Effects of artisanal gold mining activities on soil properties in a part of southwestern Nigeria

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Cogent Environmental Science (2017), 3: 1305650
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Adebayo O. Eludoyin1*, Abosede T. Ojo2, Temitope O. Ojo3 and Olusegun O. Awotoye2

Abstract: The study examined some physical and chemical characteristics of soils in an unmonitored mining community in southwestern Nigeria. This study aimed at determining if the active (recently mined), abandoned mines, adjacent farmland, and a relatively less-disturbed forest re-growth region in the community exhibit significantly different or similar characteristics. The main hypothesis is that sites of artisanal gold mining activities are characterized by higher concentrations of toxic metals than the farmland and forest sites. A 25 by 25 meters plot was demarcated in each sample area and soil samples were obtained from 0 to 15 cm soil layer (at 5 by 5 m subplot level). Soil samples were analyzed for particle size distribution, pH, organic C, total N, available P, exchangeable Ca2+, Mg2+, K+, and Na+, total acidity, and selected heavy metals (Zn, Hg, Cu, Mn, Cd, Pb, and Fe). The study showed that soils at the active and abandoned mine sites were more of sandy particles, and contained significantly higher concentrations of heavy metals but lesser concentrations of soil nutrients than the farmlands and the relatively undisturbed areas in the study area. The study concluded that artisanal gold mining activities caused severe soil degradation and loss of important soil nutrients in the area. The impact of the mining activities is a major threat to qualitative food security and sustainable livelihoods in the area.

ABOUT THE AUTHORS
Adebayo O. Eludoyin is a lecturer and researcher in the Department of Geography, Obafemi Awolowo University, Ile-Ife, Nigeria. He is a postgraduate research supervisor at the Institute of Ecology and Environmental Studies, in the same University. Olusegun Awotoye is the current director of the Institute of Ecology and Environmental Studies. He specializes in Ecological Studies. Mrs Ojo (Nee Ishabiyi) Abosede graduated from the Institute in 2015, and she is hoping to start a PhD research in 2017. Ojo Temitope is an assistant lecturer in Agricultural Economics in the University. The current research is part of the investigations into the consequences of the artisanal mining activities in parts of the southwest Nigeria. The group is currently working on the effects of the activities on vegetation in the area.

PUBLIC INTEREST STATEMENT
Locations of resources in many developing countries are often impaired because of unsustainable ways by which the resources are exploited. The present study investigated one of the main resource bases in the southwest Nigeria where unsustainable and unmonitored approach to gold mining have been found to negatively impact the soil characteristics. The mining activities also expose the residents of the rural settlement to ecological contamination. The study area is a typical community that is characterized by poor infrastructure, severe poverty and influx of unmonitored migrant workers. There is need for policy to protect resource bases from degradation to ensure sustainable development. This research is part of the postgraduate researches in the Obafemi Awolowo University, Ile-Ife, Nigeria, and has received no research fund from any source.
1. Introduction
The African continent contains about 30% of the world’s mineral resources, and possesses the largest known reserves of strategically important minerals, including gold (Bradshaw, Giam, & Sodhi, 2010; Darimani, Akabzaa, & Attuquayefio, 2013; Edwards et al., 2014; Ericsson, 1991; Mutemeri & Petersen, 2002; Taylor, Mackay, Kuypers, & Hudson-Edwards, 2009). Nigeria is one of the countries in the sub-Saharan Africa where mining formed huge source of export prior to oil boom period in 1970s (Ericsson, 1991). National interests in mining started to decline, since the oil boom period, causing increased sporadic, informal uncoordinated or unmonitored management of the existing and potential mines that resulted into intensified artisanal mining activities in the country (Edwards et al., 2014). Artisanal mining is generally a small-scale practice where the basic tools and manual labor are generally used for excavation (Canavesio, 2014). Artisanal mining activities are also an informal procedure, which though have found to cause severe environmental disruptions, have also been linked with economic benefits (including employment opportunities, tourism, technology advancements, and accessibility to both native and migrant populations) (Canavesio, 2014). The informal mining activities are characterized by low productivity, a lack of capital, poor technology, hazardous working conditions, land degradation, and pollution (Emel, Huber, & Makene, 2011).

Artisanal mining practices are common in Africa, and many researchers have investigated their attributes. For example, Hilson (2001) provides information about the workings of the small-scale mining industry in the Ghana, and argued that initiatives have recently been taken to regularize and formalize the activities of the industry, with the intention of reducing the associated environmental impacts and land-use conflicts. Except for the recent efforts by the Ministry of Mine and Steel Development, gold mining in Nigeria is largely uncontrolled, and the majority of the operators are unlicensed (Oramah, Richards, Summers, Garvin, & McGee, 2015). Studies have indicated mine sites are around farmlands where chemicals may accumulate in fruits and leaves of arable and cash crops, and that soil contamination in mine sites can cause severe heavy metal contamination of water sources and poisoning of humans and animals, if ingested (Bartrem et al., 2014; Lo et al., 2012; Oramoh et al., 2015; Plumlee et al., 2013). Poisoning by materials associated with mining has been associated with increased cases of kidney pain, respiratory problems, dizziness, and miscarriages in women, and deaths in many residents of communities where mining activities are carried out (Twerefou, Tutu, Owusu-Afriyie, & Adjei-Mantey, 2015).

This paper reports an investigation into the physical and chemical characteristics of soils in one of the gold mine sites in the southwestern Nigeria, and compared the characteristics with those of adjacent farmland and a forested region (which serves as a control for deterioration index valuation). Existing studies on the area have focused on the economic and vegetal consequences of the mining activities on the people (Adeoye, 2015; Adeyinka, Abegunde, Adeoye, & Adegem, 2011; Salami, Jimoh, & Muoghalu, 2003). The main hypothesis is that sites of artisanal gold mining activities are characterized by higher concentrations of toxic metals than the farmland and forest sites. Although the study area has a long history of gold mining (which probably commenced around 1940), the activities are up till date artisanal (Makinde, Oluyemi, & Olabanji, 2013).

2. Study area
The study area, Itagunmodi, is located within 7°30′N–7°36′N and 4°37′E–4°42′E, in the southwest Nigeria (Figure 1). Dominant land-use is agriculture, especially cultivation of cash (mainly cocoa, kola, oil palm and plantain) and food crops (including cassava, yam, and fruits). Many of the farmlands are characterized with holes that have been created during search for gold in the area (Figure 2).
Figure 2 is an image of the sites of typical fresh mines in the study area. The situation in the study area is a representative of the experience in many mine sites including Ifewara, Iloke in Ile-Ife, southwest Nigeria, and Jos in the North central Nigeria. The depressions or holes often serve as habitats for reptiles and other dangerous animals in the dry season.

The climate is characterized by tropical wet and dry climate in the rainforest ecological region. Mean annual temperature varies between 26°C and 28°C, while relative humidity over the area varies from 60 to 80%. Average rainfall is about 140 cm per year. The geology is characterized by Amphibolites rocks, and the soils belong to the Itagunmodi Association of the southwest Nigeria (Smyth & Montgomery, 1962). The vegetation characteristics vary with land-use types. An assessment of the vegetation characteristics indicated that more plant species occupied the relatively undisturbed forested region than either the mine sites or the farm plots (Figure 3). The lower frequency of climbers, shrubs, and tree species in the abandoned mine site can be attributed to the destruction of the vegetal properties around the site during the processes of soil excavations for gold.

In terms of the human geography, Itagunmodi is a typical rural area with high records of migrants that work on the mine fields. A cursory interaction with the workers at about two major sites revealed that about 80% are migrants from the northern region of the country. The migrant workers include, however, been settled (mostly temporarily) in the area.
3. Materials and methods

3.1. Soil sampling
Soil samples were obtained from the study area using a multistage procedure. First, an image of the area that was extracted from the Google Earth in 2015 was classified (after ground truthing) into active and abandoned sites, farmlands and relatively undisturbed area (areas occupied by forest or re-growth). Second, a 25 m-by-25 m sample plot was carved out of each classified area. Third, five 5 m-by-5 m subplots were systematically (arranged to include the edges and centre of the 25 by 25 m plot) mapped out in each plot. Finally, five composite soil samples randomly were taken, at 0–15 cm soil depth, using soil auger from each subplot. In all, 100 soil samples were collected. The soil samples were taken in labeled black polyethylene plastic bags for analysis at the Analytical Services Laboratory of the International Institute of Tropical Agriculture, Ibadan, Oyo State for analysis of particle size distribution, pH, organic C, total N, available P, exchangeable cations (Ca\(^{2+}\), Mg\(^{2+}\), K\(^{+}\), and Na\(^{+}\)), total acidity, and selected heavy metals (Zn, Hg, Cu, Mn, Cd, Pb, and Fe).

3.2. Laboratory analysis
The soil samples were air dried and allowed to pass through a 2-mm sieve, before they were analyzed. Samples for analysis of Zn, Hg, Cu, Mn, Cd, Pb, and Fe were also digested. Particle size distribution was analyzed using the hydrometer method (Bouyoucos, 1962) while pH was determined using pH meter. Organic matter content was determined with chromic acid oxidation method while total N was determined by Kjedahl digestion method (Persson, Wennerholm, & O'Halloran, 2008). Furthermore, available P was determined by Bray No 1 method (described in Food & Agriculture Organisation of the United Nations, FAO, 2004), concentrations of K\(^{+}\), Ca\(^{2+}\), and Na\(^{+}\) were determined.
with flame photometer while concentration of Mg\(^+\) and selected heavy metals was determined using atomic absorption spectrophotometer (Buck 205 model), at their respective wavelengths. Also, exchangeable acidity was determined by titration method.

### 3.3. Data analysis

Data were analyzed for differences under abandoned mine site, active mine site, farm, and non-cropped land using the Analysis of variance (ANOVA). Factor analysis was used to validate relationships of the ions and other variables and to derive results suggestive of the distinct properties, respectively. Change in the major physio-chemical variables (except the heavy metals) across mine sites and farms was described using the index of deterioration. The ID was computed in this study using Equation (1).

\[
ID = \frac{X_o - X_i}{X_o} \times 100
\]

where \(X_o\) = Mean value of soil parameters in relatively undisturbed site (as control site); and \(X_i\) = Mean value of soil parameter in compared site.

The quality of soil with respect to heavy metal concentrations was determined using the Nemerow Index (\(P_s\)) (Equations (2a–b)). The Nemerow Pollution Index classifies the quality of soil environment was classified into five domains; “Safety” (\(P_s = \) less than 0.7), “Precaution” (\(P_s = 0.7\)–0.99), “Slightly Polluted” (\(P_s = 1.0\)–1.99), “Moderately Polluted” (\(P_s = 2.0\)–2.99), and “Seriously or Heavily Polluted” (\(P_s = \) greater than 3.0) (Liang, Chen, Song, Han, & Liand, 2011; Qingjie, Jun, Yunchuan, Qingfei, & Liqiang, 2008).

\[
P_s = \sqrt{\frac{P_{ave}^2 + P_{max}^2}{2}}
\]

\[
P_i = \frac{C_i}{C_{ref}}
\]

where \(P_i\) = . Index; \(P_{ave}\) = Average of \(P\) of all the metals considered; \(P_{max}\) = Maximum of \(P\) of all the metals considered; \(P_i\) = the single pollution index of heavy metal (\(i\)) from at least five sampling sites; \(C_{i}\) = Mean concentrations of heavy metal (\(i\)) from at least five sampling sites; \(C_{ref}\) = Evaluation criteria value.

### 4. Results

#### 4.1. General soil characteristics at the mine sites, farmlands, and relatively undisturbed plots

Table 1 shows the general soil characteristics of the different land areas. The abandoned mine site was characterized by 72.2% sand particles, the active mine site contained 61.5% sand particles, while the sand particles at the farmlands and the relatively undisturbed plot averaged 52.6 and 54.6%, respectively (Table 1). In addition, the concentrations of the heavy metals were more in the mine sites than the other sites while concentrations of total N, available P, organic C, Ca\(^{2+}\), K\(^+\), Mg\(^{2+}\), Na\(^+\), and values of cation exchange capacity were, conversely, more in the relatively undisturbed
plot and the farmland than either the active or abandoned mine sites. While the active and abandoned mine sites were not significantly (at $p \leq 0.05$) different in terms of all the selected physiochemical variables, they were significantly ($p \leq 0.05$) from the farmlands and the relatively undisturbed plots.

### 4.2. Heavy metal contamination

The results of the $P_S$ and ID that were used to classified the mine sites and farmlands (with respect to the relatively undisturbed plot) indicated that the abandoned and mine sites are classified as “heavily polluted” under the Nemerow Pollution Index (Figure 4(a)). Both the active and abandoned mine sites were “heavily polluted” with Cd, Pb, Zn, Cu and Hg (except the active mine site), and were “slightly polluted” with Mn and Fe (Figure 4(b)). On the other hand, while Pb at the farmland was at precautionary level, other heavy metals (Cd, Pb, Zn, Cu, Hg Mn and Fe) were within the “slightly polluted” level.

### Table 1. Mean ± standard error of selected physical and chemical variables of soil samples from different landuse/cover at Itagunmodi, southwest Nigeria

| Parameters                      | Active mined site ($n = 25$) | Abandoned mine site ($n = 25$) | Farmland ($n = 25$) | Relatively undisturbed site ($n = 25$) |
|---------------------------------|------------------------------|-------------------------------|---------------------|----------------------------------------|
| % Sand                          | 61.52ª ± 0.16                | 72.22ª ± 0.22                | 52.61ª ± 0.35       | 54.64ª ± 0.22                          |
| % Silt                          | 14.80ª ± 2.30                | 12.90ª ± 3.14                | 9.21ª ± 2.14        | 9.32ª ± 1.81                           |
| % Clay                          | 13.10ª ± 4.64                | 11.30ª ± 2.65                | 14.20ª ± 3.93       | 17.00ª ± 4.70                          |
| Particle size                   | Sandy loam                   | Sandy loam                   | Loamy sand          | Loamy sand                             |
| Total N (%)                     | 0.03ª ± 0.02                 | 0.03ª ± 0.02                 | 1.1ª ± 0.23         | 1.2ª ± 0.24                            |
| Available P (mg kg⁻¹)           | 0.60ª ± 0.02                 | 0.31ª ± 0.02                 | 2.33ª ± 0.02        | 3.93ª ± 0.03                           |
| Organic C (%)                   | 1.30ª ± 0.24                 | 1.85ª ± 0.15                 | 3.77ª ± 0.22        | 4.13ª ± 0.25                           |
| Ca⁺⁺ (cmol kg⁻¹)                | 1.62ª ± 0.13                 | 1.50ª ± 0.15                 | 2.67ª ± 0.33        | 3.53ª ± 0.30                           |
| K⁺ (cmol kg⁻¹)                  | 0.07ª ± 0.01                 | 0.04ª ± 0.01                 | 0.11ª ± 0.01        | 0.12ª ± 0.01                           |
| Mg⁺⁺ (cmol kg⁻¹)                | 0.17ª ± 0.04                 | 0.15ª ± 0.04                 | 0.63ª ± 0.06        | 0.70ª ± 0.09                           |
| Na⁺ (cmol kg⁻¹)                 | 0.27ª ± 0.05                 | 0.20ª ± 0.06                 | 0.62ª ± 0.05        | 0.79ª ± 0.15                           |
| Cation exchange capacity (cmol kg⁻¹) | 1.47ª ± 0.09       | 1.29ª ± 0.08                 | 3.38ª ± 0.18        | 3.68ª ± 0.27                           |
| Total acidity (%)               | 0.05ª ± 0.25                 | 0.07ª ± 0.19                 | 0.04ª ± 0.23        | 0.05ª ± 0.39                           |
| pH (H₂O)                        | 4.16ª ± 0.18                 | 3.78ª ± 0.19                 | 6.56ª ± 0.17        | 6.76ª ± 0.07                           |
| pH (KCl)                        | 4.43ª ± 0.09                 | 4.60ª ± 0.12                 | 6.72ª ± 0.22        | 7.18ª ± 0.28                           |
| Zn (ppm)                        | 4.44ª ± 0.01                 | 4.67ª ± 0.01                 | 1.85ª ± 0.01        | 1.27ª ± 0.01                           |
| Cu (ppm)                        | 3.02ª ± 3.23                 | 2.22ª ± 3.09                 | 1.62ª ± 3.30        | 0.91ª ± 1.60                           |
| Mn (ppm)                        | 73.39ª ± 1.51                | 74.86ª ± 1.51                | 55.93ª ± 1.14       | 48.42ª ± 2.56                          |
| Fe (ppm)                        | 113.06ª ± 1.14               | 102.84ª ± 0.97               | 83.60ª ± 0.66       | 80.98ª ± 0.86                          |
| Pb (ppm)                        | 2.69ª ± 0.16                 | 2.77ª ± 0.19                 | 0.56ª ± 0.29        | 0.61ª ± 0.20                           |
| Cd (ppm)                        | 3.15ª ± 0.02                 | 2.27ª ± 0.09                 | 0.78ª ± 0.09        | 0.44ª ± 0.10                           |
| Hg (ppm)                        | 0.26ª ± 0.01                 | 0.28ª ± 0.01                 | 0.12ª ± 0.03        | 0.10ª ± 0.02                           |

Notes: The superscripts are used to indicate significant variations at 95% confidence level across rows. Means at same row with same alphabet (lower case) are not significantly different at $p \leq 0.05$. 
4.3. Index of deterioration (ID) at different landuse/cover

In terms of major cations and soil nutrients, the ID indicated that the abandoned and active mine sites exhibited at least 60% value of deterioration index in the concentrations of total N, available P, Ca$^{2+}$, Mg$^{2+}$, Na$^{+}$, and CEC when compared with the control (the relatively undisturbed plot). The concentrations of Organic C and K$^{+}$ also deteriorated by greater than 60% in the active and abandoned mine site, respectively (Table 2). Conversely, except for the available P, which degraded at 40.6%, other selected variables recorded lower than 25% deterioration index value.

Table 2. Deterioration index values (%) of soil properties under different land uses

| Soil properties | Active mine site | Abandoned mine site | Farmland |
|----------------|-----------------|---------------------|---------|
| pH(H$_2$O)     | 38.5            | 44.1                | 3.1     |
| pH(KCl)        | 38.4            | 35.9                | 6.4     |
| Total N        | 97.5            | 97.5                | 8.3     |
| Available P    | 89.8            | 92.3                | 40.6    |
| Organic C      | 68.8            | 55.4                | 8.7     |
| Ca$^{2+}$      | 54.3            | 57.7                | 24.1    |
| Mg$^{2+}$      | 75.7            | 80.0                | 11.4    |
| K$^+$          | 40.9            | 63.6                | 9.1     |
| Na$^+$         | 65.4            | 74.4                | 20.5    |
| CEC            | 60.2            | 65.1                | 7.9     |
| Total acidity  | 13.0            | 30.4                | 8.7     |
| % Sand         | 12.6            | 32.2                | 3.7     |
| % Clay         | 22.9            | 33.5                | 16.5    |
| % Silt         | 58.8            | 38.4                | 1.2     |

Note: Underlined deterioration index values are considered significant (DI > 60%).
5. Discussion
Artisanal mining generally involves non-regulated practices, and are a common approach to mineral exploitation in many developing countries (Mason, 2014). In the study area, artisanal mining of the gold resources has begun over 50 years ago but the importance of the mining activities appears unnoticed in the community based on the poor state of the infrastructure in the area. Bordo and Flandreau (2003) noticed that resource bases such as communities in a mining site are generally degraded as a result of the ecosystem disruptions that are often occasioned by the unsustainable exploitation of its resources. In the study area, areas that have been disrupted include the soil environment. Apart from the fact that the soils are deliberately excavated in the process of gold mining, once mined, the opened land portions are rarely filled up, causing them to be dangerous causes of accidents to victims that fall in them, or serve as habitats for reptiles and dangerous animals.

The results of this study identified greater percentage of sandy soils at the mine sites than either the farmland or relatively undisturbed plot. Although this study could not establish a cause-effect relationship between the mining activities and soil properties, the processes involved in the artisanal gold mining, which requires soil to be removed, sieved, or separated during gold search are capable to reducing its compaction and destroying the molecular bonds of the silicate minerals (Ge & Ma, 2007; Spiegel, Keane, Metcalf, & Veiga, 2014).

In addition, this study has shown that both the abandoned and active mine sites are not significantly different in terms of their heavy metals contents. The result of Nemerow pollution index indicated that the mine sites are “heavily polluted” with abnormally high concentrations of Cd, Zn, Pb and Cu. Studies (Olabanji, Oluyemi, Fakoya, Eludoyin, & Makinde, 2015) have argued that heavy metals in soils may be absorbed by shallow rooted plants or washed into surface water, from where they may contaminate the food chain. Long term exposure and bioaccumulation some of these metals, including Pb and Zn have been linked with inhibition of blood cells formation and brain damage in children, while exposure to Cd has been implicated to cause softening of the bones and osteoporosis in both children and adults (World Health Organisation, 2010). Lo et al. (2012) linked an outbreak of lead poisoning among children in two villages in Zamfara State, Nigeria to gold mining activities in the area.

Furthermore, the results of the deterioration index reveal significant loss of soil enriching elements (such as total N, available P and organic C) from the mine sites. This suggests that agriculture productivity is likely to decrease with increased mining activities, especially in the part of country where coping strategies are generally low based on relatively poor access to improved agricultural facilities. More studies are however required to understand the specific effect of the mining activities on cropping.

6. Conclusion
This examined the soil characteristics at a mining community in southwestern Nigeria. The main hypothesis is that sites of artisanal gold mining activities are characterized by higher concentrations of toxic metals than the farmland and forest sites. The study showed that soils at the active and abandoned mine sites were more of sandy particles, and contained significantly higher concentrations of heavy metals but lesser concentrations of soil nutrients than the farmlands and the relatively undisturbed areas in the study area. The study concludes that artisanal gold mining activities caused severe soil degradation and loss of important soil nutrients in the area. The impact of the mining activities is a major threat qualitative food security and sustainable livelihoods in the area.
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