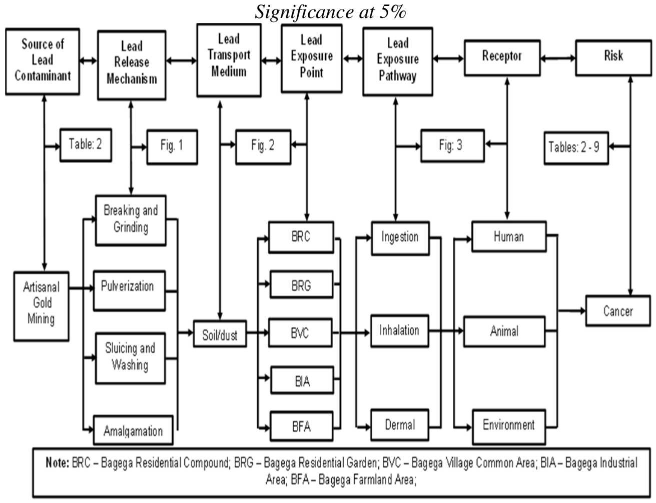

Fig 5: Health Risk Assessment Model for the Study Area

Conclusion: The study has successfully developed heath risk assessment model for lead contaminated soil. It was revealed that soil ingestion generates high cancer risk while dermal contact generates average cancer risk and that of inhalation was insignificant when compared with WHO standard for cancer risk. The testing of the significance of health risk justified that the cancer health risk in soil sample posed a significant health risk to the people of the study area. The study therefore established the importance of health risk assessment model in facilitating the selection and effectiveness of remedial options.

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