# IMPACTS OF INDUSTRIAL ACTIVITIES ON SOIL AND VEGETATION: A CASE STUDY OF ALUMINUM SMELTING COMPANY OF NIGERIA (ALSCON)

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**Abstract:** This study has been carried out at the Aluminum Smelter Plant at Ikot Abasi to determine the concentrations of trace and toxic metals (Fe, Pb, Cu, Zn and Mn) in soils and plants. Results indicate high concentration of metals, particularly Fe, Pb and Zn, which may induce serious environmental impacts. Results have shown that the total and available metal mobility followed the sequence Fe > Pb > Zn > Cu > Mn and Fe > Pb > Zn > Mn > Cu, respectively. Metal concentrations of the control profile were much lower than in the dump site. This raised the possibility of anthropogenic contribution to the dump site. The level of metals in plants was Fe (217$\pm$6.7), Mn (24.3$\pm$315), Cu 998.0$\pm$1.0), Zn (105.6$\pm$2.0) and (Pb (175 $\pm$ 15.4) mgkg$^{-1}$ respectively. High levels of metals in both soil and plants can cause important environmental problems and /or human health risk. The correlation matrix for some soil chemical properties has shown poor relationship as pH and Fe did not correlate with any metal or other soil properties. However, Pb correlated very strongly with Zn (0.982**), Mn (0.986**) and Cu (0.945**). A very strong correlation relationship existed between available and total metals in soils.

**Keywords:** environment, heavy metals, industrial activity, pollution, soil

## Introduction:

The industrialization of an area does not only deprive the environments of the pollution-free status they have been enjoying, but could adversely affect the lives of the inhabitants. In Nigeria, possible sources of industrial pollution include aluminum production, wastes from breweries, the manufacturing of paints, batteries, fertilizers, insecticides, plastics, textiles, paper, detergents, petro-chemicals and other types of consumable chemicals (Akpabio 2000). The pollutants from these industries include highly poisonous organic, inorganic and toxic metals. Extensive use and combustion of fossil fuels from industrial activities – anthropogenic activities- bring out a number of toxic trace metals which are added to the environment (Harald 2000). When anthropogenic trace metals enter the soil system, information on their relocation and transfer within the affected soil system and forest vegetation is required for assessing the short and long-term environmental consequences (Alvarez et al. 2003). Again, trace metals are distributed and redistributed

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naturally in the environment by both geologic and biologic cycles – weathering and disintegration. These elements are taken up from the soil or water by plants in the living system and passed on to higher trophic levels. The natural cycling of trace metals has, however, been disturbed by human activities in two ways. Firstly, man has caused a rapid increase in the concentration of trace elements in various components of the environment and biosphere. Secondly, they have altered the speciation chemical or biochemical form of these elements so as to make them available to the biosphere (Asthana and Asthana 2005).

As an economy grows, the industrial sector assumes a leading position and may become susceptible to the possibilities of innovation as new resources are exploited and/or explored. Such process of industrial development necessitates externalities with harmful impacts on the environment. Some of which do constitute hazards on human health ecology and biodiversity. The environmental impact of industrial pollution leads more or less to a conflict of interest between the polluters, who pursue objectives of output, profit and cost optimization and the victim of pollution, who is entitled to hazard-free environment for health living. Thus industrial pollution, which leads to different types of environmental degradation, require the control of industrial activities, which release harmful pollutants into the environment.

The central theme of contamination by trace metals is the knowledge of transport and accumulation of potentially hazardous metals such as Pb, Cu, Zn, Mn and Fe in the terrestrial ecosystem. The release of these metals in concentrations beyond the stipulated threshold is essential through anthropogenic activities such as industrial emissions. The accumulation of trace metals in agricultural and non- agricultural soils (parks, playing field and open space) poses health hazards (Alloway 1993). Health effects of trace metals in the environment include skin irritation, damage to the liver, kidney, circulatory and nerve tissues resulting from acute or chronic exposure (Duggal 1980; Hammond 1982). The development of high blood pressure and vascular diseases can be induced by intake of the metals (Bill and Bankes 1995).

Environmental degradation can be described as the in situ and encourages continuous deterioration of the quality of the available resources, for example plant cover or vegetation -to the extent that measures or strategies adopted to maintain a balance between their exploitation and conservation becomes irreversible (Ituen 2004). While the environmental impact arisen from industrial activities is any condition of environmental conditions or creation of a new set of adverse or beneficial environmental conditions caused or induced by the action or set of actions under consideration. The impacts can be generally described as either primary or secondary. Secondary impacts usually entail changes that are indirect or induced (Nwafor 2006). Man depends on the resources of the environment to provide its sustenance and meet its basic needs such as air, food, water, shelter and clothing. However, in the process of obtaining and using these environmental resources through industrial activities, man may pollute or damage the environment and so reduce the capacity of the environment to further provide the resources that they need.

According to Salami et al. (2001), some industrial activities are costly to the environment. Manufacturing increases the carbon-dioxide content of the activities here leading to the formation of acid rain which is detrimental to agricultural development and vegetation perturbation which alters the hydrologic cycle, potentially increasing or decreasing the amount of water in groundwater and the moisture in the atmosphere. Forests are valuable habitats for wild mushrooms and conservation of medicinal plants and the recharge of aquifers**.** Again, the shrinking forest cover lessens the landscape's capacity to intercept, retain and transport precipitation. Therefore, vegetation perturbation contributes to decreased evapotranspiration, which diminishes atmospheric moisture and precipitation levels and affects precipitation levels downwind from the deforested area.

The objectives of this study are: to assess the levels of trace elements concentrations at the dump site of the Aluminum Smelter plant in plants and soil, and the relationship between trace elements in the soil and plants, as well as its effects on human health.

**Materials and methods:**

Area of the study

The study has been carried out at the dump site of Aluminum Smelting Company (ALSCON) of Nigeria, Ikot Abasi. Geographically, the company is situated near the Atlantic Coast and the area lies approximately between latitude 4°30' and 4°43' North of the equator and longitude 7$^o$ 00' and 8$^o$ 00' East of the Greenwich Meridian at an altitude of 65 m above the sea level. The area is divided into two distinct seasons, the wet or rainy and dry seasons. The wet or rainy season begins from April and lasts till October. It is characterized by heavy rainfall of about 2500 – 4000 mm per annum (Edem et al. 2013). High relative humidity (79 %) and heavy cloud cover reaching the highest average temperatures of 31 $^o$C usually experienced in February / March. The period which coincides with the overhead passage of the sun (Enwezor et al. 1981) and change slightly during the year. This climatic factors favour luxuriant tropical rainforest with teeming populations of insects and fauna of extremely high terrestrial and aquatic biomass. However, both vegetation and fauna of Akwa Ibom State are largely diminished because of population pressure and some industrial activities.

The vegetation could be classified as coastal with a subdivision into the wetland-swampy salt water mangrove forest which prevails along the coast of Imo River and the fresh water swamp forest of the hinterland.

Field Studies

Three profile pits have been sited near the dump site of Aluminum Smelter Company of Nigeria (Fig. 1). The profile pits were dug at the dump and control sites and then demarcated before sampling according to the FAO (2000) guidelines for profile description. The soil samples were placed in labelled polythene bags and transported to the laboratory for analysis.

Laboratory Analysis

Soil processing and analysis

The soil samples were air dried, crushed and sieved to pass through a 2.0 mm sieve. At each of the sampling points, samples were collected at an interval of 20 cm down the profile. The soil samples from different sampling points were, on each occasion, collected in polythene sample bags and labelled accordingly. Another set of soil samples was taken to estimate the bulk density, and all the samples were then transported to the laboratory for analysis.

Laboratory methods of analyses were carried out on soil samples for particle size distribution, pH (soil reaction), organic matter contents, total nitrogen, available phosphorus and exchangeable cations (K, Ca, Mg and Na).

The particle size analysis was determined using Day's hydrometer method as described by Udo et al. (2009). After dispersing the soil particles with sodium hexametaphosphate solution and fractionation, the textural classes of the soil were determined using the textural triangle.

Bulk density was estimated by dividing the oven dry mass of the soil by volume of the soil as described by Grossman and Reinsch (2002):

$$BD\ (g\ cm^{-3}) = Ms / Vs$$

where:

BD = Bulk Density (g cm$^{-3}$)

Ms = mass of oven-dried soil samples (g)

Vs = total volume of soil (cm$^3$), (solid + pores)

The total volume of the soil was calculated from the internal diameter of the core cylinder. Total porosity was calculated from bulk density assuming the particle density of 2.65g $cm^{-3}$ as described by (Gee and Or 2002).

**Figure no. 1** Discharged effluent from ALSCON into canal near the location of profile pits.

Plant analysis

The most recently mature leaves of plants were sampled within the same site where the profile pits were dug. The leaves were placed in large envelopes and transported to the laboratory along with the soil samples. Each plant sample was a bulk of three locations. In the laboratory, the samples were gently washed with flowing distilled water before drying for analysis. The plant leaves were dried at 80 °C for 48 hours, ground and screened through a 2 mm sieve. For heavy metal analysis, 1.2 g dry ground plant tissue was exposed at 10 $JT^{o}$ for 3 hours. A two-millilitre (or 2 ml) mixture of perchloric and nitric acid was added; after allowing to stand for 30 minutes, the volume reached to 12 ml. Extraction of heavy metals (Pb, Zn, Cu and Fe) from soils was carried out using the method of Lindsay and Norvell (1978). This one uses 0.005 M DPTA + 0.01M $Calc_2$ at pH 7.3. The total heavy metal was digested using the perchloric acid mixture ($H_3CLO_4$+ HNO).

Lead, Zn, Cu and Fe in all extract solutions (soil and plant) were determined by automatic absorption spectrophotometer.

Statistical analysis

For testing statistical significance, a student's t-test has been used. Heavy metal concentrations were separated between available and total forms, which were confined at different depths. Independent sample t-test was used for finding the mean difference of each parameter with plants.

**Results and discussion:**

The results of the physico-chemical properties in the study site are summarized in Table 1. The textural class of the soils in the ALSCON dumpsite ranged from sandy loam to loamy sand. The high sand content in the soil may result in nutrient leaching particularly nitrogen and phosphorus. This could result in the contamination of underground water. The percent sand fraction ranged 757.90 to 844.60 g $kg^{-1}$ with a mean of 812.06 g $kg^{-1}$. The percent silt in the soil ranged from 60.60 to 147.30 g $kg^{-1}$ with a mean of 83.30 g $kg^{-1}$, while Clay content varied from 94.40 g $kg^{-1}$ to 13.43 g $kg^{-1}$ with mean values of 97.0 g $kg^{-1}$. The spatial variation in textural class of the soil in the experimental field was reported by Ayani (2010) to have contributed to the differences on the results of other soil parameters (such as different microbial activities, pH buffering capacity, infiltration rate and accretion) as additional factor to the treatments applied.

**Table no. 1** Summary of physico-chemical properties of the study site.

| Soil properties | Units | Depths | | | | | | SEM |
|---|---|---|---|---|---|---|---|---|
| | | 0-15 | 15-30 | 0.5 m | 1.0 m | 1.5 m | Average | |
| pH | | 5.2 | 5.2 | 5.2 | 5.2 | 5.3 | 5.21 | 0.091894 |
| $EC_{25}$ | $dSm^{-1}$ | 0.472 | 0.587 | 0.393 | 0.143 | 1.060 | 0.53 | 0.548736 |
| Organic C | % | 3.59 | 3.66 | 2.73 | 3.07 | 3.64 | 3.34 | 0.896997 |
| Total N | % | 0.09 | 0.09 | 0.06 | 0.07 | 0.09 | 0.08 | 0.021602 |
| Available P | $mgkg^{-1}$ | 20.06 | 14.75 | 22.75 | 13.57 | 15.74 | 17.38 | 9.662577 |
| Ca | cmol $kg^{-1}$ | 3.76 | 2.64 | 4.16 | 3.04 | 2.40 | 3.20 | 0.76399 |
| Mg | cmol $kg^{-1}$ | 1.20 | 1.04 | 1.84 | 1.17 | 1.12 | 1.27 | 0.277529 |
| Na | cmol $kg^{-1}$ | 0.07 | 0.06 | 0.07 | 0.07 | 0.07 | 0.07 | 0.004714 |
| K | cmol $kg^{-1}$ | 0.09 | 0.11 | 0.11 | 0.08 | 0.14 | 0.11 | 0.031517 |
| EA | cmol $kg^{-1}$ | 2.28 | 1.80 | 2.08 | 1.52 | 2.96 | 2.13 | 0.721332 |
| ECEC | cmol $kg^{-1}$ | 7.40 | 8.64 | 8.92 | 5.87 | 6.68 | 11.50 | 10.65351 |
| BS | % | 68.92 | 66.35 | 73.32 | 74.54 | 58.97 | 68.42 | 8.054767 |
| Sand | % | 83.79 | 80.46 | 75.79 | 81.79 | 84.46 | 81.26 | 4.351245 |
| Silt | % | 6.06 | 6.06 | 14.73 | 7.39 | 7.39 | 8.33 | 3.425395 |
| Clay | % | 6.12 | 13.43 | 9.44 | 10.76 | 8.76 | 9.70 | 2.558256 |

Soil Reaction and Electrical Conductivity

The reaction of the soil was moderately acidic with pH values in water ranging between 5.2 and 5.3. The electrical conductivity values were low in depths below 1.0 m with values ranging from 0.143 to 1.060 $dSm^{-1}$ with a mean conductivity of 0.530 $dSm^{-1}$. $EC_{25}$ of 1.0 – 1.5 m depth is greater than unity. This according to FAO-UNESCO (1974) indicates soil salinity. It could be seen that the level is relatively higher on the surface where it occurred and later increasing its depth due to deep percolation.

Organic Matter and Total N

Organic matter contents were high in the soils with a value content greater than 2.0 % in all the sampled horizons. According to FEPA (1991), this soil belongs to category S, described as highly suitable for crop production with respect to organic matter content. Thus, there is increased contact with other colloids and with soil solution. This results in the strong friction and cohesion bonds between particles and soil water, and is why Edem and Udoinyang (2013) reported that this high organic matter occurrence in problem soils is in unsaturated form, and are likely to be very toxic and capable of causing lungs and kidney discomfort including eye, lung and throat irritation. Total N values were low displaying values ranging from 0.06 % to 0.09 % with a mean of 0.08 %.

Available phosphorus and Exchangeable Bases

Available P determined by Bray P-1 method was low in the examined soil except on the surface horizon < 0.5 m where the value varied between 20.06 and 22.75 mg $kg^{-1}$ and the other layers ranged from 13.57 to 15.74 mg $kg^{-1}$ with a mean value of 17.37 mg $kg^{-1}$. The mean values of Ca (3.20 ± 1.31 cmol $kg^{-1}$) and Mg (1.27 ± 0.50 cmol $kg^{-1}$) were higher than those of K (0.11 ± 0.05 cmol$kg^{-1}$) and Na (0.07 ± 0.01 cmol $kg^{-1}$) respectively. Effective cation exchange capacity (ECEC) values were very low (5.87 to 8.64 cmol $kg^{-1}$) but within the range described as normally for acid sands (Hewitt and Candy 1999). Percent base saturation was relatively high with values varying from 58.97 % to 73.32 % with a mean of 68.42 % (± 12.98). According to IITA (1979), any soil having a percent base saturation value greater than 50 % is described as potentially fertile. FAO-UNESCO (2000) grouped such soils as highly suitable for crop production with respect to a certain percent base saturation.

Total and available forms of trace metals in industrial dumpsite

As expected from the sampling strategy, the Fe, Pb and Mn concentrations in the contaminated soils were extremely variable and may reach very high values. Cu and Zn showed, however, a more homogeneous distribution, with a smaller range than Pb and Fe. This may be related to the differences of the enriched elements in Fe, Pb and Mn in the studied soils, although in variable amounts**.** Fe and other heavy metal-bearing elements are likely to be more scattered in the area (Tab. 2). In most of the sampled locations, heavy metal enriched contents in soil depths (0 - 1.00 m) contained total Fe concentration varied from 1394.50 to 4682.00 mg $kg^{-1}$ and Mn concentrations from 105.40 to 424.25 mg $kg^{-1}$ relative to 41.13 and 20.42 mg $kg^{-1}$ in the control respectively. These were in agreement with those commonly found in podzolic soils that were seriously affected heavy metal (Massoura et al. 2006) and thus confirming the higher mobility of Fe and Mn down the profile during soil forming processes.

Concentration of metals in plants at industrial site

Roots of plants grown on these soils are therefore exposed to a radically different environment in the various zones than those grown on similar uncontaminated soils. Continuous or intermittent discharges from the industry induces important changes in the micro-biological and physico-chemical system of soils which may, among other things, affect nutrient availability and uptake by plants. To have an insight into nutrient dynamics and their effects on plants in these soils, considerable attention has been given to monitoring electro-chemical changes of traced elements in relation to nutrient availability and use by adapted plants.

The concentrations of Fe, Mn, Cu, Zn and Pb in the leaves obtained from the industrial dump and control sites are presented in Table 3. Trace elements usually determine several times the amount of macro nutrients absorbed or fixed in mineral soils. A study showed that the Fe in the contaminated soils ranged from 210 to 222 mg $l^{-1}$ with a mean of 217 ± 6.7, compared to about 15 percent increase in the leaves of the selected control area. Relative to the control site, the overall effects of the discharges increased Mn, Cu, Zn and Pb respectively, by about 25, 617, 96 and 100 %. The Pb values in the leaf were very high in comparison with research conducted in polluted areas elsewhere (Adriano 1986; Anijah-Obi Franca 2001; Adiukwu et al. 2005).

**Table no. 2** Selected forms of heavy metals in the affected sites.

| Heavy metals ($mgkg^{-1}$) | Depths | | | | | SEM |
|---|---|---|---|---|---|---|
| | 0-15 | 15-30 | 0.5 m | 1.0 m | 1.5 m | |
| Total forms | | | | | | |
| Fe | 1417.33 | 1394.50 | 1419.00 | 4682.00 | 1353.83 | 1502.94 |
| Pb | 278.62 | 829.00 | 245.03 | 216.52 | 222.75 | 264.04 |
| Mn | 105.40 | 151.13 | 388.57 | 424.25 | 85.00 | 205.98 |
| Cu | 218.40 | 189.45 | 179.85 | 174.10 | 149.42 | 45.02 |
| Zn | 256.03 | 257.47 | 247.70 | 222.83 | 250.40 | 18.55 |
| Average | 2237.47 | 2771.85 | 2423.78 | 5672.34 | 1982.08 | 2052.53 |
| Available forms | | | | | | |
| Fe | 24.59 | 21.88 | 20.33 | 15.71 | 13.65 | 11.36 |
| Pb | 17.01 | 15.18 | 13.18 | 11.98 | 10.30 | 6.00 |
| Mn | 10.20 | 9.02 | 7.75 | 7.04 | 5.92 | 4.05 |
| Cu | 11.07 | 10.03 | 9.17 | 9.21 | 7.98 | 2.86 |
| Zn | 217.72 | 207.77 | 191.33 | 175.47 | 171.08 | 34.55 |
| Average | 318.90 | 313.58 | 298.14 | 266.78 | 288.25 | 42.82 |

**Table no. 3** Concentration of Metals in the Leaf in the study site.

| Locations | Treatments | Fe | Mn | Cu | Zn | Pb |
|---|---|---|---|---|---|---|
| | | → | → | → | ← | ← |
| | | mg/l | | | | |
| 1 | Dump site | 222.00 | 28.00 | 99.01 | 107.10 | 188.00 |
| 2 | | 210.11 | 21.03 | 97 | 103.20 | 179.01 |
| 3 | | 221.00 | 24.20 | 98 | 105.00 | 158.11 |
| | Mean, SD | 217.1 ± 6.7 | 24.3 ± 3.5 | 98.0 ± 1.0 | 105.6 ± 2.0 | 175.0 ± 15.4 |
| | Control | 249.43 | 19.31 | 13.65 | 53.62 | 83.73 |

Correlation matrix of heavy metal and some soil properties

The extractable Pb, Zn and Mn contents were correlated with the organic matter concentrations (r = 0.562**, 0.536** and 0.596** respectively) (Tab. 4, Annexes), and the low proportion of Cu and Fe with respect to the total amount is in agreement with the data found by Hseu (2006) in the least developed terms of a polluted toposequence. The effect of parent material prevailed on the enhancement in the metal availability induced by the organic matter which is generally reported (Tiller 1989), and the maximum concentrations were found in O horizons.

The low pH of the polluted soils has probably induced a partial dissolution of Zn, Mn, Cu and Fe, which are easily plintite in acidic medium (Dixon 1989), thus accounting for the high correlation coefficient found between the total and the available Pb forms. On the other hand, the differences in the pH of the reactants justify the differences between total and exchangeable concentrations.

The available concentrations of heavy metals were, however more on the surface and ten times lower than total forms. This is probably related to the huge presence of secondary phases that provide sorption sites, such as pedogenic layer silicates and hydrated Fe oxides, which are responsible for the increase in heavy metal sorption with soil development (Uren 1992). No correlation was in fact found between Fe and the heavy metals that are mostly of lithogenic origin as indicated by the low variability among soil horizons and should therefore have a low specific surface area (Schwertmann and Taylor 1989). Clay contribute to Pb sorption and form during the very first steps of discharged effluent (Barker and Brson 2002), but only seldom did we find swelling minerals in these Entisols and Inceptisols. The presence of swelling minerals, with high cation exchange capacity, apparently did not induce any difference in the Zn, Mn and Cu concentrations (r = -0.436, -0.485 and -0.431, respectively), thus indicating that also the total forms are linked to the composition of the parent material in these heavy metal rich soils.

## Conclusions:

The samples collected from ALSCON dump site showed high concentration of metals, especially Fe, Pb and Zn, which may cause serious environmental impacts. Results of the study indicated that the total and the available metal mobility at the site followed the sequence Fe > Pb > Zn > Cu > Mn and Fe > Pb > Zn > Mn > Cu, respectively. The heavy metals concentration were significantly lower in the control profile. Therefore, it should be noted that industrial activities are costly to the environment. Thus, the lower the cost of an industrial project to the society in terms of the hazards of pollution and degradation of the soil and vegetation, the more desirable would such an industrial project be. To achieve this, the externalities of industrial projects must be internalized as much as possible through enforcement of environmental regulations. High levels of metals in both soil and plants can cause important environmental problems or risks for human health. Regarding the matrix correlation for soil, the chemical properties indicate poor relationship with heavy metal, indicating inhibition of plant nutrients. Also Cu enriched soil from the dump site contributed about 53.6 % to increase exchangeable acidity (EA).


## Rezumat:

IMPACTUL ACTIVITĂȚILOR INDUSTRIALE ASUPRA SOLULUI ȘI VEGETAȚIEI: UN STUDIU DE CAZ AL COMPANIEI NIGERIENE DE TOPIRE A ALUMINIULUI (ALSCON)

Acest studiu s-a desfășurat la Topitoria de Aluminiu din Ikot Abasi spre a determina concentrațiile metalelor toxice (Fe, Pb, Cu, Zn și Mn) în soluri și plante. Rezultatele indică mari concentrații de metale, cu precădere Fe, Pb și Zn, care pot induce grave probleme de mediu. Rezultatele au arătat că mobilitatea totalului și a metalului disponibil au urmat secvența Fe > Pb > Zn > Cu > Mn, respectiv Fe > Pb > Zn > Mn > Cu. Concentrațiile de metal din profilul de control au fost mult mai scăzute decât în zona de depozitare. Aceasta a amplificat posibilitatea contribuției antropogenice în zona de depozitare. Nivelul metalelor în plante a fost Fe (217$\pm$6.7), Mn (24.3$\pm$315), Cu 998.0$\pm$1.0), Zn (105.6$\pm$2.0), respectiv (Pb (175 $\pm$ 15.4) mgkg$^{-1}$. Nivelul ridicat de metale atât din sol, cât și din plante, poate cauza importante probleme de mediu și/sau riscuri asupra sănătății umane. Matricea de corelare pentru câteva proprietăți chimice din sol indică o relație scăzută, deoarece pH-ul și Fe nu sunt corelate cu nici un alt metal sau alte proprietăți ale solului. Totuși, Pb are o relație foarte strânsă cu Zn (0.982**), Mn (0.986**) și Cu (0.945**). O foarte puternică corelație a existat între metalele disponibile și totalul din soluri.

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## Annexes:

**Table no. 4** Correlation Matrix for heavy metals and some soil chemical properties in the study site.

| | pH | OM | EA | ECEC | BS | Clay | Pb | Zn | Mn | Cu | Fe |
|---|---|---|---|---|---|---|---|---|---|---|---|
| pH | 1 | | | | | | | | | | |
| Om | 0.411 | 1 | | | | | | | | | |
| EA | 0.052 | 0.490 | 1 | | | | | | | | |
| ECEC | -0.128 | 0.426 | 0.383 | 1 | | | | | | | |
| BS | -0.032 | -0.210 | -0.851** | 0.099 | 1 | | | | | | |
| Clay | -0.125 | -.608* | -0.524* | -0.651** | 0.234 | 1 | | | | | |
| Pb | -0.171 | 0.562* | 0.500 | 0.284 | -0.378 | -0.526* | 1 | | | | |
| Zn | 0.201 | 0.536* | 0.503 | 0.229 | -0.396 | -0.436 | 0.982** | 1 | | | |
| Mn | 0.229 | 0.596* | 0.510 | 0.245 | -0.399 | -0.485 | -0.986** | 0.988** | 1 | | |
| Cu | 0.141 | 0.508 | 0.536* | 0.270 | -0.399 | -0.431 | -0.945** | 0.980** | 0.957** | 1 | |
| Fe | 0.339 | 0.042 | -0.021 | -0.041 | 0.067 | 0.367 | 0.178 | 0.259 | 0.230 | 0.410 | 1 |