

Research Article

# Effects of Artisan Mining on Soil Degradation and Contamination in Gedarif State (Eastern Sudan)

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## Abstract

The present study was initiated with the objective to investigate the effect of artisan mining activities on soil degradation and contamination with mercury and cyanide used in gold extraction. The area of study was around AlSada village located at the northern western part of Gadarif state (eastern Sudan). sites collected were according of intensity of mining activities as high (site 1) or medium (site 2) or without mining activity referred to as reference site. Soil samples were collected using a probe to a depth of 3 meters. 5 samples from site 1 and 3 from both site 2 and reference site. The sampling from each site included the three types of soils (sandy, clay and silt). so for site 1, 15 samples were analyzed, and 9 for each site 2 and reference site. Soil samples were also taken from gold tailing. Soils samples taken from the sites were analyzed for phsi-chemical properties. Samples taken from tailing were analyzed for lead and cyanide. Physical characteristics included texture and organic matter. Chemical analysis included pH, electrical conductivity (EC), Soluble cations and anions, Sodium Adsorption Ratio (SAR), Exchangeable Sodium Percentage (ESP). The cations analyzed in saturation extracts were Ca, Mg, K, and Na, while the anions are SO<sub>4</sub> (sulfate), CO<sub>3</sub> (carbonate), HCO<sub>3</sub> (bicarbonate) and Cl (chloride). The results obtained showed that the exchangeable cations showed significant ( $P \leq 0.05$ ) lower values compared with the reference site. P concentration was the highest in the reference site, followed by site 1 ( $P \leq 0.05$ ), then site 2 and mine tailing ( $P \leq 0.05$ ). Cation exchangeable capacity (CEC) level was the highest ( $P \leq 0.05$ ) at the reference site, followed by site 2 and site 1. CaCO<sub>3</sub>% was the highest ( $P \leq 0.05$ ) at the reference site, showing the effect of the mining activity. For the heavy metals, lead showed higher levels than normal in all sites and was significantly affected by interactions of site with mine tailing. For cyanide a significant interaction was found for mine tailing with reference site. Most participants' complaint about the negative impact of mining activities in the area due to vegetation removal and animal deaths from poisoning both affected their income the change in migration routes. Most did not think mining had contributed to the development of the area and most would not change lifestyle and join in gold mining. Health hazards were due to air, soil and water pollution. Hazards for workers are due mercury inhalation.

## Keywords

Artisan Mining, Soil Degradation, Contamination

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## 1. Introduction

Processing minerals contaminate the land, water, and air, causing health problems. The environmental impact of mining includes erosion, formation of loss of biodiversity, and contamination of soil, under-groundwater and surface water by mining processes. Contaminants can modify or disturb microorganisms, thus modifying nutrient availability, causing a loss of vegetation in the area. Cultivated crops might be a problem near mines. Most crops can grow on weekly contaminated sites, but yield is generally lower than it would have been in regular growing conditions [1]. Mining can be any of the many ways of taking minerals out of the ground, which implies excavations, trenching and pitting activities that denote unavoidable negative impacts on the environment, including removal of rocks, gravel, sand and other building materials. Therefore, at least, adverse effects on the landscape should be expected. Moreover, if appropriate measures are not adopted in time, during the process of mining, serious occupational problems will emerge the mining process which led to environmental damage, the goal should be to minimize the extend of the impacts. The gold mining sector in Sudan is predominantly artisan in nature. 85-90 per cent of output comes from artisan mines. Poor educational and development services have left miners with little other choice, and inadequate health services have exacerbated the health consequences of gold mining and processing.

There are three types of mining in Sudan: artisan (traditional) mining, small-scale mining and large-scale mining. There is also considerable trade in reprocessing mining residues (using mining tailing known as “karta”). There are 173 companies involved in small-scale mining, 142 in large-scale mining and 52 karta companies. In recent years, Sudan has witnessed a wide range of gold-mining operations by artisan miners in many states in the country. As of 2016 about 2 million people from all parts of the country participated in gold mining activities. Despite the rising importance of gold mining in the national economy, the gold industry in general seems improperly managed as artisan gold mining in the country takes place on geographically extensive territories, while the government administrative bodies have often insufficient resources to monitor the mining activities, in addition to the poor governance system to manage national resources in general. Today, mining as a socio – economic activity features prominently in the national income accounts of Sudan. Therefore mining is taking over as the leading foreign exchange earner. This situation, however, has its environmental implications which demand pinpointing their adverse aspects.

## 2. Materials and Methods

### 2.1. Field Visits

Field visits were conducted to observe workers while engaged in mining activities and collect soil samples from tailing

prepared by the workers for gold extraction. Gold tailings were especially analyzed for heavy metals, mercury and cyanide.

### 2.2. Soil Sampling

Soil samples were collected using a probe to a depth of 3 meters. 5 samples from site 1 and 3 from both site 2 and reference site. The sampling from each site included the three types of soils (sandy, clay and silt). So for site 1, 15 samples were analyzed, and 9 for each site 2 and reference site. Soil samples were also taken from gold tailing. Soils samples taken from the sites were analyzed for physio-chemical properties. Soil Samples taken from tailing were analyzed for lead and cyanide.

### 2.3. Soil Analysis

#### 2.3.1. Physical Analysis (Soil Texture and Organic Matter)

Soil texture as representing the percentage or relative proportion of sand, silt and clay present in a soil was done according to FAO, Training Series (2006). Soil texture is fundamental to soil properties and their impact on plant growth and overall farm productivity. Soil organic matter plays an important role in regulating most biological, chemical and physical processes in the soil, which collectively determine soil health. Soil organic matter was determined as pointed out by FAO, Training Series (2006).

#### 2.3.2. Chemical Analysis

##### A. Soil pH

A pH meter, was used, it consisted of a glass electrode that is sensitive to hydrogen ions ( $H^+$ ). The glass electrode contains a salt solution (sodium based –  $Na^+$ ) and when this glass electrode is immersed into the soil solution, there is an exchange of ions between the soil solution. A reference electrode that produces a constant voltage was used, which when immersed with the glass electrode into the soil solution produces an electromotive force (voltage) or electrical potential that is measured by a millivolt meter. This estimated the soil's PH.

##### B. Electrical Conductivity, cations and anions

Electrical Conductivity (EC) is a measure of the ability of a solution to carry an electric current or the concentration of soluble salts in the sample at any specific temperature. EC can be measured in the field or in the laboratory using a conductivity meter, which measures the inverse of the electrical resistance of a solution. Conductivity range from less than 0.02 ds/m for distilled water to more than 20 ds/m for highly saline waters. This method utilizes the extract from a saturated paste for the determination of saline soils. Soluble cations and anions is possible to obtain by this method and estimate other important parameters such as Sodium Adsorption Ratio (SAR) which

also predicts the Exchangeable Sodium Percentage (ESP). This method is therefore routinely used where salinity is a concern. The cations analyzed in saturation extracts were calcium (Ca), magnesium (Mg), potassium (K), and sodium (Na), while the anions are  $\text{SO}_4^{4-}$  (sulfate),  $\text{CO}_3^{3-}$  (carbonate),  $\text{HCO}_3^{3-}$  (bicarbonate) and  $\text{Cl}^-$  (chloride).

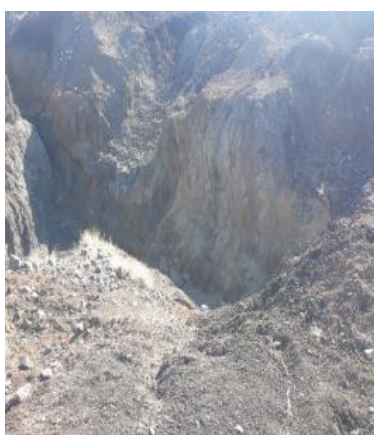
### 2.3.3. Data Analysis

One way analysis of variance (ANOVA) was used to test for the significant differences between the means for soil parameters for between and within sites.

## 3. Results

### 3.1. Field Visits and Mining Activities

Digging of the soil could go to very deep depths bringing deep soil to the surface accumulating in heaps on the soil surface (Figure 1). Gold roots were traced within the rocks (Figure 2) which were crushed (Figure 3). A sample of rock containing the gold is shown in Figure 4. Identified rocks were broken into small pieces ready to be crushed as tailing (Figure 5).



**Figure 1.** Excavation, deep soil heaps.



**Figure 2.** Tracing gold roots.



**Figure 3.** Breaking gold rocks.



**Figure 4.** A sample of rock containing gold.



**Figure 5.** Rocks containing gold prepared for tailing.

### 3.2. Soil Analysis

#### *Exchangeable cations*

The exchangeable cations were shown to be affected by gold mining as they showed significant ( $P \leq 0.05$ ) lower values compared with the reference site. Phosphorus (P) concentration was the highest in the reference site, followed by site 1

( $P \leq 0.05$ ), then site 2 and gold tailing ( $P \leq 0.05$ ), although significant differences could not be detected between both sites. CEC level was the highest ( $P \leq 0.05$ ) at the reference site, followed by site 2 and 1, although no significant differences could not be obtained between site 2 and 1 or site 2 and the reference site.  $\text{CaCO}_3\%$  was the highest ( $P \leq 0.05$ ) at the reference site (Table 1).

#### Physio-chemical Properties of Soil

pH was nearly the same showing high alkalinity. Electrical conductivity was the highest ( $P < 0.05$ ) in the reference site and gold tailing followed by site 1 but very low in site 2. For the cations, Na and Ca levels were nearly the same in reference site and site 1 and gold tailing but significantly low in

site 2 ( $P < 0.05$ ). For the anions, both  $\text{CO}_3$  and  $\text{HCO}_3$ , were significantly lower ( $P < 0.05$ ) in site 2 and gold tailing. Cl was significantly lower in site 2. Sand made the highest constituents in gold tailing ( $P < 0.05$ ) followed by site 1 and 2, with the reference site showing the least constituents ( $P < 0.05$ ). Silt and clay showed the least constituent in gold tailing. Clay constituted a high proportion of the reference site and site 1 ( $P < 0.05$ ), then site 2 ( $P < 0.05$ ), but significantly ( $P < 0.05$ ) in the gold tailing. Within the same site and for the reference site clay constituted the highest percentage. For site 1 and 2 sand and clay were in nearly same proportion. Gold tailing had the highest proportion of sand (Table 2).

**Table 1.** Exchangeable Cations, Phosphorous (P), Nitrogen (N), OC, Exchangeable Sodium Percentage (ESP), Cation exchangeable capacity (CEC), and  $\text{CaCO}_3$  (calcium carbonate) in the study sites of Al-Sadda area.

| Study site     | Exchangeable cations Cmol/kg (Na) | Phosphorus P (ppm)     | Nitrogen N% | Organic carbon OC% | Exchangeable sodium percent ESP | CEC Mol/kg               | $\text{CaCO}_3\%$       |
|----------------|-----------------------------------|------------------------|-------------|--------------------|---------------------------------|--------------------------|-------------------------|
| Reference site | 6.93±0.29 <sup>a</sup>            | 8.93±0.11 <sup>a</sup> | 0.43±0.01   | 0.20±0.01          | 13.66±0.58 <sup>a</sup>         | 51.00±1.73 <sup>a</sup>  | 17.97±0.06 <sup>a</sup> |
| Site 1         | 2.94±1.29 <sup>b</sup>            | 7.20±0.84 <sup>b</sup> | 0.03±0.01   | 0.16±0.06          | 7.60±2.07 <sup>b</sup>          | 38.80±9.71 <sup>b</sup>  | 8.40±5.68 <sup>b</sup>  |
| Site 2         | 2.40±0.30 <sup>b</sup>            | 4.33±0.58 <sup>c</sup> | 0.03±0.01   | 0.17±0.06          | 5.67±0.58 <sup>c</sup>          | 43.00±0.00 <sup>ab</sup> | 3.33±1.16 <sup>b</sup>  |
| Gold Tailing   | 3.53±1.06 <sup>b</sup>            | 5.00±1.00 <sup>d</sup> | 0.03±0.01   | 0.13±0.06          | 12.67±5.03 <sup>b</sup>         | 22.00±2.45 <sup>c</sup>  | 2.67±3.01 <sup>b</sup>  |

<sup>abcd</sup>Values (means ±sd) with different superscript on the same column are significantly different at  $P < 0.05$ .

**Table 2.** Some Physio-Chemical Soil Properties in the Study sites of Al-Sadda area, pH, EC (electric conductivity), soluble cations/anions, SAR (sodium absorption ratio), soil types (sand, silt, clay).

| Study site     | pH        | ECe dS/m               | Soluble cations Meg/l  |                        |           | SAR                    | Soluble anions Meg/l   |                        |                        | Soil Type (%)            |            |                          | Gravel |
|----------------|-----------|------------------------|------------------------|------------------------|-----------|------------------------|------------------------|------------------------|------------------------|--------------------------|------------|--------------------------|--------|
|                |           |                        | Na                     | Ca + Mg                | K         |                        | $\text{CO}_3$          | $\text{HCO}_3$         | Cl                     | Sand                     | Silt       | Clay                     |        |
| Reference site | 7.33±0.64 | 0.83±0.06 <sup>b</sup> | 5.13±0.12 <sup>a</sup> | 2.60±0.35 <sup>a</sup> | 0.23±0.06 | 3.97±0.06 <sup>a</sup> | 1.07±0.06 <sup>a</sup> | 0.56±0.29 <sup>a</sup> | 6.13±0.11 <sup>a</sup> | 27.57±0.75 <sup>c</sup>  | 25.66±0.58 | 45.33±1.56 <sup>a</sup>  | Nil    |
| Site 1         | 7.38±0.08 | 0.63±0.27 <sup>d</sup> | 5.30±1.81 <sup>a</sup> | 1.70±0.93 <sup>b</sup> | 0.20±0.00 | 3.80±0.84 <sup>a</sup> | 0.78±0.25 <sup>a</sup> | 0.26±0.11 <sup>a</sup> | 5.12±2.58 <sup>a</sup> | 42.00±12.10 <sup>b</sup> | 26.00±3.54 | 32.00±10.19 <sup>b</sup> | Nil    |
| Site 2         | 7.2±0.00  | 0.25±0.02 <sup>c</sup> | 1.17±0.12 <sup>b</sup> | 0.77±0.06 <sup>b</sup> | 0.17±0.06 | 2.00±0.00 <sup>b</sup> | 0.43±0.06 <sup>b</sup> | 0.10±0.00 <sup>b</sup> | 1.33±0.06 <sup>b</sup> | 31.33±0.58 <sup>b</sup>  | 28.33±0.78 | 40.33±0.58 <sup>a</sup>  | Nil    |
| Gold Tailing   | 7.35±0.21 | 0.93±0.57 <sup>a</sup> | 5.80±3.82 <sup>a</sup> | 2.50±1.83 <sup>a</sup> | 0.20±0.00 | 5.00±1.41 <sup>a</sup> | 0.70±0.14 <sup>b</sup> | 0.20±0.14 <sup>b</sup> | 6.95±4.03 <sup>a</sup> | 64.50±2.12 <sup>a</sup>  | 10.50±2.12 | 10.50±2.12 <sup>c</sup>  | Nil    |

<sup>abcd</sup>Values (means ±sd) with different superscript on the same column are significantly different at  $P < 0.05$ .

### 3.3. Interactions of Lead and Cyanide Among Sites

#### 3.3.1. Lead Concentration

For reference site interactions of lead with sites and gold tailing, significant interactions were obtained for the two sites and not with the gold tailing. Site 2 lead level showed significant interactions with all sites as well as gold tailing. For gold tailing interactions, significant levels were obtained due to interactions of both sites and not with the reference site. For site

1, significant interactions were obtained for all sites and gold tailing (Table 3).

#### 3.3.2. Cyanide Concentration

For cyanide concentrations in different sites and gold tailing, significant interactions were obtained for site 2 x site 1. Significant interaction was obtained for gold tailing x site 1. For site 1 interactions were significant with site 2 and gold tailing (Table 4).

**Table 3.** Lead Multiple interactions.

| Dependent Variable           |           |           | Mean Difference<br>(I-J) | Std. Error | Sig.  | 95% Confidence Interval |             |
|------------------------------|-----------|-----------|--------------------------|------------|-------|-------------------------|-------------|
|                              |           |           |                          |            |       | Lower Bound             | Upper Bound |
| Lead<br>Parts per<br>Million | Reference | Site 2    | 20.34000*                | 0.59660    | 0.000 | 18.1376                 | 22.5424     |
|                              |           | Tailing   | -4.70000                 | 2.00333    | 0.324 | -18.2511                | 8.8511      |
|                              |           | Site 1    | 10.30000*                | 0.20817    | 0.001 | 8.8578                  | 11.7422     |
|                              | Site 2    | Reference | -20.34000*               | 0.59660    | 0.000 | -22.5424                | -18.1376    |
|                              |           | Tailing   | -25.04000*               | 2.06944    | 0.010 | -37.3442                | -12.7358    |
|                              |           | Site 1    | -10.04000*               | 0.55911    | 0.000 | -12.3160                | -7.7640     |
|                              | Tailing   | Reference | 4.70000                  | 2.00333    | 0.324 | -8.8511                 | 18.2511     |
|                              |           | Site 2    | 25.04000*                | 2.06944    | 0.010 | 12.7358                 | 37.3442     |
|                              |           | Site 1    | 15.00000*                | 1.99249    | 0.043 | 1.1955                  | 28.8045     |
|                              | Site 1    | Reference | -10.30000*               | 0.20817    | 0.001 | -11.7422                | -8.8578     |
|                              |           | Site 2    | 10.04000*                | 0.55911    | 0.000 | 7.7640                  | 12.3160     |
|                              |           | Tailing   | -15.00000*               | 1.99249    | 0.043 | -28.8045                | -1.1955     |

**Table 4.** Cyanide Multiple comparison.

| Dependent Variable              |           |           | Mean Difference (I-J) | Std. Error | Sig.  | 95% Confidence Interval |             |
|---------------------------------|-----------|-----------|-----------------------|------------|-------|-------------------------|-------------|
|                                 |           |           |                       |            |       | Lower Bound             | Upper Bound |
| Cyanide<br>Parts per<br>Million | Reference | Site 2    | -0.0002000            | 0.0002000  | 0.759 | -0.001014               | 0.000614    |
|                                 |           | Tailing   | -0.0003333            | 0.0003333  | 0.768 | -0.002643               | 0.001976    |
|                                 |           | Site 1    | -0.0100000            | 0.0000000  |       | -0.010000               | -0.010000   |
|                                 | Site 2    | Reference | 0.0002000             | 0.0002000  | 0.759 | -0.000614               | 0.001014    |
|                                 |           | Tailing   | -0.0001333            | 0.0003887  | 0.984 | -0.001841               | 0.001575    |
|                                 |           | Site 1    | -.0098000*            | 0.0002000  | 0.000 | -0.010614               | -0.008986   |
|                                 | Tailing   | Reference | 0.0003333             | 0.0003333  | 0.768 | -0.001976               | 0.002643    |
|                                 |           | Site 2    | 0.0001333             | 0.0003887  | 0.984 | -0.001575               | 0.001841    |
|                                 |           | Site 1    | -.0096667*            | 0.0003333  | 0.003 | -0.011976               | -0.007357   |

| Dependent Variable |           | Mean Difference (I-J) | Std. Error | Sig.  | 95% Confidence Interval |             |
|--------------------|-----------|-----------------------|------------|-------|-------------------------|-------------|
|                    |           |                       |            |       | Lower Bound             | Upper Bound |
|                    | Reference | 0.0100000             | 0.0000000  |       | 0.010000                | 0.010000    |
| Site 1             | Site 2    | .0098000*             | 0.0002000  | 0.000 | 0.008986                | 0.010614    |
|                    | Tailing   | .0096667*             | 0.0003333  | 0.003 | 0.007357                | 0.011976    |

## 4. Discussion

It could be noted that the soil composition in the different sites differed in the percentages of sand, clay and silt which have affected mineral contents. Generally, the organic content was low in all sites as semi-arid lands are usually characterized by poor fertility, however, it was pointed out that small-scale gold mining has been responsible for the removal of vast quantities of surface vegetation and mass deforestation in Ghana [2]. Furthermore, [3] found soil organic carbon (SOC) content of mined area at 0.14%, which is below the accepted level of SOC of soil fertility, giving an indication of disruption of ecosystem functioning and loss of litter layer due to mineral mining. In line with the above finding a study conducted by [4] to assess the impact of small-scale mining on land in the western part of Ghana revealed that mining removes vegetation and topsoil, and often results in inevitable loss of farmland permanently. According to [5] the exploitation of mineral resources often leads to extensive soil degradation through the destruction of vegetation and alteration of microbial communities, resulting in low soil fertility and productivity. This further confirms the finding of [6] that many areas disturbed by mining in are highly susceptible to erosion due to lack of existing vegetation, the presence of fine, dispersed particles and steep slopes, forming huge gullies and pits. It was concluded that in all levels of mining health risks occur with dust exposure.

The exchangeable cations were shown to be affected by gold mining as they showed significant ( $P \leq 0.05$ ) lower values compared with the reference site. The cation exchangeable capacity (CEC) is a measure of the soils ability to hold cations. In surface soils the cation exchange capacity is associated with clay content, organic matter and type and retention of cations [7]. The higher the CEC the higher the potential fertility of the soils. In this study, the highest CEC found in the reference site could be related with the high clay content. Similar effects were found in phosphorus concentration. SAR was significantly higher in the gold tailing which is taken as a standard diagnostic parameter for the sodicity hazard of a soil, as determined from analysis of pore water extracted from the soil [7]. Phosphorus (P) concentration was the highest in the reference site, followed by site 1 then site 2 and gold tailing, this would

reflect the intensity of mining activity.

Soil pH is important because it influences several soil factors affecting plant growth, such as: soil bacteria, nutrient leaching, nutrient availability, toxic elements, and soil structure (Agricultural reference blog, 2007). In this study, high pH was showing alkalinity as is the characteristic of semi-arid regions. The high electrical conductivity in the reference site could be associated with on the levels of cations which the case of site 1 and gold tailing, however, K did not show significant changes. Same observations were obtained to the anions, but here gold tailing and site 2 showed lower significant values. For the anions higher levels were obtained for the reference site. The high  $\text{CO}_3$  level could be related to the high  $\text{CaCO}_3$  obtained in this site. Similarly, it was observed that Calcium carbonate is a salt and dissociates into calcium ions and when surrounded by water molecules, the carbonate becomes bicarbonate ions. The lower levels anions obtained in gold tailing could be related to the high sand constituent of the soil as on sandy soils adequate levels can be considerably lower or difficult to establish if on leaching sandy soils, which was observed in the study area, water is continuously used to for washing soil residue from gold. Samples were also taken from these residues for analysis. Therefore, the different proportions of sand to silt and clay could have affected both cation and anion levels.

Sites 1 and 2 as well as gold tailing were contaminated by both lead and cyanide. Interaction of both metals levels with soil at different sites and gold tailing showed the significant interactions. Lead concentration seemed to be more affected by site interactions with gold tailing and reference site, however interaction of reference site with gold tailing was not obtained. For cyanide interactions were obtained for site x site 2 and site 2 x gold tailing. This would point to the different levels of minerals in the soil of the different sites and the gold tailing. The insignificant interactions of lead or cyanide with gold tailing could be related to low quantity of the minerals in the reference site. It could be concluded that artisan mining affects both soil deterioration and contamination.

## Conflicts of Interest

The authors declare no conflicts of interest.

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