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Physicochemical quality, heavy-metal contamination and human health risk of drinking water from selected public secondary schools in Benin City, Nigeria

Amenze J. Asemota[1,2,*] **and Emmanuel Esosa Imarhiagbe**[1,2,3]

[1] *Department of Environmental Management and Toxicology, Faculty of Life Sciences, University of Benin, Benin City, Nigeria*
[2] *Centre for Water, Sanitation and Environmental Health Research (CeWSER), University of Benin, Benin City, Nigeria*
[3] *Applied Environmental Bioscience and Public Health Research Group (AEBPH RG), University of Benin, Benin City, Edo State, Nigeria*

[*] *Corresponding author, Email address: amenze.asemota@uniben.edu; +234 807 868 0863; ORCID 0000-0001-6339-0980*

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Abstract: Safe drinking water in schools is fundamental to child health, yet the quality of school water supplies in urban Nigeria is rarely assessed. This study evaluated the physicochemical, heavy-metal and bacteriological quality of drinking water, and quantified the associated human-health risk, in public secondary schools in Benin City, Nigeria. Water was available for sampling at five of nine schools surveyed. Physicochemical parameters and bacteriological qualities were determined using standard methods; metals were measured by atomic absorption spectrometry. Pollution status was summarised using the Heavy Metal Pollution Index (HPI), and non-carcinogenic and carcinogenic risks from ingestion were estimated for children and adults following the USEPA framework. pH ranged from 5.5 to 7.8, with one acidic supply (5.5) below guideline; electrical conductivity (42–751 µS/cm) and total dissolved solids (21–374 mg/L) remained within limits but were elevated at one school, where biochemical and chemical oxygen demand were also highest. Dissolved oxygen was uniformly low (1.2–2.0 mg/L). Lead exceeded the 0.01 mg/L guideline in four of five schools (mean 0.014 mg/L), cadmium exceeded the WHO 0.003 mg/L guideline in all schools (mean 0.007 mg/L), and manganese exceeded the national 0.05 mg/L guideline in all schools. The mean HPI (187) was far above the critical value of 100, indicating heavy-metal pollution. The estimated hazard index for children (2.01) exceeded unity driven by cadmium, chromium and lead, indicating a non-carcinogenic risk, while the adult value (0.86) did not. Total coliforms were detected in two schools, exceeding the zero-tolerance national standard, although *Escherichia coli* was absent. Five bacterial isolates were recovered. The school water supplies therefore pose chemical and bacteriological risks, particularly to children, and therefore require treatment, source protection and routine monitoring.

1. Introduction

Access to safe drinking water is a basic human right and a precondition for child health and learning, and the assessment of drinking-water quality is a core element of water, sanitation and hygiene (WASH) provision in schools (Anthonj *et al.* (2021); Morgan *et al.* (2021)). The quality of water consumed at school directly influences the risk of waterborne and chemical illness, yet whether water quality is routinely monitored as part of school WASH remains uncertain, particularly in low- and middle-income settings (Addisie (2022); Bolatova *et al.* (2021)).

Heavy metals are of particular concern in school water because they bioaccumulate and also because children are more vulnerable than adults to their toxic effects. Lead and manganese impair neurodevelopment and have been linked to reduced cognitive performance in children at low exposure levels (Lanphear *et al.* (2005); Bouchard *et al.* (2011); El Hammari *et al*., (2023)), while cadmium causes kidney damage and bone demineralisation over time (Bernard (2008)). Microbial contamination, indicated by coliform bacteria, signals vulnerability of the supply to faecal pollution and a risk of diarrhoeal disease (WHO (2017); Holcomb *et al.* (2026); Ng'ombe *et al.* (2026)). A comprehensive characterisation of school water quality therefore requires the integration of physicochemical, chemical and microbiological evidence.

Beyond comparison with guideline values, the public-health significance of contamination is best expressed through pollution indices and quantitative health-risk assessment, which combine concentration data with exposure parameters to estimate the probability of harm. Such approaches are widely used for environmental waters but are rarely applied to school drinking water in Nigeria. This study therefore evaluated the physicochemical quality, heavy-metal contamination and bacteriological quality of drinking water in public secondary schools in Benin City, benchmarked the results against World Health Organization (WHO), Standards Organisation of Nigeria (SON) and National Agency for Food and Drug Administration and Control (NAFDAC) guidelines, and quantified the associated human-health risk for children and adults using the Heavy Metal Pollution Index (HPI) and the United States Environmental Protection Agency (USEPA) risk framework.

2. Methodology

2.1 Study area and sampling

The study was conducted in Benin Metropolis, Edo State, southern Nigeria, across nine public secondary schools selected from the three local government areas (Ikpoba-Okha, Oredo and Egor). Drinking-water sources were available for sampling at five of the nine schools and no functional source was available at the remaining four at the time of fieldwork. Samples were collected from the primary drinking-water source used by students at each of the five schools (denoted S1–S5) in clean, sterile containers, with the sampling location, date, time and source characteristics recorded. Samples for microbiological analysis were transported on ice and analysed within the recommended holding time.

2.2 Physicochemical analysis

Sixteen physicochemical parameters were determined using standard methods (APHA (2005); APHA (2018)): pH (Jenway pH meter with glass electrode), electrical conductivity (EC) and total dissolved solids (TDS) (calibrated conductivity/TDS meter), salinity, colour and turbidity (spectrophotometry), total suspended solids (TSS, gravimetry), dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD, dichromate reflux), bicarbonate (HCO_3^-, titrimetry), and the major ions sodium, potassium, magnesium, chloride (argentometric titration) and calcium. pH was measured within 24 h of collection. Results were compared with WHO, SON and NAFDAC drinking-water guidelines.

2.3 Heavy-metal analysis

Nine trace elements, which were iron, manganese, zinc, copper, chromium, cadmium, nickel, lead and vanadium, together with total hydrocarbon content (THC) were determined by flame atomic absorption spectrometry using an air–acetylene flame and element-specific hollow-cathode lamps, following standard procedures (APHA (2005)). Concentrations were compared with WHO, SON and NAFDAC maximum permissible limits (El Hammari *et al.,* 2022).

2.4 Bacteriological analysis

Total heterotrophic bacterial counts and total coliform counts were determined by the standard plate count and membrane-filtration techniques on nutrient agar and selective/differential media including eosin–methylene blue, Simmons citrate and mannitol salt agar (APHA (2005); Cheesbrough (2006)). Isolates were purified by subculture and characterised by colonial morphology, Gram and spore staining, and biochemical tests (catalase, oxidase, indole, citrate, urease, motility and carbohydrate fermentation), and identified to genus or species using standard schemes.

2.5 Heavy Metal Pollution Index (HPI)

The HPI integrates the concentrations of multiple metals relative to their guideline values into a single index. It was computed as given in **Eqn. 1**:

$$HPI = \Sigma (W_i Q_i) / \Sigma W_i \qquad \text{Eqn. 1}$$

where the unit weight W_i is defined by **Eqn. 2** and the sub-index Q_i by **Eqn. 3**:

$$W_i = 1 / S_i \qquad \text{Eqn. 2}$$

$$Q_i = 100 (M_i - I_i) / (S_i - I_i) \qquad \text{Eqn. 3}$$

where S_i is the guideline value of metal *i*, M_i the measured concentration and I_i the ideal value (taken as zero). An HPI above the critical value of 100 indicates that water is unsuitable with respect to heavy-metal load.

2.6 Human-health risk assessment

Non-carcinogenic and carcinogenic risks from oral intake were estimated following the USEPA framework. The chronic daily intake (CDI, mg kg^{-1} day^{-1}) was calculated using **Eqn. 4**:

$$CDI = (C \times IR \times EF \times ED) / (BW \times AT) \qquad \text{Eqn. 4}$$

where C is the mean metal concentration (mg/L), IR the ingestion rate, EF the exposure frequency (350 days/year), ED the exposure duration, BW the body weight and AT the averaging time. The non-carcinogenic hazard quotient (HQ) and hazard index (HI) were obtained from **Eqn. 5** and **Eqn. 6**:

$$HQ = CDI / RfD \qquad \text{Eqn. 5}$$

$$HI = \Sigma HQ \qquad \text{Eqn. 6}$$

where RfD is the oral reference dose, and HI > 1 indicates a potential non-carcinogenic risk. The carcinogenic risk (CR) was estimated from **Eqn. 7**:

$$CR = CDI \times CSF \qquad \text{Eqn. 7}$$

where CSF is the oral cancer slope factor. The result was evaluated against the USEPA acceptable range of 10^{-6}–10^{-4}. Exposure parameters for children (IR = 1 L/day; BW = 15 kg; ED = 6 years) and adults (IR = 2 L/day; BW = 70 kg; ED = 30 years), and the toxicity values used, are given in **Table 4**.

2.7 Statistical analysis

Data were analysed in Microsoft Excel and using Python statistical packages. Descriptive statistics (mean, standard deviation, range and coefficient of variation) were computed for each parameter.

Because a single sample was collected from each school, between-school variation is described rather than tested inferentially.

3. Results and Discussion

The school water supplies in Benin Metropolis were broadly acceptable on conventional physicochemical grounds but showed clear chemical and microbiological warning signs that comparison with guideline values alone tends to understate. Each set of results is presented below alongside its interpretation.

3.1 Physicochemical quality

The physicochemical results are summarised in **Table 1**, with descriptive statistics in **Table 2**. pH ranged from 5.5 (S2) to 7.8 (S3); most supplies were within the WHO range of 6.5–8.5, but S2 was acidic. Electrical conductivity (42–751 µS/cm) and total dissolved solids (21–374 mg/L) were within guideline limits across all schools, but were markedly elevated at S2, which also recorded the highest salinity, bicarbonate, COD and BOD, indicating greater mineralisation and organic load. Dissolved oxygen was uniformly low (1.2–2.0 mg/L). Colour, turbidity and total suspended solids were below detection in all samples (**Figure 1**). The high coefficients of variation (**Table 2**) reflect substantial heterogeneity among the sources.

Table 1. Physicochemical quality of drinking water from five public secondary schools in Benin Metropolis, compared with WHO, SON and NAFDAC guidelines (ND, not detected; NS, no standard).

Parameter (unit)	S1	S2	S3	S4	S5	WHO	SON	NAFDAC
pH	6.7	5.5	7.8	7.4	6.4	6.5–8.5	6.5–8.5	6.5–8.5
EC (µS/cm)	62	751	42	82	243	1000	1000	NS
Salinity (g/L)	0.028	0.440	0.020	0.037	0.110	NS	NS	3.0
Colour (Pt-Co)	ND	ND	ND	ND	ND	3.0	3.0	5.0
Turbidity (NTU)	ND	ND	ND	ND	ND	5.0	5.0	5.0
TSS (mg/L)	ND	ND	ND	ND	ND	1.0	1.5	1.0
TDS (mg/L)	31	374	21	41	121	500	500	500
DO (mg/L)	1.7	1.2	2.0	1.3	1.2	< 10	< 10	< 10
BOD (mg/L)	1.5	3.8	1.2	2.0	2.7	5	5	5
COD (mg/L)	8.5	36.6	7.5	10.1	18.2	NS	NS	NS
HCO_3^- (mg/L)	36.1	90.4	28.2	45.6	51.6	100	100	100
Na (mg/L)	0.33	2.87	0.13	0.43	0.74	NS	NS	NS
K (mg/L)	0.11	1.40	0.10	0.18	0.33	NS	NS	10
Mg (mg/L)	0.53	4.46	0.27	0.88	1.18	20	0.20	75
Cl^- (mg/L)	31.0	91.0	30.0	36.6	60.2	100	100	100
Ca (mg/L)	0.78	7.41	0.66	1.24	3.25	NS	75	20

Table 2. Descriptive statistics of selected physicochemical parameters across the five sampled schools (SD, standard deviation; CV, coefficient of variation).

Parameter	Mean	SD	Min	Max	CV (%)
pH	6.76	0.90	5.50	7.80	13.3
Conductivity (µS/cm)	236.0	298.7	42.0	751.0	126.6
TDS (mg/L)	117.6	148.7	21.0	374.0	126.4
DO (mg/L)	1.48	0.36	1.20	2.00	24.3
BOD (mg/L)	2.24	1.04	1.20	3.80	46.4
COD (mg/L)	16.18	12.17	7.50	36.60	75.2
Chloride (mg/L)	49.76	26.10	30.00	91.00	52.5
Calcium (mg/L)	2.67	2.85	0.66	7.41	106.7

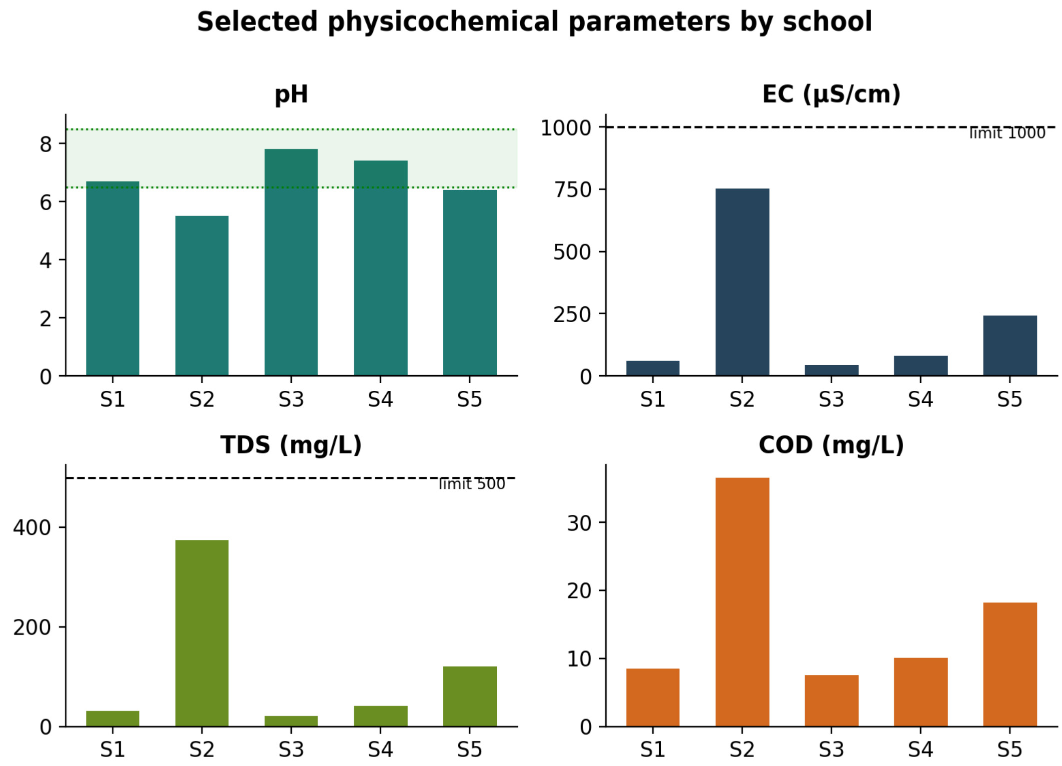

Figure 1. Selected physicochemical parameters (pH, electrical conductivity, total dissolved solids and chemical oxygen demand) by school, with guideline ranges indicated.

The acidic supply at S2 (pH 5.5) is of concern because corrosive water promotes the leaching of lead and copper from plumbing and may be associated with poorer taste and gastrointestinal discomfort. The elevated conductivity, TDS, BOD and COD at the same school indicate greater mineralisation and an organic load consistent with a contaminated or poorly maintained source (Mpenyana-Monyatsi *et al.* (2012)). The uniformly low dissolved oxygen across all supplies is similarly unfavourable, as it can favour anaerobic activity and odour.

3.2 Heavy-metal contamination

Trace-metal concentrations are presented in **Table 3** and **Figure 2**. Iron (0.211–0.355 mg/L) remained within the WHO guideline (1 mg/L) but exceeded the SON and NAFDAC limit (0.3 mg/L) at two schools. Manganese (0.057–0.104 mg/L) exceeded the SON limit (0.05 mg/L) at all five schools and approached the WHO limit (0.1 mg/L) at one. Zinc, copper, chromium and nickel were within all guideline limits. Cadmium (0.004–0.009 mg/L) exceeded the WHO guideline (0.003 mg/L) in every school, and lead (0.010–0.017 mg/L) met or exceeded the guideline (0.01 mg/L) in all five schools, exceeding it in four. Total hydrocarbon content was below detection in all samples.

Table 3. Heavy-metal and total-hydrocarbon concentrations in drinking water from the five schools, with guideline values (ND, not detected; NS, no standard). Values meeting or exceeding the strictest applicable guideline are discussed in the text.

Metal (mg/L)	S1	S2	S3	S4	S5	Mean	WHO	SON	NAFDAC
Fe	0.305	0.211	0.355	0.294	0.284	0.290	1.0	0.3	0.3
Mn	0.097	0.057	0.104	0.074	0.061	0.079	0.1	0.05	2.0
Zn	0.235	0.187	0.240	0.217	0.051	0.186	3.0	5.0	5.0
Cu	0.066	0.038	0.073	0.051	0.044	0.054	2.0	1.0	1.0
Cr	0.036	0.018	0.040	0.032	0.022	0.030	0.05	0.05	0.05
Cd	0.008	0.004	0.009	0.007	0.007	0.007	0.003	0.03	0.03
Ni	0.006	0.002	0.006	0.005	0.003	0.004	NS	NS	NS
Pb	0.017	0.010	0.017	0.013	0.011	0.014	0.01	0.01	0.01
V	0.003	0.001	0.004	0.003	0.001	0.002	NS	NS	NS
THC	ND	ND	ND	ND	ND	ND	NS	NS	NS

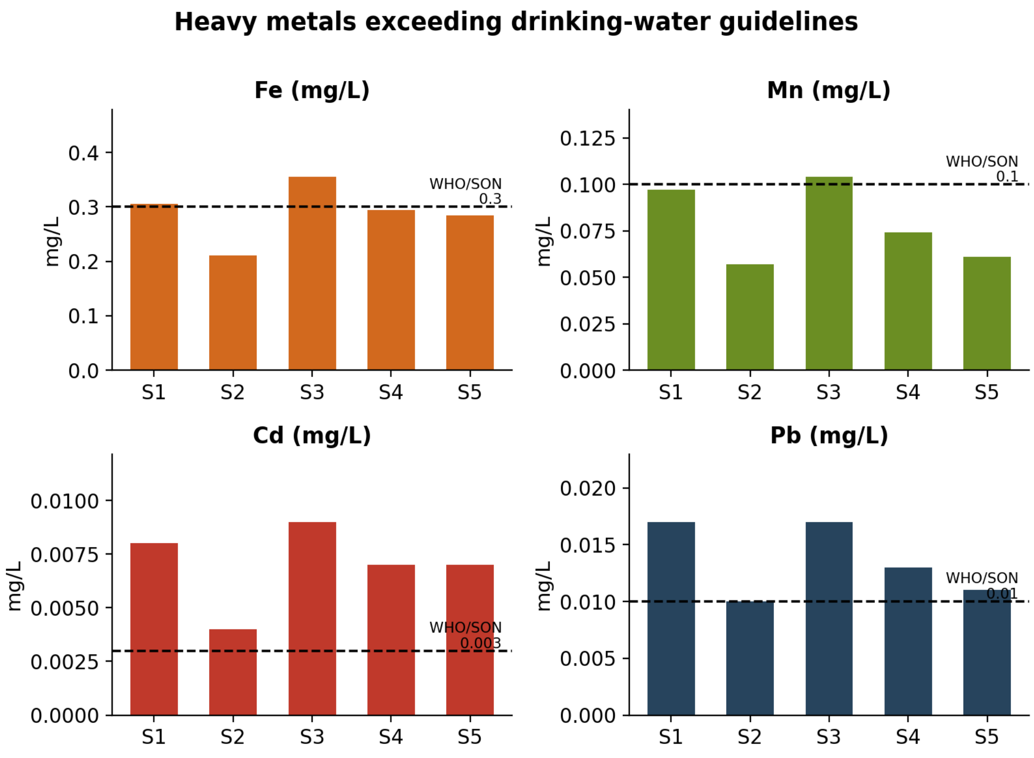

Figure 2. Concentrations of iron, manganese, cadmium and lead by school, relative to the applicable WHO/SON drinking-water guideline (dashed line). Cadmium exceeded its guideline at all schools and lead at four of five.

Cadmium and lead are of particular concern among these, being cumulative toxicants for which no safe exposure threshold is recognised in children. Lead exposure at low levels is associated with reduced cognitive function (Lanphear *et al.* (2005)), and manganese–which exceeded the national limit at all schools–has likewise been linked to impaired neurodevelopment in children (Bouchard *et al.* (2011)). These exceedances may be as a result of metal contamination in groundwater likely attributable to corroding plumbing and natural mineralization.

3.3 Pollution status and health risk

The Heavy Metal Pollution Index exceeded the critical value of 100 at all five schools, ranging from 112 to 240 with a mean of 187, indicating heavy-metal pollution of the school water supplies (**Figure 3**). The toxicity values used in the health-risk assessment are given in **Table 4**. The resulting hazard quotients and hazard indices are in **Table 5**. For children, the hazard index was 2.01, exceeding unity and indicating a potential non-carcinogenic health risk; the dominant contributors were cadmium (HQ = 0.90), chromium (HQ = 0.63) and lead (HQ = 0.25) (**Figure 4**). For adults, the hazard index was 0.86, below the threshold of concern. Illustrative carcinogenic-risk estimates for children, using mean concentrations, were 2.3×10^{-4} for cadmium and 8.1×10^{-5} for chromium, both at or above the upper bound of the USEPA acceptable range (10^{-6}–10^{-4}), and below it for lead (6.3×10^{-7}) and nickel (2.0×10^{-5}).

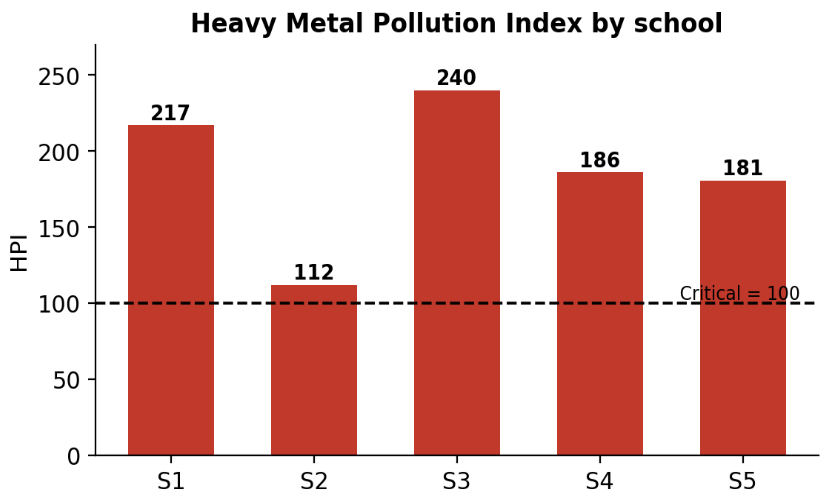

Figure 3. Heavy Metal Pollution Index (HPI) by school. All schools exceeded the critical value of 100 (dashed line).

Table 4. Oral reference doses (RfD) and cancer slope factors (CSF) used in the human-health risk assessment (USEPA values; –, not applicable).

Metal	RfD (mg kg^{-1} day^{-1})	CSF (mg kg^{-1} day^{-1})$^{-1}$
Fe	0.7	–
Mn	0.14	–
Zn	0.3	–
Cu	0.04	–
Cr	0.003	0.5
Cd	0.0005	6.1
Ni	0.02	0.84
Pb	0.0035	0.0085
V	0.005	–

Table 5. Non-carcinogenic hazard quotients (HQ) and hazard index (HI) from ingestion of school drinking water, computed from mean metal concentrations for children and adults. HI > 1 (children) indicates a potential non-carcinogenic risk.

Metal	HQ (children)	HQ (adults)
Cd	0.895	0.384
Cr	0.631	0.270
Pb	0.248	0.107
Cu	0.087	0.037
Zn	0.040	0.017
Mn	0.036	0.015
V	0.031	0.013
Fe	0.027	0.011
Ni	0.014	0.006
Hazard Index (HI)	**2.008**	**0.860**

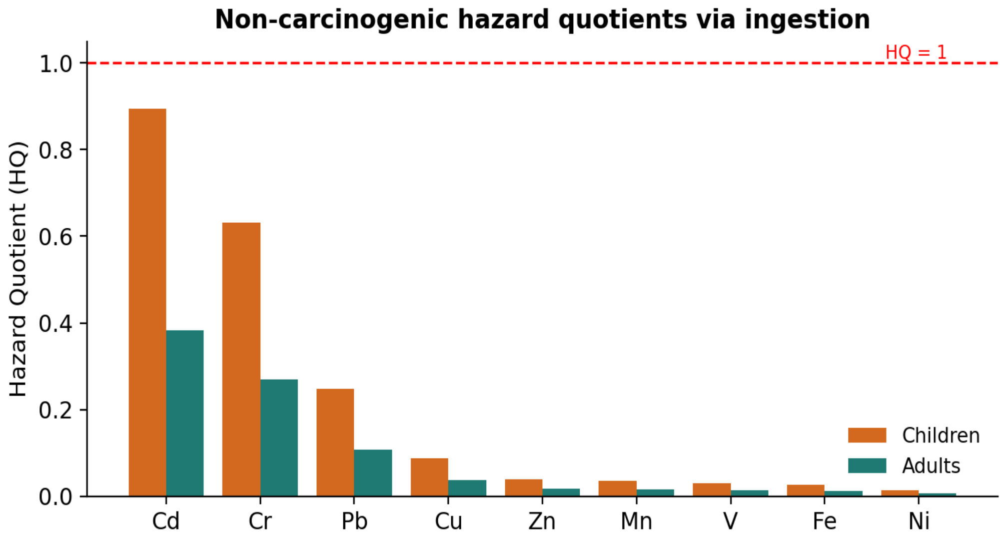

Figure 4. Non-carcinogenic hazard quotients for children and adults by metal. The dashed line marks HQ = 1; cadmium, chromium and lead dominate the cumulative hazard.

Expressed as a pollution index and as quantitative risk, these figures sharpen the interpretation. An HPI far above the critical value indicates supplies that are polluted with respect to heavy-metal load, while the divergence between the child and adult hazard indices directly from children's higher intake-to-body-weight ratio and underscores their greater vulnerability. The illustrative carcinogenic-risk estimates for cadmium and chromium at or above 10^{-4} warrant caution; they depend on the slope factors and exposure assumptions adopted and on the assumption that the measured chromium is partly hexavalent and should be regarded as screening-level rather than definitive. Nonetheless, the convergence of guideline exceedance, a critical HPI and a child hazard index above unity provides consistent evidence that the supplies require intervention.

3.4 Bacteriological quality

Total heterotrophic bacterial counts ranged from 0.2 to 0.8 × 10^2 CFU/mL, within the WHO/SON limit of < 100 CFU/mL. Total coliforms were detected at two schools (S1, 0.2 × 10 CFU/mL; S3, 0.3 × 10 CFU/mL), exceeding the national zero-tolerance standard, although *Escherichia coli* was absent from all samples (**Table 6**). Five bacterial isolates were recovered and characterised by morphological and biochemical tests (**Table 7**): *Enterobacter aerogenes*, *Micrococcus* sp., *Bacillus* sp., *Bacillus subtilis* and *Staphylococcus aureus*.

Table 6. Bacteriological indicators in drinking water from the five schools, with WHO and SON limits (THB, total heterotrophic bacteria).

Parameter	S1	S2	S3	S4	S5	WHO	SON
THB (× 10^2 CFU/mL)	0.6	0.2	0.8	0.7	0.3	< 100	< 100
Total coliforms (× 10 CFU/mL)	0.2	0.0	0.3	0.0	0.0	0	0
E. coli (CFU/mL)	0	0	0	0	0	0	0

Table 7. Morphological and biochemical characteristics and tentative identities of bacterial isolates from school drinking water (+, positive; −, negative).

Characteristic	Isolate 1	Isolate 2	Isolate 3	Isolate 4	Isolate 5
Gram reaction	−	+	+	+	+
Cell type	Rod	Cocci	Rod	Rod	Cocci
Spore stain	−	−	+	+	−
Catalase	+	+	+	+	+
Oxidase	−	+	−	−	−
Indole	−	+	−	−	−
Citrate	+	−	+	+	+
Urease	−	−	−	−	+
Motility	+	−	+	+	−
Mannitol	−	−	+	+	+
H_2S	−	−	−	+	−
Tentative identity	*Enterobacter aerogenes*	*Micrococcus* sp.	*Bacillus* sp.	*Bacillus subtilis*	*Staphylococcus aureus*

These microbiological findings reinforce the chemical picture. Coliform detection at two schools indicates that the supplies are vulnerable to faecal contamination, even though *E. coli* was absent. The absence of *E. coli* does not establish safety, as coliforms can themselves cause illness and signal the potential presence of other pathogens; their absence may reflect die-off, intermittent contamination or analytical limitation rather than a consistently protected source (Edberg *et al.* (2000); Tallon *et al.* (2005)). The recovery of organisms including *Staphylococcus aureus* and *Enterobacter aerogenes* is consistent with contamination from handling and the environment, in line with reports of widespread coliform contamination of Nigerian water sources (Jasper *et al.* (2012)).

3.5 Limitations

Several limitations should be noted. Water could be sampled at only five of the nine schools, reflecting the very absence of functional supplies that is in itself a key finding. Also, samples represent a single collection and cannot capture temporal or seasonal variation and the health-risk estimates depend on standard exposure and toxicity parameters and on mean concentrations, so they are best interpreted as screening-level indicators of relative risk. The combined physicochemical, chemical and microbiological characterisation nonetheless provides a more complete picture of school water quality than is usually available for this setting.

Conclusion

Drinking water in public secondary schools in Benin Metropolis is broadly acceptable on routine physicochemical grounds but is compromised by heavy-metal contamination–principally cadmium, lead and manganese–and by indicator-organism detection, posing a non-carcinogenic risk to children in particular. The supplies therefore require active management rather than passive reliance on an improved source. It is recommended that schools (i) treat drinking water on-site using affordable methods such as chlorination, filtration or, where metals are implicated, aeration and adsorption/reverse-osmosis approaches; (ii) protect sources through proper well construction, siting and maintenance, and replace corroding lead-bearing plumbing; (iii) institute routine physicochemical, heavy-metal and microbiological monitoring against WHO, SON and NAFDAC standards; and (iv) prioritise schools with acidic, mineralised supplies and the highest pollution indices for remediation. These measures would reduce chemical and microbial exposure and support the health and learning of school communities.

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