Prioritizing hazardous pollutants in two Nigerian water supply schemes: a risk-based approach

Ayotunde T Etchie,[a] Tunde O Etchie,[a] Gregory O Adewuyi,[a] Kannan Krishnamurthi,[b] S Saravana Devi[b] & Satish R Wate[b]

Objective To rank pollutants in two Nigerian water supply schemes according to their effect on human health using a risk-based approach.
Methods Hazardous pollutants in drinking-water in the study area were identified from a literature search and selected pollutants were monitored from April 2010 to December 2011 in catchments, treatment works and consumer taps. The disease burden due to each pollutant was estimated in disability-adjusted life years (DALYs) using data on the pollutant's concentration, exposure to the pollutant, the severity of its health effects and the consumer population.
Findings The pollutants identified were microbial organisms, cadmium, cobalt, chromium, copper, iron, manganese, nickel, lead and zinc. All were detected in the catchments but only cadmium, cobalt, chromium, manganese and lead exceeded World Health Organization (WHO) guideline values after water treatment. Post-treatment contamination was observed. The estimated disease burden was greatest for chromium in both schemes, followed in decreasing order by cadmium, lead, manganese and cobalt. The total disease burden of all pollutants in the two schemes was 46 000 and 9500 DALYs per year or 0.14 and 0.088 DALYs per person per year, respectively, much higher than the WHO reference level of 1×10^{-6} DALYs per person per year. For each metal, the disease burden exceeded the reference level and was comparable with that due to microbial contamination reported elsewhere in Africa.
Conclusion The estimated disease burden of metal contamination of two Nigerian water supply systems was high. It could best be reduced by protection of water catchment and pretreatment by electrocoagulation.

Abstracts in عربي, 中文, Français, Русский and Español at the end of each article.

Introduction

In the fourth edition of the *Guidelines for drinking-water quality*, the World Health Organization (WHO) reiterates that a risk-based approach should be used to inform management decisions on the safety of drinking-water supplies.[1] This approach entails the comprehensive assessment of both the risk to health and risk management and should encompass all stages of the water supply system, from water catchment to human consumption.[1–3] In contrast, the concentration-based approach relies solely on determining whether the end product complies with standards that ensure consumer safety.[2] Nevertheless, even with the risk-based approach, the concentration of contaminants in water ultimately determines the level of risk. However, in addition to concentration, the risk-based approach also takes into account parameters such as the level and duration of exposure to contaminants, their toxicity and the severity of the diseases they produce in assessing the need for mitigation. Furthermore, since this approach involves estimating the number of disability-adjusted life years (DALYs), it provides a framework for systematically comparing the disease burden associated with different pollutants,[4] whether microbial, chemical or radiological.[1]

In this paper, we used a risk-based approach to identify the pollutants that posed the greatest risk to human health in two Nigerian water supply schemes and which should, therefore, be prioritized for removal.

Methods

Two water supply schemes in Nigeria were investigated: the Asejire and Eleyele schemes in Oyo State, which was included in "hydrological area 6" in the WHO and United Nations Children's Fund (UNICEF) country report for Nigeria.[5] The Asejire scheme, which was commissioned in 1972, is located in a suburb of the metropolis of Ibadan, about 30 km east of the city centre; the Eleyele scheme, which was commissioned in 1942, is situated within the metropolis. Ibadan is the capital of Oyo State and covers the largest area of any city in any country in tropical Africa.[6] It is also the third most populous city in Nigeria: in 2010, the population was 2 893 137.[6]

The two water supply schemes are managed by the Water Corporation of Oyo State and together provide an urban piped water supply to around 25% of the people in Ibadan.[7,8] Water for the Asejire scheme is collected by a dam on the River Osun and the level is maintained at about 81 m[7] throughout the year, thereby ensuring a regular supply. Farming is prohibited in the catchment area[7] and trees were planted on the banks of the dam to prevent soil erosion and silting. The Eleyele scheme's dam collects water from two major rivers: the Ona and Ogunpa, which pass through Ibadan and are often polluted with effluent from unregulated industrial, commercial and residential quarters.[7] Water for the treatment works is abstracted using a low-lift pump in the Asejire scheme and by gravity in the Eleyele scheme. Water purification is carried out using the conventional techniques of screening, aeration, coagulation, flocculation, sedimentation, filtration and chlorination. Treated water is delivered to consumers by tankers and through a pipe distribution system, which includes high-lift

a Department of Chemistry (office 8, block B), Faculty of Science, University of Ibadan, Ibadan, Nigeria.
b National Environmental Engineering Research Institute, Council of Scientific and Industrial Research, Nagpur, India.
Correspondence to Gregory O Adewuyi (email: adewuyiap@yahoo.com)

pumps and booster stations in strategic locations. Piped water is supplied mostly to yard and community taps, except in a few affluent areas where domestic water systems are common. Water is often stored in household containers because the supply is inconsistent. Secondary water treatment in homes is rare. The water supply schemes are unable to recover their operating costs despite government aid. Hence, the water supply is intermittent owing to a lack of chemicals and the high cost of pumping. Moreover, infrastructure maintenance is poor and as much as 40% of water can be lost from the distribution system.[7,9]

Identifying pollutants

We searched PubMed and Google scholar using the phrase "drinking water of Ibadan" to identify scientific articles published between 2000 and 2010 on relevant hazardous pollutants. We then selected pollutants whose reported concentration exceeded regulatory guideline values. In particular, we looked for chemicals prioritized by WHO[10] (i.e. arsenic, fluoride and nitrate) but no study reported a high level. In fact, a project sponsored by WHO and UNICEF in Nigeria in 2004 and 2005[5] reported that all water from utility pipes and tankers studied complied with guidelines for arsenic, fluoride and nitrate. The hazardous pollutants we identified for inclusion in our investigation were: microbial organisms, cadmium, cobalt, chromium, copper, iron, manganese, nickel, lead and zinc.

For the two water supply schemes, we sampled water from dams, treatment works and consumer taps, which we regarded as the end-point of the distribution system, in 12 communities within the Ibadan metropolis: Apete, Eleyele, Mokola and Sango for the Eleyele scheme and Agodi, Alafara Oje, Basorun, Bere, Beyeruka, Iwo Road, Oduoba and Ojaba for the Asejire scheme. Dam water was sampled where the river enters the dam, in the middle of the dam and at the outlet to the treatment works. After treatment, samples were collected at three different taps within each treatment works. For the Asejire scheme, six different consumer taps were sampled in each community, whereas, for the Eleyele scheme, a variable number of samples was collected because water was not distributed equally at all times to all consumer taps. Before collection, we ran off the tap water for about 20

seconds, which is longer than most people would. Sampling was carried out every two months from April 2010 to December 2011. The Eleyele scheme was shut down temporarily between July 2011 and December 2011 because of flooding, which reduced the number of treated water samples collected at both the treatment works and consumer taps.

For microbiological screening, we collected water samples in aseptic, nonfluorescent 100-ml glass bottles with screw caps. Treated water samples collected at treatment works and consumer taps were dechlorinated using sodium thiosulfate. Within 2 hours of sampling, water was screened for the presence of total coliforms and *Escherichia coli* using Colilert powder. The bottles were capped and incubated for 24 hours at 35 °C. Yellow coloration indicated the presence of total coliforms and fluorescence at 365 nm indicated the presence of *E. coli*. Each water sample was screened three times.

For heavy metal analysis, water samples were collected in metal-free, plastic bottles with screw caps and nitric acid was added to achieve a pH below 2. Samples were stored in an ice chest below 4 °C and immediately transferred to a deep freezer on arrival at the laboratory. Metal digestion was carried out using nitric acid within 24 hours and metal concentrations were determined by atomic absorption spectrometry.

Table 2. Mean metal concentrations, two water supply schemes, Nigeria, 2010–2011

Location sampled	Mean upper 95% CI limit of concentration[a] (mg/l)				
	Cd	Co	Cr	Mn	Pb
Asejire water supply scheme					
Consumer tap water[b]	0.06	0.08	0.23	0.10	0.25
Treatment works	0.01	0.08	0.25	0.13	0.18
Dam water	0.20	0.19	0.34	0.43	0.49
Eleyele water supply scheme					
Consumer tap water[b]	0.04	0.09	0.12	0.23	0.31
Treatment works	0.02	0.09	0.12	0.24	0.29
Dam water	0.43	0.17	0.43	0.54	0.66
WHO MCL[1]	**0.003**	**0.10[c,d]**	**0.05**	**0.04**	**0.01**

Cd, cadmium; CI, confidence interval; Co, cobalt; Cr, chromium; MCL, maximum contaminant level; Mn, manganese; Pb, lead; WHO, World Health Organization.

[a] The mean annual upper 95% confidence interval (CI) limit for the concentration was calculated from the mean upper 95% CI limit of the concentration in the dry season (C_d) and the mean upper 95% CI limit of the concentration in the wet season (C_w) by assuming that the dry season lasted 4 months and the wet season, 8 months and using the formula: $((C_d \times 4) + (C_w \times 8))/12$.

[b] The mean upper 95% CI limit of the concentration in consumer tap water during the wet and dry seasons was calculated by averaging measurements in all supply areas for a particular scheme during the respective season.

[c] Maximum contaminant level from the environmental media evaluation guide for children (California Department of Public Health).[11]

[d] Maximum contaminant level from health-based groundwater quality criteria (New Jersey Department of Environmental Protection.)[12]

Risk assessment

We compared the concentrations of hazardous pollutants in water from treatment works and consumer taps with WHO guidelines[1] (Table 1, available at: http://www.who.int/bulletin/volumes/91/8/12-115774) and identified those that exceeded guideline limits: they were cadmium, chromium, cobalt, lead and manganese (Table 2). In assessing the risk to health associated with the presence of a particular metal, we adopted the approach used by Crawford-Brown and Crawford-Brown,[4] who related the risk of each individual health outcome associated with a particular metal to the probability of that health outcome occurring and the severity of the outcome, expressed in DALYs:

$$\text{individual risk} = \text{probability} \times \text{severity} \quad (1)$$

where the probability depends on exposure to the metal and its toxicity:

$$\text{probability} = \text{exposure} \times \text{toxicity} \quad (2)$$

Exposure

As a summary measure of biologically relevant exposure to a metal in water, we used the chronic daily intake of the metal, in mg per kg per day, by children and adult females and males, as defined in Equation 3, Equation 4 and Equation 5.[13–16]

For the oral ingestion of treated water:

$$CDI_o = \frac{C_M \times IR \times EF \times ED}{BW \times AT} \qquad (3)$$

where CDI_o is the oral chronic daily intake, C_M is the upper 95% confidence interval (CI) limit for the concentration of the metal in water, IR is the ingestion rate, EF is exposure frequency, ED is exposure duration, BW is body weight and AT is the lifetime averaging time.

For dermal contact with treated water:

$$CDI_d = \frac{k_p \times C_M \times t_{event} \times EV \times ED \times EF \times SA}{BW \times AT \times ABS_{GI}} \qquad (4)$$

where CDI_d is the dermal chronic daily intake, k_p is the skin permeability coefficient, t_{event} is the exposure event duration, EV is the event frequency, SA is the skin surface area involved and ABS_{GI} is the gastrointestinal absorption fraction.

Combining these terms, the total chronic daily intake (CDI) is given as:

$$CDI = CDI_o + CDI_d \qquad (5)$$

In calculations, we used exposure data from Adewuyi et al.[17] because they reflect typical water usage in Nigeria (Table 3, available at: http://www.who.int/bulletin/volumes/91/8/12-115774).

Toxicity

Crawford-Brown and Crawford-Brown[4] and Pennington et al.[19] argue that measures of toxicity, such as the reference dose, acceptable daily intake, tolerable daily intake and minimal risk level, were developed for assessing the health risk of individual hazardous substances in a regulatory context, not for comparing hazards. Consequently, Crawford-

Brown and Crawford-Brown proposed using the 1% benchmark dose as the metric of toxicity for the noncancerous effects of a substance. This is the dose at which 1% of the population would develop the specified health outcome and is usually expressed in mg per kg per day. Alternatively, Pennington et al. proposed a central estimate of the effect dose, ED_{10}, also expressed in mg per kg per day, which is the dose that results in a 10% increase in the incidence of the specified health outcome relative to the background level. In addition, the health risk can be extrapolated for lower doses using a slope factor, β_{ED10}. We used Pennington et al.'s approach for estimating noncancerous effects on health and selected the following algorithms for ED_{10}:

$$ED_{10} = \frac{BMD_{10}}{0.54} \qquad (6)$$

$$BMD_{10} = 1.6 \times NOAEL \qquad (7)$$

$$ED_{10} = 0.3 \times LOAEL \qquad (8)$$

For cadmium and chromium, we estimated ED_{10} using values for BMD_{10} obtained from the literature, where BMD_{10} is the lower 95% confidence limit for the dose that results in a 10% increase in the incidence of the specified health outcome relative to the background level.[19] For cobalt and manganese, we used the no-observable-adverse-effect level (NOAEL) and the lowest-observable-adverse-effect level (LOAEL), respectively, both of which are expressed in mg per kg per day. These algorithms all assume a linear relationship between dose and response. Where dose levels were obtained in mice, we used a subchronic-to-chronic conversion factor of 3.3 and an animal-to-human conversion factor of 13 to derive equivalent dose levels in humans, as recommended by Pennington et al.[19] We did not use the additional "margin-of-safety" factor of 3 that is generally used for regulatory purposes. We then calculated values for β_{ED10} from the ED_{10} values for all noncarcinogenic health outcomes associated with these four metals (Table 4, available at: http://www.who.int/bulletin/volumes/91/8/12-115774):

$$\beta_{ED_{10}} = \frac{0.1}{ED_{10}} \qquad (9)$$

Since we were not able to obtain data on the reference toxic dose for lead in water, we applied WHO's method for estimating the health risks of lead.[29] First, we compared the lead concentrations we observed with the results of a cross-sectional study carried out in the District of Columbia in the United States of America,[30,31] which linked levels of lead in water to blood lead levels. That study reported that people who drank water with a lead concentration greater than 0.3 mg per litre, which was comparable to levels observed in our study, had a blood lead level below the level of concern of the United States Centers for Disease Control and Prevention: 10 μg per dl for children aged 6 months to 15 years and 25 μg per dl for adults. Hence, we assumed that the blood lead level corresponding to the lead concentrations in water we observed (Table 1) would fall within the range of 5 to 10 μg per dl and, in calculations, we used a mean of 7.5 μg per dl, which is associated with a mean reduction of 0.65 in intelligence quotient in children and a mean increase of 0.625 mmHg and 0.4 mmHg in systolic blood pressure in adult males and females, respectively.[29]

The presence of chromium in treated water has been associated with several types of cancer, assuming all species of the metal are oxidized to Cr^{6+}: oral, oesophageal, gastric and small intestine cancer.[32,33] To estimate β_{ED10} for the carcinogenic effects of chromium, we adopted the method proposed by Crettaz et al.,[34] which relates the cancer slope factor (CSF) for chromium given by the United States Environmental Protection Agency (i.e. 0.5 kg–days per mg) to β_{ED10}:

$$\beta_{ED_{10}} = 0.5 \times CSF \qquad (10)$$

Probability

For each health outcome associated with cadmium, cobalt, chromium and manganese contamination, we used the estimates for exposure and toxicity obtained in the previous steps of the calculation to derive the probability of that health outcome:

$$LPO = CDI \times \beta_{ED_{10}} \qquad (11)$$

where LPO is the lifetime probability of the outcome.

For lead, we calculated the probability of mild mental retardation (PMMR) associated with a mean reduction of 0.65 in intelligence quotient in children aged 4 years or under using the equation given by Fewtrell et al.:[29]

$$ \text{PMMR} = \frac{C_F \times \%\text{MMR} \times \text{adjustment ratio}}{5} \quad (12) $$

where C_F is the fraction of consumers aged 4 years or under (Table 5, available at: http://www.who.int/bulletin/volumes/91/8/12-115774) and %MMR is the percentage of consumers that will enter the intelligence quotient range indicating mild mental retardation. The adjustment ratio takes into account mental retardation caused by communicable diseases and iodine deficiency and the higher incidence of mental retardation in developing countries relative to developed countries. Fewtrell et al.[29] give a value of 0.24% for %MMR and 2.05 for the regional adjustment ratio.

For adults, the probability of cardiovascular disease due to lead (PCVDL) in men and women was calculated using:

$$ \text{PCVDL} = \frac{C_F(\text{RR}-1)}{C_F(\text{RR}-1)+1} \quad (13) $$

where C_F is the fraction of consumers aged 15 to 54 years who were male or female, respectively, and RR is the corresponding relative risk of cardiovascular disease in men or women (Table 5).

Severity

The severity of each health outcome was quantified by obtaining an estimate of the associated degree of disability. For all outcomes other than cancer, we used the value of 0.67 DALYs per affected person attributable to irreversible systemic disease given by Pennington et al.[19] Crettaz et al.[34] derived the number of DALYs per person due to tumours at various sites using international data reported by Murray and Lopez:[35] for oral cavity and oropharyngeal cancer, it was

3.5 DALYs per affected person; for oesophageal cancer, 9.3 DALYs per person; and for gastric cancer, 7.2 DALYs per person. Although these authors did not report a figure for cancer of the small intestine, they suggested a default value of 6.7 DALYs per affected person.[34]

Risk

The total risk to health of each individual metal contaminant (IR), expressed in DALYs per person per year, was calculated by summing the risks for each health outcome associated with that metal:

$$ \text{IR} = \sum \frac{C_F \times \text{LPO} \times \text{severity}}{\text{average lifespan of Nigerians}} \quad (14) $$

where C_F is the fraction of consumers exposed to the health outcome (Table 6 and Table 7, both available at: http://www.who.int/bulletin/volumes/91/8/12-115774), severity is expressed in DALYs per affected person and the average lifespan of Nigerians is 54 years.[36]

Then we calculated the total risk to the consumer population (RCP) for each water supply scheme, expressed in DALYs per year, from the individual risks associated with all metal contaminants (IRMC) in each scheme, weighted according to observed contaminant levels:

$$ \text{RCP} = \sum \text{IRMC} \times \text{consumer population} \quad (15) $$

In estimating the consumer population for each water supply scheme, we used information on the distribution capacities of the schemes and the percentage of the population of Ibadan covered by the two schemes. The Asejire scheme provided 82 000 m³ per day and the Eleyele scheme, 27 000 m³ per day, which correspond to 75% and 25% of the total supplied by the two schemes, respectively. In theory, this total should have accounted for 25% of the water supply for the metropolis. However, we assumed a reduction of 5% due to leakage and another reduction of 5% due

to political exaggeration; consequently, we assumed these supplies accounted for 15% of the supply to Ibadan. Using population data for 2010, we estimated that the consumer population for the two schemes combined was 433 971: 325 478 for the Asejire scheme (i.e. 75%) and 108 493 for the Eleyele scheme (i.e. 25%).

Results

The results of our analysis of water samples from dams, treatment works and consumer taps are shown in Table 1 for selected pollutants. Although the total coliform and *E. coli* tests were positive for dam water from both water supply schemes, these contaminants were absent from water from treatment works and consumer taps.

The upper 95% CI limit for the concentrations of cadmium, chromium, lead, manganese, and nickel in dam water exceeded WHO guideline values[1] in both wet and dry seasons, whereas the concentrations of copper, iron and zinc were below guideline values. The upper 95% CI limit for the concentration of cobalt in dam water exceeded the maximum contaminant level given by both the environmental media evaluation guide for children[11] and health-based groundwater quality criteria[12] in the wet season but not in the dry season (Table 1). Although water treatment reduced these concentrations substantially, metal contamination also occurred in the distribution system: levels of cadmium, copper, iron, lead, nickel and zinc were much higher at consumer taps than in water leaving the treatment works. In particular, the upper 95% CI limit for the concentrations of cadmium, chromium, manganese and lead in treated water exceeded WHO guideline values (Table 2).[1] Consequently, these four metals were used in the risk assessment. Cobalt was also included because no WHO guideline value was available.

Table 5 shows the disease burden due to lead contamination. Table 6 and Table 7 show the estimated disease burden due to cadmium, cobalt, chromium and manganese contamination of the two water supply systems. Table 6 shows the hypothetical disease burden that would result if consumers received water directly from the treatment works. This was used for comparison with the disease burden associated with water from

Fig. 1. **Disease burden of water supply scheme contamination in Nigeria compared with literature values, 2010–2011**
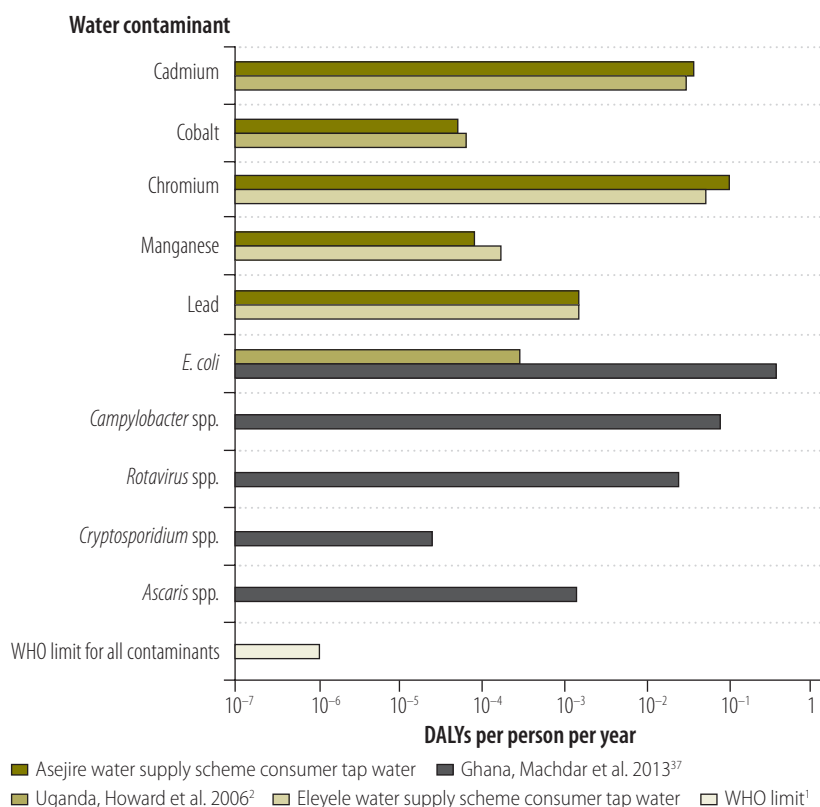
DALY, disability-adjusted life year; *E. coli, Escherichia coli*; WHO, World Health Organization.

Table 8. **Disease burden due to metal contamination of consumer tap water in populations using two water supply schemes, Nigeria, 2010–2011**

Water supply scheme	Estimated disease burden (DALYs per year)					
	Cd	Co	Cr	Mn	Pb	Total
Asejire	12 000	17	33 000	25	520	46 000
Eleyele	3400	6.8	5900	20	170	9500

Cd, cadmium; Co, cobalt; Cr, chromium; DALY, disability-adjusted life year; Mn, manganese; Pb, lead.

consumer taps (Table 7). Comparison of Table 6 and Table 7 shows that there was no difference in the disease burden due to chromium, manganese or cobalt contamination between water from treatment works and water from consumer taps. In contrast, the estimated number of DALYs per person per year attributable to cadmium contamination was much greater for water from consumer taps. We could not carry out a similar comparison for lead because we estimated the disease burden using a concentration range rather than a mean value.

We also compared our estimates of the disease burden due to water contamination at consumer taps supplied by the two water supply schemes with that associated with WHO's reference limit and with microbial contamination reported in the literature (Fig. 1). The disease burden due to chromium contamination alone in our study was around 100 000 times that associated with WHO's reference limit and around 1000 times that due to pathogenic *E. coli* contamination of treated water in Uganda, which was 0.292×10^{-3} DALYs per person per year.[2] Recently, Machdar

et al.[37] reported that the disease burden, in DALYs per person per year, due to different types of contamination in Ghana was 0.395 for pathogenic *E. coli*, 0.0813 for *Campylobacter* spp., 0.026 for rotavirus, 0.025×10^{-3} for *Cryptosporidium* spp. and 1.4×10^{-3} for *Ascaris* spp.

Table 8 shows the total disease burden due to each metal contaminant among consumers supplied by the two water supply schemes. Chromium had the largest effect on human health in both schemes, followed in decreasing order by cadmium, lead, manganese and cobalt. The total number of DALYs per year attributable to metal contamination of the Asejire and Eleyele water supply schemes was 46 000 and 9500, respectively. This is equivalent to 0.14 and 0.088 DALYs per person per year, respectively: both values are much higher than the WHO reference limit of 1×10^{-6} DALYs per person per year but lower than the 0.5 DALYs per person per year reported for microbial contaminants in Ghana.[37]

Discussion

Our risk-based approach to identifying the pollutants in two Nigerian water supply schemes that posed the greatest risk to human health showed that the most important were chromium, cadmium, lead, manganese and cobalt, in decreasing order of their effect on health. The estimated disease burden due to each metal contaminant far exceeded reference limits and was comparable with the results of African studies of the disease burden of microbial contamination. In contrast, total coliforms and *E. coli* were not present in consumer tap water in the Nigerian water supply schemes, which indicates that treatment was effective in removing microbial contaminants present in dam water. Nevertheless, given the large number of pathogens that could be present in water, this negative finding should be taken with some degree of caution.

Metal contamination also occurred in the distribution system and, in particular, post-treatment contamination was substantial for cadmium and lead. However, most of the disease burden associated with these two contaminants appeared to be due to contaminated dam water and ineffective treatment. Consequently, reducing the disease

burden could best be achieved by protecting water catchment and upgrading water treatment systems. Several studies have shown that electrocoagulation can reduce the quantity of metal ions in water to a very low level.[38–41] The technique could be particularly effective when used before conventional chemical treatment. Further, comparison of the disease burden due to metal contamina

tion observed in our study and that due to microbial contamination in other African studies indicates that chemical contaminants could be as important as microbial contaminants in piped water supplies. ■

ملخص

تحديد أولويات الملوثات الخطرة في مخططين لإمدادات المياه في نيجيريا: نهج قائم على المخاطر

الغرض ترتيب الملوثات في مخططين لإمدادات المياه في نيجيريا وفقاً لتأثيرها على صحة الإنسان باستخدام نهج قائم على المخاطر. **الطريقة** تم تحديد الملوثات الخطرة في مياه الشرب في منطقة الدراسة من الأبحاث المنشورة وتم رصد الملوثات المحددة في الفترة من نيسان/ أبريل 2010 إلى كانون الأول/ ديسمبر 2011 في مستجمعات المياه ومحطات المعالجة وصنابير المستهلكين. وتم تقدير عبء المرض الناتج عن كل ملوث بالنسبة لسنوات العمر المصححة باحتساب مدد العجز باستخدام البيانات المعنية بتركيز الملوث والتعرض للملوث وخطورة آثاره الصحية والفئات السكانية للمستهلكين.

النتائج كانت الملوثات التي تم تحديدها عبارة عن كائنات عضوية جرثومية والكادميوم والكوبلت والكروم والنحاس

والحديد والمنغنيز والنيكل والرصاص والزنك. وتم اكتشافها جميعاً في مياه المستجمعات ولكن لم يتعدى قيم المبدأ التوجيهي لمنظمة الصحة العالمية بعد معالجة المياه سوى الكادميوم والكوبلت والكروم والمنغنيز والرصاص. ولوحظ وجود تلوث بعد معالجة المياه. وكان أكبر عبء للمرض وفق التقديرات في الكروم في كلا المخططين، يليه تنازلياً الكادميوم والرصاص والمنغنيز والكوبلت. وكان إجمالي عبء المرض لجميع الملوثات في المخططين 46000 و9500 سنة من سنوات العمر المصححة باحتساب مدد العجز لكل سنة

摘要

尼日利亚两个供水方案的有害污染物排序：基于风险的方法

目的 根据对人体健康的影响，使用基于风险的方法，对尼日利亚两个供水方案的污染物进行评级。
方法 从文献检索中确定研究区域饮用水中的有害污染物，监测 2010 年 4 月到 2011 年 12 月集水区、污水处理厂和消费者的水龙头的选定污染物。使用污染物浓度、污染物接触、健康影响严重程度和消费者人群的相关数据以伤残调整寿命年 (DALY) 为单位估计每个污染物造成的疾病负担。
结果 确定的污染物有微生物、镉、钴、铬、铜、铁、锰、镍、铅和锌。所有污染物在集水区检测，但仅镉、钴、铬、锰、铅在水处理之后超过世界卫生组织 (WHO) 指导值。

观察处理后污染物。在两个方案中，铬的估计疾病负担最大，然后按递减顺序依次是镉、铅、锰和钴。在两个方案中，所有污染物的合计疾病负担分别是每年 4.6 万和 9500 DALY，或者每年每人 0.14 和 0.088 DALY，比世界卫生组织的每年每人 1×10^{-6} DALY 的参考水平高很多。对于每种金属，疾病负担均超过参考水平，与非洲其他地方报告的微生物污染造成的疾病负担相当。
结论 尼日利亚两个供水方案的金属污染物估计疾病负担较高。保护集水区和电絮凝法预处理可能是减少污染的最佳方法。

Résumé

Prioriser les polluants dangereux dans deux systèmes d'approvisionnement en eau au Nigéria: une approche fondée sur le risque

Objectif Classer les polluants dans deux systèmes nigérians d'approvisionnement en eau en fonction de leur effet sur la santé humaine, en utilisant une approche fondée sur le risque.
Méthodes Dans la zone d'étude, les polluants dangereux dans l'eau potable ont été identifiés grâce à une recherche documentaire, et certains polluants ont été suivis d'avril 2010 à décembre 2011 dans des bassins versants, des installations de traitement et au robinet des consommateurs. La charge de morbidité due à chaque polluant a été estimée en années de vie ajustées sur l'incapacité (DALY) à l'aide des

données relatives à la concentration des polluants, l'exposition aux polluants, la gravité de leurs effets sur la santé et la population des consommateurs.
Résultats Les polluants identifiés étaient des organismes microbiens, le cadmium, le cobalt, le chrome, le cuivre, le fer, le manganèse, le nickel, le plomb et le zinc. Tous ont été détectés dans les bassins versants, mais seuls le cadmium, le cobalt, le chrome, le manganèse et le plomb dépassaient les valeurs indicatives de l'Organisation mondiale de la Santé (OMS) après traitement de l'eau. Une contamination postérieure au

traitement a été observée. Selon les estimations, la charge de morbidité la plus lourde résultait du chrome dans les deux systèmes, suivi par le cadmium, le plomb, le manganèse et le cobalt, par ordre décroissant. La charge de morbidité totale de tous les polluants des deux systèmes était de 46 000 et 9500 DALY par an ou de 0,14 et 0,088 DALY par personne et par an, respectivement. Elle était donc beaucoup plus élevée que le niveau de référence de l'OMS, soit 1×10⁻⁶ DALY par personne et par an. Pour chaque métal, la charge de morbidité dépassait le niveau de

référence et était comparable à celle due à la contamination microbienne signalée ailleurs en Afrique.

Conclusion Les estimations de la charge de morbidité de la contamination métallique des deux systèmes nigérians d'approvisionnement en eau étaient élevées. Les meilleures façons de réduire la charge de morbidité seraient la protection du bassin versant et le prétraitement par électrocoagulation.

Резюме

Оценка приоритетности опасных загрязняющих веществ в двух нигерийских системах водоснабжения: риск-ориентированный подход

Цель Осуществить ранжирование загрязняющих веществ в двух нигерийских системах водоснабжения по степени их влияния на здоровье человека с использованием риск-ориентированного подхода.

Методы Опасные загрязняющие вещества в питьевой воде в исследуемом районе идентифицировались с помощью поиска литературы, а мониторинг отдельных загрязняющих веществ осуществлялся с апреля 2010 года по декабрь 2011 года в водосборных бассейнах, очистных сооружениях и кранах потребителей. Бремя заболеваний, обусловленное каждым загрязняющим веществом, оценивалось в скорректированных на нетрудоспособность годах жизни (ДАЛИ) с использованием данных о концентрации загрязняющего вещества, воздействии данного загрязняющего вещества, тяжести его последствий для здоровья и популяции потребителей.

Результаты Были идентифицированы следующие загрязняющие вещества: микроорганизмы, кадмий, кобальт, хром, медь, железо, марганец, никель, свинец и цинк. Все они были обнаружены в водосборных бассейнах, однако только содержание

кадмия, кобальта, хрома, марганца и свинца превысило нормативные значения, установленные Всемирной организацией здравоохранения (ВОЗ) для воды, прошедшей обработку. Было обнаружено присутствие загрязняющих веществ после обработки. В обеих системах расчетное бремя болезней было максимальным для хрома, а затем в порядке убывания следовали кадмий, свинец, марганец и кобальт. Общее бремя болезней всех загрязняющих веществ в двух системах составило 46 000 и 9500 ДАЛИ в год, или 0,14 и 0,088 ДАЛИ на человека в год, соответственно, что намного выше, чем контрольный уровень ВОЗ, равный 1×10⁻⁶ ДАЛИ на человека в год. Для каждого металла бремя болезней превысило контрольный уровень и было сопоставимо с влиянием микробного загрязнения, наблюдаемого в других странах Африки.

Вывод Расчетное бремя болезней в результате загрязнения металлами воды в двух нигерийских системах водоснабжения было высоким. Лучшим способом его снижения является защита водосборов и предварительная обработка воды методом электрокоагуляции.

Resumen

Dar prioridad a contaminantes peligrosos en dos sistemas de suministro de agua en Nigeria: un enfoque basado en el riesgo

Objetivo Clasificar los contaminantes de dos sistemas de suministro de agua de Nigeria en función de su efecto sobre la salud humana a través de un enfoque basado en el riesgo.

Métodos Se identificaron los contaminantes peligrosos presentes en el agua potable del área de estudio mediante una investigación bibliográfica y entre abril de 2010 y diciembre de 2011 se controlaron los contaminantes seleccionados en las cuencas, las plantas de tratamiento y los grifos de los consumidores. Se calculó la carga de morbilidad causada por cada contaminante en años de vida ajustados por discapacidad (AVAD) a partir de los datos de la concentración del contaminante, la exposición al mismo, la gravedad de sus efectos sobre la salud y la población de consumidores.

Resultados Los contaminantes identificados fueron organismos microbianos, cadmio, cobalto, cromo, cobre, hierro, manganeso, níquel, plomo y zinc. Todos los contaminantes fueron detectados en las cuencas, pero sólo las cantidades de cadmio, cobalto, cromo, manganeso y

plomo superaron los valores de referencia de la Organización Mundial de la Salud de (OMS) después del tratamiento del agua. Se observó una contaminación posterior al tratamiento. La carga estimada de la enfermedad fue mayor para el cromo en ambos esquemas, seguido en orden decreciente por el cadmio, plomo, manganeso y cobalto. La carga total de la enfermedad de todos los contaminantes en los dos sistemas fue, respectivamente, de 46 000 y 9500 AVAD por año o 0,14 y 0,088 AVAD por persona y año, muy por encima del nivel de referencia de la OMS de 1 × 10⁻⁶ AVAD por persona y año. La carga de morbilidad para cada metal superó el nivel de referencia y fue comparable con aquella por contaminación microbiana evidenciada en otras partes de África.

Conclusión La carga de morbilidad estimada de la contaminación por metales de dos sistemas de suministro de agua nigerianos fue alta. La mejor forma para reducir la carga de morbilidad sería la protección de la captación de agua y el tratamiento previo mediante electrocoagulación.

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Table 1. Metal and microbial contamination and pH for two water supply schemes, Nigeria, 2010–2011

Location sampled[a]	No. of samples	Dry season													Wet season													
		Microbial indicator[b]		pH	Upper 95% CI limit of concentration (mg/l)									Microbial indicator[b]		pH	Upper 95% CI limit of concentration (mg/l)									
		Total coliforms	E. coli		Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn	Total coliforms	E. coli		Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
Asejire water supply scheme																										
Agodi	60	–	–	7.55	0.05	0.02	0.14	0.09	0.55	0.02	0.04	0.14	0.43	–	–	7.43	0.03	0.09	0.27	0.04	0.31	0.16	0.02	0.24	0.32
Alafara Oje	60	–	–	7.54	0.05	0.02	0.15	0.05	0.65	0.01	0.06	0.17	0.50	–	–	7.41	0.05	0.08	0.24	0.02	0.34	0.15	0.02	0.25	0.29
Basorun	60	–	–	7.48	0.08	0.04	0.16	0.07	0.86	0.00	0.08	0.21	0.75	–	–	7.40	0.06	0.11	0.29	0.02	0.44	0.14	0.05	0.30	0.32
Bere	60	–	–	7.50	0.07	0.02	0.17	0.03	0.72	0.01	0.07	0.17	0.65	–	–	7.50	0.04	0.10	0.26	0.01	0.35	0.14	0.04	0.26	0.31
Beyeruka	60	–	–	7.48	0.05	0.02	0.14	0.05	0.58	0.02	0.06	0.16	0.56	–	–	7.44	0.04	0.08	0.26	0.01	0.24	0.15	0.03	0.25	0.34
Iwo Road	60	–	–	7.52	0.07	0.03	0.17	0.06	0.72	0.02	0.07	0.19	0.68	–	–	7.53	0.06	0.10	0.23	0.01	0.29	0.12	0.05	0.28	0.29
Oduoba	60	–	–	7.45	0.09	0.04	0.16	0.03	0.94	0.00	0.09	0.20	0.81	–	–	7.51	0.06	0.07	0.24	0.02	0.47	0.09	0.06	0.31	0.41
Ojaba	60	–	–	7.42	0.06	0.02	0.14	0.05	0.63	0.01	0.08	0.17	0.65	–	–	7.55	0.05	0.08	0.28	0.02	0.37	0.13	0.04	0.27	0.34
Treatment works	30	–	–	7.60	0.01	0.03	0.18	0.01	0.17	0.01	0.01	0.09	0.17	–	–	7.59	0.01	0.10	0.28	0.01	0.19	0.19	0.03	0.23	0.26
Dam water	30	+	+	7.22	0.15	0.09	0.25	0.14	0.62	0.20	0.15	0.23	0.33	+	+	7.09	0.23	0.24	0.38	0.31	1.28	0.55	0.27	0.62	0.59
Eleyele water supply scheme																										
Apete	48	–	–	7.30	0.05	0.01	0.09	0.03	0.62	0.06	0.03	0.15	0.28	–	–	7.41	0.04	0.12	0.10	0.01	0.48	0.32	0.01	0.38	0.26
Eleyele	60	–	–	7.42	0.03	0.00	0.11	0.05	0.52	0.08	0.01	0.14	0.24	–	–	7.52	0.01	0.13	0.12	0.01	0.42	0.30	0.02	0.37	0.23
Mokola	60	–	–	7.45	0.05	0.01	0.11	0.05	0.66	0.09	0.06	0.16	0.28	–	–	7.55	0.05	0.11	0.13	0.03	0.51	0.28	0.05	0.40	0.27
Sango	32	–	–	7.27	0.04	0.00	0.09	0.04	0.57	0.06	0.02	0.15	0.22	–	–	7.58	0.03	0.13	0.11	0.02	0.46	0.28	0.02	0.38	0.26
Treatment works	25	–	–	7.50	0.03	0.01	0.11	0.05	0.44	0.10	0.04	0.14	0.22	–	–	7.62	0.01	0.13	0.12	0.01	0.38	0.31	0.03	0.37	0.23
Dam water	30	+	+	7.62	0.40	0.06	0.27	0.22	0.77	0.21	0.19	0.30	0.45	+	+	7.38	0.44	0.23	0.51	0.42	1.97	0.70	0.31	0.84	0.56
WHO MCL[1]	NA	NA	NA	6.5–8.5[c]	0.003	0.10[d,e]	0.05	2.0	2.0	0.04	0.07	0.01	3.0	NA	NA	6.5–8.5[c]	0.003	0.10[d,e]	0.05	2.0	2.0	0.04	0.07	0.01	3.0

Cd, cadmium; CI, confidence interval; Co, cobalt; Cr, chromium; Cu, copper; E. coli, Escherichia coli; Fe, iron; MCL, maximum contaminant level; Mn, manganese; NA, not applicable; Ni, nickel; Pb, lead; WHO, World Health Organization; Zn, zinc.

a Water was sampled at consumer taps in the districts of Ibadan listed, at the output of treatment works and at the source dam.
b Contamination by total coliforms and Escherichia coli was recorded as present (i.e. +) or absent (i.e. –).
c Maximum contaminant level from the United States Environmental Protection Agency.
d Maximum contaminant level from the environmental media evaluation guide for children (California Department of Public Health).[11]
e Maximum contaminant level from health-based groundwater quality criteria (New Jersey Department of Environmental Protection).[12]

Table 3. **Parameters for calculating exposure to metallic contaminants in water[17]**

Parameter	Consumer[a]	Value	Type of exposure
Ingestion rate	Adult	2 l/day	Oral
	Child	1 l/day	Oral
Exposure duration	Adult	30 years	Oral and dermal
	Child	6 years	Oral and dermal
Exposure frequency	Adult or child	350 days per year	Oral and dermal
Body weight	Adult male	70 kg	Oral and dermal
	Adult female	58 kg[18]	Oral and dermal
	Child	15 kg	Oral and dermal
Lifetime averaging time	Adult or child	54 years × 365 days per year	Oral and dermal
Event frequency	Adult or child	1 event per day	Dermal
Event duration	Adult	0.25 hours per event	Dermal
	Child	0.25 hours per event	Dermal
Skin surface area	Adult	18 000 cm^2	Dermal
	Child	6600 cm^2	Dermal
Skin permeability coefficient			
Cadmium	Adult or child	1×10^{-3} cm/hour	Dermal
Cobalt	Adult or child	0.4×10^{-3} cm/hour	Dermal
Chromium	Adult or child	2×10^{-3} cm/hour	Dermal
Iron	Adult or child	1×10^{-3} cm/hour	Dermal
Manganese	Adult or child	1×10^{-3} cm/hour	Dermal
Lead	Adult or child	0.1×10^{-3} cm/hour	Dermal
Gastrointestinal absorption fraction			
Cadmium	Adult or child	5%	Dermal
Cobalt	Adult or child	80%	Dermal
Chromium	Adult or child	2.5%	Dermal
Manganese	Adult or child	6%	Dermal
Lead	Adult or child	15%	Dermal

[a] Children were aged less than 6 years and adults, 7 to 54 years.

Table 4. **Parameters for estimating the toxicity of metal contaminants in water**

Metal contaminant and health outcome	BMD$_{10}$[a] (mg/kg per day)	NOAEL (mg/kg per day)	LOAEL (mg/kg per day)	ED$_{10}$[b] (mg/kg per day)	β_{ED10}[c] (mg/kg per day)
Cadmium					
Renal abnormality	0.036×10^{-3} (0.6 µg/g creatinine)[20]	NA	NA	0.067×10^{-3}	1500
Osteoporosis	0.03×10^{-3} (0.5 µg/g creatinine)[21–23]	NA	NA	0.056×10^{-3}	1800
Cobalt					
Goitre and hypothyroidism	NA	0.05[24]	NA	0.08	1.3
Cardiomyopathy	NA	0.05[24]	NA	0.08	1.3
Polycythaemia vera	NA	0.05[24]	NA	0.08	1.3
Chromium					
Chronic liver inflammation	0.14[d, 25]	NA	NA	0.013	330
Diffuse epithelial hyperplasia in the duodenum	0.09[d, 25]	NA	NA	3.9×10^{-3}	1100
Histiocytic infiltration of the liver	0.12[d, 25]	NA	NA	5.2×10^{-3}	830
Acinus cytoplasmic alteration in the pancreas	0.52[d, 25]	NA	NA	0.022	191
Oral cavity and oropharyngeal cancer	NA	NA	NA	NA	0.25 (i.e. 0.5 × *CSF*[e])
Oesophageal cancer	NA	NA	NA	NA	0.25 (i.e. 0.5 × *CSF*[e])
Gastric cancer	NA	NA	NA	NA	0.25 (i.e. 0.5 × *CSF*[e])
Small intestine cancer	NA	NA	NA	NA	0.25 (i.e. 0.5 × *CSF*[e])
Manganese					
Neurological abnormality	NA	NA	0.081[26,27]	0.024	4.2

CSF, cancer slope factor; BMD, is the lower 95% confidence limit for the dose that results in a 10% increase in the incidence of the specified health outcome relative to the background level; ED, exposure duration; LOAEL, lowest-observable-adverse-effect level; NA, not applicable; NOAEL, no-observable-adverse-effect level.

[a] BMD$_{10}$ is the lower 95% confidence limit for the dose that results in a 10% increase in the incidence of the specified health outcome relative to the background level.[19]

[b] ED$_{10}$ is the central estimate of the effect dose associated with a 10% increase in the incidence of the health outcome relative to the background level.[19]

[c] β_{ED10} is a slope factor used for calculating health risk at low doses.

[d] Since the source BMD$_{10}$ value was for mice, the equivalent dose levels in humans were derived using an animal-to-human conversion factor of 13 and a subchronic-to-chronic conversion factor of 3.3.

[e] The cancer slope factor (*CSF*) for chromium given by the United States Environmental Protection Agency is 0.5.[28]

Table 5. **Disease burden associated with lead contamination of water from consumer taps, two water supply schemes combined, Nigeria, 2010–2011**

Consumer	Age range[a] (years)	Fraction of all consumers (C_F)	Health outcome			Estimated disease burden (DALYs per person per year [x 10⁻³])	
			Type	RR[29]	Probability	Individual health outcome	All health outcomes
All	0–4 and 15–54	0.6877	All	NA	NA	NA	1.6
Child	0–4	0.1815	Mild mental retardation	NA	0.18×10^{-3}	0.0022	NA
Adult female	15–54	0.2341	Ischaemic heart disease	1.024	8.9×10^{-3}	0.11	NA
			Stroke	1.032	0.012	0.15	NA
			Hypertensive disease	1.063	0.023	0.29	NA
			Other cardiac disease	1.007	2.6×10^{-3}	0.032	NA
Adult male	15–54	0.2721	Ischaemic heart disease	1.038	0.014	0.17	NA
			Stroke	1.052	0.020	0.25	NA
			Hypertensive disease	1.101	0.037	0.46	NA
			Other cardiac disease	1.034	0.013	0.16	NA

DALY, disability-adjusted life year; NA, not applicable; RR, relative risk.

[a] Mild mental retardation is largely irreversible and is considered to occur only in the first year of life. The burden in children aged between 1 and 14 years is attributed to events in the first year. Since the population data available were for the 0–4 year age group, we assumed that the probability of mild mental retardation for infants aged under 1 year was one fifth that for the 0–4 year age group (Equation 12).[29]

Table 6. **Disease burden due to metal contamination of water from treatment works, two water supply schemes, Nigeria, 2010–2011**

Metal contaminant and health outcome	Consumer[a]	Fraction of all consumers (C_F)	Asejire water supply scheme				Eleyele water supply scheme			
			Chronic daily intake (mg/kg per day [x 10^{-3}])	Lifetime probability of health outcome	Estimated disease burden (DALYs per person per year [x 10^{-3}])		Chronic daily intake (mg/kg per day [x 10^{-3}])	Lifetime probability of health outcome	Estimated disease burden (DALYs per person per year [x 10^{-3}])	
					Individual health outcome associated with metal	All health outcomes associated with metal			Individual health outcome associated with metal	All health outcomes associated with metal
Cadmium										
Renal abnormality	All	1	NA	NA	NA	6.1	NA	NA	NA	15
	All	1	NA	NA	2.8	NA	NA	NA	6.8	NA
	Child	0.2425	0.073	0.11	NA	NA	0.18	0.26	NA	NA
	Adult female	0.3726	0.19	0.28	NA	NA	0.47	0.69	NA	NA
	Adult male	0.3849	0.16	0.25	NA	NA	0.39	0.59	NA	NA
Osteoporosis	All	1	NA	NA	3.3	NA	NA	NA	8.3	NA
	Child	0.2425	0.073	0.13	NA	NA	0.18	0.32	NA	NA
	Adult female	0.3726	0.19	0.35	NA	NA	0.47	0.84	NA	NA
	Adult male	0.3849	0.16	0.29	NA	NA	0.39	0.71	NA	NA
Cobalt										
Goitre and hypothyroidism	All	1	NA	NA	NA	0.051	NA	NA	NA	0.063
	All	1	NA	NA	0.017	NA	NA	NA	0.021	NA
	Child	0.2425	0.53	0.65×10^{-3}	NA	NA	0.62	0.77×10^{-3}	NA	NA
	Adult female	0.3726	1.4	1.7×10^{-3}	NA	NA	1.6	2.1×10^{-3}	NA	NA
	Adult male	0.3849	1.2	1.5×10^{-3}	NA	NA	1.4	1.7×10^{-3}	NA	NA
Cardiomyopathy	All	1	NA	NA	0.017	NA	NA	NA	0.021	NA
	Child	0.2425	0.53	0.65×10^{-3}	NA	NA	0.62	0.77×10^{-3}	NA	NA
	Adult female	0.3726	1.4	1.7×10^{-3}	NA	NA	1.6	2.1×10^{-3}	NA	NA
	Adult male	0.3849	1.2	1.5×10^{-3}	NA	NA	1.4	1.7×10^{-3}	NA	NA
Polycythaemia vera	All	1	NA	NA	0.017	NA	NA	NA	0.021	NA
	Child	0.2425	0.53	0.65×10^{-3}	NA	NA	0.62	0.77×10^{-3}	NA	NA
	Adult female	0.3726	1.4	1.7×10^{-3}	NA	NA	1.6	2.1×10^{-3}	NA	NA
	Adult male	0.3849	1.2	1.5×10^{-3}	NA	NA	1.4	1.7×10^{-3}	NA	NA
Chromium										
Chronic liver inflammation	All	1	NA	NA	NA	110	NA	NA	NA	54
	All	1	NA	NA	15	NA	NA	NA	7.2	NA
	Child	0.2425	1.8	0.60	NA	NA	0.87	0.29	NA	NA
	Adult female	0.3726	4.6	1.5	NA	NA	2.2	0.73	NA	NA
	Adult male	0.3849	3.9	1.3	NA	NA	1.9	0.62	NA	NA

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Metal contaminant and health outcome	Consumer[a]	Fraction of all consumers (C_p)	Asejire water supply scheme					Eleyele water supply scheme				
			Chronic daily intake (mg/kg per day [x 10^{-3}])	Lifetime probability of health outcome	Estimated disease burden (DALYs per person per year [x 10^{-3}])			Chronic daily intake (mg/kg per day [x 10^{-3}])	Lifetime probability of health outcome	Estimated disease burden (DALYs per person per year [x 10^{-3}])		
					Individual health outcome associated with metal	All health outcomes associated with metal				Individual health outcome associated with metal	All health outcomes associated with metal	
Diffuse epithelial hyperplasia in the duodenum	All	1	NA	NA	50	NA		NA	NA	24	NA	
	Child	0.2425	1.8	2.0	NA	NA		0.87	0.96	NA	NA	
	Adult female	0.3726	4.6	5.1	NA	NA		2.2	2.4	NA	NA	
	Adult male	0.3849	3.9	4.3	NA	NA		1.9	2.1	NA	NA	
Histiocytic infiltration of the liver	All	1	NA	NA	38	NA		NA	NA	18	NA	
	Child	0.2425	1.8	1.5	NA	NA		0.87	0.72	NA	NA	
	Adult female	0.3726	4.6	3.8	NA	NA		2.2	1.8	NA	NA	
	Adult male	0.3849	3.9	3.3	NA	NA		1.9	1.6	NA	NA	
Acinus cytoplasmic alteration in the pancreas	All	1	NA	NA	8.7	NA		NA	NA	4.2	NA	
	Child	0.2425	1.8	0.35	NA	NA		0.87	0.17	NA	NA	
	Adult female	0.3726	4.6	0.89	NA	NA		2.2	0.42	NA	NA	
	Adult male	0.3849	3.9	0.75	NA	NA		1.9	0.36	NA	NA	
Oral cavity and oropharyngeal cancer	All	1	NA	NA	0.034	NA		NA	NA	0.015	NA	
	Child	0.2425	0.98	0.25×10^{-3}	NA	NA		0.45	0.11×10^{-3}	NA	NA	
	Adult female	0.3726	2.7	0.67×10^{-3}	NA	NA		1.2	0.30×10^{-3}	NA	NA	
	Adult male	0.3849	2.3	0.57×10^{-3}	NA	NA		1.0	0.26×10^{-3}	NA	NA	
Oesophageal cancer	All	1	NA	NA	0.091	NA		NA	NA	0.041	NA	
	Child	0.2425	0.98	0.25×10^{-3}	NA	NA		0.45	0.11×10^{-3}	NA	NA	
	Adult female	0.3726	2.7	0.67×10^{-3}	NA	NA		1.2	0.30×10^{-3}	NA	NA	
	Adult male	0.3849	2.3	0.57×10^{-3}	NA	NA		1.0	0.26×10^{-3}	NA	NA	
Gastric cancer	All	1	NA	NA	0.071	NA		NA	NA	0.032	NA	
	Child	0.2425	0.98	0.25×10^{-3}	NA	NA		0.45	0.11×10^{-3}	0.032	NA	
	Adult female	0.3726	2.7	0.67×10^{-3}	NA	NA		1.2	0.30×10^{-3}	NA	NA	
	Adult male	0.3849	2.3	0.57×10^{-3}	NA	NA		1.0	0.26×10^{-3}	NA	NA	
Small intestine cancer	All	1	NA	NA	0.066	NA		NA	NA	0.030	NA	
	Child	0.2425	0.98	0.25×10^{-3}	NA	NA		0.45	0.11×10^{-3}	NA	NA	
	Adult female	0.3726	2.7	0.67×10^{-3}	NA	NA		1.2	0.30×10^{-3}	NA	NA	
	Adult male	0.3849	2.3	0.57×10^{-3}	NA	NA		1.0	0.26×10^{-3}	NA	NA	

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Metal contaminant and health outcome	Consumer[a]	Fraction of all consumers (C_p)	Asejire water supply scheme					Eleyele water supply scheme				
			Chronic daily intake (mg/kg per day [x 10⁻³])	Lifetime probability of health outcome	Estimated disease burden (DALYs per person per year [x 10⁻³])			Chronic daily intake (mg/kg per day [x 10⁻³])	Lifetime probability of health outcome	Estimated disease burden (DALYs per person per year [x 10⁻³])	
					Individual health outcome associated with metal	All health outcomes associated with metal				Individual health outcome associated with metal	All health outcomes associated with metal
Manganese	All	1	NA	NA	NA	0.099		NA	NA	NA	0.18
Neurological abnormality	All	1	NA	NA	0.099	NA		NA	NA	0.18	NA
	Child	0.2425	0.96	0.40×10^{-3}	NA	NA		1.7	7.1×10^{-3}	NA	NA
	Adult female	0.3726	2.5	0.010	NA	NA		4.5	0.018	NA	NA
	Adult male	0.3849	2.1	8.6×10^{-3}	NA	NA		3.8	0.016	NA	NA

DALY, disability-adjusted life year; NA, not applicable.
[a] Children were aged under 6 years and adults, 7 to 54 years.

Table 7. Disease burden due to metal contamination of water from consumer taps, two water supply schemes, Nigeria, 2010–2011

Metal contaminant and health outcome	Consumer[a]	Fraction of all consumers (C_f)	Asejire water supply scheme				Eleyele water supply scheme			
			Chronic daily intake (mg/kg per day [x 10^{-3}])	Lifetime probability of health outcome	Estimated disease burden (DALYs per person per year [x 10^{-3}])		Chronic daily intake (mg/kg per day [x 10^{-3}])	Lifetime probability of health outcome	Estimated disease burden (DALYs per person per year [x 10^{-3}])	
					Individual health outcome associated with metal	All health outcomes associated with metal			Individual health outcome associated with metal	All health outcomes associated with metal
Cadmium										
Renal abnormality	All	1	NA	NA	NA	38	NA	NA	NA	31
	All	1	NA	NA	17	NA	NA	NA	14	NA
	Child	0.2425	0.44	0.66	NA	NA	0.36	0.53	NA	NA
	Adult female	0.3726	1.1	1.7	NA	NA	0.93	1.4	NA	NA
	Adult male	0.3849	0.96	1.5	NA	NA	0.79	1.2	NA	NA
Osteoporosis	All	1	NA	NA	21	NA	NA	NA	17	NA
	Child	0.2425	0.44	0.80	NA	NA	0.36	0.65	NA	NA
	Adult female	0.3726	1.1	2.1	NA	NA	0.93	1.7	NA	NA
	Adult male	0.3849	0.96	1.8	NA	NA	0.79	1.4	NA	NA
Cobalt										
Goitre and hypothyroidism	All	1	NA	NA	NA	0.051	NA	NA	NA	0.063
	All	1	NA	NA	0.017	NA	NA	NA	0.021	NA
	Child	0.2425	0.53	0.65×10^{-3}	NA	NA	0.62	0.77×10^{-3}	NA	NA
	Adult female	0.3726	1.4	1.7×10^{-3}	NA	NA	1.6	2.1×10^{-3}	NA	NA
	Adult male	0.3849	1.2	1.5×10^{-3}	NA	NA	1.4	1.7×10^{-3}	NA	NA
Cardiomyopathy	All	1	NA	NA	0.017	NA	NA	NA	0.021	NA
	Child	0.2425	0.53	0.65×10^{-3}	NA	NA	0.62	0.77×10^{-3}	NA	NA
	Adult female	0.3726	1.4	1.7×10^{-3}	NA	NA	1.6	2.1×10^{-3}	NA	NA
	Adult male	0.3849	1.2	1.5×10^{-3}	NA	NA	1.4	1.7×10^{-3}	NA	NA
Polycythaemia vera	All	1	NA	NA	0.017	NA	NA	NA	0.21	NA
	Child	0.2425	0.53	0.65×10^{-3}	NA	NA	0.62	0.77×10^{-3}	NA	NA
	Adult female	0.3726	1.4	1.7×10^{-3}	NA	NA	1.6	2.1×10^{-3}	NA	NA
	Adult male	0.3849	1.2	1.5×10^{-3}	NA	NA	1.4	1.7×10^{-3}	NA	NA
Chromium										
Chronic liver inflammation	All	1	NA	NA	NA	100	NA	NA	NA	54
	All	1	NA	NA	14	NA	NA	NA	7.2	NA
	Child	0.2425	1.7	0.55	NA	NA	0.87	0.29	NA	NA
	Adult female	0.3726	4.3	1.4	NA	NA	2.2	0.73	NA	NA
	Adult male	0.3849	3.6	1.2	NA	NA	1.9	0.62	NA	NA

(...*continued*)

Metal contaminant and health outcome	Consumer[a]	Fraction of all consumers (C_f)	Asejire water supply scheme					Eleyele water supply scheme				
			Chronic daily intake (mg/kg per day [x 10⁻³])	Lifetime probability of health outcome	Estimated disease burden (DALYs per person per year [x 10⁻³])			Chronic daily intake (mg/kg per day [x 10⁻³])	Lifetime probability of health outcome	Estimated disease burden (DALYs per person per year [x 10⁻³])	
					Individual health outcome associated with metal	All health outcomes associated with metal				Individual health outcome associated with metal	All health outcomes associated with metal
Diffuse epithelial hyperplasia in the duodenum	All	1	NA	NA	46	NA		NA	NA	24	NA
	Child	0.2425	1.7	1.8	NA	NA		0.87	0.96	NA	NA
	Adult female	0.3726	4.3	4.7	NA	NA		2.2	2.4	NA	NA
	Adult male	0.3849	3.6	4.0	NA	NA		1.9	2.1	NA	NA
Histiocytic infiltration of the liver	All	1	NA	NA	35	NA		NA	NA	18	NA
	Child	0.2425	1.7	1.4	NA	NA		0.87	0.72	NA	NA
	Adult female	0.3726	4.3	3.5	NA	NA		2.2	1.8	NA	NA
	Adult male	0.3849	3.6	3.0	NA	NA		1.9	1.6	NA	NA
Acinus cytoplasmic alteration in the pancreas	All	1	NA	NA	8.0	NA		NA	NA	4.2	NA
	Child	0.2425	1.7	0.32	NA	NA		0.87	0.17	NA	NA
	Adult female	0.3726	4.3	0.82	NA	NA		2.2	0.42	NA	NA
	Adult male	0.3849	3.6	0.69	NA	NA		1.9	0.36	NA	NA
Oral cavity and oropharyngeal cancer	All	1	NA	NA	0.032	NA		NA	NA	0.015	NA
	Child	0.2425	0.90	0.23×10^{-3}	NA	NA		0.45	0.11×10^{-3}	NA	NA
	Adult female	0.3726	2.5	0.62×10^{-3}	NA	NA		1.2	0.30×10^{-3}	NA	NA
	Adult male	0.3849	2.1	0.52×10^{-3}	NA	NA		1.0	0.26×10^{-3}	NA	NA
Oesophageal cancer	All	1	NA	NA	0.084	NA		NA	NA	0.041	NA
	Child	0.2425	0.90	0.23×10^{-3}	NA	NA		0.45	0.11×10^{-3}	NA	NA
	Adult female	0.3726	2.5	0.62×10^{-3}	NA	NA		1.2	0.30×10^{-3}	NA	NA
	Adult male	0.3849	2.1	0.52×10^{-3}	NA	NA		1.0	0.26×10^{-3}	NA	NA
Gastric cancer	All	1	NA	NA	0.065	NA		NA	NA	0.032	NA
	Child	0.2425	0.90	0.23×10^{-3}	NA	NA		0.45	0.11×10^{-3}	NA	NA
	Adult female	0.3726	2.5	0.62×10^{-3}	NA	NA		1.2	0.30×10^{-3}	NA	NA
	Adult male	0.3849	2.1	0.52×10^{-3}	NA	NA		1.0	0.26×10^{-3}	NA	NA
Small intestine cancer	All	1	NA	NA	0.060	NA		NA	NA	0.030	NA
	Child	0.2425	0.90	0.23×10^{-3}	NA	NA		0.45	0.11×10^{-3}	NA	NA
	Adult female	0.3726	2.5	0.62×10^{-3}	NA	NA		1.2	0.30×10^{-3}	NA	NA
	Adult male	0.3849	2.1	0.52×10^{-3}	NA	NA		1.0	0.26×10^{-3}	NA	NA

(*continues...*)

(...continued)

Metal contaminant and health outcome	Consumer[a]	Fraction of all consumers (C_f)	Asejire water supply scheme				Eleyele water supply scheme			
			Chronic daily intake (mg/kg per day [x 10⁻³])	Lifetime probability of health outcome	Estimated disease burden (DALYs per person per year [x 10⁻³])		Chronic daily intake (mg/kg per day [x 10⁻³])	Lifetime probability of health outcome	Estimated disease burden (DALYs per person per year [x 10⁻³])	
					Individual health outcome associated with metal	All health outcomes associated with metal			Individual health outcome associated with metal	All health outcomes associated with metal
Manganese Neurological abnormality	All	1	NA	NA	NA	0.077	NA	NA	NA	0.18
	All	1	NA	NA	0.077	NA	NA	NA	0.18	NA
	Child	0.2425	0.74	3.0×10^{-3}	NA	NA	1.6	6.8×10^{-3}	NA	NA
	Adult female	0.3726	1.9	7.8×10^{-3}	NA	NA	4.3	0.018	NA	NA
	Adult male	0.3849	1.6	6.6×10^{-3}	NA	NA	3.6	0.015	NA	NA

DALY, disability-adjusted life year; NA, not applicable.
[a] Children were aged under 6 years and adults, 7 to 54 years.