Estimated Annual Discharge Rates of Heavy Metals from Industrial Sources around Lagos; a West African Coastal Metropolis

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Abstract

A survey to determine the physico-chemical characteristics and heavy metal content of industrial effluents collected from different categories of industries around the Lagos metropolis, Nigeria, was carried out over a 12–month period. The annual discharge rates of the identified heavy metal species were estimated using results of the chemical measurements and other relevant information. The most prominent heavy metals occurring at the first four highest concentrations in the sampled effluents were Fe (1.82–4.4 mg l^{-1}), Mn (0.099–0.295 mg l^{-1}), Cu (0.011– 0.27 mg l^{-1}) and Co (0.156–0.49 mg l^{-1}). Mercury, occurring at 0.004 mg l^{-1}, was only detected in effluents of the chemical and allied category of industries. Using appropriate relationships and information, and taking all investigated categories of industries into account, a total of 161,717.9 kg of Fe was discharged into the environment around metropolitan Lagos, followed by Cu (22,341.4 kg), Mn (20,589.6 kg), Co (15,682.6 kg), Cr (5,285.1 kg), Pb (2,258.6 kg), Zn (702.2 kg), Ni (613.7 kg), Cd (537.8 kg) and Hg (277.8 kg) in descending order of total discharge per annum. The importance of such data in environmental management is discussed while stressing the need to combine such information with results from bio-monitoring studies to avoid misleading conclusions.

Introduction

Industrialization remains an extant need to meet the increasing demands of the world's teeming millions for more food, energy, goods and services. However, pollution inevitably arises therefrom. Although the economic benefits of industrialization are incontestable, there is the need to make industrialization compatible with a reasonably healthy environment in which contaminant levels are minimized. Consequently, there has been a number of studies aimed at understanding relevant characteristics of the environment and man-made inputs as benchmarks for judicious management (Flos *et al.*, 1987; Clements *et al.*, 1990; Ayodele *et al.*, 1991; Chen *et al.*, 1991; Bryan & Langston, 1992; Ortego & Benson, 1992). The focus of most of these studies is usually the determination of ambient concentrations of critical contaminants and pollutants and, sometimes, aspects of their biological effects but in most cases without attempts at quantifications of the magnitude and rate of mobilization. Yet, for proper environmental management, it is also useful to know the rate of discharge of these contaminants or pollutants into the environment.

In this regard, studies such as the one reported in this work should provide useful information on rates of mobilization of heavy metals into the environment and also serve as useful inputs into the global quantitative inventory of land–based sources of pollution

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by heavy metals and other classes of pollutants. In addition, information from such quantitative studies will permit the identification and ranking of these species in terms of potential ecological accumulation and other effects. Furthermore, coupling of information from such studies with those from studies on biological effects will, among others, facilitate the formulation or modification of more appropriate and effective guidelines, limitation standards and other environmental management measures within a sustainable framework.

Lagos is a major metropolitan centre along the West African coast. With a population of about 12 million, it is the most populous coastal metropolis in the Gulf of Guinea. In addition, over 60% of all industries in Nigeria are situated in the Lagos metropolitan area (FMHE, 1983; Portman *et al.*, 1989; Oyewo, 1998). In a study on industrial database for Lagos State in Nigeria, WES (1997) enumerated more than 2,000 industrial establishments around Lagos metropolis. Effluents from these industries are discharged into the various compartments of the environment along with their loads of heavy metals and other pollutants.

Materials and methods

In a chemical survey of industrial effluents as sources of critical pollutants, FMHE (1983) identified four industrial areas in the Lagos Metropolis. To update this information, two more were added in this study making a total of six. Nine industrial effluent points (comprising at least one from each of these areas) were sampled (Table 1). Effluents were collected every other month from all nine discharge points for 12 months between March 1989 and March 1990.

On each sampling day and at each sampling point, morning (8.0–9.30 a.m. and afternoon 12.00–2.00 p.m.) samples were collected to reflect a more representative effluent composition. At the point of collection, the appearance, dissolved oxygen (DO), temperature, *p*H and discharge rates were measured using visual appraisal, Winkler's method, electronic thermometer, *p*H meter and 'flow timing', respectively. The samples were kept in pre-cleaned, screw–cap containers (2 l capacity) and taken to the laboratory for storage in a refrigerator. To prevent adsorption, the

TABLE 1

Locations of different discharge points from which effluents were sampled

Sampling point location	*Zone*	*Type of industry*
Adeniyi Jones Aromire street junction	Ikeja	+ Chemical and allied
Ashade market precinct	Ikeja	Chemical and allied
Akinola close discharge point, Onigbongbo	Ikeja	Chemical and allied
Eric-Moore road discharge point	Iganmu	Textile
Anthony Village Flyover/Oshodi expressway junction	Icupeju	Textile
Oshodi express way collection point 1	Isolo	Textile
Oshodi express way collection point II	Isolo	Textile
Oregun road/Lagos Ibadan express road	Oregun	Food and beverages
Lagos Harbour collection point	Apapa	Soaps, detergents and cosmetics

+ Chemical and allied grouping includes chemical plants, metal products, plant manufacturing, plastic plants, pharmaceuticals, printing presses and rubber products.

samples were acidified to $pH < 2$ (APHA, AWWA, WPCF, 1980). Subsequently, the composite effluent samples were properly mixed and digested with nitric acid following standard procedures (APHA, APWA, WPCF, 1980). Instrumental analysis was done by comparing sample absorbances when aspirated into flame, with those of factory-prepared AAS standard solutions using an Alpha-4 Cathodeon Atomic Absorption Spectrophotometer for all the metals except Hg, for which the Cold Vapour Accessory of the same equipment was used. For data quality assurance, particular attention was paid to the cleanliness of all wares. In addition, factory-prepared AAS standard solutions were run as samples at pre-determined intervals to check accuracy and precision.

In order to estimate the annual rate of discharge of heavy metals *via* industrial effluents at their points of discharge around Lagos, the following parameters were investigated: mean concentration of heavy metal species in industrial effluent samples, rate of effluent discharge per unit time at sampling points, approximate number of hours of effluent flow per day of production and number of days of industrial production accompanied by effluent discharge per year. The entire investigation was facilitated by a combination of the foregoing chemical measurements, visual observations of colour and appearance as well as interviews with factory workers and citizens working or living near the investigated industries, and/ or their effluent discharge points for information on number of working hours per day and number of working days per year which, in this particular study, are 15 and 300, respectively. For the purpose of this study, the investigated industries were grouped into four on the basis of their products.

Employing the foregoing parameters, the following relationship (Oyewo, 1998) was used to give the required estimate:

$$\text{EADR (kg)} = \frac{\text{NWHD} \times \text{NWDY} \times \text{C} \times \text{D (3,600)}}{1{,}000{,}000}$$

(1 h = 3,600 secs); (1 kg = 1,000,000 mg)

On reduction to lower terms, this relationship can also be written as:

$$\text{EADR (kg)} = \frac{\text{NWHD} \times \text{NWDY} \times \text{C} \times \text{D} \times 9}{2{,}500}$$

where EADR = Estimated annual discharge rate; NWHD = Number of working hours per day; NWDY = Number of working days per year; C = Average concentration of heavy metals in mg l^{-1} in effluent sample; D = Rate of effluent discharge (L sec^{-1})

Results

Physico–chemical characteristics of sampled industrial effluents

Observations of effluents at the points of entry into drainages or other water bodies revealed that at different times, they were of various colours ranging from brown to green to yellow. There were also differences in the measured physico-chemical characteristics. The temperature ranged between 27 and 48 °C, pH values were in the range 6.9-10.7 while the dissolved oxygen (DO) ranged between 2.79 and 4.97 mg l^{-1} (Table 2).

Presence and concentrations of heavy metals in industrial effluents

All the industrial effluents sampled contained different types of heavy metals occurring in varying concentrations (Fig. 1, Table 3).

On the basis of proportion of occurrence

TABLE 2

Physico-chemical characteristics and discharge rates of effluents at their discharge points

Types of industires	*Discharge points*	*Appearance*	p*H mean ±SE*	*Temperature (°C) mean ±SE*	*Dissolved oxygen mg l^{-1} mean ±SE*	*Discharge rate l sec^{-1} mean ±SE*
Chemical and allied	Adeniyijones/ Aromire Street Junction, Ikeja	Turbid and varicoloured	9.5±0.48	29.07±0..91	4.19±0.26	9.1±2.32
Chemical and allied	Ashade Market Area, Ikeja	Varicoloured	7.3±0.17	28.89±0.65	4.80±0.25	5.26±1.72
Chemical and allied	Akinola Close, Onigbongbo, Ikeja	Varicoloured	7.5± 0.14	48.33±1.81	3.54± 0.32	10.13±1.80
Textile	Eric-Moore Road, Iganmu	Turbid and varicoloured	10.7±0.94	30.90±0.79	2.79±0.21	2.5±0.45
Textile	Anthony Village Flyover/Oshodi Express Junction, Ilupeju	Varicoloured	6.9±0.11	28.37±0.71	3.31±0.33	2.13±0.32
Textile	Oshodi Expressway collection point 1, Isolo	Varicoloured	7.5 + 0.45	27.70 + 0.66	3.43 + 0.20	0.58 + 0.08
Textile	Oshodi Expressway collection point II, Isolo	Varicoloured	8.3±0.38	39.76±1.14	3.03±0.20	1.39±0.08
Food and beverages	Oregun Road Lagos-Ibadan Expressway, Oregun	Slightly turbid and varicoloured	7.6±0.22	27.9±71.14	4.86±0.37	2.34±0.24
Soaps, detergents and cosmetics	Lagos Harbour collection point, Apapa	Varicoloured	8.5±0.33	27.73±0.74	4.97± 0.34	1.91±0.17

of heavy metals analysed, the constituents of the effluents were shown to vary within industries that produced similar products and between those that produced different products (chemical and allied, textile, food and beverages, soaps and detergents) (Fig.1, Table 3). The mean concentration of heavy metals within each group/type of industrial effluents sampled showed that with the chemical and allied industries, the concentration of Fe was the highest (1.85 mg l^{-1}) followed by Cu, Mn, Co, Zn, Cd, Pb, Ni, Cr and Hg (0.004 mg l^{-1}) in a descending order (Table 4). With the textile industries, Fe was again the heavy metal that occurred at the highest concentration (1.82 mg l^{-1}) followed by Co, Zn, Mn, Cu, Cd, Pb, Cr and Ni (0.001 mg l^{-1}) in descending order, whereas Hg was not detected (Table 3). In the food and beverages industries, Fe and Cr occurred at the highest and lowest concentrations, respectively (Table 3). Typical AAS instrumental detection limits are presented in Table 3a.

Taking all categories of industries together, the highest concentration of Fe was recorded in the food and beverages industries followed by soaps and detergents, chemical and allied,

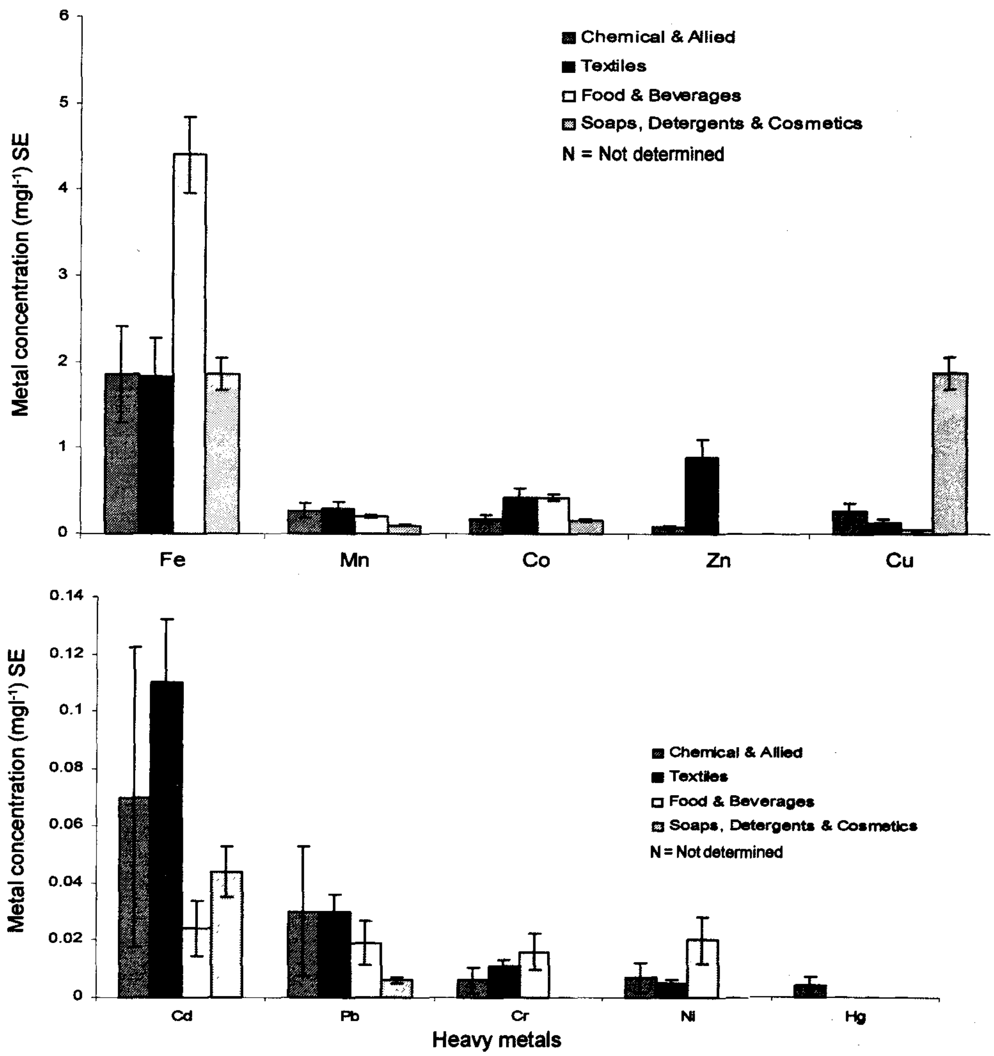

Fig. 1. Mean concentrations of heavy metals (mg l^{-1}) ±SE measured in effluents collected fron categories of industries

and textile in descending order (Table 3). Mercury was only detected in effluents from the chemical and allied industries. The most prominent heavy metals occurring at the first four highest concentrations in the various industrial effluents were Fe, Mn, Cu and Co (Fig. 1, Table 3).

Estimation of the amount of heavy metals discharged into the environment with industrial effluents around Lagos metropolis

Based on the relationship described earlier, the amount of heavy metals introduced into the environment annually per single industry varied between 215.18 kg of Fe and 0.47 kg of Hg for the chemical

Table 3a

Mean concentrations of heavy metals in effluents from different categories of industries

Type of industries	Mean heavy metal concentration (mg l^{-1}) ± SE									
	Fe	*Cu*	*Ni*	*Cd*	*Mn*	*Pb*	*Cr*	*Zn*	*Hg*	*Co*
Chemical and allied	1.85 ±0.61	0.27 ±0.092	0.007 ±0.002	0.07 ±0.046	0.269 ±0.61	0.03 ±0.03	0.006 ±0.002	0.073 ±0.015	0.004 ±0.002	0.17 ±0.048
Textile	1.82 ±0.28	0.13 ±0.026	0.005 ±0.002	0.11 ±0.032	0.295 ±0.046	0 0.03 ±0.006	0.011 ±0.004	0.88 ±0.07	nd	0.49 ±0.055
Food and beverages	4.4 ±0.377	0.039 ±0.011	0.02 ±0.008	0.024 ±0.011	0.203 ±0.019	0.019 ±0.008	0.016 ±0.008	ND	nd	0.423 ±0.042
Soaps, detergent and cosmetics	1.86 0.072	1.87 ±0.026	nd	0.044 ±0.008	0.099 ±0.019	0.006 ±0.004	nd	ND	nd	0.156 ±0.011

nd = Not detected
ND = Not determined

Table 3b

*Typical AAS instrumental detection limits (DL)**

Metal	*Flame*	*Furnace*	*Vapour*
Fe	0.06 mg l^{-1}	1.5 pg	-
Cu	0.04 mg l^{-1}	1.8 pg	-
Ni	0.063 mg l^{-1}	3.6 pg	-
Cd	0.034 mg l^{-1}	0.98 pg	-
Mn	0.029 mg l^{-1}	0.57 pg	-
Pb	0.10 mg l^{-1}	1.50 pg	-
Cr	0.05 mg l^{-1}	0.72 pg	-
Zn	0.013 mg l^{-1}	0.22 pg	-
Hg	-	-	1.2 µg l^{-1}
Co	0.081 mg l^{-1}	2.5 pg	-

* Source: Pye Unicam 969 AAS Cookbook

and allied industries, 48.65 kg of Fe and 0.13 kg of Ni for the textile industries, 166.80 kg of Fe and 0.6 kg of Cr for the food and beverages industries, and 57.86 kg of Cu and 0.19 kg of Pb for the soaps and detergents industries (Table 4). When these estimated amounts of discharged heavy metals per unit industry were multiplied by an estimated number of industries within each category (after MAN, 1989, World Environment Systems, 1997), the total amount of each metal that was discharged by each group of industries per annum are given in Table 5. Out of all the heavy metals detected in the various effluents, the amount of Fe discharged per annum was the highest in all categories of industries, with the greatest amount discharged from 591 chemical and allied industries (127171.4 kg) followed by the estimated 56 food and beverages industries (27188.4 kg), 85 textile industries (4135.3 kg) and 56 soaps, detergent and cosmetic industries (3222.8 kg) (Table 5). Other prominent heavy metals discharged along with industrial effluents included Cu, Mn, Co, Zn, Cd and Pb in descending order in terms of amounts while Ni, Cr and Hg occurred in relatively small quantities.

Overall, the estimates showed that a total of 161,717.9 kg of Fe was discharged into the environment in metropolitan Lagos by all investigated categories of industries in this study followed by Cu (22,341.4 kg), Mn (20,589.6 kg), Co (15,682.6 kg) and Zn (7,026.2 kg)–estimate from only two categories of industries and not four (Tables 5 and 6); Cr (5285.1 kg), Ni (613.7 kg), Cd (537.8 kg) and Hg (277.8 kg) in descending order of total discharge per annum.

TABLE 4

Estimated annual discharge rates (EADR) of heavy metals per industry at the effluent discharge points of different categories of industries

Industry category	Heavy metal sampled (kg) Fe	Cu	Ni	Cd	Mn	Pb	Cr	Zn	Hg	Co
Chemical and allied	215.18	31.41	0.81	8.14	31.29	3.49	0.70	8.49	0.47	19.77
Textile	48.65	3.49	0.13	2.94	7.89	0.80	0.29	23.63	0.00	13.10
Food and beverages	166.80	1.48	0.76	0.91	7.70	0.72	0.61	ND	0.00	16.04
Soaps, detergents and cosmetics	57.55	57.86	0.00	1.36	3.06	0.19	0.00	ND	0.00	4.83

ND = Not determined

TABLE 5

Estimated amount of annual discharge of heavy metals from different categories of industries⁺ in Lagos metropolis

Industrial category		Heavy metal (kg) Fe	Cu	Ni	Cd	Mn	Pb	Cri	Zn	Hg	Co
Chemical and allied	1	127171.4	18,563.3	478.7	4810.7	18,492.4	2062.6	413.7	5017.6	277.8	11,684.1
Textile	2	4135.3	296.7	11.1	249.9	670.7	68.0	24.7	2008.6	0.00	1113.5
Food and beverages	3	27188.4	241.2	123.9	148.3	1255.1	117.4	99.4	-	0.00	2614.5
Soaps, detergents and cosmetics	4	3222.8	3240.2	0.00	76.2	171.4	10.6	0.00	-	0.00	270.5
Total		161717.9	22341.4	613.7	5285.1	20589.6	2258.6	537.8	7026.2	277.8	15682.6

+ Based on all industries
Estimated number of industries after MAN, 1989 and World Environmental Systems, 1997

1 : 591
2 : 85
3&4 : 56

Discussion

Using the empirical relationship mentioned earlier, it was estimated that a total of 161,717.9 kg of Fe, 22,341.4 kg of Cu, 20,589.6 kg of Mn, 15,682.6 kg of Co and 7,026.2 kg of Zn were discharged from industrial sources alone into the environment annually. Although no similar estimates based on empirical measurements and observations are available for the study area, these figures are likely to be particularly realistic because the underlying assumptions were based on observations and interviews with relevant persons and agencies, and relevant studies were carried out over a 12-month period. The results of such interviews were the basis for knowing the number of working hours per day and the number of days in a year accompanied by production. Additionally, the estimated number of industries should be very close to reality since it included even small–scale enterprises as well.

Given the fact that the discharges are continual, the estimates offer possible explanation to the effect that the concentration of some heavy metals in the Lagos lagoon (the ultimate recipient of the loads of the discharges) sediments and water have already exceeded their toxicity thresholds against sensitive species like *Mugil* sp., *T. guineensis* and *Cypris* sp., established in laboratory bioassays in a related study (Oyewo, 1998). Furthermore, comparison with a similar study carried out in India shows that the estimated discharge rates of Cr in this study was higher whereas the estimated discharge rates of Zn, Cu, Hg and Pb were lower in each case when compared to the rates of discharge of the respective metals into the Ulhas and Kalu-Waldhuni tributaries around Bombay (Patel *et al.*, 1985).

It is noteworthy that the distribution of *p*H and DO in the entire lagoon system are generally uniform in time and space irrespective of effluent reception status (Oyewo, 1998). Thus, in spite of the known effects of these parameters on speciation, availability and toxicity of heavy metals, the *p*H and DO status of the effluents do not seem to exert sufficient influence for any significant changes in these parameters in the Lagos lagoon environment. However, the amounts of heavy metals discharged into the environment as a result of industrial activities around Lagos metropolis will likely increase in the future as more industries are established.

The estimated rates of heavy metal discharge provide good experimental evidence to support the need for imposing stricter limitation standards for industrial effluents, and enforcement *via* regular monitoring to ensure compliance. It is, however, pertinent to caution that the figures presented in this paper do not necessarily represent potential toxicity magnitudes. The information should thus be used along with data from bio-monitoring and other relevant investigations to avoid misleading conclusions. For example, whereas Cu has a higher discharge rate than Mn, the latter has a much higher toxicity threshold (Oyewo,1998) suggesting that it is less toxicologically significant. However, Fe has the highest discharge rate and the highest toxicity threshold of all the investigated metals in a related earlier study (Oyewo, 1998).

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