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# Environmental Assessment of Lead Contaminated Site from Artisanal Gold Mining in Bagega Community, Nigeria

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***Authors' contributions***

*This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.*

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## ABSTRACT

**Aims:** The study assesses the extent of lead pollution in contaminated site from artisanal gold mining for remediation purposes.
**Study Design:** Experimental design was used in field sampling of soil and water samples based on the land use and sources of water.
**Study Area and Methodology:** Bagega Community is located in Anka Local Government Areas in Zamfara State between the longitude 5.999E and 6.049E; And latitude 11.873N and 11.861N. Stratified random sampling method was used to collect soil samples from sites SSA, SSB, SSC, SSD and SSE while water samples were collected from wells, boreholes and ponds in accordance with ASTM D 6970 and EPA standard procedures. The lead values in soil and water samples were determined in accordance with ASTM D 3559 and ASTM D 1976 standard methods. The data were analyzed using inferential statistical methods of multivariable mean with use of the turkey test to separate the mean, while the significance of lead pollution was determined with one sample t – test.
**Results:** The mean value of lead in SSA was 3521.31 mg/kg, SSB was 3628.76 mg/kg, SSC was 3546.19 mg/kg, SSD was 9012.44 mg/kg and SSE was 7251.72 mg/kg, while the one sample t –

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test established that the mean value of lead in soil sample was significantly different from 400 mg/kg USEPA standard. The lead value in well and borehole water were within the WHO standard except the unprotected wells and boreholes with lead values as high as 131.0 µg/l and 30.33 µg/l in unprotected wells and boreholes. Meanwhile, 67.0% of the pond water recorded lead values that exceeded the WHO standard with a mean value of 1103.33 µg/l.

**Conclusion:** The soil and water samples with lead values that were above USEPA and WHO standards should be subjected to remediation.

*Keywords: Artisanal gold mining; lead concentration; soil and water pollution; pollution index.*

## 1. INTRODUCTION

The frequent report of lead contaminated sites in Nigeria from artisanal gold mining (AGM) in recent time has been a major concern for the people, government and the entire world. A lead contaminated site can be an area of land, water or groundwater that would present a risk of harm to human health or the environment [1]. A lead contaminated site from artisanal gold mining in Nigeria was first reported in Zamfara state in 2010 [2] while the subsequent one was reported in Niger state in 2013 [3]. The lead contaminated site was responsible for the monumental lead poisoning of children and animals reported in these states [3]. Artisanal gold mining is a livelihood strategy adopted primarily in rural areas by using simple tools and equipment [4]. It is sometimes called “informal sector”, which is outside the legal and regulatory framework [5]. Artisanal gold mining was viewed negatively by governments and environmentalists when not formalized because of its potential for environmental damage, social disruption and conflicts [6]. Most artisanal miners work in difficult and often very hazardous conditions in the absence of the required safe mining regulations to safeguard the operations [4]. This is because toxic materials can be released into the environment, posing large health risks to the miners, their families and surrounding communities [5]. This was exactly what happened in Zamfara and Niger state. The gold mining operations in these areas are particularly dangerous, as they often use mercury to extract gold from ores [7]. Despite serious dangers posed by this activity, artisanal gold mining operations continue to spread due to rise in the demand for gold and unattractive nature of other means of livelihoods such as farming in the rural areas where the mineral is substantially available [7]. In view of these problems, the study had characterized the extent of lead contamination in soil, water and food crops of the study area.

## 2. MATERIALS AND METHODS

### 2.1 Description of the Study Area

Bagega Community is located in Anka Local Government Areas in Zamfara State which is one of the seven states that form the Northwest geopolitical zone of Nigeria [8]. The longitude and latitude of Bagega Community are between 5.999E and 6.049E; 11.873N and 11.861N. Agriculture is the main occupation of the people in the study area until recent time when artisanal gold mining becomes important socio-economic activities of the people due to rise in worldwide gold prices [9]. The major agricultural produce includes carrot, sweet potatoes, millet, guinea-corn, maize, rice, groundnuts, cotton, vegetables, tobacco and beans.

### 2.2 Soil Sampling and Analysis

Soil samples were collected from five different sites, namely: SSA, SSB, SSC, SSD and SSE. A total of fifteen soil samples was collected between the depth of 0 and 20cm at site SSA, five samples at site SSB, twelves samples at site SSC, eleven samples at site SSD and eight samples at site SSE using standard methods of ASTM [10]. The laboratory analyses of the samples were carried out at Central Research Laboratory, Federal University of Technology, Akure, Ondo State, Nigeria. The digestion of soil sample was carried out in accordance with ASTM [11] standard methods. The pH meter (Jenway 3015 Model) probes were immersed into the sample and allowed to stabilized at 25ºC and the pH values were taken while the concentration of lead metal was determined by Atomic Absorption Spectrophotometer (AAS) in accordance with ASTM [12] standard methods. The data obtained from the analysis were analyzed using inferential statistical methods of multivariable mean with use of the turkey test to separate the mean, while the significance of lead pollution was determined with one sample t –

test. The pollution index and its classification were estimated in Equation (1) as proposed by Liu et al. [13]

$$\mathrm{MPI} = \frac{C_{\mathrm{soil\ (sample)}}}{C_{\mathrm{reference}}} \quad (1)$$

Where $C_{soil}\,(sample)$ is the heavy metal concentration in soils from artisanal gold mining area and $C_{reference}$ is heavy metal concentration in soils from non-mining (control) areas.

## 2.3 Water Sampling and Analysis

A total of fifteen well (W) water, ten borehole (BH) water and fifteen pond (PO) water were taken across the study area with standard methods of EPA [14]. Liquid digestion of representative water sample was carried out in accordance with ASTM [15] standard procedures. The concentration of lead metal in water samples was determined using Atomic Absorption Spectrophotometer (AAS) in accordance with ASTM [16] standard methods. The data obtained from the analysis were analyzed using inferential statistical methods of multivariable mean with use of the turkey test to separate the mean.

# 3. RESULTS AND DISCUSSION

## 3.1 Soil Sample

The letters ‘a’ – ‘i’ in the tables show that samples with the same letters were not significantly difference from each other while those with different letters were significantly difference from each other. Hence, the level of lead concentration decreases from letter ‘a’ to ‘i’ which means ‘a’ has the highest concentration while ‘i’ has the lowest concentration

### 3.1.1 pH value in soil sample

pH is very important in determining soil quality since it plays significant roles in metals solubility and toxicity. Table 1 presents that there was no significant difference between the pH mean values in soil samples SSA, SSB, SSC, SSD and SSE as means in the same column followed by the same letters are not significantly different at *P* = .05. The pH values in all the sites were acidic in nature which enhanced the solubility and toxicity of metals being released to the soil as a result of gold processing.

**Table 1. Multivariable mean analysis of pH in soil sample**

| SITEID | b | a |
|---|---|---|
| SSE | 5.8308 | |
| SSA | 5.842 | |
| SSD | 5.8538 | |
| SSC | 5.8662 | |
| SSB | | 6.0878 |

*Mean in the same column followed by the same letters are not significantly different at P≤ 0.05*

### 3.1.2 Pb Pollution in soil sample SSA

Table 2 illustrates that lead concentration were not significantly different at SSA/03, 12 and 15; SSA/04, 05, 13 and 14; SSA/06 and 11; SSA/07 and 09 as values in the same column followed by the same letters are not significantly different at *P* = .05. Also, the estimated marginal means for the site SSA recorded minimum value of 595.74 mg/kg at SSA/12 and maximum value of 18175.70 mg/kg at SSA/10 which was significantly higher than 400 mg/kg USEPA [17] standard for soil.

Also, the pollution index classification shows that sites SSA/02 and 10 were extremely polluted, SSA/01 and 08 were very severely polluted while the remaining sites were either severely or moderately polluted (Table 2). The presence of high level of the lead pollution index was an indication of long time gold ore processing at site SSA. The habitants in this site were exposed to lead contaminated soil through ingestion, inhalation and dermal contact or eating of lead contaminated foods. Therefore, site SSA was not good for human habitation and therefore recommended for remediation.

### 3.1.3 Pb pollution in soil sample SSB

At site SSB, Table 3 shows that lead concentration in site SSB was significantly different from one another as means in different column followed by the same letters are not significantly different at *P* = .05. Meanwhile, the estimated marginal means for the site SSB recorded minimum value of 1895.59 mg/kg at SSB/02 while the maximum value of 6433.37 mg/kg was recorded at SSB/03 which was significantly higher than 400 mg/kg USEPA standard for soil. Therefore, this site was not good for human habitation.

Consequently, it was shown that the classification of lead pollution at site SSB were extremely, very severely and severely polluted

(Table 3). This established that people make use of site SSB were exposed to lead contaminants through ingestion of food crops/vegetables brought from the garden. Therefore, this site SSB was not good for human habitation and requires remediation.

#### 3.1.4 Pb pollution in soil sample SSC

The lead concentrations in selected soil samples at SSC were significantly not different at SSC/01 and 07; SSC/08 and 10, SSC/02 and 04, SSC/06 and 12 while all remaining samples were significantly different from one another as mean values in the same column followed by the same letters are not significantly different at *P* = .05 as shown in Table 4. Hence, the estimated marginal means for the site SSC recorded minimum value at SSC/07 while maximum value was recorded at SSC/11 which was significantly higher than 400 mg/kg USEPA standard for soil. Therefore, site SSC was not good for human habitation.

Moreso, only sample SSC/11 was excessively polluted while the remaining samples were either moderately or very severely polluted (Table 4). This justifies that the people of site SSC were exposed to lead contaminant through soil ingestion when playing. Therefore the site SSC was not suitable for playing and is recommended for remediation.

#### 3.1.5 Pb pollution in soil sample SSD

At site SSD, Table 5 shows that the lead concentrations in selected soil samples were significantly not different at SSD/02 and 10; SSD/04 and 06; SSD/03 and 09 as means values in the same column followed by the same letters are not significantly different at *P* = .05. Though, the estimated marginal means for

**Table 2. Multivariable mean analysis and pollution index classification in Site SSA**

| SITE ID | h | g | f | e | d | c | b | a | |
|---|---|---|---|---|---|---|---|---|---|
| SSA/12 | 595.74 | | | | | | | | Slightly Polluted |
| SSA/15 | 704.88 | | | | | | | | |
| SSA/03 | 826.56 | | | | | | | | |
| SSA/14 | | 1031.92 | | | | | | | Moderately Polluted |
| SSA/13 | | 1232.54 | | | | | | | |
| SSA/05 | | 1233.78 | | | | | | | |
| SSA/04 | | 1458.18 | | | | | | | |
| SSA/11 | | | 2166.35 | | | | | | Severely Polluted |
| SSA/06 | | | 2207.59 | | | | | | |
| SSA/07 | | | | 2324.85 | | | | | Very Severely Polluted |
| SSA/09 | | | | 2375.25 | | | | | |
| SSA/08 | | | | | 3542.61 | | | | |
| SSA/01 | | | | | | 5830.43 | | | |
| SSA/02 | | | | | | | 8315.51 | | Excessively Polluted |
| SSA/10 | | | | | | | | 18175.7 | |

*Mean in the same column followed by the same letters are not significantly different at P = .05*

**Table 3. Multivariable mean analysis and pollution index classification in site SSB**

| SITE ID | e | d | c | b | a | |
|---|---|---|---|---|---|---|
| SSB/02 | 1895.59 | | | | | Severely Polluted |
| SSB/04 | | 2363.55 | | | | |
| SSB/05 | | | 2789.19 | | | |
| SSB/01 | | | | 4662.48 | | Very Severely Polluted |
| SSB/03 | | | | | 6433.37 | Excessively Polluted |

*Mean in the same column followed by the same letters are not significantly different at P = .05*

**Table 4. Multivariable mean analysis and pollution index classification in site SSC**

| SITE ID | h | g | f | e | d | c | b | a |
|---|---|---|---|---|---|---|---|---|
| SSC/07 | 1032.06 | Moderately Polluted | | | | | | |
| SSC/01 | 1123.51 | | | | | | | |
| SSC/08 | | 1621.55 | | | | | | |
| SSC/10 | | 1844.42 | | Severely Polluted | | | | |
| SSC/04 | | | 1915.41 | | | | | |
| SSC/02 | | | 2305.78 | | | | | |
| SSC/06 | | | | 3736.85 | | | | |
| SSC/12 | | Very Severely Polluted | | 4102.53 | | | | |
| SSC/03 | | | | | 4588.33 | | | |
| SSC/05 | | | | | | 5226.15 | | |
| SSC/09 | | | | | | | 6203.47 | |
| SSC/11 | | | | | | Excessively Polluted | | 8854.22 |

*Mean in the same column followed by the same letters are not significantly different at P = .05*

the site SSD recorded minimum value of 1322.38 mg/kg at SSD/05 while the maximum value of 18727.75 mg/kg was recorded at SSD/07 which was significantly higher than 400 mg/kg USEPA standard for soil. Therefore, site SSD was not good for human activities.

However, the majority of soil samples collected from site SSD were extremely polluted as presented in Table 5. This justifies that people working on site SSD were exposed to high level of lead contaminant through soil ingestion and inhalation. Therefore the site SSD was not suitable for working condition and recommended for remediation.

#### 3.1.6 Pb pollution in soil sample SSE

Table 6 shows that the lead concentration in site SSE was significantly different from one another as the mean values in the same column followed by the same letters are not significantly different at *P* = .05. Although, the estimated marginal means for the site SSE recorded minimum value of 1082.97 mg/kg at SSE/03 while the maximum value of 16032.15 mg/kg was recorded at SSE/08 which were significantly higher than 400 mg/kg USEPA standard for soil.

The level of lead pollution was presented in Table 6 as SSE/02, 04, 07 and 08 were excessively polluted while SSE/05 and 06 were very severely polluted and SSE/01 and 03 were moderately polluted. This established that people farming in these sites were exposed to lead contaminants through ingestion of soil and ingestion of food crops/vegetables brought from the farmland. Therefore, site SSE was not suitable for farming as a result of human exposure to lead contaminants.

#### 3.1.7 Significance of lead contaminant in soil samples

The significance of lead pollution in soil samples were tested with one sample t-test statistic in order to determine whether remediation of the sites were necessary or not. Table 7 shows that the one sample t-test statistic and their respective *P*-values statistic for each site are less than 0.05 (level of significance). Since all the *P*-values statistic (Table 7) is less than 0.05, it is therefore established that the mean concentrations of lead in each site are significantly different from 400 mg/kg USEPA standard thereby remediation of the sites is necessary. Also, the average concentrations of lead in each site were exceeded the USEPA standard in descending order of SSD<SSE<SSB<SSC<SSA as illustrated by mean difference.

### 3.2 Water Sample

#### 3.2.1 Pb Concentration in Well (W) water

Table 8 shows that there was no major significant difference in lead concentration of well

**Table 5. Multivariable mean analysis and pollution index classification in Site SSD**

| SITE ID | h | g | f | e | d | c | b | a |
|---|---|---|---|---|---|---|---|---|
| SSD/05 | 1322.38 | | Severely Polluted | | | | | |
| SSD/02 | | 2669.39 | | | | | | |
| SSD/10 | | 3317.56 | | Very Severely Polluted | | | | |
| SSD/06 | | | 4263.45 | | | | | |
| SSD/04 | | | 4753.46 | | | | | |
| SSD/01 | | Excessively Polluted | | 8675.26 | | | | |
| SSD/03 | | | | | 12537.84 | | | |
| SSD/09 | | | | | 12912.33 | | | |
| SSD/11 | | | | | | 13634.85 | | |
| SSD/08 | | | | | | | 16322.54 | |
| SSD/07 | | | | | | | | 18727.75 |

*Mean in the same column followed by the same letters are not significantly different at P = .05*

water except W/02, 04, 06 and 09 which were unprotected wells and they were significantly different from one another as means in the same column followed by the same letters are not significantly different at *P* = .05. Also, the estimated marginal means of lead in selected well water samples were within the WHO standard except those of unprotected wells which exceeded WHO [18] standard. Therefore, children were only exposed to lead contaminated water through oral intake of water from unprotected wells.

### 3.2.2 Lead (Pb) concentration in Borehole (BH) water

Table 9 shows that there was no major significant difference in lead concentration of well water except W/02, 04, 06 and 09 which were unprotected wells and they were significantly different from one another as means in the same column followed by the same letters are not significantly different at *P* = .05. Also, the estimated marginal means of lead in selected well water samples were within the WHO standard except those of unprotected wells which exceeded WHO (2008) standard. Therefore, children were only exposed to lead contaminated water through oral intake of water from unprotected wells.

### 3.2.3 Lead (Pb) concentration in pond (PO) water

Table 10 shows that concentrations of lead in pond water were significantly different from one another with 80% of the samples were significantly exceeded the WHO standard, while

**Table 6. Multivariable mean analysis and pollution index classification in site SSE**

| SITE ID | h | g | f | e | d | c | b | a |
|---|---|---|---|---|---|---|---|---|
| SSE/03 | 1082.97 | | Moderately Polluted | | | | | |
| SSE/01 | | 1420.33 | | | | | | |
| SSE/05 | | | 3983.97 | | Severely Polluted | | | |
| SSE/06 | | | | 5268.37 | | | | |
| SSE/04 | | | | Excessively Polluted | 7275.05 | | | |
| SSE/02 | | | | | | 9433.16 | | |
| SSE/07 | | | | | | | 13517.89 | |
| SSE/08 | | | | | | | | 16032.06 |

*Mean in the same column followed by the same letters are not significantly different at P = .05*

**Table 7. One Sample t-test statistic for lead pollution in study area**

| | | | Test value = 400 | | | |
|---|---|---|---|---|---|---|
| **ID** | **t** | **df** | **Sig. (2-tailed)** | **Mean difference** | **95% confidence interval of the difference** | |
| | | | | | **Lower** | **Upper** |
| SSA | 2.59 | 14 | 0.021 | 3068.12 | 530.33 | 5605.91 |
| SSB | 3.83 | 4 | 0.019 | 3228.83 | 885.74 | 5571.92 |
| SSC | 4.57 | 11 | 0.001 | 3146.21 | 1631.94 | 4660.46 |
| SSD | 4.70 | 10 | 0.001 | 8612.43 | 4529.08 | 12695.78 |
| SSE | 3.56 | 7 | 0.009 | 6851.72 | 2296.82 | 11406.62 |

*Significance at 5%*

**Table 8. Multivariable mean analysis of lead concentration in well (W) water**

| SITE ID | i | h | g | f | e | d | c | b | a | |
|---|---|---|---|---|---|---|---|---|---|---|
| W/11 | 0.88 | | | | | | | | | |
| W/14 | 0.90 | | | | | | | | | |
| W/03 | | 1.76 | | | | | | | | |
| W/07 | | 2.43 | | | | | | | | |
| W/13 | | | 4.17 | | | | | | | Protected Wells |
| W/01 | | | | 5.24 | | | | | | |
| W/08 | | | | 5.64 | | | | | | |
| W/10 | | | | 5.98 | | | | | | |
| W/12 | | | | | 8.89 | | | | | |
| W/15 | | | | | 9.03 | | | | | |
| W/05 | | | | | 9.14 | | | | | |
| W/09 | | | | | | 27.16 | | | | |
| W/06 | | | | | | | 42.03 | | | Unprotected Wells Polluted |
| W/04 | | | | | | | | 56.00 | | |
| W/02 | | | | | | | | | 131.00 | |

*Mean in the same column followed by the same letters are not significantly different at P= .05*

**Table 9. Multivariable mean analysis of lead concentration in Borehole (BH) water**

| SITE ID | g | f | e | d | c | b | a | |
|---|---|---|---|---|---|---|---|---|
| BH/03 | 0.94 | | | | | | | |
| BH/11 | | 2.44 | | | | | | |
| BH/06 | | 2.67 | | | | | | |
| BH/01 | | | 3.72 | | | | | |
| BH/04 | | | 3.73 | | | | | Protected Boreholes Not Polluted |
| BH/07 | | | 4.30 | | | | | |
| BH/10 | | | | 5.02 | | | | |
| BH/02 | | | | 5.89 | | | | |
| BH/05 | | | | | 8.10 | | | |
| BH/08 | | | | | 8.40 | | | |
| BH/12 | | | | | | 24.60 | | Unprotected Boreholes Polluted |
| BH/09 | | | | | | | 30.33 | |

*Mean in the same column followed by the same letters are not significantly different at P = .05*

**Table 10. Multivariable mean analysis of lead concentration in pond (PO) water**

| SITE ID | h | g | f | e | d | c | b | a | |
|---|---|---|---|---|---|---|---|---|---|
| PO/12 | 2.54 | | | | | | | | |
| PO/03 | 3.99 | | Unpolluted Pond Water | | | | | | |
| PO/11 | 6.83 | | | | | | | | |
| PO/13 | 7.40 | | | | | | | | |
| PO/07 | 8.33 | | | | | | | | |
| PO/15 | | 36.66 | | | | | | | |
| PO/01 | | | 106.00 | | | | | | |
| PO/14 | | | | 123.00 | | | | | |
| PO/06 | | | | | 195.70 | | | | |
| PO/09 | | | | | 266.00 | | | | Polluted Pond Water |
| PO/08 | | | | | | 384.30 | | | |
| PO/10 | | | | | | 416.00 | | | |
| PO/02 | | | | | | 421.70 | | | |
| PO/05 | | | | | | | 605.70 | | |
| PO/04 | | | | | | | | 1103.00 | |

*Mean in the same column followed by the same letters are not significantly different at P= .05*

only 20% were significantly below WHO standard for lead in water. This justifies that pond water was mostly used for gold processing in the study area due to easy accessibility and dumping of wastes.

## 4. CONCLUSION

The lead concentration in soil samples of the study area shows that site SSA had the mean value of 3521.31 mg/kg, SSB had 3628.76 mg/kg, SSC had 3546.19 mg/kg, SSD had 9012.44 mg/kg and SSE had 7251.72 mg/kg respectively. When these results are compared with USEPA standard for soil, they exceed the 400 mg/kg USEPA regulatory values for soil. According to Liu et al. [13] pollution index classification, it was shown that the majority of soil samples were either very severely or extremely polluted. The testing of significance of lead pollution established that the mean concentrations of lead in soil samples are significantly different from 400 mg/kg USEPA standard thereby remediation of the sites is necessary. The lead values in well and borehole water were within the 10 µg/l WHO standard except the unprotected wells and boreholes with lead concentration as high as 131.0 µg/l and 30.33 µg/l in unprotected wells and boreholes. Meanwhile, 67.0% of the pond water had lead values that are above WHO standard with a mean value of 1103.33 µg/l. The study, therefore, recommended immediate remediation of the all the soil and water with lead concentration that exceeded USEPA and WHO standards.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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