Oxides and Heavy Metals Concentration around a Cement Plant at Yandev, Central Nigeria

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Authors' contributions

Author FU designed the study, performed the statistical analysis, wrote the protocol and first draft of the manuscript. Author MMA managed the analyses and literature searches of the study. All authors read and approved the final manuscript.

Original Research Article

ABSTRACT

Aims: To determine the level of concentration of oxides (chemicals) and heavy metals in 6 soil samples. To further compare the results with acceptable soil quality standards to ascertain the status of soil quality within the study area.
Study Design: Collection and analyses of soil samples from the vicinity of Dangote Cement factory, Yandev.
Place and Duration of Study: A total of 6 soil samples were collected: using a 2-kilometer interval, five samples were collected within the study area starting from the center of the Cement factory while the sixth soil sample was collected from a Control Community (Tarhembe) located 12 kilometers from the Cement factory in a part of Benue State, Nigeria. The total of six soil samples was collected in May 2013.
Methodology: Laboratory analyses were conducted for 27 soil parameters. Mean, maximum and minimum values and standard deviation, coefficient of determination (R^2) and ANOVA for all 27 parameters was derived using SPSS Version 15 software. Using guidelines applied in various soil quality studies, the concentration levels of pollutants in soils samples were determined for all 27 parameters to establish whether or not their level of concentration at the study area constitute significant health problems.
Results: The mean values indicate high concentration levels above permissible limits for Iron (III) oxides, Calcium oxides, Magnesium oxides, Sodium oxides and Potassium oxides. Although the permissible limit values for other oxides could not be obtained, their

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mean concentration values appear to be generally higher in all soil samples closer to the factory than the Control sample. Heavy metals content in the 6 soil samples indicate that the mean values recorded for Iron, Lead, Manganese, Zinc, Copper and Conductivity exceed the permissible limits while the mean values for Organic Carbon, Calcium, Magnesium and pH occur below the permissible limit. Furthermore, the control sample reveals concentration below the permissible limits for Organic Carbon, Lead, Calcium and Magnesium, whereas samples 1, 2, 3, 4 and 5 (2km, 4km, 6km, 8km and 10km from factory) contain concentration levels above the permissible limit.

Conclusion: Analysis indicates that the soils are polluted with some oxides and heavy metals originating from limestone mining and cement production. Therefore, the study concludes by recommending ameliorative strategies including consistent monitoring of the soil quality status, adoption of specialized technologies to curtail the rate of plume emission from stacks and the development of a phased environmental management plan (EMP) and/or impact mitigation plan (IMP) by local planning authorities.

1. INTRODUCTION

The major pollutants identified at limestone mining sites and cement production plants are typically a combination of fugitive dusts, fluns, smoke, plume, particulate matter, vapour and gas [1,2,3,4]. From limestone blasting activities through transportation to different stages of cement processing, pollutants are emitted as by-products and if not properly disposed, they constitute harmful agents within the surrounding ecosystem thereby, directly affecting soil quality and indirectly, the health status of human, animal and plant populations. Principally, the burning of raw materials (limestone, gypsum and red alluvium) in the kiln and fuels within the factory area are responsible for and constitute multiple sources of soil and water pollution in and around the surrounding environment (1; 2; 3; 4).

Although these pollutants exhibit unique health risk profile, specifically on humans and animals, they generally impact soils, water, air and plant components of the surrounding physical environment. These impacts could agglomerate and reflect at the community, country, regional and/or global levels. For instance, WHO [5] estimates indicate that the proportion of the global burden of disease associated with environmental pollution hazards ranges from 23% to 30%. These estimates include infectious diseases related to soils, drinking water, sanitation and food hygiene; respiratory diseases related to severe indoor and ambient air pollution and vector-borne diseases and zoonosis (VBDZs) with a major environmental component, such as malaria. WHO [6] reveal that these three categories of diseases individually contribute approximately 6% to the updated estimate of the global burden of diseases.

Furthermore, ambient air pollution contributes as much as 0.6% to 1.4% of the burden of disease in developing regions (including Nigeria), while other pollution elements (such as lead, magnesium, iron, zinc, etc.) in water, air and soil, may contribute 0.9% [6]. While these figures may appear minute, the contribution from most risk factors other than the "top 10" is within the 0.5% to 1.0% range [6].

Soil quality is "the continued capacity of soil to function as a vital living system, within ecosystem and land-use boundaries, to sustain biological productivity, maintain the quality of

air and water environments and promote plant, animal and human health". In the literature, soil 'quality' and soil 'health' are often used interchangeably. However, soil health is most often used to emphasize the linkage between soil and human or animal health and the idea that soil works as an organism or system, while soil quality is used as the more technical term.

Limestone processing and cement production has been a major source of soil pollution resulting from particulate matter (PM), fugitive dust and other gaseous pollutants. These particles infiltrate the soil as dry, humid or occult deposits and may impact soils' physico-chemical properties [7]. It has been recorded that soils around cement factories exhibit elevated pH levels [8], very high levels of chromium, silica, iron and calcium [9], with considerable depletion in levels of contamination as distance from the factory is gained. This generally plays a vital role in creating imbalances to the host environment. Therefore, it is instrumental in monitoring the soil quality at the surrounding environment of cement manufacturing plants [10].

Various methods of soil assessment are found in the literature. These include (but not limited to) the principal component analysis using GIS technology [10], pollution index, enrichment factor, geo-accumulation index [11], comparative analyses [12] and integrated pollution index [13]. These methods have been adopted for various soil quality assessments at the vicinity of cement plants at different location across the world. The unifying factor among the listed methods is their ability to uniquely provide information on the status of soil quality at the respective study areas.

This study was carried out at Dangote Cement PLC, Yandev, Central Nigeria. Limestone mining and cement production activities have been on-going over the past 3 decades at the study area. The study is deemed necessary as there was no environmental impact assessment carried out prior to the establishment of the factory in 1980. Additionally, soil as a major environmental component is invaluable to the human population at the study area as they are predominantly farmers. Hence, investigation into the status of soil quality at the study area and indeed elsewhere, is of scientific, economic and environmental significance. Therefore, the study focuses on:

- Determination of the concentration levels of pollutants in soils within the study area;
- Comparison of soil quality between the factory's host communities and a control community to ascertain the degree of variance in amount of soil pollutants present between the two and
- Comparison of soil quality guidelines with amount of pollutants found in soils within the study area to assess soil quality status.

2. MATERIAL AND METHODS

2.1 Study Area

The cement factory is located at Yandev, near Gboko town, in Gboko Local Government Area (LGA) of Benue State in Nigeria's north-central region. The central location of the factory is at 7° 24' 42.45"N and 8° 58' 31.28"E, at about 532 feet above mean sea level (Fig. 1). The study area, is located within a sub-humid tropical region with mean annual temperature ranging from 23ºC to 34ºC and is characterized by two distinct seasons: the dry season occurring between December and March and rainy season occurring between April

and November. The mean annual precipitation is about 1,370mm and is described by [14] as having a bimodal pattern. The average wind speed over the study area is about 1.50 m/s, while the average ambient air temperature is about 30ºC [15]. The soils of the region within which the study area is found are classified as Acrisols (Ortic and Ferric subgroups) and Dystric Cambisols [16]. The well drained soils of the study area have predominantly low activity clay fractions (kandic property), low to medium base status and low water and nutrient retaining capacities like most other upland soils of the sub-humid region [17]. The soils are generally agriculturally rich and support high cereals and tuber produce. Naturally, the area was dominated by southern guinea savanna vegetation, although at present, extensive cultivation, annual bush-burning, limestone mining and several other anthropogenic activities have transformed the vegetation into shrubs and bushes.
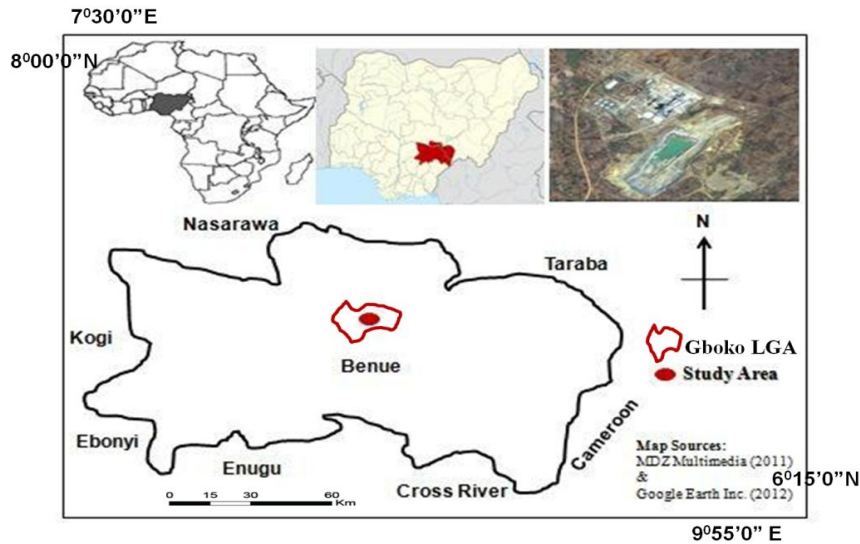

Fig. 1. Location of study area.

The area is located within the general area of the Benue Trough, which according to [18] is largely covered by Cretaceous continental (to the north) and marine (to the south) sediments. The limestone reserves at the study area are of Cretaceous formation and in excess of 70 million tonnes [19]. The River Benue is the second largest river in Nigeria and the most prominent geographical feature in Benue state. Within the study area however, the most significant water bodies to be found are two streams – 'Ahungwa' and 'Oratsor'. During the construction of the cement factory, Ahungwa stream was dammed to impound water for use by the various production processes at the factory. Similarly, the area is characteristically a flat plain without hills or rocky outcrops. The major communities within the 10-kilometre radius (comprising the area of interest to this study) include '*Mbaiwan', 'Mbatyula', 'Mbausu', 'Mbagar', 'Mbaataiwa'* and '*Mbawav'* kindreds of '*Mbatyu'* in '*Mbayion'*, Gboko LGA. The most prominent communities within the study area are '*Tse-Kucha'* and '*Tse-Amua'*. The inhabitants are largely pre-occupied in subsistence agriculture and wildlife hunting.

2.2 Collection and Analysis of Soil Samples

Soil samples were collected at 2-kilometer intervals (from the factory site) up to 10 kilometers and at *Tarhembe*, the control community located 12 kilometers to the West of the

factory (Fig. 2). A composite total of 6 soil samples were collected for the study and analysed. Soil analysis to determine the content of oxides in the soil samples was conducted at the National Geosciences Research Laboratory, Nigeria Geological Survey Agency, Kaduna. Soil heavy metals content analysis was carried out at the Kaduna State Environmental Protection Agency (KEPA) Laboratory, Nigeria. Collectively, each soil sample was analysed for 27 parameters (see analysed parameters in Tables 1 and 2).
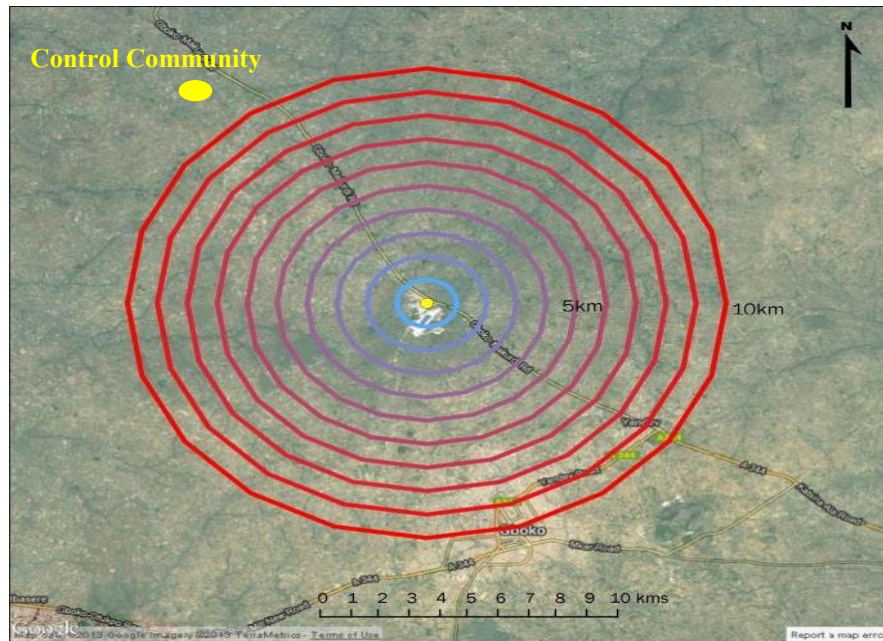
Fig. 2. Ten-kilometer buffer around factory showing soil sampling points

2.2.1 Digestion procedure

At the laboratory, 1g of soil/sediment was weighed accurately into a conical flask.12ml of conc. HNO_3 was added to the sample in the conical flask and placed in a fume cupboard. It was heated to boiling on a hot plate until fumes of acid evolved and continued heating to precipitate most of the silica. The mixture was cooled and 20ml of de-ionized water was added and boiled again to bring the metals into solution. The solution was allowed to cool again then it was filtered with 125mm filter paper into 100ml standard flask and made to the mark with de-ionized water. The 100ml digested sample solution was transferred to 100ml plastic container and taken for heavy metals determination on Atomic Absorption Spectrometer (AAS). A blank of the de-ionized water was prepared using the same procedure and subjected to the same analytical procedure.

2.2.2 Calibration standards

Calibration standard containing only the elements to be analysed was prepared. 5 sets of standards were prepared in order to obtain a good precision. Working standard solutions were prepared by diluting stock and intermediate standards. The working standards were as follows: 2, 4, 6, 8 and 10 ppm. Standard Pye Unicam hollow cathode lamps were used for each element.

2.2.3 Spectrometer specification

Thermo scientific iCE 3000 series AA spectrometers
6 lamps Automated carousal
Coded hollow cathode lamps
Wavelength range 180nm to 900nm
Absorbance range -0.150A to 3.000A

2.2.4 Flame parameters

Flame type: Air/acetylene
Nebulizer uptake: 4secs
Burner height: 7.00mm
Fuel flow: 1.2L/min

2.2.5 Calibration parameters

Calibration curve: normal
Excess curvature limits: -10% to +40%
Line fit: segmented curve
Rescale limit: 10.0%
Scaling factor: 1.000

2.3 Data Analysis

Descriptive statistics were computed for every chemical parameter for each soil sampling location. The parameters computed include mean, minimum and maximum values, standard deviation and variance. Furthermore, mean values of the parameters obtained for the various locations were compared with the various permissible limits and benchmarks set by other relevant studies (20; 21; 22) in order to identify elements with concentrations capable of causing soil pollution at the study area. Additionally, using distance as the variable, coefficient of variation (R^2) and ANOVA statistical technique were also used to determine how significantly variable the concentration of pollutants (oxides and heavy metals) found at the 6 sample points.

3. RESULTS AND DISCUSSION

Table 1 presents the oxide content of soils from the 6 sampling locations. The mean values indicate high concentration levels above permissible limits for Iron (III) oxides, Calcium oxides, Magnesium oxides, Sodium oxides and Potassium oxides. The permissible limit values were adopted from extensive studies conducted by [20]. Although the permissible limit values for other oxides could not be obtained, their mean concentration values appear to be generally higher in all soil samples closer to the factory than the Control sample. The concentration of oxides in soils around the cement factory is directly linked to plume from stacks, cement dust during packing, burning of fuels and to a lesser extent blasting of limestone as indicated by similar studies [7,10,11,12] from other parts of the world. It is important to note that geological formations also influence the presence of some oxides in the soil, however the quantities are usually trace. Higher concentrations (such as the levels recorded in this study) are driven largely by pollutants from anthropogenic (industrial and other human) activities.

Heavy metals content in soil from the 6 sampling locations (Table 2) reveal variations in concentration of the analysed parameters, and across the 6 samples. The permissible limit for soil heavy metals content is adopted from [21] and [22]. The results indicate that the mean values recorded for Iron, Lead, Manganese, Zinc, Copper and Conductivity exceed the permissible limits while the mean values for Organic Carbon, Calcium and Magnesium occur below the permissible limit. Iron, Manganese, Lead and Copper show extremely high concentration values in soils samples. Furthermore, the control sample reveals concentration below the permissible limits for Organic Carbon, Lead, Calcium and Magnesium, whereas samples 1, 2, 3, 4 and 5 (2km, 4km, 6km, 8km and 10km from factory) contain concentration levels above the permissible limit. Parameters that have displayed significant variations from the permissible limits are also shown on Tables 1 and 2, whereas Fig. 3 and Fig. 4 show the variation in concentration of oxides and heavy metals in soils across the 6 soil samples.

Further statistical analyses using the coefficient of determination (R^2) and ANOVA indicate the extent and significance of variation in concentration of oxides and heavy metals in soils at the 6 sample locations around the cement factory (Tables 3 and 4). The statistical analyses reveal variations at sample locations for both analytical methods. The R^2 values are highest for magnesium oxide, copper, pH and conductivity. The values of the (ANOVA) *F*- distribution for the analysis vary widely (Tables 3 and 4), thus indicating that the concentration of oxides and heavy metals significantly varies over the study space/sample points (2km, 4km, 6km, 8km, 10km, and the Control Community at 12km). These results collectively imply that the values of the means of the distribution (concentration of pollutants as sampled across the study area) differ more than would be expected by chance alone.

The results of soil analysis reveal relatively high concentration of pollutants in soils which are harmful to plant, animal and human populations. All oxides assessed show high levels in soils especially at the vicinity of the factory. The case is similar with heavy metals concentration. The general trend (see Fig. 3 and Fig. 4) reveals higher average concentration levels of pollutants (oxides and heavy metals) in soils within the 2km – 10 km sampling points than at the control point (12 km). Therefore, the contaminated quality of soil at the study site can hardly be excused from the limestone mining and cement production activities at Dangote Cement Plc, Gboko, given the results obtained from this study.

The implications of these levels of concentration of pollutants in soils in other parts of the world have been described by [8,9,10,12] as unhealthy for the buoyancy of plants and ecosystems. This implies that a similar scenario will play (or is playing) out at the study area.

 It is however, interesting to note that a study conducted at the study area by [23] concluded that the level of cement dust emission from the factory enhances soil properties. The findings of this study, reinforced by similar research conducted in other parts of the world [7,10,11,12,21,22], contradict the assertions by [23].

The results obtained from this study need to be emphasized among policy makers and within the research community with a view to improving the overall quality of life for human, animal and plant communities within the study area. This requires natural resource planning practices and education at the local level that would buy into the concept of sustainable development, which is rapidly unfolding in virtually all disciplines and practices across the world. As we approach the terminal year of the MDGs by 2015, it becomes undoubtedly imperative to measure up with the expectation of the sustainability principles that informed

the creation of the MDGs. This is important to avoid the risk of global intervention policies being perceived as policies designed to fail *ab initio* and with no real linkages between their provisions and prevailing peculiar conditions tenable at local environments at which such policies are directed. This appears to be the case with the study area where no environmental/social impact assessment (ESIA) was carried out prior to the establishment of the factory, neither was an environmental audit conducted subsequently. A study that provides baseline data for the study area is therefore, deemed a valuable research contribution.
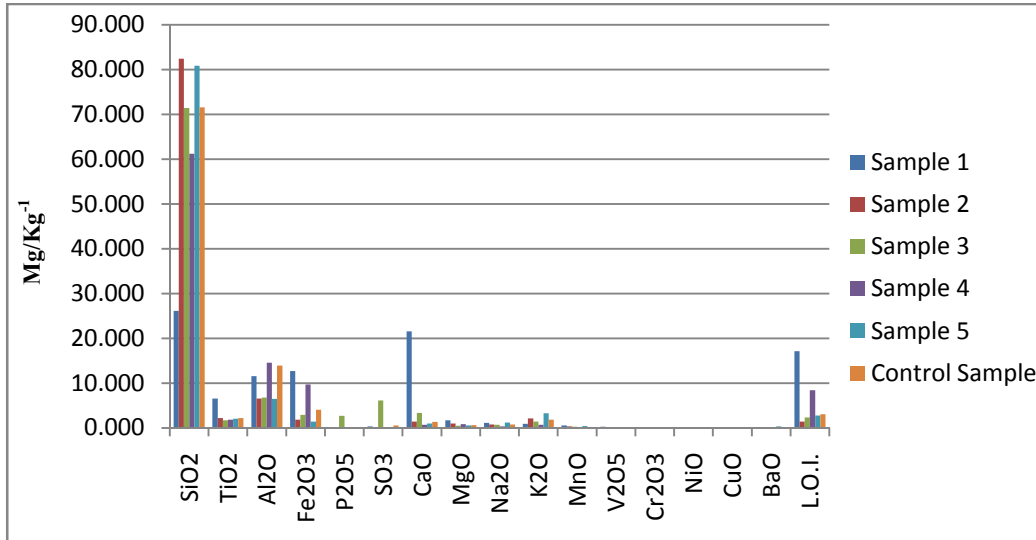

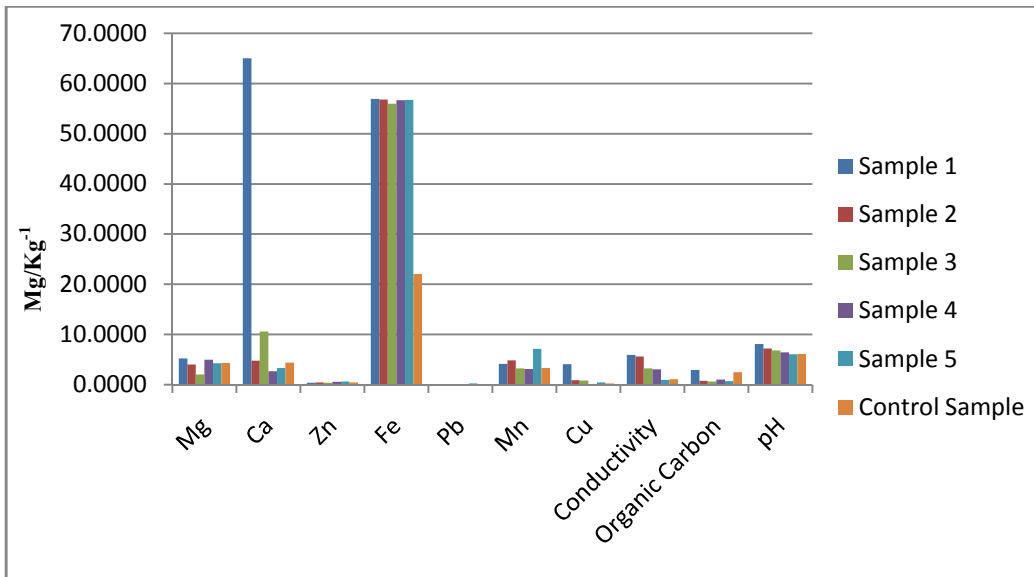**Fig. 3. Variation in oxides content in soils across the sampling points**

Fig. 4. Variation in heavy metals content in soils across the sampling points

Table 1. Oxides content in soil samples

Parameters	SiO₂ (%)	TiO₂ (%)	Al₂O₃ (%)	Fe₂O₃ (%)	P₂O₅ (%)	SO₃ (%)	CaO (%)	MgO (%)	Na₂O (%)	K₂O (%)	MnO (%)	V₂O₅ (%)	Cr₂O₃ (%)	NiO (%)	CuO (%)	BaO (%)	LOI (%)
Sample 1	26.10	6.50	11.55	12.64	ND	0.27	21.50	1.63	1.07	0.89	0.51	0.23	0.01	ND	ND	ND	17.10
Sample 2	82.44	2.14	6.51	1.81	ND	ND	1.34	0.93	0.74	2.11	0.31	0.07	0.19	0.19	ND	ND	1.35
Sample 3	71.40	1.67	6.76	2.88	2.70	6.10	3.31	0.48	0.69	1.40	0.20	0.06	0.02	0.02	0.02	ND	2.30
Sample 4	61.20	1.79	14.55	9.64	ND	ND	0.68	0.81	0.29	0.64	0.12	0.09	0.01	0.01	0.02	ND	8.40
Sample 5	80.85	1.99	6.43	1.40	ND	ND	0.93	0.50	1.15	3.23	0.36	0.07	0.02	0.02	ND	0.31	2.75
Control Sample	71.54	2.18	13.86	4.04	ND	0.54	1.32	0.61	0.70	1.83	0.19	0.09	0.01	0.02	0.02	ND	3.04
Mean	54.24	4.08	10.49	7.02	3.05	11.09	1.05	0.72	1.94	0.14	0.02	0.054	0.01	0.15	9.22	1.35	0.28
Minimum	26.10	1.67	6.43	1.40	0.00	0.68	0.48	0.29	0.64	0.06	0.00	0.00	0.00	0.00	1.35	0.00	0.12
Maximum	82.44	6.50	14.55	12.64	6.10	21.50	1.63	1.15	3.23	0.23	0.04	0.19	0.02	0.31	17.10	2.70	0.51
Standard Deviation	20.81	1.87	3.83	4.64	2.43	8.21	0.43	0.31	0.94	0.06	0.01	0.07	0.01	0.13	6.06	1.10	0.14
Variance	432.95	3.48	14.68	21.49	5.92	67.43	0.19	0.10	0.88	0.00	0.00	0.01	0.00	0.02	36.68	1.22	0.02
** Permissible Limit	NP	NP	NP	0.577	NP	NP	0.25	0.25	0.15	0.15	NP	NP	NP	NP	NP	NP	NP
Remarks	-	-	-	APL	-	-	APL	APL	APL	APL	-	-	-	-	-	-	-

*** Permissible Limit Values in %, * APL = Above Permissible Limit, * BPL = Below Permissible Limit, * NP = Not Provided, ** Source: (20)*

Table 2. Heavy metals content and physical properties in soil samples

Parameters	Organic Carbon (%)	Iron (mg.Kg⁻¹)	Lead (mg.Kg⁻¹)	Calcium (mg.Kg⁻¹)	Magnesium (mg.Kg⁻¹)	Zinc (mg.Kg⁻¹)	Manganese (mg.Kg⁻¹)	Copper (Mg.Kg⁻¹)	Conductivity (dS.m⁻¹)	pH
Sample 1	2.95	56.90	0.05	65.00	5.21	0.37	4.15	4.10	5.92	8.09
Sample 2	0.78	56.78	0.06	4.80	4.01	0.44	4.84	0.90	5.60	7.20
Sample 3	0.62	55.98	0.05	10.60	2.03	0.37	3.27	0.80	3.21	6.80
Sample 4	0.99	56.66	0.13	2.65	5.00	0.58	3.15	0.07	3.04	6.44
Sample 5	0.67	56.74	0.26	3.34	4.30	0.66	7.13	0.44	0.97	6.08
Control Sample	2.51	22.06	0.00	4.37	4.33	0.45	3.33	0.28	1.09	6.15
Mean	1.78	39.48	0.13	33.82	3.62	0.45	5.14	2.53	3.44	7.08
Minimum	0.62	22.06	0.01	2.65	2.03	0.25	3.15	0.07	0.97	6.08
Maximum	2.95	56.90	0.26	65.00	5.21	0.66	7.13	4.10	5.92	8.09
Standard Deviation	1.03	14.11	0.09	24.59	1.13	0.15	1.52	1.50	2.12	0.76
Variance	1.07	199.08	0.01	604.96	1.28	0.02	2.32	2.26	4.52	0.58
** Permissible Limit	1.0-3.0	6.3	0.01	1000	100	0.05	0.01	0.05	0.5-1.0	7.00
Remarks	WPL	APL	APL	BPL	BPL	APL	APL	APL	APL	BPL

*** Permissible Limit Values in ppm, * APL = Above Permissible Limit, * BPL = Below Permissible Limit, * WPL = Within Permissible Limit, ** Source: (21) and (22)*

Table 3. The R^2 model summary and ANOVA values for oxides in soil samples

Parameter	R	R^2	Adjusted R^2	Std. Error of the Estimate	ANOVA (f)	ANOVA (sig)
LOI	.530	.280	.100	5.744	1.559	.280
BaO	.393	.154	-.057	.130	.730	.441
CuO	.488	.238	.048	.011	1.250	.326
NiO	.311	.096	-.129	.077	.427	.549
Cr_2O_3	.235	.055	-.181	.015	.233	.654
V_2O_5	.560	.313	.141	.059	1.823	.248
MnO	.577	.333	.167	.129	2.001	.230
K_2O	.416	.173	-.033	.953	.838	.412
Na_2O	.039	.002	-.248	.371	.006	.942
MgO	.841	.708	.635	.243	9.682	.036
CaO	.682	.465	.331	6.715	3.476	.136
SO_3	.104	.011	-.236	2.706	.044	.844
P_2O_5	.131	.017	-.229	1.222	.070	.805
Fe_2O_3	.432	.187	-.017	4.675	.918	.392
Al_2O	.266	.071	-.161	4.129	.306	.610
TiO_2	.628	.394	.243	1.624	2.606	.182
SiO_2	.545	.297	.122	19.501	1.692	.263

Table 4. The R^2 model summary and ANOVA values for heavy metals in soil samples

Parameter	R	R^2	Adjusted R^2	Std. Error of the Estimate	ANOVA (f)	ANOVA (sig)
Organic Carbon	.112	.013	-.234	1.147	.051	.833
Iron	.658	.433	.291	11.881	3.051	.156
Lead	.249	.062	-.173	.100	.264	.635
Calcium	.686	.470	.338	20.018	3.548	.133
Magnesium	.027	.001	-.249	1.266	.003	.960
Zinc	.578	.334	.167	.107	2.002	.230
Manganese	.095	.009	-.239	1.697	.036	.858
Copper	.754	.569	.461	1.104	5.276	.083
Conductivity	.962	.925	.906	.652	49.160	.002
pH	.943	.889	.861	.284	32.007	.005

4. CONCLUSION

The need for consistency in similar investigations in the future at the study area is indeed, debatable. Although redemptive measures are listed as part of recommendations and suggestions, it is nonetheless important to note that in real-life situations a host of other factors also come into play in determining vulnerability including socio-economic status, cultural competence and the physical environment. In a world of myriad "*what if*" scenarios surrounding environmental degradation, it becomes very complicated to create wise health policies for the future because of the uncertainty of predicting environmental change and human decisions. The need for sound empirical decisions (such as is being offered in this study) on which to base such policies becomes more critical than ever. Therefore, the study concludes by recommending ameliorative strategies including consistent monitoring of the soil quality status, adoption of specialized technologies to curtail the rate of plume emission from stacks and the development of a phased environmental management plan (EMP) and/or impact mitigation plan (IMP) by local planning authorities.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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