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Impact of cement dust deposition on the elemental composition of soils in the vicinity of Ashaka cement factory, Nigeria

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Abstract

The elemental composition, distribution and some physicochemical aspects of soils in the vicinity of Ashaka cement factory were scrutinized. The pollution load and its impact on the environment were assessed using high-resolution energy dispersive X-ray fluorescence (EDXRF) spectrophotometer. The facility was integrated with computer system capable of determination of elemental composition of samples and some physiochemical aspects in form of their oxides. The major elemental components investigated in soil ranged as follows; CaO (1.13-14.17%), $CaCO_3$ (2.02-23.40%), SiO_2 (52.41-94.06%), Al_2O_3 (6.75-15.78%), Fe_2O_3 (1.52-3.97%), K_2O (1.80-6.25%) and heavy metals Zn (47.47-76.23mgkg^{-1}), Mn (515.01-960.00mgkg^{-1}), Cu (68.83-103.30mgkg^{-1}) and Pb (43.60-119.00mgkg^{-1}). Physicochemical properties determined included lime saturation factor (LSF) (0.42-12.67), silica ratio (SR)3.33-10.92%, alumina ratio (AR) 2.47-7.38) and loss on ignition (LOI)(0.85-5.89%). The major components CaO and $CaCO_3$ together with LSF were used as pollution tracers. These components along with the heavy metals show soil enrichment along the wind directions (northeast and southwest) with maximum pollution load at 5 and 7km distance. Similar patterns were observed with vertical distribution along the wind directions. Although levels of some elements were low in some areas, the mean concentration of most of the components were 2 – 10 folds greater in order of magnitudes than the levels expected in unpolluted soil.

Keywords: Cement, pollution, dust, soil, X-ray.

INTRODUCTION

Environmental pollution is generally regarded as any discharge of material or energy into water, land and air that causes, short term or long terms effects detrimental to the earths ecological balance or lowers the quality of life (Brown, 1990). In cement plants, the major areas of dust emission are the precipitator exhaust stack and the cement mill stack (Greer, 1992). Other locations of gas emissions are leakages through the compressors and F.K pump transport screw pipes. Also the quarry, the packing plant, the cement and raw materials grinding mills are other emission sources. Dust which is emitted during cement processes is eventually deposited on soil, sediment, water and plants. It is believed that the production of one ton of cement involves the pulverization of about 2.6 to 2.8 tons of raw materials clinker, gypsum, oil or coal. Between 5 and 10% of these finely pulverised materials are agitated and suspended as dust, (Makoju, 1992).

The dust emitted from cement plants are of two categories. There are cement and clinker dusts which contain cement mineral compounds such as tricalcium silicate (C_3S), dicalcium silicate (C_2S),tricalcium aluminate (C_3Al) and tetracalcium aluminoferrite (C_4AlF) because they are calcined products (Crolius, 1992). The second category is the raw mill and precipitator dust that have not been calcined and they contain calcium carbonates, oxides of iron, silicon, aluminium, magnesium and other minor elements.

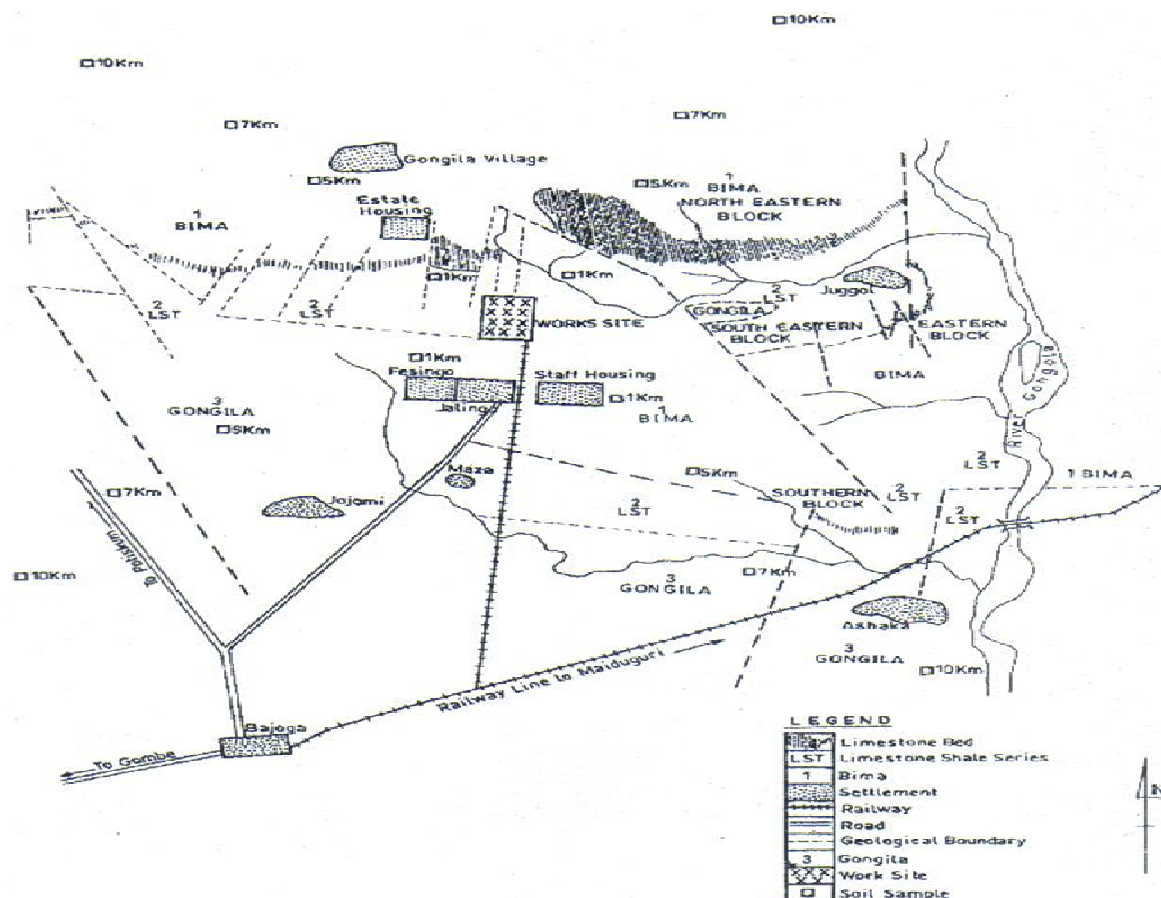*Corresponding Author E-mail: drmaimaina@yahoo.com

Figure 1. Map showing soil location around Ashaka cement company.

The dust emissions from cement and other related industries therefore have to be given attention for control. This is necessary in view of the pollution load and its impact on the environment.

Pollutants have devastating effects on plants when taken by direct absorption through leaves or by water through the roots (Kabata – Pendias and Pendia, 1992). Studies has been carried out by a number of researchers to determine the effect of dust on plants. Almost all the results have indicated the absorption of dust into plants through the leave stomata (Ajayi *et al.,* 1994). Some experimental results indicated physical effects including the destruction of the chlorophyll.

Detrimental effects of cement dust on plants, for example, have been observed by (Sree, 1973) during studies of three dusts on photosynthetic pigments on some crops. The three types of dust; cement, coal and fly-ash were applied by the above researchers, on plant leaves for a period of one month. Small chlorotic spots and marginal chlorotic sports appeared in leaves sprayed with cement and coal dust, respectively. Cement dust was found to be more toxic to chlorophyll than coal dust while a slight increase was noted in case of fly ash (Lal and Ambasht, 1982).

Excessive concentration of both essential and heavy metals from pollutants, therefore, may result in phytotoxicity in plants (Kabata-Pendias and Pendia 1992 and Neisoer and Richardson 1980).

Animals and humans are affected by pollution load from several sources. One is through the ingestion of dust and gases inhaled from polluted environment. Second source is from food obtained from plants and animals contaminated with heavy metal elements.

Many varieties of crops are grown in the vicinity of Ashaka cement factory and such crops such as millet, maize and vegetables are affected to a large extent by the dust emitted from the factory. The crops grown along the easterly and westerly wind directions are most affected by the dust deposition.

MATERIALS AND METHOD

Sample Location, Collection and Preparation

The map of Ashaka cement factory and its environment showing soil sample location and sites where samples were collected is in Figure 1. Sampling sites were along

Table 1. The Mean Composition of Major Components in Soil in the North-East Direction at 0 – 5cm Depth.

Distance (km)	CaO	MgO	SiO$_2$	Al$_2$O$_3$	Fe$_2$O$_3$	SO$_3$	K$_2$O	Na$_2$O	*LOI	*LSF	*SR	*AR	CaCO$_3$
1	2.95	0.23	59.47	14.40	2.89	0.05	5.63	0.28	4.06	3.59	3.33	4.95	5.25
	(0.5)	(0.1)	(6.1)	(1.2)	(0.8)	(<0.5)	(1.1)	(0.04)	(1.3)	(0.4)	(0.8)	(1.1)	(0.8)
5	12.92	0.27	53.17	10.69	3.97	0.11	3.87	0.44	2.77	12.67	3.73	2.69	23.4
	(1.2)	(0.04)	(2.5)	(1.4)	(1.2)	(0.01)	(1.3)	(0.05)	(1.3)	(2.1)	(0.8)	(1.4)	(4.1)
7	10.67	0.13	52.41	15.78	3.87	0.09	6.01	0.76	4.17	6.86	3.55	4.08	20.83
	(1.3)	(0.01)	(4.8)	(1.4)	(0.9)	(<0.1)	(1.3)	(0.05)	(1.4)	(2.7)	(2.1)	(3.1)	(4.2)
10	2.98	0.0	77.53	10.44	3.04	0.04	2.21	0.54	1.98	0.63	7.09	3.43	2.61
	(1.4)	(<0.01)	(6.7)	(2.8)	(1.4)	(<0.01)	(0.4)	(0.02)	(0.7)	(0.07)	(1.8)	(4.2)	(0.8)

Values in parenthesis refer to the standard deviation of four analyses
* LOI= Loss on Ignition *LSF = Lime Saturation Factor *SR = Silica Ratio *AR = Alumina Ratio

north-east (NE), south-west (SW), which are the seasonal wind directions. Samples were also taken along North-west (NW) and south-east (SE). Samples were taken at intervals of 1, 5, 7 and 10km in each direction. Each sample point had three samples taken at the following depths; 0-5, 5-10, and 10-25 cm.

The control samples were taken in areas that are likely to be less polluted by cement dust which is the north-west and south-east directions.

Sampling, sample collection and preparation were done in line with the procedure described by James and Wells, (1990). Leaves, grasses and logs were removed from the surface before sampling. Since soil depth was important, samples that were collected were obtained using corers. A polyvinyl chloride (PVC) cylinder of about 12cm in diameter with height of about 40 cm lengths was used as corer. The corer tube was hammered into each sample point to obtain the desired sample. A gross sample of about one kilogram (1kg) was obtained at each point. The samples were air dried, quartered and ground in agate mortar. A representative sample weighing about 100g was obtained after quartering and passing the ground material through a 90 micron sieve. This was stored in polypropylene bottles with cover before analytical determinations.

Determination of Elemental Concentrations in Samples

Elemental concentration in samples were determined by X-ray fluorescence Spectrophotometer. The X-ray fluorescence (XRF) used in this work was the high energy dispersive X-ray fluorescence (EDXRF) Lab-X3500 at Ashaka cement factory. The instrumental set-up and method used was similar to that of Funtua,1999.

The analyses procedure involved two steps. Sample preparation and instrumental operation for the determination of the components: 20g of sample was weighed and added on to a 0.4g of stearic acid powder which acted as a binding acid or buffer so as not to allow the sample to disperse or scatter away. The sample was transferred into a grinding mill barrette where it was ground into a fine powder. It took 100 seconds for grinding process. The aluminium cup of the x-ray machine was half filled with stearic acid powder followed by the addition of the finely ground sample powder. The aluminium cup was over-filled with the sample. The excess was removed with a spatula in order to level the aluminium cup content. The cup was then put into a hydraulic pump compression machine and compressed at 200KN for 10 seconds which then form a pellet. The sample holder with the prepared pellet was put in loading possil of XRF and measured unknown sample was selected and entered into the computer and the desired programme was typed on the PC screen.

Before any X-ray analyses commenced for samples, a standard sample was analyzed for elemental composition to calibrate the instrument. The standard sample was provided by Blue Circle Industries (BCI) The spectrophotometer set up consists of the main spectrophotometer machine to which was connected a micro-processor screen and keyboard for communication. From the spectrometer main menu, quantitative analyses were selected by using the cruiser. The pressed sample pellet was then put into the X-ray fluorescence spectrometer sample holder. The results were displayed after 70-80 seconds on the PC screen and were printed.

RESULTS AND DISCUSSION

Major Components Distribution in Soils along Radial Direction

The weighted mean composition of each of the major components at different locations is presented in Tables1-4 for 0 – 5cm depth in all directions. The results

Table 2. The Mean Composition of Major Components in Soil in the South West Direction at 0 – 5cm Depth.

Distance (km)	CaO	MgO	SiO$_2$	Al$_2$O$_3$	Fe$_2$O$_3$	SO$_3$	K$_2$O	Na$_2$O	*LOI	*LSF	*SR	*AR	CaCO$_3$
1	9.76	0.12	71.00	12.50	2.67	0.05	4.59	0.27	3.13	1.82	4.79	4.68	5.14
	(2.7)	(0.02)	(4.0)	(2.3)	(0.8)	(<0.05)	(1.3)	(0.03)	(1.2)	(0.9)	(1.5)	(2.1)	(2.8)
5	13.44	0.13	65.86	11.14	2.94	0.04	3.48	0.20	2.79	5.63	3.78	3.78	13.57
	(2.5)	(<0.3)	(5.8)	(1.2)	(0.8)	(<0.04)	(1.5)	(0.01)	(0.7)	(1.8)	(1.2)	(1.4)	(27.57)
7	14.17	0.06	64.99	10.36	2.98	0.03	6.28	0.31	5.89	8.49	6.56	3.48	25.09
	(1.8)	(<0.06)	(4.7)	(1.3)	(0.4)	(0.05)	(2.1)	(0.02)	(2.1)	(2.8)	(1.6)	(1.9)	(3.5)
10	1.65	0.02	92.88	6.76	2.74	0.04	3.75	0.24	1.56	0.62	10.92	2.47	2.95
	(0.4)	(<0.05)	(8.7)	(1.9)	(1.1)	(<0.01)	(0.2)	(0.03)	(1.2)	(0.03)	(2.1)	(1.2)	(0.2)

Values in parenthesis refer to the standard deviation of four analyses
* See Table 1

Table 3. The Mean Composition of Major Components in Soil in the North-West Direction at 0 – 5cm Depth.

Distance (km)	CaO	MgO	SiO$_2$	Al$_2$O$_3$	Fe$_2$O$_3$	SO$_3$	K$_2$O	Na$_2$O	*LOI	*LSF	*SR	*AR	CaCO$_3$
1	4.64	0.06	78.69	10.42	1.52	0.43	5.30	0.30	2.21	1.2	6.59	6.84	5.93
	(0.2)	(<0.1)	(6.5)	(1.2)	(0.5)	(0.01)	(0.8)	(0.04)	(0.8)	(0.4)	(2.1)	(1.8)	(2.2)
5	7.29	0.10	71.09	13.21	2.69	0.04	5.95	0.53	3.21	0.60	4.80	4.91	10.37
	(0.5)	(0.01)	(6.4)	(1.2)	(0.5)	(<0.01)	(1.4)	(0.05)	(0.8)	(0.04)	(0.9)	(0.7)	(1.2)
7	1.53	0.11	68.15	13.53	1.84	0.03	5.68	1.25	3.30	0.73	4.54	7.35	2.73
	(0.4)	(0.01)	(4.7)	(1.4)	(0.6)	(<0.01)	(1.2)	(0.4)	(0.8)	(0.04)	(1.5)	(1.1)	(0.8)
10	1.13	0.03	94.06	6.75	1.77	0.03	2.58	0.28	2.66	0.42	13.14	3.81	2.02
	(0.4)	(<0.01)	(7.4)	(1.6)	(0.4)	(<0.01)	(0.8)	(0.01)	(0.09)	(0.04)	(0.8)	(1.4)	(0.4)

Values in parenthesis refer to the standard deviation of four analyses
* See Table 1

Table 4. The Mean Composition of Major Components in Soil in the South-East Direction at 0 – 5cm Depth.

Distance (km)	CaO	MgO	SiO$_2$	Al$_2$O$_3$	Fe$_2$O$_3$	SO$_3$	K$_2$O	Na$_2$O	*LOI	*LSF	*SR	*AR	CaCO$_3$
1	1.63	0.14	73.40	12.14	2.23	0.04	4.44	0.29	2.98	0.74	5.11	5.44	4.91
	(0.8)	(<0.1)	(7.4)	(1.2)	(0.5)	(<0.01)	(0.8)	(0.02)	(0.4)	(0.08)	(1.3)	(0.8)	(1.2)
5	1.20	0.07	88.99	7.82	2.49	0.02	1.80	0.20	1.33	0.46	9.36	3.14	2.74
	(0.4)	(<0.01)	(6.8)	(1.4)	(0.4)	(<0.01)	(0.7)	(0.05)	(0.6)	(0.05)	(1.5)	(1.1)	(0.7)
7	1.27	0.14	83.17	9.02	2.45	0.04	2.19	0.25	1.88	0.52	7.38	3.68	2.27
	(0.4)	(0.02)	(7.5)	(1.2)	(0.4)	(<0.01)	(0.6)	(0.07)	(0.6)	(0.04)	(0.6)	(1.3)	(0.8)
10	1.18	0.06	90.64	7.39	1.97	0.03	3.68	0.29	0.85	0.45	11.87	3.75	2.11
	(0.8)	(<0.05)	(6.8)	(1.4)	(0.5)	(<0.01)	(1.7)	(<0.01)	(0.04)	(<0.01)	(1.5)	(1.7)	(0.6)

Values in parenthesis refer to the standard deviation of four analyses
* See Table 1

are the percent compositions on mole bases of the elements measured within the analytical windows of the energy dispersive X-ray fluorescence (EDXRF) detector. conclusions may emerge from these data based on radial distribution, of soil samples collected. The principal elements Si, Al and Fe in the earth's crust have maintained their relatively high levels in all the samples studied and their ranges are; SiO$_2$ (52.41-94.06%), Al$_2$O$_3$(6.75-15.78%), and Fe$_2$O$_3$(1.52-3.97%). The elements Mg, S, and Na are relatively small in terms of magnitude compared to other elements at all the sampling locations.

The marker and critical element (Ca) though low in samples, has a general trend in both the oxide and the carbonate forms particularly in the wind directions. Reference to Tables 1 and 2 shows that the tracer element Ca generally increases to the maximum at 5km and 7km distances along the northeast (upwind side) and southwest (downwind side) of the factory. Similar trend is observed for CaCO$_3$ content and LSF. Silica is the most

Table 5. Heavy Metal Levels in Soil along Northeast Direction.

Distance (km)	Concentration (mgKg-1)			
	Zn	Mn	Cu	Pb
1	53.67	680	87.73	67.13
	(3.21)	(51)	(8.06)	(5.22)
5	76.23	795	103.3	73.07
	(4.45)	(62)	(7.57)	(1.86)
7	63.30	836.7	100.67	119
	(3.07)	(72.61)	(19.01)	(2.94)

Table 6 Heavy Metal Levels in Soil along Southwest Direction.

Distance (km)	Concentration (mgKg-1)			
	Zn	Mn	Cu	Pb
1	69.93	866.67	79.47	62.93
	(1.94)	(61.96)	(4.53)	(2.16)
5	76.40	960	100.10	81.70
	(6.64)	(61.64)	(17.03)	(6.23)
7	60.23	953.33	87.43	93.37
	(4.29)	(106.17)	(6.61)	(14.48)
10	53.27	515.00	78.70	81.27
	(2.81)	(50.17)	(4.26)	(7.79)

Values in parenthesis refer to the standard deviation of four analyses

Table 7. Heavy Metal Levels in Soil along Northwest Direction

Distance (km)	Concentration (mgKg-1)			
	Zn	Mn	Cu	Pb
1	64.13	926.67	87.50	57.33
	(7.75)	(51.04)	(3.49)	(4.85)
5	58.10	761.67	102.7	46.27
	(5.10)	(70.04)	(9.06)	(1.09)
7	51.83	692	83.57	49.27
	(11.89)	(14.99)	(2.82)	(1.67)
10	47.9	635	88.57	43.60
	(3.83)	(18.71)	(4.76)	(1.34)

Values in parenthesis refer to the standard deviation of four analyses

abundant component and the amount is significantly higher than other components considered but has no trend in any direction.

There is no obvious trend for the distribution of either the CaO or $CaCO_3$ content along the northwest and southeast. The higher concentration of Ca0, LSF and $CaCO_3$ at 5km and 7km along north east and south west compared to northwest and southeast follows the pattern of atmospheric deposition rates around some cement plants (Bowen, 1979 and Takatsuka, 1977). Apart from Ca and $CaCO_3$, the other components do not exhibit
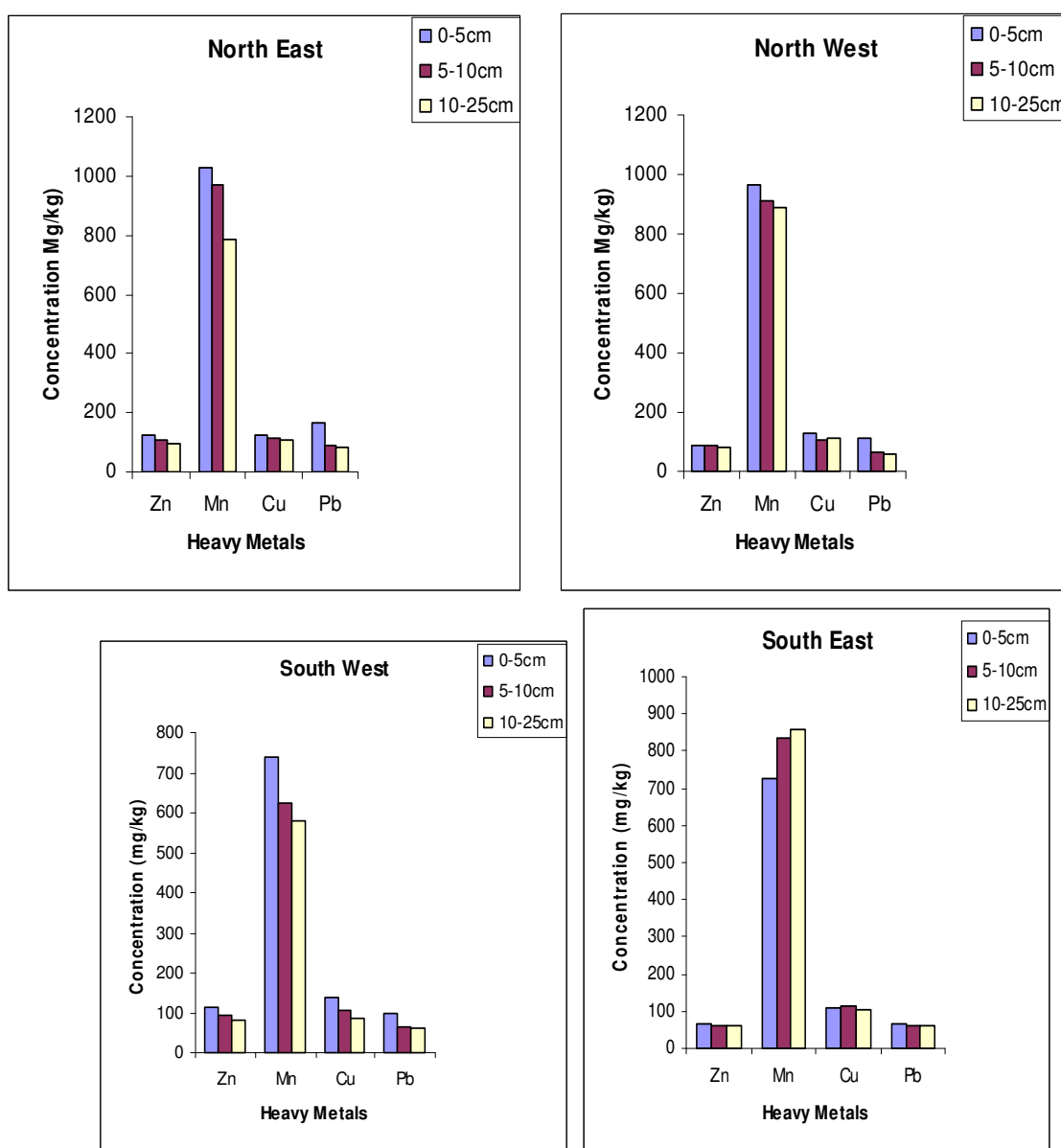
noticeable trend.

Heavy metal distribution along radial direction

Heavy metal levels along radial directions are shown in Tables 5-8 and results are expressed in $mgKg.^{-1}$ Results are weighted average values of 0-25cm depth. The general heavy metal composition around the factory indicates that the values are generally below 120 $mgKg^{-1}$ except manganese whose concentration is significantly

Table 8. Heavy Metal Levels in Soil along Southeast Direction.

Distance (km)	Concentration (mgKg-1)			
	Zn	Mn	Cu	Pb
1	57.57	793.33	84.53	55.07
	(3.68)	(74.87)	(4.17)	(1.97)
5	66.30	1093.33	90.70	65.20
	(6.61)	(19.27)	(6.68)	(0.85)
7	58.80	726.67	77.03	56.13
	(5.08)	(25.19)	(4.21)	(4.03)
10	59.03	529.67	91.23	55.97
	(10.59)	(103.72)	(12.47)	(1.27)

Values in parenthesis refer to the standard deviation of four analyses

Figure 2. Variation of Heavy Metals with Depth (cm) at 1 km Distance.
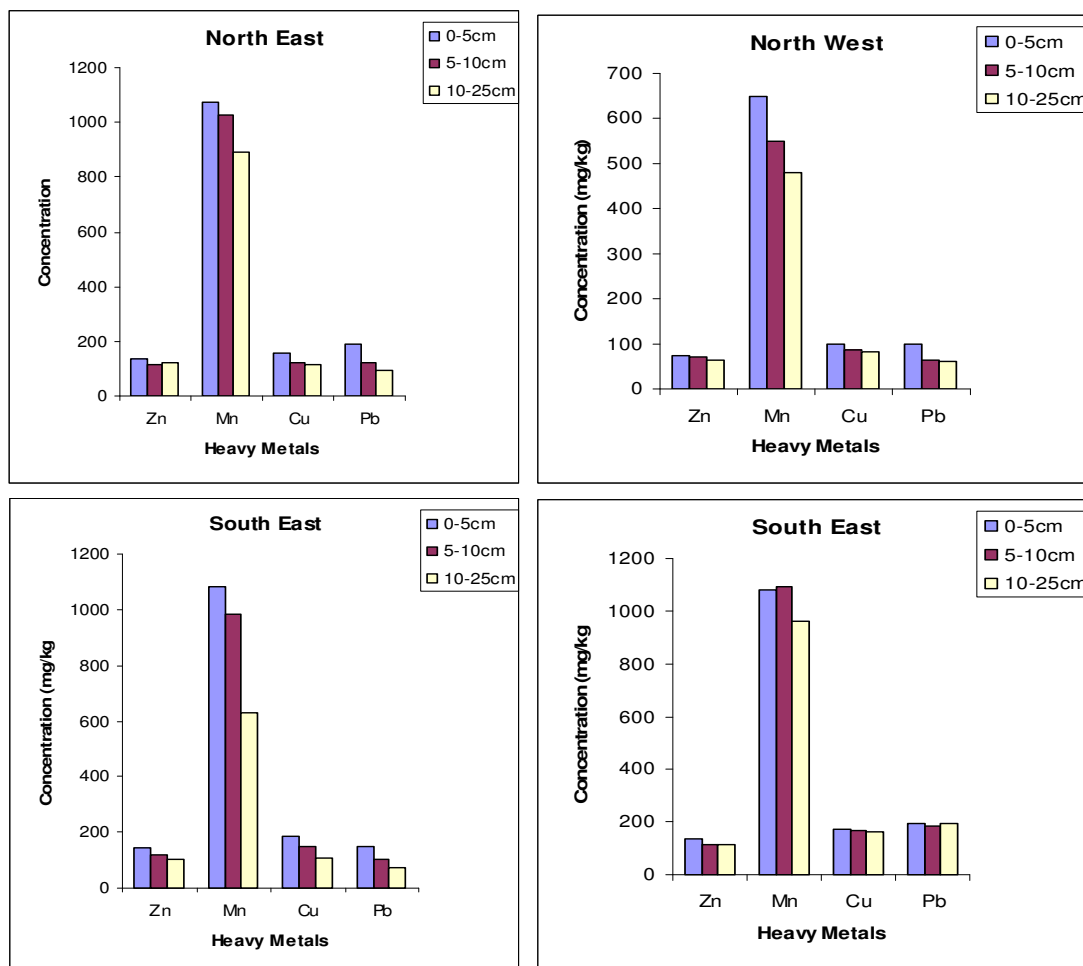
Figure 3. Variation of Heavy Metals with Depth (cm) at 5 km Distance.

higher with a range of 515 – 1093 mgKg[-1]

The concentration of Cu and Pb is significantly higher than values reported in most uncontaminated soils whose upper limit is 150mg/kg. Zn reported values have been between 10 – 300mgKg[-1] and therefore Zn lies within the acceptable values. The high concentration of metals is attributed to enhanced cement dust deposition especially in the wind directions.

The results for all the metals also indicate concentrations above the minimum values found in many soils (Kabata-Pendias and Pendias, 1992). There appears to be an increase in soil enrichment of heavy metals with distance away from the factory with maximum values between 5 and 7 km distance along the wind directions.

The seasonal westerly and easterly winds along northeast and southwest of factories may enhance the deposition of the factory stack dust further away from the factory.This certainly might have enhanced enrichment of all the metals in soil at 5 and 7km distances. At about 10km distance from the factory, the low dust deposition is not unexpected, as most of the dust particles might

have been deposited earlier leaving very small airborne dust.

There is no obvious reason for the inconsistent trend in heavy metal levels in   the northwest and southeast direction. There is however, a considerably high concentration of heavy metal elements in the regions closer to the factory in both southeast and northwest. This may be due to none point sources emission and deposition of factory dust that occur closer to the factory premises.

Heavy Metal Distribution with Depth

Figures 2 - 5 show the heavy metal distribution at 1, 5, 7 and 10km at various depths. All the heavy metals Mn, Zn, Cu and Pb were found in significant amounts at different levels at all locations and at different depths.

Almost all the metals were more concentrated on the surface (0-5cm depth) than at other depths. This is in agreement with results from many researchers. The concentration of Mn is conspicuously higher in all the
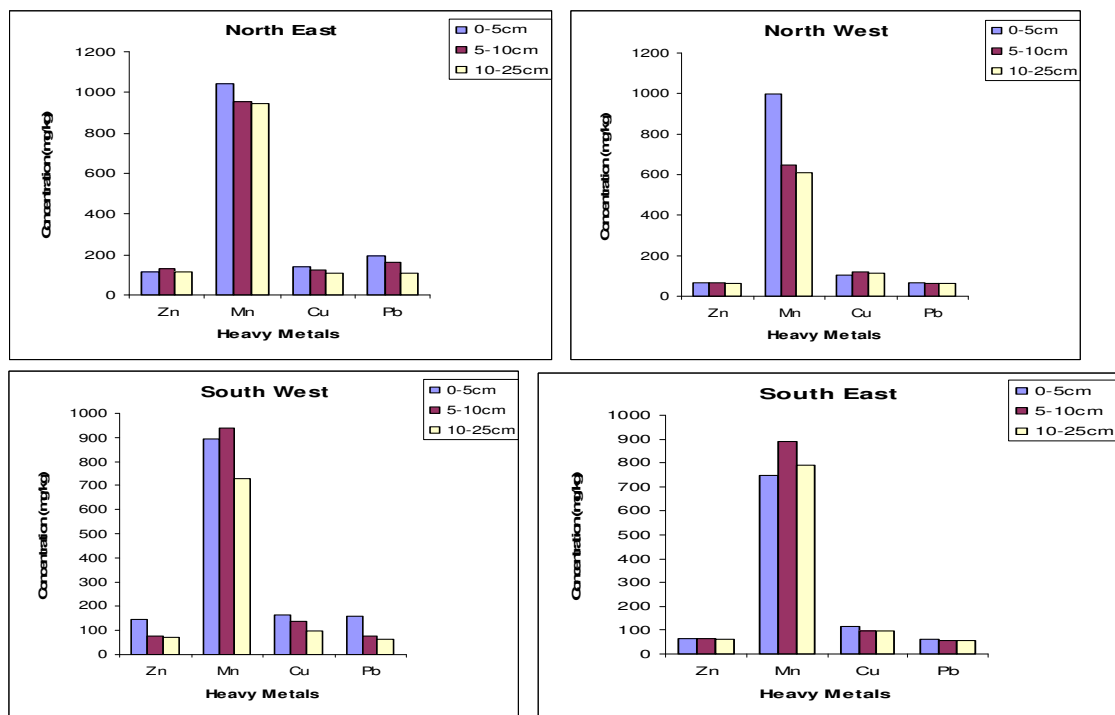
Figure 4. Variation of Heavy Metals with Depth (cm) at 7 km Distance.
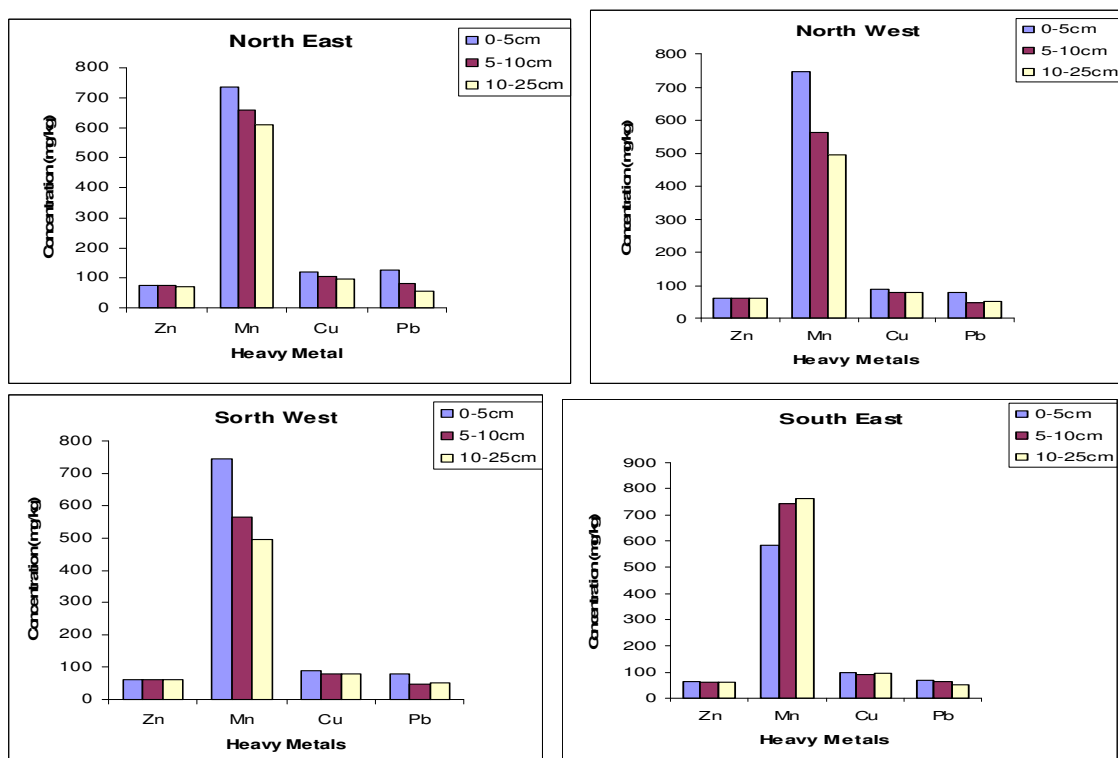

Figure 5. Variation of Heavy Metals with Depth (cm) at 10 km Distance.

directions, for all the distances and at various depths. Lead concentration was found to be more on the surface (0-10cm) than of Zn and Cu. This may be due to low rate of lead leaking as reported by Steinnes, 1992.

CONCLUSION

In this study, it has been established that the soil in the vicinity of the Ashaka cement factory has been polluted to a large extent by the major elemental components and heavy metals. The principal components SiO_2, Al_2O_3, Fe_2O_3 have maintained their relatively high levels in all the samples studied. The radial distribution of components show that CaO, LSF, and $CaCO_3$ along with the heavy metals Mn, Cu, Zn and Pb show soil enrichment increase along the wind direction (northeast and southwest) with a maxima around 5 and 7 kilometres. There appears to be no trend along the northwest and southeast directions, although the soil enrichments of the components and heavy metals are significantly high especially areas closer to the factory. Mn levels have been found to be very much higher than all the other heavy metal elements and their concentrations in soil follow the order

Mn>>Cu>Zn>Pb.

Soil profile results also indicate high levels of metals on the surface but decreases with soil depth. It is recommended that appropriate measure for dust control be put in place for the factory. This is necessary in view of the devastating effect of toxic metals on plants and animals.

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