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THE EFFECTS OF MINING ACTIVITIES ON THE SOIL QUALITY OF IKWO, EBONYI STATE NIGERIA

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Abstract

Indiscriminate and unrestrained mining activities can result to major negative environmental impacts such as pollution of land and water bodies, thus affecting soil quality; and leading to decrease in soil fertility as well as land degradation and changes in landscape. Therefore, this study was conducted to determine the effects of lead-zinc mining activities on the soil quality of Ikwo in Ebonyi State, and to document the present state of soil physicochemical properties and heavy metal status of soil in the study location. In the study, two major factors were considered: Factor A - distances of sampling points (100m apart) and factor B - soil depth zone (0-15cm and 16-30cm). Three samples labeled MD, TP and WT were collected maintaining a distance of 100m, and these were compared alongside a control established 1.5km away from the mine site. The samples were tested and analyzed for heavy metal concentrations of Pb, Cr, As, Zn, Ni, and Cu, as well as physicochemical parameters such as pH, EC, Ca, Mg, P, K, Na and OM for wet and dry seasons. The study revealed relative concentrations of heavy metals in soils at Ikwo mine sites in the following order: Zn >Pb> Cu > Ni > As>Cr. The Zn content of the soils was extremely high with a range of 1.97 – 9.11 mg/kg. For physicochemical analyses, soil pH, electrical conductivity, phosphorus and total organic matter of the control were higher compared to that of other sampling points, but exchangeable calcium, sodium, magnesium and potassium of most sampling points were lower than the control. The mean concentration of the physicochemical parameters are as follows: pH (6.075 for dry season and 5.85 for wet season), EC (0.383 for dry season and 0.385 for wet season), P (28.69 for dry season and 17.85 for wet season), Ca (331.9 for dry season and 241 for wet season), Mg (356.9 for dry season and 306.7 for wet season), K (5.605 for dry season and 5.308 for wet season), Na (0.385 for dry season and 0.315 for wet season), and OM (0.808 for dry season and 0.833 for wet season). The result of single linear regression model revealed high value of contamination both in physicochemical analyses and heavy metal concentrations in the dry season compared to the wet season. It was recommended the Government's Ministry of Environment at all levels should adopt a good management approach to the incessant and inadequate mining activities going on in the study location.

Keywords: Mining, Heavy metals, Environmental Impacts, Soil Quality, Ikwo

Introduction

Heavy metals occur naturally in the environment, but may also be introduced as a result of land use activities. Mining industry throughout history has seriously caused immense environmental pollution in industrialized and developing countries. According to the Environmental Data Report of the United Nations Environmental Programme (UNEP, 2013), there is an increasing awareness that the health of populations is at risk from pollution hazards. Mining generates 2.7 billion tons of waste, an amount which far exceeds the world's total accumulated municipal garbage and is responsible for an increase in certain heavy metals in soils, sediments and groundwater reserves occurring within the influence sphere of the mine (Aucamp, 2003).

According to Brandy and Weil (2009), the soil is a multi-component system consisting of solid, liquid and gaseous phases as well as living organisms. Soil is dynamic and sensitive to almost every aspect of its surroundings and represents a chemical system where mineral transformation occurs continuously. Thus, when environmental changes occur, such as mining activity, the soil responds. Any such change produces a gradual alteration of soil characteristics until a new balance is reached. Naturally occurring as well as anthropogenically introduced concentrations of metals in near-surface soil can vary significantly due to different physical and chemical processes operating within soils geographic regions. Amongst the range of contaminants that may be found in soils, potentially toxic elements or heavy metals are of particular interest for a number of reasons. Firstly, they show a tendency, under normal circumstances, to accumulate in soils and have a long persistence time because of the interactions with particular soil components. Secondly, they are ubiquitous in soils and arise from both natural and anthropogenic sources, with pathways including inheritance from the parent rocks, application of wastes, as well as local and long-range atmospheric and fluvial deposition of emissions from industry and mining (Akhionbare *et al.*, 2010). Also, many of the heavy metals are essential at low concentrations for plant, animal and human health but at higher concentrations, they can be toxic. Toxic metals are being released to the environment in increasing amounts and they are daily ingested by humans, either through the air or through food, water and soil. Unfortunately heavy metals are not subject to chemical degradation. Once the elements become part of this cycle, they may accumulate in animal and human body tissue to toxic levels (Akhionbare, 2015). Exposure to heavy metals is normally chronic, due to food chain transfer. Acute poisoning from heavy metals is rare through ingestion or dermal contact, but possible. This situation is especially critical for fish and other wildlife and humans at the top of the food chain. The most common problem-causing metals are mercury, cadmium, lead, nickel, copper, zinc, chromium, manganese, arsenic, molybdenum and selenium.

There are screening levels or regulatory limits for metal concentration in soils set to protect wildlife. Standards also exist for protection of aquatic life from metal toxicity in surface waters.

In spite of these regulations, there is still uncertainty as to the nature and extent of heavy metal pollution in mine areas, particularly the soils on which crops are grown. Thus, there is little information available on the level of heavy metals in the surface or near-surface soil in areas associated with mining activities in Nigeria. A detailed study of lead-zinc mine areas could uncover the inherent danger posed to the communities where these mining activities occur. Heavy metal pollution could constitute serious environmental and health hazards in such communities within the country. This study focuses on the lead-zinc mining activities in Ikwo, Ebonyi State of Southeastern Nigeria and their effect on the environment with emphasis on heavy metal concentration. The importance of the study lies on the fact that although the degradation of soil quality by pollution may be localized, the environmental impacts are usually quite large. It is believed that contamination of the soil can pose a significant threat to human health and aquatic life.

The study area

The area of study is Ikwo Local Government Area in Ebonyi State. It is geographically located on Nigeria's Benue Trough, which is a major mining province with large deposits in the lower and middle Benue regions. The project area is referenced geographically on a point location of Latitude 06^{O}10'29.6" and Longitude 08^{O}08'08.0".

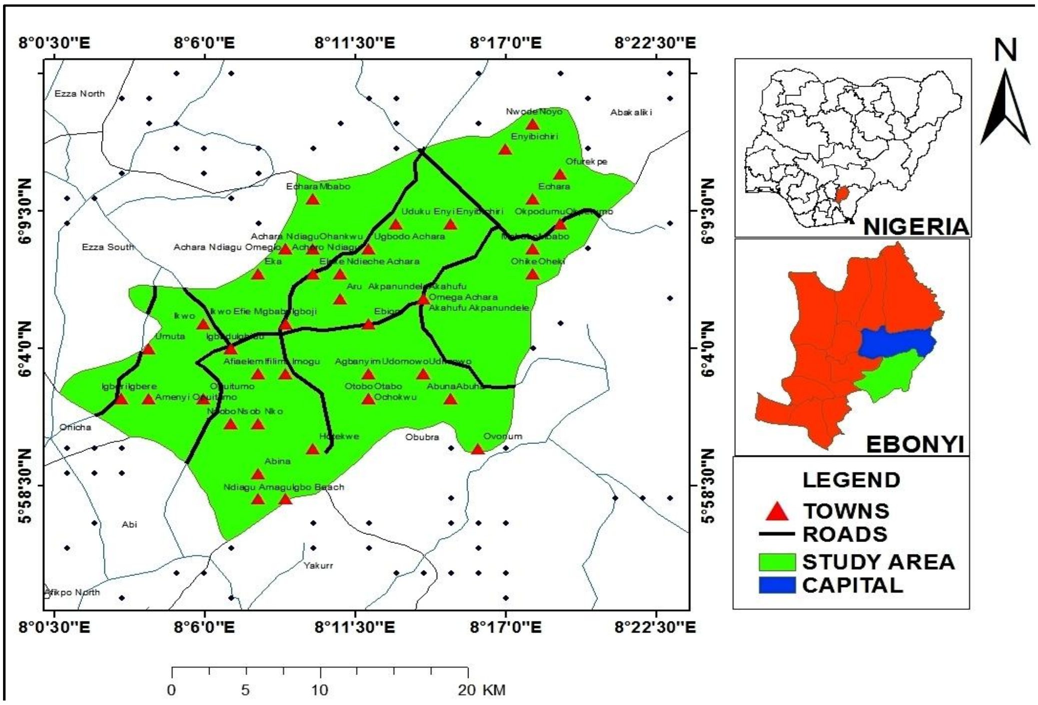

Fig 1: Map of Ebonyi State showing Ikwo LGA the study area

Sample collection

Soil samples were randomly collected at three (3) different points within the facility, maintaining a distance of 100 meters apart, and at horizons namely 0-15cm and 15-30cm. They were composited to form one sample per location. Random sampling involves the arbitrary collection of samples within a defined area and this was done in order to eliminate the tendency of biasing the samples. Samples were collected during the dry season of the year 2018 and rainy season of the year 2019. A control site was selected at a distance of 1.5km away from the facility and labeled "Control", and the other three (3) samples were collected within the facility from a tailing pond labeled "TP", a material dump-yard labeled "MD" and a water treatment plant labeled "WT", which are approximately within an established distance of about 100m per sampling point. The soils of the control site and those of the mine site labeled were assumed to be pedologically similar. All samples were taken to the laboratory for analysis within six hours after collection.

Sample Preparation

The analyses of the soil samples to determine the composition of heavy metals were carried out. The samples collected from the surface and subsurface soil of each sampling point were later mixed to form composite sample for each sampling location. The collected samples were ground in a laboratory after air drying for 24 hours at ambient temperature of 21^{o}C to 27^{o}C, then crushed and sieved through a 10 mesh (2mm) screen sieve, and then used for laboratory analyses.

Organic carbon was determined by dichromate oxidation method of Walkley and Black wet oxidation, and corrected to soil organic matter by multiplying with a correction factor of 1.724, particle size analysis of the soil was determined using the Bouyoucos hydrometer method. The soil samples were analyzed for the following physicochemical parameters: pH, Electrical conductivity, available phosphorus, exchangeable calcium, potassium, sodium, total organic matter. Heavy metal concentrations of the samples were also determined using atomic absorption spectrophotometer (ASS) for the following heavy metals: lead (Pb), zinc (Zn), copper (Cu), chromium (Cr), nickel (Ni) and arsenic (As). Available phosphorus was extracted using Bray II extractant as described by Bray and Kurtz (1945). Exchangeable Calcium, Magnesium, Sodium and Potassium were extracted with ammonium acetateethylenediaminetetraacetic acid (NH_4OAC-EDTA). Calcium and Magnesium were determined using Ethylene Diamine Tetra-acetic Acid disodium salt (EDTA) titration method while Potassium and Sodium were determined by flame photometer (Rhoades, 2002). Cation exchange capacity was determined titrimetrically using 0.01N NaOH. Exchangeable acidity was determined titrimetrically using 0.05N NaOH. Bulk density was determined on the core samples by core method as described by Anderson and Ingram (2013).

Physicochemical Analysis

The physicochemical properties of the soil samples were determined according to standard methods. Soil pH was determined using digital pH meter according to the method described by Bates (2004). Soil electrical conductivity was determined using conductivity meter according to the method outlined by Godson *et al*, (2002). Calcium and magnesium in soil samples were determined by versenate titration method as outlined by Piper (1966). Potassium was determined by flame photometrically after extracting the soil with neutral normal ammonium acetate (Jackson, 2003). Available phosphorus was extracted using Bray II extractant as described by Bray and Kurtz (2015). Sodium in soil samples was determined turbidometrically. The intensity of turbidity was measured using spectrophotometer at 420 nm of wavelength as outlined by Piper (1966). Total organic matter was determined according to the method outlined by Osuji and Adesiyan (2005).

Determination of Heavy Metals

The concentrations of heavy metals in all the samples were determined using the Perkin-Elmer atomic absorption spectrophotometer (Model 403). One gram of each sample was introduced into a digesting tube then 10 ml of concentrated HNO_3 was added. The samples were placed in the digester for 8 hours at 96^{0}C with alternating turning. When the digestion has completed, the samples were filtered into 100 ml volumetric flask using Whatman filter paper. Samples were made up to 100 ml mark in the volumetric flask using distilled deionised water. The concentrations of lead (Pb), zinc (Zn), copper (Cu), chromium (Cr), nickel (Ni) and arsenic (As) in the solution were determined using Varian Spectra AA 600 atomic absorption spectrophotometer (AAS), with air acetylene flame connected to it.

Results

Physicochemical Quality of Soil

The results of the laboratory investigations on the variation of physicochemical quality of soil samples taken in this study are presented in Tables 1 – 4.

Table 1: Physicochemical properties of soil samples from the study site during wet season

S/N	PARAMETERS	MD	TP	WT	CONTROL
1	pH	5.7	5.7	5.2	6.8
2	Electrical conductivity (µs/cm)	0.01	0.02	0.01	1.5
3	Available phosphorous (mg/kg)	2.589	3.964	4.326	60.51
4	Exchangeable Calcium (mg/kg)	310	296	316	41.82
5	Exchangeable magnesium (mg/kg)	420	396	405	5.91
6	Potassium (mg/kg)	5.61	7.60	6.82	1.20
7	Sodium (mg/kg)	0.18	0.21	0.17	0.70
8	Total Organic matter	0.061	0.054	0.027	3.19

Table 2: Physicochemical properties of soil samples from the study site during dry season

S/N	PARAMETERS	MD	TP	WT	CONTROL
1	pH	6	5.8	5.3	7.2
2	Electrical conductivity (µs/cm)	0.05	0.07	0.06	1.35
3	Available phosphorous (mg/kg)	3.797	4.563	5.378	101.04
4	Exchangeable Calcium (mg/kg)	456	375	462	34.58
5	Exchangeable magnesium (mg/kg)	510	412	501	4.68
6	Potassium (mg/kg)	6.16	8.71	7.25	0.30
7	Sodium (mg/kg)	0.38	0.46	0.29	0.41
8	Total Organic matter	0.083	0.072	0.047	3.03

Variation of pH and Electrical Conductivity

Tables 1 and 2 show the soil pH at the four (4) sample locations (MT, DP, WT and Control) to be 5.7, 5.7, 5.2 and 6.8 respectively for wet season and 6, 5.8, 5.3 and 7.2 respectively for dry season. The recorded values of samples collected within the proximity of the site are lower than the pH recommended value range of 6.6 to 7.5 for optimum plant growth (Queensland Department of Environment and Heritage Protection(QDEHP), 2019), but the control sample is within the recommended limit. More so it was observed that the pH was slightly higher during dry season. Also, it can be seen that the electrical conductivity (EC) for both seasons are less than 2µs/cm.

Variation of Phosphorous, Calcium and Magnesium (mg/kg)
Table 1 shows the available phosphorus to be 2.589, 3.964, 4.326 and 60.59, for exchangeable calcium 310, 296, 316 and 41.82 and for exchangeable magnesium 420, 396, 405, and 5.91; for the four (4) samples (MD, TP, WT and Control) respectively during wet season. Table 2 shows the available phosphorus to be 3.794, 4.563, 5.378 and 101.04, for exchangeable calcium 456, 375, 462 and 34.58, and for exchangeable magnesium the results recorded were 510, 412, 501 and 4.68; for the four (4) samples (MD, TP, WT and Control) respectively during the dry season. However there was a significant decrease in the level of exchangeable magnesium at TP (Table 1)

Variations of Potassium (mg/kg), Sodium (mg/kg) and Total Organic Matter
The results of potassium for both wet and dry season were recorded to be 5.61, 7.60, 6.82 and 1.20 for wet season, and 6.16, 8.71, 7.25 and 0.30 for dry season, for Sodium the recorded values were 0.81, 0.21, 0.17 and 0.70 for wet season, and 0.38, 0.46, 0.29 and 0.41 for the dry season, for total organic matter the results obtained were 0.061, 0.054, 0.027 and 3.19 for the wet season, and 0.083, 0.072, 0.047 and 3.03 for the dry season from the four (4) sampling points (MD, TP, WT and Control) respectively. The result shows that sample TP from the tailing pond is observed to have the highest value of potassium for both seasons. For soil sodium, it is evidenced that soil sodium concentration varied significantly with a range of 0.17 mg/kg to 0.70 mg/kg for the wet season, and 0.29 to 0.46 for the dry season. For total organic matter, higher values were observed and recorded during dry season ranging from 0.027 to 3.19 for the wet season and 0.047 to 3.03 for the dry season (Tables 1 and 2)

Heavy Metal Quality of the sampled Soil
Table 3: Variation of heavy metals concentration in soil at the study site for wet season

S/N	Heavy Metals (mg/kg)	MD	TP	WT	Control	**Mean**
1	Lead	4.69	6.32	6.81	1.21	**4.8**
2	Zinc	7.36	8.91	7.45	1.97	**6.4**
3	Copper	4.60	4.32	5.01	0.45	**3.6**
4	Chromium	3.69	4.54	3.88	0.06	**3.0**
5	Arsenic	1.81	2.64	3.76	0.03	**2.1**
6	Nickel	0.94	0.87	0.91	0.49	**0.8**

Table 4: Variation of heavy metals concentration at the study site for dry season

S/N	Heavy Metals (mg/kg)	MD	TP	WT	Control	**Mean**
1	Lead	4.89	6.70	6.95	1.64	**5.0**
2	Zinc	7.78	9.11	8.45	3.90	**7.3**
3	Copper	5.01	4.92	5.25	1.58	**4.2**
4	Chromium	3.82	4.6	3.99	0.002	**3.1**
5	Arsenic	1.94	2.82	4.01	0.24	**2.3**
6	Nickel	1.01	0.96	0.95	0.05	**0.7**

The levels of lead recorded were 4.69, 6.32, 6.81 and 12.1 for the MD, TP, WT and Control respectively for wet season, and 4.89, 6.70, 6.95 and 1.21 respectively for the dry season. The concentrations of zinc obtained for MD, TP, WT and Control were 7.36, 8.91, 7.45 and 1.64 respectively for the wet season and 7.78, 9.11, 8.45 and 3.90 for dry season. The concentrations of copper for MD, TP, WT and Control are 4.60, 4.32, 5.01 and 0.45 for the wet season samples, and 5.01, 4.92, 5.25 and 1.58 respectively for the dry season. The concentrations of chromium for MD, TP, WT and Control are 3.69, 4.54, 3.88 and 0.06 respectively for the wet season samples, and 3.82, 4.60, 3.99 and 0.002 for the dry season. The concentrations of arsenic for MD, TP, WT and Control are 1.81, 2.64, 3.76 and 0.03 respectively for the wet season, and 1.94, 2.82, 4.01 and 0.24. The concentrations of nickel for MD, TP, WT and Control are 0.94, 0.87, 0.91 and 0.49 respectively for the wet season samples, and 1.01, 0.96, 0.95 and 0.05 for the dry season.

Statistical Analysis

This study was considered as a factorial experiment in which distance from the mine pit and soil depth were two factors under consideration. The experiment was laid out in 2 X 5 factorial in randomized complete block design (RCBD) replicated four times compared alongside a control. Single linear regression model was used to analyse the mean of the heavy metals concentration for the two seasons. The statistical analysis was done using XL Stat embedded in Microsoft Excel.

Data were presented using tables and charts, and single linear regression model. The significant means were separated using the Turkey method of significant differences at 5% level of probability.

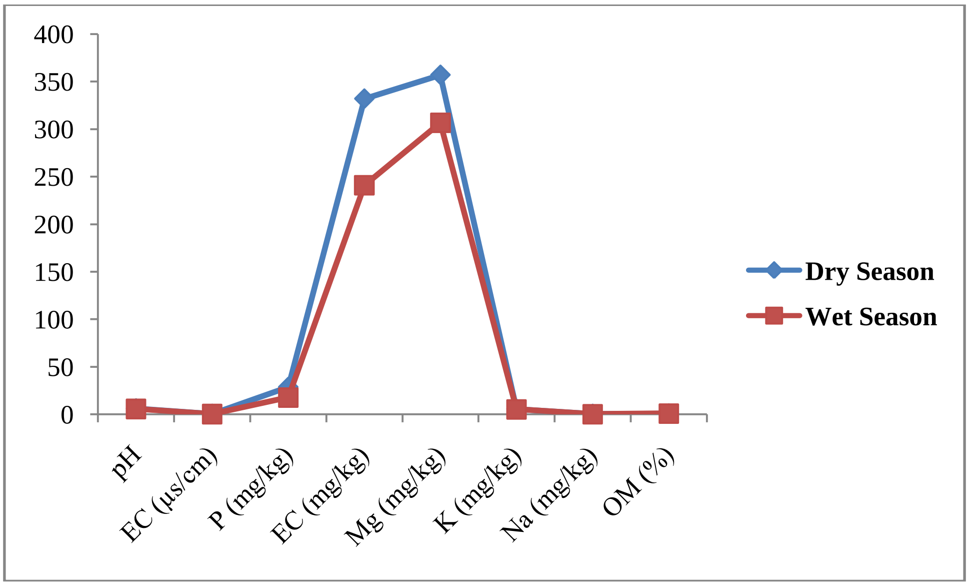

Figure 2: A Graph of Mean Concentration of Physicochemical Parameters analyzed for both wet and dry seasons.

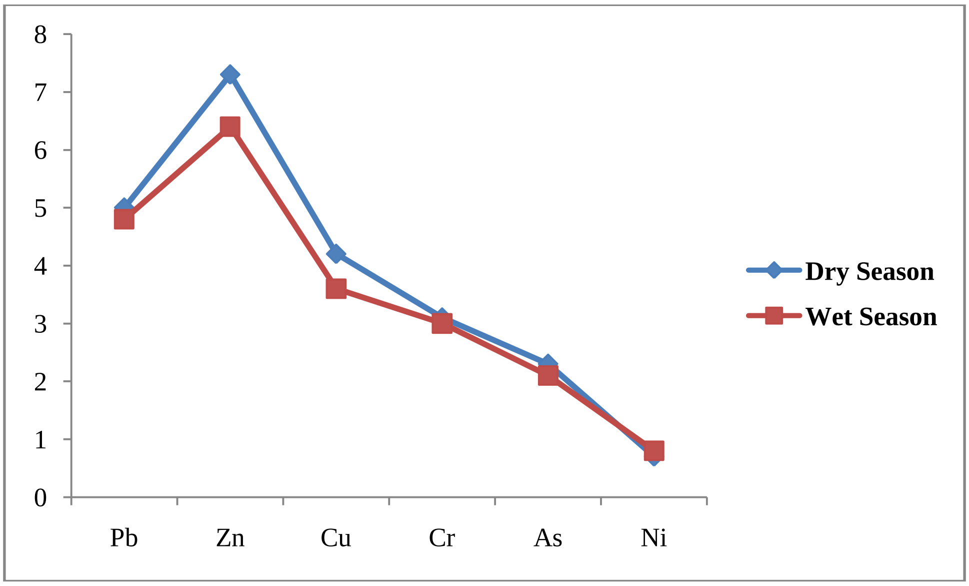

Figure 3: A Graph of Mean Concentration of Heavy Metals analyzed for both wet and dry seasons.

Findings on Regression Analysis

Regression analysis was conducted to examine the effect of independent variables (mean concentration for the wet season) on the dependent variable, (mean concentration for the dry season). Regression analysis was used to test the significance contribution of each independent variable to the dependent variable.

Table 5: Regression Model Summary Table

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.998345748
R Square	0.996694234
Adjusted R Square	0.995592311
Standard Error	0.138500039
Observations	5

The above model summary table presented in table 5 provides the multiple R value, the R square values, adjusted R squared (which is the coefficient of determination), standard error of the regression and the observation. The R value represents the simple correlation and is (0.998345748 $\simeq$ 1.0) which indicates a high degree of correlation, which is a confirmation that the linear relationship is strong. The R square value indicates how much of the total variation in the dependent variable (the mean concentration for the dry season) location can be explained by the independent variable (mean concentration for the wet season) and it is 0.996694234 which is 99%. This means that 99% of the dependent variable is explained by the independent values. The adjusted R square is an alternative to R square. But in this context, R square is used instead. Observation refers to the number of samples tested.

Table 6: Regression Coefficient Table

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.21	0.12	1.80	0.17	-0.16	0.58	-0.16	0.58
5	0.84	0.03	30.07	0.00	0.75	0.93	0.75	0.93

The above coefficient table provides with the necessary information to ascertain the extent to which the activities of mining going on in the study locations has affected the soil; which contributes statistically significantly to the model by looking at the sig column. Based on the above coefficient table, the predicted equation for both the dependent variable and the independent variable gives the equation and the linear graph below:

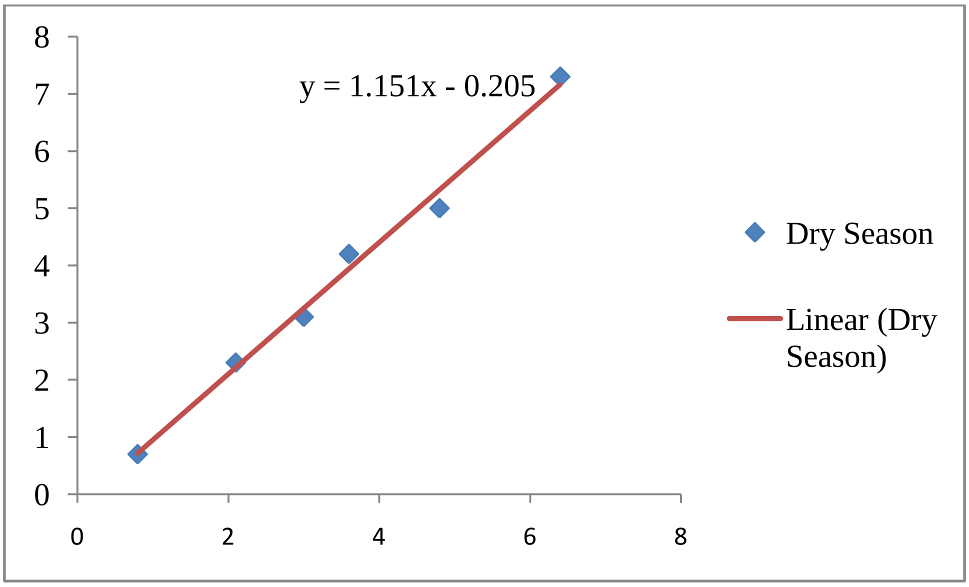

Figure 4: Linear Regression Graph for the both seasons

Discussion

The soil pH at the four (4) sampled locations were found to be 5.7, 5.7, 5.2 and 6.8 respectively for wet season and 6, 5.8, 5.3 and 7.2 respectively for dry season. This signifies that the soil has become acidic as a result of the mining activities carried out on the site, with that of the water treatment plant (WT) more pronounced. The recorded values of samples collected within the proximity of the site are lower than the pH recommended value range of 6.6 to 7.5 for optimum plant growth (QDEHP, 2019), but the control sample is within the recommended limit. It was observed that the pH was slightly higher during dry season than the wet season. This could be as a result of the absence of the alkaline leaching effect caused by rainfall which allows acidic compounds to replace base thereby decreasing the soil pH. The electrical conductivity (EC) for both seasons are less than 2µs/cm which is the limit required by most plants for effective crop yield ("Ultimate Guide to Testing EC", 2019). The levels of phosphorus recorded above from the results indicate the decrease of available phosphorus at the TP and MD in both seasons due to the mining activity carried out on the soil. However higher values of available phosphorus where recorded during the dry season, this could be due to the absence of soil water which influences the transportation of available phosphorus in plant uptake (Food and Agriculture Organization of the United Nations (FAO), 2008). The level of exchangeable calcium from the results signifies a reduction in the available exchangeable calcium due to the mining activity. However there was a significant decrease in the level of exchangeable magnesium at TP as recorded. This noticeable decrease could be associated to the mining activities carried out on the site. The high values recorded for total organic matter higher in dry season may be due to inadequate soil water that comes as a result of dry season thereby increasing plant and organism death (FAO, 2008). In addition, more studies are required to assess the evolvement of new species (speciation), movement (mobility) and bioavailability of these heavy metals in plants and the associated health problems of the mining activities to the inhabitants of the studied location.

Generally, it was observed that the mean concentrations of the tested physicochemical parameters, as well as the heavy metals are higher in the dry season than in the wet season.
Okolo (2014) evaluated the impact of solid minerals mining on selected soil and water properties in Enyigba, Ebonyi State, Nigeria. The study examined the extent to which heavy metals from mining activities have contaminated the soil as well as the surface waters within the vicinity of mine. The study was conducted only for one season, thus lack accurate representation of the seasonal variation of the parameters analyzed. A similar study by Nwokemodo (2009) assessed the environmental effects of lead-zinc mining at Enyigba to document the present state of the environment in areas affected by the mining operations. The study examined the extent to which heavy metals from abandoned mine pits and mine waste rocks at Amagu, Enyigba, Alibaluhu and Ameria, Ebonyi State have polluted the soil as well as the ground water and surface water. The study was analysed for only heavy metals concentration, but no consideration was given to physicochemical parameters. Although the results of the soil samples showed environmental pollution from the mining activities in the studied locations. Another study by Aloh *et al.,* (2016) assessed the effects of lead-zinc mining on water and soil quality in Ameka mining area of Ezza South, Ebonyi State, Nigeria using standard protocols. The results of physicochemical properties of the soil samples showed pollution from anthropogenic interference which is in line with the outcome of this study. Although, the soil samples were collected at depths of 0-20cm which may not show an extensive level of penetration of the heavy metals tested.

Summary of Findings

The major aim of this study was to determine the effects of mining activities on soil quality, to ascertain the level of pollution/contamination. In view of the foregoing, two major factors were considered, which include: distances of sampling points (100m apart) and soil depths zone (0-15cm and 16-30cm). The experiment was laid out in 2 X 5 factorial in randomized complete block design (RCBD) replicated four times compared alongside a control in order to control variations. Core and soil auger samples were collected and analysed in the laboratory following standard methods.

For physicochemical analyses, soil pH, electrical conductivity, phosphorus and total organic matter of the control were higher compared to that of other sampling points, but exchangeable calcium, sodium, magnesium and potassium of most sampling points were lower than the control. For heavy metals concentrations, the control recorded the lowest levels compared to the other sampling points.

The study revealed relative concentrations of heavy metals in soils at Ikwo mine sites in the following order: Zn >Pb> Cu > Ni > As>Cr. The Zn content of the soils was extremely high (1.97 – 9.11 mg/kg).

The study revealed high value of contamination both in physicochemical analyses and heavy metal concentrations in the dry season compared to the wet season.

Conclusion

This study revealed that the mining activities going on in Ikwo LGA in Ebonyi State Nigeria have a negative impact on the soil by introducing heavy metals above the threshold limit, and altering the soil's physicochemical parameters; thereby causing severe pollution of the soil. There is urgent need to compose guiding principles that will guide and regulate mining activities especially artisanal mining activities in this area in order to prevent numerous poisoning effects of these heavy metals as the transverse the ecological unit.

In addition, more studies are required to assess the evolvement of new species (speciation), movement (mobility) and bioavailability of these heavy metals in plants and the associated health problems of the mining activities to the inhabitants of the studied location.

Recommendation

Based on the conclusion of this study, the following recommendations are made:

1. The government (Local, State and Federal) should come up with appropriate guiding principles, and establish policies on the pollution of the environment and its conservation; and where they are already in vogue, they should be meted out without biasness.
2. For any serious mining to be carried out in Ikwo, there must be a second project which would involve processing of brine-salt production; as such, proper procedures would been taken to ensure that the soil pH does not increase thereby preventing the soil from heavy metal contamination.
3. The use of artisanal miners must be seriously discouraged to avoid long-term effects in the future. It has been recently established that the occurrence of lead poisoning or toxicity has cultural, political and sociological implications.
4. The researcher also recommends the need for environmental awareness using enlightenment campaigns on illegal mining and artisanal mining activities, control and monitoring techniques in the study location which will be geared towards satisfactory quality environmental conditions.
5. Also, the intermittent monitoring of the quality of soil around the mines should be encouraged at both government and organizational levels to always ascertain the concentration of the assessed soil parameters.
6. Lastly, the Government's Ministry of Environment at all levels should adopt a good management approach to the incessant and inadequate mining activities going on in the studied location, and ensure proper handling of all the activities that goes on within the mine site to ensure they conform within the set standards.

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