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Faecal indicator bacteria and toxic metal concentrations in domestic and irrigation water from main gardening sites in Kinshasa, Democratic Republic of the Congo

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ABSTRACT

In Sub-Saharan African countries, urban market gardening plays a significant socio-economic role in enhancing food security, combating hunger, supporting daily livelihoods, and reducing unemployment. Fresh vegetable gardening is widely practiced in urban and peri-urban communities, employing thousands of people and providing over 70 % of the fresh vegetables consumed in cities. Many urban and peri-urban families live near or on these production sites and use water from springs, shallow wells, and untreated contaminated river water for irrigation and domestic use. Consequently, monitoring and assessing the water quality is key to preventing potential health risks, not only for users, but also for irrigated vegetables; when consumed raw, they are at risk of becoming contaminated with pathogens. In this study, water samples were collected from two major market gardening sites in Kinshasa-Lutendele and Cecomaf-and analyzed for microbiological and physicochemical parameters. The microbiological assessment focused on faecal indicator bacteria (FIB), including *Escherichia coli* (*E. coli*), *Enterococcus* (ENT) and total coliforms (TC). The physicochemical analysis includes parameters such as pH, electrical conductivity (EC), dissolved oxygen (O_2), dissolved organic carbon (DOC), total organic carbon (TOC), major soluble ions (Na^+, K^+, NH_4^+, PO_4^{3-}, SO_4^{2-}, NO_3^-, and NO_2^-), and metals and metalloids (Cu, Zn, Cr, Ni, Co, Ag, Cd, Sb, Pb, As, Se, Fe, Mn, V and Ti) . Microbiological analysis of water samples from all sites showed elevated levels of FIB, reaching concentrations of 5.5×10^3, 1.9×10^4 and 2.2×10^4 CFU 100 mL^{-1} for *E. coli*, ENT and TC, respectively. Concentrations of soluble ions such as PO_4^{3-}, NO_3^-, NH_4^+, and K^+ were 2 to 10 times above the acceptable limits according to the World Health Organization (WHO) and the Food and Agriculture Organization (FAO) guidelines for irrigation and domestic use. Despite this, almost all metal concentrations remained below FAO and WHO guidelines. However, given the above acceptable limits of FIB and soluble ions detected in irrigation water, the use of such water may pose potential health risks through direct consumption, contamination of raw vegetables, or dermal contact during irrigation.

1. Introduction

The 2030 Agenda for Sustainable Development, adopted by all United Nations member states in 2015 following the Rio+20 Conference, includes a dedicated goal for water and sanitation-Sustainable Development Goal 6 (SDG-6). The first target (6.1) emphasizes equitable and universal access to safe and clean drinking water for all (UN-Water, 2020). Furthermore, the Target 6.2 highlights the urgent need to expand the access to adequate and the equitable sanitation and the hygiene, and to eliminate open defecation. These goals are essential not only to protecting the quality of natural water sources, but also for addressing frequent contamination by pathogens. To ensure public

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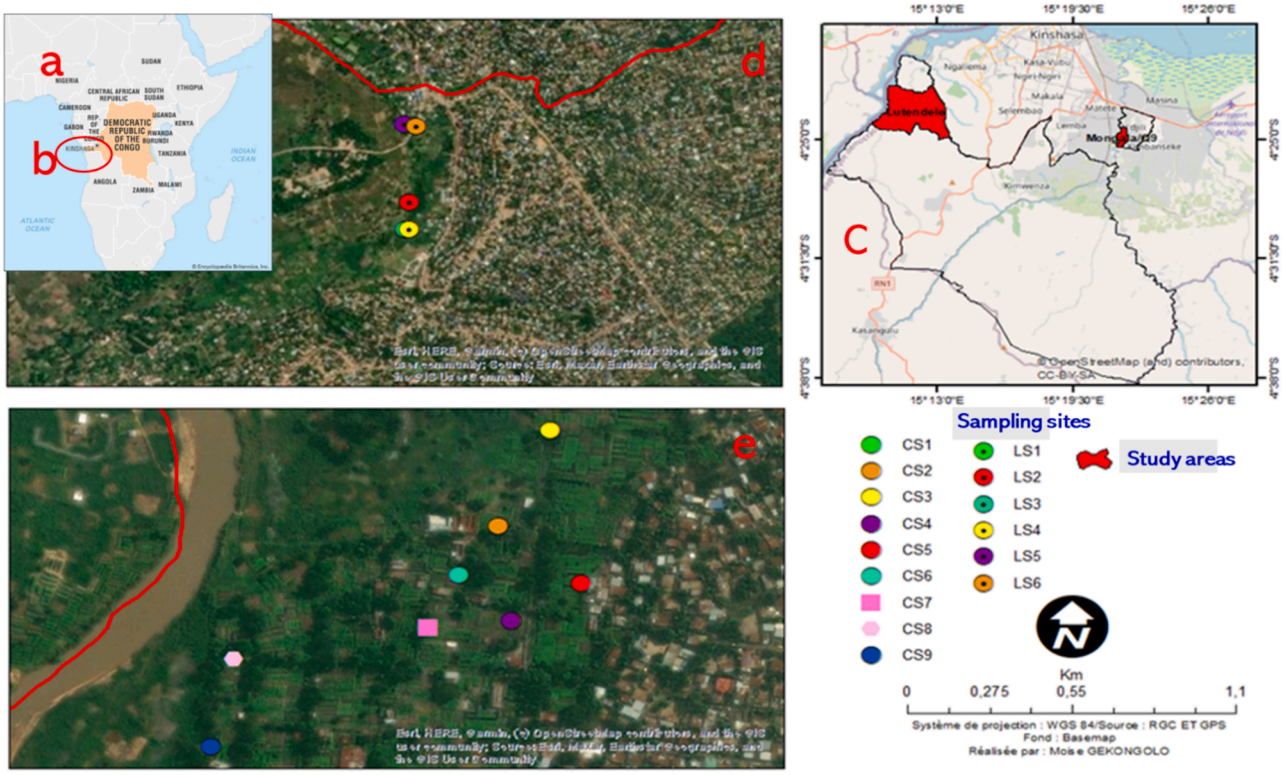

Fig. 1. Sampling site adapted from Google Earth indicating; (a) Africa continental map, (b) Map showing the location of Kinshasa City in Democratic Republic of the Congo, (c) sampling sites in Lutendele station, and (d) sampling sites in Cecomaf station.

health, SDG 6.3 aims to halve the proportion of untreated wastewater from households and economic activities. Additionally, it aims to increase the amount of water that is recycled and reused properly worldwide.

Nevertheless, the quality of water used for irrigation in developing countries like the Democratic Republic of Congo (DRC) is of particular concern. As a result of intensive human activity in urban areas, both surface and groundwater is adversely affected. (Ngandote et al., 2025; Kapembo et al., 2019, 2022; Laffite et al. 2020; Kayembe et al. 2018a, 2018b). Consequently, irrigation with such contaminated water can introduce a wide range of harmful pollutants -such as toxic metals, chemical pollutants, pharmaceutical residues, and pathogenic microorganisms- into fresh produce, posing health risks to consumers and affecting food security (Tshibanda et al., 2024; Ngweme et al., 2020; Mavakala et al., 2022; Zhang et al., 2019; Bhatia and Singh et al., 2015; Meng et al. 2016; Chen et al. 2010). Poor water quality can also adversely affect agricultural productivity, soil health and long-term ecosystem damage. Therefore, fresh produce can also serve as vehicles and reservoirs for food-borne pathogens when irrigated with contaminated water (Wang et al., 2024; Gemmell and Schmidt, 2012). Coliforms, *E.coli*, and enterococci have traditionally been employed as indicators to assess the microbiological quality of water (Ferguson et al., 2012). In Kinshasa, the capital and largest city of the DRC with an estimated population of 17 million, urban agriculture plays a central role in social and economic life. It contributes around 70 % of the city's fresh vegetable supply and supports the livelihoods of thousands of families, employing approximately 100,000 people (Ngweme et al., 2020, 2021; Musibono et al. 2011). Many of these families live within or near farming sites and use water from springs, ponds, shallow wells, canals, and rivers for both domestic purposes and irrigation (Ngweme et al., 2020, 2021; Kapembo et al., 2019, 2022; Kayembe et al. 2018a, 2018b; Kilunga et al. 2017; Tshibanda et al. 2024; Mwanamoki et al., 2014). However, fresh produce is at considerable risk of contamination as irrigation urban river water becomes increasingly polluted by intensive anthropogenic activities. Consequently, the assessment of fecal contamination in irrigation water is essential for implementing effective management practices for preventing public health risks. A number of factors can contribute to the contamination of water, including open defecation, surface run-off from urban areas, direct discharge from latrines, discharge from boats, agricultural runoff, and improperly maintained septic systems (Verlicchi and Grillini, 2020;Devane et al., 2020). A report by the World Health Organization (WHO) estimates that approximately 2 billion people rely on contaminated water for drinking and irrigation (WHO, 2023). Additionally, previous research has underscored the importance of microbiological assessment of irrigation water for the safe production of leafy vegetables (Decol et al., 2019). Moreover, tropical temperatures are recognized as favorable for the survival and proliferation of fecal indicator bacteria (FIB) in the environment (Byappanahalli and Fujioka, 1998). Considering all the above factors, regular assessment and monitoring of water quality is crucial to determine whether contaminants-particularly pathogens and toxic metals-are being transferred from irrigation water to fresh produce and to mitigate associated health risks.

Despite the potential public health implications, limited data exist on the occurrence of pathogens and toxic metals in water used for irrigation and domestic purposes at major gardening sites in Kinshasa. Based on the recommendations from previous studies (Ngweme et al., 2020; 2021; Tshibanda et al., 2024), the main aim of this research is to evaluate the quality of water from various sources used by the local population for domestic use and irrigation in two major urban gardening areas in Kinshasa. The assessment was established by the quantification of (i) the water physicochemical parameters (T, pH, Electrical Conductivity (EC) and the soluble ions (Na^+, K^+, NH_4^+, PO_4^{3-}, SO_4^{2-}, NO_3^-, NO_2^-), (ii) the metals and metalloids (Cu, Zn, Cr, Ni, Co, Ag, Cd, Sb, Pb, As, Se, Fe, Mn, V and Ti), and the FIB (*Escherichia coli*, Enterococcus (ENT), and total coliform (TC).

Table 1
Sampling GPS coordinates and description related to activities performed around the sites.

Sampling site	Latitude	Longitude	Sample sources	Colour	T (°C)	pH	EC (µS cm^{-1})	O_2 (mg l^{-1})
LS1	04°22′42.7″	015°11′59.3″	Spring	Soft	26.5	3.8	270.0	3,5
LS2	04°22′39.4″	015°11′59.6″	Well	Soft	26.7	4,1	691.0	3,5
LS3	04°22′42.7″	015°11′59.3″	Well drilling	Clear	27.5	6.5	658.0	2,8
LS4	04°22′42.7″	015°11′59.7	Well	Soft	26.8	5.7	250.0	1,7
LS5	04°22′29.7″	015°11′59.1″	River	yellowish	25.9	6.8	312.0	2,1
LS6	04°22′30.00″	015°12′00.4″	River	yellowish	26.0	6.9	308.0	0,9
CS1	04°25′10.4″	015°21′48.6″	Spring	Soft	28.9	6.3	536.0	2.6
CS2	04°25′07.9″	015°21′48.3″	Spring	Soft	29.1	7.0	58.3	4.5
CS3	04°25′05.4″	015°21′49.5″	Spring	Soft	29.7	6.6	780.0	6.4
CS4	04°25′10.4″	015°21′48.6″	Well drilling	Clear	27.7	7.3	55.0	8.5
CS5	04°25′09.4″	015°21′50.2″	Spring	Soft	28.3	6.3	526.0	2.2
CS6	04°25′09.2″	015°21′47.4″	Spring	Soft	27.2	6.9	500.0	1.7
CS7	04°25′10.6″	015°21′46.7″	Spring	Soft	27.0	6.9	513.0	3.4
CS8	04°25′11.4″	015°21′42.2″	Well	Soft	27.6	6.9	372.0	2.9
CS9	04°25′13.7″	015°21′41.7″	River	yellowish	27.1	6.9	173.2	1.8
WHO[a]					12–25	6.5–9.5	200–800	4–6
FAO					20–33	6.5–8.4	0–3000	–

LS1-LS6: Water samples from the Lutendele station; CS1-CS9: Water samples from the Cecomaf station.
WHO[a] regulation for drinking water.
WHO[b]: regulation for irrigation water.
FAO: regulation for irrigation water.

Fig. 2. Photos of the largest site of Lutendele taken by Anaïs Kipelo in August 2024, indicating; 2A: Field sampling and treatment of water samples; 2B: Field of a most cultivated raw vegetable (*Amaranthus viridis*) when the vegetable reached the stage of harvest, 2C: Urban plant watering/irrigation mode, and 2D: Different raw vegetables reached the stage of harvest during sampling.

2. Materials and methods

2.1. Study site description

This study was performed at two major urban agriculture sites in Kinshasa, the capital city of DRC: the Cecomaf station in the commune of Ndjili and the Lutendele station in the commune of Mont-Ngafula (Fig. 1). These sites are among the most active centers of intensive urban agriculture in Kinshasa. Their selection was based on prior studies (Ngweme et al., 2020, 2021), which highlighted gaps in data regarding physicochemical and bacteriological pollution of domestic and irrigation water, land occupation, crop variety, and water usage practices. Sampling points were designated as Lutendele station (n = 6, LS1-LS6) and Cecomaf station (n = 9, CS1-CS9). Sample identifiers and GPS coordinates are presented in Table 1.

2.2. Water sampling procedure

We collected water samples during the dry season (June-August 2024), when urban agricultural activity is at its peak, water use is widespread, and crop productivity is high (Fig. 2). Water samples were collected aseptically at each site in triplicate using 2 L autoclaved plastic bottles. A handcrafted device consisting of a 1 L clean polyethylene bottle attached to a rope (one-time use) was used to draw water from the well, which was then transferred to 2 L autoclaved containers. The autoclaved bottles were submerged directly into the spring water to

collect the water. Samples were collected in accordance with appropriate procedures to avoid microbiological and physicochemical contamination. We stored all the water samples in ice coolers (4 °C) immediately and transported them to the University of Kinshasa laboratory for microbiological analysis and to the University of Geneva's analytical platform for physicochemical and metal analysis.

2.3. Water physicochemical analysis

Water samples pH, temperature (T), and electrical conductivity (EC) were measured using a multiparameter probe (Multi 350i, WTW, Germany). Concentrations of the major dissolved ions (Na^+, K^+, $NH4^+$, PO_4^{3-}, SO_4^{2-}, NO_3, NO_2) were determined using Ion Chromatography (Dionex ICS-3000, Canada), by the following methods described by Graham et al. (2014) and Mavakala et al. (2016). Results were reported in ppb (μg l^{-1}). To ensure analytical accuracy, Ontario-99 Certified Reference Material (National Water Research Institute, Canada) was used, with all results falling within acceptable certification ranges.

2.4. Metals analysis in water samples

For metal analysis each water sample was filtered through 0.45 μm membranes (Millipore Darmstadt, Germany) and acidified with HNO_3 1 % v/v (Suprapur®, Merck KGaA, Darmstadt Germany). Trace metals and metalloids (Cu, Zn, Cr, Ni, Co, Ag, Cd, Sb, Pb, As, Se, Fe, Mn, V and Ti) were quantified using Inductively Coupled Plasma-Mass Spectroscopy (ICP-MS, Agilent 7700x, Santa Clara, USA). Helium collision modes and interference correction equations were applied to mitigate spectral interference. Calibration was performed using Merck IV (Merck, KGaA, Darmstadt Germany) multi-element standards at different concentrations (0, 0.2, 1, 5, 20, 100 and 200 μg l^{-1}). The accuracy and sensitivity of the instrument were verified using TMDA 61.3 Certified Reference Material (CRM Sales, Burlington, Canada), with results within accepted CRM limits. The concentration of metals in water samples was expressed in ppb (μg l^{-1}). Replicate measurement deviations were under 2.5 %, and procedural blanks were below 1 % of the sample signal intensity.

2.5. Microbiological analysis of water samples

Faecal indicator bacteria (FIB), including *E. coli*, ENT, and total coliforms (TC), were quantified using the membrane filtration method in accordance with APHA (2005). Triplicate 100 mL water filtered through a 0.45 μm membranes (Prat Dumas, France) and cultured on selective media (Biolife, Italiana, Italy): (i) *E. coli*: Incubated on Tryptone Soy Agar at 37 °C for 4 h, following by Tryptone Bile X-Gluc Agar at 44 °C for 24 h; (ii) ENT: Incubated on Slanetz Bartley Agar at 44 °C for 48 h, then transferred to Bile Aesculin Agar at 44 °C for 4 h; and (iii) TC: Incubated on Endo agar at 35 °C for 24 h. Results were reported as the colony-forming units per 100 mL of water samples (CFU 100 mL^{-1}). Triplicate procedure ensured reproducibility, and field and laboratory controls were employed to detect potential contamination, as outlined in Kapembo et al. (2019, 2022).

2.6. Statistical analysis

All analyses were conducted in triplicate. Spearman rank correlation was used to assess relationships among variables using SigmaStat 11.0 (Systat Software, USA).

3. Results and discussion

3.1. Water physicochemical characteristics

The results of irrigation water's physicochemical parameters, including temperature (T), pH, electrical conductivity (EC), and dissolved oxygen (O_2), are shown in Table 1. Physicochemical properties

Table 2
Average concentration (mg l^{-1} ± SD (standard deviation)) of soluble ions in water samples and their respective permissible limits set by WHO/FAO.

Sampling site	Na^+	K^+	NH_4^+	PO_4^{3-}	SO_4^{2-}	NO_3^-	NO_2^-
LS1	112.9 ± 12.8	83.5 ± 9.3	6.2 ± 2.4	72.2 ± 8.5	35.8 ± 4.3	435.4 ± 17.3	1.5 ± 0.8
LS2	92.4 ± 2.3	72.3 ± 5.9	12.3 ± 3.5	44.6 ± 9.3	51.6 ± 5.6	538.4 ± 20.4	0.9 ± 0.3
LS3	82.5 ± 11.4	78.4 ± 6.8	8.2 ± 1.9	87.4 ± 8.2	34.7 ± 3.2	581.3 ± 16.6	2.3 ± 0.6
LS4	104.3 ± 13.8	91.5 ± 11.2	7.7 ± 2.1	91.3 ± 7.4	72.4 ± 8.3	645.9 ± 23.7	0.3 ± 0.0
LS5	63.5 ± 6.5	57.6 ± 8.4	13.3 ± 3.8	78.1 ± 6.8	44.5 ± 9.2	389.3 ± 13.8	0.6 ± 0.1
LS6	96.2 ± 7.8	86.3 ± 11.4	9.4 ± 2.2	87.4 ± 7.1	48.3 ± 6.2	381.1 ± 11.4	2.6 ± 0.7
CS1	99.4 ± 7.2	36.2 ± 6.3	402.5 ± 23.6	0.4 ± 0.1	36.2 ± 4.1	402.5 ± 16.7	0.4 ± 0.0
CS2	67.6 ± 9.3	41.1 ± 3.7	435.6 ± 29.4	0.5 ± 0.1	41.2 ± 2.5	435.6 ± 12.6	0.5 ± 0.1
CS3	91.7 ± 5.3	37.7 ± 6.9	636.0 ± 72.4	1.6 ± 0.3	37.7 ± 3.4	636.0 ± 18.4	1.6 ± 0.7
CS4	62.7 ± 8.6	24.3 ± 2.7	674.6 ± 65.7	1.3 ± 0.3	24.3 ± 2.6	674.6 ± 16.3	1.3 ± 0.4
CS5	74.8 ± 8.1	25.9 ± 6.2	473.3 ± 70.2	1.8 ± 0.5	25.9 ± 3.2	473.3 ± 13.5	1.8 ± 0.6
CS6	89.3 ± 8.2	61.2 ± 7.4	539.8 ± 57.3	0.2 ± 0.0	61.2 ± 5.3	539.8 ± 15.9	0.2 ± 0.0
CS7	53.3 ± 3.9	28.6 ± 4.7	362.3 ± 44.7	0.6 ± 0.1	28.6 ± 3.7	362.3 ± 10.7	0.6 ± 0.1
CS8	74.7 ± 5.7	36.2 ± 3.4	518.4 ± 62.6	0.1 ± 0.0	36.2 ± 4.3	518.4 ± 18.5	0.1 ± 0.0
CS9	87.4 ± 4.6	22.9 ± 5.1	287.3 ± 34.2	1.5 ± 0.3	22.9 ± 2.8	287.3 ± 9.6	1.5 ± 0.3
WHO[a]	200.0	0.5–5.0	0.5	0.5	250.0	50.0	0.5

LS1-LS6: Water samples from the Lutendele station; CS1-CS9: Water samples from the Cecomaf station.
WHO[a] regulation for drinking water.

are key indicators of assessing water quality for irrigation and domestic use. There are no national water quality regulations in the DRC. Therefore, the results were compared with the international standards recommended by WHO and the FAO. Except for the pH values observed in the spring (site LS1, with a value of 3.8) and the well (site LS2, with a value of 4.1), all measured parameters (T, pH, EC and O_2) fall within the limits set by WHO/FAO for water intended for domestic and agricultural purposes. These results are consistent with those reported previously by Ngweme et al. (2020) at the Cecomaf market gardening site (Ngweme et al., 2020). Regarding the color of the water samples, it was observed that, apart from the well drilled water samples from the Lutendele and Cecomaf sites (LS3 and CS4), which exhibited clear coloration, river water appeared yellowish, while water from springs and traditional wells was soft. The clarity of drilled well water can be attributed to the natural filtration process through multiple layers of sand, gravel, and rock, which effectively removes solid particles, resulting in clear water. Conversely, the yellowish coloration of river water is due to the large amount of suspended particles it carries, as well as its direct exposure to

Table 3
Average concentration (µg l^{-1}) of metal and metalloids in water samples and their respective permissible limits set by WHO/FAO.

Sampling site		Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Ag	Cd	Sb	Pb
LS1		19.8	1.1	0.9	4.2	1384.7	0.2	0.3	2	2	0.7	0	0.2	<LD	0.8	0.1
LS2		13.9	0.4	0.4	74.2	226.6	0.8	0.7	0.1	9.6	0.1	0.2	0.2	<LD	0.2	0.1
LS3		1.7	0.1	0.2	63.4	29.5	0.9	0.2	<LD	1.9	<LD	0.2	0.1	<LD	<LD	0.1
LS4		2.3	0.1	0.2	18.1	384.6	0.1	<LD	0.4	0.6	0.4	0	<LD	<LD	0.1	<LD
LS5		2.7	0.2	0.3	137.3	764.3	0.2	<LD	0.5	0.3	0.7	0.6	<LD	<LD	0.1	<LD
LS6		2.5	0.2	0.2	207.5	674.6	0.2	<LD	<0	0.2	0.7	0.7	<LD	<LD	0.1	<LD
CS1		7.1	1.4	0.4	126.6	338.6	0.1	0.1	3.7	31.4	0.3	<LD	<LD	0.1	1.3	12.9
CS2		10.7	0.8	0.7	159.2	213.8	0.7	2.0	41.9	45.4	0.3	<LD	<LD	2.5	1.3	14.6
CS3		1.2	0.5	0.3	5.3	115.7	0.1	0.2	1.8	43.3	0.1	<LD	<LD	0.1	1.0	0.1
CS4		0.4	0.2	0.2	4.3	17.2	0.1	<LD	2.4	7.6	0.1	<LD	<LD	0.0	<LD	<LD
CS5		5.2	0.9	0.6	135.2	293.3	0.5	1.4	28.5	34.8	0.2	<LD	<LD	2.1	1.1	0.8
CS6		1.0	1.1	0.3	10.9	77.7	0.1	0.0	1.4	7.5	0.1	0.2	<LD	<LD	0.7	<LD
CS7		1.8	1.3	0.3	3.1	86.4	0.1	0.1	3.3	2.9	0.3	0.2	<LD	<LD	2.2	0.1
CS8		0.7	0.8	0.2	1.8	59.1	0.1	0.0	1.1	7.5	0.1	1.0	<LD	<LD	0.9	<LD
CS9		1.1	0.5	0.4	179.5	62.5	0.2	0.6	1.4	106.0	0.1	0.2	<LD	0.2	0.3	<LD
TMDA 61.3	Ref. Value	–	70.5	67.7	76.4	79.7	63.7	56.9	62.1	72.8	35.2	40.2		59.3		56.1
	Det. Value	36.3	70.4	63.2	75.8	81.1	62.9	56.9	62.9	73	34.7	33.3	15.4	59.4	33.2	48.2
FAO (1985)		-	100	100	200	5000	50	200	200	2000	100	20	–	10	–	5000

LS1-LS6: Water samples from the Lutendele station; CS1-CS9: Water samples from the Cecomaf station.
Total variation coefficients for triplicate measurements are smaller than 5 % for ICP-MS analysis. The recovery values from measurements for reference material (TMDA 61.3) were above 82 % for all elements the ICP-MS triplicate. LD: Limit of detection.

weather conditions, soil erosion, and surface runoff. Meanwhile, the water from springs and traditional wells is soft because it originates from shallow aquifers or emerges naturally, thus potentially containing fine suspended particles.

The concentrations of soluble ions including Na^+, K^+, NH_4^+, PO_4^{3-}, SO_4^{2-}, NO_3^- and NO_2^- in the water samples are presented in Table 2. At both the Lutendele and Cecomaf stations, the concentrations of Na^+ and SO_4^{2-} were within the permissible limits set by WHO for drinking water (200 mg l^{-1} for Na+ and 250 mg l^{-1} for SO_4^{2-}). The maximum average values of Na^+ were 112.9 and 99.4 mg l^{-1}, at the Lutendele and Cecomaf stations, respectively. For SO_4^{2-}, the maximum values were 72.4 and 61.2 mg l^{-1}, at the Lutendele and Cecomaf stations, respectively.

Regarding the concentrations of K^+, NH_4^+, PO_4^{3-}, NO_3^-, and NO_2^-, except for samples CS1, CS6, and CS8 which showed concentrations exceeding the 0.5 mg l^{-1} limit set by the WHO, all other samples exhibited concentrations higher than the WHO's recommended limits. The concentrations of K^+, NH_4^+, PO_4^{3-}, NO_3^-, and NO_2^- at Lutendele and Cecomaf varied as follows: 51.6–91.5 mg l^{-1} and 61.2–22.9 mg l^{-1} for K^+; 6.2–13.3 mg l^{-1} and 287.3–674.6 mg l^{-1} for NH_4^+; 44.6–91.3 mg l^{-1} and 0.1–1.8 mg l^{-1} for PO_4^{3-}; 381.1–645.9 mg l^{-1} and 287.3–674.6 mg l^{-1} for NO_3^-; 0.3–2.6 mg l^{-1} and 0.1–1.8 mg l^{-1} for NO_2^-. The elevated concentrations of K^+, NH_4^+, PO_4^{3-}, NO_3^-, and NO_2^- can primarily be attributed to the use of nitrogen-potassium-phosphorus (NPK) agricultural fertilizers to optimize agricultural activities at both Lutendele et Cecomaf sites.

3.2. Metal concentration in water samples

Table 3 shows the concentrations of metals and metalloids (Cu, Zn, Cr, Ni, Co, Ag, Cd, Sb, Pb, As, Se, Fe, Mn, V and Ti) in water samples. The values obtained at both Lutendele and Cecomaf are generally lower than the permissible limits set by the FAO (FAO, 1985) for nearly all the analyzed elements, except silver (Ag). The highest concentrations recorded (µg l-1), respectively for Lutendele and Cecomaf, are as follows: 1.1 and 1.4 for Ti, 0.9 and 0.7 for Cr, 207.5 and 179.5 for Mn, 1384.7 and 338.6 for Fe, 0.9 and 0.7 for Co, 0.7 and 2 for Ni, 2 and 41.9 for Cu, 9.6 and 106 for Zn, 0.7 and 0.3 for As, 0.7 and 1 for Se, 0.2 (at Lutendele) for Ag, 2.5 (at Cecomaf) for Cd, 0.8 and 2.2 for Sb, and 0.1 and 14.6 for Pb. These concentrations are also higher than those reported by Ngweme et al. (2020) for irrigation water at the Cecomaf site (Ngweme et al., 2020). The elevated levels of trace elements in the water samples at both market gardening sites likely result from intensive agricultural practices, including the use of chemical fertilizers and pesticides, as well as organic amendments such as manure, compost, and sewage sludge. Previous studies have reported high concentrations of these elements in soils and sediments of the N'djili River near the Cecomaf site (Lundemi et al., 2022), along with high levels of persistent organic pollutants, including pesticides (Tshibanda et al., 2024).

Table 4
Average values of *Escherichia coli (E. coli),* Enterococcus (ENT) and Total coliforms (TC) in water samples from Luntendele and Cecomaf stations.

Sampling site	*E. coli* (CFU± SD)x10^2 100 mL^{-1})	ENT (CFU± SD)x10^2 100 mL^{-1})	TC (CFU± SD)x10^3 100 mL^{-1})
CS1	41.0 ± 1.2	7.5 ± 0.2	18.5 ± 0.7
CS2	8.7 ± 0.3	2.5 ± 0.2	14.3 ± 0.4
CS3	12.5 ± 0.6	31.5 ± 1.3	18.7 ± 0.9
CS4	5.0 ± 0.3	2.0 ± 0.1	15.6 ± 0.8
CS5	11.0 ± 0.3	1.0 ± 0.1	17.5 ± 1.1
CS6	17.5 ± 1.2	1.4 ± 0.1	6.5 ± 0.1
CS7	11.0 ± 0.5	7.0 ± 0.2	17.6 ± 0.9
CS8	20.0 ± 0.7	46.0 ± 1.3	10.4 ± 0.8
CS9	12.5 ± 0.4	1.2 ± 0.2	21.7 ± 0.8
LS1	12.0 ± 0.3	127.5 ± 2.4	18.5 ± 0.6
LS2	31.5 ± 1,7	22.5 ± 0.6	7.6 ± 0.1
LS3	55.0 ± 1.9	3.5 ± 0.1	20.0 ± 0.7
LS4	8.5 ± 0.2	N/A	11.0 ± 0.6
LS5	13. ± 0.22	9.0 ± 0.2	19.4 ± 0.8
LS6	28.0 ± 0.9	47.5 ± 1.5	20.0 ± 0.7

LS1-LS6: Water samples from the Lutendele station; CS1-CS9: Water samples from the Cecomaf station.
N/A: analysis no performed.

3.3. Microbiological indicator quality of water

In this study, we examined the levels of FIB contamination in irrigation water at two gardening sites in the Democratic Republic of Congo. The microbiological analysis revealed that all water samples collected from both studied stations (Lutendele and Cecomaf) were possibly contaminated with faeces. FIB concentrations in water samples are shown in Table 4. Ferguson et al. (2012) reported that FIB such as *E. coli* can be used to assess irrigation water for microbial contamination (Ferguson et al., 2012). According to another previous study, *E. coli* can be used to determine the quality of water (Holcomb and Stewart, 2020). It has been reported that contaminated environmental resources could play a key role in the dissemination of multiple antibiotic resistant bacteria (Larsson et al., 2018). All sampling sites exhibited high levels of

Table 5
Spearman's Rank Order Correlation of some selected parameters[a] analysed in water samples from Lutendele and Cecomaf stations.

Lutendele	*E. coli*	ENT	Na^+	K^+	NO_2	NO_3^-	O_2	pH	PO_4^{3-}	SO_4^{2-}	NH_4^+	TC
EC	**0.56**	0.44	**0.75**	0.17	**0.57**	**0.63**	0.46	0.25	0.34	0.34	**0.64**	**0.54**
E. coli		**0.94**	**0.74**	**0.50**	0.35	0.04	**0.78**	**0.85**	**0.78**	**0.82**	0.07	**0.57**
ENT			**0.82**	**0.63**	−0.25	**0.63**	**0.89**	**0.88**	−**0.65**	**0.73**	−0.33	**0.59**
Na^+				**0.85**	**0.51**	0.42	−**0.65**	0.27	**0.63**	**0.57**	0.44	0.43
K^+					**0.53**	**0.57**	**0.65**	**0.78**	**0.90**	0.49	0.07	**0.64**
NO_2^-						0.04	**0.53**	0.24	0.32	**0.56**	−0.37	**0.83**
NO_3^-							**0.78**	0.32	**0.74**	0.29	0.49	0.34
O_2								0.49	**0.62**	**0.78**	0.37	**0.76**
pH									**0.68**	**0.68**	−**0.74**	0.46
PO_4^{3-}										0.35	−0.09	0.40
SO_4^{2-}											0.08	0.54
NH_4^+												**0.74**
Cecomaf	***E. coli***	**ENT**	Na^+	K^+	NO_2^-	NO_3^-	O_2	**pH**	PO_4^{3-}	SO_4^{2-}	NH_4^+	**TC**
EC	**0.74**	0.37	**0.68**	0.24	**0.73**	0.36	**0.57**	−0.42	**0.57**	**0.79**	**0.52**	**0.67**
E. coli		**0.53**	−0.45	**0.76**	**0.54**	**0.71**	−0.38	**0.69**	0.48	**0.83**	−0.42	**0.86**
ENT			**0.61**	−0.39	**0.79**	−0.19	**0.64**	−0.31	**0.63**	−0.27	0.48	**0.75**
Na^+				0.73	−0.22	−0.37	**0.55**	**0.67**	0.34	**0.85**	−0.32	0.38
K^+					**0.84**	**0.68**	**0.76**	**0.64**	−0.26	−0.56	**0.67**	−0.27
NO_2^-						−0.26	0.67	0.23	**0.58**	**0.76**	**0.74**	**0.73**
NO_3^-							0.39	**0.73**	**0.74**	**0.72**	**0.62**	0.46
O_2								**0.83**	**0.63**	−0.35	0.44	−0.32
pH									**0.73**	0.23	**0.56**	**0.63**
PO_4^{3-}										**0.65**	−0.41	0.44
SO_4^{2-}											**0.78**	**0.77**
NH_4^+												**0.56**

Significant coefficients ($p < 0.05$) are in bold.

FIB including *E. coli*, ENT and FC. The levels of FIB varied significantly across sampling locations (P < 0.05), indicating spatial differences in contamination levels. All the sampling sites presented a high level of *E. coli*, ENT and TC that exceeded the allowable limits set by WHO guidelines for drinking or domestic use (Widmer et al., 2025; Nienie et al., 2017). A similar result was reported by Akrong et al. (2012) who found that irrigation water used in fresh produce contained fecal coliforms that exceeded WHO guidelines (Akrong et al., 2012). It is important to note that although FIB quantification offers valuable risk assessment in irrigation water, it is not always related to the presence of specific pathogens. The elevated microbial concentrations observed at all sites likely originate from the use of untreated manure and organic amendments, urban runoff, agricultural runoff, household wastewater discharge, and—most notably—the overflow of latrine effluent during the rainy season upstream of the sampling sites (Althaus et al., 2012). Poor or absence of proper waste management infrastructure and

Table 6
Spearman's Rank Order Correlation of analysed metals and metalloids in water samples from Lutendele and Cecomaf stations.

Lutendele	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Ag	Cd	Sb	Pb
Ti	**1.00**	**0.83**	−0.14	**0.66**	0.03	**0.58**	**0.67**	0.43	0.43	−0.03	**0.52**	0.20	**0.83**	**0.52**
V		**0.83**	−0.14	**0.66**	0.03	**0.58**	**0.67**	0.43	0.43	−0.03	**0.52**	0.20	**0.83**	**0.52**
Cr			−0.26	0.37	0.49	**0.87**	**0.52**	**0.66**	0.03	−0.12	**0.76**	**0.52**	**0.60**	**0.76**
Mn				−0.09	−0.09	−0.32	−**0.52**	−**0.60**	0.26	**0.99**	−0.39	−0.12	−**0.54**	−0.39
Fe					−0.49	−0.12	**0.75**	−0.26	**0.83**	0.00	−0.21	−0.49	0.49	−0.21
Co						**0.72**	−0.41	**0.60**	−0.49	0.00	**0.76**	**0.93**	−0.14	**0.76**
Ni							0.22	**0.90**	−0.41	−0.22	**0.95**	**0.81**	0.49	**0.95**
Cu								0.23	0.29	−0.47	0.09	−0.35	**0.75**	0.09
Zn									−**0.54**	−**0.55**	**0.94**	**0.75**	**0.60**	**0.94**
As										0.32	−0.39	−0.46	0.20	−0.39
Se											−0.31	−0.04	−0.49	−0.31
Ag												**0.89**	**0.52**	**1.00**
Cd													0.12	**0.89**
Sb														**0.52**
Cecomaf	**V**	**Cr**	**Mn**	**Fe**	**Co**	**Ni**	**Cu**	**Zn**	**As**	**Se**	**Ag**	**Cd**	**Sb**	**Pb**
Ti	**0.57**	**0.87**	**0.53**	**0.92**	**0.87**	**0.78**	**0.80**	0.38	**0.77**	−**0.53**	0.06	**0.58**	**0.83**	**0.96**
V		0.35	0.07	**0.62**	0.35	0.03	0.38	−0.37	**0.77**	0.09	−0.37	−0.12	**0.67**	**0.51**
Cr			**0.80**	**0.72**	**1.00**	**0.93**	**0.63**	**0.63**	0.48	−0.37	0.13	**0.78**	**0.57**	**0.74**
Mn				0.45	**0.80**	**0.78**	0.37	**0.85**	−0.07	−0.31	0.19	**0.88**	0.02	0.37
Fe					**0.72**	**0.64**	**0.73**	0.30	**0.70**	−**0.57**	−0.05	**0.53**	**0.73**	**0.89**
Co						**0.93**	**0.63**	**0.63**	0.48	−0.37	0.13	**0.78**	**0.57**	**0.74**
Ni							**0.59**	**0.80**	0.31	−**0.52**	0.24	**0.88**	0.44	**0.68**
Cu								0.22	**0.58**	−**0.79**	**0.56**	0.47	**0.67**	**0.90**
Zn									−0.25	−0.44	0.23	**0.90**	−0.12	0.26
As										−0.18	−0.19	−0.03	**0.97**	**0.79**
Se											−**0.59**	−0.49	−0.29	−**0.66**
Ag												0.35	−0.10	0.23
Cd													0.10	0.49
Sb														**0.85**

Significant coefficients ($p < 0.05$) are in bold.

sanitation facilities, such as household waste collection systems, sewage networks, and sewage overflows at study sites significantly contributes to the widespread microbial contamination of water sources in the market gardening areas of Lutendele and Cecomaf. Further, the study indicates that contaminated irrigation water may also be a source of microbiological contamination on fresh produce, potentially causing health risks for consumers (Jongman and Korsten, 2017)

3.4. Statistical correlation between parameters

The Spearman correlation coefficients between the physicochemical parameters, major dissolved ions, and bacteriological indicators assessed at the Lutendele and Cecomaf sites are presented in Table 5. Notably, positive correlations ($P < 0.05$) observed between the physicochemical parameters (EC, O_2, and pH), the bacteriological parameters (*E. coli*, ENT and TC), and the major dissolved ions (Na^+, K^+, NO_2-, NO_3^-, PO_4^{3-}, SO_4^{2-} and NH_4^+) suggesting that the physicochemical parameters positively influence the transport of both bacteria and dissolved ions. Furthermore, a positive correlation observed between microbiological parameters and NO_3^- and NH_4^+ indicates that feces are the likely source of nutrients. Additionally, chemical fertilizer may also contribute to the NO_3^-, and NH_4^+ in the study sites. A negative correlation between Na^+ and O_2 (R^2 = -0.65) indicates that oxygen may influence sodium transport. Significant correlations exist between major dissolved ions and bacteriological parameters, suggesting that bacteria and soluble ions may share a common source. *E.coli*/TC for Lutendele site (R^2 = 0.94) and *E. coli*/TC for Cecomaf site ($R^2 = 0.53$) demonstrate a positive correlation, which indicates a strong (Lutendele) and a moderate relationship between these two bacterial populations in water samples. There is a possibility that bacterial contamination of water may occur as a result of open defecation at these sites and surface runoff. It was found that *E. coli*/ENT ($r = 0.57$), ENT/TC ($R^2 = 0.59$) at Lutendele site and *E. coli*/ENT (R^2 = 0.86), ENT/TC (R^2 = 0.75) at Cecomaf site were positively correlated, which suggests that the bacteria originate from a common source (human or animal faecal matter, either a natural source) and are transported in the same manner (Ngandote et al., 2025; Mudinga et al., 2024). However, to identify the source of FIB contamination (*E. coli* and ENT) host specific marker genes should be examined by PCR using specific primers (Thevenon et al., 2012; Tshibanda et al., 2014). Table 6 presents the Spearman correlation coefficients between the heavy metals measured at the Lutendele and Cecomaf sites. Correlations between certain heavy metals ($p < 0.05$) are indicative of a common origin or transport pathway, while negative correlations are indicative of opposing sources or influences during transport.

4. Conclusions

This baseline study investigated the physicochemical and bacteriological parameters of water used for domestic and irrigation purposes at two major market gardening sites—Lutendele and Cecomaf—located in Kinshasa, Democratic Republic of Congo. Analysis focused on parameters including pH, EC, O_2, soluble ions (K^+, Na^+, NH_4^+, PO_4^{3-}, SO_4^{2-}, NO_3^-, NO_2^-), the metals and metalloids (Cu, Zn, Cr, Ni, Co, Ag, Cd, Sb, Pb, As, Se, Fe, Mn, V and Ti), and the bacterial indicators (*E. coli*, ENT and TC). The results indicate that water from these sources is unsuitable for domestic consumption and agricultural irrigation. These findings also suggest that further research is required to identify FIBs with host-specific markers. Furthermore, irrigation water should be investigated for its potential to transmit specific pathogens to fresh produce.

Several samples exhibited acidic pH levels—specifically LS1 (3.8), LS2 (4.1), LS4 (5.7), CS1 (6.3), and CS5 (6.3)—all falling outside the acceptable ranges set by WHO and FAO. Additionally, the concentrations of K^+, NH_4^+, PO_4^{3-}, NO_3^-, and NO_2^- exceeded WHO guideline values by factors of 18.3, 1349.2, 182.6, 13.49, and 5.2, respectively. It was found that most of the metal and metalloid concentrations analyzed were below FAO permissible limits. Furthermore, all water samples were significantly contaminated with fecal indicator bacteria, including *E. coli*, ENT, and TC. Based on these findings, the study strongly recommends the implementation of control measures and regulatory oversight, including public awareness campaigns to limit the use of such water for domestic and irrigation purposes. In this regard, individual and community members can use the most reasonable and feasible methods in treating water, including filtration, boiling and chlorination, for domestic use. Moreover, considering that many of these farming activities take place near busy roads, relocation of the sites is advised to reduce contamination by vehicular emissions. The authors also advocate regular and detailed monitoring of dissolved ions, heavy metals, and fecal indicator bacteria to better assess and manage potential risks to human health.

CRediT authorship contribution statement

Anaïs M. Kipelo: Writing – original draft, Visualization, Validation, Software, Methodology, Formal analysis, Data curation, Conceptualization. **Emmanuel K. Atibu:** Writing – original draft, Software, Formal analysis, Data curation, Conceptualization. **Periyasamy Sivalingam:** Writing – original draft, Visualization, Validation, Software, Data curation, Conceptualization. **John W. Poté:** Writing – original draft, Visualization, Validation, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Compliance with ethical standards

We confirm that field studies did not involve endangered and protected species. The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Data availability

The datasets generated or analyzed during the current study are available from the corresponding author on reasonable request.

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