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Heavy Metal Contamination In Soils Around Onyeama And Okpara Coal Mines In Enugu, Southeastern Nigeria

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Abstract: *The paper assessed the levels of heavy metals in soil collected in the vicinity of Onyeama and Okpara Coal Mines in Enugu, South East of Nigeria. The concepts of Pollution Index (Pi) and Enrichment Factor (EF) were used to evaluate the heavy metal pollution status in areas around the coal mines. The mean concentration of the metals ranged from 1.00 - 14.37 mg/kg for Cd, 0.37-7.25 mg/kg for Pb, 0.75-18.50 mg/kg for Ni, 0.12-0.37 mg/kg for As, 0.25-11.25 mg/kg for Cu, 0.12-1875 mg/kg for Cr. The concentration patterns of the metals follows the order Fe> Ni> Zn > Cd > Pb > Cu > Mn > Co > As. The Enrichment Factor (EF) of the metals follows the order Cd >Pb > Ni > Cu > Zn > Co > Cr > Mn > Fe. The source of metal enrichment in soils in the areas is suspected to be leachates import from overlying coal waste dumps into the soil and selective leaching of these metals from their concentration trends. Enrichment factors and Health risk levels indices in the examined area were respectively Cd (192.67, 5); Cr (2.04, 2); Cu (7.30, 3); Mn (0.34, 0); Ni (10.60, 2); Pb (24.03, 4); C0 (3.61, 2) and As (8.30, 3).The results indicate significant enrichment of Pb, Cd and Ni in the examined sites compared to any other elements studied.*

Keyword: *Pollution index, Enrichment factor, Leachate import, Health risk level*

I. Introduction

Soil, whether in urban or agricultural areas, represent a major sink for metals released into the environment from a variety of anthropogenic activities [Kabata-Pendias and Pendias,1992] The high levels of mine-related soil pollution have recently become a major issue and chemical analysis of soil is important for environmental monitoring [Zhang et al.,2000]. Contamination by heavy metals in mined environments, especially coal is a major concern because of their toxicity, treat to human life and the environment. The objective of the present study is to determine the characteristic levels of heavy metals in soil in the vicinity of Onyeama and Okpara coal mined areas with a view to providing information on the degree of contamination so as to enable assessment of possible environmental impacts that could occur due to coal mining activities. Also, assess the distribution of heavy-metals in the back ground soil sediments far away from mined area to determine their contribution to abnormal elemental concentrations.

II. Materials And Methods

The work involved integrated geological and chemical studies. Field study involved the application of precise techniques in sample collection to ensure that data from each analysis performed on the samples are reproducible. Various soils collected were largely loose, friable, weathered to reddish brown in color and lateritic. Sample numbers ON-1 to 22, were collected from Onyeama coal mine areas. Sample numbers OK-23 to 47 were collected from Okpala coal mine areas and sample numbers BGS 48 to 61 were background soils (Tables 1, 2 and 3). A total of 47 soil and14 control background soil samples were systematically collected. Sample locations are shown in (Figure 1). Soil samples were oven dried at $105^{O}C$ for 24 hours to remove moisture. Each sample was crushed in a mortar and mechanically sieved to increase surface area so as to enhance efficiency of subsequent chemical attack. A 0.2g of each sample was weighed and kept in dried crucibles. Total digestion method was applied. The method releases all elements in a sample [Crock et al., 1983 and Briggs,1996]. Samples were dissolved in acid mixture of 5 ml metric acid, 3ml perchloric acid and 2ml hydrofluoric acid. The cooled solution was made up to 250ml in volumetric flask with de-ionized water. The solutions were chemically analyzed for Cd, Cr, Cu, Mn, Ni, Pb, Fe, Zn, As and Co by use of Bulk Scientific Atomic Absorption Spectrophotometer (AAS), model 210 VGP. The selection of these metals is because of their high concentrations and related impact on the environment. The pollution and enrichment factor indices for soil in the area were calculated and used for interpretation of the pollution status. The results are presented in tables and figures to place them in proper perspective.

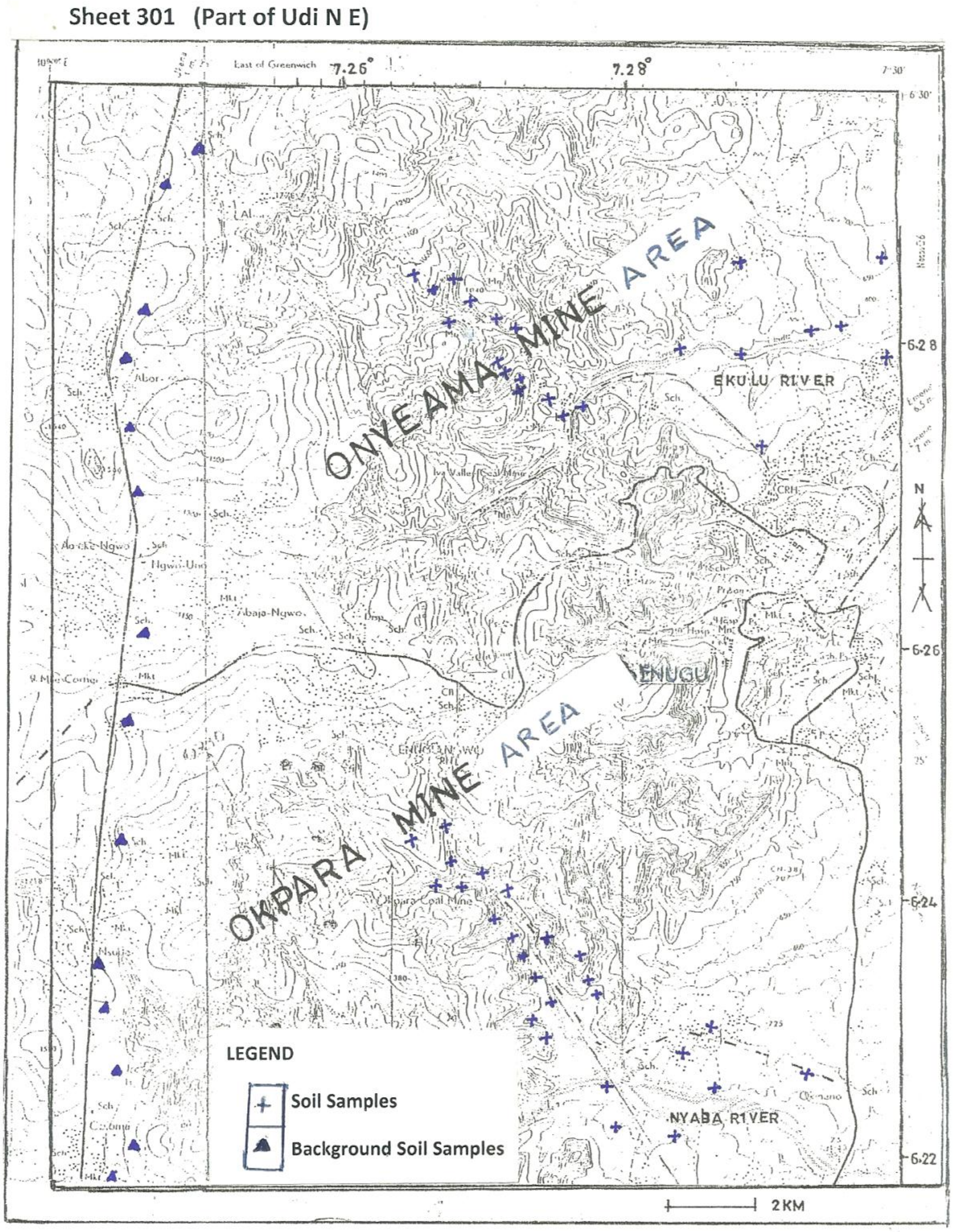

Fig 1: Map of the Study Area (Onyeama and Okpara Mines) showing Soil and Background Soil Samples locations.

Sample ID	Latitude ^{o}N	Longitude ^{o}E	Remarks
ON-1	06 28 136	07 27 232	
ON-2	06 28 149	07 27 243	Dark grey, clayey soil
ON-3	06 28 145	07 27 171	Well sorted fine sand, reddish
ON-4	06 28 145	07 27 054	Poorly sorted
ON-5	06 28 137	07 27 210	Fissile, soft shale
ON-6	06 28 139	07 27 260	Ferruginous sands.
ON-7	06 28 108	07 27 266	Coarse grained sand
ON-8	06 27 436	07 27 836	Boulders of sandstone
ON-9	06 27 437	07 28 006	Muddy, grayish soft soil.
ON-10	06 27 860	07 28 436	Dark colored soft soil
ON-11	06 27 409	07 28 085	Friable soil
ON-12	06 27 409	07 28 047	Fine grained soil
ON-13	06 27 410	07 28 724	Loose, clayey soil
ON-14	06 27 295	07 26 089	Brown colored, friable coarse sand
ON-15	06 28	436	07 28 836 Well sorted soft soil
ON-16	06 28 327	07 26 789	Clayey soil
ON-17	06 28 327	07 26 756	Medium grained soil
ON-18	06 28 825	07 29 891	Cray colored, medium grained soil
ON-19	06 28 146	07 28 528	Loose soil
ON-20	06 28 856	07 28 798	Reddish, well sorted soil
ON-21	06 28 106	07 28 865	Black, soft soil
ON-22	06 28 282	07 29 533	Reddish, erosion cut.

Table 1: Locations of Soil Samples (Onyeama Mine Area)

Table 2: Locations of Soil Samples (Okpara Mine Area)

Sample ID	Latitude ^{o}N	Longitude ^{o}E	Remarks
OK-23	06 24 086	07 27 004	
OK-24	06 24 153	07 26 989	Lateritic, coarse grained soil
OK-25	06 23 922	07 27 126	Fine grained sand
OK-26	06 23 925	07 27 168	Friable sand
OK -27	06 23 720	07 27 248	Clayey sand
OK-28	06 23 690	07 27 223	Grey colored, muddy sand
OK-29	06 23 731	07 27 272	Lateritic, reddish hard soil.
OK-30	06 28 925	07 27 168	Fine sand.
OK-31	06 23 968	07 27 122	
OK-32	06 23 933	07 27 291	Grayish, clayey soil.
OK-33	06 23 712	07 27 253	Fine grained sand.
OK-34	06 24 167	07 26 062	Mixed Clay, siltstone and fine sand.
OK-35	06 24 161	07 26 942	
OK-36	06 24 645	07 27 049	
OK-37	06 23 915	07 27 155	Silty, grayish sand
OK -38	06 23 547	07 27 240	Yellow colored, fine grained sand.
OK-39	06 23 716	07 27 189	Loose, fine grained sand
OK-40	06 23 652	07 27 284	

OK-41	06 22 652	07 27 328	Reddish, loose sand
OK-42	06 22 795	07 27 430	Clayey soil
OK-43	06 22 171	07 27 518	Well sorted fine sand
OK-44	06 22 547	07 28 159	Yellowish loose soil.
OK -45	06 22 756	07 28 643	
OK-46	06 22 387	07 28 217	Angular grained friable sand
OK-47	06 22 187	07 28 055	Ferruginous, pebbly soil

Table 3: Locations of Background Soil Samples

Sample ID	Latitude N(deg)	Longitude E (deg)	Elevation (m)	Remarks
BGS-48	06 29 529	07 25 661	457.5	Coarse grained Ironstones, red soil, poorly sorted lateritic sands.
BGS-49	06 29 029	07 24 029	451.50	Ironstone boulders, red colored soil.
BGS-50	06 28 474	07 24 414	414.90	Dark, well sorted fine sand.
BGS-51	06 27 496	07 24 350	449.70	Medium grained, dark colored well sorted sand.
BGS-52	06 27 023	07 24 422	413.40	Angular grained, white sand, flat terrain with scanty vegetation cover.
BGS-53	06 26 536	07 24 439	376.20	Loose, friable, grey colored, well sorted
BGS-54	06 25 019	07 24 267	377.10	Ironstone rubbles, Dark grey coloured, poorly sorted lateritic sands.
BGS-55	06 25 406	07 24 181	429.00	Thick vegetation cover with tall grasses, medium grained well sorted sand.
BGS-56	06 24 497	07 24 133	460.80	Light brown, fine grained, and well sorted, excavated sand.
BGS-57	06 23 334	07 24 109	484.50	Brown ironstones and quartz pebbles
BGS-58	06 22 748	07 24 089	429.00	Fine grained friable sand and Ironstone rubbles with concretions.
BGS-59	06 22 299	07 24 061	398.40	Grey colored clayed soil, thick tall grasses vegetation cover.
BGS-60	06 21 803	07 24 034	420.30	Loose, friable white sand. Well sorted at Obioma High School compound.
BGS-61	06 22 748	07 24 186	420.30	Fine grained, well sorted friable, loose sand. Flat terrain dotted with shrubs.

III. Results And Discussion

Concentration of metals in milligram per kilogram (mg/kg) as analyzed from the Atomic Absorption Spectrophotometer (AAS) are presented in Tables 4, 5 and 6.

Table 4: Concentration (mg/kg) of Metals in Soil Samples (Onyeama Mine Area)

Sample ID	Concentration of Metals in mg/kg									
	Cd	Cr	Cu	Mn	Ni	Pb	Co	Fe	Zn	As	pH
ON-1	1.37	1.50	1.25	1.50	3.78	3.50	0.75	241.25	1.12	ND	6.5
ON-2	2.50	1.12	1.25	4.62	2.62	1.62	0.75	253.75	0.25	0.15	4.5
ON-3	1.75	1.25	5.00	3.12	3.50	1.25	1.62	1092.50	Nil	0.25	4.5
ON-4	2.87	1.12	3.75	0.50	6.00	1.50	0.25	192.50	1.12	ND	4.5
ON-5	2.12	1.37	Nil	6.12	Nil	1.00	1.25	192.25	0.87	0.12	4.5
ON-6	3.12	2.62	1.25	1.50	Nil	0.75	0.12	523.75	1.12	0.25	6.5
ON-7	1.75	1.12	1.25	0.12	Nil	0.87	1.25	202.50	0.12	012	5.0
ON-8	8.00	1.50	0.87	0.12	15.37	2.00	0.12	1205.00	14.87	0.25	4..5
ON-9	10.25	0.872	1.50	0.25	18.50	3.87	0.13	752.50	10.75	0.25	4.5
ON-10	13.87	1.62	0.25	0.63	7.37	4.00	0.13	926.25	1.37	0.12	4.5
ON-11	5.37	2.13	4.12	0.13	12.75	3.12	0.13	780.00	15.87	0.25	4.5
ON-12	9.37	0.87	1.37	0.75	5.12	3.62	0.13	1093.75	5.25	0.12	5.5
ON-13	8.75	1.75	0.50	0.37	16.00	4.12	1.87	1100.00	6.50	ND	4.5
ON-14	9.75	1.50	1.00	0.25	8.37	2.25	0.13	1315.00	15.25	0.12	5.0
ON-15	4.25	3.25	2.87	0.25	1.12	4.12	0.25	937.50	12.00	ND	5.0
ON-16	4.87	2.75	1.75	0.12	4.00	4.62	0.12	575.00	3.37	0.12	5.5
ON-17	1.00	1.62	1.12	0.12	14.50	3.50	0.12	1438.75	8.25	0.25	5.5
ON-18	4.25	2.00	2.00	0.25	10.87	1.75	0.25	1312.50	2.50	0.12	4.4
ON-19	5.12	2.00	1.12	0.25	8.25	3.87	0.12	1190.00	3.97	0.25	5.5
ON-20	6.25	5.62	0.62	ND	3.25	2.25	0.12	1081.25	5.62	0.12	6.5
ON-21	14.37	1.87	3.75	ND	13.12	1.87	0.12	655.00	8.50	0.37	4.5
ON-22	1.50	3.00	0.87	ND	ND	7.25	0.12	648.75	8.62	0.37	4.5
TOTAL	**122.45**	**41.44**	**37.46**	**21.96**	**154.56**	**69.38**	**9.84**	**17711.74**	**123.06**	**3.52**	**110.4**
Average	**5.56**	**1.88**	**1.70**	**0.99**	**7.02**	**3.15**	**0.44**	**805.07**	**5.59**	**0.16**	**5.01**

Table 5: Concentration (mg/kg) of Metals in Soil Samples (Okpara Mine Area)

Sample ID	Concentration of Metals in mg/kg									
	Cd	Cr	Cu	Mn	Ni	Pb	Co	Fe	Zn	As	pH
OK-23	3.37	2.12	3.75	0.37	8.25	3.75	1.87	432.50	0.37	0.25	4.5
OK-24	4.38	1.37	1.25	2.88	2.25	1.12	Nil	405.00	0.62	0.25	5.5
OK-25	3.50	1.75	2.50	1.25	Nil	1.00	1.25	160.00	0.87	0.25	4.5
OK-26	2.38	2.38	2.50	Nil	6.37	1.75	0.50	247.50	1.12	0.12	4.4
OK-27	2.75	2.12	1.25	5.25	8.50	2.50	1.00	548.75	1.00	0.12	6.5
OK-28	2.50	1.50	1.50	5.75	Nil	2.00	0.75	416.25	1.50	0.12	4.5
OK-29	2.75	3.75	3.75	2.26	Nil	2.12	Nil	917.50	1.37	ND	4.5
OK-30	3.50	2.12	Nil	Nil	4.00	0.37	0.37	175.00	1.00	0.12	4.5
OK-31	5.12	1.62	Nil	2.88	0.75	0.37	0.75	211.25	0.37	0.25	5.5
OK-32	3.12	2.38	Nil	0.25	0.87	2.00	Nil	388.75	0.87	0.12	4.5
OK-33	Nil	0.37	Nil	0.25	2.50	3.50	0.25	398.75	0.87	0.25	5.5
OK-34	7.37	2.12	0.62	0.12	11.25	3.00	ND	1656.25	6.87	0.25	4.5
OK-35	5.50	1.75	1.00	2.50	16.62	5.87	0.12	938.75	10.87	0.25	4.5
OK-36	15.25	1.37	0.50	0.12	9.50	1.37	0.12	655.00	14.87	0.25	4.5
OK-37	15.50	3.00	5.12	0.25	6.50	3.25	0.12	1143.75	18.87	0.25	5.5
OK-38	6.00	3.37	1.62	0.12	14.50	2.25	0.12	15.3.75	17.87	0.12	5.5
OK-39	6.75	1.00	1.87	0.12	117.75	2.50	0.12	1155.00	9.25	0.12	4.5
OK-40	14.12	5.00	1.25	0.37	8.62	3.25	0.12	867.50	18.75	ND	5.5
OK-41	6.00	2.12	2.25	ND	14.12	3.25	0.12	1080.00	4.12	0.37	4.5
OK-42	5.50	3.25	3.25	0.12	12.00	3.00	0.12	1173.75	5.50	0.25	6.5
OK-43	9.75	2.50	1.87	0.12	9.12	2.25	0.12	1177.50	3.50	0.25	5.5
OK-44	11.00	11.25	11.25	0.12	5.87	2.25	0.12	1625.00	4.87	0.12	4.5
OK-45	4.25	1.37	0.75	0.25	4.50	43.87	ND	1127.50	6.75	0.12	5.5
OK-46	2.37	2.12	0.87	ND	9.25	3.50	0.12	1123.75	10.25	0.25	4.5
OK-47	11.25	2.62	1.00	0.12	6.37	4.12	ND	831.25	8.00	0.25	5.5
TOTAL	**138.48**	**62.58**	**50.72**	**25.83**	**179.46**	**63.20**	**9.31**	**19201.00**	**150.30**	**4.70**	**125.4**
Average	**5.53**	**2.50**	**2.02**	**1.03**	**7.17**	**2.52**	**0.37**	**768.04**	**6.01**	**0.18**	**5.01**

Table 6: Concentrations (mg/kg) of Metals in Background Soil Samples

Sample ID	**Concentration of Metals in mg/kg**										
	Cd	Cr	Cu	Mn	Ni	Pb	Co	Fe	Zn	As	Ph
BGS-48	0.37	2.37	2.00	6.37	0.75	3.75	0.25	831.25	6.25	0.25	6.0
BGS-49	1.12	5.12	1.12	9.12	1.62	3.50	0.87	1113.75	7.25	0.25	6.0
BGS-50	1.62	2.12	0.62	Nil	11.87	2.62	0.37	1127.50	2.62	0.12	6.0
BGS-51	1.50	Nil	3.75	4.00	6.62	1.37	0.25	1177.50	3.50	0.12	6.0
BGS-52	Nil	3.62	0.87	Nil	11.00	2.25	0.87	1173.75	Nil	0.25	5.0
BGS-53	0.25	3.75	2.25	0.50	11.12	0.50	0.37	1080.04	5.00	0.37	6.0
BGS-54	0.72	1.12	1.87	0.62	0.87	3.25	Nil	648.75	6.00	0.37	5.0
BGS-55	1.12	Nil	0.12	1.37	4.00	4.75	0.37	1190.00	4.00	Nil	6.0
BGS-56	1.12	Nil	0.75	0.87	10.12	1.87	0.62	1313.75	1.87	0.25	6.0
BGS-57	2.50	3.00	1.00	3.37	2.62	2.25	1.12	1451.25	4.37	0.12	6.0
BGS-58	4.62	4.00	0.12	0.87	6.75	1.75	Nil	587.50	3.62	0.25	6.0
BGS-59	4.75	Nil	0.37	5.50	10.37	3.50	Nil	937.50	2.87	Nil	5.0
BGS-60	5.25	1.50	2.50	6.62	1.50	0.87	0.37	976.50	7.00	0.12	6.0
BGS-61	6.12	1.37	2.87	5.62	6.36	4.12	0.62	1625.00	7.00	0.37	6.0
Total	**30.59**	**27.97**	**20.21**	**44.83**	**85.57**	**36.35**	**6.08**	**15234.100**	**61.85**	**2.77**	**81**
Average	**2.18**	**1.99**	**1.44**	**3.20**	**6.11**	**2.59**	**0.43**	**1088.00**	**4.41**	**0.19**	**5.7**

Results of calculated Enrichment Factors (EF) for the metals are presented in Tables 7, 8 and 9. The term Enrichment Factor (EF) is used to describe the ratio of individual metals. EF can fully reflect the impact which was brought to the environment by human activities [Liao et al.,2006] Its basis method is to compare the concentration of sample with the baseline element which can be considered condition of this heavy metal in an environment believed not polluted (i.e. control back ground soil samples). The Enrichment Factor (EF) was computed using the [Liao etal., 2006] and [Buat-Menard and Chesselet,1979] formula.

$$\text{Enrichment Factor (EF)} = \frac{\text{Cn (sample) /C ref (sample)}}{\text{Bn (sample)/ Bref (Background)}}$$

Where Cn (sample) is the content of the examined element in the examined environment. Cref (sample) is the content of the reference element in the examined environment. Bn (background) is the content of the reference element in the reference environment. In this study, Fe is used as reference element because it is the most naturally abundant element in soil [Nwajei and Iwegbu, 2007]. Calculated enrichment factors are shown in tables 7, 8 and 9.Based on the Enrichment Factors (EF), the Heath Risk Level (HRL) is known, Table 10.

Table 7**: Enrichment Factors (EF) of Soil Samples (Onyeama Mine Area)**

Sample ID	Enrichment Factors (EF)									
	Cd	Cr	Cu	Mn	Ni	Pb	Co	Fe	Zn	As
ON-1	126.99	3.09	12.87	0.41	17.81	88.48	10.42	0.99	4.32	0.00
ON-2	220.33	2.19	12.24	1.22	11.74	38.93	9.91	0.99	0.99	12.69
ON-3	35.81	0.06	0.02	0.19	3.64	6.97	4.97	0.99	Nil	6.14
ON-4	333.39	2.89	48.40	0.52	35.44	47.52	1.47	0.99	0.06	0.00
ON-5	241.60	3.47	Nil	0.17	Nil	31.08	21.36	0.99	4.13	16.41
ON-6	133.24	2.48	5.93	0.78	Nil	8.73	0.76	0.99	1.99	12.81
ON-7	193.25	2.74	15.33	0.37	Nil	26.20	20.70	0.99	0.05	15.90
ON-8	148.20	0.61	1.79	0.00	14.48	10.10	0.33	0.99	11.48	5.56
ON-9	304.42	0.57	4.95	0.02	27.93	31.34	0.57	0.99	13.30	8.91
ON-10	334.72	0.86	0.67	0.01	9.04	26.32	0.47	0.99	1.37	3.47
ON-11	153.94	1.35	13.12	0.04	18.58	24.39	0.55	0.99	18.95	8.60
ON-12	191.58	0.39	3.11	0.02	5.31	20.17	0.39	0.99	4.46	2.94
ON-13	177.91	0.79	1.12	0.01	16.54	22.84	5.70	1.00	5.50	0.00
ON-14	165.76	0.56	1.88	0.01	7.23	10.43	0.33	0.99	10.80	2.44
ON-15	101.29	1.72	7.60	0.01	1.35	31.59	0.89	0.99	11.91	0.00
ON-16	189.28	2.47	7.55	0.00	7.90	48.97	0.69	0.99	5.70	5.59
ON-17	15.53	0.55	1.93	0.01	11.45	14.82	0.27	0.99	5.33	4.66
ON-18	72.39	0.75	3.78	0.00	9.41	8.12	0.63	1.00	1.77	2.45
ON-19	79.75	2.83	2.33	0.01	7.87	19.80	0.33	0.99	3.02	5.63
ON-20	191.66	2.58	1.42	0.00	3.41	12.68	0.37	0.99	3.02	5.63
ON-21	490.49	2.41	14.22	0.00	22.77	17.40	0.61	0.99	12.08	15.15
ON-22	51.70	2.29	3.33	0.00	0.00	68.15	62	0.99	12.37	15.30
TOTAL	**3953.29**	**34.55**	**163.59**	**3.80**	**232.10**	**614.90**	**82.31**	**21.80**	**133.51**	**147.62**
Average	**179.09**	**1.57**	**7.43**	**0.17**	**10.55**	**27.95**	**3.74**	**0.99**	**6.06**	**6.91**

Table 8: Enrichment Factors (EF) of Soil Samples (Okpara Mine Area)

Sample ID	Enrichment Factors (EF)									
	Cd	Cr	Cu	Mn	Ni	Pb	Co	Fe	Zn	As
OK-23	174.22	2.43	21.54	0.05	21.68	52.87	14.50	0.99	0.79	15.51
OK-24	241.63	1.67	7.66	0.47	6.31	16.85	Nil	0.99	1.42	16.55
OK-25	489.18	5.43	38.82	0.52	Nil	38.11	26.20	0.99	5.06	41.93
OK-26	215.07	4.77	25.18	Nil	29.26	43.12	6.77	0.99	4.21	13.01
OK-27	101.83	1.91	5.65	0.64	17.60	27.77	6.11	1.00	1.69	5.86
OK-28	134.33	1.79	8.96	0.92	Nil	29.30	6.04	0.99	3.35	7.73
OK-29	67.00	2.03	10.16	0.19	Nil	14.08	Nil	0.99	1.39	0.00
OK-30	447.30	6.02	Nil	Nil	25.99	12.89	7.09	0.99	5.32	18.40
OK-31	542.03	3.81	Nil	0.91	4.03	10.68	11.91	0.99	1.63	31.76
OK-32	179.50	3.04	Nil	0.04	2.54	31.38	Nil	0.99	2.08	8.28
OK-33	Nil	4.60	Nil	0.04	7.12	38.22	2.10	0.99	2.03	16.82
OK-34	99.49	0.63	0.93	0.00	7.72	11.04	0.00	0.99	3.86	4.05
OK-35	130.90	0.92	2.64	0.17	20.11	38.10	0.42	0.99	10.77	7.14
OK-36	520.53	1.03	1.89	0.01	16.49	12.75	0.61	0.99	21.14	10.24
OK -37	303.28	1.30	11.13	0.01	6.21	17.34	0.35	1.00	15.38	5.87
OK-38	89.20	1.23	0.27	0.00	10.96	9.12	2.49	0.99	11.06	2.14
OK-39	43.50	0.42	4.01	0.00	17.44	13.18	0.34	0.99	7.45	2.78
OK-40	363.82	2.86	3.57	0.02	11.29	22.83	0.46	0.99	20.13	0.00
OK-41	124.20	0.97	5.17	0.00	14.86	18.34	0.37	0.99	3.55	9.19
OK-42	104.68	1.37	6.87	0.00	11.61	15.51	0.34	0.99	4.36	5.71
OK-43	184.92	1.05	3.94	0.00	8.79	11.63	0.34	0.99	2.76	5.69
OK-44	151.06	3.43	17.16	0.00	4.09	8.42	0.24	0.99	2.78	1.97
OK-45	84.29	0.60	1.65	0.01	4.53	5.40	0.00	0.99	5.57	2.85
OK-46	47.16	0.93	1.92	0.00	9.35	18.99	0.35	0.99	8.49	5.97
OK-47	302.62	1.56	0.59	0.00	8.71	30.22	0.00	0.99	8.96	8.07
TOTAL	**5741.73**	**55.17**	**179.70**	**4.00**	**226.68**	**548.14**	**87.03**	**24.77**	**155.18**	**247.52**
Average	**205.66**	**2.51**	**7.18**	**0.16**	**10.66**	**21.92**	**3.48**	**0.99**	**6.20**	**9.90**

Table 9: Enrichment Factor (EF) of Background Soil

Sample ID	**Enrichment Factors(EF) of Metals**									
	Cd	Cr	Cu	Mn	Ni	Pb	Co	Fe	Zn	As
BGS-48	9.95	1.41	5.97	0.51	1.02	27.51	1.00	0.99	7.00	8.07
BGS-49	22.47	2.28	2.49	0.54	1.65	19.15	2.61	0.99	6.06	6.02
BGS-50	32.13	0.93	1.36	ND	11.97	14.17	1.10	0.99	2.16	2.85
BGS-51	28.45	ND	7.90	0.22	6.38	7.08	0.71	0.99	2.76	1.95
BGS-52	NB	1.53	1.83	ND	10.64	11.67	2.48	0.99	ND	5.71
BGS-53	5.17	1.72	5.17	0.03	11.70	2.82	1.14	0.99	4.31	9.19
BGS-54	24.81	0.85	7.16	0.06	1.52	30.55	ND	0.99	8.61	15.30
BGS-55	21.01	ND	0.25	0.07	3.81	24.31	1.04	0.99	3.12	ND
BGS-56	19.04	ND	1.41	0.04	8.74	8.67	1.58	0.99	1.32	5.10
BGS-57	38.50	1.02	1.71	0.15	2.05	9.45	2.58	0.99	2.80	2.21
BGS-58	175.86	3.38	0.50	0.09	13.06	18.16	ND	0.99	5.74	11.42
BGS-59	113.20	ND	0.97	0.39	12.56	22.75	ND	0.99	2.85	ND
BGS-60	120.22	0.76	6.36	0.45	1.74	5.43	1.27	0.99	6.67	3.29
BGS-61	84.04	0.41	4.37	0.23	4.44	15.43	1.27	0.99	4.00	6.09
Total	**694.85**	**14.29**	**47.45**	**2.74**	**91.28**	**217.15**	**16.78**	**13.86**	**54.41**	**77.20**
Average	**49.63**	**1.02**	**3.38**	**0.19**	**6.52**	**15.51**	**1.19**	**0.99**	**3.88**	**5.51**

Note: ND means not detected.

Table 10: Metal Enrichment Factor (EF) and HRL of Soil and Background Soil media.

Media	Parameters
Soil	
EF	Cd > Pb > Ni > As > Cu > Zn > Co > Cr > Mn > Fe
HRL	5 4 3 3 3 3 2 2 0 0 0
Pollution Level	High Intermediate Low Absence
Background soil	
EF	Cd > Pb > Ni > As > Zn > Cu > Cr > Fe > Co > Mn
HRL	5 3 3 3 2 2 1 0 0 0
Pollution Level	High Intermediate Low Minimal Absence

Note: EF = Enrichment Factor
HRL= Health Risk Level

Pollution Index (Pi) was introduced as part of assessing the pollution levels by considering the joint effects of all polluting metals in soils [Li and Yang,2008]. The pollution index (Pi) was extensively used for soil pollution assessment in China [Chem et al.,2005], [Fang et al.,2006], [Li et al.,2005] and [Zheng et al.,2006] proved to be simple and effective because it related to a certain quality criterion. The pollution index was computed by averaging the ratios of the total concentration of heavy metals to the tolerable levels [Ju-yong et al., 2002] and [Kabata-Pendias.,1984]. Pollution Index (Pi) = Ci/Si. Ci = Concentration of heavy metal in the medium, Si = relevant Standard for this metal [Rudmick and Geo, 2003]. Results of pollution indices for the sampled soils are shown in Tables 11, 12 and 13.

Table 11: Pollution Index of Metals in Soil Samples (Onyeama Mine Area)

	Pollution Index (Pi) of Metals									
Sample ID	Cd	Cr	Cu	Mn	Ni	Pb	Co	Fe	Zn	As
ON-1	17.12	0.01	0.04	0.00	0.06	0.31	0.03	0.00	0.01	0.00
ON-2	31.25	0.00	0.04	0.00	0.04	0.14	0.03	0.00	0.00	0.06
ON-3	21.87	0.00	0.18	0.00	0.05	0.11	0.08	0.01	0.00	0.10
ON-4	35.87	0.00	0.13	0.00	0.10	0.13	0.01	0.00	0.01	0.00
ON-5	26.50	0.01	0.00	0.00	0.00	0.09	0.06	0.00	0.01	0.04

ON-6	39.00	0.01	0.04	0.00	0.00	0.06	0.00	0.00	0.01	0.10
ON-7	21.87	0.00	0.04	0.00	0.00	0.07	0.06	0.00	0.00	0.04
ON-8	100.00	0.00	0.03	0.00	0.26	0.18	0.00	0.00	0.20	0.10
ON-9	128.12	0.00	0.05	0.00	0.31	0.35	0.00	0.00	0.14	0.10
ON-10	173.37	0.01	0.00	0.00	0.12	0.36	0.00	0.00	0.01	0.04
ON-11	67.12	0.01	0.15	0.00	0.20	0.28	0.00	0.00	0.22	0.10
ON-12	117.12	0.00	0.05	0.00	0.08	0.32	0.00	0.01	0.07	0.04
ON-13	109.37	0.00	0.01	0.00	0.27	0.37	0.09	0.01	0.09	0.00
ON-14	121.87	0.00	0.03	0.00	0.14	0.20	0.00	0.01	0.21	0.04
ON-15	53.12	0.02	0.10	0.00	0.01	0.37	0.01	0.01	0.16	0.00
ON-16	60.87	0.02	0.06	0.00	0.06	0.42	0.00	0.00	0.04	0.04
ON-17	12.50	0.01	0.04	0.00	0.24	0.31	0.00	0.02	0.11	0.10
ON-18	53.12	0.01	0.07	0.00	0.18	0.15	0.01	0.01	0.03	0.04
ON-19	64.00	0.01	0.04	0.00	0.13	0.35	0.00	0.01	0.05	0.10
ON-20	78.12	0.04	0.02	0.00	0.05	0.20	0.00	0.01	0.07	0.04
ON-21	179.62	0.01	0.13	0.00	0.22	0.17	0.00	0.00	0.11	0.14
ON-22	18.75	0.02	0.03	0.00	0.00	0.05	0.00	0.00	0.11	0.14
Total	**1530.55**	**0.19**	**1.28**	**0.00**	**2’52**	**4.99**	**0.38**	**0.10**	**1.66**	**1.36**
Average	**69.57**	**0.00**	**0.05**	**0.00**	**0.11**	**0.22**	**0.01**	**0.00**	**0.07**	**0.06**

Table 12: Pollution Index (Pi) of Metals in Soil Samples (Okpara Mine Area)

Pollution Index (Pi) of Metals

Sample ID	Cd	Cr	Cu	Mn	Ni	Pb	Co	Fe	Zn	As
OK-23	42.12	0.01	0.13	0.00	0.13	0.34	0.09	0.00	0.00	0.10
OK-24	54.62	0.01	0.04	0.00	0.03	0.11	0.00	0.00	0.00	0.10
OK-25	43.75	0.01	0.09	0.00	0.00	0.09	0.06	0.00	0.01	0.10
OK-26	29.75	0.01	0.09	0.00	0.10	0.15	0.02	0.00	0.01	0.04
OK-27	34.37	0.01	0.04	0.00	0.14	0.22	0.05	0.00	0.01	0.04
OK-28	31.25	0.01	0.05	0.00	0.00	0.18	0.03	0.00	0.02	0.04
OK-29	34.37	0.02	0.12	0.00	0.00	0.19	0.00	0.01	0.01	0.00
OK-30	43.75	0.01	0.00	0.00	0.06	0.03	0.01	0.00	0.01	0.04
OK-31	64.00	0.01	0.00	0.00	0.01	0.03	0.03	0.00	0.00	0.10
OK-32	39.00	0.01	0.00	0.00	0.01	0.18	0.00	0.00	0.01	0.04
OK -33	0.00	0.00	0.00	0.00	0.03	0.31	0.01	0.00	0.01	0.10
OK-34	92.12	0.01	0.02	0.00	0.19	0.27	0.00	0.02	0.09	0.10
OK-35	68.75	0.01	0.03	0.00	0.28	0.53	0.00	0.01	0.15	0.10
OK-36	190.62	0.01	0.01	0.00	0.16	0.12	0.00	0.00	0.20	0.10
OK-37	193.75	0.02	0.18	0.00	0.11	0.29	0.00	0.01	0.26	0.10
OK-38	75.00	0.02	0.06	0.00	0.24	0.20	0.00	0.00	0.24	0.04
OK-39	84.37	0.00	0.06	0.00	1.99	0.22	0.00	0.01	0.12	0.04
OK-40	126.50	0.03	0.04	0.00	0.14	0.29	0.00	0.01	0.26	0.00
OK-41	75.00	0.01	0.08	0.00	0.23	0.29	0.00	0.01	0.05	0.14
OK-42	12.50	0.02	0.12	0.00	0.20	0.27	0.00	0.01	0.07	0.10
OK-43	121.87	0.01	0.06	0.00	0.15	0.20	0.00	0.01	0.04	0.10
OK-44	137.50	0.08	0.41	0.00	0.09	0.20	0.00	0.01	0.06	0.04
OK-45	53.12	0.01	0.02	0.00	0.07	3.98	0.00	0.01	0.09	0.04
OK-46	29.62	0.01	0.03	0.00	0.15	0.31	0.00	0.01	0.14	0.10
OK-47	140.62	0.01	0.03	0.00	0.10	0.37	0.00	0.01	0.11	0.10
Total	1823.95	0.36	1.71	0.00	4.84	9.25	0.30	0.13	1.97	1.80
Average	72.95	0.01	0.06	0.00	0.19	0.37	0.01	0.00	0.07	0.07

Table 13: Pollution Index (Pi) of Metals in Background Soil Samples

	Pollution Index (Pi) of Metals									
Sample ID	Cd	Cr	Cu	Mn	Ni	Pb	Co	Fe	Zn	As
BGS-48	4.62	0.01	0.07	0.00	0.01	0.34	0.01	0.01	0.08	0.10
BGS-49	14.00	0.03	0.04	0.00	0.02	0.31	0.04	0.01	0.10	0.10
BGS-50	20.00	0.01	0.02	0.01	0.20	0.23	0.01	0.01	0.03	0.04
BGS-51	18.75	0.00	0.13	0.00	0.11	0.12	0.01	0.01	0.04	0.04
BGS-52	0.00	0.02	0.03	0.01	0.18	0.20	0.04	0.01	0.00	0.10
BGS-53	3.12	0.02	0.08	0.01	0.18	0.04	0.01	0.01	0.06	0.14
BGS-54	9.00	0.00	0.06	0.00	0.01	0.29	0.00	0.00	0.08	0.14
BGS-55	14.00	0.00	0.00	0.00	0.06	0.43	0.01	0.01	0.05	0.00
BGS-56	14.00	0.00	0.02	0.01	0.17	0.17	0.03	0.01	0.02	0.10
BGS-57	31.25	0.02	0.03	0.00	0.04	0.20	0.05	0.01	0.06	0.04
BGS-58	57.75	0.02	0.00	0.00	0.11	0.15	0.00	0.00	0.05	0.10
BGS-59	59.37	0.00	0.01	0.01	0.17	0.31	0.00	0.01	0.03	0.00
BGS-60	65.62	0.01	0.09	0.00	0.02	0.07	0.01	0.01	0.03	0.04
BGS-61	76.50	0.01	0.10	0.00	0.10	0.37	0.03	0.02	0.09	0.14
Total	**138.23**	**0.15**	**0.79**	**0.05**	**1.38**	**3.23**	**0.25**	**0.13**	**0.72**	**1.08**
Average	**27.73**	**0.01**	**0.03**	**0.00**	**0.09**	**0.14**	**0.01**	**0.00**	**0.05**	**0.07**

Heavy metal pollution in soils is a widely documented problem [Xie et al., 2005]. In Nigeria, many workers have reported high levels of heavy metal ions in the soils, rivers and ground water in different areas [Njoku and Onyeka, 2007] and [Nwajei and Iwegbu,2007]. In order to interpret the level of pollution of metals in soils, only their concentration values are considered [Xie et al., 2005]. The metal concentration results obtained from soils analysis from Onyeama and Okpara Mines are presented in Tables 4, 5 and 6. The soils from Onyeama Mines were characterized by elevated concentrations of Fe (202.50 - 1438.75 mg/kg), Ni (< 1.12 - 18.50 mg/kg), Mn (0.12 - 4.62 mg/kg) and Cd (1.00 - 14.37 mg/kg), and the concentration trend follows the order Fe > Ni > Zn > Cd > Pb > Cr > Cu > Mn > Co > As. The metals from Okpara Mine show, Fe (160.00 - 1625.00 mg/kg), Ni (0.75 - 17.75 mg/kg), Mn (0.12 - 2.88 mg/kg) and Cd (0.00 - 15.50mg/kg) and the concentration trend is the same as in Onyeama Mine, that is, Fe > Ni > Zn > Cd > Pb > Cr> Cu >Mn > Co > As. This similarity suggests that Onyeama and Okpara mines are of the same geologic formation. Mean concentration of Fe from both mines is 756.55 mg/kg. This value, 756.55 mg/kg is considered to be high in soils but it is below the established tolerable 54000mg/kg limit of [Krauskopf, 1979]. The higher (756.55 mg/kg) mean concentration of Fe in soil may indicate that the soil is probably rich in iron oxides. Iron oxides have been established to be good adsorbent of heavy metals such as Cd and Co [Adekola and Saidu, 2005]. Pb was detected (0.37 - 7.25 mg/kg) with mean value of 2.83 mg/kg. The mean 2.83 mg/kg is far below the 19mg/kg tolerable limit set by [Shacklette and Boerngen, 1984] and 100 mg/kg [Kabata-Pendias, 1984]. The source of Pb may be from equipment used by miners for blasting during coal excavation.

Ni (0.75-18.50 mg/kg) with mean value 7.05 mg/kg in soil is higher than what it is in the background soil values- Ni (0.75-11.12 mg/kg) with mean 6.11 mg/kg, but below 50 mg/kg tolerable limits set by [Bowen,1979]. The toxicity of excess Ni present in the soil at the dump sites could possibly account for the scanty and poor growth of weeds at these locations. Nickel is carcinogenic and affects the reproductive health of organism [Finkelman and Zheng, 1999].

Soil pH ranged from 4.5-6.5 and averaged 5.01 in Onyeama Mine Area (Table 4). In Okpara Mine Area (Table 5), soil pH ranged from 4.4-6.5 and averaged 5.01 also, indicating an acid nature [Li and Yang, 2008].

The Enrichment Factors (EF) of soil is presented in (Tables 7, 8 and 9). Table 10 represents the enrichment factor (EF) trend of soil medium in descending order: Cd> Pb > Ni > As > Cu > Zn > Co > Cr > Mn. The data indicate high level of pollution by Cd and Pb according to [Liao et al., 2006] criteria and HRL of 5 and 4 respectively (Table 10). Ni, As, Cu, and Zn moderately polluted the environment with HRL of 3. Co and Cu showed low level of pollution, with HRL 2. Mn has zero risk level, which implies no harmful impact on the soil environment.

Generally, crops cannot grow and flourish in a polluted soil. Increase in salinity of the soil makes it unfit for vegetation, thus making it useless and barren. Yet, if some crops manage to grow, then those would be poisonous enough to cause health problems in people consuming them. Environmental impacts to soils as a result of coal mining activities are associated with erosion and heavy metals Cd, Pb, and Ni contamination.

Characteristics of Background Soil Samples medium

Fifteen (14) background control soil samples were collected at distances between ten and fifteen kilometers away from areas of mining activities. The samples were believed not contaminated as a result of coal mining. Table 6 shows concentrations (mg/kg) of metals determined from the background soil samples. Table 6 shows Cd (<0.37-6.12 mg/kg), Cr (< 1.12-5.12 mg/kg), Cu (0.12-3.75 mg/kg), Mn (0.50-6.37mg/kg), Ni (0.87-11.87 mg/kg), Pb (0.50-4.75 mg/kg), Zn (1.87-7.25 mg/kg), Co (<0.25-1.12mg/kg), As (<0.12 – 0.37 mg/kg) and Fe (587.50 – 1625.00 mg/kg). The concentration sequence in descending order is: Fe >Ni> Zn > Mn > Pb > Cd > Cr > Cu > Co>As. The average values of these metals (Table 6), are Cd (2.18 mg/kg), Cr (1.19 mg/kg), Cu (1.44 mg/kg), Mn (3.20 mg/kg), Ni (6.11 mg/kg), Pb (2.59 mg/kg), Zn (4.41 mg/kg), Co (0.43 mg/kg), As (0.19 mg/kg) and Fe (1088.00 mg/kg).

Cr, Mn, Co and As were below detectable limits in some locations. Average concentrations of these metals, Cr (1.17 mg/kg), Mn (3.20 mg/kg), Co (0.43 mg/kg) and As (0.19 mg/kg), were very low when compared with established limits of [Rudmick and Geo, 2003], [Shacklette and Boerngen, 1984] and [Bowen, 1979]. They therefore pose no risk to health and the environment.

Table 9 shows the enrichment factors (EF) in background soil and Table 10 indicates the enrichment trend of the metals in this order: Cd > Pb > Ni > As > Zn > Cu > Cr >Fe> Co > Mn.

Fe, and Mn have zero health risk ratio (HRL) and indicate pollution condition as absent according to [Liao et al.,2006]. Co and Cr, each has HRL of 2 and this indicates low level pollution condition. Ni, As, Zn and Cu are at intermediate levels of pollution with HRL of 3. Cd and Pb show respective HRL of 5 and 3 .Their pollution levels is considered high.

IV. Conclusions

Soil medium is highly polluted by Cd and Pb with HRL of 5 and 4 respectively. Ni, As, Cu and Zn moderately contaminated the soils with HRL of 3. Co and Cr indicated low level of pollution (Table 10). Fe and Mn show zero HRL, indicating no contamination by the two metals.

`Metal enrichment factor (EF) trend (Table 10) for background soil medium shows high pollution level for Cd and Pb. Their health risk levels are 5 and 3 respectively. Ni, As, Zn and Cu indicate intermediate levels of pollution with HRL of 3. Co and Mn indicate zero HRL. This, according to [Liao et al., 2006], Co and Mn pollution condition is absent.

Comparatively, metal concentrations are generally higher in the soils of Onyeama and Okpara mines than in background control soil samples. It is suspected that there is leachates import from the overlying coal waste dumps into the soil and selective leaching of these metals from their concentration trends (Table 10). Fe concentration (587.50 – 1451.25 mg/kg) and average 1088.00 mg/kg in the background soil was notably higher than those in Soil (175.00 – 1656.25 mg/kg) with 756.55 mg/kg average. The difference may be due to the nature of anthropogenic activities within the undisturbed background soil. Coal mining in Onyeama and Okpara mine areas caused a number of harmful effects on the ecological, geological, agricultural, and general impacts on the environment. It has impacted on the existing flora and fauna community in general. The lands are losing their productivity potential with the passage of time. Consequently, the ecosystem suffers not only disequilibria but also pronounced degradation on the food chain [Adepelumi et al., 2006]. According to [Liao et al., 2006], combined action of oxygen, acidic leachates and low pH, considerable concentrations of hazardous elements (Cd, Ni, Cr, Pb) released contaminate soil, surface and underground waters and endangering the quality of the ecosystem. The effects of pollution on soils are quite alarming. Heavy metals concentrations investigated in this work show that, the study area has been highly polluted by Cd and Pb. but moderately polluted with respect to Ni, As, Cu, Zn and Co. Soil pollutants would bring in alteration in the soil structure, which would lead to death of many essential organisms in it [Chem et al., 2005]. This would affect the larger predators and compel them to move to other places, once they lose their food supply. Generally, crops cannot grow and flourish in a polluted soil.

In conclusion, interpretation of all the field and geochemical data reveal that soils around the Enugu coal mines exhibit characteristics that moderately affect the environment and therefore, there is health safety risk. The coal mines contain considerable amounts of oxidizable and toxic elements. Therefore, production of and migration of acidic leachates that may contaminate soil, surface and underground water is expected to take place for a prolonged time.

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