Multivariate Analysis of Potentially Toxic Metals in Sediments of a Tropical Coastal Lagoon

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Abstract

Surface sediments collected from the Lagos Lagoon, Nigeria, and three adjoining rivers were analysed for their physicochemical properties and pseudototal concentration of the potentially toxic metals (PTM) Cd, Cr, Cu, Pb and Zn. The concentration of the PTM varied seasonally and spatially. Odo-Iyaalaro was observed to be the most polluted river, with highest concentrations of 42.1 mg kg^{-1}, 102 mg kg^{-1}, 185 mg kg^{-1}, 154 mg kg^{-1} and 1040 mg kg^{-1} of Cd, Cr, Cu, Pb and Zn respectively, while Ibeshe River was the least contaminated, apart from a site affected by Cu from the textile industry. Some of the sediments were found to be above the consensus-based probable effect concentrations and Dutch sediment guideline for metals. Overall metal concentrations were similar to those reported for other tropical lagoon and estuarine systems affected by anthropogenic inputs as a result of rapid urbanisation. Due to the large number of samples, principal component analysis was used to examine relationships within the data set. Generally, sediments collected during the dry season were observed to have higher concentration of PTM than those collected during the rainy season. This means that PTM could accumulate over a prolonged period and then be released relatively rapidly, on an annual basis, into tropical lagoon systems.

Keywords: Lagos Lagoon, Potentially toxic metals, principal component analysis, sediments

1. Introduction

Rapid urbanisation and industrialisation can lead to the release of a wide variety of pollutants, from both point and diffuse sources, and thus place considerable pressure on aquatic resource such as coastal and riverine systems. This is of particular concern in developing countries where expansion of urban area may be relatively unregulated and where environmental protection may be, or may historically have been, inadequate (Fonesca *et al*. 2011; Li *et al.* 2007; Manning 2011; Nriagu 1992; Ramessur *et al.* 2010).

Sediments in tropical lagoon and estuarine systems of developing countries are increasingly studied because they can act as both sinks for potentially toxic metals (PTM), allowing records of past inputs to be reconstructed where no contemporary monitoring data exists, and as sources, with potential impacts on ecosystems and human health (Acevedo-Figueroa *et al.* 2006; Ahmad *et al*. 2010; Alagarsamy 2006; Alaoui *et al.* 2010; El Ati Hellal *et al.* 2011; Fonesca *et al*. 2011; Jara-Marini *et al.* 2008; Li *et al.* 2007; Pereira *et al.* 2010; Vázquez-Sauceda *et al.* 2011; Xu *et al.* 2009; Zourarah *et al.* 2007). Pollutant metals may affect the population directly through contact with contaminated sediment or water and *via* the food chain. A further exposure route exists where contaminated sediment is dredged and used for land reclamation or construction.

Lagos State is Africa's biggest city and the fastest growing metropolis in the world. It is the most heavily industrialised city in Nigeria, with much of the nation's wealth and economic activities located there. The City of Lagos is currently undergoing an extensive program of expansion and development with the aim of becoming a 'megacity' and major international focus for trade and industry (Howden 2010; Thisday's Special Intenational Project 2007). The state is reported already to be home to over 70% of the country's medium and large-scale manufacturing industries (Oketola and Osibanjo 2007). Some of the manufactured goods produced in the city include machinery, motor vehicles, electronic equipment, chemicals, beer, processed food, and textiles. The urban area is built on a number of flood plains and encompasses a network of marshes, swamps, streams, creeks and rivers which receive large quantities of storm water run-off, together with domestic, municipal and industrial waste effluents, and these receptors empty into the Lagos Lagoon. Odo-Iyaalaro, Shasha and Ibeshe Rivers are three main trans-urban rivers in the state, receiving domestic and industrial wastes from numerous sources.

The Lagos Lagoon is a brackish coastal lagoon – the largest in the West African coast – located between longitude 3º 23’ and 3º 40’E and between latitude 6º 27’ and 6º 48’N. It is a fairly shallow expanse of water (0.3-3 m deep) which is about 50 km long and 3 to 13 km wide and separated from the Atlantic Ocean by a narrow strip of barrier bar complex. The lagoon is used for fishing, irrigation and recreation.Its pollution by PTM has potential adverse effects on both aquatic life and onhuman beings whose life and livelihood depend on the Lagos Lagoon (Abayomi *et al*. 2011; Isebor *et al*. 2006; WES 1997). Dredging of sediment from the lagoon, although illegal, is commonplace to satisfy local demand for building materials.

Relatively few researchers have worked previously on the pollutant levels in Lagos Lagoon and its environs. Ihenyen (1991) measured high concentrations of PTM in sediments from areas within the Lagos Harbour, which he attributed to the impact of industrial effluent. Otitoloju and colleagues conducted experiments on the uptake of Cd, Cu, Hg, Pb and Zn by benthic organisms from the lagoon (Otitoloju 2003; Otitoloju and Don-Pedro 2004; Otitoloju *et al*. 2007). In their study, it was observed that sediment samples from the western part of the lagoon generally had higher concentrations of PTM compared to the eastern region. Most recently, Abayomi *et al.* (2011) studied the contribution of roadside soil to phosphorus loading in the Lagos Lagoon, but this was not related to the concentration of PTM in the water or sediments. Thus, despite rapid industrialization in this region, there has been a dearth of recent robust information on sediment-metal concentrations and relationship between sediment properties and metal levels. Further, there is no information on seasonal-variations in metal-pollutant loads, which may be of importance in tropical regions affected by distinct dry and rainy seasons.

Many studies focusing on the aquatic environment now use multivariate analysis techniques to aid in interpretation of results. For example, Altm *et al*. (2009) in their study on the assessment of seasonal variations of surface water quality characteristics of Porsuk stream used a variety of methods to display the information concealed in the variables observed in a water quality monitoring network. Some of the multivariate statistical techniques which have been used in literature include cluster analysis, principal component analysis, discriminant analysis and multiscaling analysis. Kikuchi *et al*. (2009) used both cluster analysis and principal component analysis to evaluated spatial and seasonal variations in the concentrations of PTM in Nhue River and one of its tributaries, the To Lich River. The two multivariate analyses showed that the level of PTM in water of To Lich River was distinctly different from that of Nhue.

The aims of the current study are to (i) quantify the levels of Cd, Cr, Cu, Pb and Zn in sediments of the Lagos Lagoon systems. (ii) examine relationships between pH, % organic matter, CEC, grain size, Cd, Cr, Cu, Pb and Zn in the sediments using principal component analysis (iii) investigate seasonal variations in the PTM contents in sediments of these waterbodies, and (iv) compare concentrations with other aquatic systems and with sediment quality standards to inform the development of appropriate management strategies for the lagoon.

2. Experimental

2.1 Study areas

The study areas include the Lagos Lagoon and three rivers: Odo-Iyaalaro, Shasha and Ibeshe Rivers. Sediments samples were collected from each of the rivers six times during the year at different seasons (rainy and dry). Samples were collected at three points along each river, at the points of discharge of each of the rivers, and at points approximately 1 km offshore and to the east and west of the discharge of the rivers into the Lagos Lagoon (Figure 1 shows the sampling stations). The Lagos Lagoon was sampled three times during the year. Samples were only collected once from points 1 and 2 due to lack of access thereafter. Thus, 26 sediment samples were collected from Odo-Iyaalaro River, 36 samples each were collected from Shasha and Ibeshe Rivers, and 15 samples were collected from the Lagos Lagoon (a total of 103 sediment samples).

2.2 Sediment samples

The samples were collected using a stainless steel grab sampler deployed from the riverbank, a bridge, or a boat. Samples were placed in polyethylene containers and taken to the laboratory. Once in the laboratory, the sediment samples were air dried, homogenized in a mortar, sieved to pass through a 2 mm stainless steel sieve and stored in polyethylene containers prior to analysis.

The pH of the sediments was determined according to BS ISO 10390 (1995), using a Philips PW 9420 pH meter and the organic matter content (%OM) was estimated by Walkley-Black method (1934). The cation exchange capacity (CEC) was determined by first saturating the sediment with sodium ion, the sodium ion was then exchanged for ammonium ion. The amount of sodium exchanged was determined by flame atomic absorption spectrometry (FAAS), using caesium as an ionisation suppressant (Ryan *et al*. 2001). Grain size analysis was carried out on the dry sediment samples by laser granulometry using the method of Webster *et al*. (2000). The concentrations of Cd, Cr, Cu, Pb and Zn were determined by digesting 1 g of each of the sediment samples with 20 ml *aqua-regia* in a microwave (CEM MDS-2000) (British Standard, ISO 11466 1995) with microwave power from 0 to 630 W depending on the number of samples digested. The total period of digestion was 50 mins. The digests were filtered using Fisherbrand QL 100 filter paper (11 cm) into 100 ml standard flasks, made up to the mark with distilled water and stored in plastic bottles at a temperature of 4 ^{o}C prior to analyses. The sediment samples were digested in triplicate. The quantification of the analytes was performed by FAAS using a Perkin Elmer AAnalyst 200 instrument with air-acetylene flame under optimal conditions. The detection limit of the instrument ($DL_{inst.}$) for each of the metal of interest was determined using the equation below. Procedural detection limits ($DL_{pro.}$) were also calculated taking into consideration the digestion methods used(Vandecasteele and Block 1997).

$$DL_{inst.} = {}^{3s}\!/_{b}$$

where

s = standard deviation of the ten replicate measurements of the calibrant solution

b = slope of the calibration curve

2.3 Quality control

For the determination of potentially toxic metals, the precision and accuracy of the method used was determined by using reference material BCR CRM 143R. This is a sewage sludge amended soil which is a certified reference material for *aqua-regia* soluble metals. The digestion of the sediments was carried out in triplicates for each sample, and for each batch of digestion there was a procedural blank.

2.4 Multivariate analysis

In order to reduce the relatively large number of variables to a smaller number of orthogonal factors, the original data obtained was processed by multivariate statistical methods. The associations of parameters in sediments were determined by principal components analysis (PCA) and applying varimax with Kaiser Normalization rotation method to facilitate easier interpretation. Varimax rotation maximizes the sum over components of the variances of the squared loadings, thereby emphasizing cluster recognition. The eigenvalues were used to determine the number of PCs to be retained in order to comprehend the trends in the data. The PCA was carried out with factors that have eigenvalues greater than 1. The PCA was carried out using the SPSS for windows software version 13.0

3. Results and discussion

3.1 Quality control

Table 1 shows the results of PTM concentration in the certified reference material BCR CRM 143R. Found values were within two standard deviations of the certified values for all metals in the *aqua regia* digests, and a recovery of 95 to 105% was obtained. This indicated that the analysis was under control. Further, the relative standard deviation obtained for analysis of triplicate test portions of the lagoon sediment samples was < 10% in most cases.

3.2 Sediment properties and pseudototal metal concentration

Sediment properties and pseudototal metal concentration during the rainy and the dry seasons are summarized in Table 2, while the actual values for the different sampling points are given in online resources 1 and 2.

3.2.1 Odo-Iyaalaro River

For Odo-Iyaalaro River, the sediment pH ranged from 2.8 to 5.6 during the dry season, and from 3.6 to 5.1 during the rainy season, indicating that the sediments were acidic throughout the year. The % organic matter ranged from 0.8 to 21.0 and 1.4 to 15.7, while the CEC of the sediments ranged from 2.0 to 14.6 meq/100g and 4.2 to 14.2 meq/100g during the dry and rainy seasons respectively. Sediment samples collected from points 5 and 6 were on most occasions observed to have higher organic matter content than those from other points in the river. This could arise from decaying plant material as there are large quantities of plants growing at the bank of the river at these sites. Samples from points 5 and 6 in Odo-Iyaalaro River were also observed to generally have higher concentrations of metals compared to other points along the river (apart from site 1, discussed below) for both dry and rainy seasons. This could be due to the high organic matter content of the sediment since organic matter is known to influence PTM adsorption in sediments (Loska and Wiechu 2003). Furthermore, the high concentration of metals at points 5 and 6 could be because that they are close to other tributaries emptying into the Lagos Lagoon, and the water from these tributaries may contain high concentrations of PTM.

Samples collected from points 3 to 6 showed distinct seasonal trends, with generally higher metal concentrations found in sediments collected during the dry season (up to double the amount found in the rainy season for Cd and Zn at sites 5 and 6). The month of March, which is the peak of dry season, had particularly higher concentration of metals when compared with samples collected from the same point in other months (21.3, 139, 119 and 777 mg kg^{-1} for point 5 and 34.4, 185, 154 and 1040 mg kg^{-1} for point 6, for Cd, Cu, Pb and Zn respectively). This may be as a result of accumulation of these PTM in sediment during the dry season, and remobilisation during the rainy season. The current study did not investigate whether the metals are mobilised in solution or suspension, but the importance of particulate transport for PTM in aquatic systems is well established (Viers *et al.* 2009) and the change observed in average sediment grain size distributions at sites 3-6 from 52% sand + 18% silt + 30 % clay in the dry season to 64% sand + 14% silt + 22% clay in the rainy season shows that, as would be expected, fine particles are lost when river flow rate increases (results of grain size analysis for all sediment samples are provided in online resources 3 and 4).

Previous workers have reported seasonal influence on sediment metal concentrations in tropical systems, but findings are contradictory. Similar to the current study, Bahena-Manjarrez *et al.* (2002) found highest metal concentrations in the dry season in the Coatzacoalcos River, Mexico, and this was supported by Alagarsamy (2006) who reported lowest metal concentrations during the monsoon in the Mandovi estuary, India. However, whereas a significant difference between pre-monsoon and monsoon concentrations of Cd in sediments of Buriganga River (Dhaka, Bangladesh) was noted recently (Ahmad *et al.* 2010) no seasonal differences were found in the same study for levels of Cu, Cr, Ni or Pb. Indeed, Jara-Marini (2008) reported that sediment metal concentrations in the Mazatlan Harbour increased during the rainy season, although that was as a site where deposition and accumulation of material washed down from the upper reaches of the river system might have been important.

The sample collected from point 1 had amongst the highest concentrations of Cd, Pb and Zn found in the Odo-Iyaalaro River (42, 108 and 805 mg kg^{-1} respectively). This point is under a road bridge and so the high concentrations could be due to anthropogenic input from vehicle wear and exhausts. Descriptive statistics (Table 2) showed Odo-Iyaalaro to be the most polluted of the three trans-urban rivers in terms of the average concentrations of Cd (9.6 and 4.8 mg kg^{-1}), Pb (56.7 and 63.5 mg kg^{-1}) and Zn (292 and 147 mg kg^{-1}) during the dry and rainy seasons respectively.

3.2.2 Shasha River

For Shasha River, the pH ranged from 4.3 to 7.3 during the dry season, and from 4.2 to 7.7 during the rainy season. This indicates acidic to neutral sediments. For this river, the highest concentrations of PTM were observed at point 7 during both the rainy and dry seasons. This may be because the sampling point is very close to a bridge which normally has a high traffic density and is also close to industries. Lead levels as high as 202 mg kg^{-1} were found which, as in the case with samples from point 1 from Odo-Iyaalaro, could be caused by the exhausts of vehicles since tetraethyl lead is still used in petrol in Nigeria. The concentration of Cd was found to be generally less than the procedural detection limit of 0.9 mg kg^{-1}, except in a few cases. This showed that Cd is not a pollutant in this river. The PTM concentrations in sediments from Shasha River were observed to decrease with decreasing distance from the Lagos Lagoon. This variation may be correlated with the location of industries and their waste disposal system: there are more industries closer to point 7 than other points along this river and their effluents are reflect in the higher PTM levels upstream, whereas the sediments far away from these source will be diluted with uncontaminated material. The average concentration of PTE in Shasha River were lower than in Odo-Iyaalaro River, except for Cr in the rainy season, and no clear seasonal trends were evident.

3.2.3 Ibeshe River

In Ibeshe River, Cu was observed to be the major metal pollutant. The low concentration of other PTM could be because the water body is located in a relatively rural area where there is very little emission from either industrial effluents or vehicular traffic. There was an increase in Cu concentration at site 14 relative to site 13, which is probably due to the discharge of effluents by a textile company that uses Cu as one of the components of dye. The highest concentrations of Cu at point 14 were observed in the months of February (332 mg kg^{-1}) and March (246 mg kg^{-1}) which is the dry season while the concentration became lower (average < 50 mg kg^{-1}) during the rainy season. The concentration of Cu was also found to decrease downstream from point 14 to point 18 which is in the Lagos Lagoon.

3.2.4 Lagos Lagoon

In the Lagos Lagoon, points 19, 20 and 21 were observed to have higher concentration of Cd, Cu, Pb and Zn than points 22 and 23 for all the months sampled. This is in agreement with Otitoloju *et al.* (2007) who observed higher concentration of metals in the western part of the lagoon. The higher concentrations in this area could be because these points are close to a bridge or other site where human activities take place, and because the sediments differ in composition from those in the centre of the lagoon. Sediment from sites 19-21 have approximately 70% of particles in the sand size fraction and contain 6.3% organic matter on average, whereas samples from sites 22 and 23 are dominated (> 95%) by sand and contain ≤ 0.5% organic matter. Compared to the rivers under investigation, Cr concentration in the Lagos Lagoon is quite high and the range is small. This may indicate that the source of Cr in this water body is geogenic. No systematic differences were observed between concentrations of metals in rainy and dry seasons in the lagoon, nor were there marked seasonal differences in grain size distribution, as had been observed in some of the tributary rivers. This is to be expected because according to Lund-Hansen *et al*. (1999) re-suspension rate was observed to be 10 times higher than sedimentation rate in shallow coastal lagoons and the depth of Lagos Lagoon water body means that deposition, as well as re-suspension, is likely to occur throughout the year.

3.2.5 Comparison with literature and regulatory concentrations

Table 3 gives historical data on the Lagos Lagoon and some recent literature values for PTM concentration in other tropical and semi-tropical lagoons and river estuaries. Levels of PTM found in lagoon sediments in the present study are broadly similar to those reported previously (Otitoloju *et al.* 2007) allowing for the fact that the current study sampled from both the western and eastern parts of the lagoon. The highest concentrations of Cd, Cu, Pb and Zn found overall i.e. including points from the three trans-urban rivers, are similar to maxima reported in aquatic systems impacted by rapid urbanisation in other developing countries, such as the Pearl River in China (Li *et al.* 2011), the Buriganga River in Bangladesh (Ahmad *et al*. 2010) and the Rodrigo de Freitas Lagoon in Brazil (Fonseca *et al*. 2011), but the concentration of Cd at point 1 (42 mg/kg) is remarkably high.

There is currently no legislation in Nigeria governing acceptable levels of PTM in sediments and so it is not possible to assess the current findings within a local regulatory framework. Included in Table 3 are consensus-based probable effect concentrations (PEC) recommended by MacDonald (2000) and Dutch sediment guideline (Grimwood and Dixon 1997). Of the 103 sediments studied, 11 exceed the PEC for Cd (all in the Odo-Iyaalaro); two exceed the PEC for Cr (sites 7 and 8 in the Shasha River); four exceed the PEC for Cu (one from Odo-Iyaalaro and three from Ibeshe River); three exceed the PEC for Pb (including site 7 in Shasha River in both dry and rainy seasons); and four exceed the PEC for Zn (three in Odo-Iyaalaro and, again, site 7 in Shasha River). Forty of the sediments were above the Dutch sediment guideline for Cu and four (three from Odo-Iyaalaro during the dry season) exceed the guideline for Zn.

3.3 Principal component analysis

The data were subjected to PCA to elucidate geochemical factors influencing PTM distribution in the Lagos Lagoon system. Eigenvalues were used to determine the number of principal components that should be retained for further study. For both seasons, the first three principal components had eigenvalues greater than 1, and explained 71.19 % of the variance during the dry season, and 74.95% of the variance during the rainy season.

For the dry season, the first factor (PC1) explaining 40.89% of the total variance was observed to be strongly and positively correlated to % OM, CEC, Pb, Cd, and Zn. The second factor (PC2) explained 20.00% of the variance, and was observed to be positively correlated to % silt and clay and negatively correlated to % sand, while the third factor (PC3), explaining 10.30% of the variance, was positively correlated to Cr, and negatively correlated to pH (Fig. 2a).

According to several studies, (Bloemen *et al*. 1995; Davies 1997; Ujevic *et al* 2000) an association of Cd, Pb and Zn with each other suggests anthropogenic influence. These metals often associate in urban systems, and so their relationship in the Lagos Lagoon system indicates that it is being affected by the rapid urbanization in Lagos State. The plot of scores shows that samples 1D, 9D, 10D, 15D and 21D (samples collected from points 1, 5 and 6 in Odo-Iyaalaro and points 7 in Shasha River) are highly correlated to PC1, and this reflects the presence of high concentration of Cd, Zn Pb and % organic matter and CEC. This indicates that these two rivers pollute the Lagos Lagoon in terms of those anthropogenic metals as compared to Ibeshe River. It is also consistent with, for example, the findings of Loska and Wiechu, (2003) who applied PCA to surface sediments from a reservoir Poland and found that all the metals analysed were positively correlated to organic matter.

In the rainy season, the first PC which explained 42.60 % of the total variance was observed to be correlated to Cd, CEC and %OM, and negatively correlated to pH, while the second PC, which accounts for 18.32 % of the total variance, is correlated to Pb, Zn, Cu, and Cr (Fig.3a). The plot of scores (Fig. 3b) shows that samples 4R, 8R, 2R, 3R, 12R, 7R, and 11R – all in the Odo-Iyaalaro River – have the highest association with PC1. All these samples have relatively high %OM and/or CEC and they represent the only points where Cd was detected at appreciable concentrations in the rainy season. Samples 51R and 56R collected from the Lagos Lagoon were also observed to have a high correlation with PC1 due to their high %OM and CEC. Sample 13R collected from point 7 in Shasha River (immediately below a road bridge) in May was observed to have the highest association with PC2 due to the presence of high concentrations of Cr, Cu, Pb and Zn. May is just at the onset of the rainy season, and the volume of rainfall at this time may not have been enough to flush out the pollutants from the sediments.

4. Conclusion

The physicochemical parameters and PTM concentration of sediments from three rivers and the Lagos Lagoon has been determined and the data subjected to statistical analysis. Odo-Iyaalaro was the most contaminated of the rivers in terms of Cd, Pb and Zn, and this can be attributed to the various industries in the environs which empty their untreated effluents into the Lagos Lagoon via this river. Samples collected from points either under a bridge or close to a bridge with high traffic density was observed to have high concentrations of, in particular, Pb. Sediments from Ibeshe River were generally less contaminated than other tributaries, but specific points were observed to be highly enriched in Cu from the effluent of the textile industry. PTM concentrations in lagoon sediment were generally low at locations towards the centre of the lagoon, but higher along the western margin where the major urban and industrialised areas are located. The concentration of Cr in the Lagos Lagoon was observed to be fairly constant which may indicate that Cr is a natural part of the sediments from this waterbody. Maximum analyte concentrations were similar to the highest values reported in other rapidly expanding urban areas in developing countries, with potentially harmful levels present at some sites. Sediments collected during the dry season were often observed to have higher concentration of PTM compared to those collected during the rainy season. This supports the hypothesis that PTM accumulate in catchment areas during the dry season and are then remobilised during the rainy season into tropical lagoon systems. Further work is required to determine the forms of metals transported and retained in the sediments and the timescale over which they are released at the onset of the rains. In the meantime, steps should be taken to minimise human exposure to PTM in the Lagos Lagoon system. These could include prevention of access to the most highly contaminated areas, temporal restrictions on activities such as dredging so that material is collected when pollutant concentrations are minimal, or flushing away of fine-grained material from dredgings to retain only the sand-sized fraction.

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Table 1 Results of analysis of certified reference material BCR CRM 143R (mg kg^{-1})

	Cd	*Cr*	*Cu*	*Pb*	*Zn*
Certified	72 ± 1.8	426±12	128±7*	174±5	1063±16
Found (n = 5)	71.5 ± 3.5	412±8	122±6	172±8	1074±12

Found results are mean values ± standard deviation for n = 5 (pseudototal digestion)
* = indicative (non-certified) value

Table 2 Descriptive statistics of physicochemical properties and PTM concentration in sediments of dry and rainy seasons

Parameter	Dry			Rainy		
	Minimum	Maximum	Mean	Minimum	Maximum	Mean
Odo-Iyaalaro						
pH	2.8	5.6	4.0	3.6	5.1	4.2
OM *(%)*	0.8	21	7.8	1.4	15.7	8.5
CEC	2.0	14.6	7.6	4.2	14.2	9.6
Cd (*mg kg*$^{-1}$)	< 0.9	42.1	9.6	< 0.9	12.8	4.8
Cr (*mg kg*$^{-1}$)	< 17.5	102	31.0	<17.5	28.9	22.9
Cu (*mg kg*$^{-1}$)	15.6	185	60.9	15.8	105	55
Pb (*mg kg*$^{-1}$)	< 15.8	154	56.7	21.6	108	63.5
Zn (*mg kg*$^{-1}$)	53.1	1040	292	18.7	377	147
Shasha River						
pH	4.3	7.3	5.6	4.2	7.7	6.2
OM *(%)*	0.1	8.2	2.4	0.2	7.4	2.1
CEC	1.6	9.8	3.9	1.6	10.2	3.8
Cd (*mg kg*$^{-1}$)	< 0.9	1.2	0.9	<0.9	1.7	1.0
Cr (*mg kg*$^{-1}$)	<17.5	56.7	27.8	<17.5	140	40.6
Cu (*mg kg*$^{-1}$)	< 2.8	78.5	31.3	<2.8	106	32.0
Pb (*mg kg*$^{-1}$)	< 15.8	189	38.6	<15.8	202	45.5
Zn (*mg kg*$^{-1}$)	1.7	467	101	13	641	104
Ibeshe River						
pH	3.6	7.4	5.1	3.2	7.3	4.5
OM *(%)*	0.3	7.2	2.3	0.2	7.6	2.4
CEC	1.6	4.2	2.5	1.8	5.2	3.0
Cd (*mg kg*$^{-1}$)	< 0.9	<0.9	0.9	<0.9	<0.9	0.9
Cr (*mg kg*$^{-1}$)	<17.5	48.3	27.1	<17.5	54.5	31.3
Cu (*mg kg*$^{-1}$)	< 2.8	332	62.0	<2.8	115	23.3
Pb (*mg kg*$^{-1}$)	<15.8	26.3	16.2	< 15.8	21.8	15.8
Zn (*mg kg*$^{-1}$)	4.6	158	35.9	6.0	57.5	21.3
Lagos Lagoon						
pH	4.3	6.6	5.4	4.1	7.0	5.6
OM *(%)*	0.1	12.6	4.2	0.1	10.8	3.7
CEC	1.8	11.2	5.0	2	11.0	4.9
Cd (*mg kg*$^{-1}$)	<0.9	2.1	1.2	<0.9	<0.9	<0.9
Cr (*mg kg*$^{-1}$)	34.4	51.7	44.7	23.8	51.7	35.8
Cu (*mg kg*$^{-1}$)	< 2.8	33.7	20.6	< 2.8	43.0	18.8
Pb (*mg kg*$^{-1}$)	< 15.8	39	28.4	<15.8	39.2	25.6

Zn *(mg kg^{-1})*	1.3	190	103	1.3	246	118

Table 3 Literature values for pseudototal metal concentration of PTM in sediments of Lagos Lagoon and other areas (mg kg^{-1})

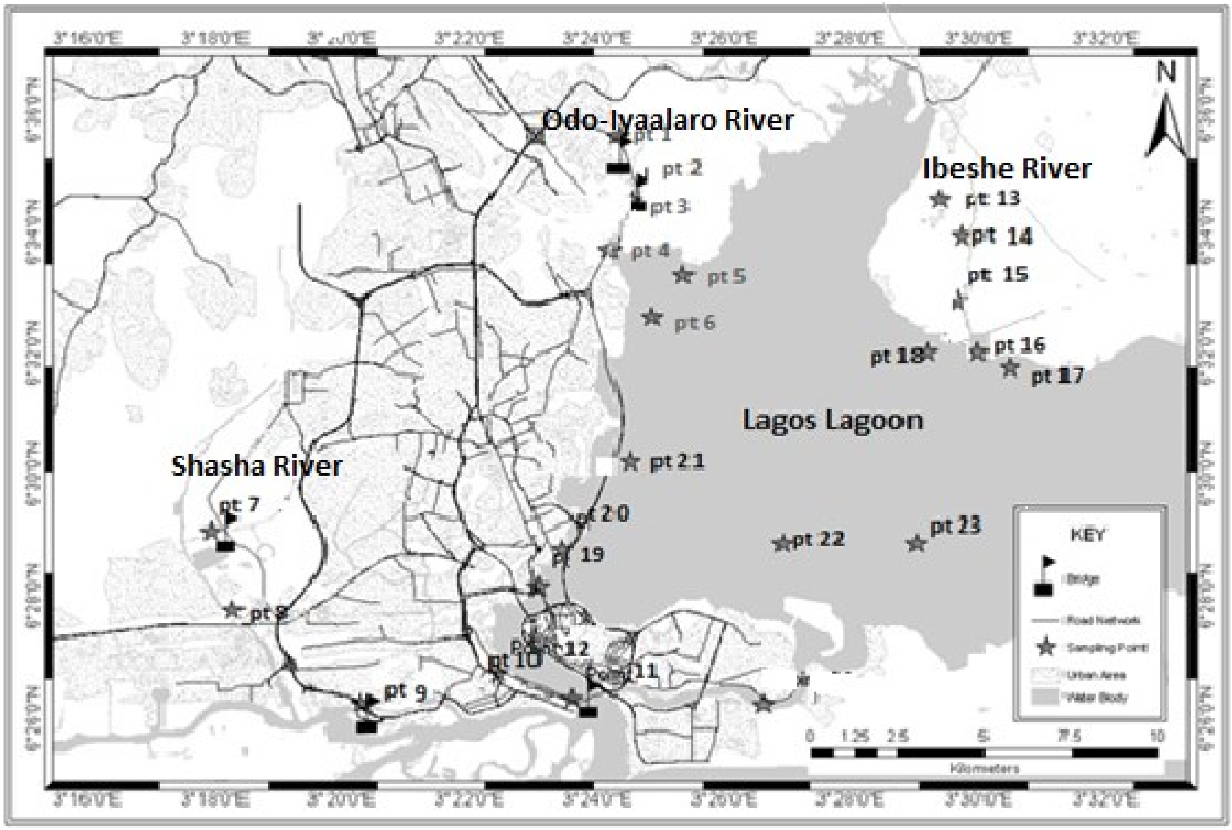
Site	Cd	Cr	Cu	Pb	Zn
Lagos Lagoon Harbour (Ihenyen 1991)	*	97-120	16-41	16-52	10-43
Lagos Lagoon West (Otitoloju et al. 2007)	0.12-0.53	*	11-26	300-420	120-170
Lagos Lagoon East (Otitoloju et al 2007)	0.10 0.26	*	1.9-12	93-140	8.4-34
Mazatlan Harbour, Mexico (Soto-Jimnez and Paez-Osuna 2001)	*	7.6-42	7.7-91	*	46-350
Coatzacoalcos River, Mexico (Bahena-Manjarrez et al. 2002)	0.97-2.8	40-60	22-42	11-58	88-109
St Louis River, Mauritius (Ramessur and Ramjeawon 2002)	*	100	*	14	170
Coatzacoalcos estuary, Mexico (Rosales-Hoz et al. 2003)	*	37-73	12-120	21-40	69-240
Fanga' uta Lagoon, Kingdom of Tonga (Morrison and Brown 2003)	≤ 0.1	*	7-15	3-8	13-38
Sidi Moussa Lagoon, Morocco (Maanan et al. 2004)	*	97	30	*	50
Joyuda Lagoon Puerto Rico (Acevedo-Figueroa et al. 2006)	0.10	*	22	7.6	52
Mandovi estuary, India (Alagarsamy 2006)	*	*	12-78	4.5-46	20-84
San Jose Lagoon Puerto Rico (Acevedo-Figueroa et al. 2006)	1.8	*	100	220	530
Oualidia Lagoon, Morocco (Zourarah et al. 2007)	*	46-62	20-90	31-88	200-260
Pearl River estuary, China (Li et al. 2007)	1.8-6.4	14-190	≤ 350	12-86	120-480
Mazatlan Harbour, Mexico (Jara-Marini et al. 2008)	3.1-3.3	*	32-45	50-54	220-320
Tanapag Lagoon, Commonwealth of the Northern Mariana Islands (Denton et al, 2009)	<0.17-1.7	1.4-18	0.50-100	0.65-160	2.4-360
Buriganga River, Bangladesh (Ahmad et al. 2010)	2.4-4.2	120-220	22-32	65-77	*
Mãe-Bá Lagoon, Brazil (Pereira et al. 2010)	0.03-0.92	2.4-29	0.47-12	1.5-21	1.6-32
Moulay Bousselham Lagoon, Morocco (Alaoui et al. 2010)	0.02 - 0.84	19-110	22-310	6.2-32	170-760
Lake Shinji, Japan (Ahmed et al. 2011)	*	18-240	3-43	11-39	16-200
North-Eastern Tunisian Lagoons (El Ati Hellal et al. 2011)	*	8.7-62	11-36	13-60	60-230
Rodrigo de Freitas Lagoon, Brazil (Fonseca et al. 2011)	*	10-150	5-120	5-220	≤ 390
Sable Noir estuary, Mauritius (Ramessur et al. 2011)	*	*	*	44	200
San Andres Lagoon, Mexico (Vázquez-Sauceda et al. 2011)	1.1	*	*	0.89-1.0	8.4-9.3
Probable effect concentration (MacDonald et al. 2000)	4.98	111	149	128	459
Dutch sediment guideline (Grimwood and Dixon 1997)	*	380	36	530	480

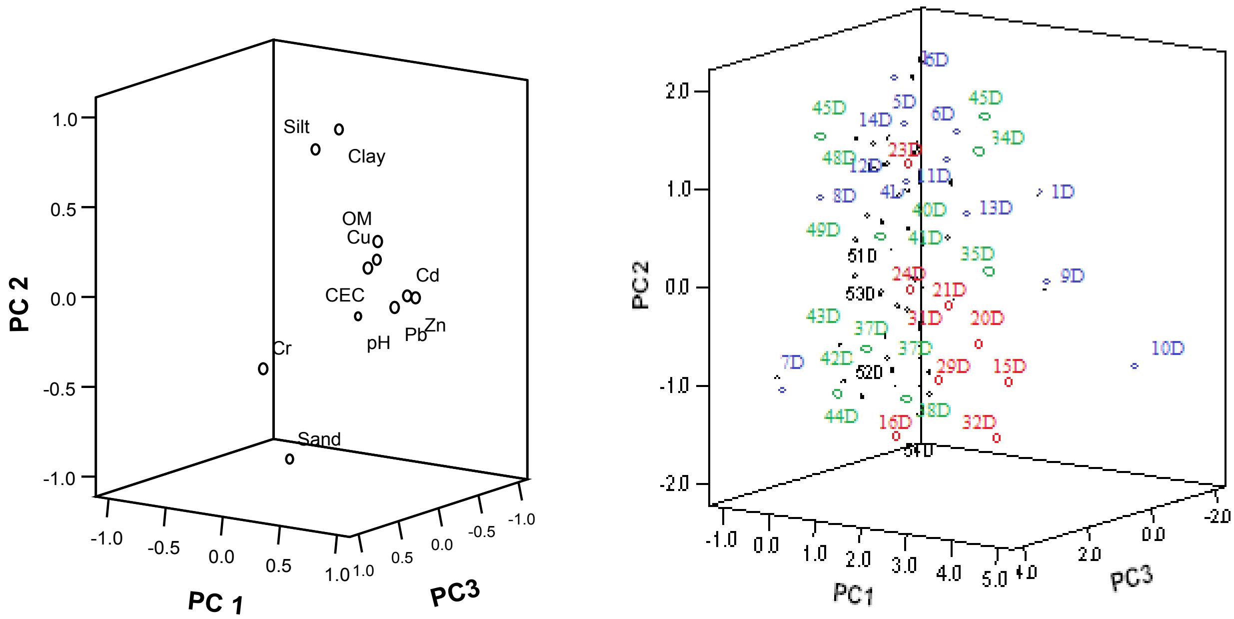
Concentrations are in μg/g. * Not reported.

Fig. 1 Map of the Lagos Lagoon and tributary rivers

Fig. 2 (a) Plot of loadings during the dry season
(b) Plot of scores during the dry season
(Odo-Iyaalaaro – blue; Shasha – red; Ibeshe – green; Lagos Lagoon – black)

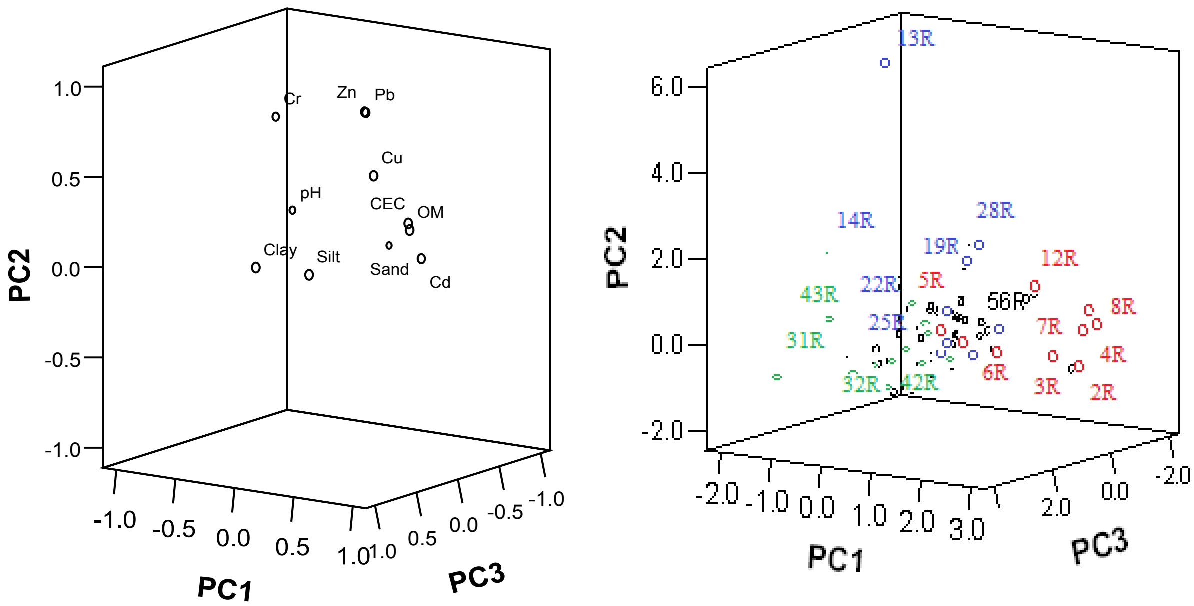
Fig. 3 (a) Plot of loadings during the rainy season
(b) Plot of scores during the rainy season
(Odo-Iyaalaaro – blue; Shasha – red; Ibeshe – green; Lagos Lagoon – black)


3°16'0"E
3°18'0"E
3°20'0"E
3°22'0"E
3°24'0"E
3°26'0"E
3°28'0"E
3°30'0"E
3°32'0"E
N
Odo-Iyaalaro River
Ibeshe River
Lagos Lagoon
Shasha River
pt 1
pt 2
pt 3
pt 4
pt 5
pt 6
pt 7
pt 8
pt 9
pt 10
pt 11
pt 12
pt 13
pt 14
pt 15
pt 16
pt 17
pt 18
pt 19
pt 20
pt 21
pt 22
pt 23
KEY
Bridge
Road Network
Sampling Point
Urban Area
Water Body
0 1.25 2.5 5 7.5 10
Kilometers



PC 2
1.0
0.5
0.0
-0.5
-1.0
Silt
Clay
OM
Cu
Cd
CEC
Pb
Zn
pH
Cr
Sand
PC 1
-1.0
-0.5
0.0
0.5
1.0
PC3
1.0
0.5
0.0
-0.5
-1.0
PC2
2.0
1.0
0.0
-1.0
-2.0
45D
5D
14D
6D
34D
48D
23D
12D
11D
1D
8D
13D
40D
49D
35D
51D
24D
9D
21D
53D
43D
20D
37D
10D
7D
42D
29D
15D
52D
44D
16D
32D
PC1
-1.0
0.0
1.0
2.0
3.0
4.0
5.0
PC3
4.0
2.0
0.0
-2.0

(a) (b)



PC2
1.0
0.5
0.0
-0.5
-1.0
Cr
Zn
Pb
Cu
pH
CEC
OM
Clay
Silt
Sand
Cd
-1.0
-0.5
0.0
0.5
1.0
PC1
1.0
0.5
0.0
-0.5
-1.0
PC3
6.0
4.0
2.0
0.0
-2.0
13R
14R
28R
19R
12R
5R
22R
43R
56R
8R
25R
7R
31R
4R
6R
3R
32R
42R
2R
-2.0
-1.0
0.0
1.0
2.0
3.0
2.0
0.0
-2.0

(a) (b)

Supplementary Information

Online Resource 1

Physicochemical properties and PTM concentration in sediments during the dry season.

Sample no	Sampling Month	Sampling Points	pH	OM %	CEC (meq/ 100g)	Cd (mg/kg)	Cr (mg/kg)	Cu (mg/kg)	Pb (mg/kg)	Zn (mg/kg)
Odo-Iyaalaro										
1D	January	1	3.8	6.2	4.0	42.1±1.8	31±2.4	94.5±5.4	108±3	805±25
2D	January	2	4.2	1.4	2.0	2.1±0.3	24.8±1.9	15.6±2.2	41.3±1.9	100±6
3D	January	3	3.8	4.3	5.8	3.6±0.2	31.5±2.1	32.9±1.3	43.5±3.2	110±6
4D	January	4	4.6	8.2	10.4	2.9±0.2	30.8±2.0	25.2±1.2	36±2.4	84.5±4.8
5D	January	5	4.2	11.6	7.4	1.9±0.1	<17.5	15.9±2.6	25.5±1.7	64.5±3.2
6D	January	6	3.9	16.4	7.5	8±0.5	29±1.5	62.2±2.3	54.8±3.7	266±8.4
7D	March	3	3.1	5.1	4.2	4.8±0.4	102±3.3	54.4±2.3	45.3±3.7	157±3
8D	March	4	2.8	7.8	11.2	1.9±0.3	<17.5	38.8±0.8	<15.8	75.2±3.4
9D	March	5	3.9	10.2	14.6	21.3±0.6	<17.5	139±2	119±8	777±16
10D	March	6	4.8	21	12.7	34.4±0.9	30.2±1.9	185±2	154±3	1040±5
11D	November	3	5.6	0.8	3.8	<0.9	<17.5	29.3±2.2	19.7±0.5	53.1±2.7
12D	November	4	3.3	5.9	6.8	<0.9	<17.5	44.1±0.8	28±3.7	82.6±3.7
13D	November	5	5.0	6.1	7.7	6.9±0.4	<17.5	67.4±3.4	60.6±3.6	298±4.2
14D	November	6	3.4	4.4	8.9	2.2±0.1	<17.5	48.6±1.1	43.1±3.7	165±3
Shasha River										
15D	January	7	5.3	5.8	9.8	<0.9	43.1±2.6	48.6±3.7	189 ±7	433±7
16D	January	8	4.9	1.4	2.2	<0.9	24.2±3.2	42.7±1.9	24.5±2.4	87.6±3.2
17D	January	9	4.3	2.1	3.2	<0.9	<22	33.8±1.6	32.6±2.1	43.6±1.9
18D	January	10	5.2	0.8	2.2	<0.9	26.1±1.3	26.6±1.6	36.8±4.2	34.2±1.8
19D	January	11	4.3	8.2	6.4	<0.9	<17.5	44.8±4.7	19.4±1.8	65.9±2.8
20D	January	12	7.2	0.6	4.8	<0.9	<17.5	62.8±3.5	<15.8	40.2±2.5
21D	March	7	4.9	4.8	7.6	1.2±0.2	56.7±2.8	78.5±4.2	93.4±5.5	467±17

22D	March	8	5.2	0.9	2.4	<0.9	53.2±3.8	32.4±2.1	54.2±3.8	93.4±1.3
23D	March	9	4.3	3.2	3.4	<0.9	26.7±2.6	28.6±1.9	56.8±5.6	74.6±2.9
24D	March	10	4.6	0.9	1.8	<0.9	<17.5	15.9±1.9	<15.8	43.2±3.5
25D	March	11	6.7	7.6	3.2	<0.9	<17.5	78.2±1.7	34.2±2.2	129±4
26D	March	12	7.2	0.6	1.6	<0.9	<17.5	16.3±1.4	<15.8	20.1±1.2
27D	December	7	5.7	1.4	7.8	<0.9	25.1±1.5	11.9±0.8	30.4±2.5	53±2.2
28D	December	8	6.1	0.3	2.4	<0.9	<17.5	<2.8	<15.8	1.7±0.3
29D	December	9	6.4	0.4	3.6	<0.9	<17.5	3.4±0.5	<15.8	9.7±0.8
30D	December	10	5	1.6	2.4	<0.9	<17.5	16±1.6	<15.8	82.8±3.3
31D	December	11	5.4	2.2	4.2	<0.9	25.1±1.5	17.7±0.9	<15.8	139±8
32D	December	12	7.3	0.1	2.0	<0.9	<17.5	<2.8	<15.8	3.6±0.4
Ibeshe River										
33D	February	13	6.2	4.1	2.0	<0.9	<17.5	4.2±0.3	<15.8	20.7±2.2
34D	February	14	5.8	6.1	3.2	<0.9	<17.5	332±11	<15.8	96.9±8.1
35D	February	15	5.2	1.8	2.2	<0.9	<17.5	264±10	<15.8	98.3±2.1
36D	February	16	3.7	0.4	2.0	<0.9	<17.5	4.2±0.2	<15.8	4.6±0.1
37D	February	17	4.8	0.4	1.8	<0.9	<17.5	3.4±0.9	<15.8	6±0.5
38D	February	18	6.5	0.3	1.8	<0.9	<17.5	3.6±0.2	<15.8	8.6±1.1
39D	March	13	6.3	3.8	2.6	<0.9	<17.5	<2.8	<15.8	11.3±1.7
40D	March	14	4.2	7.2	3.3	<0.9	32.1±1.3	246±4	<15.8	53.7±0.6
41D	March	15	4.6	2.1	3.2	<0.9	<17.5	84.6±3.1	<15.8	45.9±2.1
42D	March	16	3.9	1.0	2.2	<0.9	42.1±1.8	24.5±2.5	<15.8	10.3±1.2
43D	March	17	4.6	0.6	2.0	<0.9	48.3±2.4	7.2±1.3	<15.8	7.6±0.4
44D	March	18	4.8	0.4	1.6	<0.9	41.2±1.6	9.3±0.9	<15.8	7.6±0.2
45D	December	13	7.4	3.6	3.4	<0.9	<17.5	15.7±1.5	26.3±2.2	158±6
46D	December	14	5.7	4.1	4.2	<0.9	<17.5	13.7±1.1	18±3.3	43.3±1.1
47D	December	15	4.6	1.8	3.2	<0.9	<17.5	13.8±1.3	<15.8	19.7±1.4
48D	December	16	4.8	0.8	2.0	<0.9	34.4±1.2	14.2±0.7	<15.8	13.5±0.7
49D	December	17	3.6	0.8	2.0	<0.9	25.7±1.5	68.2±2.4	<15.8	27.5±1.5
50D	December	18	4.5	1.2	2.2	<0.9	<17.5	5.2±0.7	<15.8	13.1±1.2

Lagos Lagoon										
51D	December	19	4.5	3.5	5.1	<0.9	34.4±2.1	33.7±2.1	33.2±0.7	164±8
52D	December	20	5.4	4.1	4.8	1.3±0.2	51.7±3.2	30±0.8	39±2.3	146±5
53D	December	21	4.3	12.6	11.2	2.1±0.2	51.7±4.8	33.7±1.5	39±3.4	190±4
54D	December	22	6.4	0.1	2.0	<0.9	42.5±1.3	<2.8	<15.8	1.3±0.1
55D	December	23	6.6	0.5	1.8	<0.9	43.0±3.2	<2.8	<15.8	14.8±1.9

Results are mean values ± standard deviation for n = 3; < indicates a value below the detection limit

Online Resource 2

Physicochemical properties and PTM concentration in sediments during the rainy season.

Sample no	Sampling Month	Sampling Points	pH	OM %	CEC (meq/ 100g)	Cd (mg/kg)	Cr (mg/kg)	Cu (mg/kg)	Pb (mg/kg)	Zn (mg/kg)
Odo-Iyaalaro										
1R	May	3	4.5	1.4	5.2	<0.9	<17.5	27.5±2.0	21.6±3.7	18.7±2.8
2R	May	4	4.2	11.3	8.6	12.8±1.9	<17.5	40.2±1.9	52.3±4.2	68.3±4.5
3R	May	5	3.9	12.3	12.8	6.9±0.3	<17.5	67.8±1.6	43.8±3.6	105±10
4R	May	6	4.3	15.7	12.6	8.6±0.6	<17.5	105±4	46.9±2.1	224±22
5R	July	3	4.9	5.1	4.2	<0.9	<17.5	15.8±2.2	98.2±5.8	134±11
6R	July	4	3.9	7.2	10.2	<0.9	<17.5	38.2±2.1	48.5±3.6	64.3±3.6
7R	July	5	4.5	10.9	11.2	5.5±0.7	25.6±1.7	58.9±3.7	108± 3	264±8
8R	July	6	4.2	15.3	12.4	10.2±1.1	28.9±1.6	92.4±2.4	89.7±4.8	197±13
9R	September	3	5.1	2.9	4.6	<0.9	<17.5	41.1±2.0	59.5±2.7	64.8±5.9
10R	September	4	3.6	4.5	7.8	<0.9	<17.5	43.8±1.9	48.5±3.6	59.9±2.9
11R	September	5	4.2	8.1	14.2	2.6±0.4	<17.5	51.1±2.4	58.2±3.2	190±7
12R	September	6	3.6	7.5	11.8	6.1±0.2	<17.5	77.9±1.3	86.7±4.5	377±5
Shasha River										
13R	May	7	5.9	6.6	8.2	<0.9	140±3	106±2	202±5	641±25
14R	May	8	4.4	1.6	3.4	<0.9	112±8	33.8±2.6	44.2±1.9	112±12
15R	May	9	4.5	2.6	4.4	<0.9	34.2±3.3	15.4±2.1	67.8±3.5	40.1±2.1
16R	May	10	4.4	1.0	2.3	<0.9	<17.5	28±0.4	39.2±1.1	42.1±1.9
17R	May	11	6.8	1.2	3.8	<0.9	<17.5	15.9±1.1	<15.8	23.8±1.5
18R	May	12	7.7	0.4	2.2	<0.9	26.1±3.8	23.8±1.3	<15.8	21.4±1.2
19R	July	7	4.8	7.4	10.2	1.4±0.2	47.2±3.8	98.6±4.3	75.2±3.8	301±4
20R	July	8	5.6	0.9	2.4	<0.9	35.5±3.2	<2.8	18.6±1.4	102±10
21R	July	9	4.2	3.8	4.8	<0.9	29.8±2.8	<2.8	43.2±1.5	32.1±1.9
22R	July	10	7.2	0.8	2.2	<0.9	45.5±3.3	26.8±2.0	19.9±0.8	34.7±2.8
23R	July	11	7.7	3.1	2.8	<0.9	25.9±2.2	54.4±4.1	35.6±3.2	124±6
24R	July	12	7.6	0.5	2.0	<0.9	<17.5	44.2±4.1	<15.8	34.2±2.9
25R	October	7	5.6	1.4	6.4	<0.9	<17.5	27.9±1.9	39±1.2	34.6±3.1
26R	October	8	6.3	0.2	3.2	<0.9	40.7±2.4	<2.8	<15.8	13±1.3
27R	October	9	5.4	0.3	3.6	<0.9	25.6±2.1	<2.8	<15.8	18.6±1.9

28R	October	10	7.5	3.5	2.2	1.7±0.4	35.5±2.1	64±3.1	104±7	190±4
29R	October	11	7.7	1.9	3.2	<0.9	<17.5	13.6±1.1	22.4±1.2	70.8±4.1
30R	October	12	7.7	0.4	1.6	<0.9	<17.5	11.5±1.0	30.4±2.9	38±3.8
Ibeshe River										
31R	May	13	6.0	0.7	2.4	<0.9	<17.5	<2.8	<15.8	17.6±2.0
32R	May	14	4.0	7.6	4.8	<0.9	<17.5	115±2	<15.8	24.8±1.0
33R	May	15	3.4	1.4	3.2	<0.9	<17.5	42.2±1.6	<15.8	10.5±1.3
34R	May	16	4.8	5.3	2.0	<0.9	52.1±2.6	10.2±0.4	<15.8	33.1±2.7
35R	May	17	4.7	0.2	2.2	<0.9	54.5±4.2	5.7±1.1	<15.8	6±0.9
36R	May	18	3.8	0.5	2.4	<0.9	48.8±4.7	8±0.4	<15.8	11.2±1.4
37R	July	13	7.3	3.0	4.6	<0.9	45.6±3.9	15.2±0.4	21.8±2.4	57.5±0.9
38R	July	14	4.1	5.2	4.8	<0.9	34.5±2.1	13.6±0.4	<15.8	54.2±1.2
39R	July	15	4.3	1.5	3.2	<0.9	<17.5	6.8±1.2	<15.8	21.8±0.5
40R	July	16	3.8	1.0	2.0	<0.9	37.2±4.2	13.5±1.3	<15.8	18.5±1.2
41R	July	17	4.3	4.7	2.2	<0.9	35.9±2.1	74.7±3.7	<15.8	45.6±2.7
42R	July	18	4.5	0.3	1.8	<0.9	33.3±1.6	56.7±2.7	<15.8	16.8±0.9
43R	October	13	6.9	2.8	4.0	<0.9	<17.5	3.6±0.5	<15.8	7.8±0.4
44R	October	14	3.6	6.2	5.2	<0.9	24.3±1.9	12.4±1.7	<15.8	18.2±1.2
45R	October	15	3.2	1.3	2.2	<0.9	<17.5	12.2±1.7	<15.8	12.2±0.7
46R	October	16	3.6	1.0	2.6	<0.9	<17.5	12.7±0.8	<15.8	11.1±0.8
45R	October	17	4.8	0.4	2.4	<0.9	<17.5	6.2±0.9	<15.8	9.7±0.4
48R	October	18	4.5	0.3	2.8	<0.9	<17.5	7.8±0.4	<15.8	7.3±0.3
Lagos Lagoon										
49R	July	19	4.6	3.7	5.4	<0.9	23.8±0.9	31±1.3	29.8±1.3	146±6
50R	July	20	5.9	4.3	6.2	<0.9	28.1±2.4	16.5±1.6	39.2±0.7	112±5
51R	July	21	4.4	10.8	11.0	<0.9	26.5±1.1	29.2±1.9	34.1±2.8	223±2
52R	July	22	6.7	0.2	2.2	<0.9	45.6±0.8	4.2±0.6	19.2±1.9	16.7±0.9
53R	July	23	6.5	0.1	2.0	<0.9	51.7±2.7	<2.8	<15.8	43.3±1.8
54R	October	19	4.1	3.3	4.2	<0.9	34.4±1.8	35.2±2.8	33.2±1.8	238±14
55R	October	20	7	4.4	4.4	<0.9	34.4±1.4	19.5±1.6	<15.8	142±11
56R	October	21	4.1	9.8	8.8	<0.9	25.7±0.9	43±3.4	39±3.1	246±11
57R	October	22	6.6	0.1	2.2	<0.9	51.7±1.9	<2.8	<15.8	1.3±0.3
58R	October	23	6.4	0.2	2.2	<0.9	36.2±1.3	4.2±0.6	<15.8	13.2±0.9

Results are mean values ± standard deviation for n = 3; < indicates a value below the detection limit

Online Resource 3

Grain size analysis of sediments collected during the dry season.

Sample no	% sand	% silt	% clay	Sample no	% sand	% silt	% clay
Odo-Iyaalaro							
1D	31.48	29.89	38.63	8D	61.61	13.37	25.02
2D	40.64	24.52	34.84	9D	59.7	18.41	21.89
3D	54.44	12.85	32.71	10D	67.21	13.44	19.35
4D	49.96	16.06	33.98	11D	47.32	16.46	36.22
5D	42.26	27.37	30.37	12D	48.23	14.96	36.81
6D	43.25	28.81	27.94	13D	45.82	22.93	31.25
7D	73.31	10.68	16.01	14D	38.14	18.21	43.65
Shasha River							
15D	64.57	10.67	24.76	24D	77.67	13.47	8.86
16D	95.81	1.92	2.27	25D	32.17	17.79	50.04
17D	44.88	16.09	39.03	26D	74.08	11.94	13.98
18D	77.67	13.47	8.86	27D	58.83	17.84	23.33
19D	32.17	17.79	50.04	28D	95.20	2.40	2.40
20D	77.08	11.94	13.98	29D	91.02	2.78	6.20
21D	54.58	17.77	27.65	30D	67.15	17.94	14.91
22D	79.42	13.73	6.85	31D	79.29	13.37	7.34
23D	41.64	17.1	41.26	32D	97.66	0.35	1.99
Ibeshe River							
33D	35.27	19.76	44.97	42D	93.35	6.47	0.18
34D	46.44	20.17	33.39	43D	82.81	12.36	4.83
35D	64.78	15.28	19.94	44D	95.08	4.92	0.00
36D	75.67	14.21	10.12	45D	29.7	17.53	52.77
37D	87.28	9.28	3.44	46D	19.78	13.92	66.30
38D	96.71	3.12	0.17	47D	93.88	3.32	2.80
39D	42.28	18.4	39.32	48D	54.03	34.71	11.26
40D	54.20	18.23	27.61	49D	68.21	19.92	11.87
41D	64.28	19.27	16.45	50D	46.98	32.17	20.85
Lagos Lagoon							
51D	61.08	18.95	19.97	54D	100.00	0.00	0.00
52D	79.76	8.87	11.37	55D	91.12	8.83	0.05
53D	68.84	13.53	17.63				

Online Resource 4

Grain size analysis of sediments collected during the rainy season.

Sample no	% sand	% silt	% clay	Sample no	% sand	% silt	% clay
Odo-Iyaalaro							
1R	86.43	5.18	8.39	7R	55.23	25.15	19.62
2R	57.85	14.95	27.20	8R	57.18	27.21	15.61
3R	60.18	15.31	24.51	9R	80.36	7.88	11.76
4R	63.62	11.37	25.01	10R	59.14	11.58	29.28
5R	74.86	7.28	17.86	11R	54.03	20.35	25.62
6R	59.76	18.21	22.03	12R	57.90	13.13	28.97
Shasha River							
13R	55.92	17.05	27.02	22R	79.03	11.28	9.69
14R	50.79	17.61	31.6	23R	90.24	3.71	6.04
15R	82.76	8.56	8.68	24R	91.28	2.73	5.99
16R	76.68	13.61	9.71	25R	52.18	20.17	27.65
17R	89.99	8.87	1.14	26R	81.19	10.12	8.69
18R	96.04	0.70	3.26	27R	79.92	10.71	9.37
19R	56.42	19.20	24.38	28R	92.37	3.76	3.87
20R	77.72	16.54	5.74	29R	94.28	3.10	2.62
21R	90.81	7.26	1.93	30R	91.76	2.78	5.46
Ibeshe River							
31R	1.09	6.71	92.20	40R	80.51	18.21	1.28
32R	16.07	20.70	63.23	41R	76.47	11.22	12.31
33R	98.95	1.05	0.00	42R	68.27	16.15	15.58
34R	62.25	16.82	20.93	43R	33.29	12.69	54.02
35R	98.59	1.34	0.07	44R	84.96	7.20	7.84
36R	85.52	11.02	3.46	45R	80.49	7.23	12.28
37R	30.21	18.24	51.55	46R	54.36	29.23	16.41
38R	31.27	46.01	22.72	45R	60.21	16.74	23.05
39R	82.61	7.52	9.87	48R	47.23	21.00	31.77
Lagos Lagoon							
49R	71.25	18.21	10.54	54R	68.01	17.26	14.73
50R	75.32	19.27	5.41	55R	77.21	9.86	12.93
51R	61.62	20.12	18.26	56R	62.67	17.21	20.12
52R	97.64	1.12	1.24	57R	95.27	4.61	0.12
53R	95.76	4.18	0.06	58R	96.72	3.28	0.00