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Quality of water resources in the Niger basin and in the region of Lagos (Nigeria)

Olusegun Adeaga[1]*, Gil Mahe[2], Claudine Dieulin[2], Francoise Elbaz-Poulichet[2], Nathalie Rouche[2], Jean-Luc Seidel[2], Eric Servat[2]

[1] University of Lagos, Nigeria
[2] HydroSciences Montpellier Laboratory, France

* **Correspondence:** Department of Geography, University of Lagos, Nigeria. E-mail: oadeaga@unilag.edu.ng

Abstract. Water quality studies in Nigeria are usually conducted at local scales and limited to a restricted number of chemical contaminants, while reliable data on trace metal concentrations (including arsenic) are relatively scarce. This study focuses on the quality of available renewable water resources in terms of major ion and trace element concentrations at selected sampling locations in the Lower River Niger basin and part of the Lagos region. A screening of water contamination by arsenic and heavy metals was carried out through water sampling at selected locations using in situ measurement and laboratory testing to estimate heavy metal concentrations and water type. The analysis reveals moderate trace element contamination of the water resources, with the exception of Pb, while Mn and, to a lesser extent, Al exceeded WHO quality standards, but the Arsenic concentrations are within drinking water quality standards and are safe for consumption and irrigation, while the water type is Bicarbonate.

Key words:
Niger Delta,
River Niger,
water quality,
Arsenic

Introduction

Heavy metals are metallic elements present in both natural and contaminated environments due to differences in geography and geologies, as well as in anthropogenic activities (Berner and Berner 1987; Bricker and Jones 1995). Metals such as copper, zinc and chromium are nutritionally essential for a healthy life, while others such as lead, mercury, arsenic and cadmium are mostly poisonous to humans due to their non-degradability, persistence and bio-accumulation in the food chain. Thus, once deposited in the environment, for years they remain poisonous to humans through inhalation, ingestion and skin absorption.

Although heavy metals naturally occur at low concentrations with relatively short residence times in water, river catchments can become a source of concern if the level of heavy metals in them exceeds health guideline concentrations. The sources of heavy metal load include weathered soil or rocks, mining and metallurgical releases, and industrial emissions (Olatunji and Osibanjo 2012). Others include disposal of untreated and partially treated effluents that contain toxic metals, metal chelates from various industries, and the indiscriminate use of heavy metals in the production of agricultural and household goods, such as fertilisers and pesticides.

It should be noted that concentrated heavy metal loads potentially threaten the environment and ecosystem because they can accumulate in the human body, causing damage to the nervous system and internal organs, with many severe health implications (Salomon and Forestner 1984; Lee et al. 2007; Adelana et al. 2012).

In Nigeria, the sources of metal pollution in rivers are usually attributed as industrial discharges, corrosion of iron and steel materials in buildings, leachates from dumpsites and vehicles, among others (Ayenimo et al. 2005; Jaji et al. 2007). Studies on water quality in Nigeria are usually conducted at local scales and limited to a restricted number of chemical contaminants, while reliable data on trace metal concentrations (including arsenic) are relatively scarce, as pointed out in the synthesis of the British Geological Survey (2003). Animi et al. (2008) estimated that there is a probability of being more than 0.75 above the World Health Organization's recommended arsenic concentration (10µg/l) in about 9% of the Nigerian drinking water resources, due to increasing contamination, mostly from anthropogenic sources.

Studies on heavy metal concentrations within the River Niger basin system is therefore absolutely imperative, considering the health consequences of the various increased anthropogenic activities in the system over the years, especially in the lower section of the Niger basin. These activities include increased agricultural and industrial waste, as well as the deposition of untreated domestic and industrial effluent. Thus, the objective of this study was to provide an update of trace metal and arsenic concentrations in the waters of the Niger basin and the region of Lagos. It should be noted that this study is part of the BFP Niger programme.

Regional setting

The lower Niger Basin system begins at the entry point of the River Niger into Nigeria at about 162 km north of Lake Kainji and continues to the outlet into the Gulf of Guinea through the Niger Delta region (Fig. 1). The Sokoto River joins the Niger approximately 75 km downstream of the Nigerian border and extends upstream with a broad floodplain for about 387 km (Hughes and Hughes 1991). Other tributaries of the River Niger in Nigeria include the rivers Rima, Kaduna, Gbako, Gurara and Anambra. In its lower course, the Niger forms a confluence with the Benue River at Lokoja, after which the Benue River remains its major tributary, as well as significant local precipitation, which strongly increase the flow. The tributaries of the Benue River include the Gongola, Taraba, Donga, Katsina-Ala and Mada Rivers.

The lower Niger basin receives an annual rainfall of between 1,000 and 4,000 mm with inter-annual rainfall variability ranging from 10% to 20%. The system has a drainage basin of about 629,545 km^2 with a discharge contribution of about 117km^3/year, constituting about 64.3% of the River Niger's total flow. The flooding of the upper and middle Niger lasts from July to November, with the low-water period lasting from December to June. As the river receives tributaries from different climatic areas, the merging of the different flood regimes may produce a second peak, as in the North of Nigeria (Mahe et al. 2001; Niger-HyCOS 2006).

In addition, over the years the lower Niger has been experiencing a marked decrease in flow, with a mean flow of 6,055 m^3s^{-1} (191 km^3/year) for 1929–1970 compared to 5,066 m^3s^{-1} (160 km^3/year) for the period 1971–2001; a decrease of about 17%. Also recorded is a reduction in annual average discharge to about 20% downstream of the Kainji Dam, before dropping to 45% due to Bakolori, Kiri and Pankshin.

It should be noted that since the beginning of this century, the Niger River has been subjected to several natural and anthropogenic perturbations resulting from the Sahelian drought of the 1970s. In the lower Niger basin, especially downstream of the confluence at Lokoja, extensive environmental pollution from increasing anthropogenic activi-

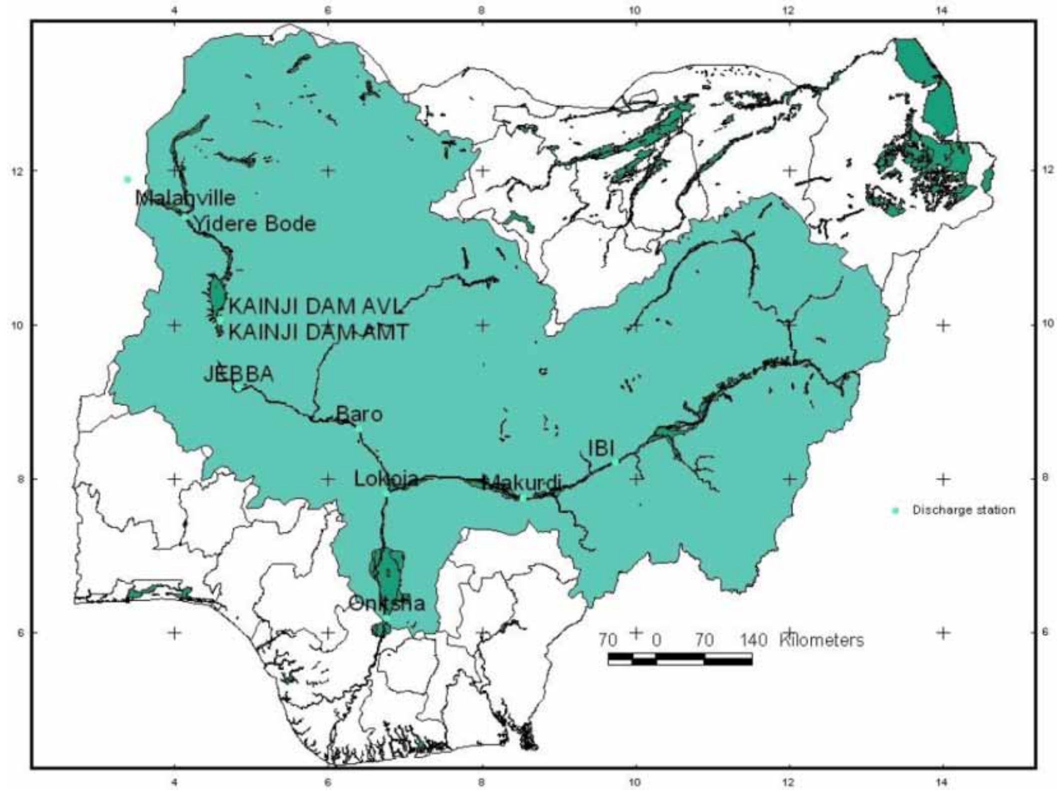

Fig. 1: Lower Niger River basin - position of the sample stations show on the map

ties is all too evident, with untreated industrial and human effluent and waste. Dam-building and numerous irrigated perimeters have also modified the hydrological conditions of the Niger. Severe environmental problems in the lower Niger Basin, especially downstream of the Onitsha station, include oil- and gas-related development activities, oil spills, refinery operations, oil transportation, gas flaring, dredging of canals and land taken for the construction of facilities.

Methodology

Water sampling and sample pre-treatment

Water-contamination screening for arsenic and heavy metals was carried out in January 2009 in the lower part of the Niger and Benue Rivers and in the region of Lagos. Sampling was carried out on the water from the Niger, the Benue (Fadamas and well water) and the River Ogun (Lagos region). 'Fadama' is a Hausa name for irrigable land which usually relates to low-lying plains which are underlain by shallow aquifers and found along major river systems in the alluvial plain of Northern Nigeria. This plain is a major year-round water resource source for fish farming, agriculture and stockbreeding activities.

The collecting of water samples entails traversing through New Bussa to Onitsha and the Ogun River using a local motor boat to access the sampling points along the river's course. The sampling points (Stations LN, LB, OG1 & OG2) were selected along the River Ogun due to the fact that this river drains the largest portion of Lagos Mega city. The studied water resource (river, fadamas) drains a sedimentary formation. In total, twelve sampling points were selected and they are described in Table 1.

The pH and temperature measurements of sampled water were carried out in the field using an in-situ device. Samples were later filtered on Nuclepore polycarbonate membranes (0.22 µm) and stored in polyethylene bottles as a pre-treatment to proper analysis procedures. For trace element

Table 1. Description of water sampling station

Station	Description	Longitude	Latitude
New Bussa (K1)	Upstrean of Kainji Dam (Niger River)	004° 34'14.9"	09° 51'45.0"
New Bussa (K2)	Fadama land on River Niger	004° 34'04.7"	09° 51'43.3"
Lokoja (LB)	Gbobe Town (River Benue) upstream confluence at Lokoja	006° 45'35.8"	07° 46'4.8"
Lokoja (LN)	Ganaja village, Downstream confluence	006° 44'58.1"	07° 47'17.8"
Lokoja (LX)	Around Ganaja village	006° 45'21.1"	07° 44'25.2"
Onitsha (ON1)	Niger River	006° 45'48.0"	06° 07'59.4"
Onitsha (ON2)	Fadama land at Onitsha on River Niger	006° 45'13.9"	06° 08'05.1"
Lagos (LA1)	River Iyaalaro	003° 22'22.6"	06° 34'47.7"
Lagos (LA2)	Farm land on River Iyaalaro floodplain	003° 22'22.7"	06° 40'48.8"
Ogun (OG1)	On River Iju	003° 20'20.2"	06° 40'18.2"
Ogun (OG2)	River Ogun	003°22'38.2"	06° 40'47.4"
Ogun (OG3)	River Ogun	003° 22'35.3"	06° 40'49.4"

pre-analysis, these bottles were carefully washed with nitric acid. Water sample analysis was carried out at the HSM Laboratory (Montpellier), France.

Water quality analysis procedure

At the HSM laboratory, samples for major cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) and trace elements were acidified to pH2 with HNO_3 Merck Suprapur. Cations and major anions (Cl^{-}, SO_4^{2-}) were then determined using ionic chromatography. HCO_{3-} and CO_3^{2-} were analysed using titration. Trace elements (Li, B, Al, V, Cr, Mn, Co, Ni, Cu, Zn, As, Pb, Rb, Sr, Mo, Cd, Ba, Pb and U) were quantified using ICP-MS.

Quantitative analyses of the sampled water were performed using a conventional external calibration procedure with Indium as an internal standard to correct for instrumental drift and possible matrix effects (Elbaz-Poulichet et al. 2006). Certified reference materials from the National Research Council of Canada, i.e. SLRS-4 (freshwater sample), were also used to check analytical accuracy and precision of major and trace element concentrations in the waters of the lower Niger and Benue basins and of the region of Lagos.

For standardisation and comparison of the major and trace element concentrations in the waters of the Niger and Benue basins and of the region of Lagos, WHO maximum allowable concentrations in drinking water and mean annual European Quality standards (EQS) for priority metals in surface water as well as trace element concentrations in the Seine (Elbaz-Poulichet et al. 2006), Rhone (Elbaz-Poulichet et al. 1996), Thames (Neal et al. 2000) and Lena River (Martin et al. 1993) are provided for comparison.

For Cd and Cd-compound concentrations, comparison with the European Quality standards (EQS) was based on the water hardness, as defined by the five following classes:

Class 1: <40 mg $CaCO_3$/L,
Class 2: 40–50 mg $CaCO_3$/L,
Class 3: 50–100 mg $CaCO_3$/L,
Class 4: 100–200 mg $CaCO_3$/L,
Class 5: ≥200 mg $CaCO_3$/L.

In addition, the Piper diagram was adapted to reveal the hydrochemical regime of sampled water with respect to the presence of ions and identification of the designated water type. A Piper diagram consists of a geometrical combination of two outer triangles and a middle or inner diamond-shaped quadrilateral. Water types are designated according to the zones in which these points fall on the middle quadrilateral plot (Piper 1944; Manoj et al. 2013).

Results and discussion

pH and water temperature distribution

Water temperature at the sampled stations varies from 25°C (Station LN and LB) to 30.8°C (Station OG1 and OG2) while there is an average of 26.3°C within the Niger Rivers and part of Lagos. It should be noted that water temperature in most rivers in Nigeria ranged between 24 and 28°C (26.17 ± 1.47°C), with the lowest temperature measured during the wet season.

The pH values of the sampled waters range from 6.13 (station OG1) (slightly acidic) to 8 (station LN) (slightly alkaline), with an average of 7.1 (almost neutral). It should be noted that water that passes through the urbanised region with high human population density and low regolith buffer capacity are slightly acidic, as evident in sampled stations (ON2, LA1, LA2, OG1). In comparison with the water from the sampled river, pH along the lower River Niger ranges from 6.9 to 7.2 (7.1 ± 0.12) (Onwugbuta-Enyi et al. 2008) while the average values for the Rivers Seine, Rhine and Thames and the World Health Organization (WHO) drinking water quality standard are 8.10, 8.10 and 8.15 (slightly basic), and (8.2–8.8), respectively. Thus, the pH value of the sampled water along the lower Niger River basin and part of the Lagos region falls within

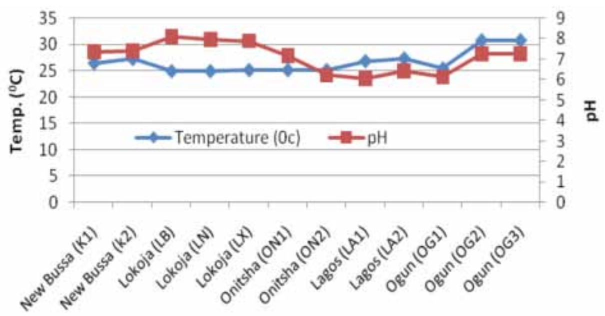

Figure 2. Surface water temperature and pH distribution at the selected stations

the acceptable WHO and EU standard for drinking water quality. The relationship between temperature and pH of sampled stations is shown in Figute 2.

The water quality index estimation based on sampled water temperature shows that stations K1, K2 and ON1 had excellent surface water quality, while stations LB, LN and LX were good, and LA1, LA2, OG1, OG2 and OG3 stations were mendium (fair) (Fig. 3).

Heavy metal concentration hydrochemistry of the sampled water

The availability of metals, as shown in Table 2, is in the order: Mn > Al > Sr > Ba > Co > B > Zn > Rb > Li > Cu > V > Ni > Pb > As > Cr > Mo > U > Cd. The average concentrations (mg/L) of the heavy metals in the water are: Mn (150.25), Al (70), Sr (69.83), Ba (51.08), Co (40.55), B (26.31), Zn (14.01), Rb (8.17), Li (1.83), Cu (1.73), V (1.42), Ni (1.29), Pb (0.60), As (0.36), Cr (0.33), Mo (0.19), U (0.06) and Cd (0.05). The level of Mn was noted to be the most abundant of all the metals tested for during the study, followed by Al. Meanwhile, Cd had the lowest concentration among the metals determined in water samples from the River Niger and part of the Lagos region.

Concentrations of major and trace elements in the sampled water were generally below the maximum allowable concentrations defined by the WHO for drinking water, with the exception of Mn (up to 506 <mg/L) and, to a lower extent, Al (up to 399.3<mg/L) (Table 2). The magnesium (Mn) concentration (506 < 419 mg/L) at the ON2, LA1 and LA2 stations exceeded the WHO allowable standard, while concentrations at the LA1, LA2, OG2 OG3 and ON2 stations (506 < 61 mg/L) exceeded EU quality standards for surface water (EC 2005). The consumption of this water resource might be dangerous, since manganese is a neurotoxic metal (Centeno et al. 2004). Elevated Mn concentrations at these stations might be from the application of fertiliser and from industrial effluents. An elevated aluminum concentration is recorded at the LN station followed by the ON1 station, while station ON2 had the lowest concentaration (Fig. 4). Aluminum makes up around 8% of the Earth's surface, making it the third most common element. It can be selectively leached from rock and soil to enter any water source, as well as from disposed-of unsorted waste, most especially cans and waste alloys; its concentrations increase with increasing water depth. Ex-

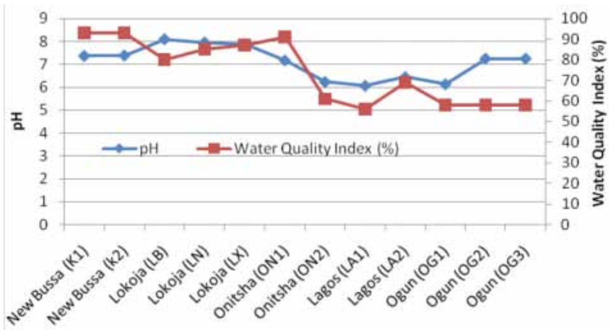

Figure 3. pH and surface water quality index distribution at the selected stations

Table 2. Distribution of major trace elements in the lower Niger River basin and part of the Lagos region

Item / µg/L	Li	B	Al	V	Cr	Mn	Co	Ni	Cu	Zn	As	Rb	Sr	Mo	Cd	Ba	Pb	U
New Bussa (Kl)	0.22	4.9	45.6	1.02	0.12	5.4	0.093	0.65	2.98	6.2	0.35	3.9	53	0.087	0.027	46	0.73	0.03
New Bussa (k2)	6.61	2.3	3.2	6.4	0.15	1.3	0.05	0.67	2.55	22.9	0.07	0.3	144	0.156	0.025	71	0.44	0.326
Lokoja (LB)	0.12	2.2	29.5	1.92	0.1	1.1	0.032	0.23	0.79	1.4	0.11	2.4	61	0.186	0.003	30	0.11	0.054
Lokoja (LN)	0.24	4.1	399.3	1.2	0.42	2.4	0.084	0.56	0.78	1.2	0.25	3.5	47	0.146	0.001	38	0.16	0.057
Lokoja (LX)	0.13	3.7	60.2	0.91	0.09	1.8	0.042	0.44	0.8	0.8	0.2	3.5	48	0.101	0.001	36	0.12	0.051
Onitsha (ONI)	0.27	3.7	119.1	1.26	0.21	16	0.093	0.47	2.23	3.4	0.23	3.4	48	0.117	0.014	34	0.15	0.034
Onitsha (0N2)	0.49	7.8	2.3	0.11	0.07	469	3.157	0.99	1.4	15.8	0.29	10.7	63	0.009	0.022	62	0.02	0.01
Lagos (LAI)	6.52	123	51.7	0.74	0.98	259	2.435	4.65	1.81	33.9	1.03	24.6	88	0.47	0.219	59	2.56	0.016
Lagos (LA2)	5.75	137	46.8	0.67	1.23	506	3.28	5.7	3.48	54.5	1.18	33.9	138	0.66	0.251	109	2.22	0.03
Ogun (061)	0.59	7.8	17	0.22	0.08	419	477	0.05	0.48	17.1	0.19	5.9	37	0.088	0.001	33	0.02	0.004
Ogun (0G2)	0.52	9.6	31.5	1.26	0.22	61	0.178	0.45	1.63	10.7	0.21	2.9	55	0.114	0.015	47	0.33	0.053
Ogun (0G3)	0.53	9.6	33.8	1.34	0.29	61	0.193	0.59	1.82	0.22	0.22	3	56	0.12	0.019	48	0.36	0.054
Average	1.83	26.31	70.00	1.42	0.33	150.25	40.55	1.29	1.73	14.01	0.36	8.17	69.83	0.19	0.05	51.08	0.60	0.06
Std. Deviation	2.70	48.60	108.17	1.64	0.38	203.49	137.45	1.84	0.95	16.51	0.36	10.35	35.48	0.19	0.09	22.25	0.86	0.09
WHO	n.d.	500	200	n.d.	50	400		70	2000	3000	10	n.d.	n.d.	70	3	700	10	15
EU	n.d.	1000	200	n.d.	50	50		20	1000	n.d.	10	n.d.	n.d.	n.d.	5	700	10	n.d.
AA-EQS	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	20	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	7.2	n.d.
MAC-EQS	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	20	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	7.2	n.d.
River Seine	n.d.	38.3 - 87	n.d.	n.d.	n.d.	0.46-14.4	n.d.	n.d.	0.49-3.47		0.36-1.28	n.d.	n.d.	0.05-2.15	0.008 - 2.44	24.3	0.073 - 1.21	n.d.
River Rhine	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	1.6	2.2	0.19	1.95	n.d.	n.d.	n.d.	0.033	n.d.	0.083	n.d.
River Thames	n.d.	214	n.d.	n.d.	n.d.	100	n.d.	n.d.	4.3		2.9	n.d.	n.d.	3.2	n.d.	n.d.	0.4	n.d.
River Lena	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.3	0.2-0.6	0.35	0.15	n.d.	n.d.	n.d.	0.003-0.008	n.d.	0.017	n.d.

n.d. - no data

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cess exposure to Al is related to nerve damage and allergies, and is believed to be carcinogenic.

Cd concentrations at all sampled stations were below the maximum allowable values in drinking water. Upstream of the Niger and Benue River confluence, before the Lokoja station, the sampled water was weakly contaminated by most trace elements except by Pb (2.56 < 0.02 mg/L), as compared to the Lena River, which is considered to be one of the most pristine of the large rivers. The contamination is probably due to the use of Pb as an anti-knock additive in gasoline. The use of leaded petrol in vehicles, disposal of vehicles and dry deposition of particulate lead in water bodies – mostly from untreated industrial effluents – are also common sources of Pb in the Nigerian water system (Galadima et al. 2011). The use of Pb has been banned in most Northern countries, but persists in the South (Nriagu et al. 2008).

Downstream of the confluence of the River Niger at Lokoja stations LB, LN and LX, the increase in metal concentrations was more prominent. For example, Kakulu and Osibanjo (1992) reported higher concentrations of heavy metals in the Warri and Calabar Rivers – both tributaries to the River Niger. Meanwhile, the Lagos region (Ogun River) displays the highest concentrations of several trace elements (B, Cr, Ni, Zn, As, Mo, Cd and Pb) at the Lagos stations LA1 and LA2, with particularly high concentrations of nitrate (5.7 < 4.65 mg/L) and Boron (137 < 123 mg/L) as compared to other stations. The occurrence of these contaminants reflects the contamination of this water resource by domestic effluents (Rabiet et al. 2006). Boron is released from rocks and soils through weathering, and subsequently ends up in the water through inadequately sealed domestic landfills. It serves as a typical indicator compound for the presence of other hazardous substances, and high boron concentrations in water may be toxic to fish species. Boron is largely used as a bleaching agent in laundry washing products.

Hydrochemistry of the sampled water

The dominant hydrochemical mechanisms that account for the compositional variations of the chem-

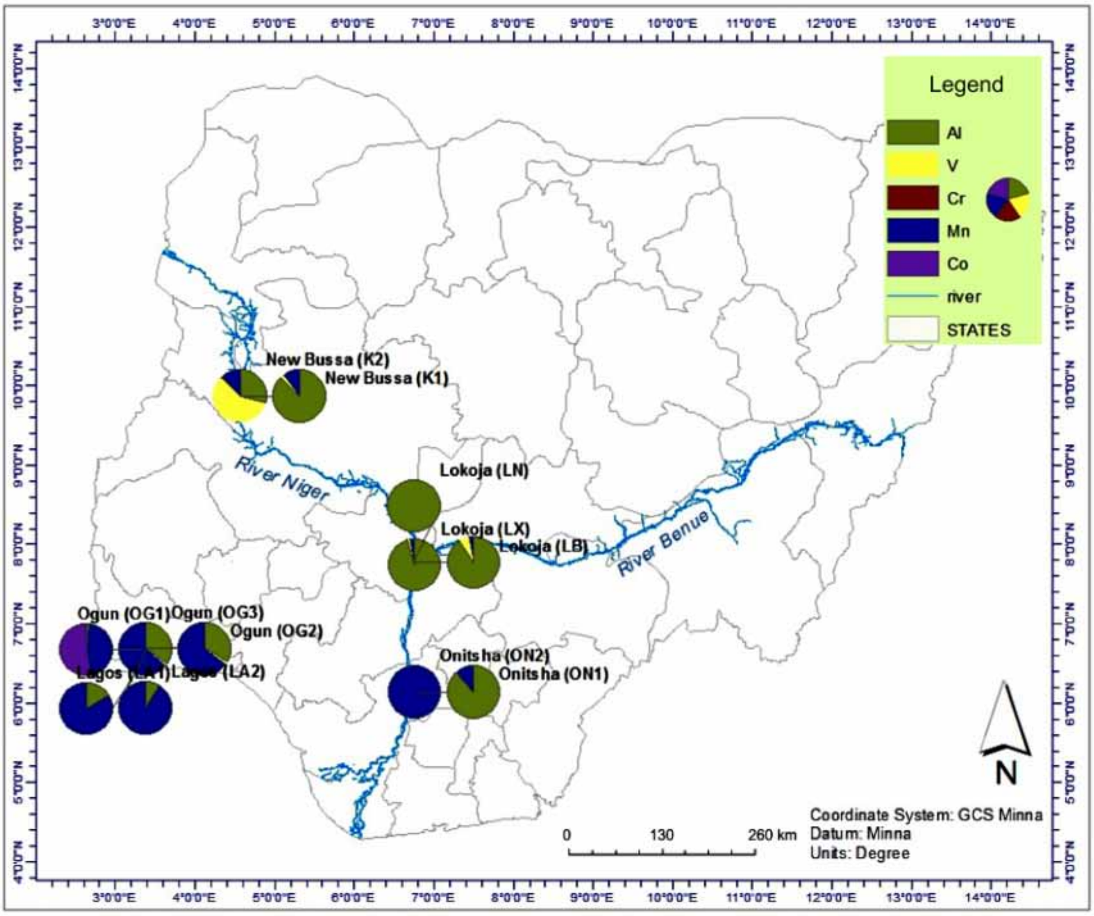

Figure 4. Selected trace element distributions in sampled water stations

Table 3: Distribution of major anions and cations in the lower Niger River basin and part of the Lagos region

Station	Anions					Cations			
	Cond/(mS/cm)	HCO3mg/L	CI mg/L	NO3mg/L	SO4mg/L	Ca mg/L	Mg mg/L	Na mg/L	K mg/L
New Bussa (K1)	141	40.7	1.2	0.2	0.4	5.5	1.9	3.7	3.3
New Bussa (k2)	283	170.2	4	2.2	0.9	26.9	7.5	23.4	1.6
Lokoja (LB)	73	42	0.8		0.7	6.5	2.2	4.6	2
Lokoja (LN)	63	35.2	0.9		0.6	5.6	1.9	3.3	2.7
Lokoja (LX)	63	42	1	0.2	0.5	5.6	1.9	3.4	2.8
Onitsha (ON1)	64	35.3	1.3		0.7	5.5	1.8	4	2.5
Onitsha (ON2)	87	55.6	0.8		0.3	9.3	2.3	3.9	3.2
Lagos (LA1)	408	150.6	29.5	17.6	8.2	24.3	3.1	46.8	11.2
Lagos (LA2)	532	171.7	37.4	38.9	10.7	39.5	5.6	52.7	18.7
Ogun (OG1)	129	36.9	10	1.3	18.5	11.8	2.5	10.2	4.3
Ogun (OG2)	103	48.8	5.6		1.5	8.1	2.8	7.8	2.1
Ogun (OG3)	101	48.9	5.6	0.1	1.4	8.1	2.8	7.9	2.2

ical profile of the sampled water of the lower Niger Basin and part of the Lagos region shows that major chemical variations are reflected in the range of conductivity (63–532 μS/cm) with total cations charge (1.6mg/L<Σ+<14.31mg/l) and total anions (6mg/L<Σ+<14.31mg/l) (Table 3).

Ion concentrations, as measured from the conductivity of the sampled water, ranges from 63 to 532 (mS/cm) with an average of 170.58 (mS/cm). Stations with relatively high conductivity include Lagos (LA1, LA2) and New Bussa (K1, K2), and this is due to the presence of more ions and probably indicative of the presence of more pollutants than at the other stations.

The concentrations of major anions and cations in the sampled stations' waters were in the following order of abundance HCO_3 > NO_3 > Cl > SO_4 and Ca_2^+ > Na^+ > K^+ > Mg_2^+, respectively. The only exception is the Lagos stations (LA1 & LA2), where elevated Na^+ might be due to seawater intrusion along coastal areas, waste deposition, leaking landfills and natural saline seeps. The highest concentration of calcium in water is its natural occurrence in the earth's crust; it is an important determinant of water hardness and functions as a pH stabiliser because of its buffering qualities, as well as improving the water's taste.

Calcium (Ca_2^+), sodium (Na^+), potassium (K^+) and magnesium (Mg_2^+) account for about 40.47%, 34.72%, 13.76% and 11.05% of the total cation. The average concentrations of the cations in the sampled water were: calcium (13.06 mg/l), sodium (14.31 mg/l), potassium (7.48 mg/l) and magnesium (2.67 mg/l). the concentration of Ca_2^+ may reflect the chemical weathering of silicates and the common occurrence of calcium carbonate (Langmuir 1997). For calcium (Ca_2^+), the dominant concentrations ranges from 5.5 to 39.5 mg/l. Sodium (Na^+) concentration ranges from 3.3 to 52.7 mg/l. Other cations, potassium (K^+) and magnesium (Mg_2^+) have ranges of 1.6–18.7 mg/l and 1.8–7.5 mg/l, respectively. Potassium occurs in various minerals, from which it may be dissolved through weathering processes. Sources of potassium include domestic waste landfills and synthetic fertilisers and it is essentially an indicator for the presence of other toxic compounds in groundwater. Magnesium on the other hand is usually washed from rocks and subsequently ends up in water.

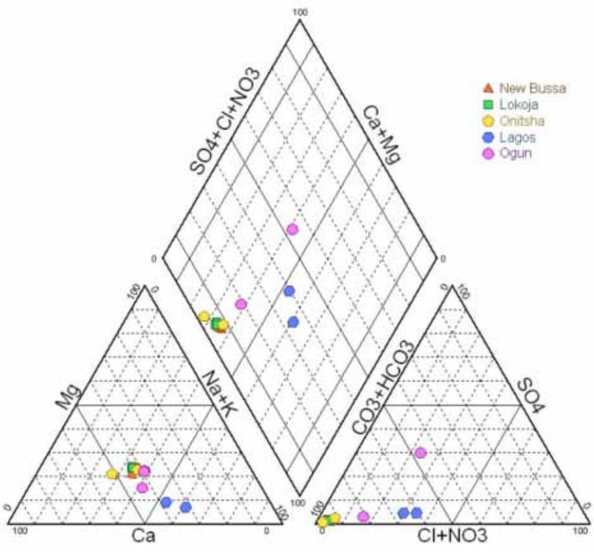

Fig. 5 Piper diagram of sampled water of lower Niger River basin and part of the Lagos region (Nigeria)

Furthermore, the hydrochemical regime of the sampled water with respect to the presence of ions shows that the sampled water type was Ca-bicarbonate as revealed by the Piper diagram (Fig. 5). It should be noted that bicarbonate water is predominantly within the pH range 6.36–10.25 in fresh water (Adeaga et al. 2013).

Conclusion

The water resource from the Niger and Benue Basins is moderately contaminated upstream of their confluence excepted for Pb. Downstream of their confluence, and in the vicinity of Lagos, drinking water exceeds the WHO quality standards for Mn and, to a lesser extent, Al. Manganese is neurotoxic and can provoke Parkinson's disease (Centeno et al. 2005).

The study has also shown that Cd occasionally displays values that are higher than the European quality standards in surface water (EQS-MA). Arsenic concentrations are lower than the drinking water quality standards and are safe for consumption and irrigation. Nevertheless, further analyses would be necessary in water draining other type of rocks in Nigeria (in the northeast and northwest) and also in the Niger delta, where some of the geologic conditions that are usually responsible for the geogenic contamination of water by arsenic are present.

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References

ADEAGA O., MAHÉ G., DIEULIN C., ELBAZ-POULICHET F., ROUCHÉ N., SEIDEL J.L., SERVAT E., 2013, Analysis of surface water quality upstream Niger delta system. [in:] Young G., Perillo G.M.E., Aksoy H., Bogen J., Gelfan A., Mahé G., Marsh P., Savenije H., Deltas: landforms, ecosystems and human activities: proceedings of HP1, IAHS-IAPSO- IASPEI assembly. Wallingford: AISH, 358: 124-125.

ADELANA S.M.A., OLASEHIND P.I., VRBKA P., 2006, Isotope and geochemical characterization of surface and subsurface waters in the Semi-arid Sokoto basin, Nigeria, African Journal of Science and Technology (AJST) Science and Engineering Series, 4, 2: 80–89.

AMADI A. N., YISA J., OGBONNAYA I.C., DAN-HASSAN, M. A., JACOB J. O., ALKALI Y. B., 2012, Quality Evaluation of River Chanchaga Using Metal Pollution Index and Principal Component Analysis. Journal of Geography and Geology, 4, 2.

ANIMI M., ABBASPOUR K., BERG M., WINKEL L., HUG S.J., HOEHN E., YANG H., JOHNSON C.A., 2008, Statistical Modeling of global geogenic arsenic contamination in groundwater. Environmental Science and Technology, 42: 3669–3675.

AYENIMO J.G., ADEYINWO C.E., AMOO I.A., ODUKUDU, F., 2005, A preliminary investigation of heavy metals in periwinkles from Warri River, Nigeria. Journal of Applied Polymer Science, 5, 5: 813–815.

BERNER E.K., BERNER R.A., 1987, The global water cycle: Geochemistry and Environment: Englewood Cliffs, NJ: PrenticeHall, Inc.: 142–155.

BRICKER O.P., JONES B.F., 1995, Main factors affecting the composition of natural waters. [in:] Salbu Ch. 1, B., Steines E. [eds], Trace Metals in Natural Waters, CRC Press: 1–19.

CENTENO J., MULLICK F., ISHAK K., ET AL., 2005, Environmental pathology. [in:] Selimus et al., [eds], Essential of medical Geology, Elsevier: 563–594.

EC, 2005, Commission Regulation (EC). 78/2005 of 19 January 2005.

ELBAZ-POULICHET F., GARNIER J.M., GUAN D.M., MARTIN J. M., THOMAS A. J., 1996, The conservative behaviour of trace metals (As, Cd, Cu, Ni and Pb) in the surface plume of stratified estuaries: example of the Rhone river (France). Estuarine Coastal and Shelf Science, 42: 289–310.

ELBAZ-POULICHET F., SEIDEL J.L., CASIOT C., TUSSEAU-VILLEMIN M.H., 2006, Short-term variability of dissolved trace element concentrations in the Marne and Seine Rivers near Paris. Science of the Total Environment, 367: 278–287.

GALADIMA A., GARBA Z.N., LEKE L., ALMUSTAPHA M.N., ADAM, I.K., 2011, Domestic Water Pollution among Local Communities in Nigeria; Causes and Consequences. European Journal of Scientific Research, 52,4: 592–603.

HUGHES, R.H., HUGHES J.S., 1991, A directory of African wetlands, IUCN, Gland, Switzerland.

JAJI M.O., BAMGBOSE O., ODUKOYA O.O., AROWOLO T.A., 2007, Water quality assessment of Ogun River, South West Nigeria. Environmental Monitoring Assessment, 33, 1–3: 473–482. DOI: 10.1007/s10661-006-9602-1.

KAKULU S.E., OSIBANJO O., 1992, Pollution studies of Nigerian rivers: Trace metal levels of surface waters in the Niger Delta. International Journal of Environmental Studies, 41: 287–292.

LANGMUIR D.A., 1997, Aqueous Environmental Geochemistry; Prentice-Hall, Upper Saddle River, NJ: 600.

Lee, C.S.L., Li, X.D., Zhang, G., Li, J., Ding, A.J., Wang, T., 2007. Heavy metals and Pb isotopic composition of aerosols in urban and suburban areas of Hong Kong and Guangzhou, South China Evidence of the long-range transport of air contaminants. Environmental Pollution, 41, 2: 432–447.

MAHE G., L'HOTE Y., OLIVRY J.C., WOTLING G., 2001, Trends and discontinuities in regional rainfall of west and central Africa – 1951–1989. Hydrological Sciences Journal, 46, 2: 211–226.

MANOJ K., GHOSH S., AND PADHY P.K., 2013, Characterization and classification of hydrochemistry using multivariate graphical and hydrostatistical techniques, Research Journal of Chemical Sciences, 3, 5: 32–42.

Martin J.M., Guan D.M., Elbaz-Poulichet F., Thomas, A.J., Gordeev, V.V., 1993, Preliminary assessment of the distribution of some trace elements (As, Cd, Cu, Fe, Ni, Pb and Zn) in a pristine aquatic environment: the Lena River estuary (Russia). Marine Chemistry, 43, 1/4: 185–199.

NEAL C., JARVIE H., WHITTON B., GEMMELL J., 2000, The water quality of the River Wear, north-east England. Science of the Total Environment, 251/252: 153–172.

NIGER-HYCOS, 2006, An information system for water resources assessment and management of the Niger Basin, a Sub-regional component of the WHYCOS Project Document – July 2006.

NRIAGU J., AFEICHE M., LINDER A., AROWOLO T,. ANA G., SRIDHAR M.K., OLORUNTOBA E.O., OBI E., EBENEBE J.C., ORISAKWE O.E., ADESINA A., 2008, Lead poisoning associated with malaria in children of urban areas of Nigeria. International Journal of Hygiene and Environmental Health, 211: 591–605.

OLATUNJI O.S., OSIBANJO O., 2012, Determination of selected heavy metals in inland fresh water of lower River Niger drainage in North Central Nigeria. African Journal of Environmental Science and Technology, 6, 10: 403–408.

ONWUGBUTA-ENYI J., ZABBEY N., ERONDU E.S., 2008, Water Quality of Bodo Creek in the Lower Niger Delta basin. Advances in Environmental Biology 2, 3: 132–136.

PIPER A.M., 1944, A graphic procedure in the geochemical interpretation of water analyses, Transaction of American Geophysical Union, 25: 914–928.

Rabiet M., Togola A., Brissaud F., Seidel J.-L., Budzinski H., Elbaz-Poulichet F., 2006, Consequences of treated water recycling as regards pharmaceuticals and drugs in surface and ground waters of a medium-sized Mediterranean catchment. Environmental Science and Technology, 40: 5282–5288.

SALOMON W., FORSTNER U., 1984, Metals in the Hydrocycle. Berlin, Springer: 349.

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