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Air and heavy metal pollution around a steel foundry in Ogijo, Ogun State, Nigeria

Olayinka*, O. O. Adedeji, O. H. and **Balogun, Y.**
Department of Environmental Management and Toxicology, Federal University of Agriculture,
P.M.B. 2240, Abeokuta, Nigeria
Correponding author: fummy2favour@yahoo.com.ph

Abstract

A whole range of bye-products from industries such as steel plants and metal processing facilities create serious pollution to the environment, with negative health implications. In this study, we examined environmental pollution around African Steel Foundry in Ogun State, Nigeria. Air sampling was carried out using Land Duo Multi gas monitor to determine air pollutants such as Total Suspended Particulate Matter (TSP), Carbon monoxide (CO), Carbon dioxide (CO_2), Nitrous oxide (NO), Nitrous oxide and Nitrogen dioxide (NOx), Hydrogen sulphide (H_2S) and Sulphur dioxide (SO_2). Thirty soil and plant samples were collected from Steel Foundry. Concentrations of selected heavy metals (Fe, Cu, Cd, Ni and Pb) were determined in both soil and plant (cassava, pawpaw and maize leaves) samples using an Atomic Absorption Spectroscopy (AAS). The results show that total suspended particulate matter (TSP) ranged from 123.46 μgm^{-3}-353.74 μgm^{-3}, while CO, CO_2, NO, NO_x, H_2S, and SO_2 ranged from 3.20-13.33 ppm, 3.55-5.04 ppm, 1.36-5.69 ppm, 2.02- 8.50 ppm, 0.96-1.93 ppm and 1.63-3.96 ppm respectively. Some of these values exceeded the USEPA guideline limit of clean air. Mean concentrations of Fe, Cu, Cd, Pb and Ni found in the plants and soils were below WHO guideline limit of heavy metals. The results revealed the high concentration TSP, NO, and SO_2 which may lead to health risk after long time of exposure and also accumulation of these metals overtime may lead to contamination of the agricultural soils which eventually pose threat to organisms that feed on the plants.

Keywords: Heavy metals; foundry; environmental pollution; total suspended particulate.

Introduction

Iron and steel industries are establishments that enhance the economic welfare of citizens and supplies materials for daily life activities. Steel is pivotal to the industrialization and development of any country as it is required in the construction of buildings, household appliances, processing/manufacturing plants, equipment, and vehicles amongst others. The non-operational status of the Ajaokuta Steel Rolling Mill in Kogi State, Nigeria and its inability to effectively supply billets to the inland rolling mills such as Delta Steel Company (DSC) and Osogbo Steel Company has led to emergence of small-scale foundries, which are located close to many urban centres in Nigeria [1]. Steel companies depend on recycling of scrap iron and steel obtained mostly from municipal solid waste [2] and use either outdated or the least practicable technologies for processing due to economic constraints. [3], often resulting in the release of harmful wastes into the environment. Iron and steel industry have been linked with emission of large quantities of gaseous and particulate matter [4, 5]. The industry is also one of the most important sources of heavy metals in soils [6, 7]. Emissions from steel production spread along large areas through wind and rain, which are accumulated in soils, plants and animals and may have negative human health implications. Pollutants from iron and steel industries are of different types including gas (SO_x, NO_x, HC, CO, H_2S), and heavy metals. Four of these pollutants (CO, Pb, NO, and SO2) are emitted directly from a variety of sources [8].

Industrial pollution is of great concern in many countries globally due to its potential impact on health and environmental quality. Ambient air pollution levels

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in industrial areas of Asia, Latin America and Africa now rival and often exceed the levels experienced in developed countries [9]. Major processes in the production of finished steel include coke production, sinter production, iron making, steel making, alloying, casting, shaping, and finishing. Typically, steel is made by blowing oxygen into a blend of molten iron and scrap steel in a basic oxygen process furnace (BOF). The pollutants are hazardous because they could have adverse effects on the health of organisms, or biotic and abiotic components of the environment, or a reduction in air visibility [10]. Most of the hazardous air pollutants (HAPS) generated in BOF are heavy metals, which include iron, cadmium, chromium, lead, manganese, and nickel. Pollution prevention technologies for the reduction of heavy metals at the BOF are almost nonexistent in small-scale steel industries in Nigeria. Factors affecting HAPs emissions from the BOF include the degree of oxidation of the molten steel and the amount of time required to process the melting. Iron oxide emissions increase with the amount of time the hot metal is exposed to air and agitated by the heating process or during transfer [11]. HAPS, are also called toxic air pollutants or air toxics has been reported to be related to the prevalence of cancer or other serious health effects, including reproductive or birth defects. Several epidemiological assessments suggest that impacts on public health may be considerable [12, 13, 14]. In addition to air and water pollution, metallurgical processes can quite often pollute soil indirectly near the process itself or at the area used either for the storage of raw materials or disposal of produced waste [15].

The types of pollution from metallurgical processes depend on the nature of operation conducted in a given location and their duration [15]. Studies have reported pollution and emission from steel industries during production process [16, 17,] or the influence of created waste and of harmful substances they contain on the environment [18, 19]. For instance, during the melting of steel scrap in a furnace, heavy metals and other unwanted inorganic and organic constituents participate in a very complex reaction process involving pyrolysis and pyrosinthesis that result in the production of an array of compounds. These potentially very dangerous pollutants are then emitted into the environment as gases and particulate matter from electric arc furnace [15]. Toxic heavy metals in air, soil and plant materials are a growing problem around steel processing industries such as the African Steel Mill Foundries, Ogijo, Ogun State, Nigeria. Residents of Ajose in the immediate surroundings of the foundry have complained of heavy black smoke emanating from the factory especially at night during production process. The black smokes are released into the air through the chimney and are deposited on nearby soil and plants. Confirmed cases of ill health including respiratory, lung diseases and even deaths of some of the residents due to these emissions have been reported. (Personal observation).

Materials and methods

Study area

African Steel Mill Foundries is located on Latitude $6^0 42'$N-$6^0 51'$N and Longitude $3^0 31'$E- $3^0 42'$E in Ajose Community, Ogijo, Ogun State, Nigeria (Figure 1). It is an indigenous steel producing company, established in 2010 and provides employment to the people in the area. Several other industries are located in the Ikorodu Industrial Area due to its proximity to Lagos Metropolis, which is the commercial nerve centre of Nigeria. The climate is equatorial and is characterized by both dry and rainy seasons.

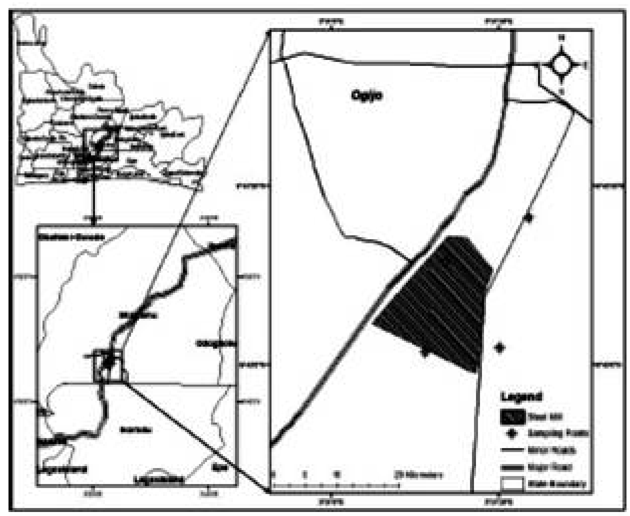

Figure 1. African Steel Foundry, Ajose, Ogijo, showing sampling points.

Sample collection

Air sampling

Air pollution indices were determined from March-November, 2013 using L and Duo Multi gas monitor and PDR 1200. Land duo is a multi-gas monitor operated with passive method using in- built sensor. It was placed on an elevated platform of 1.5 m in height at each of the sampling points and measured gas was digitised and recorded. Each measurement was determined after 5 minutes in order to ensure that a stable reading was recorded. Samples collected in a 5 m, 10 m, and 15 m radius north, west, east, and south of the steel industry. Simultaneously, the level of the pollutants Total suspended particulate matter (TSP), Carbon monoxide (CO), Carbon dioxide (CO_2), Nitrogen oxide (NO), Nitrogen oxide and Nitrogen dioxide (NO_X), Hydrogen sulphide (H_2S), Sulphur dioxide (SO_2) at each of the sampling sites was determined during peak periods (production time) for two consecutive days.

Soil and plant sampling

Soil and plant (leaves) samples of maize *Zea mays*, pawpaw *Carica papaya* and cassava *Manihot esculenta* were collected from sites in the east, west, north, and south directions of the Africana Steel Foundry (Figure 1) from March-April and October-November 2013. In addition, control soil samples were taken from an unpolluted region located far from steel foundry (Magbon) and other sources of heavy metal emission such as traffic (200 m). In all, thirty samples were taken from the chosen and marked quadrants 50x100 m. Surface soil samples were taken with a stainless steel auger at 0-15 cm depth. Mature plant samples were collected from the same points as the soil samples for analysis. Three replicate analyses were carried out for each sample.

Sample preparation

Soil samples were air-dried for two days under room temperature. Air-dried soil samples were homogenized and sieved using 2 mm mesh and stored in cleansed plastic bottles prior to laboratory analysis. The plant samples were washed with distilled water to remove soil and debris. They were then oven dried at 110°C for 4 hours to remove moisture contents. Dried plant samples were grinded in a mortar to powdered form and then stored in plastic bottles prior to digestion.

Digestion of soil and plant samples

One gram each of soil and plant samples were weighed into different conical flasks. 4 mls of concentrated nitric acid, and 2 mls of perchloric acid were added to samples in a ratio of 2:1 and digested at 180°C for 5-7 minutes. Samples were cooled, made up to 50 mls with distilled water in a volumetric flask and analysed for heavy metals (Fe, Cu, Cd, Pb and Ni) using a model 200A Buck Scientific atomic absorption spectrometer (AAS).

Transfer factor (TF)

Transfer factor (TF) is the ratio of the concentration of heavy metal in a plant to the concentration of heavy metal in soil. Transfer factor (TF) was computed for the heavy metals based on the formula:

$$\mathrm{Ps}\left(\mu g g^{-1}\right) / \mathrm{St}\left(\mu g g^{-1}\right)$$

where Ps is the plant metal content (Pg) originating from the soil dry weight (g) and St is the total metal contents in the soil [20].

Statistical analysis

Data were analyzed using descriptive, analysis of variance and Pearson’s correlation coefficients of heavy metals in soil and plants. A variance analysis (Scheffe’s test) was performed to evaluate correlations in plant <=> soil system using SPSS Version 18.0.

Results

Particulate air concentration

The concentration of total suspended particulate matter at African Steel Mill Foundries in Ajose Community ranged from 123.46 μgm^{-3} to 353.74 μgm^{-3} (Table 1), while TSP in the northern direction exceeded USEPA guideline limit for air quality (150 μgm^{-3}) [21].

Total suspended particulate matter (TSP) with other air pollutants may pose threat to the environment. Elevated total suspended particulate in the atmosphere in conjunction with oxides of sulphur and nitrogen may lead to cardiopulmonary effect which may eventually lead to death. Carbon monoxide (CO) concentrations in the sampling locations ranged between 3.20 ppm and 13.33 ppm, which exceeded international guidelines like the European Cooperation guideline limit (10 ppm) [22]. NO_X emissions around the foundry ranged from 2.02 ppm in the south direction to 8.5 ppm in the northern direction (Table 1). The NO_x recorded in the area was in the form of NO and NO_2. NO can be oxidized to NO_2 in the atmosphere ,which in turn may give rise to secondary pollutants that are injurious, NO_2 may also lead to formation of HNO_3 which may be precipitate out of the atmosphere as acid rain. The value recorded for SO_2 exceeded the European Cooperation guideline limit (0.01 ppm and [22].

Heavy metals concentrations in soils and plants

The results of the heavy metal concentrations determined in top layers of soils and plant tissues are presented in Tables 2-3. Table 2 shows the means of heavy metal concentrations in soil sample and standards from some European countries according to European Commission Director General Environment, ECDGE [23]. Iron (Fe) appeared to be the major metal pollutant in the study-area compared to the other metals determined. Concentrations of Iron were generally high compared to the values obtained for other heavy metals. Highest concentration of 322.3 mg/kg of Fe was observed in soils collected in the southern part of the study area. This was followed by the northern part with 292.8 mg/kg. Both cadmium and lead were below detection limits in the soils. Copper levels in the soil ranged from 0.17 to 0.28 mg/kg with a mean of 0.21 mg/kg. The heavy metal levels in the control-soil were within the background level range for farming.

Table 1. Means of air pollutants determined for two days compared with guideline limits.

Air pollutants	Sampling locations				Mean±SD	FMEnv. Nigeria, 1991	EU, 2006	USEPA, 2010
	West	East	North	South				
TSP(μgm^{-3})	140.56	123.46	353.74	125.32	185.77±29.2	250μgm^{-3}	150 μgm^{-3}	150μgm^{-3}
CO (ppm)	4.23	4.17	13.33	3.20	6.23±2.38	10 ppm	10 ppm	10ppm
CO_2 (ppm)	4.53	4.53	4.53	3.55	4.46±0.32	–	–	0.03-0.04% or 300 ppm-400 ppm
NO (ppm)	1.36	2.39	5.60	1.89	2.81±0.95	0.04-0.06 ppm	–	–
NO_X (ppm)	2.56	2.96	8.50	2.02	4.01±1.51	-	–	0.053 ppm
H_2S (ppm)	0.96	1.16	1.93	1.19	1.31±0.21	-	–	10 ppm
SO_2 (ppm)	1.63	1.63	3.96	3.43	2.66±0.61	0.01	0.01	0.03 ppm

Table 2. Means of heavy metal concentrations in soil sample (mgkg^{-1} dry matter).

Heavy Metals	Sampling Locations				Mean±SD	Control	Germany	Netherlands	United Kingdom
	West	East	North	South					
Fe(mgkg^{-1})	207.29	244.78	292.81	322.29	266.8±50.9	2.01	–	–	–
Cu (mgkg^{-1})	0.17	0.18	0.28	0.21	0.21±0.09	0.03	40	40	3
Cd (mgkg^{-1})	< 0.01	< 0.01	< 0.01	< 0.01	0.01±0.00	ND	1	0.5	135
Pb (mgkg^{-1})	< 0.04	< 0.04	< 0.04	< 0.04	0.04±0.00	ND	70	40	300
Ni (mgkg^{-1})	0.10	0.11	0.14	0.05	0.10±0.03	ND	50	15	75

Table 3. Means of heavy metals in plant sample (mg/kg dry matter).

Heavy metals/sampling locations		Samples			Control site			Safe Limit of Heavy Metals (plants)	
		Pawpaw	Cassava	Maize	Pawpaw	Cassava	Maize	WHO 2001	Codex Alimentarius Commission 2011
Fe:	West	42.48	6.67	24.49	0.05	0.02	0.03	425	–
	East	11.12	8.73	9.94					
	North	9.42	9.56	9.49					
	South	6.59	6.97	6.78					
Cu:	West	1.30	0.19	0.76	0.03	0.01	0.02	73.0	–
	East	0.15	0.14	0.15					
	North	0.31	0.31	0.30					
	South	0.20	0.21	0.21					
Cd:	West	0.00	0.00	0.00	ND	ND	ND	0.20	0.05-0.2
	East	0.00	0.00	0.00					
	North	0.00	0.00	0.00					
	South	0.00	0.00	0.00					
Pb:	West	0.00	0.00	0.00	ND	ND	ND	0.30	0.1-0.3
	East	0.00	0.47	0.25					
	North	0.00	0.00	0.00					
	South	0.00	0.00	0.00					
Ni:	West	0.12	0.06	0.09	ND	ND	ND	2.00	–
	East	0.03	0.03	0.03					
	North	0.13	0.13	0.14					
	South	0.02	0.11	0.08					

Iron has the highest concentration in the plant material (pawpaw) as recorded in soil samples. However, it was observed that plant samples collected in the western part of the study-area had the highest concentration of Fe (Table 3).

Transfer factors (TF) from soil to the plants

Table 4 shows the transfer factor (TF) of heavy metals from the soil to plants, which is the ratio of the concentration of metals in plants to the total concentration in the soil. The TF values for Fe, Ni, Cu, and Zn, for the plants varied greatly between these and locations (Table 4). It was observed that Cu had the highest transfer factors in the west location which was 4.41 mg/kg compared to Fe and Ni whose TF values were 0.11 and 0.92 respectively. Transfer factor for Cd and Pb were very low compared to Cu in all location except in the eastern side where Pb had a TF value of 1.66 compared to 0.04, 0.83 and 0.27 for Fe, Cu and Ni respectively. Soil electrolyte plays an important role in the process of metal transfer [24]. The electrochemical properties of soil reflected through the temperature, pH, and electrolyte concentration, etc. thus influenced the migration transformation ability of toxic metal indirectly [25].

Table 4. Transfer factor of heavy metal from soil to plant.

Location	Fe (mg/kg)	Cu (mg/kg)	Cd (mg/kg)	Pb (mg/kg)	Ni (mg/kg)
West	0.11	4.41	< 0.01	< 0.04	0.90
East	0.04	0.83	< 0.01	1.66	0.27
North	0.03	1.10	< 0.01	< 0.04	0.92
South	0.02	1.00	< 0.01	< 0.04	0.14

There was a strong positive correlation between Fe and Cu in both the soil and plant materials in the study-area compared to other heavy metals examined (Table 5). Linear correlation coefficients showed a distinct dependence between content of heavy metals in plants and soils.

Table 5. Pearson's correlation between different heavy metals in the soil and plants near African Steel Foundry, Ogijo.

Soil					
	Fe	Cu	Cd	Pb	Ni
Fe	1				
Cu	0.955	1			
Cd	0.000	0.000	1		
Pb	- 0.233	- 0.503	0.000	1	
Ni	- 0.475	0.307	0.000	- 0.445	1
Plant					
	Fe	Cu	Cd	Pb	Ni
Fe	1				
Cu	0.641	1			
Cd	0.000	0.000	1		
Pb	-0.288	-0.403	0.000	1	
Ni	-0.342	0.448	0.000	0.178	1

Discussion

Air pollution

Mean concentrations of air pollutants including particulate matter were TSP-185.77 µgm^{-3}, CO-6.23 ppm, CO_2-4.46, NO-2.81 ppm, NO_x-4.01, H_2S-1.31 ppm and SO_2-2.66 ppm. Total suspended particulate matter in the study-area exceeded the USEPA standard limit of 150 µgm^{-3} [10]. Particulate air pollution is a mixture of particles that vary in number, size, shape, surface area, chemical composition, solubility and origin [26, 27]. The size distribution is typically trimodal, including coarse particles (aerodynamic diameter >2.5 ìm), fine particles (aerodynamic diameter between 0.1 and 2.5 µm) and ultra-fine particles (UFP, aerodynamic diameter <0.1 µm) [26, 28, 29]. Particulate air pollution is of particular concern with fine particles receiving worldwide attention due to their ability to cause adverse health effects such as asthma and death [30, 31, 32, 33]. They have been found to be consistently and independently related to the most serious effects of air pollution, including daily and longer-term average mortality [9, 34, 35]. It has been observed that the effects of particulate matter on mortality were modified by mean concentrations of nitrogen dioxide [36]**.** It has been reported that the effects of PM_{10} were greater in cities while $PM_{2.5}$ comprised a higher proportion of $PM_{10.}$ [37] and attributed maximum concentration of PM_{10} of 68 µgm^{-3} has been reported in a study in Dhaka, Bangladesh mostly to the synergistic effects of both anthropogenic and natural sources[38].

$PM_{2.5}$ is reported to have a stronger risk factor than the coarse part of PM_{10} (particles in the 2.5-10 µm range) and long-term exposure to $PM_{2.5}$ is associated with an increase in the long-term risk of cardio-pulmonary mortality by 6-13% per 10 µg/m^3 of $PM_{2.5}$ [39,40,]. This calls for reduction of emissions from the foundry in the study-area in order to reduce the probable health impacts that breathing in such pollutants may have on the local residents. Pope reported that in the Utah Valley hospital admissions for severe respiratory diseases decreased significantly during 1986-1987 when the local steel mill was closed [41].

Heavy metals concentration

The average concentrations of heavy metals obtained in the top layer soil and plant tissue in this study are given in Tables 2 and 3. Results of the study indicate that the concentrations of heavy metals decreased with the distance from the steel foundry and are higher than the levels detected in the control-soil. Majority of the metals, especially Fe, had pronounced maximum concentrations in the sites located in the influence zones of steel foundry with ferrous processing activities. Concentration of Fe in the topsoil in the vicinity of the foundry range from 207.3 mg/kg and 322.3 mg/kg with mean value of 266.8 mg/kg. Analysis of metal uptake by plants serving as biosensors permits an evaluation of pollution in the studied area [42]. Fe has the highest concentration in the plant tissue ranging from 6.78 mg/kg to 24.60 mg/kg. It is a fact that high concentrations of heavy metals in soils are reflected by higher concentrations of the metals in plants, and consequently in animal and human bodies [43]. Concentration of Cu found in the soil range from 0.17 mg/kg to 0.28 mg/kg, while Ni ranged from 0.1 mg/kg to 0.14 mg/kg. Cu was found to be higher in the plant tissues suggesting other additional sources of the metal. It must be noted that heavy metal accumulation may occur in tissues gradually [44, 45] and over time could reach toxic concentration levels, much beyond permissible limits [46].

Heavy metal pollution not only affects the production and quality of crops, but also influences the quality of the atmosphere and water bodies, and may have potential adverse effects on animals and humans through the food-chain. Studies have shown that soils contaminated with toxic metals from point sources are potential exposure routes for surrounding population [42, 47]. Heavy metals accumulated in cultivated soils could be transferred to humans through various exposure pathways causing adverse effects on human health [47]. Heavy metals are known as one of the major contaminating agents in food [48, 49] and accumulation of these metals in agricultural soils pose threat to food safety and health due to soil-to-plant transfer of metals [50]. The study reveals that Fe is the most abundant in the soil samples. Fe is ubiquitous in the surroundings of the study-site and this may be associated with the activities of the steel foundry which pose significant environmental risks [51]. Although Fe is an essential nutrient for humans, excess concentration of Fe in food crops may cause hemochromatosis in the body-system, with a concomitant damage. In addition, exposure of Pb may affect the blood, kidneys, and the central nervous system, cardiovascular, and reproductive systems [52]. There are differences in the metal concentrations of the plant materials and the soil in the vicinity of the foundry (Table 3). The observed differences may be attributed to a different pollution level of the examined-places [42]. However, continuous consumption of these metals could lead to accumulation and adverse health implications particularly for Fe, Cu and Ni, which may be due to the leaching and run off from the industry to the farmlands.

Conclusion

The study reveals the presence of all analysed metals in the soils and plants around the foundry. The concentrations of the metals in the soils were in the order of Fe>Cu>Ni> Pb>Cd and also below recommended limits. The metals analyzed in plants were below the recommended limits; however accumulation of these metals overtime may lead to contamination of the agricultural soils which eventually pose threat to organisms that feed on the plants. TSP, NO, and SO_2 were higher than air quality guideline limits which may result into health risks after long time of exposure. Therefore, there is need for monitoring the total suspended particulate matter in both urban and semi-urban areas with industrial establishments such as Ogijo to assess population exposure and to assist local authorities in establishing protocols for improving environmental quality.

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