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Urban Highway Runoff in Nigeria 1: Heavy Metals in Sheet Flow from the Main Expressway in Lagos Metropolis

B.I. Alo, A.A. Abayomi, B.A. Osuntogun and K.O. Olayinka
Department of Chemistry, University of Lagos, Nigeria

Abstract: Whole-unfiltered-water samples were collected from the runoff of a major highway in Lagos metropolis at four different points along the road and at the receiving stream through which the runoff eventually discharges into the lagoon. The study was conducted to characterize the types and levels of pollutants on a typical Nigerian road and was carried out during three different rainy days between the months of February and May, 2004. The collected samples were analysed for the presence of heavy metals; Cd, Cr, Cu, Pb and Zn. Pollution-indicating indices such as dissolved oxygen, BOD5, total solids, conductivity, chlorides, hardness, alkalinity and acidity were also determined. The results of the analyses showed that Zn was most prominent in the sampled runoffs with mean concentrations of 68.7±3.0, 119.7±58.3 and 33.1±24.0 ppb in the three sampled events. Cd -at a concentration of 0.6 ppb was only detected in one of the samples. The concentrations of these metals were shown to vary with the time of sampling during the precipitation. Levels were generally higher in first flush samples.

Key words: First flush, heavy metals, highway, pollution, precipitation, runoff

INTRODUCTION

Pollution from non-point sources such as highway runoff has continued to be a major source of concern for environmental regulatory bodies and other stakeholders the world over as they contribute to the pollutant load of the receiving environment, in most cases the water bodies and farmlands. This results to a gradual degradation of the receiving water quality and an eventual impairment of the beneficial uses of such receiving environment (Pitt *et al*., 1995). The Nigerian situation is further exacerbated by the reality of increasing large-scale importation of old/fairly used vehicles for use on the Nigerian highways. Lagos is the commercial capital of Nigeria and it's the fastest growing metropolis in Nigeria (and probably in sub-Saharan Africa) with the nation's largest population and network of highways. Hence, there is a need for a comprehensive study on the effect (s) of runoff from these highways on the proximate environment.

A wide range of pollutants have been shown to be present in highway runoff with about 75% (by dry weight) of these pollutants derived directly or indirectly from vehicles, road surface degradation, atmospheric sources and road maintenance (Ellis and Revitt, 1991). Heavy metals such as copper, cadmium, chromium, lead and zinc among others are constantly being studied and monitored in highway runoffs because of their probable mobilization to useable water systems such as the beaches and underground water, where at elevated concentration levels could cause public health risks (Dwight *et al*., 2002). As these heavy metals and other pollutants are continuously mobilized to such water bodies and exposed land mass, they ultimately lead to soil and water pollution (Perdikaki and Mason, 1999). Though, the level of the pollution depends on the nature of civil works on the highway, the duration of the Antecedent Dry Period (ADP) before the rainfall, size of the rainfall, volume of traffic per day of the study site and nature of land use of the adjoining area (Driscoll *et al*., 1990), various studies have emphasized on the importance of the first flush phenomenon, which are basically samples collected within the first few minutes of the commencement of rainfall, as being a suitable marker towards identifying the upper limits of these pollutants (Barret *et al*., 1993; Soller *et al*., 2004; Mangani *et al*., 2005).

Globally, the concentration, transport and fate of some of these pollutants are usually difficult to generalise on especially in most runoff studies (Grenato and Smith, 1999) because rainfall occur not at fixed and definite times, but randomly with varying intensity, resultant volume and quality of the runoff (Marsalek *et al*., 1997; Luke and

Corresponding Author: B.I. Alo, Department of Chemistry, University of Lagos, Nigeria

Barrie, 2001). Nevertheless, persistent efforts directed at monitoring these pollutants have shown that Zinc, Lead, Copper, Cadmium and Nickel along with some other heavy metals could all be found in urban and highway runoffs (Marsalek *et al*., 1997; Luke and Barrie, 2001; Mangani *et al*., 2005). Other pollutants that could be found in highway runoff include hydrocarbons and bacteria of human origin such as faecal coliforms (Barret *et al*., 1993), along side pollution-indicator indices such as total solids, total suspended solids, dissolved oxygen (DO), Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) (Perdikaki and Mason 1999; Hvitved-jacobson and Yousef, 1991).

The monitoring of the composition of wet-deposition (e.g., rain, sleet, snow) on urban highways and its effects on urban pollution has been an important part of environmental studies in many countries (Mangani *et al*., 2005; Backstrom *et al*., 2003), where rich data have been generated on the composition of highway and other urban source runoff. Although, increasing urbanization in Nigeria has led to thousands of kilometers of highway in Nigeria's cities, yet, no study has ever been undertaken on pollution from highway runoff, even though there are heavy tropical downpours for about 9 months of the year, thus necessitating this research especially when viewed against the backdrop of a general lack of extant vehicular maintenance and road management culture in Nigeria.

The impacts are further escalated by the rampant use of derelict or fairly used automobiles with uncertified engines imported from other countries as well as vehicle maintenance with substandard motor spare parts. Yet, residences of teeming populations border the highways. Hence, a series of studies were commenced to determined the nature and levels of some trace metals in runoffs from strategic highways in Nigeria, identify other pollutants including nutrients that may be contained there-in, establish the maximum levels of these pollutants as may be contained in the first flush analysis and propose suitable BMPs to address any anomaly that may be uncovered.

MATERIALS AND METHODS

Study location: The study site was the Ikorodu expressway in the metropolis of Lagos, southwest Nigeria. The road is a main dual carriage 8-lane highway, traversing the entire mainland of the metropolis and stretches from Jibowu in Lagos Mainland to the nearby twin-city of Ikorodu in the state. It is a major highway that links various parts of the state via a rich network of adjoining access roads. It is also a major route for vehicles conveying different products; commercial, petroleum and agricultural, into and from Lagos. Other features of the road include a uniform bitumen coated asphalt surface with concrete curbs and median, service lanes on both sides, a subsurface drainage system with runoff inlets at intervals along the entire length of the road, a mixed land use of mainly residential, administrative and commercial enterprises and a relative traffic volume of about 30,000 vehicles per day (Table 1).

Sampling: For this systematic assessment, a 2.4 km strip of the road was chosen based on it proximity to a receiving stream (location ST) and a less probability of pollutant influence from other non-highway related activities that may lead to their introduction from other sources such as industrial and domestic wastes. The sampling site was then subdivided into four geo-referenced sampling locations (Table 2) at the Onipanu (OP), Palmgrove (PG), Obanikoro (OK), Anthony Village (AT) areas of the city along the highway. These locations were chosen as a result of their different elevations along the road with location OK being the lowest point of the four at 75 ft above sea level. The receiving stream at an elevation of 64 ft drains off the runoff via the sub-surface pipe and eventually discharges it contents into the Lagos lagoon.

Sampling was conducted on 2nd February, 13th April and 19th May, 2004, all between 10-13 h local time. Due to the unpredictability of rain even in a tropical country like Nigeria, the sampling regime adopted was a flexible one

Table 1: Site description of ikorodu road, lagos, Nigeria

Characteristics	Attributes	Mode of analysis
Average Daily Traffic (ADT)	>30,000	Estimation
Lanes	4+4	Observation
Road shoulder type	Curbed	Observation
Road surface type	Asphalt coated	Observation
Annual mean rainfall		
Topography	Slightly sloppy	GPS
Land use	Administrative, Commercial, Residential.	Observation
Imperviousness	>90%	Estimation
Maintenance regime	Occasional street sweeping	Observation
Runoff treatment	None	Observation

Adapted from Backstrom *et al.* (2003)

that permits the collection of whole-water runoff samples as soon as the sampling team could be mobilized to the various locations on indication of possible rainfall while bearing in mind the need for at least 72 h antecedent dry period before runoff sampling (US EPA 1992) and the need to capture the first flush samples. Though one of the sampled events did not meet this requirement but sampling was nevertheless conducted for comparison basis. Acid pre-washed 2 L polyethylene bottles were placed in such a way that their openings were at the same level with the edge of the drainage while their bulks were held at an angle of about 30° in the drainage inlets. The tilting angle ensures that the bottles were filled up to the brim to exclude air. The bottles were then tightly secured and immediately transported to the lab for analysis. One sample per location per sampled event were obtained and the mean for each location evaluated.

Sample treatment and chemical analysis: The Temperature and pH of each sample was determined in-situ using a mercury-in-glass thermometer and pH meter respectively. Other analyses were carried out in the laboratory immediately after sampling. The Dissolved Oxygen (DO) and the Biochemical Oxygen Demand (BOD_5) were determined by the azide modification method; the conductivity was determined by electrometrical method; the chloride was determined by the silver nitrate method; hardness, acidity, alkalinity, total solids and dissolved solids were determined by standard methods for water and waste water analysis (APHA-AWWA-WPCF).

The trace metals were determined by atomic absorption spectrophotometry (AAS) using the BULK SCIENTIFIC 200 instrument. Two hundred fifty milliliter of each acidified sample were pre-concentrated to about 20 mL with nitric acid digestion and the volume made up to 50 mL with distilled water. A procedural blank of the nitric acid and distilled water was also subjected to the same treatment to correct for any tailing effect from the reagent. All parameters were determined within their holding time with necessary preservatives added were applicable.

Table 2: Geo-referenced position of sampling locations

Sampling location	Position	Elevation (ft)
OP	N06°31'57.9''	
	E03°22'01.9''	91
PG	N06°32'23.9''	
	E03°22'01.4''	104
OK	N06°32'39.0''	
	E03°22'01.1''	75
AT	N06°33'36.3''	
	E03°22'00.1''	90
ST	N06°33'01.4''	
	E03°22'03.2''	64

OP = Onipanu, PG = Palmgrove, OK = Obanikoro, AT = Anthony Village, ST = Receiving Stream, ft = feet

RESULTS AND DISCUSSION

The pH values obtained for the runoff samples were predominantly neutral, 6.50-7.53, with a mean of 6.93±0.28 (Table 3). But those of the receiving stream, ST, were alkaline with a maximum of 10.31 and a mean of 9.80±0.69 (Table 4). This may be ascribed to the nature of the soil in the stream. The conductivity obtained correlated with the observed chloride levels with mean of 11.9±0.8 μS cm^{-1}; 4.7±3.3 ppm and 11.7±0.3 μS cm^{-1}; 3.7±0.6 ppm for the runoff and stream, respectively. The DO level for the runoff with a mean of 9.0±2.9 ppm was lower than that of ST with a value of 12.7±0.6 ppm. This may be due to the increase dilution effect and agitation of the rainwater when collecting in the stream. Overall, the values for the

Table 3: Physico-chemical parameters of sampled runoffs

	OP			PG			OK			AT			
Parameters	S_1	S_2	S_3	S_1	S_2	S_3	S_1	S_2	S_3	S_1	S_2	S_3	Mean±SD
pH	6.70	7.02	6.50	6.84	7.37	6.90	6.77	7.53	6.82	6.75	6.99	6.91	6.93±0.28
Temp. (°C)	26.0	26.0	26.0	26.0	26.0	26.0	25.5	25.0	26.0	26.0	26.0	25.5	25.8±0.3
Conduct (μS cm^{-1})	11.4	12.0	11.6	11.4	11.6	11.6	12.2	11.8	11.4	14.4	11.6	11.4	11.9±0.8
TS (ppm)	284	251	200	216	261	216	273	231	213	198	239	158	228±35
TDS (ppm)	115	124	135	176	154	130	202	100	153	163	138	121	142±28
DO (ppm)	6.5	10.9	10.7	4.6	10.5	11.5	4.9	10.5	11.3	4.9	10.9	11.1	9.0±2.9
BOD_5 (ppm)	ND	61.4	61.3	63.2	65.3	57.5	80.5	21.1	19.2	49.8	34.5	36.4	45.9±23.7
Acidity (ppm $CaCO_3$)	50.9	22.3	20.7	25.4	24.9	23.9	22.8	19.6	22.3	23.3	19.6	16.9	24.4±8.7
Alkalinity (ppm $CaCO_3$)	42.9	39.0	27.3	42.9	35.1	23.4	35.1	31.2	21.5	39.0	42.9	31.2	34.3±7.5
Hardness (ppm $CaCO_3$)	89.1	41.8	41.8	79.9	41.8	39.9	76.6	41.8	39.9	79.9	39.9	41.8	54.5±20.0
Chlorides (ppm)	10.0	7.0	4.0	3.0	3.0	3.0	2.0	12.0	2.0	3.0	3.0	5.0	4.7±3.3

OP = Onipanu, PG = Palmgrove, OK = Obanikoro, AT = Anthony village, TS = Total Solids, TDS = Total Dissolved Solids, TSS = Total Suspended Solids, DO = Dissolved Oxygen, BOD_5 = Biochemical Oxygen Demand, ND = Not Detected, ppm = part per million, S_1 = 2nd Feb. event, S_2 = 13th April event, S_3 = 19th May event

Table 4: Physico-chemical parameters of the receiving stream

	Receiving Stream (ST)			
Parameters	S_1	S_2	S_3	Mean±SD
pH	10.31	10.07	9.02	9.80±0.70
Temp. (°0C)	25.50	25.50	26.00	25.7±0.3
Conduct (μS cm^{-1})	11.60	11.40	12.00	11.7±0.3
TS (ppm)	350.00	360.00	325.00	345±182
TDS (ppm)	114.00	196.00	213.00	174±53
DO (ppm)	13.50	12.80	12.30	12.7±0.6
BOD_5 (ppm)	65.40	19.10	40.20	41.6±23.2
Acidity (ppm $CaCO_3$)	6.40	5.30	3.20	4.9±1.6
Alkalinity (ppm $CaCO_3$)	66.30	70.20	58.50	65.0±6.0
Hardness (ppm $CaCO_3$)	39.90	41.80	41.00	40.9±1.0
Chlorides (ppm)	4.00	4.00	3.00	3.7±0.6

S_1 = 2nd February event, S_2 = 13th April event, S_3 = 9th May event, ppm = part per million, SD = Standard Deviation

Table 5: Concentration range (ppm) of some pollutant indicators in highway runoff

Pallutant indicators	UK*	US FHWA**
Total solids	-	437-1147
Dissolved solids	-	356
Suspended solids	11-105	45-798
BOD_5	8-25	12.7-37.0
COD	-	14.7-272.0
Chlorides	1.3-27	-
Total phosphorous	-	0.113-0.998
Oil/ total hydrocarbons	2.8-31.0	2.7-27.0
Total coliforms	-	570-6200

* The Institute of Highways and Transportation, UK, 2001, ** US FHWA, 1996

Table 6: Comparison of heavy metal concentration in highway runoff (ppm)

			Present study	
Heavy metals	UK*	US FHWA**	Runoff (n = 12)	Stream (n = 3)
Zinc	0.02-1.90	0.056-0.929	0.013-0.200	0.076-0.118
Lead	0.01-0.15	0.073-1.780	0.003-0.074	0.017-0.026
Copper	0.01-0.12	0.022-7.033	0.011-0.048	0.022-0.142
Cadmium	-	0.00-0.04	0.006^+	BDL
Chromium	-	0.00-0.04	0.001-0.016	0.003-0.007

* = The Institute of Highways and Transportation, UK, 2001, ** = US FHWA, 1996, + = Only detected in one sample, BDL = Below Detection Limit

DO did not show a significant depletion of oxygen with just 20% of the total analysed samples having values below 5.0 ppm. Fifty percent of the runoff samples showed values exceeding the 50 ppm recommended BOD_5 levels by the FMEnv, Nigeria for discharges to surface water (FMEnv, 1991), though, the mean were 45.9±23.7 and 41.6±23.2 for the runoff and stream samples, respectively. The acidity levels were low with the lowest range observed for the samples from ST, though they have higher alkalinity, which is as a result of their high pH values. The mean values obtained for the acidity and alkalinity were, respectively 24.4±8.7; 34.3±7.5 ppm $CaCO_3$ and 4.9±1.6; 65.0±6.0 ppm $CaCO_3$, respectively for the runoff and stream samples.

The results obtained for the analysis of the trace metals (Table 8) showed that Zinc was more prominent in all the sampled events with a mean concentrations of 68.7±3.0 119.7±58.3 and 33.1±24.0 ppb, respectively for the S_1, S_2 and S_3 events. Cadmium was only detected at site OK during the S_2 event. Also, the concentrations of Lead, Copper and Chromium were higher during the S_2 event with values of 54.0±28.4, 31.3±11.7 and 7.75±5.7 ppb, respectively. The higher values observed for the S_2 event could be attributed to the fact that these could be termed a first flush event as sampling was achieved within 15-20 min of the start of rainfall unlike the other events which sampling were carried out between 30-35 min from the start of rainfall. Amongst the samples obtained for the first flush event, location OK generally had higher concentrations for all the metals analysed (Table 7). This was adduced to the fact that OK is at a lower elevation to all the other locations, thus there is a strong tendency for it to experience a wash-down process whereby pollutants in runoffs from places of higher elevations are by the force of gravity washed down and thus collect at this point before draining off. Though this trend was not noticed in the other events, it does not totally foreclose this process as it may have been masked by the dilution effect at the time of sampling. The levels of trace metals obtained in the samples from the receiving stream, ST (Table 7) were generally lower than those of the runoff from the highway. This is as a result of the high dilution factor in the stream.

Comparatively, the results from this study are consistent with the trend of similar studies around the world as shown in Table 5 and 6 (US FHWA, 1996;

Table 7: Concentrations (ppb) of heavy metals in sampled runoff at each location

	Zn			Pb			Cu			Cr			Cd		
Sampling locations	S_1	S_2	S_3	S_1	S_2	S_3	S_1	S_2	S_3	S_1	S_2	S_3	S_1	S_2	S_3
OP	65.0	125.4	48.0	20.0	68.0	55.0	15.0	29.0	26.0	3.0	5.0	1.0	0.0	0.0	0.0
PG	72.2	75.3	59.0	22.0	12.0	0.0	13.0	21.0	12.0	3.0	3.0	1.0	0.0	0.0	0.0
OK	67.9	200.0	12.7	11.0	74.0	0.0	11.0	48.0	13.0	3.0	16.0	3.0	0.0	0.6	0.0
AT	69.7	77.9	12.7	22.0	62.0	3.0	12.0	27.0	37.0	11.0	7.0	3.0	0.0	0.0	0.0
ST	56.6	117.5	46.1	17.0	26.0	0.0	22.0	41.5	23.5	4.0	7.0	3.0	0.0	0.0	0.0

S_1 = 2nd February event, S_2 = 13th April event, S_3 = 9th May event, ppb = part per billion

Table 8: Mean concentrations (ppb) of heavy metals in sampled runoff

Heavy metals	S_1 2nd Feb.	S_2* 13th April	S_3 19th May
Zinc	68.7±3.0	119.7±58.3	33.1±24.0
Lead	18.8±5.3	54.0±28.4	14.5±27.0
Copper	12.8±1.7	31.3±11.7	22.0±11.9
Cadmium	ND	0.6**	ND
Chromium	5.0±4.0	7.75±5.7	2.0±1.6
Rainfall size (mm)+	11.2	46.2	0.6
ADP (days)+	3	4	1

* First flush concentrations, ** Only detected in the S_2 event at location Ok, + Data provided from the nearest meteorological station to sampling site by the Nigerian Meteorological Agency, Oshodi, Lagos

Institute of Highway and Transportation, UK 2001). Recently, Backstrom *et al.* (2003) showed that Zn at a concentration of 89.3 and 124 ppb was more prominent in runoff collected in summer and winter, respectively in Svaneberg, Sweden. Also, Mangani *et al.* (2005) concluded that Zn was the most abundant of the heavy metals studied from the first flush analysis of runoff from a highway in central Italy, with variabilities in observed concentrations ascribed to site characteristics and rainfall pattern. Soller *et al.* (2004) in a study conducted in San Jose, US, showed that the concentrations of heavy metals in first flush samples is dependent on the antecedent dry period and the size of the rainfall with an observed range of 25-260, 40-470 and 0.7-18.5 ppb for Zn, Cu and Pb, respectively. For the present study, the high concentrations of the metals observed for the S_2 event could be ascribed to the antecedent dry period, ADP (Table 7) and period of sampling while those of the S_3 were due to the fact that a larger size of rainfall of 18.9 mm witnessed a day prior to the sampling must have washed most of any accumulated pollutant off the road surface.

This is also coupled with the fact that the period of sampling was not as early as that of S_2. By and large, the range of the S_2 event showed the importance of ADP and early sampling for first flush analysis.

CONCLUSIONS

By and large, the following were deduced from this study:

- The range obtained for the heavy metals were in tandem with those of similar studies elsewhere as shown in Table 6.
- They were also below the permissible concentrations of trace metals in water being discharged to surface water as established by the FMEnv., Nigeria.
- Further studies are on-going on the PAHs' and nutrients' levels in the Lagos highway runoff as well as those from other states of southern Nigeria.
- Also, the Nigerian authorities are being engaged to incorporate suitable Best Management Practice, BMP, when designing highways as is being practiced in developed countries to check pollution from road runoff.

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