Assessment of the Physicochemical Characteristics and Potentially Toxic Metals in Soils at Agbara Industrial Estate, Ogun State, Nigeria

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Abstract
This study investigated the impact of industrial activities on the physicochemical characteristics and potentially toxic metals (PTMs) of the soil samples around Agbara Industrial Estate, south-western Nigeria. The pH, organic matter, mechanical properties (% sand, % clay and % slit) and PTMs (Ni, Co, Cu, Fe, Pb, Cr and Cd) of the surface soil samples were determined using standard methods. Pollution was assessed by the contamination factor (CF), pollution load index (PLI), and geoaccumulation index (I_{geo}). The results showed that the pH and organic matter ranged from 5.98–6.24 and 2.12–4.01, respectively. The soil samples were sandy and the concentrations (mg/kg) of the PTMs were Ni (5.89 ± 0.84); Co (4.34 ± 1.00); Cu (9.86 ± 0.89); Fe (14100 ± 2500); Pb (14.4 ± 2.00); Cr (19.1 ± 1.80) and Cd (0.84 ± 0.30). The levels of Ni, Co, Cu, Fe and Cd in the samples were significantly different to those of the control soil. The CF revealed moderate contaminations for Ni, Pb and Cd while the other metals had low contaminations. PLI < 1 indicated a baseline of pollution of the metals and the I_{geo} suggested no pollution to moderate pollution of the metals.
The soil samples in and around the Industrial Estate were moderately contaminated as a result of the industrial activities therein and could pose a serious threat to humans and the environment.

Keywords: contamination factor, pollution load index, potentially toxic metals, soil

Introduction

Rapid industrialisation is vital to a nation's socio-economic development and has the potential to help achieve a variety of social objectives, such as: employment, poverty eradication, gender equality, labour standards and greater access (Singh and Singh, 2007). However, such indiscriminate growth has subjected soils and the environment in general to increased toxic substances, giving rise to soil pollution and environmental deterioration. Industrial pollution is a major source of pollution in most of the developed world (Adebisi and Fayemiwo, 2010).

In the USA, for instance, the industry is the chief source of pollution, accounting for more than half the volume of all water pollution and for the most deadly pollutants. Some 370,000 manufacturing facilities use large quantities of freshwater to remove wastes of different kinds. The waste-bearing water or effluent is discharged into streams, lakes or oceans, which in turn disperse the polluting substances (The Columbia Electronic Encyclopedia, 2012). In developing nations, such as Nigeria, the location of industries is determined by various criteria; some of which are environmentally unacceptable thereby posing serious threats to public health. Although, in the developed industrialised countries, environmental regulations and new technologies are reducing the environmental impact per unit produced, industrial activities and the growing demand for goods are still putting pressure on the environment and natural resources base (Jain *et al*., 2005).

Industrial pollution is the major source of soil pollution (Venkatasubramani and Meenambal 2007). There are different kinds of industrial pollution affecting land: construction debris, petrochemical transportation from transport and fuels, chemicals and potentially toxic metals (PTMs) (Sundar *et al.*, 2010). Industrial wastes and emissions contain toxic and hazardous substances, which include PTMs and toxic organic chemicals, such as: pesticides, dioxins, polychlorinated biphenyls (PCBs), polyaromatic and phenolic compounds. Soils are the major sinks for the PTMs released into the environment by the aforementioned anthropogenic activities and unlike organic contaminants, which are oxidised, metals do not undergo microbial or chemical degradation and persist in soils for a long time after their introduction (Anjal *et al.*, 1987).

The pollution of soils by PTMs has attracted a lot of research work these past few decades. Soils may become contaminated by the accumulation of PTMs and metalloids through emissions from the rapidly

expanding industrial areas, mine tailings, disposal of high metal wastes, leaded gasoline and paints, land application of fertilisers, animal manures, pesticides, sewage sludge, coal combustion residues, wastewater irrigation, spillage of petrochemicals and atmospheric deposition (Nouri *et al.*, 2009).

PTMs constitute an ill-defined group of inorganic chemical hazards and those most commonly found at contaminated sites include: lead (Pb), chromium (Cr), arsenic (As), zinc (Zn), cadmium (Cd), copper (Cu), mercury (Hg) and nickel (Ni) (Wang *et al.*, 2005). The removal of heavy metals from polluted soils is difficult. Once deposited, certain metals, such Pb and Cr may become permanent (Adriano, 2003). Oil spills on soils by industries to cut cost or by accidental leakages also increase soil contamination in the industrial areas (Azumi and Bichi, 2010).

The Agbara Industrial Estate is a large industrial city in Ogun State, south-western Nigeria with different manufacturers in food, plastics, bleaches, glassware, pharmaceuticals and drinks, etc. To the best of our knowledge, no comprehensive report is available on the PTMs pollution of the soils in and around the Estate. In this study, efforts were made to evaluate the levels of PTMs, mechanical properties, organic carbon, organic matter and pH of the soils in the Estate and to assess the levels of pollution, with the aid of contamination factor (CF), pollution load index (PLI) and geoaccumulation index (I_{geo}). This study also uses multivariate analysis for the data obtained.

Materials and Methods

Study Area

The Agbara Industrial Estate is located along the Lagos–Badagry expressway ($6^{o}30'28"$ N and $3^{o}5'37"$ E). It is an area of lowland behind the swamp of the Ologe Lagoon. The Estate lies at the boundary of Ogun State with Lagos State. It is approximately 50 feet above sea level; gently sloping into River Owo and the swamp areas to the south and east, respectively, and undulating to the north and west. A brief description of the sampling stations selected for this study is recorded in Table 1.

Sample Collection and Preservation

Soils were randomly collected, biweekly, along major roadsides in the Agbara Industrial Estate over a period of 3 months (May–July, 2012) from 5 different sampling stations and a sixth sample from a region outside the Estate as a control point. 4 samples were taken from each station and mixed at the laboratory to make composites. All soils were sampled at the top surface (0–15 cm in depth) using a soil auger. The soil samples were collected in polythene containers and labelled. To avoid contamination, disposable gloves were worn during soil sampling. The soil samples were air-dried for about 3–5 days, homogenised and then sieved through a 2 mm mesh-sized sieve. The samples were them stored at room temperature prior to analyses.

pH Analysis

The pH of the samples was determined using a pH meter (Hanna model HI96304). 20 g of soil samples was weighed into a 20 mL of water (1:1). The mixture was stirred and allowed to stand for 30 minutes; stirring occasionally with a glass rod. The pH reading was taken by inserting the calibrated meter probe into the partly settled suspension without stirring during measurements. The results were recorded as soil pH measured in water.

Analyses of Potentially Toxic Metals

For the PTMs analyses, 5 g of samples were digested in 20 mL of freshly prepared aqua regia (HNO_3:HCl; 1:3) on a water bath for about 2 hours and allowed to cool. The digested samples were then filtered and made up to 25 mL with deionised water and stored in sterilised polyethylene/plastic containers. The metals in the soil samples were analysed using an Atomic Absorption Spectrometer (Perkin Elmer, Model A Analyst 200, Waltham, USA). Soil mechanical analysis was done by the Bouyoucos hydrometer method (Gee and Bauder, 1979) and organic carbon content in soil by the Nelson and Sommers' (1996) method.

Assessment of the PTMs' Contamination Levels

Contamination Factor (CF)

The level of contamination of the soil by a metal is expressed in terms of the contamination factor (CF) calculated as:

$$\mathrm{CF} = \frac{C_m\ sample}{C_m\ background} \qquad (1)$$

C_m is the concentration of the metal (mg/kg) in the sample and background/control.

Where CF < 1 = low contamination, $1 \leq \mathrm{CF} < 3$ = moderate contamination, $3 \leq \mathrm{CF} \leq 6$ = considerable contamination and CF > 6 = very high contamination.

Pollution Load Index (PLI)

Each site was evaluated for the extent of metal pollution by employing the method developed by Thomilson *et al.* (1980), based on the pollution load index (PLI) as follows:

$$\mathrm{PLI} = (\mathrm{CF}_1 \times \mathrm{CF}_2 \times \mathrm{CF}_3 \times \mathrm{CF}_4 \times \ldots \mathrm{CF}_n)^{1/n} \qquad (2)$$

Where *n* is the number of metals studied (*n* = 8 in this study) and CF is the contamination factor.

Table 1: Global Position System Location and Description of Sampling Points of Soils at Agbara Industrial Estate

Sample Code	Composite Sampling Points	GPS Location		Description
SAM	SAM_1	Lat:6°30.0731' N	Long:3°5.4905' E	This marks the entrance to the Estate.
	SAM_2	Lat:6 °30.2714' N	Long:3°5.4805' E	
	SAM_3	Lat:6 °30.1710' N	Long:3°5.4592' E	
	SAM_4	Lat:6 °30.1040' N	Long:3°5.4692' E	
SAB	SAB_1	Lat:6°30.6590' N	Long:3°5.4829' E	The banking area of the Estate.
	SAB_2	Lat:6°30.0460' N	Long:3°5.4240' E	This area is surrounded by industries:
	SAB_3	Lat:6°30.5680' N	Long:3°5.3612' E	plastics, glass, food and household items,
	SAB_4	Lat:6°30.2900' N	Long:3°5.3115' E	such as bleach and toileteries
SAE	SAE_1	Lat:6°30.4343' N	Long:3°5.0405' E	This point is towards the far end of the
	SAE_2	Lat:6°30.7724' N	Long:3°5.4711' E	Estate. It consists of pharmaceutical and
	SAE_3	Lat:6°30.4245' N	Long:3°5.4425' E	food industries.
	SAE_4	Lat:6°30.3837' N	Long:3°5.4616' E	
SAN	SAN_1	Lat:6°30.1920' N	Long:3°5.2835' E	A part of the Estate with sites such as
	SAN_2	Lat:6°30.1699' N	Long:3°5.3023' E	food and plastic industries. Other
	SAN_3	Lat:6°30.0863' N	Long:3°5.3023' E	anthropogenic activities such as repairs
	SAN_4	Lat:6°30.0448' N	Long:3°5.3263' E	of transportation trailers takes place in this area causing oil spills on the soil.
SAR	SAR_1	Lat:6°30.2758' N	Long:3°5.2944' E	A residential area in the Estate.
	SAR_2	Lat:6°30.3377' N	Long:3°5.2364' E	
	SAR_3	Lat:6°30.3143' N	Long:3°5.1799' E	
	SAR_4	Lat:6°30.3411' N	Long:3°5.1423' E	
SAC	SAC_1	Lat:6°30.5145' N	Long:3°5.3845' E	This area is located outside the Industrial
	SAC_2	Lat:6°30.5114' N	Long:3°5.3245' E	Estate – a remote area. This is the control.
	SAC_3	Lat:6°30.4724' N	Long:3°5.3378' E	
	SAC_4	Lat:6°30.4743' N	Long:3°5.3255' E	

The PLI provides a simple but comparative means of assessing the quality of the sites, where PLI < 1 is for perfection; PLI = 1 indicates that only baseline levels of the pollutants are present and PLI > 1 indicates a deterioration of site quality (Thomilson *et al.*, 1980).

Geoaccumulation Index (I_{geo})

The enrichment of metal concentrations above baseline concentrations was calculated using the method proposed by Muller (1969); termed the geoaccumulation index (I_{geo}). This method assesses metal pollution in terms of 7 enrichment classes (0 to 6), ranging from background concentration to heavily polluted, as follows:

$$I_{geo} = log_2 \frac{C_m\ sample}{1.5\ x\ C_m\ background} \qquad (3)$$

A factor of 1.5 was introduced into the equation (3) to minimise the effect of possible variations in the background values, C_m *background*, which may be attributed to lithogenic variations in the soils. The 7 proposed descriptive classes for I_{geo} values are given in Table 2 (Muller, 1969).

Quality Control

Quality control measures were observed and analytical grade chemicals were also used. Reference standard material (GLAURM) was done. The results obtained showed no significant difference in the certified reference values for the metals and the measured values (at 95% confidence limit) indicating a good quality control and data validation.

Table 2: The I_{geo} Classes with respect to Soil Quality

I_{geo} value	I_{geo} class	Designation of soil quality
> 5	6	Extremely contaminated
4–5	5	Strongly to extremely contaminated
3–4	4	Strongly contaminated
2–3	3	Moderately to strongly contaminated
1–2	2	Moderately contaminated
0–1	1	Uncontaminated to moderately contaminated
0	0	Uncontaminated

Source: Muller, 1969

Statistical Analysis

In order to study the characteristics of the surface soils, the data obtained were subjected to correlation analysis, Principal Component Factor Analysis (PCA) and Hierarchical Cluster Analysis (HCA) by IBM SPSS Statistics 19 and Past 3 to determine the association and differences in concentrations between different sampling points.

Results and Discussion

The results of the levels of physicochemical parameters and PTMs in the soils around the Estate

are represented in Tables 3 and 4, respectively. It can be seen that the metal pollution load varies with different sampling points due to varying industrial activities. The results of this study suggest diverse sources of metals in the Estate, with iron showing the highest level of contamination at all the sampling points. The pH of the soils and % organic matter varied from 5.98–6.24 and 2.12–4.01, respectively. The soil pHs did not show dastic differences between sampling stations and the control area (Table 3).

The sampling points: SAN and SAE (see Table 3) gave the maximum and minimum % organic matter, respectively. The % organic matter was relatively low in all the soils around the Estate compared to similar work done by Etim and Onianwa (2013) on soils around an industrial site. The relatively low % organic matter indicates that the discharge of organic pollutants by the industries is minimal.

Table 3 also shows the mechanical characteristics of the soil samples. The particle sizes of the soils ranged from 76.6–83.9 for % sand, 8.45–10.9 for % clay and 7.7–10.6 for % silt. The sampling points with the highest sand percentile have the lowest heavy metal concentration and the higher the clay percentile, the higher the metal concentration in the soil. Results in Table 3 show that the sampling point SAE had the lowest percentile of sand particles and the highest percentile of clay particles and agree with the reason for the high levels of metals. All the sampling points showed high % sand and could be said to be medium sandy. Medium sandy-textured soils have lower organic matter due to their poor ability to support vegetation. This observation correlates with the observed low organic matter in the soils (Table 3).

The concentrations (mg/kg) of the PTMs in the soil samples around the Estate are given in Table 4 and varied thus: Cd (0.52–1.21), Cu (9.1–11.2), Cr (17.5–21.6), Fe (11,000–17,000), Co (2.9–5.4), Ni (5.7–6.1) and Pb (10.7–16.8). The maximum and minimum levels of PTMs were, respectively, at sampling points SAB and SAR for Cd, SAE and SAM for Cu, SAB and SAM for Cr, SAE and SAB for Fe, SAE and SAM for Ni, and SAB and SAR for Pb (Table 4).

The soil Pb levels in the areas studied were higher than those reported by Aktaruzzaman *et al.* (2013) on the soil samples around Dhaka Aricha Road, Savar, Bangladesh with coordinates Lat. 23 °39′69″ N and Long. 91.25′63″ E (7.31 ± 5.04 mg/kg) whereas the industrial soil area of Dhaka, Bangladesh, with coordinates Lat. 23°42′ N and Long. 90°22′ E (49.71 mg/kg) as reported by Jasim and Abdul (2010) and the soils of Gazipur, Bangladesh, with coordinates of Lat. 23°59′20″ N and Long. 90°22′30″ E at 54–59 mg/kg; reported by Habib *et al.* (2009) were higher than those of the Agbara Industrial Estate. A similar study by Inuwa *et al*. (2007) reported a high level of Pb in soils around major industrial areas in north-western Nigeria with a range of 152–540 mg/kg.

The Cr levels reported by Aruleba and Ajayi (2012) for the soils in Ado-Ekiti, south-western Nigeria (21.51 mg/kg); urban soils (54.9 mg/kg) of Hong Kong by Li *et al.* (2001); industrial soils in north-western Nigeria (14.2–92.7 mg/kg) by Inuwa *et al.* (2007) and urban soils and roadside dust of China (159.3 mg/kg) by Shi *et al.* (2008) were higher than the studied area.

The soil Cd levels reported by Inuwa *et al*. (2007) in

Table 3: Physicochemical Parameters of Soils in Agbara Industrial Estate

Site Code	pH	% Organic Carbon	% Organic Matter	% Sand	% Clay	% Slit
SAM	5.98 ± 0.08	1.99 ± 0.52	3.43 ± 0.91	78.9 ± 7.1	10.9 ± 1.9	10.2 ± 5.9
SAB	6.00 ± 0.15	1.85 ± 0.50	3.42 ± 0.41	81.4 ± 7.1	8.9 ± 1.6	8.1 ± 2.3
SAE	6.24 ± 0.09	1.24 ± 0.37	2.12 ± 0.63	76.6 ± 6.9	10.9 ± 2.6	10.5 ± 5.3
SAN	5.98 ± 0.08	2.32 ± 0.29	4.01 ± 0.53	83.9 ± 2.1	8.4 ± 1.1	7.7 ± 1.6
SAR	6.08 ± 0.08	1.57 ± 0.38	2.71 ± 0.66	77.9 ± 3.0	8.5 ± 1.0	8.5 ± 3.1
SAC	6.02 ± 0.15	1.65 ± 0.50	2.81 ± 0.89	78.3 ± 5.1	9.5 ± 1.4	8.7 ± 2.5

Table 4: Concentrations (mg/kg) of Potentially Toxic Metals (PTMs) in Soil Samples in Agbara Industrial Estate

Site Code	Ni	Co	Cu	Fe	Pb	Cr	Cd
SAM	5.66 ± 1.5	4.17 ± 0.9	9.12 ± 1.9	15700 ± 450	14.86 ± 2.9	17.46 ± 2.9	0.97 ± 0.2
SAB	5.98 ± 1.5	2.90 ± 0.7	9.93 ± 3.2	11000 ± 3700	16.83 ± 6.7	21.56 ± 6.7	1.21 ± 0.5
SAE	6.09 ± 1.7	4.90 ± 1.2	11.2 ± 2.2	17100 ± 5200	11.69 ± 2.6	18.50 ± 4.6	0.57 ± 0.2
SAN	5.80 ± 1.7	5.39 ± 1.9	9.22 ± 2.7	12600 ± 2700	14.02 ± 3.3	18.80 ± 2.9	0.62 ± 0.2
SAR	5.71 ± 1.6	4.27 ± 1.1	9.38 ± 2.3	14100 ± 4600	10.69 ± 2.8	18.09 ± 2.8	0.52 ± 0.1
SAC	4.30 ± 1.3	5.77 ± 1.5	11.0 ± 2.2	14500 ± 1300	14.18 ± 2.9	19.64 ± 2.2	0.59 ± 0.1

soils around major industrial areas in north-western Nigeria (0.1–0.7 mg/kg) and roadside soils in Botswana (0.02 mg/kg) by Mmolawa *et al*. (2011) were lower than those obtained in this study. However, the study by Aruleba and Ajayi (2012) and Demirezen and Aksoy (2006) of the soils of Ado-Ekiti, south-western, Nigeria (2.8 mg/kg) and urban soils of Hong Kong (2.73 mg/kg), respectively, reported higher values for Cd.

This present study also found lower concentrations of Cu compared to the soil of Gazipur, Bangladesh (55–65 mg/kg), reported by Habib *et al.* (2009) and by Etim and Onianwa (2013) on soils around an industrial site in south-western Nigeria (5.10–131 mg/kg). Co (4.3 mg/kg), in this study, was much lower than the corresponding value of 17.6 mg/kg on soils around an industrial site in south-western Nigeria. The Ni levels in this study was also lower than the value obtained in similar studies by Inuwa *et al*. (2007) (3.5–24.7 mg/kg) and Etim and Onianwa (2013) (3.83–71.0 mg/kg). The Fe levels in the study by Ezejiofor *et al*. (2013) reported a value of 784 ± 45 mg/kg; this is lower than the natural concentration ranging between 3000–5000 mg/kg (Awokunmi *et al*., 2010). However, the Fe levels (14100 ± 2500 mg/kg) in this study were higher than the natural concentration.

The results of the PTM levels in the soils analysed were compared with the soil quality parameters from other countries as shown in Table 5. It was observed that the levels of the PTMs analysed were lower in the soils studied compared to other countries'. However, the Fe levels were significantly higher in the studied soil areas compared to other countries'. Awokunmi *et al*. (2010) and Elias and Gbadegesin (2012) also reported high Fe levels in Nigerian soils.

The level of significant difference at $p = 0.05$ was tested between the metal contents of the sampling points and that of the control. There was a significant difference between the control soil and sampling points SAM, SAB and SAR in the Co content while the Cu levels were significantly different between the control soil and SAM, SAB, SAN and SAR sampling points, respectively. The levels of Pb and Cr were also significantly different between the control soil and SAB, SAE and SAR while it was only different for Cr in SAM. There were no significant differences in the Ni, Cd and Fe contents between the control soil and the sampling points.

Assessment of the Levels of Contamination of the Soils around Agbara Industrial Estate

For a better estimation of anthropogenic input, sampling sites were assessed for their degrees of contamination. Contamination factors (CF), pollution load index (PLI) and geoaccumulation index (I_{geo}) were used for the estimations.

Contamination Factor (CF)

Table 6 shows the soil contamination factors for the Estate. From the CF categories described in equation (1), Ni had moderate contamination for all the sampling points whereas Co and Cu were low in contamination for the sampling points, except for SAE for Cu that was of moderate contamination for sampling point SAE. Fe had moderate contamination for sampling points SAM and SAE while Pb had moderate contamination for SAM and SAB. Cr had moderate contamination for SAB and Cd was moderate in SAM, SAB and SAN sampling points.

Table 6: Contamination Factor (CF) for Potentially Toxic Metals in Soils around Agbara Industrial Estate

PTM	Site Code				
	SAM	**SAB**	**SAE**	**SAN**	**SAR**
Ni	1.32	1.40	1.41	1.35	1.33
Co	0.72	0.50	0.85	0.93	0.74
Cu	0.83	0.90	1.02	0.84	0.85
Fe	1.09	0.76	1.18	0.87	0.98
Pb	1.05	1.19	0.82	0.99	0.75
Cr	0.89	1.10	0.94	0.96	0.92
Cd	1.64	2.05	0.97	1.05	0.88

Pollution Load Index (PLI)

The Agbara Industrial Estate was also evaluated for

Table 5: Soil Quality Criteria for Some Countries Compared with Levels (µg/g) Obtained from this Study

Country		Potentially Toxic Metals (PTMs)						
		Pb	**Cd**	**Fe**	**Cu**	**Cr**	**Ni**	**Co**
Nigeria (Agbara)[1]	Mean	14.4 ± 2.0	0.84 ± 0.30	14100 ± 2500	9.86 ± 0.89	19.1 ± 1.8	5.89 ± 0.84	4.3 ± 1.0
	Range	11–17	0.52–1.21	11000–17100	9.22–11.2	17.5–21.6	5.66–6.09	2.9–5.77
Norway[2]		50	1.0	150	100	100	30	–
Netherland[2]	Action level	530	12	720	190	380	210	240
Switzerland[3]	Guide Value	50	0.8	200	50	–	–	–
Canada[4]	Industrial	600	22	360	91	87	50	–
	Commercial	260	22	360	91	87	50	–
Hong Kong[5]		90	0.9	59	16	–	–	–

Source: [1]This study, [2]Reimann *et al.* (1997), [3]FOEFL (1987), [4]CCME (1999), [5]Chen *et al.* (1997).

the magnitude of PTM pollution, using the PLI developed by Thomilson *et al.* (1980). The soil PTM levels in terms of PLI showed perfection for sampling points SAN and SAR while SAE, SAB and SAM indicated a deterioration of site with the metals studied as shown in Figure 1. The level of PLI is in order of SAM > SAB > SAE > SAN > SAR.

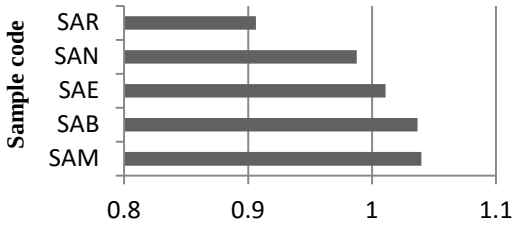

Figure 1: Pollution Load Index (PLI) for the Metals Studied from the Soils in Agbara Industrial Estate

Geo-accumulation Index (I_{geo})

The enrichment of metal concentrations above baseline concentrations was calculated using the method proposed by Muller (1969) (see Table 2).

Table 7 shows the calculated geoaccumulation index (I_{geo}) values. It was evident that the uncontaminated to moderately contaminated I_{geo} values of 0–1 of class 1 was observed in SAM and SAB for Cd with values of 0.13 and 0.45, respectively. The other PTMs analysed had values of $I_{geo} < 1$ for the other sampling positions, which showed non-contamination.

Table 7: Geoaccumulation Index (I_{geo}) for PTMs in Soils in Agbara Industrial Estate

PTM	Site Code				
	SAM	SAB	SAE	SAN	SAR
Ni	–0.19	–0.10	–0.09	–0.15	–0.18
Co	–1.06	–1.58	–0.83	–0.68	–1.02
Cu	–0.85	–0.73	–0.56	–0.84	–0.81
Fe	–0.46	–0.98	–0.34	–0.78	–0.62
Pb	–0.52	–0.34	–0.86	–0.60	–0.99
Cr	–0.75	–0.45	–0.67	–0.65	–0.70
Cd	0.13	0.45	–0.63	–0.51	–0.77

Therefore, as revealed from the three pollution assessment methods used, the soils of SAM, SAB and SAE were pollution-impacted as a result of the high levels of the PTMs studied.

Multivariate Analysis of Potentially Toxic Metals' Distribution in Soils

In order to reduce the relatively large number of variables to a smaller number of orthogonal factors, the original data obtained was processed using multivariate statistical methods. The distribution pattern of individual associations of elements in soils was determined by the Principal Component Factor Analysis (PCA) and Hierarchical Cluster Analysis (HCA).

Table 8: Principal Component Analysis of Soils for Heavy Metal Data in this Study

	PC 1	PC 2
Ni	0.33829	–0.75837
Co	–0.79968	0.39101
Cu	–0.34251	0.67439
Fe	–0.77948	–0.18731
Pb	0.82021	0.34128
Cr	0.71004	0.59434
Cd	0.9183	–0.05196
Eigenvalue	3.49902	1.6903
% of Total Variance	49.986	24.147
Cumulative (%)	49.986	74.13

Table 8 shows the eigenvalues from the PCA of the soils analysed. Based on the eigenvalues, the first two factors with the highest values were used. The two factors explained 74.1% of the total variance. The first factors explained 50.0% of the total variance, which was strongly related to Co, Fe, Pb, Cr and Cd while the second explained 24.1% of the total variance and gave loadings for Cu and Ni as shown in Figure 2.

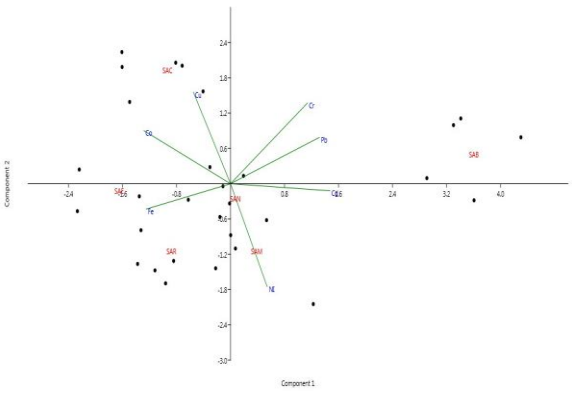

Figure 2: Principal Component Analysis Bi-Plot

The first component, which accounted for the 50.0% variance indicated that the sampling points SAM and SAB had elevated levels of total PTMs. However, the points were not clustered; meaning that there were variations in the PTM levels in the soils for the various points. This could be due to various industrial processes. Sampling points to the left of the origin (SAE, SAR and SAC) indicated high levels of Cu, Co and Fe while the sampling points on the right, from the origin, (SAM and SAB) indicated high levels of Cr, Pb, Cd and Ni.

For the Hierarchical Cluster Analysis (HCA), the soil samples were classified into 3 clusters (Figure 3).

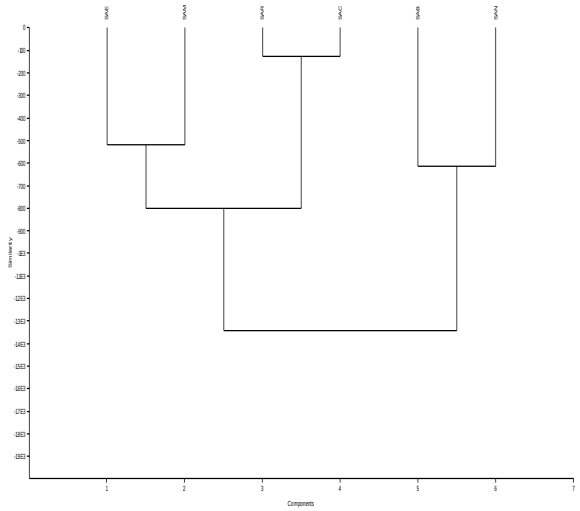

Figure 3: Hierarchical Cluster Analysis Dendrogram for Soil Samples

There were two sites each in clusters I (SAE and SAM), II (SAR and SAC) and III (SAB and SAN). The decreasing pollution order of the PTM concentrations in the soils were cluster I > cluster III > cluster II. From the statistical analysis, it was established that the soil samples from the sampling point SAM had the highest concentration of PTMs.

Table 9 shows the Pearson Correlation Coefficient results between the parameters determined from the soil samples in the Agbara Industrial Estate. There were low positive correlation between Fe and Co (r = 0.389), Fe and Cu (r = 0.364), and Cd and Cr (r = 0.430) while low negative corrections existed between Pb and Co (r = –0.375) at 95% confidence level. At 99% confidence level, there were correlations between Pb and Cd (r = 0.799) and Pb and Cr (r = 0.566).

Conclusions

The purpose of this study was to assess the pollution levels of soils in the Agbara Industrial Estate using pollution indices. There were significant differences in the levels of cobalt (Co), copper (Cu), chromium (Cr) and lead (Pb) between the surface soil samples and the control. The geoaccumulation index (I_{geo}) indicated that the soils, in the Industrial Estate, at sampling points SAM and SAB were uncontaminated to moderately contaminated in cadmium (Cd). The measure of the degree of pollution load index (PLI) at the various sampling points indicated signs of pollution deterioration at SAM, SAB and SAE. The contamination factor (CF) also showed moderate contamination for most of the metals studied for SAM and SAB. The industrial discharges appear to have made minor contributions as sources of heavy metals in this area. A spatial variation in the potentially toxic metal (PTM) levels among the different sampling stations suggests a diverse source of PTMs in the Agbara Industrial Estate. There is, therefore, the need for constant monitoring of these toxic metals by the national environmental agencies.

Table 9: Pearson Correlation Coefficient for Metal Contents of Soils in the Agbara Industrial Estate

	Ni	Co	Cu	Fe	Pb	Cr	Cd
Ni	1						
Co	–0.347	1					
Cu	–0.297	0.280	1				
Fe	–0.044	0.389[a]	0.364[a]	1			
Pb	–0.016	–0.375[a]	–0.128	–0.578	1		
Cr	0.004	–0.319	0.261	–0.631	0.566[b]	1	
Cd	0.134	–0.672[b]	–0.234	–0.448	0.799[b]	0.430[a]	1

[a] Significant at the 0.05 level; [b] Significant at the 0.01 level

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