Watershed land use, surface water vulnerability and public health risks of two urban rivers, Ado-Ekiti, South-West Nigeria

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Received: 2 April 2020 / Accepted: 22 September 2020 / Published online: 8 October 2020
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Abstract

The disruption of watersheds due to indiscriminate land use and urban development increases the vulnerability of adjacent surface water to contaminants of anthropogenic origin. This study assessed the relationship between disrupted watershed, drinking water quality and health risks of two urban rivers: Ureje and Awedele, Ado-Ekiti (Nigeria). Monthly samples of surface water ($n = 60$, per river) collected across seasons for 6 months (January–June, 2017) were analyzed for twenty-nine drinking water parameters including metals, nutrients (phosphates and nitrates) and pathogens using standard methods. The difference in the mean concentration of parameters between rivers was determined using t test, while the association between change in seasons and water quality parameters of both rivers was highlighted using principal component analysis (PCA). The risk was assessed based on on-site inspection studies and water sample analysis using WHO semiquantitative risk matrix approach. Inferences on surface water vulnerability were made from percentage built-up areas, riparian cover and stream order within each watershed. Mean concentrations of Pb, Cd, Fe, Mn, nitrates and coliform presence in samples from Awedele river (0.02 ± 0.00 ; 0.005 ± 0.001 ; 5.44 ± 1.33 ; 0.81 ± 0.03 ; 58.03 ± 0.10 mg/L; 1.2×10^6 MPN/100 ml, respectively) and Cd, Fe, Mn, nitrates and coliform in samples from Ureje river (0.004 ± 0.0001 ; 4.96 ± 0.12 ; 0.54 ± 0.01 ; 62.08 ± 0.02 mg/L; 1.6×10^3 MPN/100 ml, respectively) were above the permissible limits of WHO drinking guidelines. Risk assessment revealed urban runoff and unsanitary practices within the watershed as possible hazardous events which may compromise water quality of both rivers, while the PCA associated greater likelihood of surface water deterioration with areas of a higher percentage built-up area and lesser riparian density and width. We infer that disrupted watersheds and greater riparian depletion due to urbanization increased chances of metals and pathogens incidence that negatively impacts water. A twofold strategy of policy protection of watersheds and public health education on sourcing polluted surface water is recommended.

Keywords Urban runoff · Water quality index · Target hazard quotient · Riparian buffer · Built-up areas · Remote sensing

1 Introduction

Intense urbanization marked by built-up areas, necessitated by greater population influx into cities, increases pressure on resources and infrastructure, including a resultant lowered potable water per capita [49, 63]. Such

scenarios amidst the reality of the poor economic situation in developing countries have warranted individuals and local communities to seek alternatives to conventional public water supply [24, 64]. Thus, there are concerns of high risks of disease burden like *Salmonella* spp., especially among low- and middle-income populations due to intake

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of unsafe drinking water and poor sanitary conditions [84, 102]. Prevalence of water shortages and the lack of access to clean drinking water have led many communities to be dependent on rivers systems as sources of last resort for their water needs [51, 87]. Aside the problem of the huge cost of drilling boreholes to access portable water [42, 48], the increased reliance on river systems as sources of drinking water has been attributed to high rate of wells and borehole failure [26, 69]. This situation is direr in urban areas where the lower potable water per capita provokes indiscriminate and incessant exploitation that overwhelms the groundwater recharge regime, causing insufficient yield and higher incidences of borehole failure [49, 63].

About 80% of health issues in low- and middle-income societies are linked to unhealthy water sources [40, 52]. Loss of natural land areas and increased pressure on infrastructure due to urbanizations have contributed to increased runoff of pollutants from nonpoint sources into surface water that traverse municipal corridors [103]. Increased risks of toxicity and bioaccumulation of pollutants like metals among populations who ingest contaminated water have been documented [4, 45, 77]. Ingestion of metals via drinking water in quantities that exceed desirable or permissible limits could cause a range of systemic effects from cardiovascular issues, kidney diseases, high blood pressure, sterility, neurotoxicity and other disorders in humans [92]. As such, urban events like indiscriminate waste disposal, unsanitary activities and agricultural practices common in developing countries can pose substantial risks to local communities by elevating concentrations of trace metals like lead (Pb), iron (Fe), manganese (Mn) and cadmium (Cd) in surface water used for drinking [79, 104]. Pathogens like fecal coliform which constitute a potential health risk when elevated in drinking water also gain entry into river systems through direct introduction of waste matter largely from storm runoff from cultivated watersheds and seepages of untreated human sewage due to poor sanitary infrastructure [27, 86].

Because of unregulated anthropogenic activities, hazards are often introduced throughout the watershed, from catchment to consumer [3, 83]. This, in turn, has elicited efforts to protect public health through routine monitoring of water resources and strategic steps to identify risk factors that limit the availability of potable water, toward improving the safety of the water system [22, 98]. Hence, to help risk management focus on the needed improvements that contribute most to water supply safety, and evidence-based justification for an improvement plan for the water supply system, some form of classification or quantification of the risks in terms of health impact is required [99]. Thus, the need to determine the magnitude and priority of the risks necessitates, a risk matrix in which the likelihood of a hazardous event occurring and the

severity or consequence of the hazard is rated separately and subsequently combined into an overall risk score [10]. In its most basic form, this can be a qualitative assessment based on expert judgment ranking risks as, for example, significant, uncertain or insignificant [101]. A more extensive approach is the semiquantitative assessment where a risk matrix is used to derive a final risk score to evaluate the range of different (water quality-associated) risks [94].

Beyond field-based studies, current advances in remote sensing have allowed the ease of visualizing anthropogenic modifications to landscape and watersheds using satellite data [47, 82]. Even hydrological information on watersheds, basin size, level of fragmentation, flood vulnerability, runoff discharge points, stream order and stream networks within the watershed can also be evaluated remotely [44, 67]. Studies have also assessed the loss of riparian vegetation around freshwater systems (e.g., normalized difference vegetation index) as a measure of anthropogenic impact and rapid urbanization [20, 59]. Different data types including high resolution (MODIS and SPOT imagery) or lower resolution (Landsat OLI, ETM), and more recently high-resolution Google Earth images, have been harnessed to gain insight into different types of land-cover and land-use classes [18, 60, 73]. Despite the extensive application of these techniques in more developed climes, a strategic description of various aspects of the Nigerian environment to increase the understanding and scope of environmental degradation is still limited.

The Ado area lies within the basement complex terrain of SW Nigeria, characterized by Precambrian crystalline rock units, classified by hydro-geophysical investigations as a moderate groundwater yield zone [12] and marked by complex and erratic groundwater occurrences [26]. Awedele river and Ureje river are part of the small-sized rivers and streams which characterize the basement complex terrain and serve as major sources of water supply for its urban population and neighboring communities [41, 71]. However, anthropogenic activities along the urban watershed like these rivers have increased concerns of adverse health outcomes associated with exposure to poor water quality [28, 75]. This inherently brings to bear the critical importance of watershed (entire land areas that route stormwater and anthropogenic runoff into a specific river or river system) management in the determination of river health [23]. Land-use pressures and population growth around urban watersheds increase ubiquitous effects on surface water quality [57, 80], habitat alteration [25, 35] and loss of biodiversity [68, 90].

This study sought to assess the relationship between disrupted watershed, drinking water quality and health risks of two urban rivers: Ureje and Awedele, Ado-Ekiti (Nigeria). We hypothesized that the vulnerability and, by extension, the level of deterioration in water quality of urban rivers (i.e., the concentration of metals, phosphates

and nitrates and pathogens) would be relatable to the intensity of urbanization and severity of disruption within the watershed area of each river.

2 Materials and methods

2.1 Description of study area

The study area (Ado-Ekiti) is the capital city or administrative headquarter of Ekiti state, Nigeria. The study focused on river Ureje in Ado Local Government Area and river Awedele in Ado North Local Government Area, Ekiti state. River Awedele is located between $7^{\circ} 38' 32.91'' \text{N}$ – $7^{\circ} 38' 8.13'' \text{N}$ and $005^{\circ} 12' 6.86'' \text{E}$ – $005^{\circ} 12' 47.14'' \text{E}$, while river Ureje is located between $07^{\circ} 35' -07^{\circ} 40' \text{N}$ and $005^{\circ} 10' -005^{\circ} 15' \text{E}$ (Fig. 1). The state capital has an estimated population of 2.3 million people (the Federal Republic of Nigeria, 2006 Population Census). Both rivers are major recipients of untreated effluent and domestic waste from nonpoint sources in the

area. Human activities along both rivers were largely characterized by spots of open refuse dumps which release leachates into the rivers especially during wet seasons. Waste elements commonly found on the refuse dumps include agricultural by-products, cosmetics, plastics, metal scraps from used electronics and construction debris [89]. Features specific for Ureje river included a small oil palm processing mill sited not too far from the riverbank, which used water from the river for its processing activities with discharges of untreated wastewater into the river system. Also observed within the Ureje watershed are construction works which release backwash of cement into the river.

2.2 Built-up intensity and vulnerability of urban rivers

GIS analysis of the Ekiti river basin was carried out using impervious areas, riparian coverage and river order, to establish the vulnerability of these rivers located within urban settlement [109].

Fig. 1 Map of Awedele river and Ureje river, Ado-Ekiti, Ekiti state, Nigeria

2.2.1 Estimation of impervious area

To visualize the land use–land cover of the watershed of both urban rivers, high-resolution imagery was acquired from Google Earth and subjected to spectral mixture analysis using unsupervised classification–Iso cluster algorithm in ArcMap 10.4 [53]. Using the attribute table, the relative percentage coverage of built-up/impervious areas within 1 km of the watershed was estimated [5].

2.2.2 Riparian coverage

To estimate the riparian coverage within the recommended 120 m of the watershed requirement for surface water protection [55], cloud-free Landsat 8 operational land imager (OLI) was downloaded from www.earthexplorer.usgs.gov and analyzed using the normalized difference vegetation index (NDVI). Processing of Landsat OLI was carried out in ArcMap 10.4. Before the NDVI analysis, buffer analysis was carried out to delineate the 120 m width of the watershed. The standardized vegetation index is sensitive to plant vigor and abundance by illustrating the disparity between the visible red band and the near-infrared band [56]. The equation is provided as follows:

$$\text{NDVI} = (\text{PIR} - \text{R}) / (\text{PIR} + \text{R}) = (\text{B4} - \text{B3}) / (\text{B4} + \text{B3}) \quad (1)$$

where B3 and B4 are the red bands and near-infrared band, respectively.

2.2.3 River order analysis

To determine the river order of both rivers, the digital elevation model (DEM) of the Ekiti region was downloaded from www.earthexplorer.usgs.gov [91]. Hydrological analysis using spatial analyst tools in ArcMap 10.4 was performed on the DEM to fill sinks (pits) and to generate data on flow direction, flow accumulation, catchments, streams, stream segments and watersheds. These data were then used to develop vector representations and drainage network within each catchment [72].

2.3 Sample collection

Monthly water samples ($n = 60$, 12 samples per sampling station) were collected from five different stations covering the whole stretch of Ureje and Awedele rivers, on the 15 of each month, between 007 and 009 h from January to June 2017. For each station, samples were collected facing upstream, in areas of fast-moving water, about 20 cm deep and reachable from a stable and firm area of the stream bank (rocky, not soft/spongy spot) [65]. Before sampling collection, each sampling bottle was triple-rinsed and held

approximately 15 cm beneath the surface until full and then capped underwater leaving no headspace [65]. Water samples were collected into 200 mL sterilized polyethylene bottles and acidified using concentrated hydrochloric acid to ensure that the respective ions remain in solution pending analysis.

2.4 Sample analysis

In the laboratory, water samples for heavy metal analysis were filtered and digested with 10 mL of concentrated analytical grade nitric acid to 200 mL of the water sample. The solutions were evaporated in a beaker on a hot plate crucible to approximately 5 mL, then filtered into 20 mL standard flask and made up to the mark with distilled water [2].

The digested water samples were then analyzed at the Environmental Research Laboratory of the National Research Institute for Chemical Technology, Zaria Kaduna, Nigeria, for lead (Pb), cadmium (Cd), chromium (Cr), manganese (Mn), nickel (Ni), copper (Cu), iron (Fe) and zinc (Zn) using a flame atomic absorption spectrophotometer (AAS) model (Model: AA-6800 Shimadzu, Japan). The metal concentrations in each digested sample were determined by comparing their absorbance with aqueous calibration standard prepared from the stock standard solutions of the respective elements [7].

2.4.1 Quality control and quality assurance (QC/QA)

To obtain precise and accurate results, strict quality control and several routine checks on standards and protocol were made according to the procedure given by Lloyd and Heathcote [54]. Before quantification and analysis, the instruments were calibrated via calibration standards. Each and every chemical used was of analytical grade and purchased from Merck (Germany). The reagent blanks were also used to check the contamination. All the glassware were washed with double-deionized water, oven-dried and rinsed with acids. GFAAS was used for the measurement of trace metals in the samples. Detection limits were approximately three times of the standard deviations of the blank (double-deionized water). The validity, as well as reliability of extraction and cleanup methods, was ensured by the recovery of an internal standard. The overall recovery rate for each metal in water samples was above 85%.

Physicochemical parameters like temperature and pH were recorded at the time of sample collection, by using thermometer and pocket digital pH meter, while other parameters such as DO, TDS, TSS, hardness, chlorides, alkalinity, electrical conductivity, phosphate and nitrate were estimated in the laboratory through standard methods [7]. Microbial analysis was carried out by pour-plating method

using the serial dilution technique [11]. The fecal coliform analysis was carried out using the most probable number (MPN) method [8].

The mean value of the physiochemical parameters was compared with the standard set by World Health Organization [98, 100] and National Environmental (Surface and Groundwater Quality Control) Regulations [66].

2.5 Risk assessment

Based on on-site inspection observations and water sample analysis, a semiquantitative risk analysis was used to categorize risks of chemical and biological hazards by comparative scores [101]. Hazard observations and inferences from each river were represented using likelihood and severity/consequence descriptors significant [62].

For risk prioritization matrix, descriptor for likelihood categories was:

- 5- Almost certain (is expected to occur in most circumstances as it has been observed and recorded regularly in the field and is also confirmed by water quality data),
- 4- Likely (will probably occur in most circumstances as it has been observed and recorded occasionally in the field and is also confirmed by water quality data),
- 3- Moderate (might occur at some time/the event should occur at some time as it has been observed occasionally with few recordings in the field, but water quality data has no significant trends that confirm risk),
- 2- Unlikely (could occur at some time but has not been observed in the field, and water quality data have some outliers but no trends that confirm risk) and
- 1- Rare (may occur only in exceptional circumstances but has not been observed in the field and water quality data show no indication of any risk).

The descriptor for consequence/severity of impact was:

- 1- Insignificant (negligible impact in terms of severity of disease or numbers of people likely to be affected),
- 2- Minor (minor aesthetic impact causing dissatisfaction but not likely to lead to the use of alternative fewer safe sources),
- 3- Moderate (major aesthetic impact possibly resulting in the use of alternative but unsafe water sources),
- 4- Major (morbidity expected from consuming water),
- 5- Catastrophic (mortality expected from consuming water).

Risk rating for each hazard category was achieved by multiplying the derived likelihood ratings with the derived consequence ratings to produce a risk rating with a score

[6]. A risk matrix, otherwise called the 5*5 matrix table (Table 1), was used to communicate the semiquantitative risk assessment [62]. A higher score implies that a bigger risk of a hazardous event occurs and hence should be prioritized. Risks identified as high or very high from the matrix were classified as significant [62].

2.6 Statistical analysis

Descriptive analysis of water quality variables was presented as mean and standard deviations. All analysis was carried out using Statistica® version 12 (Statsoft USA, Inc). Since land-use impacts around the watersheds of Ureje and Awedele rivers were not from any identifiable point sources, but rather originated from diffuse sources, values of physicochemical properties, metals and microbes measured from different stations along the watershed of each river were pooled to give mean concentrations [43].

The relationships between urbanization intensities (as measured percentage impervious area, riparian cover and stream order), physicochemical properties and occurrence of metals in surface water were assessed via multivariate correlation using principal component analysis (PCA). Since most water parameters are lognormally distributed, data were log-transformed before multivariate analysis [38, 39].

3 Results

3.1 Measures of urbanization intensity

Unsupervised classification of high-resolution Google Earth images for Awedele watershed (Fig. 2a) and Ureje watershed (Fig. 2b) showed a resolution of 7 and 5 different land-use classes, respectively. Relative percentage

Table 1 Risk matrix and significance scale

	Likelihood				
	1	2	3	4	5
Severity					
1	Negligible	Negligible	Negligible	Negligible	Low
2	Negligible	Negligible	Low	Medium	Medium
3	Low	Low	Medium	High	High
4	Medium	High	High	Very high	Very high
5	High	Very high	Very high	Very high	Very high
Risk score	< 6	6–9	10–15	> 15	
Risk rating	Low	Medium	High	Very high	

(A)

(B)

Fig. 2 Unsupervised classification of Google imagery for **a** Awedele and **b** Ureje watershed; percentage land-use–land-cover classes for **c** Awedele and **d** Ureje watershed areas

Fig. 2 (continued)

pixel coverage for Awedele watershed showed: vegetation (10.4%), water (13.8%), shrubland (8.2%), wetland (6.1%), road network (9.5%), bare surface (12.2%) and built-up area (39.8%) (Fig. 2c). For Ureje watershed area, land-use spectral classes were resolved into riparian vegetation (13.76%), water body (25.82%), low vegetation (12.77%), built-up area (34.98%) and road network (12.67%) (Fig. 2d).

Riparian cover assessment within 120 m of the watershed left and right along the course of each river using NDVI analysis revealed that the whole length of both rivers run entirely within urban corridors and is largely surrounded by the riparian extent of less than 120 m ("Appendix 1"). Although the general NDVI output (< 0.3) of both sites largely reflected sparse riparian vegetation, the mean

NDVI scores across watersheds revealed greater riparian presence within the Ureje area (0.157) compared to the Awedele area (0.137) ("Appendices 2 and 3").

Stream order analysis of the watershed and basin of the Ureje and Awedele rivers within the Ado area revealed that both rivers are first-order rivers having no upstream concentrated flow ("Appendix 4").

3.2 Physicochemical properties and permissible limits

Since land-use impacts around the watersheds of Ureje and Awedele river were not from any identifiable point sources, but rather originated from diffuse sources, values of physicochemical properties, metals and microbes

measured from different stations along the watershed of each river were pooled to give mean concentrations for the watershed area [43]. Given in Table 2 are values for the physicochemical, heavy metals and microbial analysis of water collected from Ureje and Awedele surface water to assess the quality of the water for domestic consumption. For both rivers, the electrical conductivity of surface waters (Awedele = 620 ± 48 μ S, Ureje = 380 ± 22 μ S) exceeded WHO acceptable limits for drinking water quality (Table 2). Mean concentrations obtained for Pb, Cd, Fe and Mn at Awedele river (0.02 ± 0.00 ; 0.005 ± 0.001 ; 5.44 ± 1.33 ; 0.81 ± 0.03 mg/L, respectively) were above the permissible limits of WHO drinking guidelines. Concentrations of Cd, Fe and Mn (0.004 ± 0.0001 ; 4.96 ± 0.12 ; 0.54 ± 0.01 mg/L) at Ureje also exceeded permissible limits. Mean

Table 2 The mean values of physicochemical variables

Parameters	Ureje river	Awedele river	WHO [98]	NESREA [66]
Temperature (°C)	27.1 ± 2.19	27.6 ± 2.46	0–32	–
pH	8.07 ± 0.01	8.12 ± 0.02	6.5–9.5	6.5–8.5
DO (mg/L)	5.69 ± 1.19	3.91 ± 1.09	–	> 6
BOD ₅ (mg/L)	0.40 ± 0.02	0.41 ± 0.01	6	3.0
E.C (μ S)	$380 \pm 22^*$	620 ± 48	250	–
Turbidity (NTU)	0.01 ± 0.00	0.05 ± 0.00	–	–
TS (mg/L)	0.30 ± 0.11	0.34 ± 0.12	–	–
TDS (mg/L)	0.04 ± 0.03	0.22 ± 0.09	–	–
TSS (mg/L)	0.26 ± 0.02	0.12 ± 0.01	–	0.25
Total hardness (mg/L)	110.00 ± 0.02	90.00 ± 0.12	200	–
Total alkalinity (mg/L)	30.00 ± 0.05	26.00 ± 0.04	–	–
Chlorides (mg/L)	23.08 ± 0.15	46.15 ± 0.07	250	300
Nitrates (mg/L)	82.08 ± 13.12^a	68.03 ± 9.10	50	9.1
Phosphates (mg/L)	33.05 ± 4.06	29.00 ± 3.00	–	3.5
Sulfates (mg/L)	88.00 ± 22.00	130.00 ± 15.50	500	100
Calcium (mg/L)	$13.75 \pm 0.03^*$	11.25 ± 0.04	–	180
Magnesium (mg/L)	$22.91 \pm 0.03^*$	18.75 ± 0.02	150	40
Pb (mg/L)	0.02 ± 0.001	0.03 ± 0.001	0.01	0.01
Zn (mg/L)	0.59 ± 0.01	0.88 ± 0.01	3	0.01
Cd (mg/L)	0.004 ± 0.001	0.005 ± 0.001	0.003	0.005
Mn (mg/L)	0.54 ± 0.08	0.81 ± 0.13	0.5	–
Cr in (mg/L)	0.002 ± 0.001	0.001 ± 0.001	0.05	0.5
Fe (mg/L)	4.96 ± 0.12	5.44 ± 1.33	1.0*	0.05
Ni (mg/L)	0.01 ± 0.00	0.01 ± 0.00	0.02	–
Cu (mg/L)	0.12 ± 0.01	0.19 ± 0.01	2	0.001
Bacterial (CFU/ml)	$4700 \pm 120^*$	$10,000 \pm 320$	–	–
Yeast (CFU/ml)	ND	ND	–	–
Fungi (CFU/ml)	$20 \pm 8^*$	40 ± 5	–	–
Fecal coliform	$1.6 \times 10^3 \pm 300$	$1.2 \times 10^6 \pm 580$	–	50

CFU/ml=colony forming unit per ml, MPN/100=most probable number of coliforms per 100 ml sample, ND=not detected

*Current aquatic life standard based on toxic effects [50]

NB: superscript alphabet indicates a significant difference between parameters

concentrations of nitrate parameters of surface water at Awedele (58.03 ± 0.10 mg/L) and Ureje (62.08 ± 0.02 mg/L) also exceeded known permissible limits for WHO drinking water quality. Microbial analyses of water samples showed the presence of coliform (1.2×10^6 MPN/100 ml) and (1.6×10^3 MPN/100 ml) in Awedele and Ureje river water, respectively. Yeast was absent in samples, while the mean values obtained for bacteria in Awedele and Ureje river were 10000 CFU/ml and 4700 CFU/ml, respectively (Table 2).

Comparing water quality parameters for each river with national guidelines for Nigeria as specified by NESREA, it was observed that although pH was strongly alkaline, it was within acceptable limits. Dissolved oxygen for both rivers was not within acceptable limits. Total suspended solids at Ureje river exceeded acceptable limits, while that of Awedele were within acceptable limits. Chloride levels in surface water of both rivers were within acceptable limits, while nitrates and phosphates exceeded acceptable limits. Levels of sulfate in surface water at Ureje were within acceptable limits, while that of Awedele exceeded acceptable limits. Levels of calcium and magnesium ions in surface water were within acceptable limits. Concentrations of Pb, Zn, Fe and Cu ions in surface water of both rivers exceeded acceptable limits specified by NESREA. The concentration of Cd and Cr for both rivers was within acceptable limits.

The difference in means using t test indicated that nitrate levels were significantly higher at Ureje site (68.03 ± 0.02 mg/L) compared to Awedele (82.08 ± 13.12 mg/L). Similarly, levels of calcium, magnesium, total hardness, TSS, TDS and DO were significantly higher at Ureje compared to Awedele (Table 1). On the other hand, electrical conductivity (EC) was significantly higher at Awedele (620 ± 48 μ S) compared to surface water from Ureje (380 ± 22 μ S). Other parameters significantly higher at Awedele river include microbial profile, i.e., bacteria count, fungi and fecal coliform count (Table 2).

3.3 Semiquantitative risk assessment

From our assessment, all categories of hazards for both rivers showed either high risks or very high risks. And in all categories of hazards, urban runoff appears to be a recurring hazardous event that contributes to altered water quality. Pathogen presence in surface water was identified as a high risk in both rivers because of the

frequent incidences of unsanitary practices, i.e., urination, bathing, open defecation, indiscriminate disposal of domestic wastes, leachates from open dumps within each watershed and the very high likelihood of severe effects in affected populations. The high-risk score for metals in Ureje and Awedele rivers could be attributed to the frequency of anthropogenic activities in the area (e.g., artisanal metal works, urban runoff from impervious built-up areas, leachates from open waste dumps which increase the availability of these metals in urban runoff and storm-water) and the high likelihood of adverse health impact to adults and children in receiving populations (Table 3). The high-risk category of nitrates and phosphates at Ureje compared to the medium-risk rating at Awedele could be attributed to the higher concentration of these nutrients in surface water at Ureje (Table 4). On-site observation revealed that activities like food processing and interspersed agricultural activities within the Ureje watershed could be a contributing factor to its higher risk factors.

3.4 Multivariate analysis

Multivariate analysis using PCA analysis to determine the association between water quality parameters across sites and dynamics across seasons revealed that surface water from both Awedele and Ureje sites showed a strong positive relationship with elevated water quality parameters, i.e., Pb, EC, pH, hardness, TDS, TSS, Cd, Mn and alkalinity. From the biplot, it was also observed that the strong positive relationship between surface water from Awedele and Ureje and priority water quality parameters was also associated with the rainy season. The stronger polarity of Awedele site compared to Ureje site on the PC 1 axis of the biplot indicates that Awedele was marked with a greater elevation of water quality parameters compared to Ureje (Fig. 3).

4 Discussion

4.1 Surface water quality across sites

Measures of electrical conductivity (EC) were used to infer the concentration of nutrients, salt or impurities in the water [17]. The electrical conductivity of surface water from Ureje and Awedele showed values that exceeded the permissible limit specified by WHO for drinking water.

Table 3 Semiquantitative risk assessment for surface water from Awedele river

Hazard	Hazard type	Hazard event	Description of source and cause	Water quality data verification	Likelihood	Consequence/severity	Risk score	Risk rating
Heavy metals	Chemical	Urban runoff from impervious areas	Urban vehicular traffic, combustion of fossil fuel, domestic pesticide applications increase the bioavailability of metals on impervious surfaces within the watershed, which are eventually transported into surface water by urban runoff and stormwater	Concentrations of metals, Pb, Mn, Cu, Fe exceeded WHO guidelines and permissible limits	5	4	20	Very high
Microbes (bacteria, yeast, fungi, fecal coliform)	Biological	Urban runoff from dumpsites and broken sewers	Open defecation, a poor sanitary condition in urban areas, bathing, washing, cattle rearing within the watershed	Microbial concentration in the water exceeded 20 MPN	4	4	16	Very high
Nutrient (phosphates and nitrates)	Chemical	Urban runoff from farm activities and open dumps within the watershed	In addition to the fewer agricultural activities, other major sources of phosphates and nitrates into surface water include manure, industrial wastewaters, sanitary landfills and garbage dumps	Concentrations of nitrates and phosphates in surface water were higher than WHO and NESREA standards	3	3	9	Medium

Table 4 Semiquantitative risk assessment for surface water from Ureje river

Hazard	Hazard type	Hazard event	Description of source and cause	Water quality data verification	Likelihood	Consequence/severity	Risk score	Risk rating
Heavy metals	Chemical	Urban runoff from built-up surfaces	Anthropogenic activities contributing to heavy metal pollution in the aquatic environment include vehicular exhaust emissions, pesticide application from agricultural cultivation and atmospheric precipitation	Concentrations of metals, Pb, Mn, Cu, Fe exceeded WHO guidelines and permissible limits	4	3	12	High
Pathogens and microbes (bacteria, yeast, fungi, fecal coliform)	Biological	Urban runoff	Communal bathing, washing, open defecation by cattle and humans within the watershed	Microbial concentration in the water exceeded 20 MPN	4	4	16	Very high
Nutrient (phosphates and nitrates)	Chemical	Urban runoff from farming activities within the watershed	Potential sources of excess nitrate and phosphate reaching surface water at Ureje include food processing industries, agricultural activities and applications of fertilizers and manure	Concentrations of nitrates and phosphates in surface water were higher than WHO and NESREA standards	4	3	12	High

Fig. 3 Principal component analysis of water quality parameters of Ureje and Awedele rivers, Ekiti state, Nigeria

Thus, the mean conductivity values for water from Ureje and Awedele from this study indicate augmented levels of nutrients, salts and impurities. In other studies, increased conductivity of surface water downstream canalization outlets that discharge drainage and stormwaters from urban settlements have been reported [19, 34].

Observations for heavy metals in surface water samples revealed that all metals measured were within WHO specified limits, except Pb, Cd, Fe and Mn in surface water of both rivers which were above the recommended limits. Since no major industrial activity was observed within the watershed of both rivers, concentrations of these metals in surface water could be largely attributed to urban runoff, including agricultural runoff from subsistence farmlands and sewage discharge [111]. Documented sources of Mn in surface water include municipal wastewater discharges, sewage sludge, emissions from artisanal metal works and the combustion of fossil fuels [88] all of which

were observed within these watersheds. Other reports have implicated nonpoint sources such as silt-laden runoff from built-up and developing areas as contributors to elevated levels of heavy metals in surface water [58, 106]. The elevated concentrations of Pb, Cd, Fe and Mn recorded in water samples from Ureje and Awedele rivers in this study raise concerns of adverse health concern to adult and child populations that ingest these metals via drinking water. Instances have been reported where exposure to Pb and Cd resulted in accumulation in several body organs including bones, causing severe health defects such as sub-encephalopathic, neurological and behavioral effects [92, 93]. Elsewhere, epidemiological studies have documented potential for teratogenic effects following Pb exposure including decrease in fetal weight and retardation of the development of the skeleton and internal organs [37] and mutagenic effects in children [92]. While manganese is an essential element for many

living organisms, including humans, overexposure due to elevated levels in the environment could be lethal [46].

Water samples from Ureje and Awedele rivers showed high mean fecal coliform concentrations of 1.2×10^6 MPN/100 ml, 1.6×10^3 MPN/100 ml, respectively, indicating pathogenic risks to user populations. Studies have documented a positive association between high fecal coliform bacteria concentrations in surface water and proximity to impervious areas and soft urban natural surfaces (e.g., pastures, lawns and gardens) vulnerable to runoff from nonpoint sources [105]. Elsewhere, predictive associations between urban density in watershed areas and adjacent surface water quality have also been documented [107]. Emphasis has also been made on the positive association between urbanization intensity and incidence of multiple nutrients (total nitrogen and total phosphorus) and indicator bacteria (thermotolerant coliforms) [16] in adjacent surface water. Since high-density urban areas are marked by highly populated residential settlements [108], it is expected that watersheds with a greater percentage of built-up land use will record greater microbial presence in surface water due to increased domestic wastewater or sewage runoff. This corroborates findings from this study where the rivers with more built-up areas (i.e., Awedele river) within its watershed showed greater deterioration of surface water quality. The greater activity of bacteria, fungi and coliform detected in surface water from Awedele compared to samples from Ureje is typical of rivers receiving input from bathing and related unsanitary practices and portends a greater likelihood for diarrhea-related illnesses when such contaminated drinking water is ingested [30].

4.2 Urbanization intensity, riparian cover, stream order and surface water vulnerability

As cities increase in density, urban forest patches eventually become smaller or more segregated [14]. Previous findings from metrics analyses revealed that the intensity of land-use diversity and landscape fragmentation is positively related to the intensity of urbanization [97]. Built-up areas are notable of all land-use classes because they contribute the largest changes to volumes and patterns of runoffs travelling through catchments into adjacent surface water [95]. Surface runoff from impervious urban surfaces is often laden with metal complexes from

high-density vehicular traffic deposition and combustion from heavy engines [85].

Riparian cover assessment within 120 m of the watershed left and right along the course of each river using NDVI analysis revealed that the whole length of both rivers run entirely within urban corridors and is largely surrounded by a sparse riparian cover, with a buffer extent of less than 120 m. Riparian areas of fluvial systems function as natural buffer vegetation which spans both sides of the stream bank and function in mitigating the impact of flood, sedimentation and pollutant runoff from adjoining land areas [33, 36]. Since riparian buffers regulate the flow of species, energy and various materials including contaminants between these ecosystems [29], urban pressure which depletes this resource will put surface water at risk. This explains why Awedele appeared more impacted with higher contaminant levels compared to Ureje.

Stream order analysis of the watershed and basin of the Ureje and Awedele rivers within the Ado area revealed that both rivers are first-order rivers having no concentrated flow upstream. The concept of stream order analysis has been used to infer their vulnerability to pollution [21], particularly for lower-order or first-order streams which are susceptible to nonpoint pollution via overland flow [9]. By implication, Ureje and Awedele urban rivers will have a high propensity for nonpoint source pollution problems and could derive more benefit from wider riparian buffers than higher-order rivers. Reports on the Ado-Ekiti basement complex terrain depict a high occurrence of medium- to small-sized rivers [74], an indication that surface water vulnerability may be a regional-scale problem.

4.2.1 Surface water quality and built-up intensity

Fluvial systems which traverse urban corridors are vulnerable to a significant deterioration in quality and health status [1, 78, 96]. The vulnerability of river watersheds to diffuse pollutants has been attributed to anthropogenic pressure around riverine environments [1, 70]. To ascertain the quality of such vulnerable systems, a combination of water quality parameters measured along the stretch of watersheds has been used to demonstrate the impact of various anthropogenic stressors entering from surrounding landscapes [110]. Our results connect the intensity of built-up area with elevated metal concentrations in surface water and increased risks to local populations who

source these waters for drinking and domestic use. Urbanization has been reported to affect the water quality of city rivers with excess nutrients, endocrine disrupting chemicals, heavy metals, antibiotics and steroid hormones [81], particularly in more built-up areas and larger cities with increased human activity [32].

4.2.2 Multivariate analyses

The marked positive association of pollutants in surface water of both rivers particularly EC, Pb, Cd, Fe, pH, alkalinity and nitrates with rainy season depicted in the PCA implicates the role of runoff from surrounding built-up areas in the deterioration of these urban rivers. Urbanization-related activities have been implicated as contributory factors to elevated levels of nitrates, alkalinity and the total dissolved solids in adjacent surface waters [15, 31]. Elsewhere, reports confirm that sewage from urban runoff consists of distinctive chemical characteristics including high concentrations of ammonium, nitrate, high conductivity (due to high dissolved solids), high alkalinity, bacteria and metal complexates which are washed into adjacent surface water by rains [32, 61]. In developing climes, this is a more serious scenario because their urban areas lack municipal storm sewer systems and, even where present, often discharge stormwater without treatment to streams, rivers and other water bodies [76, 106].

4.3 Urban land-use hazards and semiquantitative risk assessment

The risk posed to human health by the three main classes of hazards was assessed based on water quality parameters and intensity/frequency of anthropogenic activities within the watershed of both rivers. From this study, inferences on risks and hazards due to the high concentration of pathogenic microbes and metals within surface water have been largely attributed to these land-use activities and urban runoff transporting contaminants into adjacent surface water. Hazard events typical within the watershed of Ureje and Awedele river including runoff from impervious areas, open dumpsites and haphazard unsanitary activities have been highlighted by other studies to constitute a serious risk to surface water [13, 16].

5 Conclusion and recommendations

This study demonstrates that rivers within corridors of more intense built-up/impervious areas and greater riparian depletion recorded greater contaminant load compared to rivers within corridors of less built-up areas. Besides, the concentrations of heavy metals (Pb, Fe, Cd, Mn) in surface water from the two urban rivers, i.e., Ureje and Awedele rivers, in Ado-Ekiti area (Nigeria) exceeded WHO drinking water guidelines, suggesting that these water sources are contaminated and unsafe for human consumption. The risk assessment of the surface water quality for both rivers showed portends high risks for all categories of hazards that could endanger the health of citizens if control strategies are not provided. The most important of hazard events contributing to risk is the urban runoff due to extensive impervious areas of the watershed and unsanitary practices within the watershed. Worse of all, water from these rivers is used without any purification. In general, our results connect the intensity of built-up area, and disruption of the watersheds with elevated metal contents and increased risks of adverse effects to local populations. It is recommended that environmental enforcement and monitoring agencies undertake a systematic assessment and monitoring approach of surface drinking water sources to establish their suitability for drinking and reduce pollution vulnerability of drinking water resources by developing a statewide watershed management plan.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Appendix 1

See Fig. 4.

Fig. 4 Riparian cover analysis for **a** Ureje watershed and **b** Awedele watershed, using normalized difference vegetation index (NDVI)

Appendix 2

See Fig. 5.

Count:	1056
Minimum:	0.073107593
Maximum:	0.259662837
Sum:	145.4757161
Mean:	0.137761095
Standard Deviation:	0.043739739

Fig. 5 Distribution curve of vegetation pixels (NDVI) within Awedele watershed

Appendix 3

See Fig. 6.

Fig. 6 Distribution curve of vegetation pixels (NDVI) within Ureje watershed

Appendix 4

See Fig. 7.

Fig. 7 Stream order analysis of Awedele and Ureje rivers

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