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Geoenvironmental assessment of the environs of the Aluminium Smelting Company in Ikot Abasi, southeastern Nigeria

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Abstract

The Aluminium Smelting Company, located in Ikot Abasi area, lies within the dominantly clastic rocks of the Benin Formation of the eastern Niger Delta. In order to evaluate the level of environmental contamination associated with this major industrial project, concentrations of trace elements and major elements in representative samples of soil, stream sediments and water in the vicinity of the industrial complex were determined by ICP-OES (for soil and stream sediments) and Atomic Absorption Spectrophotometer (AAS) (for water). Samples from a control site, about 3km from the complex were also collected and analyzed for the same set of elements,

Results revealed that concentrations of all the elements in the sampled materials were within background levels in comparison with those from the control site. The trace and major element variations show some slight decreasing concentration with increase distance from the factory site for mostly Pb, Zn Cu, Ni for the trace elements and Ca for the major element. There is no significant variation in the soil profile with depth for the elements. Generally, concentration of elements is in the order: Zn>Pb>Ni>Cu and Fe>Al>Ca>Mg>Na>K for the trace and major elements respectively.

Computation of geo-accumulation index for the soils revealed no secondary enrichment. Application of R-mode factor analysis shows four groupings, reflecting lithological and environmental controls. The stream sediments show generally low concentrations that fall within the concentration range of sediments of similar provenance elsewhere. Metal concentration levels in the water show higher values for the surface water. Both hydrophysical and chemical parameters have slight elevated values when compared with the control and reflect a dominant geogenic source. Generally, they lie within the ambits of the World Health Organization (WHO) Standards of water quality and pose no threat to aquatic or human community.

Introduction

Consequent to the recent tide of technological development in the challenging global economic climate, most nations have witnessed tremendous growths in industrialization. Nigeria most certainly has its fair share over the last twenty to thirty years as evident in establishment of both large and small scale exploration, production and processing factories across the nation. However, various ecological and human disasters in various parts of the world have been largely connected to industries and their operations as they have turned out to be major contributors to environmental pollution and degradation at various magnitudes. Heavy metals such as Pb, Zn, Cu, Ni and Cr are prominent components of most industrial effluents and emissions and they play key roles in pollution of the ecosystem (Thuy *et al.*, 2000).

Soils, sediments, ground and surface waters in most countries have long been known to be polluted by heavy metals. The highest concentrations of these metals are dominant in vicinities of mining and smelting sites. Instances abound where high amounts of heavy metals and/or toxic substances are found in the vicinity of mining / industrial sites. Zachmann and Block (1993) reported high amounts of toxic elements, notably lead, in soils and sediments around a lead smelting site in Hartz Mountains in Germany. Elueze *et al.,* (2001a) reported concentrations of Pb, Zn, Cu and Cd as potential pollutants in soils, sediments, surface and ground waters in the vicinity of the Exide battery factory in Ibadan, southwestern Nigeria. Yukselen (2002), through soil and water sampling around a copper mining and smelting site in Cyprus, demonstrated that increase in Cu and As levels exceed accepted limits in soils, while the Cr, Ni and Cu concentrations posed threats to marine fauna. Majunatha et al, (2001) showed how Al, Fe, Ni and Co enrichment in soils, suspended particulate matter (SPM) and bottom sediments of Kali River and environs, southwestern coast of India, resulted from anthropogenic activities.

Trace elements and well known toxic ones, such as As, Ag, Cd, Al, etc. are useful to organisms for cell metabolism and maintenance of health (Mertz and Coratzer, 1971). When a measurable deficit in the diet is allowed of some of these trace elements, the growth and vitality of human, animal and plant populations are reduced to a certain degree (Edet *et al.,* 2003). However, some trace elements may result in diverse health effects in circumstances where their presence is not readily assimilated by living organisms. Gasparon and Burgess (1999) have shown that these elements when present in a system, migrate and precipitate, based on their geochemical mobility, and are deposited in different components of the systems. Exposure to these pollutant trace elements results in ailments such as dermatitis, cardiovascular diseases, central nervous system (CNS) disorders, lung, kidney and liver damages, birth defects and cancer (Nriagu, 1990; Merian, 1991; Manahan, 1994).

In order to curb the hazardous effects of these metal concentrations, efforts are regularly geared towards the determination of concentration levels in the environments and thereby institute monitoring for areas where significant anthropogenic inputs are expected from urban, commercial and industrial activities. The Aluminium Smelting

Company of Nigeria (ALSCON), located in Ikot Abasi, southeastern Nigeria (Fig. 1) was established to generate and conserve foreign exchange for the nation. However, the possible direct or indirect impact of its operation cannot be overemphasized.

This study examines the abundance of selected potentially toxic, trace and major elements in the sampled materials and elucidates the spatial distribution patterns as well as the indices of such patterns. Furthermore, the sources of the elements and their distribution patterns will be determined in order to provide a baseline data for the area, especially in the absence of such. This will allow for future monitoring and vulnerability assessment of the area.

Location of study area

The study area lies within Ikot Abasi in southeastern Nigeria and delimited by Longitudes 7°32′ and 7°35′E and Latitudes 4°32′ and 4°36′N. It covers an area of about 4.8sq.km and include the following settlements: Ata, Ikot Essien, Ikpetim and Ikot Udo (Fig. 1). The topography of the area is flat-lying and the major drainage system in proximity to the area is the Imo River, with associated creeks such as the Jaja and Esene. They drain the area with a number of tributaries and the entire streams and channels give a dendritic pattern.

The area belongs to a humid tropical climate with high temperature (annual mean 26°C) and high relative humidity (annual mean 85%). Edet and Okereke (2001) reported high precipitation, averaging 3,855mm annually, which greatly exceeds annual evaporation of 1,680mm with annual recharge of 2,175mm. The area is within the Tropical Rainforest belt, characterized by giant trees, which are stratified. Extensive mangrove forest with dense luxuriant growth is characteristic of tidal flushing areas where several marshlands and shallow waterways have formed. Typical trees in the areas include mahogany, ebony and oil palm, mostly cultivated for economic purposes.

The area belongs to part of the Cenozoic Niger Delta basin (Fig. 2). Generally, the area is devoid of rock exposure apart from the dominant alluvial and beach sands. These represent deposition of materials derived from the continental crust with sources, such as, the Cameroon volcanic ridge, Calabar Flank and the Anambra basin. The topmost exposed sedimentary sequence belongs to the Benin Formation (Oligocene-Recent) of the Niger Delta. The Benin Formation is made up of continental sands and gravels (Short and Stauble, 1967; Edet and Okereke, 2001)

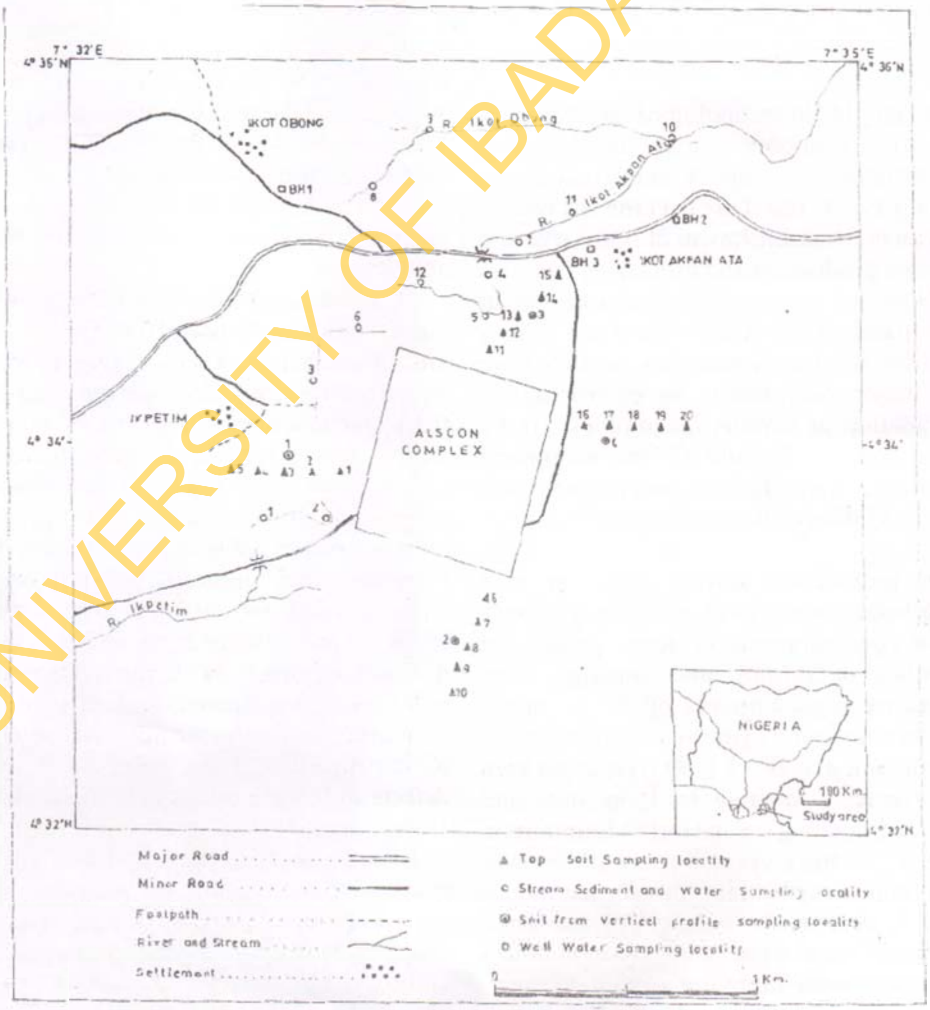


Fig. 1. Map of study area showing sampling points

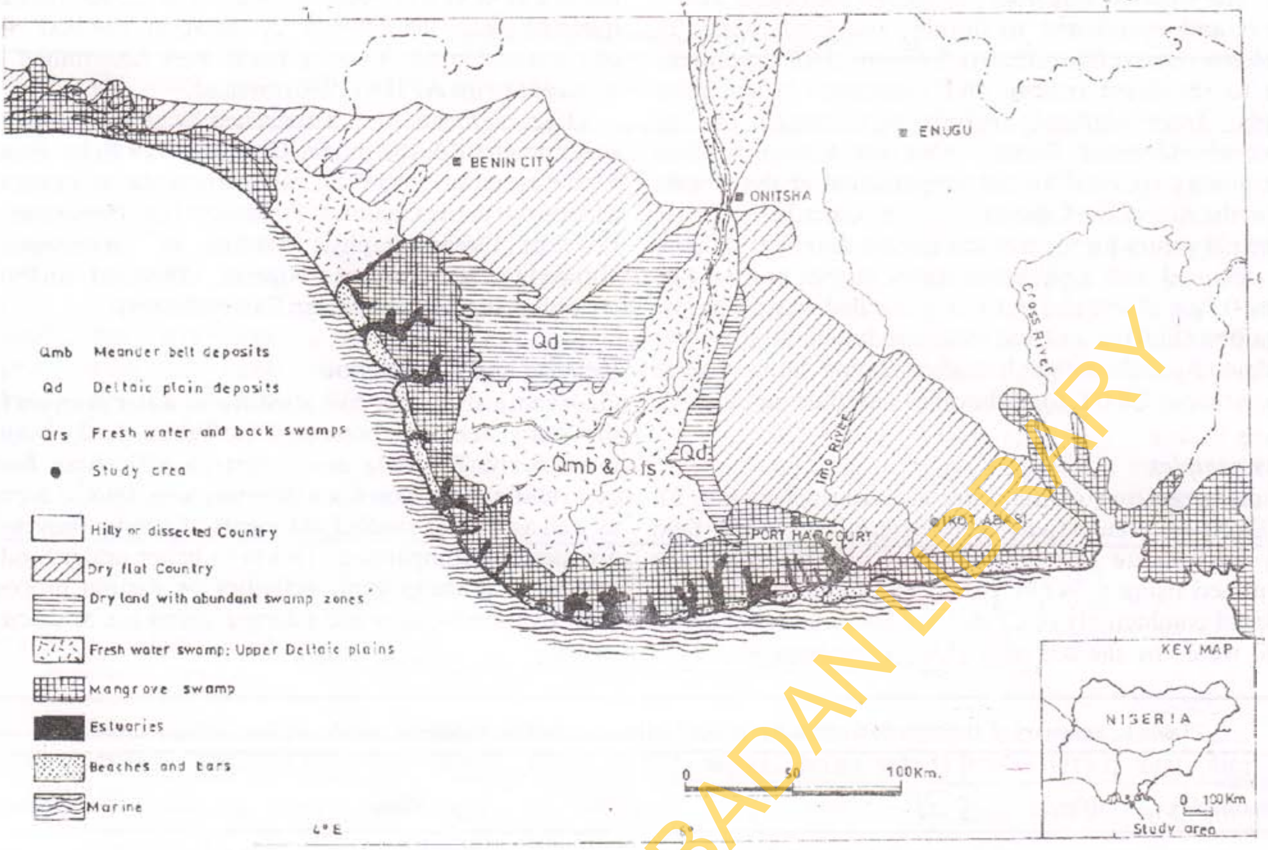


Fig. 2. Facies variations in the Niger delta (After Reijers et al., 1996)

Methods and materials

Sampling

A total of fifty-four (54) samples, made up of 27 (soil), 15 (water) and 12 (stream) sediments including those from the control site (3km from the complex outside the mapped area) were collected for geochemical analysis. Twenty (20) topsoil samples were collected at depth of (0-5cm) and at intervals of 100m along traverse lines in four cardinal directions with reference to the complex (Fig. 1). With this spread, a total of five (5) samples, each weighing 0.5kg were obtained at each location in each direction, and stored in clean polythene bags. Four other samples were collected from vertical profiles in these directions at depth of (15-20cm) to account for possible geochemical variations with depth. Sampling traverse lines and locations were chosen to avoid obstruction in their courses as well as areas proned to inputs not representative of the true nature of samples. Such include areas with thick vegetation cover, undecomposed leaf litter and ensuring a distance of at least 10m away from motored roads to curb the effects of lead emission from vehicle exhaust on the samples.

Twelve (12) stream sediments and fifteen (15) water samples (made up of 12 surface water and 3 groundwater (Fig. 1) were collected from channels within the study area. The sediments were collected by hand scooping and subsequently stored in clean labeled polythene bags prior to treatment and analysis.

The water samples were collected directly using 75cl polythene bottles. Prior to sample collection, the bottles were soaked in 10 % HNO_3 for 24 hours and rinsed several times with deionised water as reported by Edet *et al.*, (2003). The water samples were collected in polythene bottles rinsed with aliquots of the stream water, prior to immersing them well below the surface to collect samples devoid of the top film. This precautionary method was necessary as it has been shown that the top film could be a possible source of heavy metal (Duce *et al.*, 1972). The groundwater samples were collected from hand-dug wells in the vicinity of the study area. The samples were later acidified to pH ca. 2 with 0.5ml concentrated HNO^3 and stored at a temperature of 4°C prior to hydrochemical analysis.

The soil and stream sediment samples were air dried and disaggregated in a porcelain mortar using a rubber-end pestle. A nylon sieve was used to obtain <63μm fraction of the sediments for further chemical analysis.

Geochemical analyses

Soil and stream sediments

About 0.5g of the active fraction (<63μm) of soil and stream sediments were subjected to geochemical analysis. An initial digestion using the Heinrichs and Hermann (1990) method was applied. This involved reaction of the samples with a combination of concentrated $HF-HNO^{3-}HCl$ acids. The solution was then transferred into clean Teflon beakers and evaporated to dryness on a hot plate. To completely remove fluoride ions, 5ml conc. HCl were added twice to the dried residue and evaporated to incipient dryness. Trace element analysis was carried out by Inductively Coupled Plasma -Optimal Emission Mass Spectrometry (ICP-OES). All instrumental analyses were done at the Activation Laboratories Ltd., Canada.

The pH values for the soil and stream sediment samples were obtained with a pH meter from slurries prepared by mixing 0.5gm of samples in 10ml of distilled water. The loss on ignition (LOI) of soil and stream sediment samples was calculated from the weight loss after heating the samples to temperature of 1000°C for 24 hours in a muffled furnace.

Water samples

Physical parameters of the water samples such as pH, Eh and Electrical conductivity were determined in the field using appropriate instruments. The pH and Eh were determined using a WTW pH meter. Determinations of Electrical conductivity (EC) and the Total dissolved solids (TDS) were by the use of a HACH conductivity/ TDS meter, model 44600 while Turbidity was determined by the use of a HACH spectrophotometer model, DR/3000.Total hardness was determined by titration method while calcium and magnesium contents were determined with reference to the APHA (1980) method.

Other elements were determined by atomic absorption spectrometry (AAS) model Unicamp 919 Solar System: Flame atomisation (1992). All instrumental analyses were carried out at the Chemical Pollution Unit, Department of Physical Oceanography, Institute of Oceanography, University of Calabar, Nigeria. Detailed analytical procedure can be consulted in Ekwere (2004).

Results and Discussion

Geochemical data for soil, stream and water samples from the study area are presented in Tables 1, 2, 3 and 4 respectively. The data are compared with those from a control site about 3km from the study area. Global averages as well as data of studied sediments of similar provenance are used for comparison. This is to better understand the impact of anthropogenic activities on natural processes. Statistical deductions and interpretations are as discussed below.

Table 1. Summary of elements concentrations in the Top soils around the industrial complex in four cardinal directions

Distance from complex	100m		200m		300m		400m		500m		Control
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Mean
Zn (ppm)	33-59	47.75	33-57	46.50	36-44	39.75	35-38	36.75	31-39	35.25	36
Cu (ppm)	3-9	6.50	5-9	7.00	3-8	5.50	6-9	7.00	4-11	7.25	4
Pb (ppm)	10-23	16.25	9-24	15.25	11-20	14.50	13-18	14.25	13-17	15.25	20
Ni (ppm)	6-21.5	12.13	5-20	10.75	7-15	10.0	6-17	11.25	7-13	10.75	17
Ca (%)	0.09-0.52	0.22	0.09-0.43	0.22	0.09-0.37	0.18	0.06-0.22	0.11	0.03-0.20	0.095	0.025
Mg (%)	0.03-0.12	0.07	0.03-0.09	0.07	0.03-0.06	0.05	0.04-0.07	0.06	0.02-0.09	0.053	0.07
Fe (%)	1.34-5.07	2.52	1.37-4.63	2.38	1.63-3.43	2.29	2.04-3.20	2.55	2.16-3.32	2.74	2.215
K (%)	0.03-0.13	0.070	0.02-0.11	0.06	0.03-0.07	0.06	0.05-0.09	0.07	0.05-0.11	0.070	0.095
Na (%)	0.013-0.0215	0.019	0.02-0.021	0.02	0.013-0.020	0.02	0.012-0.027	0.02	0.015-0.046	0.025	0.066
Al (%)	0.96-4.26	2.28	1.22-3.54	2.12	1.86-2.92	2.30	1.92-2.88	2.35	2.17-2.81	2.548	3.245
LOI (%)	4.2-6.8	5.78	4.6-8.4	6.15	4.2-8.2	6.65	5.4-7.2	6.50	6.2-9.8	7.15	6.4
pH	5.9-6.7	6.4	6.1-6.5	6.3	6.1-6.5	6.40	6.3-6.7	6.40	5.9-6.7	6.2	6.6

Table 2. Concentrations of elements with depth (15-20cm) in soils around the factory

Elements	North	South	East	West	Control (mean)
Zn (ppm)	33	40	41	58	44
Cu (ppm)	8	6	5	12	13
Pb (ppm)	20	22	20	27	22
Ni (ppm	12	20	24	28	22
Ca (%)	0.16	0.04	0.02	0.02	0.04
Mg (%)	0.05	0.08	0.07	0.09	0.09
Fe (%)	2.01	4.70	4.54	5.36	3.09
K (%)	0.05	0.06	0.08	0.13	0.09
Na (%)	0.039	0.033	0.032	0.032	0.029
Al (%)	1.92	4.14	5.09	6.05	3.77
LOI	4.0	4.2	3.8	5.4	4.8
pH	6.1	5.9	6.0	5.7	6.2

Table 3. Data for Stream sediment analysis

Parameter	SDI	SD2	SD3	SD4	SD5	SD6	SD7	SD8	SD9	SD10	SD11	SD12	Range	Mean	Control (Mean)
Zn(ppm)	111	132	48	62	67	52	74	160	72	65	66	42	42-160	79.25	117
Cu (ppm)	14	11	8	13	22	7	14	37	23	11	11	23	7-37	16.42	8
Pb (ppm)	20	22	23	25	30	23	11	29	21	23	14	24	11-30	22.42	8
Ni (ppm)	14	16	17	14	14	16	18	27	16	17	9	13	9-27	15.92	11.5
Fe (%)	8.61	6.82	11.20	10.82	7.94	13.10	6.70	5.10	4.4	5.2	2.83	7.80	2.83-13.10	7.85	0.075
Ca (%)	0.46	0.52	0.25	0.63	0.52	0.23	0.37	0.40	0.24	0.26	0.24	0.23	0.23-0.063	0.40	0.225
Mg (%)	0.09	0.18	0.08	0.10	0.07	0.08	0.09	0.21	0.10	0.08	0.09	0.12	0.07-0.21	0.12	0.085
Na (%)	0.047	0.051	0.067	0.074	0.066	0.070	0.043	0.431	0.065	0.043	0.040	0.038	0.038-0.431	0.085	0.065
K (%)	0.08	0.09	0.08	0.07	0.05	0.10	0.10	0.16	0.07	0.08	0.08	0.06	0.05-0.16	0.094	0.070
Al (%)	2.94	2.56	3.02	2.84	2.46	3.37	2.40	2.25	2.11	2.14	1.29	2.18	1.29-3.37	2.48	1.71
LOI(%)	4.60	5.40	5.80	6.20	4.60	5.00	4.20	7.40	5.10	4.60	6.30	5.60	4.2-7.4	5.47	5.4
pH	6.50	6.30	6.70	6.80	6.50	6.60	6.80	6.80	6.40	6.30	6.50	6.90	6.3-6.9	6.64	6.6

Table 4. Hydro physico-chemical parameters for both surface and groundwater

Parameter	WTS1	WTS2	WTS3	WTS4	WTS5	WTS6	WTS7	WTS8	WTS9	WTS10	WTS11	WTS12	BH1	BH2	BH3
EC (μs/cm)	121.3	116.8	115.7	166.2	142.3	207	260.3	365.5	165.2	170.3	416.7	338.6	60.6	103.1	242.4
pH	6.25	6.45	6.63	6.56	6.97	6.41	6.76	6.54	6.80	6.54	6.79	6.75	6.45	6.59	6.53
Eh	0.24	0.14	0.18	0.13	0.44	0.30	0.56	0.93	0.43	0.43	0.33	0.43	0.12	0.32	0.21
TDS (mg/l)	60.65	58.40	57.85	83.10	71.15	103.7	130.1	181.7	82.60	85.15	208.3	169.3	30.3	51.55	121.2
Turb (FTU)	6.0	57.85	12	3	16	7	0	43	32	29	11	2	108	3	0
Fe (ppm)	0.551	0.217	0.144	0.759	0.765	0.150	1.671	1.925	0.643	0.113	1.449	1.211	0.088	0.098	0.000
Zn (ppm)	0.002	0.014	0.010	0.013	0.032	0.039	0.000	0.020	0.039	0.000	0.000	0.000	0.006	0.000	0.000
Cu (ppm)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pb (ppm)	ND	0.000	0.000	0.001	0.001	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cd (ppm)	ND	0.000	0.000	0.000	0.000	0.000	0.001	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ni (ppm)	ND	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.001	0.000	0.000	0.000	0.000
Ca (ppm)	7.44..	6.49	6.50	9.40	8.37	12.09	15.80	21.5	9.30	9.30	25.05	20.3	3.72	5.58	14.00
Mg (ppm)	0.73	0.64	0.63	1.00	0.82	1.18	1.53	2.06	0.90	0.99	2.45	1.97	0.36	0.54	1.36
Na (ppm)	24.55	21.5	21.5	33.85	27.7	40.10	52.25	70.7	30.7	33.65	83.20	67.75	12.3	18.35	46.1
K (ppm)	0.91	0.80	0.80	1.26	1.01	1.49	1.94	2.62	1.15	1.25	3.07	2.52	0.45	0.70	1.72

BH 1-3: Boreholes; WT1-12: Surface water

Soil

Summary of the results of the soil analysis are shown in Tables 1 and 2. These present the mean and range of concentration of each element at specific distances from the smelting complex. The values for the control samples are as well presented. The trend of dominance among the trace metals is Zn>Pb>Ni>Cu and Fe>Al>Ca>Mg>Na>K among the major elements.

Table 5. Comparison of metal levels in Stream sediments with various geologic environments

Element	Present Study		1a	2a	3b	4b	5b	6b	7a
	Range	Mean							
Zn	42-160	79.08	95	53	60-420	226-1,416	180-1,410	0.8-27	115
Cu	7-37	16.42	4.5	28	33-84	14-60		0.3-48	51
Pb	11-30	22.42	20	25	8-70	15-40	7.2-45.5	0.6-30	30
Ni	9-27	15.92	68	39	38-77	10-72		1.2-22.5	46
Fe	2.88-11.2	7.85	472		13,000-53,000		3,000-452,000	0.2-2,880	32,350
Ca	0.23-0.63	0.398							
Mg	0.07-0.21	0.117	1.5						
Na	0.038-0.431	0.085	0.96						
K	0.05-0.16	0.094	2.66						
Al	1.29-3.37	2.484	8						
LOI	4.2-7.4	5.47							
pH	6.3-6.9	6.64							

(a mean, b range)

1a. Average shale values (Turekian and Wedepohl, 1961)
2a. Cross River Sediments (Azmatullah and Ekwere, 1985)
3b. Calabar River sediments (Ntekim *et al.*, 1993)
4b. Qua Iboe River sediments (Ekwere *et al.*, 1992)
5b. Bight of Bonny sediments (Ntekim and Okon, 1993)
6b. Calabar River sediments (Akpan *et al.*, 2002)
7a. Fossil Rhine sediments (Forstner and Muller, 1981)

Preliminary visual interpretation of individual spatial distribution patterns of elements show no significant variation with distance from the complex. Comparison with the control samples shows that the concentrations reflect background levels. Also comparison with average shale composition of elements for each element and for other published data elsewhere (Table 5) are of background level.

Graphical presentation of concentrations of elements with distance in the four cardinal directions with reference to the complex is as shown in Figs. 3-6. The graphs show decrease in concentration with increasing distance away from the factory for both trace and major elements in the south, west and the eastern sectors (Figs 4, 5 and 6). These imply that the elemental concentration of the soil medium decreases with increasing distance from the factory site and portrays some level of pollution arising from the processes and activities. Data from the northern section of the factory somehow is inconsistent from the plot with distance (Fig. 3). Also, there is no significant variation of the concentration of the elements with depth (Table 2).

Geo-accumulation Index (I geo)

As a simple measure to quantify metal accumulation resulting from possible contamination, data for the soil samples were subjected to computation of geo-accumulation index (I geo). The geo-accumulation index has been widely applied for evaluating the degree of metal pollution in different environments (Salmons and Forstner, 1984; Forstner *et al,*, 1990; Bhosale and Sahu, 1991; Manjunatha *et al.*, 2001; Tijani *et al.*, 2004). The geo-accumulation index is expressed as;

$$I\,geo = \log_2 (An/Bn \times 1.5)$$

where

An = concentration of element A in a sample

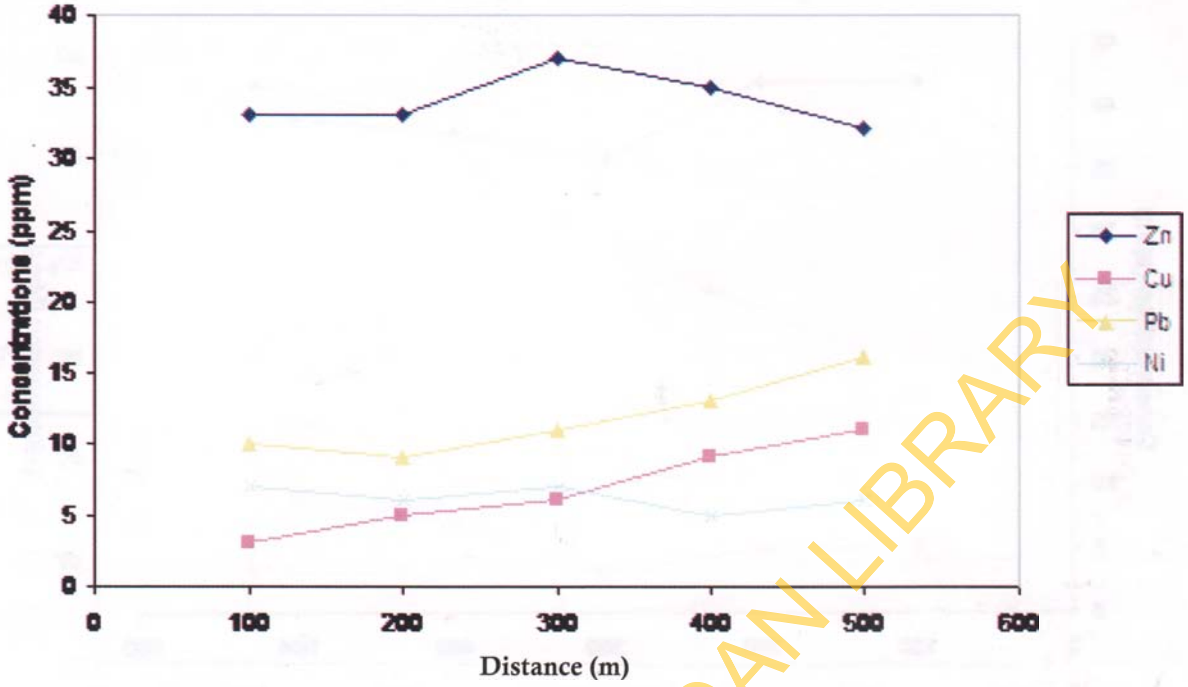
Bn = background value (i.e. control) of element A, and

1.5 = factor for possible variations in background data due to lithologic effects

I geo computation for the soils is as shown in Table 6a. Interpretation with references to the seven grade classification (Table 6b) according to Muller (1979) shows that the soils are unpolluted for most of the elements except Ca with moderate enrichment. Cu on the other hand shows unpolluted to moderately polluted near the factory site between 100-200m. All other elements are within the background levels, implying no significant industrial inputs.

R-mode factor analysis

R-mode factor analysis is a multivariate statistical technique that is widely used to aid interpretation of geochemical data and enhance subtle but significantly single-element anomalies (Garret and Nichol, 1969). In other words, factor analysis has the simple objective of revealing an underlying relation that is presumed to exist



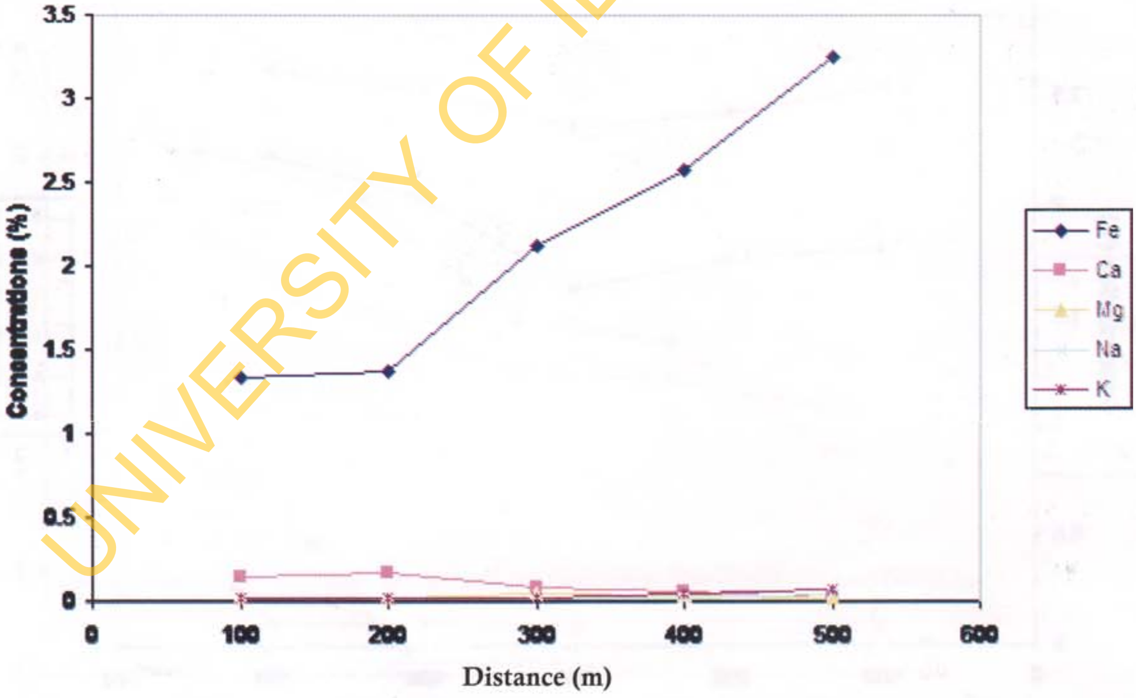


Fig. 3. Plot of trace and major elements conc. with distance for North of complex

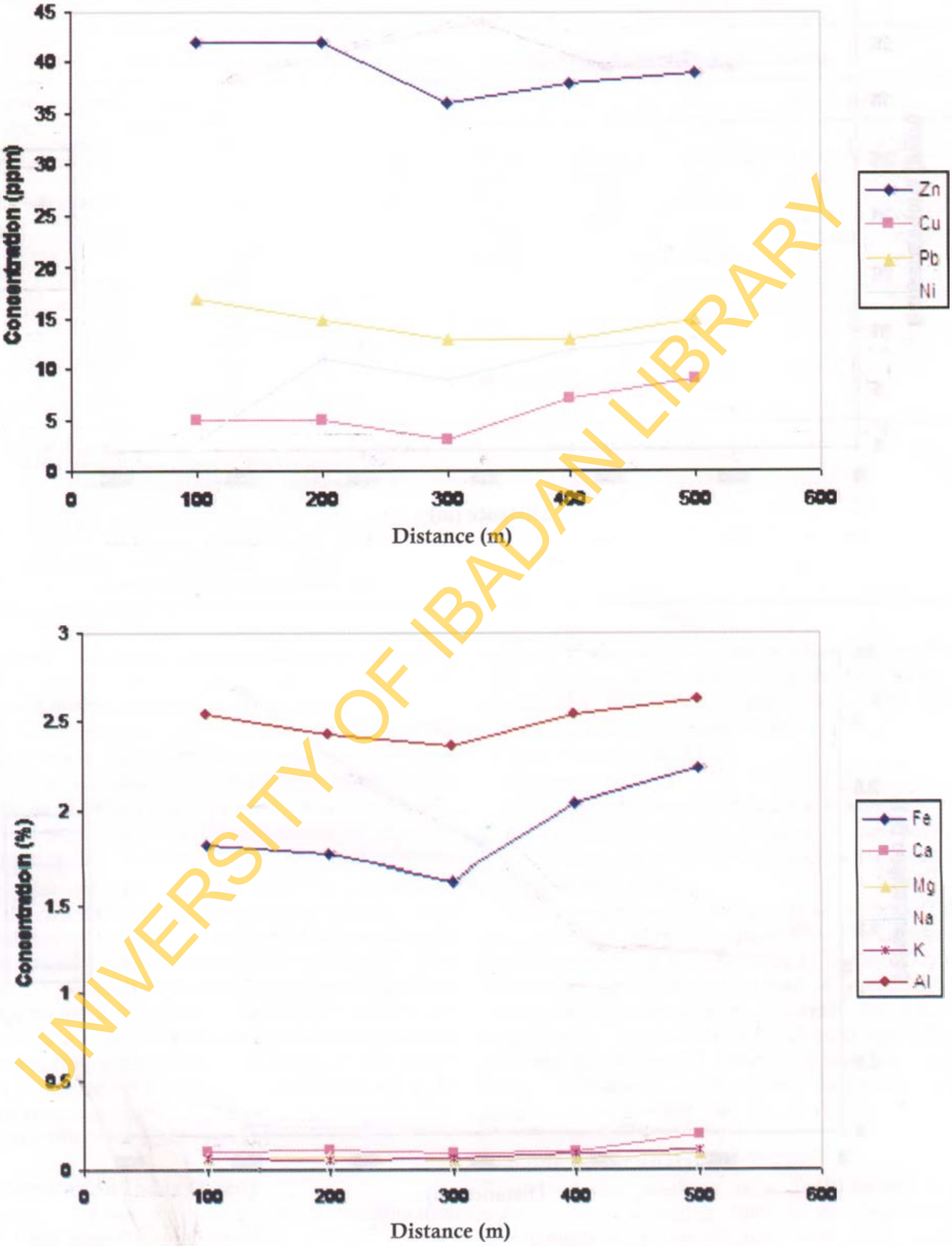
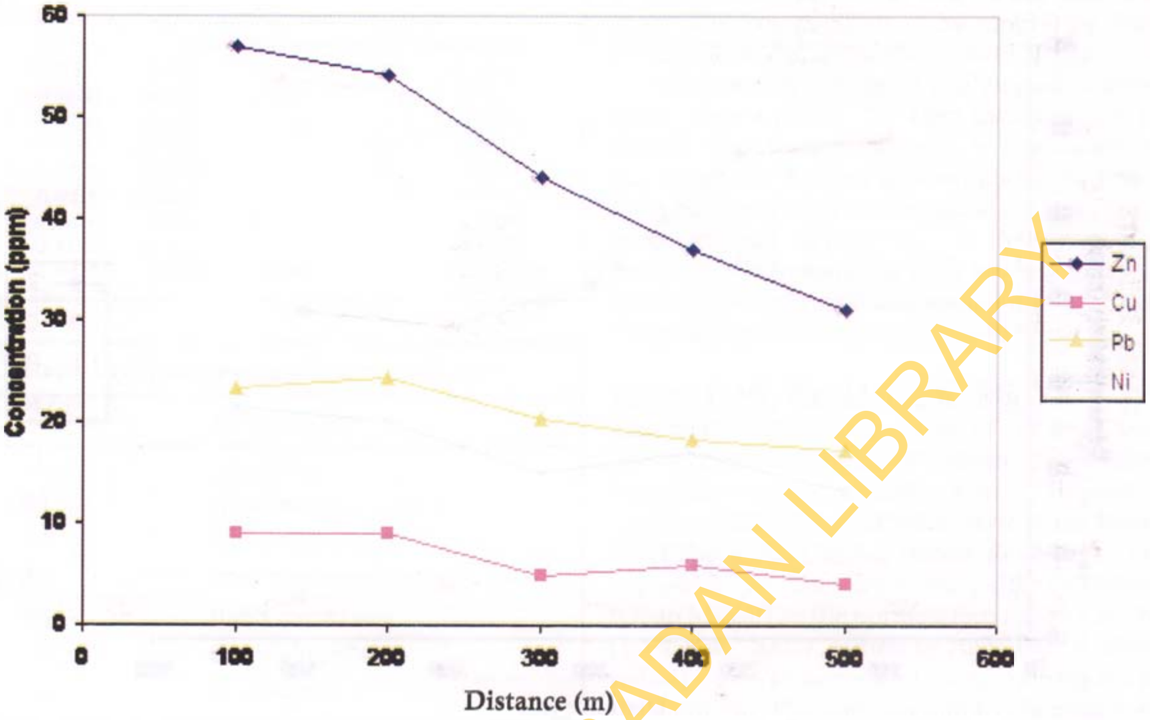


Fig. 4. Plots of trace and major elements conc. with distance for South of Complex



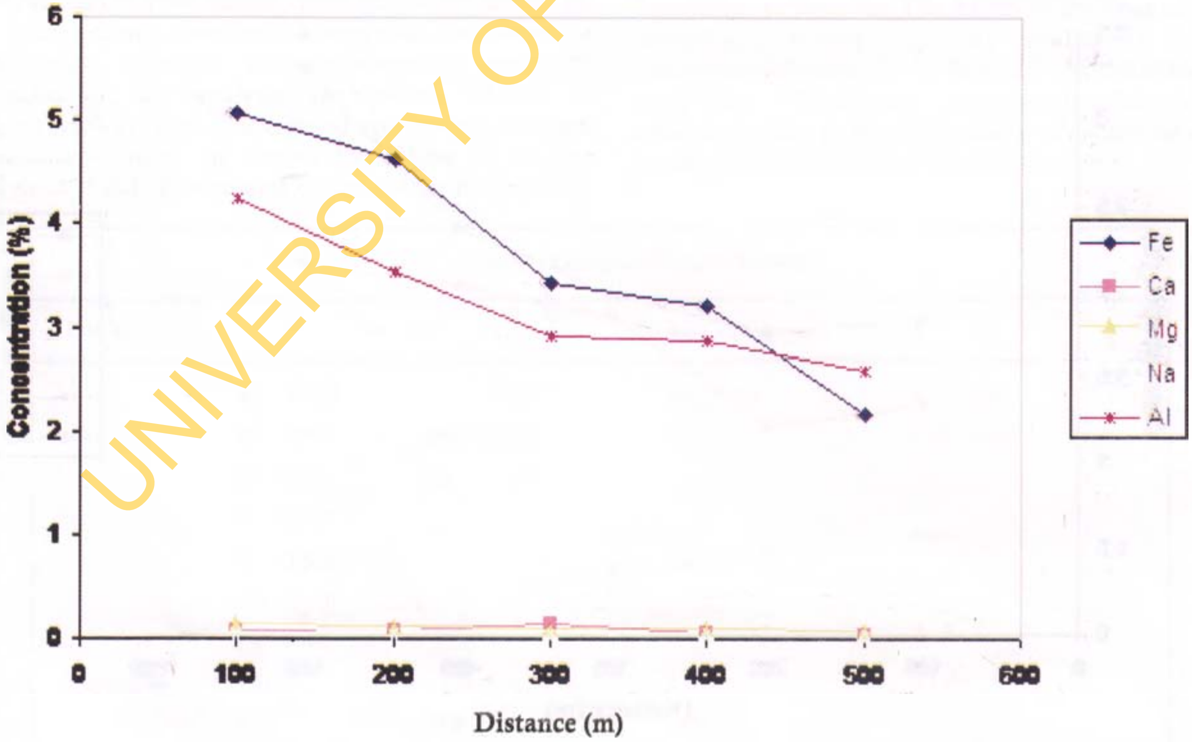
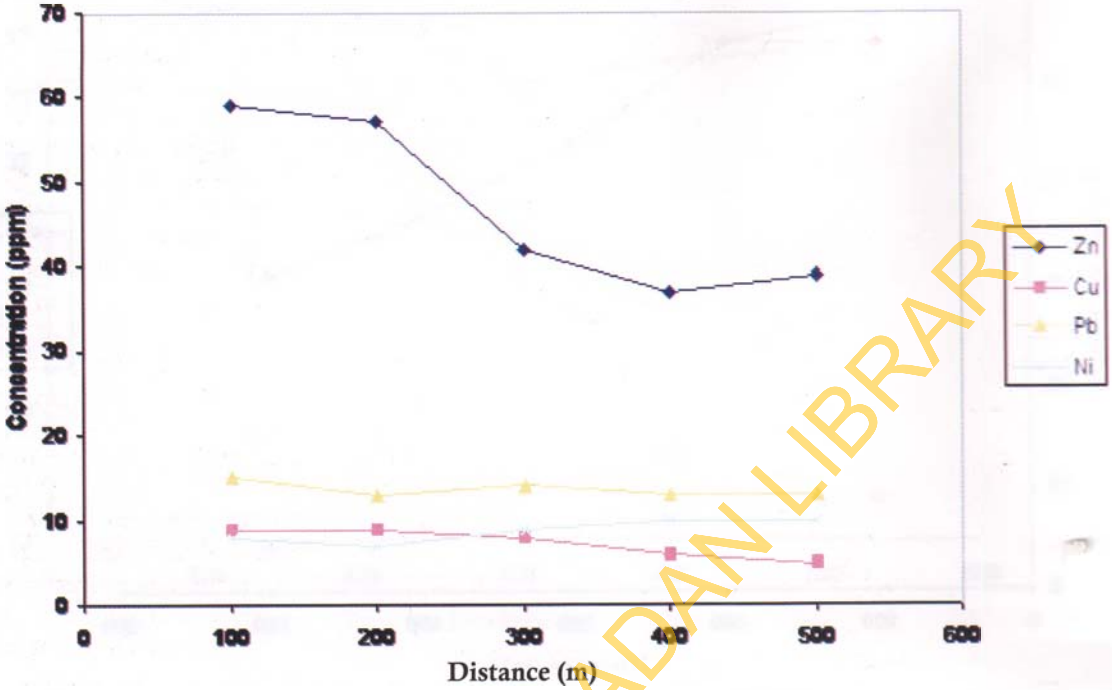


Fig. 5. Plots of trace and major elements conc. with distance for West of Complex



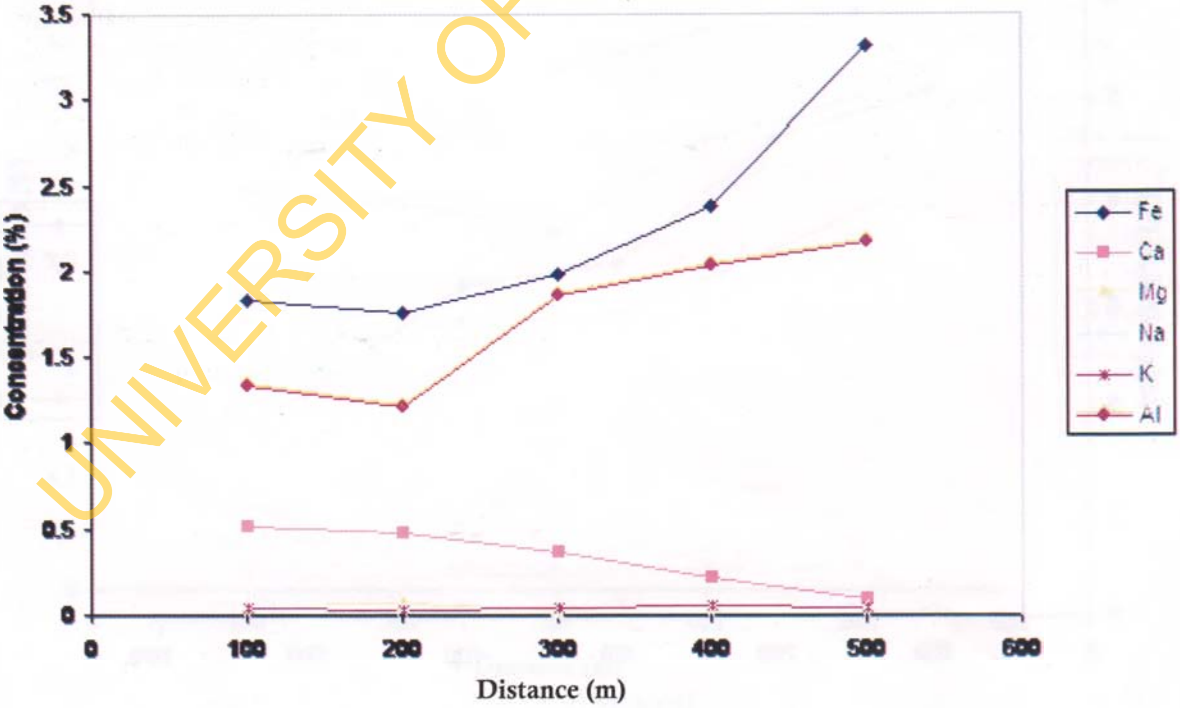


Fig. 6. Plots of trace and major elements conc. with distance for East of Complex

Table 6 a. Geo-accumulation index of top soils around the smelting quarry

Distance/ Element	100m	200m	300m	400m	500m
Zn	-0.1774	-0.2156	-0.4420	-0.553	-0.66154
Cu	0.1155	0.2224	-0.1255	0.2224	0.2730
Pb	-0.8846	-0.9763	-1.0490	-1.0741	-0.9763
Ni	-1.0726	-1.2463	-1.3506	-0.3554	-1.2463
Ca	2.5196	2.5196	2.2431	1.5851	1.3412
Mg	-0.6375	-0.6919	-1.0705	-0.9350	-0.9864
Fe	-0.4018	-0.4814	-0.5370	-0.3829	-0.2781
K	-1.0256	-1.3095	-1.3736	-1.1326	-1.0256
Na	-2.4124	-2.2720	-2.5169	-2.3591	-1.9857
Al	-1.0974	-1.2026	-1.0848	-1.0537	-0.9339

Table 6b. Igeo classification grade (after Muller, 1979)

I geo Class	Sediment quality
<0	Unpolluted
0-1	Unpolluted-moderately polluted
1-2	Moderately polluted
2-3	Moderately-highly polluted
3-4	Highly very polluted
4-5	Highly-very polluted
5-6	Extremely polluted

within a set of multivariate observations (Davis, 1986). The analysis groups related variables into principal associations (factors) based on their mutual correlation coefficients and these associations may be interpreted in terms of mineralization, lithology and environmental processes. Application of this analysis has proven effective in hydrogeochemical, lithogeochemical and stream sediment reconnaissance survey as shown by a host of workers (Imeokparia, 1984; Elueze and Olade, 1985; Elueze *et al.*, 2001b; Meng and Maynard, 2001; Edet *et al.*, 2003).

R-mode factor analysis is applied in this study to process data as an effort to determine the sources of incipient element concentration, as well as, the factors controlling such. The computation is by employing the statistical package for social sciences software (SPSS).

The results of the factor analyses are summarized in a factor matrix (Table 7). After inspection of the various models that were computed, a four-factor model that accounted for 88.4% of data variance was considered to be most consistent with known geological and environmental processes and appropriate to the limit of analytical precision. Only variables with loading greater than 0.40 were considered significant members of a particular factor. These different factors are discussed below:

Factor 1: Ni, Pb, Al, Fe, K, Mg, Zn

This factor accounts for 46.3% of the total data variance. The loadings reflect an interaction of sediments of two probable lithologic controls. A mafic lithological control suggests sediments believed to have come from the Cross River Delta (Rio Del Rey Basin), Reijers *et al.*, (1996). Also a possible sourcing from the mafic basement complex (Oban Massif) on the northeastern flank of the Niger Delta (Edet *et al.*, 2002), cannot be ruled out. A second control reflects inputs of acidic rain water leaching altered rocks of the adjoining Precambrian and Cretaceous ages (Calabar Flank) (Edet *et al.*, 2002). Sandstone has been shown to be a major source of trace elements (Lohc, 1980; Preda and Cox, 1999), thus supporting the role of the Cretaceous Awi Sandstone in this view. The Al-Fe-Ni loadings reflect their immobility during chemical weathering and their adsorption subsequently by Al and Fe oxides (Manjunatha *et al.*, 2001). The reported occurrence of galena (PbS) and sphalerite (ZnS) in the Abakaliki area cannot be ruled out for the presence of Pb and Zn in this loading.

Table 7. Factor matrix table for soils

Loading	1	2	3	4
	Ni 0.961	Ca 0.902	Na 0.881	K 0.480
	Pb 0.951	Zn 0.831	Cu 0.731	LOI 0.919
	Al 0.904	Cu 0.533		
	Fe 0.804			
	K 0.825			
	Mg 0.770			
	Zn 0.465			
Eigenvalue	5.551	2.159	2.015	0.889
% of Total var.	46.3	18.0	16.8	7.4
Cum. %	46.3	64.2	81.0	88.4

Table 8. Summary of result for water analysis (N=15) compared to WHO (1993)

Parameter	Range	Av. Values for surface water	Av. Values for Ground water	Mean	Control (mean)	Acceptable level**	Maximum Acceptable Level **
Elect Cond. (μs/cm)	60.6-416.7	215.48	135.37	199.49	167.8		1400
pH	6.25-6.97	6.62	6.52	6.72	6.5	6.6	9.5
Eh	0.29-0.93	0.38	0.22	0.47			
TDS (mg/l)	30.3-208.3	107.67	67.68	99.67	83.88	500.0	1000.0
Turb. (FTU)	0.00-108.0	18.24	37.0	18.6	30.5		
Zn (mg/l)	0.00-0.039	0.014	0.002	0.01008	0.0195		50.00
Cu (mg/l)	0.00-0.00	0.00	0.00	0.00	0.00		1.00
Pb (mg/l)	0.00-0.02	0.0003	0.00	0.00031	0.00		0.01
Ni (mg/l)	0.00-0.002	0.00025	0.00	0.00023	0.00		20.0
Fe (mg/l)	0.00-1.924	0.80	0.093	0.7518	0.378	0.3	1.00
Ca (mg/l)	3.71-25.10	12.63	7.77	11.7017	9.298	75.0	200.0
Mg (mg/l)	0.36-2.46	1.24	0.75	1.1735	0.943	50.00	150.0
Na (mg/l)	12.3-67.8	42.28	25.6	38.9400	32.175	20.0	200.00
K (mg/l)	0.45-3.07	1.568	0.96	1.4831	1.20	10.0	12.0

** WHO (1993)

Factor 2: Cu, Zn, Ca

This factor accounts for about 18% of the total data variance. The grouping suggests a lithogeochemical input representative of weathering and composition of sediments of carbonate origin. The Mfamosing Limestone and New Netim Marl within the Calabar Flank in close proximity may be the possible progenitors. The mixed siliciclastic/carbonates lithofacies in portions of the Mfamosing Limestone, reflecting hinterland erosion may fit this presumption. However, a possible input of the lower upper reaches cannot be ruled out. These are described as texturally and mineralogically matured second-cycle sediments, which had undergone prolonged chemical weathering (Reijers and Nwajide, 1996).

The polymetallic sulphide lodes of galena (PbS), sphalerite (ZnS), and chalcopyrite ($CuFeS_2$) within the Abakaliki area may raise some interest in this view in this grouping.

Factor 3: Na, Cu and Factor 4: K, LOI accounting for 16.8% and 7.4% total data variance respectively, appear erratic in their loadings and independent of lithology. The correlation between alkali metal seawater and organic content suggests a probable tidal flushing influence considering the nature of the environment prior to the construction of factory. Organic content has been shown to control natural metal concentration (Harding and Brown, 1975; Azmatullah and Ekwere, 1985). This loading suggests a need for further research efforts.

Stream Sediments

Summary of geochemical analysis of the stream sediments is shown in Table 3. This presents the mean and range of concentrations as well as mean concentrations from the control sites. The trend of dominance among the trace metals is Zn>Pb>Ni>Cu> and Fe>Al> Ca> Mg> Na>K among the major elements.

The pH values obtained for the stream sediments range between 6.3-6.9 and characterized by a higher concentration of Zn and Pb compared to that of Cu and Ni. Cu generally does not precipitate at pH values lower than 5.5 (Hawkes and Webb, 1962) and so the low concentrations of Cu and Ni in the sediments may have caused by low acidity of the solution.

Inspection of the concentration values and comparison with average shale values and studies of sediments of similar provenance (Table 5) shows that the values are within background levels. A noticeable higher concentration of most of the elements and organic content in SSD 8 (Table 3) compared to other samples shows inputs of mixing in tidal flush areas within the study area. A mixing process with mobilization by solubilization from suspended particles may lead to enhance concentration in such locations (Azmatullah and Ekwere, 1985). The heavy metals fixed to the suspended matter are trapped and solubilization including cation exchange leads to an increase in the heavy metal at various locations reflects inputs of human activities by the local people e.g. car wash and domestic refuse disposal. This is typical for locations in proximity to local population centre.

Water

Geochemical results of the water exhibit a similar trend of dominance as in the soils and stream sediments; Zn>Pb>Ni>Cu> for the trace elements and Fe>Ca>Mg>Na>K among the major elements. A summary of the data set for the water samples in comparison with values from the control site and the World Health Organization (WHO, 1993) is shown in Table 8. Both physical and hydrochemical parameters show that there is slight elevation of these parameters when compared with the control.

All the trace and major elements have concentration levels lower than the common averages. Comparison between mean concentrations for surface and groundwater indicates that the levels are higher in surface water. Two reasons may most probably be responsible for this. The first, which is natural or geogenic is due to the fact that the sampled streams are tributaries of a larger Imo River and its creeks. This could have resulted in draining various geological units from its upper continental reaches through to the study area. A second and minor reason is anthropogenic from human activities such as riverine transport, grease and wash- offs from car washes, domestic waste disposal such as wash off from machines and food processors.

A noticeable higher concentration of most of the elements in sample WTS 8 (same location of stream sediments sample SD 8) satisfies an expected scenario reflecting inputs of tidal flushing, especially with concentrations of seawater indicator elements (alkali and alkaline earth).

Summary and conclusions

The geochemical results of the water samples show concentration levels that are within the permissible limits and thus pose no harm to human and aquatic biota. Higher concentration of elements in the surface water compared to ground water suggests inputs of natural sources and to a little extent anthropogenic.Significant element concentration levels also mark the active tidal flush zone.

The trend of dominance for trace and major elements with distance from the factory site shows some influence of the processes and activities at the factory. The study has provided background information for vulnerability assessment of the sampled areas as well as for future investigation and development planning. However a need for implementation and enforcement of environmental laws may just be the best means of pollution control within the area.

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