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Health Risk Ranking of Lead Contaminated Sites in Bagega Community, Zamfara State, Nigeria

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ABSTRACT

Background: The release of lead dust during the processing of lead-gold ore has become an environmental threat. Therefore the protection of miners' health and their environment required remediation which can be achieved by ranking the risk posed by lead in order to prioritize the allocation of resources during remediation.
Methods: Soil and water samples were collected at BRC, BRG, BVC, BPA and BFA; BWE, BBH and BPO using stratified random and grab sampling methods. Lead concentrations in the samples were determined using AAS while health risk index (HRI) via ingestion was estimated using USEPA equations. The ranking of HRI was done using Detailed Quantitative Risk Assessment while the difference between the HRI and USEPA standard were determined using one sample t test.
Results: The result showed that BRC/10, BRG/03, BVC/11, BPA/02 and BFA/08 were ranked highest in soil samples, while BWE/02, BBH/09 and BPO/04 were ranked highest in water samples as they posed elevated health risk effects to miners. One sample t test established that the BRC, BPA, BFA and BPO were significantly different from United States Environmental Protection Agency (US EPA) standard.
Conclusion: The study discovered that the users of both the lead contaminated soil and water were seriously exposed to potential health risk. It therefore suggested that decision makers should give priority in allocating resources to those sites with elevated lead concentrations during the remediation.

1. Introduction

The releases of lead dust during the processing of gold in villages where there is abundant gold deposit in Nigeria have become an environmental threat. Needleman et al [1] noted that the release of lead harmful substance into the environment usually poses danger to the people and their environment which requires the intervention of experts to take action that deems necessary to remediate the environment.

The protection of public health and the environment required remediation of the areas that posed danger to the people and environment by carrying out a health risk assessment. Huimei [2] described health risk assessment as a way of assessing the potential for exposure to contamination and the severity of the effect of such exposure.

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The application of health risk assessment to lead contaminated site problems is widely advocated by many regulators, industries and land developers [3].

Health risk assessment is a tool that provides the necessary information for decision makers regarding the requirements for management of the lead contamination [4]. Health risk assessment ensures the allocation of the necessary resources in a prioritized and defensible manner during the remediation through risk ranking systems. Risk ranking systems are developed and used to distinguish the contaminated sites with higher risk effects on human systems from those with lesser risk effect [5]. Huimei et al., [6] enumerated the various types of risk screening systems developed in some countries as: Preliminary Risk Assessment (PRA) developed in the United States [7]. Methods for Inventories of Contaminated Sites (MICS) developed in Sweden [8]. Risk Screening System (RSS) developed in New Zealand and National Classification System for Contaminated Sites (NCSCS) developed in Canada [9, 10].

Alaba and Opafunso [11] reported that the first lead pollution disaster was reported in Zamfara state in 2010 while the subsequent cases were reported in Niger state in 2013. Investigation from field of experts revealed that more than 400 children under the age of 5 years have been dead due to the lead poisoning from gold processing [12, 13, 14, 15, 16]. Plumlee et al., [17] attributed the causes of the death to the local methods adopted by the miners in processing gold, which enhanced the release of substantial amounts of lead dust which was spread across the community. The study by the Centers for Disease Control and Prevention [18] revealed that the ingestion of lead contaminated dust that spread over the soil, water and food crops of the study area was responsible for the monumental death of the children.

Meanwhile, Kids Health Organization [19] described lead as a deadly element that affects different part of body systems, most especially unborn babies and young children are at extreme risk of health problems from lead poisoning because their smaller, growing bodies make them more susceptible to absorbing and retaining the lead. Adrienne [20] estimated that childhood lead exposure contributes to about 600,000 new cases of children developing intellectual disabilities every year and estimated that lead exposure account for 143,000 deaths per year with the developing countries recorded the highest burden. The remediation of the areas covered by the lead dust was one of the principal and most comprehensive decisions undertaking by the Nigerian government with the support of international organizations [21].

Therefore, the purpose of this study is to rank the health risk posed by lead contaminated sites via ingestion in order to prioritize the allocation of resources during the remediation. The risk ranking system was used to distinguish the sites with higher risk effects on human systems from those with lesser risk effect which would ensure the allocation of available resources in a defensible manner during the decision making of sites remediation.

2. Materials and Methods

2.1. Description of the Study Area

Bagega Community is situated in Anka Local Government Areas in Zamfara State, Nigeria with the coordinates between 5.999E and 6.049E longitude; 11.873N and 11.861N latitude as shown in Fig. 1. Anka River is the main surface water body in the area, which lies about 3km kilometer to the north of the town with numerous streams and ponds located across the area. Those streams/ponds with well and borehole water is used as sources of water for gold processing, domestic use, irrigation and livestock watering, especially during the wet season. Vegetation in the entire region is generally sparse, and has been described by Russ [22] as savannah forest together with scrubs, which thin out in a northerly direction, with semi- deciduous high forests along streams and depressions. The main occupation of the people in the study area is farming until recent time when artisanal gold mining becomes important socioeconomic activities of the people due to rise in worldwide gold prices [23].

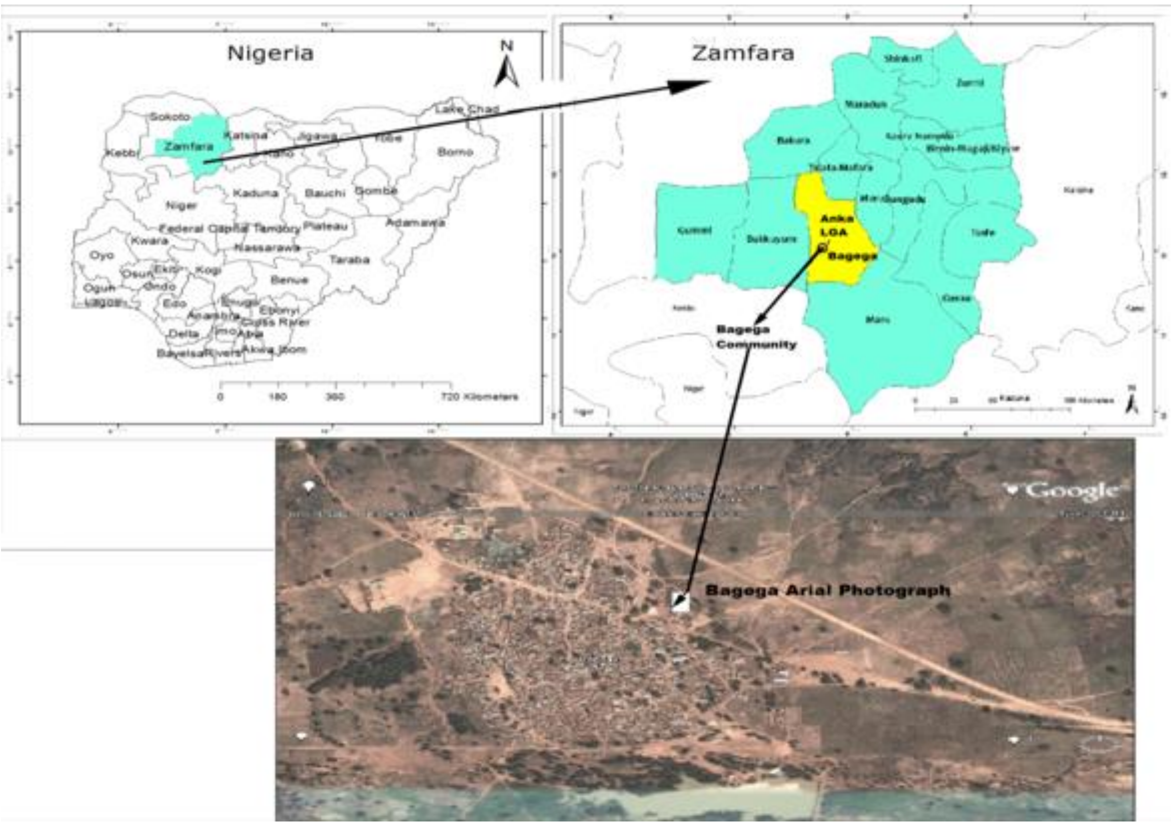

Fig. 1: Location of the Study Area (Source: Google Earth, 2010).

2.2. Soil and Water Sampling and Analyses

Stratified random sampling method was used to collect soil sample between the depths of 0 – 20 cm with an auger in accordance with standard methods of ASTM D6907 while grab sampling method was used to collect water sample in accordance with American Public Health Association (APHA) standard methods [24]. Soil samples were collected from residential compounds (BRC), residential gardens (BRG), village common areas (BVC), industrial areas (BPA) and farmland areas (BFA) while water sample was taken from the water source that were used for gold processing which include Well (BWE) water, Borehole (BBH) water and Pond (BPO) water. The laboratory analyses of soil and water samples were carried out at Central Research Laboratory, Federal University of Technology, Akure, Ondo State, Nigeria. Soil sample was digested with aquaregia and a mixture of bromine and hydro- bromic acid in accordance with standard procedures of ASTM D5513 while water sample was digested with concentrated Nitric acid and heated until the volume of the water reduced to 50ml in accordance with ASTM D1971 standard procedures. The determinations of lead value in soil and water samples were carried out using Buck Scientific Atomic Absorption Spectrophotometer (AAS) Model VGP 210 in accordance with standard methods of ASTM D3559 for soil and ASTM D1976 for water.

2.3 Health Risk Ranking of Lead Contaminated Site

The health risk index (HRI) of lead contamination via ingestion in soil and water were estimated using equations (1) and (2) as proposed by US EPA [25]. The ranking of health risk index was carried out using Detailed Quantitative Risk Assessment (DQRA) as proposed by Health Canada [26]. This was done by characterization of health risk assessment of the lead contaminated sites in order to determine site priority based on assessments of existing information. The health risk index with values above 1.00E+00 US EPA standard were classified as high while those below the US EPA standard was classified as low.

$$HI_S = \frac{IR_S \times C_S \times EF \times ED}{BW \times AT \times 365days/yr} \times \frac{1}{RfD} \quad (1)$$

$$HI_w = \frac{IR_w \times C_w \times EF \times ED}{BW \times AT \times 365days/yr} \times \frac{1}{RfD} \quad (2)$$

where, HI_s/HI_w are the hazard indexes of lead metal for soil/water ingestion exposure pathway; IR_s/IRw are soil/water ingestion rate [mg/day]; CF is conversion factor [1E-06, kg/mg]; C_s/C_w concentration of lead pollutant in soil/water [mg/kg; litre/day]; EF is exposure frequency [350 days/year] [27]; ED is exposure duration [70 years] [27]); BW is body weight [70nkg] [27]; AT is average time (25550 years) [27] and RfD is reference dose (oral) (0.0036 mg/kg-day) [27].

3. Results and Discussion

The hazard index estimated from the investigated sites showed very strong elevation when compared with international permissible standards as reported by United States Environmental Protection Agency [28]. The hazard index at the residential compound ranges from 1.84E+01 (BRC/10) to 6.02E-01 (BRC/12) as shown in Table 1. The result showed a remarkable increase in health risk ranking from BRC/10 to BRC/12 based on the level of involvement of each resident in gold processing. It was noted that three (BRC/03, 12 and 15) out of fifteen of the residential compounds investigated has a value below 1.00+00 US EPA standard. This is interpreted to mean that residents of the remaining compounds most especially young children and pregnant women are exposed to serious health risk. This result revealed that investigated compounds contained relatively the same amount of Pb of 85.20-631.16 mg/kg obtained in residential compounds at Dareta Village, Zamfara, Nigeria [29] while is higher than 0.162 to 0.431 obtained in Abandoned Municipal Waste Disposal Site in Aba, Nigeria [30].

Table 1: Health Risk Ranking in Bagega Residential Compound (BRC).

Site ID	Hazard Index	Site Status	Risk Severity	Action Recommended
BRC/10	1.84E+01	Pose Risk	1st	Remediation
BRC/02	8.42E+00	Pose Risk	2nd	Remediation
BRC/01	5.90E+00	Pose Risk	3rd	Remediation
BRC/08	3.59E+00	Pose Risk	4th	Remediation
BRC/09	2.40E+00	Pose Risk	5th	Remediation
BRC/07	2.35E+00	Pose Risk	6th	Remediation
BRC/06	2.23E+00	Pose Risk	7th	Remediation
BRC/11	2.19E+00	Pose Risk	8th	Remediation
BRC/04	1.48E+00	Pose Risk	9th	Remediation
BRC/05	1.25E+00	Pose Risk	10th	Remediation
BRC/13	1.25E+00	Pose Risk	11th	Remediation
BRC/14	1.04E+00	Pose Risk	12th	Remediation
BRC/03	8.36E-01	No Risk	13th	No Remediation
BRC/15	7.16E-01	No Risk	14th	No Remediation
BRC/12	6.02E-01	No Risk	15th	No Remediation

At, residential garden, the hazard index ranges from 2.45E+00 (BRG/03) to 7.21E-01 (BRG/02) as shown in Table 2. As the result compared to the US EPA standard, BRG/01, 03 and 05 posed health risk to their users, which means that people working in these residential gardens are exposed to serious health risk. Similar results are also reported in Maru, Abare and Dareta Villages in Zamfara State, Nigeria [31].

Table 2: Health Risk Ranking in Bagega Residential Garden (BRG).

Site ID	Hazard Index	Site Status	Risk Severity	Action Recommended
BRG/03	2.45E+00	Posed Risk	1st	Remediation
BRG/01	1.77E+00	Posed Risk	2nd	Remediation
BRG/05	1.06E+00	Posed Risk	3rd	Remediation
BRG/04	8.99E-01	No Risk	4th	No Remediation
BRG/02	7.21E-01	No Risk	5th	No Remediation

Meanwhile, the hazard index recorded in village common areas ranges from 3.37E+00 (BVC/11) to 3.93E-01 (BVC/07) as shown in Table 3. When the results compared with US EPA standard, six out of twelves village common areas studied posed health risk to their users while the remaining sites posed no health risk to their users. Similar results were reported in market place and play ground in Dareta village, Anka, Nigeria [29] and in open space in Bagega, Sunke, Abare, Tugar Guru Communities Zamfara State, Nigeria [14, 18, 23].

The hazard index at processing areas ranges from 7.13E+00 (BPA/07) to 5.03E-01 (BPA/05) as presented in Table 4. As the results compared with US EPA standard, only one processing area (BPA/05) out of eleven posed no health risk to their workers. This is interpreted to mean that workers of the remaining processing areas who work vigorously to earn their living get exposed to serious health risk. The result also revealed that examined processing areas recorded relatively the same amount of Pb obtained in processing areas at Dareta, Sunke, Duza Villages, Zamfara, Nigeria [23, 29, 32] while is higher than that obtained in Wassa-Amenfi-West District of Ghana [33]; contaminated soil in Taiwan [34] and central zone of Belgrade (Serbia) [35].

Table 3: Health Risk Ranking in Bagega Village Common (BVC) Areas.

Site ID	Hazard Index	Site Status	Risk Severity	Action Recommended
BVC/11	2.41E+00	Pose Risk	1st	Remediation
BVC/09	1.69E+00	Pose Risk	2nd	Remediation
BVC/05	1.42E+00	Pose Risk	3rd	Remediation
BVC/03	1.25E+00	Pose Risk	4th	Remediation
BVC/12	1.12E+00	Pose Risk	5th	Remediation
BVC/06	1.01E+00	Pose Risk	6th	Remediation
BVC/02	6.27E-01	No Risk	7th	No Remediation
BVC/04	5.20E-01	No Risk	8th	No Remediation
BVC/10	5.01E-01	No Risk	9th	No Remediation
BVC/08	4.41E-01	No Risk	10th	No Remediation
BVC/01	3.05E-01	No Risk	11th	No Remediation
BVC/07	2.80E-01	No Risk	12th	No Remediation

At farmland areas, the hazard index ranges from 6.10E+00 (BFA/08) to 4.12E-01 (BFA/03) as presented in Table 5. Two farmland areas (BFA/01 and 03) out of eight posed no health risk to the farmers while the remaining farmland areas posed health risks to the farmers when compared with US EPA standard. When the results compared to the other results from agricultural soil, Pb risk at investigated farmland areas was found to be present in high concentration [33, 36, 37].

Table 4: Health Risk Ranking in Bagega Processing Areas (BPA).

Site ID	Hazard Index	Site Status	Risk Severity	Action Recommended
BPA/07	7.13E+00	Posed Risk	1st	Remediation
BPA/08	6.21E+00	Posed Risk	2nd	Remediation
BPA/11	5.19E+00	Posed Risk	3rd	Remediation
BPA/09	4.91E+00	Posed Risk	4th	Remediation
BPA/03	4.77E+00	Posed Risk	5th	Remediation
BPA/01	3.30E+00	Posed Risk	6th	Remediation
BPA/04	1.81E+00	Posed Risk	7th	Remediation
BPA/06	1.62E+00	Posed Risk	8th	Remediation
BPA/10	1.26E+00	Posed Risk	9th	Remediation
BPA/02	1.02E+00	Posed Risk	10th	Remediation
BPA/05	5.03E-01	No Risk	11th	No Remediation

The result of hazard index in the studied well and borehole water is range from 3.89E+00 (BWE/02) to 2.19E-02 (BWE/11) for well water and 1.75E+00 (BBH/02) to 1.74E-02 (BBH/03) for borehole water as presented in Tables 6 and 7.

As the result compared with US EPA standard, it was depicted that unprotected wells (BWE/02, 04, 06 and 09) and damaged boreholes (BBH/02 and 04) posed health risk to their users. This result showed wide variation when compared with the value of drinking water obtained from Urban Areas of the Tigray Region, Northern Ethiopia and Cairo city, Egypt [38, 39]. Meanwhile, similar result of high risk of lead was reported in drinking water from unprotected well and damaged boreholes in villages where gold ore are being processed in Zamfara state Nigeria [23]. This was established that lead was introduced to unprotected wells and damaged boreholes from the surface during gold processing [11].

Table 5: Health Risk Ranking in Bagega Farmland Areas (BFA).

Site ID	Hazard Index	Site Status	Risk Severity	Action Recommended
BFA/08	4.36E+00	Pose Risk	1st	Remediation
BFA/07	3.67E+00	Pose Risk	2nd	Remediation
BFA/02	2.56E+00	Pose Risk	3rd	Remediation
BFA/04	1.98E+00	Pose Risk	4th	Remediation
BFA/06	1.43E+00	Pose Risk	5th	Remediation
BFA/05	1.08E+00	Pose Risk	6th	Remediation
BFA/01	3.86E-01	No Risk	7th	No Remediation
BFA/03	2.94E-01	No Risk	8th	No Remediation

The hazard index values recorded at pond/stream water ranges from 6.17E+01 (BPO/04) to 2.01E-02 (BPO/12) as presented in Table 8. As the results compared with US EPA standard, seven sluice pond water were seriously posed health risk to their users. The high severity of health risk from sluice pond was also established from the investigation carried out in Sunke, Abare, Dareta and Yargalma Communities in Zamfara state, Nigeria [14, 18, 23].

One sample t-test statistic was used to determine whether the health risk index value in soil and water samples was significantly not different from 1.00+00 US EPA standard. Tables 9 and 10 present the respective t-value (t), the degrees of freedom (df), and the statistical significance (2-tailed, p-value) of the one sample t-test in soil and water samples (BRC, BRG, BVC, BPA, BFA and BWE, BBH, BPO). The p-values in BRC, BPA and BFA were less than 0.05 ($p< 0.05$) while the p-value in BRG and BVC were greater than 0.05 ($p> 0.05$). This established that the health risk index values in BRC, BPA and BFA was significantly different from 1.00+00 US EPA standard, while that of BRG and BVC exposure point was significantly not different from 1.00+00 US EPA standard. Consequently, the *p*-value in BPO was less than 0.05 ($p< 0.05$) while the p-value in BWE and BBH was greater than 0.05 ($p> 0.05$).

This established that the health risk index value in BPO was significantly different from 1.00+00 US EPA standard, while that of BWE and BHH exposure points were significantly not different from 1.00+00 US EPA standard.

4. Conclusion

The health risk ranking assessment of lead contaminated site was successfully carried out for the allocation of available resources in prioritize and defensive manner during the remediation. The ranking of severity of the health risk shows that BRC/10, BRG/03, BVC/11, BPA/02 and BFA/08 have the highest potential health risk effects on the people in soil samples while BWE/02, BBH/02 and BPO/04 have the highest health risk effects to their users in water samples. Meanwhile, the one sample t test shows the ranking order of soil samples in descending order of BRC<BPA<BFA<BRG<BVC while water samples in descending order of BPO<BBH<BWE.

Table 6: Health Risk Ranking in Bagega Well (BWE) Water.

Site ID	Hazard Index	Site Status	Risk Severity	Action Recommended
BWE/02	3.89E+00	Posed Risk	1st	Remediation
BWE/04	2.71E+00	Posed Risk	2nd	Remediation
BWE/06	1.08E+00	Posed Risk	3rd	Remediation
BWE/09	1.04E+00	Posed Risk	4th	Remediation
BWE/05	1.42E-01	No Risk	5th	No Remediation
BWE/15	1.39E-01	No Risk	6th	No Remediation
BWE/12	5.58E-02	No Risk	7th	No Remediation
BWE/10	5.39E-02	No Risk	8th	No Remediation
BWE/01	4.92E-02	No Risk	9th	No Remediation
BWE/08	4.55E-02	No Risk	10th	No Remediation
BWE/13	3.98E-02	No Risk	11th	No Remediation
BWE/07	2.86E-02	No Risk	12th	No Remediation
BWE/03	2.61E-02	No Risk	13th	No Remediation
BWE/14	2.21E-02	No Risk	14th	No Remediation
BWE/11	2.19E-02	No Risk	15th	No Remediation

Table 7: Health Risk Ranking in Bagega Borehole (BBH) Water.

Site ID	Hazard Index	Site Status	Risk Severity	Action Recommended
BBH/02	1.75E+00	Posed Risk	1st	Remediation
BBH/04	1.32E+00	Posed Risk	2nd	Remediation
BBH/01	2.83E-02	No Risk	9th	No Remediation
BBH/03	1.74E-02	No Risk	11th	No Remediation

Table 8: Health Risk Ranking in Bagega Pond (BPO) Water.

Site ID	Hazard Index	Site Status	Risk Severity	Action Recommended
BPO/04	6.17E+01	Posed Risk	1st	Remediation
BPO/05	4.27E+01	Posed Risk	2nd	Remediation
BPO/02	4.13E+01	Posed Risk	3rd	Remediation
BPO/10	4.12E+01	Posed Risk	4th	Remediation
BPO/08	3.34E+01	Posed Risk	5th	Remediation
BPO/09	2.49E+01	Posed Risk	6th	Remediation
BPO/06	1.67E+01	Posed Risk	7th	Remediation
BPO/14	9.36E-01	No Risk	8th	No Remediation
BPO/01	8.07E-01	No Risk	9th	No Remediation
BPO/15	7.86E-01	No Risk	10th	No Remediation
BPO/07	6.34E-02	No Risk	11th	No Remediation
BPO/11	5.96E-02	No Risk	12th	No Remediation
BPO/13	5.78E-02	No Risk	13th	No Remediation

Table 9: One Sample t-test for Health Risk in Soil Sample.

Test Value = 1.00						
ID	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
BRC	2.096	14	0.04	2.510	-0.059	5.079
BRG	1.234	4	0.29	2.288	-2.860	7.436
BVC	1.342	11	0.21	0.351	-0.225	0.926
BPA	3.483	10	0.01	2.429	0.875	3.983
BFA	2.401	7	0.04	1.759	0.026	3.491

Significant at 5%

Table 10: One Sample t-test for Health Risk in Water Sample.

Test Value = 1.00						
ID	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
BWE	-1.255	14	0.230	-0.377	-1.021	0.267
BBH	-0.497	3	0.654	-0.22107	-1.6381	1.1959
BPO	3.020	14	0.009	16.644	4.822	28.466

The study therefore concluded that during the decision processes of allocating resources, the decision makers should use the results of the ranking health risk assessment plus other factors in establishing priorities for the site remediation.

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