Environmental and Experimental Biology (2014) 12: 179–186 *Original Paper*

Ecological impact of mining on soils of Southwestern Nigeria

Oluwatosin G. Oladipo[1,3]*, Akin Olayinka[2], Olusegun O. Awotoye[3]

[1]National Centre for Technology Management (NACETEM), P.M.B. 012, Obafemi Awolowo University, Ile-Ife, Nigeria
[2]Department of Soil and Land Resources Management, Faculty of Agriculture, Obafemi Awolowo University, Ile-Ife, Nigeria
[3]Institute of Ecology and Environmental Studies, Faculty of Science, Obafemi Awolowo University, Ile-Ife, Nigeria

*Corresponding author, E-mail: tosin1oladipo@gmail.com; thosyney2k1@yahoo.co.uk

Abstract

This paper investigated the current status of soils from three mine sites (Awo, Itagunmodi and Ijero-Ekiti) in Southwestern Nigeria. Composite soil samples were collected at 0 to 15 cm depth, air-dried and analysed for physical, chemical properties and heavy metal contents (cadmium, copper, lead, arsenic and iron) using routine procedures with atomic absorption spectrophotometer. Microbial analyses were carried out on freshly collected soil samples for total heterotrophic bacteria (THB) and total heterotrophic fungi (THF) followed by identification of the isolated microorganisms. Data were analysed using ANOVA, with means separated using Duncan's Multiple Range Test at 95% significance level, correlation and cluster analysis. The results showed low soil pH in mine soils (Awo, 5.1; Itagunmodi, 5.3 and Ijero-Ekiti, 3.5) with soil chemical properties (organic carbon, total nitrogen, available phosphorus and exchangeable cations), and THB and THF populations significantly differing ($p < 0.05$) to those of their corresponding undisturbed sites. In soils of the mine sites, copper concentration had positive significant correlation ($p < 0.05$) with THB and THF, while manganese, zinc, copper and sodium concentration showed significant correlation ($r = 0.666$, $p = 0.05$) with THB and THF. Heavy metal concentrations in mine soils were higher than the FAO guidelines for agricultural soils. In total, five heterotrophic bacteria species (*Pseudomonas aeruginosa, Acinetobacter calcoaceticus, Klebsiella edwardsii, Pseudomonas pseudomallei* and *Klebsiella pneumonia*) and 10 heterotrophic fungi species (*Aspergillus fumigatus, Aspergillus glacus, Rhizopus stolonifer, Rhizopus japonicus, Penicillium expansium, Trichoderma viride, Fusarium sp., Microsporium audouinii, Cladosporium werneckii* and *Scopulariopsis brevicaulis*) were identified. The study concluded that soils of mine sites were ecologically degraded, as soil had low pH, reduced organic carbon, total nitrogen, available phosphorus, exchangeable cations, elevated heavy metal contents and higher THF counts. These results underline the need for strict mining operation policies in Nigeria and suggest immediate remediation strategies.

Key words: heavy metal, impact, microorganisms, mining, soil degradation, soil ecology.
Abbreviations: CFU, colony forming units; THB, total heterotrophic bacteria; THF, total heterotrophic fungi.

Introduction

The mining sector worldwide is greatly important for income generation, employment, economical growth, development and competitive advantage (Jerome 2003; Oelofse et al. 2008). Mining, however, poses major threats and hazards that can jeopardize ecosystems of nations. Nigeria has been actively engaged in solid mineral exploitation for decades and is endowed with deposits of more than 34 solid minerals, including coal, tin, columbite, gold, lead, zinc, thorium, lignite, uranium and tantalum in more than 450 locations across the country (Mining Journal 2006). The southwestern part of the country, according to Adekoya et al. (2003), has about 25% of the total land mass consisting of sedimentary rocks, and hence mining activities are common.

Mining operations completely alter a site's ecosystems by disrupting the ecological balance, natural landscapes, agricultural lands, forests, plantations and vegetation as well as the economic food and tree crops. Other impacts of mining include alteration of the soil structure, loss and overturning of the fertile top soil, air, soil and water pollution, instability of soil and rock masses, destruction of flora and fauna and noise pollution, causing mass exodus of species of animals (Ojo and Adeyemi 2003; Aigbedion and Iyayi 2007; Adegboye 2012). Specifically, soil degradation resulting from generated mine wastes during exploitation activities results in low pH, solubility of heavy metals, depleted organic matter, nutrients, reduced biological activities, poor physical structure, texture, drainage and porosity (Akcil and Koldas 2006; Oelofse et al. 2008; Awotoye et al. 2009; Adegboye 2012; Oladipo et al. 2013).

The presence of microorganisms on contaminated sites has been reported (Fourest et al. 1994; Bai and Abraham 2001; Malik 2004; Kumar et al. 2011; Alireza et al. 2012) with higher total heterotrophic fungi than total heterotrophic bacteria. Bacteria species of *Klebsiella, Staphylococcus, Bacillus, Citrobacteria, Thiobacillus, Mycobacterium*, *Rhodococcus* and fungal species of *Penicillum, Fusarium, Trichoderma* and *Aspergillus* have been identified in heavy metal-contaminated sites (Gadd 1990; Gunsekaran et al., 2003; Malik 2004; Jaboro et al. 2013). Similar studies carried out by Price et al. (2001) and Kumar et al. (2010) also reported that *Aspergillus niger* tolerated Cd and Zn. This study was designed to determine the current soil physical, chemical properties, heavy metal levels, and size and diversity of microbial populations in mine sites of Southwestern Nigeria.

Materials and methods

Study areas

Purposive sampling was used to select three active mining sites: (1) Awo mining site (7°46′N, 4°2′E) where feldspar (gemstone), tourmaline, tantalum and columbite are exploited using crude technologies; (2) Itagunmodi mining site (7°30′N, 4°49′E) where gold is mined and (3) Ijero-Ekiti mining site (7°49′N, 5° 50′E) where tourmaline, tantalum, feldspar (gemstone), tin, kaolin, dolomite and mica are exploited on a mechanized scale.

Soil sampling

Soil samples were randomly collected at depth 0 to 15 cm from the mining sites to obtain representative samples. Control soil samples were obtained from undisturbed forest areas about 3 km away from the mine sites. The soil samples were air-dried, thoroughly mixed and passed through a 2-mm sieve. For microbiological analysis, fresh soil samples were collected in cellophane bags, labelled and preserved in air-tight containers in ice chests. Samples were replicated in triplicates.

Physical, chemical and heavy metal analysis of soils

Soil particle size analysis was conducted using the hydrometer method (Bouyoucos 1962); soil pH was determined in 0.01 M $CaCl_2$ extracts using a glass electrode. Organic carbon was determined by chromic acid oxidation method (Walkley, Black 1934). Total N was determined using micro Kjeldahl procedure followed by steam distillation (Bremner, Keeney 1966). Available P was extracted using the Bray method (Bray and Kurtz, 1945). Exchangeable cations (Ca, Mg, K and Na) were determined in neutral 0.01 M NH_4OAc extracting solution. The concentrations of potassium (K^+) and sodium (Na^+) were determined using a Gallenkamp model FH 500 Flame Photometer. Magnesium (Mg^{2+}), calcium (Ca^{2+}), and heavy metals (Cd^+, Cu^{2+}, Pb^{2+}, As^+ and Fe^{2+}) were extracted using 0.1 N HCl solution and determined using a Perkin Elmer model 703 Atomic Absorption Spectrophotometer.

Estimation of total heterotrophic bacterial (THB) count

Soil samples (1 g) were rehydrated with 10 mL sterile distilled water in MacCartney bottle in which some glass chips were inserted (10^{-1} w/v). Ten-fold serial dilutions of the soil extract were made in a set of test tubes, containing 9.0 mL of sterile distilled water. The same serial dilution was repeated for each of the water samples in duplicate, employing sterile nutrient agar medium kept in melted form. The medium was then poured at 45 °C, swirled, and allowed to cool and set. The culture plates were then incubated aerobically at 35 °C for 36 to 48 h. The numbers of colony-forming units (CFU) in plates with 30 to 299 colonies were counted. The average viable count was multiplied by the dilution factor and then expressed per gram of sample.

Estimation of total heterotrophic fungal (THF) count

The culture medium used was malt extract agar. The same procedure as for THB was followed except that 100-fold serial dilutions of the soil extract were made in a set of test tubes, each containing 9.9 mL sterile distilled water and plates were incubated at 30 °C with growth monitored for 3 to 5 days.

Isolation and identification of soil microorganisms

Bacterial and fungal isolates were sub-cultured on nutrient and malt extract agar slants for further assays. Identification of bacteria was based on colonial characteristics (elevation, shape of edges, texture and pigmentation, cell morphology, arrangement and shape), and Gram reaction and biochemical tests. For primary identification of the bacterial isolates, each bacterial isolate was sub-cultured. Moulds and yeast isolates were identified by their growth characteristics: texture, pigmentation, form and spore formation. This was followed by microscopic examination of prepared slides. The cultural and morphological characteristics were compared with those described by Robert et al. (1984).

Statistical analysis

Statistical analysis of data collected was carried out using the Analysis of Variance (ANOVA) at the 0.05 level of significance with Statistical Analysis System program. Separation of means was obtained using the Duncan's New Multiple Range Test. Correlation and cluster ($r = 0.666$, $p < 0.05$) analysis were used to determine interrelationships between the parameters.

Results

Table 1 shows the physical, chemical and heavy metal contents of the soils sampled at Awo, Itagunmodi and Ijero-Ekiti mine sites and the control sites. The textural class at Ijero-Ekiti was sandy loam while that at Awo and Itagunmodi was loamy sand. Low soil pH values were observed in the three mine sites: pH 3.5 at Ijero-Ekiti, pH 5.1 at Awo and pH 5.3 and Itagunmodi. Generally, significant differences ($p < 0.05$) were observed for concentrations of

Table 1. Physical and chemical characteristics and heavy metal concentrations of soils of Awo, Itagunmodi and Ijero-Ekiti mines and respective control sites. Means followed by different letters in the same row are significantly different ($p < 0.05$) according to the Duncan's Multiple Range Test

Properties	Awo		Itagunmodi		Ijero-Ekiti		ANOVA	
	mine	control	mine	control	mine	control	*F* value	*P* value
Sand (g kg^{-1})	73.80 e	79.80 b	77.80 d	79.80 b	67.90 f	85.80 a	2472	0.000
Silt (g kg^{-1})	13.40 b	7.40 e	11.40 c	9.4 d	15.4 a	2.80 f	3326	0.000
Clay (g kg^{-1})	12.80 b	12.80 b	10.80 e	10.80 e	16.80 a	11.40 d	1538	0.000
Textural class	Loamy sand	Loamy sand	Loamy sand	Loamy sand	Sandy loam	Loamy sand	–	–
pH (0.01 M $CaCl_2$)	5.10 e	6.50 c	5.30 d	6.70 a	3.50 f	6.80 a	590	0.000
Organic C (g kg^{-1})	133.90 b	151.30 a	43.50 e	79.90 c	40.60 f	78.50 d	134956	0.000
Total N (g kg^{-1})	13.94 d	15.72 a	8.56 e	14.34 c	5.12 f	15.24 b	175457	0.000
Available P (mg kg^{-1})	86.64 b	101.04 a	55.90 e	78.89 c	49.13 f	60.51 d	673129	0.000
Mn (mg kg^{-1})	25.17 f	27.14 e	323.24 b	576.48 a	96.27 d	216.22 c	1.95 10^8	0.000
Zn (mg kg^{-1})	2.57 e	1.97 f	9.56 a	8.00 b	4.04 c	3.90 d	84619	0.000
Exchangeable cations (cmol kg^{-1})								
Ca	30.13 c	34.58 b	22.48 e	41.82 a	14.96 f	29.54 d	683451	0.000
Mg	4.24 d	4.81 b	3.92 e	5.91 a	3.06 f	4.68 c	1982	0.000
K	0.11 f	0.30 b	0.23 e	1.20 a	0.25 d	0.30 b	1909	0.000
Na	0.28 e	0.70 a	0.47 c	0.69 a	0.24 e	0.41 d	137	0.000
Heavy metals (mg kg^{-1})								
Cd	0.35 a	0.12 e	0.20 b	0.15 d	0.17 c	0.09 e	46	0.000
Cu	3.68 d	3.40 e	48.60 a	11.48 b	4.34 c	1.58 f	560401	0.000
Pb	19.05 e	12.21 f	35.00 b	25.00 d	46.65 a	34.89 c	280397	0.000
As	20.45 e	13.69 f	34.80 b	32.90 c	35.43 a	31.06 d	7288	0.000
Fe	240.24 c	123.41 e	296.20 b	100.31 f	367.06 a	134.11 d	5.52 10^7	0.000

organic carbon, total nitrogen, available phosphorus and exchangeable cations (Ca, Mg, K and Na) between soils of mine site and control areas. The study also showed elevated heavy metal concentrations (Cd, Cu, Pb, As and Fe) in the Awo, Itagunmodi and Ijero-Ekiti mine soils, compared to the undisturbed sites.

Table 2 presents total bacterial and fungal counts in soils of the mine and control sites. There were significant differences ($p< 0.05$) in the THB count between the mine and control sites, with lower levels at Awo and Ijero-Ekiti mine sites and higher level at Itagunmodi mine site. The total THF at Awo and Itagunmodi mine sites was significantly higher ($p < 0.05$) than at control sites, but the opposite relationship was evident for Ijero-Ekiti site.

Table 2. Microbial populations (CFU g^{-1}) in soils of Awo, Itagunmodi and Ijero-Ekiti mines and control sites. Means followed by different letters in the same column are significantly different ($p < 0.05$) according to the Duncan's Multiple Range Test

Location	Site	THB	THF
Awo	Mine	1.60 10^7 c	5.5 10^4 c
	Control	2.40 10^7 b	2.9 10^3 f
Itagunmodi	Mine	9.85 10^7 a	2.5 10^5 b
	Control	1.10 10^7 c	7.5 10^3 e
Ijero-Ekiti	Mine	4.50 10^6 e	2.4 10^4 d
	Control	7.50 10^6 d	3.5 10^5 a

Tables 3 and 4 show the relationships between soil physicochemical properties, heavy metal concentrations and total microbial counts of bacteria and fungi in soils of the Awo, Itagunmodi and Ijero-Ekiti mine sites. In mine site soils Mn concentration significantly correlated ($p < 0.05$) with THB, while Cu significantly correlated ($p < 0.05$) with both THB and THF. Fig. 1 shows that at Mn, Zn, Cu and Na concentrations were significantly related ($r = 0.666$, $p = 0.05$) with THB and THF.

Tables 5 and 6 reveal that In Awo, Itagunmodi and Ijero-Ekiti control sites, pH was significantly negatively correlated ($p < 0.05$) with THB; a lower pH was associated with higher THB counts (Tables 5 and 6). For THF, Na showed a negative significant correlation ($p < 0.05$). THF had significant relationship with sand content ($r = 0.666$, $p = 0.05$; Fig. 2). The number of bacterial and fungal species were identified in the three mine sites. Analysis of microbial diversity showed the presence of five heterotrophic bacteria (*Pseudomonas aeruginosa, Acinetobacter calcoaceticus, Klebsiella edwardsii, Pseudomonas pseudomallei* and *Klebsiella pneumoniae*). The number of isolated heterotrophic fungal species was 10: *Aspergillus fumigatus, Aspergillus glacus, Rhizopus stolonifer, Rhizopus japonicus, Penicillium expansium, Trichoderma viride, Fusarium sp., Microsporium audouinii, Cladosporium werneckii* and *Scopulariopsis brevicaulis*.

Table 3. Relationships between physico-chemical parameters and total bacterial and fungal counts in mine soils. *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$

	Sand	Silt	Clay	pH	Organic C	Total N	Available P	Mn	Zn	Ca	Mg	K	Na	THB	THF
Sand	0														
Silt	−0.99***	0													
Clay	−0.99***	0.98***	0												
pH	0.94***	−0.90***	−0.97***	0											
Organic C	0.14	−0.03	−0.22	0.43	0										
Total N	0.49	−0.39	−0.55	0.73*	0.93***	0									
Available P	0.28	−0.17	−0.35	0.56	0.99***	0.97***	0								
Mn	0.65	−0.73*	−0.59	0.38	−0.66	−0.35	−0.55	0							
Zn	0.67	−0.75*	−0.61	0.41	−0.64*	−0.32	−0.53	0.99***	0						
Ca	0.59	−0.49	−0.65	0.80*	0.88**	0.99***	0.94***	−0.23	−0.20	0					
Mg	0.78**	−0.70*	−0.83**	0.93 ***	0.73*	0.93***	0.82**	0.028	0.06	0.96***	0				
K	−0.23	0.11**	0.31**	−0.53	−0.97***	−0.94***	−0.97***	0.57	0.54	−0.90***	−0.77*	0			
Na	0.86**	−0.89**	−0.81	0.65	−0.31	0.035	−0.18	0.88**	0.89*	0.15	0.39	0.22	0		
THB	0.60	−0.66	−0.60	0.52	−0.27	-0.01	−0.17	0.67*	0.68	0.08	0.26	0.15	0.57	0	
THF	0.56	−0.62	−0.57	0.49	−0.24	0.00	−0.15	0.63	0.63	0.08	0.25	0.15	0.54	0.96***	0

Discussion

The mining of feldspar (gemstone), tourmaline, tantalum and columbite at the Awo mine site, gold at the Itagunmodi mine site and gemstone, tourmaline, tantalum, columbite, tin, kaoline, dolomite and mica at the Ijero-Ekiti mine site was found to negatively influence soil quality. The very strongly acid soil pH at Ijero-Ekiti mine site is due to mechanized technologies adopted which resulted in the overturning of the top soil. At Awo and Itagunmodi mine sites, where manual technologies are utilized, the soil pH values were higher but still strongly acid. The technology adopted at Ijero-Ekiti mine also affected soil texture; sandy loam soil indicated the pulverization of soil into higher silt and clay fractions.

Comparing the heavy metal concentrations of the mine soils with the heavy metal permissible limits for agricultural soils by FAO (1984) and Kabata-Pendias and Pendias (1992; 2011), it was observed that Awo mine soil had elevated As (20.45 mg kg^{-1}) compared to the acceptable concentration of 20.00 mg kg^{-1}. The Itagunmodi mine soil had elevated concentrations of Cu (48.50 mg kg^{-1}) and As (34.80 mg kg^{-1}) compared to acceptable limits of 30.00 and 20.00 mg kg^{-1}, respectively, and the Ijero-Ekiti mine soil had elevated Pb and As concentrations of 46.65 and 35.43 mg kg^{-1} compared to the limits of 35.00 and 20.00 mg kg^{-1}, respectively. Oelofse et al. (2008) also reported elevated concentrations of As, Cu, Cd and Pb on mine sites. Cooke and Johnson (2002), Akcil and Koldas (2006) and Arogunjo (2007) observed that low pH in mine soils promoted solubility of heavy metals.

While concentrations of heavy metals in the mine soils were elevated, plant nutrient concentrations were lower. Lower organic C, total N, available P, and high Zn concentration occurred in the three mine sites, as previously reported by Martinez and Motto (2000) and Oelofse et al. (2008), that mining activities negatively affected the mineralization of plant nutrients. The elevated Cu and As contents at Itagunmodi, where gold mining took place, was supported by the findings of Okoya et al. (2011) and Straskraba and Moran (2006). The elevated Fe concentration in all the mine soils, according to Giwa et al. (2009) and Aghimien and Osemwota (2010), is characteristic of soil parent material of the southwestern part of Nigeria. The high Mn concentrations found in the control sites were similar to the findings of Okoya et al. (2011) in soils of the Ife-Ijesa area in southwestern Nigeria.

Comparison of the results with a study conducted 10 years ago by Salami et al. (2003) on soils of Itagunmodi mine specifically showed increases in soil Cd and Pb concentration. The results obtained in 2003 for Cd and Pb were 0.13 and 2.54 mg kg^{-1}, compared to 0.20 and 35.00 mg kg^{-1} in the present study. This shows that within a period of 10 years there was an increase by about 54% and 1278 % in Cd and Pb concentrations of the mine soils. This

Table 4. Relationships between heavy metals and total bacterial and fungal counts in Awo, Itagunmodi and Ijero-Ekiti mine sites. *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$

	Cd	Cu	Pb	As	Fe	THB	THF
Cd	0						
Cu	−0.37	0					
Pb	−0.95***	0.10	0				
As	−0.98***	0.48	0.92***	0			
Fe	−0.89**	−0.05	0.99***	0.85**	0		
THB	−0.12	0.71*	−0.02	0.26	−0.13	0	
THF	−0.11	0.66*	−0.02	0.23	−0.13	0.96***	0

supports the finding of Oelofse et al. (2008) that continuous exploitation of solid minerals on a particular site causes increased soil degradation, high soil acidity and hence increased solubility of heavy metals in soils.

The lower THF at the Ijero-Ekiti mine site may be caused by the significantly low pH and low nutrient contents while the increased THF counts of soils of Awo and Itagunmodi mine sites may be attributed to the suitable physico-chemical conditions for microbial activity. According to Faborode (2008), fungi are tolerant to heavy metal pollution in soils. Iram et al. (2009) also reported that fungi exhibit aggressive growth, high biomass, and extensive hypha ramification in contaminated soils, which enables the extraction of pollutants. The positive relationship between Mn, Zn, Cu and Na with THB and THF in the three mine sites is supported by findings of Ahmad et al. (2005) who found that bacteria and fungi can adapt to Cu, Cd, Cr, Hg, Mn, Ni, Pb and Zn contaminated soils. The negative relationship between pH and THB in the undisturbed sites supports the findings of Oladipo (2013) that pH influences microbial counts and viability.

The diversity of bacteria and fungi in the mine sites supports the findings of Watanabe et al. (2001) and Dubey (2004), who described diverse kinds of microorganisms due to the numerous types of pollutants present that act as sources of nutrients. The higher diversity of fungi species found in the mine sites supports the findings of Müller et al. (2001) and Khan and Scullion (2002) that fungi exhibit high resistance to heavy metal contamination.

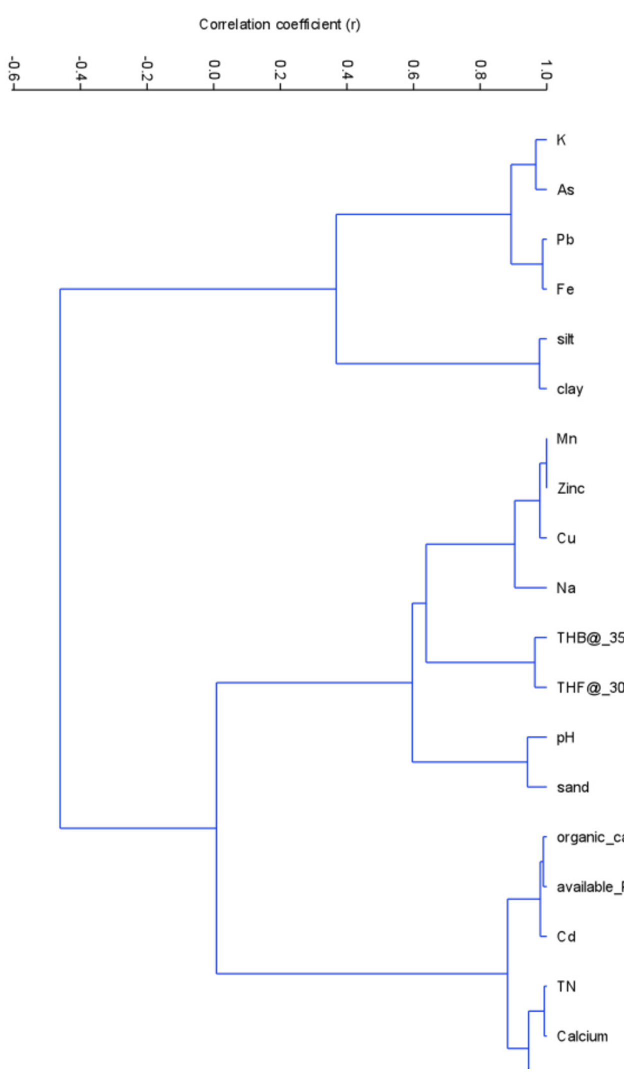

Fig. 1. Cluster analysis of physico-chemical parameters, heavy metal contents and total bacterial and fungal counts in mine sites.

Conclusions

This study showed the impact of mining activities on soil nutrient status and microbial population size and diversity in the study areas. It has provided up-to-date empirical data on the current state of soil degradation as a result of exploitation of solid minerals in Southwestern Nigeria. The study concludes that soils of Awo, Itagunmodi and Ijero-Ekiti mine sites were ecologically degraded with low soil pH, reduced organic carbon, total nitrogen, available phosphorus, exchangeable cations, elevated heavy metal contents and higher THF counts. The presence of indigenous microorganisms on the sites indicates their potential to be used for bioremediation purposes. The study underpins the need for strict mining operation policies in Nigeria and suggests immediate remediation strategies to salvage degraded agricultural lands.

Table 5. Relationships between physico-chemical parameters and total bacterial and fungal counts in undisturbed sites. *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$

Silt	−0.95***	0												
pH	0.67*	−0.47	−0.67*	0										
Total N	0.17	−0.46	0.91***	−0.44	0.76*	0								
Mn	−0.18	0.46	−0.91***	0.45	−0.75*	−0.99***	−0.39	0						
Ca	−0.81**	0.95***	−0.38	−0.20	−0.09	−0.72*	0.36	0.72*	0.74*	0				
K	−0.50	0.73*	−0.72*	0.17	−0.49	−0.94***	−0.05	0.94***	0.95***	0.91***	0.99*	0		
THB	−0.37	0.24	0.41	−0.76*	0.52	0.31	0.51	−0.33	−0.32	0.05	−0.14	−0.17	0.32	0

References

Adegboye M.A. 2012. Effect of mining on farming in Jos South Local Government Area of Plateau State. *J. Soil Sci. Envrion. Manage.* 3: 77–83.

Adekoya J.A., Kehinde-Phillips O.O., Odukoya A.M. 2003. Geological distribution of mineral resources in Southwestern Nigeria. In: Elueze A.A. (ed.) Prospects for Investment in Mineral Resources of Southwestern Nigeria. Nig. Mining and Geosci. Soc. (NMGS), pp. 1- 13. ISBN 978-36831-0-1.

Ahmad I., Hayat S., Ahmad A., Inam A., Samiullah 2005. Effect of heavy metal on survival of certain groups of indigenous soil microbial population. *J. Appl. Sci. Environ. Manage.* 9: 115–121.

Aghimien E.A., Osemwota I.O. 2010. Profile distribution of total, extractable iron and manganese in hydromorphic soils of Southern Nigeria. *Nigerian J. Soil Sci.* 20: 114–121.

Aigbedion I., Iyayi S.E. 2007. Environmental effect of mineral exploitation in Nigeria. *Int. J. Phys. Sci.* 2: 33–38.

Akcil A., Koldas S. 2006. Acid Mine Drainage (AMD): causes, treatment and case studies. *J. Cleaner Prod.* 14: 1139–1145.

Alireza S., Hajar A., Zohreh R., Hossein Z., Fatemeh M. 2012. Isolation and characterization of *Pseudomonas* resistant to heavy metals and poly aromatics hydrocarbons (PAHs) from Persian Gulf sediments. *African J. Biotechnol.* 11: 4418–4423.

Arogunjo A.M. 2007. Heavy metal composition of some solid minerals in Nigeria and their health implications to the environment. *Pak. J. Biol. Sci.* 10: 4438–4443.

Awotoye O.O., Adewole M.B., Salami A.O., Ohiembor M.O. 2009. Arbuscular mycorrhiza contribution to the growth performance and heavy metal uptake of *Helianthus annus* LINN in pot culture. *African J. Environ. Sci. Technol.* 2: 107–115.

Bai S., Abraham T.E. 2001. Biosorption of chromium (VI) from aqueous solution by *Rhizopus nigricans. Bioresour. Technol.* 79: 73–81.

Bray R.H., and Kurtz L.T. 1945. Determination of total organic and available forms of phosphorus in soils. *Soil Sci.* 59: 39–45.

Bremner J.M., Keeney D.R. 1966. Determination of nitrogen in soils: 3. Exchangeable ammonium, nitrate and nitrite by extraction-distillation methods. *Soil Sci. Soc. Am. Proc.* 30: 577–582.

Bouyoucos G.F. 1962. Hydrometer method improved for making particle size analysis of soils. *Agron. J.* 54: 464–465.

Cooke J.A., Johnson M.S. 2002. Ecological restoration of land with particular reference to the mining of metals and industrial minerals: A review of theory and practice. *Environ. Rev.* 10: 41–71.

Dubey R.C. 2004. *Biotechnology*. 3rd Edition. S. Chand & Company Ltd. New Delhi, India. 365 p.

Faborode J.O. 2008. Effects of the rates of Application of Copper and Lead on Soil Microbial Activities. M.Sc. Thesis of the Institute of Ecology and Environmental Studies. Obafemi Awolowo University, Ile–Ife, Nigeria. 100 p.

FAO. 1984. Plant Production and Protection Series-Agrochmatological Data for Africa. Countries north of the Equator. FAO, Rome. 1(22): 8 pp.

Fourest E., Canal C., Roux J.C. 1994. Improvement of heavy metal biosorption by mycelial dead biomass (R*hizopus arrhizus, Mucor miehei* and *Penicillium chrysogemum*): pH control and cation activation. *FEMS Microbiol. Rev.* 14: 325–332.

Gadd G.M. 1990. Heavy metal accumulation by bacteria and other

Table 6. Relationships between heavy metals and total bacterial and fungal counts in Awo, Itagunmodi and Ijero-Ekiti control sites. *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$

	Cd	Cu	Pb	As	Fe	THB	THF
Cd	0						
Cu	0.68*	0					
Pb	−0.31	−0.10	0				
As	0.070	0.42	0.86*	0			
Fe	−0.71*	−0.99***	0.24	−0.29	0		
THB	−0.23	−0.08	−0.52	−0.51	0.01	0	
THF	−0.29	−0.47	0.62	0.34	0.55	−0.10	0

microorganisms. *J. Ann. Exp.* 46: 834-840.

Giwa A.A., Bello, L.A., Amuda, O.S., Abdus-Salam, N. and Adelowo, F.E. 2009. Some heavy metals in urban and rural topsoils of Ibadan, Nigeria. *Int. J. Chem. Sci.* 2: 133–147.

Gunsekaran P., Muthukrishnan J., Rajendran P. 2003. Microbes in heavy metal remediation. *Indian J. Exp. Biol.* 41: 935-944.

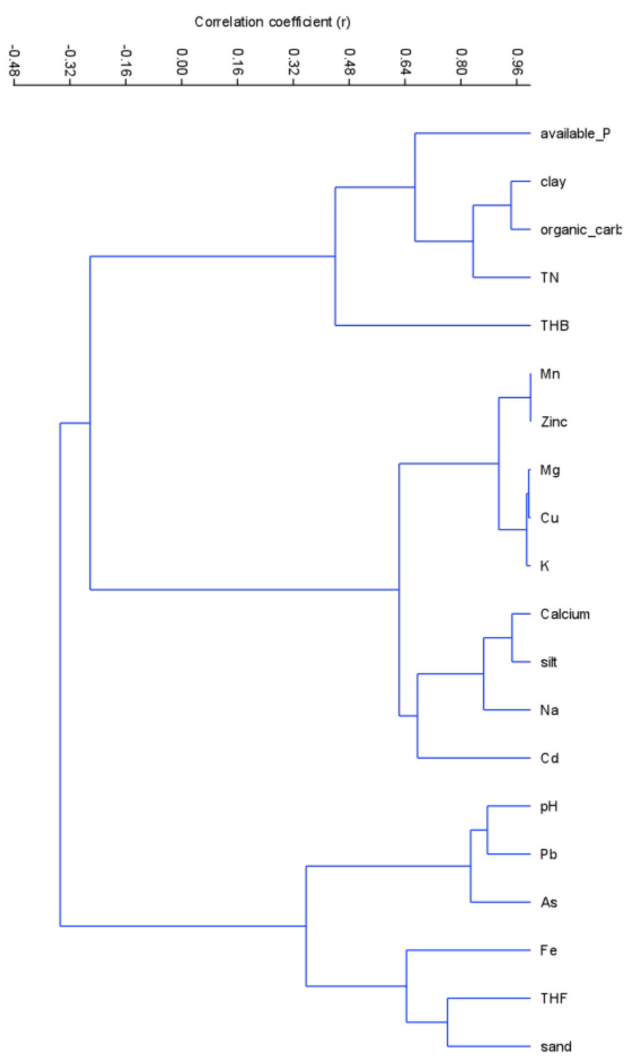

Fig. 2. Cluster analysis of physico-chemical parameters, heavy metal contents and total bacterial and fungal counts in control sites.

Iram S., Ahmad I., Stuben D. 2009. Analysis of mines and contaminated agricultural soil samples for fungal diversity and tolerance to heavy metals. *Pak. J. Bot.* 41: 885–895.

Jaboro A.G, Akortha E.E., Obayagbona O.N. 2013. Susceptibility to heavy metals and hydrocarbonclastic attributes of soil microbiota. *Int. J. Agric. Biosci.* 2: 206–212.

Jerome A. 2003. Preparation of Investment Profiles for Ventures in Mineral Resources. In: Elueze A.A. (ed.) Prospects for Investment in Mineral Resources of Southwestern Nigeria. Nig. Mining and Geosci. Soc. (NMGS), pp. 107-1103. ISBN 978-36831-0-1.

Kabata-Pendias A., Pendias H. 1992. *Trace Elements in Soils and Plants.* CRC Press, Boca Raton. 2nd Ed. 365 p.

Kabata-Pendias A., Pendias H. 2011. *Trace Elements in Soils and Plants.* CRC Press, Boca Raton. 4th Ed. 520 p.

Khan M., Scullion J. 2002. Effects of metal (Cd, Cu, Ni, Pb or Zn) enrichment of sewage-sludge on soil micro-organisms and their activities. *Appl. Soil Ecol.* 20: 145–155.

Kumar A., Balwant S. B., Joshi V. D. 2010. Biosorption of Heavy Metals by four acclimated microbial species, *Bacillus* spp., *Pseudomonas* spp., *Staphylococcus* spp. and *Aspergillus niger.* J. Biol. Environ. Sci. 4: 97–108.

Kumar A., Bisht B.S. Joshi V.D., Dhewa T. 2011. Review on Bioremediation of polluted environment: A management tool. *Int. J. Environ. Sci.* 1: 1079–1093.

Malik A 2004. Metal bioremediation through growing cells. *Environ. Int.* 30: 261–278.

Martínez C.E., Motto H. L. 2000. Solubility of lead, zinc and copper added to mineral soils. *Eniron. Poll.* 107: 153–158.

Mining Journal Special Publication. 2006. Nigeria: An exciting new mining destination. *Mining J.* 1–20.

Mu¨ller A.K., Westergaard S., Christensen S., Sørensen J. 2001. The effect of long-term mercury pollution on the soil microbial community. *FEMS Microbiol. Ecol.* 36: 11–19.

Oelofse S.H.H. Hobbs P.J., Rascher J.,Cobbing, J.E. 2008. The pollution and destruction threat of gold mining waste on the Witwatersrand - A West Rand case study. Symposium on Environmental Issues and Waste Management in Energy and Mineral Production (SWEMP 2007), 11-13 December 2007. Bangkok. Pp. 1–10.

Ojo J.S. and Adeyemi G.O. (2003). Opportunities for ventures in construction materials. In: Elueze A.A. (ed.) *Prospects for Investment in Mineral Resources of Southwestern Nigeria.* Nig. Mining and Geosci. Soc. (NMGS). pp 47- 54. ISBN 978-36831-0-1.

Okoya A.A. Asubiojo O.I. and Amusan A.A. 2011. Trace element concentrations of soils of Ife-Ijesa area Southwestern Nigeria. *J. Environ. Chem. Ecotox.* 3: 173-179.

Oladipo O.G. 2013. Effects of Microbial Heavy Metal Remediation in Soils from Selected Mine Sites in Osun and Ekiti States, Nigeria. PhD. Thesis of the Institute of Ecology and Environmental Studies, Obafemi Awolowo University, Ile–Ife, Nigeria. Pp. 325.

Oladipo O.G., Awotoye O.O., Olayinka A. 2013. Effects of organic amendments on microbial activity for the remediation of degraded mined soils. *Int. J. Ecol. Environ. Stud.* 1: 85–91.

Price M., Classen J., Payne G. 2001. *Aspergillus niger* absorbs copper and zinc from swine wastewater. *Bioresour. Technol.* 77: 41–49.

Robert A.S., Ellen S.H., Connie A.N.V. 1984. *Introduction of Food-borne Fungi.* Inst. of the Royal Netherlands Academy of Arts Science, Netherlands.

Salami A.S. Jimoh M.A., Muoghalu, J.I. 2003. Impact of gold mining on vegetation and soil in Southwestern Nigeria. *Int. J. Environ. Stud.* 60: 343–352.

Straskraba V., Moran R.E. 2006. Environmental Occurrence and Impacts of Arsenic at Gold Mining Sites in the Western United States. Mine Water and the Environment Int. Mine Water Ass. www.IMWA.info 181–191.

Walkley A., Black I.A. 1934. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Sci.* 37: 29-38.

Watanabe K., Kodoma Y., Stutsubo K., Harayama S. 2001. Molecular characterization of bacterial populations in petroleum-contaminated ground water discharge from underground crude oil storage cavities. *Appl. Environ. Microbiol.* 66: 4803–4809.

Received 10 July 2014; received in revised form 26 September 2014; accepted 23 November 2014