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Research article

Public health risks associated with drinking water consumption in the upper Awash River sub-basin, Ethiopia, sub-Saharan Africa

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ABSTRACT

The Upper Awash sub-basin characterized by urban, industrial, agricultural and population growth, has impacted the quality of its water sources. This study focuses on the assessment of public health risks associated with drinking water sources in the sub-basin. In accordance with WHO guidelines, 120 water samples were collected from 60 water supply schemes in dry and wet seasons located in areas with low and high water pollution risk (WPR). Multi-meter, Photometer, Digital Arsenator, and Microbiological test kit measured the concentration of parameters. The assessment uses methods of hazard identification, exposure and dose-response analysis, and risk characterization, including Hazard Quotient (HQ), Cancer Risk (CR), Hazard Index (HI), and probability of infection. Monte Carlo simulation analyzes non-cancer risks from Nitrite, Nitrate, Chromium, Iron, Fluoride, and Arsenic, and CRs from Chromium and Arsenic, and infection risks from *Escherichia coli* (*E.coli*). As a result, the Hazard Quotient (HQ) of Nitrate was beyond unity (HQ > 1) in the dry season for all groups. HQ of Chromium was HQ > 1 for Women (1.1E+00) and Children (1.4E+00) in the wet season in the high WPR area. Chromium HQ > 1 for children (1.4E+00) in the wet season and Fluoride (HQ > 1) for Children (3.2E+00) in the dry season in the low WPR area. Arsenic CR was above 1 in 10,000 persons for children in the dry season, for all groups, and for women and children in the wet season in the high WPR areas. The CR of chromium ranged from 1 in 1000 persons, which is beyond the limit. Moreover, the Hazard Index (HI) was higher than the unity (HI > 1) for most cases. All *E coli* infection risks daily and annually exceeded the acceptable risks. Therefore, Public health concerns in the Sub-basin were quantified, and evidences were generated for risk management to undertake source protection through integrated watershed management and appropriate water treatment technologies.

1. Introduction

Water source protection is an essential measure for limiting toxins in water sources to safeguard public health. It can be used to regulate water supply systems at the watershed level in spite of challenges related to drought, intensive irrigation, rapid industrialization, population growth, and basin hydrological characteristics of the basins [1]. For instance, Upper Awash sub-basin is the most important basin in the country with high burden of urbanization, industrialization, agricultural activities and climate change impacts.

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These affected on the quality of water sources located in the basin [2]. The evaluation of vulnerability, the inventory of land use, identifying contaminants and their sources, quantifying risk levels, and delineating of watersheds are all important components of source protection [3].

These should be strategically incorporated into implementing the Water Safety Plan (WSP) to improve the water quality of the drinking water supply [4]. However, not just in less developed countries but also in developed ones, source protection and risk management can fail, resulting in outbreaks of waterborne disease [5]. As a result, for drinking water supply, Hazard Analysis and Critical Control Point (HACCP), WHO's WSP, Bonn charter, and Quantitative Microbial Risk Assessment (QMRA), are appropriate risk management methodologies for producing safe water supply for the user population. These approaches can help assess and control the risks of pollution by implementing corrective steps within the water supply system. Nevertheless, there are constraints to implementing water source protection due to a lack of capacity, proof of risks, and source protection awareness [6]. The WHO's preventative management framework for safe drinking water can help to mitigate these constraints via WSP. It comprises health-based objectives, system evaluation, operational monitoring, management plans, and system-independent surveillance [7].

The evaluation of public health problems and system assessment tries to evaluate water quality and quantify associated risks, which is the primary emphasis of this research. As a result, by identifying water quality hazards and quantifying water supply-related risks, this study offers evidence of public health concerns among drinking water consumers in the upper Awash River Sub-basin. The types of water quality parameters selection for analysis were determined by their public health significance and the regular occurrence in these locations. For example, heavy metals and metalloids serve a crucial purpose in understanding the potential health risks linked to water consumption and exposure. Undertaking risk assessment prolongs to identifying their environmental impact, ensuring adherence to regulatory standards, gaining insights into the influence of anthropogenic activities on water quality, and addressing long-term ecological concerns such as persistence and bioaccumulation. From a public health point of view, the term heavy metal usually refers to a metal or semi-metal that can potentially cause human or environmental toxicity. These may include lead, mercury, cadmium, cobalt, nickel, iron, thallium, bismuth, and arsenic [8]. Heavy metals are found naturally in the earth crust. Human activities are affecting the concentration of heavy metal, and hence, heavy metal may enter into plant, animal, and human tissues via inhalation, ingestion, and manual handling. The harmful effect and toxicity mechanisms of Mercury, Arsenic, Lead and other toxic elements are Oxidative and Nitrative stress, depletion of intracellular antioxidants, binding to specific locations and dislocation of essential ion, damage to macromolecules, inhibition of repair machinery, chromosomal abnormalities and altered gene expression, membrane damage, inhibition of oxidative phosphorylation, disruption of protein structure, hypertension [9]. For instance, Arsenic exposure may lead to hyperpigmentation, keratosis, and possible vascular complications. Fluoride is linked to dental fluorosis, while nitrate exposure is associated with methemoglobinemia. Nitrite, another parameter, is also linked to methemoglobinemia. Iron in water can contribute to gastrointestinal toxicity [10]. Chromium (VI) causes DNA damage, stomach malignancies, skin tumors, lung cancer, and impacts on immunological, gastrointestinal, liver, and kidney systems and cancer mortality [11]. Cadmium has effects on the kidneys, liver, and bones and increases the potential risk of cancer in the breast, bladder, and lungs [12]. Understanding these associations is crucial for assessing the potential health risks associated with water consumption and exposure to these parameters. As the result, the principal objectives of this and other investigation is crucial to develop prevention and control strategies particularly to mitigate water pollution problems before happening of its impact on the human health and the environment. These findings are undeniable because they were conducted in the Upper Awash sub-river basin, the most polluted, populated, urbanized, and socioeconomically significant river basin in the country. The assessment of public health risks in drinking water is a comprehensive strategy focused on safeguarding community well-being. It involves identifying, mitigating, and preventing potential health hazards in water sources. This approach enables informed decision-making to reduce the risk of waterborne diseases, maintain water quality within safe limits, and contribute to policy development and regulatory standards. Additionally, it promotes community awareness, aids in resource allocation, and ensures the ongoing safety and health of drinking water sources.

Public health risk assessment is a structured process that estimates the potential health impacts of hazards, including infectious diseases and environmental pollutants. The chemical risk assessment involves four steps: hazard identification (identifying hazard type and nature), exposure assessment (evaluating likelihood and extent of exposure), health effect or dose-response assessment (estimating probability and severity of health outcomes), and risk characterization (integrating information for risk description).

The risk assessment was completed using the four steps: hazard identification, exposure and dose-response assessment, and risk characterization for risk management and communication [13]. Hazard identification and exposure assessment were carried out using geographic information systems (GIS) and geostatistical approaches to designate prone and polluted sites from which distinct public health risks were assessed. Collectively, to assess individual and cumulative risks for targeted sites, problem formulation, exposure analysis, toxicity analysis, and risk and uncertainty characterization are vital for presenting the findings [14]. In addition to the deterministic method, the Monte Carlo simulation method, the most extensively used method for risk analysis, was employed to estimate the probabilistic health risks [15]. It describes the sensitivity to various exposure factors and characterizes the overall risks regarding infection probability for microbial risks, Hazard Question and Hazard Index for non-cancer risks, and carcinogenic risk probability for public health significant chemicals [16]. Additionally, for several reasons, *E. coli* is a valuable tool for health risk assessment. It is a reliable indicator of fecal contamination, inhabiting the intestines of warm-blooded animals, including humans. With its abundance in human and animal feces and longer persistence in the environment than many waterborne pathogens, *E. coli* is a dependable indicator of recent contamination. Its detection and quantification are easily achievable through standard microbiological methods, making it a practical choice for water quality assessment. Additionally, the presence of *E. coli* indicates potential contamination by pathogenic microorganisms, leading regulatory agencies and guidelines to frequently use it as a key indicator for establishing and monitoring water quality standards. Similarly, Quantitative Microbial Risk Assessment (QMRA) assesses health risks associated with microbial contaminants in various media. QMRA supports risk management, regulatory decisions, and public health protection. *E. coli* is identified as a major public health hazard, especially in drinking water, due to its indicators of human origin in low economic settings. Pathogenic strains of *E. coli* can cause severe health issues, including Hemolytic Uremic Syndrome (HUS), acute diarrhea, bloody diarrhea, abdominal cramping, headache, and hemorrhagic colitis. Microbial exposure analysis assumes daily water consumption as the exposure route, with dose-response analysis using the beta-Poisson model to predict infection probability [17–20]. Approximately 8 % of *E. coli* identified in drinking water is estimated to be pathogenic [21–23]. Microbial risk characterization follows WHO standards, indicating acceptable contamination levels based on daily and annual infection risks. In risk analysis, Monte Carlo simulations can be performed for statistical inferences and uncertainty analysis [24].

In general, public health can be considered through the lens of Integrated Watershed Management (IWSM) as it enhances health and social-ecological resilience by examining watershed characteristics linked with water quality and public health. This approach helps to build policy and local-specific solutions for source protection and risk mitigation. This study aims to investigate the public health risks associated with water consumption from drinking water sources located in the upper Awash sub-basin.

2. Materials and methods

2.1. Study area

Ethiopia has twelve river basins, one of which is the Awash River basin. It is subdivided into basins. The uppermost sub-basin is the upper Awash River sub-basin, which is the focus of this study (Fig. 1). It began at Ginchi 75 km west of Addis Ababa, and ended at Koka Dam. It is situated between approximately 8°12′59.39"N to 9°18′00.64"N latitude and 37°06′41.73"E to 39°16′53.09"E longitude. It has higher altitude of 3000 m above mean sea level and lower altitude 1500 m above mean sea level. It is traveling about 200 km until it reaches to Koka reservoir. The Akaki, Holeta, Berga, and Legedadi Rivers are the sub-basin's four primary tributaries. The primary land use-land cover of the sub-basin comprises 93.2 % cultivated agricultural land, grassland, and shrubland, while the remaining 6.8 % is characterized by other land cover types [25]. The rainy season lasts from June to September, and the dry season lasts from October to May, with moderate rainfall from March to May. The hottest month is May and the coldest months are November and December. Rainfall distribution is mostly unimodal and usually controlled by the movement of the Inter-Tropical Convergence Zone [26]. The sub-basin has an average annual rainfall of 1052 mm, with variations ranging from 400 mm to 1900 mm per year [27]. Mean annual temperatures range from 20.8 °C to 29 °C at Koka [28]. According to a 2007 survey by the Central Statistical Agency (CSA 2007), 14.9 million people live in the Awash River Basin as an entire area in which more than 65 % (9,7 million) of this population lives in the Upper Awash sub-basin, which is composed of 4,415,324 rural people and 5.3 million urban people. The sub-basin has population

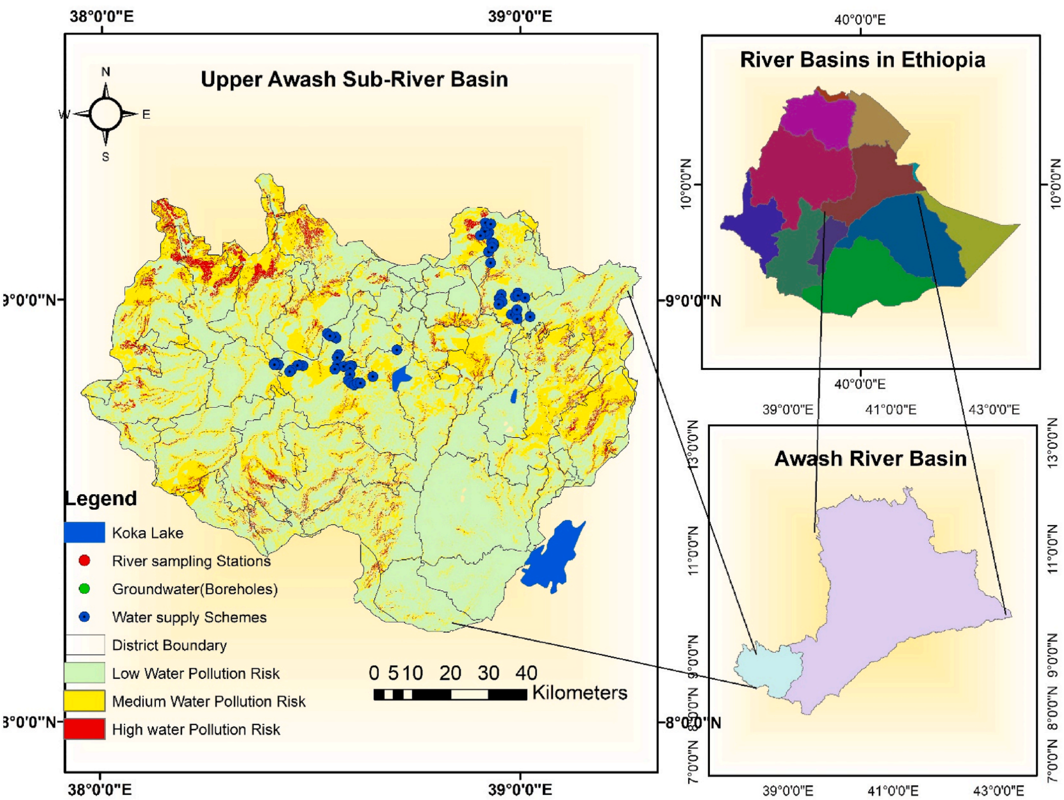

Fig. 1. Distribution of sampled water supply schemes in the study area.

densities ranging from 110 to 270 persons per km^2. The sub-basin includes the city government of Addis Ababa, the Oromia region, and small portions of the Amhara and South Nation Nationalities Regions. It encompassed many urban residents with industrial, agricultural, and other socio-economic activities. About 65 % of industries in the country are located in this sub-basin [29]. Moreover, the Awash Basin accommodates 48–70 % of the country's existing large-scale irrigated agriculture. Within the sub-basin, a combined total of existing and potential large-scale irrigated land covers 33,900 ha, constituting 22.4 % of the entire Awash Basin [30]. The sub-basin includes the city government of Addis Ababa, the Oromia region, and small portions of the Amhara and South Nation Nationalities Regions. This study area is prioritized for investigation as the Upper Awash sub-river basin, centrally located encompass the capital city, intensively utilized, the most polluted, populated, urbanized, and socioeconomically significant river basin in the country.

2.2. Water quality sampling and testing

The number of samples was determined by applying the minimal sample size requirements for statistical analysis [31]. Sixty samples were chosen from areas with low (Sebeta-Hawas District) and high (Bereh District) Water Pollution Risk (WPR), which was prepared by the Author to map water pollution risk in order to estimate the exposed population. The precise location of the samples was determined by using the GIS environment to overlay the WPR map with the National WASH Inventory (NWI-2) database [32] (Fig. 1). Sixty water supply schemes were sampled in the dry and wet seasons. 37 (62 %) of the schemes were shallow wells, 9 (15 %) were hand-dug wells, 5 (8 %) were boreholes, 4 (%) were protected springs which are spring that has been made more readily available to the user community and is protected from contamination and 5 (8 %) were unprotected springs.

The types of water quality indicators chosen for analysis were determined by their public health significance and the regular occurrence in these locations. Thenecessary equipment and materials were prepared, representative water samples were collected, records were documented, and requirements of sample preservation, handling, storage, and transportation were undertaken based on quality assurance protocols. In addition, to maintain data quality, aseptic equipment sterilization, blank measurements, and triplicate analysis were utilized under WHO drinking water sampling guidelines for microbiological, chemical, and physical water quality analysis. Thermos scientific Multi-meter (Orion Thermo Scientific Star A 325) was used to measure Tem (C^o), TDS (mg/l), and EC(S/cm) on-site [33]. Calibration and validation were conducted prior to analysis, and specific dates and intervals were verified in accordance with the manufacturer's documentation. Palintest 7100 Photometer was used to examine water quality parameters such as Fe (mg/l), Mn (mg/l), F^-(mg/l), Cr(VI) (mg/l), NO_2^-(mg/l), NO_3^-(mg/l), NH_3(mg/l), SO_4^{2-}(mg/l), Mg (mg/l), Ca (mg/l), Alkalinity (mg/l), Total Hardness (mg/l) and HCO_3(mg/l) [34]. In accordance with the user's manual, reagents in tablet form designated for the Palintest Photometer 7100 device were employed for these parameters. Reagents colorize the water sample based on the parameter's concentration. The photometer detects this by measuring how a specific light wavelength interacts with the color. Calibration and validations had been performed by the manufacturer, and specific dates and intervals were verified in accordance with the provided documentation of the manufacturer. Arsenic (μg/l) was also analyzed using a portable digital arsenator [35]. The Palintest digital Arsenator water quality testing was initiated with the activation of the device, followed by the insertion of a blank slide and the initiation of the calibration process. Subsequently, the slide was replaced with a tri-filter arsenic trap, and the timer was started. Concurrently, a water sample was prepared, and the reaction vessel was connected, awaiting the completion of the timer countdown. Upon reaching zero, key was pressed to retrieve the result, revealing the arsenic concentration in μg/l. The procedure was concluded by removing and safely disposing the arsenic trap, and the reaction vessel was rinsed in preparation for subsequent tests.

The Aquasafe WSL25 Plus microbiological test kit was used for microbial test and analysis [36]. The membrane filter technique specified in the American Public Health Association's (APHA) Standard Methods for the Examination of Water and Wastewater was used. *Total Coliform(TC)* and *Escherichia coli(E.coli)* in Water Detected by Membrane Filtration and Simultaneous Detection (M-broth). Sampling.

Bacteriological sampling procedures such as cleaning, disinfection using alcohol and taking appropriate amount of water by sample bottle were undertaken. A 100 mL sample was filtered and incubated at 37 °C for 24 h. Finally, recording the red and blue colonies as *TC* and the blue colonies as *E. coli* and report as *E. coli* or *TC* per 100 mL of drinking water [37]. The number of Colony Forming Unit (CFU) for each bacteria were calculated using equision (1) and (2).

In addition, the laboratory of Ministry of Water and Energy (MoWE), Ethiopia, data security is rigorously maintained to ensure the protection and integrity of sensitive information related to environmental and water quality parameters. Measures are in place to prevent unauthorized access, alteration, or data loss. In any procedure, standardized and Certified Reference Materials (CRMs) are used for water quality analysis, providing quality controls.

$$E.coli \Big/ 100\text{mL} = \frac{\text{Number of blue colonies}}{\text{Volume of sample filtered } (mL)} x\ 100 \tag{1}$$

$$TC \Big/ 100\text{mL} = \frac{\text{Number of fluorescent colonies} + \text{Number of blue, non} - \text{fluorescent colonies (if any)}}{\text{Volume of sample filtered } (mL)} x\ 100 \tag{2}$$

2.3. Risk assessment procedure and assumptions

2.3.1. Chemical risk assessment

i. **Hazard identification**: a review of the literature was conducted to justify the chemical risks of water supply that can potentially cause toxicity. *E. coli* species was assessed, as it is one of the most prevalent etiological agents for diarrheal disease and an indicator organism for risk-based regulation [41].
ii. **Dose-Response**: Arsenic, Chromium (VI), Fluoride, Nitrate, Nitrite, and Iron Reference Dose (RfD) (mg/kg-day) and Slop Factors of Chromium and Arsenic were retrieved from the USEPA's IRIS database and other sources (Table 1) [10].

iii. **Exposure Assessment:** Chemicals in drinking water are calculated in this step based on their concentrations, frequency of occurrence, and duration of exposure to drinking water. The laboratory results of six water quality measures and the assumptions indicated in the following table were used to calculate daily chronic intakes for each group (Table 2) [38].

To calculate intake:

$$\mathbf{I} = \frac{\boldsymbol{CxIRxEFxED}}{\boldsymbol{BW}} \boldsymbol{x} \frac{\mathbf{1}}{\mathrm{AT}} \tag{3}$$

where:
I: Daily Chronic Intake;
C: Average concentration (mg/l);
IR: Contaminant medium ingested per day (L/d);
EF: Exposure frequency per year (days/year);
ED: Exposure duration, lifetime (year);
AT: Average time (days) and.
BW: Average body weight.

iv. Chemical Risk Characterization

The cancer, non-carcinogenic, and aggregated risks of the parameters were characterized. Hazard Quotient (HQ) Equation-(3) and (4) was used to assess non-cancer risk. If HQ is more than one, it is taken as potential noncancer effects from exposure. This signifies that if the exposure concentration exceeds the Reference Dose (RfD)/threshold level, the likelihood of noncancer risk is significant.

$$\textbf{Hazard Quotient} = \frac{\mathbf{I}}{\mathrm{RfD}} \tag{4}$$

where;
I: Daily chronic Intake, mg/kg body weight – day (Equation −2).
RfD: Reference Dose, mg/kg body weight – day (Equation- 1).

Hazard Quotient (HQ) Equation (3) was used to assess non-cancer risk. If HQ is more than one, it is taken as potential non-cancer effects from exposure. This signifies that if the exposure concentration exceeds the Reference Dose (RfD)/threshold level, the likelihood of non-cancer risk is significant (Table 1). To interpret the risk data, if it is less than 1.00E-06 (1 in 1,000,000 people), it is considered safe; if it is between 1.00E-04 and 1.00E-06, it is considered satisfactory; and if it is larger than 1.00E-04, it is considered an unacceptable carcinogenic risk [42].

Table 1
Parameters' Reference dose (RfD) for risk quantification for oral exposure route.

No	Parameters	Some of the health effects (Hazards)	RfD	Slope factor and Age Dependent Adjustment Factor (ADAFs)	Ref.
1	Arsenic	Hyperpigmentation, keratosis, and possible vascular complications	3 × 10-4 mg/kg-day	CSF: 1.5 ADAFs: 3 (for <16 years of age) ADAFs:1 (>16 years)	[10]
2	Chromium (VI)	None reported	3 × 10-3 mg/kg-day	CSF: 0.5 ADAFs: 3 (for <16 years of age) ADAFs:1 (>16 years)	[10]
3	Fluoride	Dental fluorosis	6 × 10 -2 mg/kg-day		[10]
4	Nitrate	Methemoglobinemia	1.6 mg/kg-day		[10]
5	Nitrite	Methemoglobinemia	1 × 10 -1 mg/kg-day		[10]
6	Iron	Gastrointestinal toxicity	7 × 10-1 mg/kg/day		[10]

Table 2
Sources for the calculation of Daily Chronic Intake exposure.

Exposure parameter and description		Unit	Value	Ref.
I	Daily Chronic Intake	mg/kg/d		
AT	The period over which exposure is averaged	day	365	[38,39]
BW	Average body weight over the exposure period	kg		
	Men (>15 Years)	kg	(56.4, 15.95)	[40]
	Women (>15 Years)	kg	(51.8, 14.96)	[40]
	Child <15 years	kg	23	[38,39]
C	Average concentration ingested over the exposure period	mg/L	–	–
IR	Contaminant medium ingested per day	L/d		
	Men (>15 Years)	L/d	2	[38,39]
	Women (>15 Years)	L/d	2	[38,39]
	Child <15 years	L/d	1.4	[38,39]
EF	Exposure frequency per year	days/y	25,550.00	[39]
ED	Exposure duration (lifetime).	y	70	[39]

$$\text{Risk} = \text{IxSFxADAFs} \tag{5}$$

where:

Risk: a unitless probability of an individual developing cancer;
I: Chronic daily intake average over exposed years (mg/kg-day);
SF: Slope factor (mg/kg-day) and.
ADAFs: Age-Dependent Adjustment Factors.

Based on Equation (6), the Hazard Index (HI) is estimated by summing the Non-carcinogenic Risk, which is based on the HQs from Equation (4) for th six water quality indicators. A satisfactory HI result is less than one (HI < 1), as in HQ [43].

$$\textbf{Hazard Index} = \frac{\mathbf{I(F)}}{\mathrm{RfD}_{\mathbf{F}}} + \frac{\mathbf{I(NO2)}}{\mathrm{RfD}_{\mathbf{NO2}}} + \frac{\mathbf{I(Fe)}}{\mathrm{RfD}_{\boldsymbol{Fe}}} + \frac{\mathbf{I(Cr)}}{\mathrm{RfD}_{\mathrm{Cr}}} + \frac{\mathbf{I(NO3)}}{\mathrm{RfD}_{\mathbf{NO3}}} + \frac{\mathbf{I(As)}}{\mathrm{RfD}_{\mathrm{As}}} \tag{6}$$

where.

I: Exposure level for the specified toxicant and

RfD: Reference Dose for the specified toxicant.

2.3.1.1. V. Monte Carlo simulation for chemical risk analysis. A Monte Carlo simulation was performed to make statistical inferences from the sample statistics. The probability of exposure and risks calculated for stratified areas with high WPR. The analysis was carried out with the help of Microsoft Excel 2016 and SPSS version 25. The concentrations of parameters such as F, NO_2, Fe, Cr (VI), As, and NO_3 with the sample mean, standard deviation, and 95 % confidence intervals were determined using a Random Number Generator (RNG) with 10,000 iterations under the assumption of normal distribution. The values were entered into the daily chronic intake calculation. The technique assures that the output risk distributions are converging and stable. This Two-dimensional Monte Carlo Analysis was performed to meet the criteria for probabilistic risk assessment [24].

2.3.2. Microbial risk analysis

1. **Microbial Exposure analysis**: the analysis assumes a daily ingestion of 2 L of contaminated water per person. The exposure frequency is 90 days per year during the rainy season, 275 days per year during the dry season, and 365 days per year for the annual average. The analysis assumes daily water consumption as the exposure route, equal susceptibility across the population, and neglects secondary infections by pathogens [38,39].
2. **Microbial dose-response analysis**: It has been calculated using an approximate beta-Poisson model (Equation -(5) [44].

$$\boldsymbol{Pi(D)} = \mathbf{1} - (\mathbf{1} + \boldsymbol{D})/\boldsymbol{\beta})^{-\boldsymbol{\alpha}} \tag{7}$$

where, Pi (D): the probability of infection; D = mean dose; β = 1.78E+6 and α = 0.1778 for *E. coli* (pathogenic strain) based on literatures, 8 % of the CFU of *E. coli* identified in drinking water supply is estimated as pathogenic *E. coli* [23]. In addition, the annual microbial infection probability calculated as

$$\boldsymbol{P} = \mathbf{1} - (\mathbf{1} - \boldsymbol{Pinf})^{\boldsymbol{n}} \tag{8}$$

where P (annual and seasonal infection probability); Pinf (the probability of infection for a single exposure to a dose D of *E. coli*) and n (the frequency of exposure- 365 days/year) [45].

3. **Microbial Risk characterization**: this characterization is used WHO criterion for the daily infection risk (1 in 10, 000, 000) and the annual infection risk (1 in 10,000 people) [46].
4. **Monte Carlo simulation**: the simulation was carried out with the help of Microsoft Excel 2016 Random Number Generator (RNG). It produced random numbers with a normal distribution for *E. coli* dose/2 L of water and 10,000 iterations based on the sample mean and standard deviation of microbial dose. SPSS version 25 was used to examine the data set's and to provide potential hazards (mean and standard deviation with 95 % CI).

3. Results and discussion

3.1. Descriptive statistics

3.1.1. Physicochemical water quality parameters

The dry season results in Bereh district revealed that the mean value of three parameters, Alkalinity, Cr(VI), and Nitrate, and the maximum value of PH, EC, Mn, and Calcium did not meet the Compulsory Ethiopian Standard. (CES-58) or WHO's drinking water standard. Wet season tests from this district revealed that iron, alkalinity, Cr (VI), and magnesium levels exceeded drinking water regulations (Table 3). The maximum EC, Mn, Calcium, Nitrate, and magnesium readings were not by the aforementioned criteria, whereas the mean value of EC, Mn, Cr, and Mg in the dry season and EC, Alkalinity, and Cr (VI) in the wet season in the Sebeta-Hawas district (low water pollution risk areas) satisfied CES-58 (WHO standard). The temperature was 19.71 in Bereh District during the dry season and 24.98 in Sebeta-Hawas district during the dry season in both seasons and districts (Table 4). The maximum values for six parameters in the dry and eight parameters in the wet seasons were much lower than the drinking water standards. The mean values of pH, TDS, Fluoride, Nitrite, Sulfate, and Arsenic were within CES-58 for all situations. EC, Alkalinity, Magnesium, Cr (VI), Mn, Iron, and Nitrate did not always comply with the standards.

The results of this study explored the temperature level does not meet the 15° Celsius required value of Canadian and British drinking water supply standards, even though temperature is not mentioned in the CES-58. Management techniques and alternative measures that have been well explored are required to prevent the effects of elevated temperature in drinking water since the temperature affects the physical, chemical, and biological characteristics of water quality [47]. These findings point to dangers and risks that may have particular negative health implications. Seasonal variations in the parameters are substantial. In the dry season, the EC and Total Hardness dropped from the upper to lower portions of the Awash River Basin [48]. Ca^{2+} and Mg^{2+} predominate in the highland aquifer in the region's upper Awash sub-basin, while HCO_3 is the predominant anion [49]. These different kinds of groundwater support the local EC, alkalinity, and magnesium parameter associations.

Drinking water contains chromium from both anthropogenic and natural sources. As there were no industrial activities in sampling areas, contamination shall be from a natural source or other anthropogenic sources as it is widely scattered across the Earth's crust. Evidence from a comprehensive review indicates that in Ethiopia, the maximum value is closest to the study's mean value, with the mean content of chromium in drinking water ranging from 0.0089 mg/l to 0.054 mg/l [50].

Chromium was also detected in Akaki River water used for irrigated vegetables [51]. The conversion of Cr (III) to Cr(VI) is supported by the presence of minerals like Mn and alkalinity. Even though it was increased to 0.120 mg/l, which is this study's maximum value, the total chromium concentration in drinking water is often less than 0.02 mg/l, according to a WHO report [52]. Surface water in the basin contained increased concentrations of Mn and Fe when compared to WHO drinking water quality criteria. Since the upper

Table 3
Water quality status of Bereh Districts in dry and wet seasons.

S/N	Water quality Parameters	Bereh district – dry season				Bereh district -Wet season				CES-58
		Mean	Std.D	Min	Max	Mean	Std.D	Min	Max	
1	Tem (C°)	19.71	3.78	18.00	25.20	21.67	1.77	18.50	25.60	
2	PH	7.52	0.39	6.55	8.60	7.41	0.32	6.88	8.30	6.5–8.5
3	TDS (mg/l)	176.48	103.08	66.04	575.0	191.12	91.88	88.30	535.00	1000
4	EC(S/m)	385.11	346.30	11.55	1810.0	333.95	138.29	105.30	654.00	
5	F^- (mg/l)	0.30	0.18	0.08	0.80	0.48	0.23	0.10	0.96	1.5
6	NO_2(mg/l)	0.03	0.05	0.01	0.26	0.03	0.06	0.01	0.26	3
7	Fe (mg/l)	0.05	0.04	0.01	0.15	0.57	1.50	0.01	8.00	0.3
8	Mn (mg/l)	0.42	0.21	0.01	1.16	0.10	0.23	0.01	1.16	0.5
9	SO_4 (mg/l)	5.96	7.52	0.00	24.0	4.00	6.09	0.30	25.00	250
10	Alk(mg/l)	243.13	64.83	130.00	400.0	303.34	84.46	145.00	450.00	200
11	HCO_3(mg/l)	300.72	74.48	160.00	490.0	370.19	104.24	175.00	550.00	
12	$CaCO_3$(mg/l)	146.66	38.70	80.00	240.0	182.05	50.65	85.00	270.00	
13	Cr(VI) (mg/l)	0.05	0.03	0.00	0.10	0.07	0.02	0.05	0.10	0.05
14	Ca (mg/l)	53.53	28.51	2.00	160.0	59.07	28.77	6.00	160.00	75
15	NH_3(mg/l)	0.03	0.03	0.00	0.17	0.02	0.01	0.01	0.06	1.5
16	TH (mg/l)	126.24	49.38	5.00	235.0	151.64	59.70	10.00	270.00	300
17	As (μ/l)	0.87	1.57	0.00	6.00	0.30	1.055	0.00	5.00	0.01
18	NO_3(mg/l)	65.28	53.03	1.00	300.0	6.86	16.88	0.59	80.00	50
19	Mg (mg/l)	13.81	8.10	0.49	38.88	90.12	45.16	4.00	178.00	50

Table 4
Water quality status of Sebeta-Hawas district.

S/N	Parameters	Sebeta-Hawas –Dry season				Sebeta-Hawas –Wet Season				CES-58
		Mean	Std.D	Min	Max	Mean	Std.D	Min	Max	
1	Tem (C°)	24.98	4.04		36.6	23.90	1.65	20.00	26.90	
2	PH	6.76	0.28	6.5	7.12	6.89	0.29	6.27	7.27	6.5–8.5
3	TDS (mg/l)	298.61	195.09	1000	883.0	303.80	179.96	55.60	915.00	1000
4	EC(S/m)	594.53	358.69		1495.0	616.75	369.50	6.32	1834.00	
5	F (mg/l)	0.67	0.32	1.5	1.41	0.74	0.40	0.01	1.43	1.5
6	NO_2(mg/l)	0.01	0.01	3	0.05	0.52	1.79	0.01	8.00	3
7	Fe (mg/l)	0.06	0.15	0.3	0.84	0.23	0.27	0.00	0.90	0.3
8	Mn (mg/l)	0.57	0.60	0.5	2.50	0.36	1.15	0.01	6.00	0.5
9	SO_4 (mg/l)	19.45	45.94	250	180.0	15.03	24.09	0.50	100.00	250
10	Alk(mg/l)	313.27	166.43	200	700.0	460.52	308.27	75.00	1125.00	200
11	HCO_3(mg/l)	383.33	204.91		870.0	565.50	381.98	95.00	1375.00	
12	$CaCO_3$(mg/l)	179.33	90.65		400.0	247.42	175.60	45.00	687.50	
13	Cr(VI) (mg/l)	0.05	0.09	0.05	0.50	0.07	0.08	0.02	0.120	0.05
14	Ca (mg/l)	60.67	32.01	75	190.0	66.53	31.39	16.00	129.00	75
15	NH_3(mg/l)	0.27	0.22	1.5	0.67	0.39	117.75	0.02	0.67	1.5
16	TH (mg/l)	211.53	98.52	300	470.0	207.73	85.65	55.00	350.00	300
17	As (μ/l)	0.034	0.182	0.01	1.00	0.00	0.000	0.00	0.001	0.01
18	NO_3(mg/l)	15.98	30.34	50	128.5	11.81	18.10	0.09	73.48	50
19	Mg (mg/l)	148.93	70.65	50	280.0	21.64	42.60	0.01	225.00	50

Awash River sub-basin is hydraulically connected to the Awash River [53]. It is proposed that the reduction in water quality along the Awash River can be utilized to explain these poor water quality indicators [51]. Additionally, the geochemistry of the basin, the growth of metropolitan centers, and the growing usage of fertilizers have an impact on the study area's drinking water quality [49]. Contrarily, a research carried out in the basin revealed that groundwater quality indices including pH, EC, TDS, Ca^{2+}, Mg^{2+}, HCO_3^-, SO_4^{2-}, and F^- were within WHO guidelines [54].

3.1.2. Microbial water quality parameter

In comparison to the dry season, the rainy season had a greater mean dose of *E. coli* per 100 mL. In contrast to the Bereh District, samples from the Sebeta-Hawas District had higher *E. coli*. In order to prevent waterborne disease, the Sebeta-Hawas District's 28.15 mean dosage of *E. coli* (27.57–28.74, 95 % CI) required more attention than the Bereh district's 23.44 mean dose (22.85–24.03, 95 % CI). However, the mean dose of *E. coli* in the rainy season was higher than in the dry season (Table 5).

3.2. Public health risk analysis and risk characterization

3.2.1. Non-cancer risk analysis

The Hazard Quotient (HQs) of NO_3 is more than unity in the dry season for all three categories, according to a risk study of 60 samples from the Bereh district (30 samples in the dry and 30 samples in the wet seasons) (Table 6). This suggests that NO_3 is a potential risk for the area's population. In Bereh District, during the wet season, only the chemical chromium poses a concern to women and children.

There are no season-specific non-cancer hazards associated with the other characteristics.

The findings presented in Table 7 indicate specific parameters posing potential non-cancer risks for the Children group in the Sebeta-Hawas district. During the dry season, Fluoride is identified with a hazard quotient (HQ) of 3.2E+00, signifying its significance as a potential risk factor. Additionally, Chromium, with an HQ of 1.4E+00, emerges as a potential non-cancer risk for children during the rainy season. These results highlight the importance of monitoring and addressing these specific parameters to mitigate health risks associated with water quality in the Sebeta-Hawas district, particularly for the vulnerable Children group.

According to the seasonal average in Table 8, NO_3 and Chromium may pose non-cancer dangers to Children, while NO_3 may do so

Table 5
Mean dose of *TC* and E.coli/100 mL and daily mean dose of *TC* & *E.coli*/2000 mL and Monte Carlo simulation result of mean dose of *E.coli*.

S/N	Descriptive	Sample Mean (CFU/100 mL)		Daily Mean (CFU/2000 mL)		E.coli Mean (CFU/2000 mL)	Std. D	95 % CI for Mean	
		TC	*E.coli*	*TC*	*E.coli*			Lowe Bound (LB)	Upper Bound (UB)
1	*E.coli* dose in dry season	46	14	929	287	23.17	25.83	22.66	23.67
2	*E.coli* dose in wet season	88	18	1753	355	27.94	42.51	27.11	28.78
4	*E.coli* average dose (Bereh District)	56	15	1124	293	23.44	30.28	22.85	24.03
5	*E.coli* average dose (Sebeta Hawas District)	78	17	1558	349	28.15	29.80	27.57	28.74
3	*E.coli* seasonal average dose					25.25	30.20	24.66	25.84

Table 6
Hazard Quotient of drinking water quality parameters (Bereh District).

No	Group	WQP	Dry Season				Wet Season			
			Mean	Std. D	Lower bound	Upper bound	Mean	Std. D	Lower bound	Upper bound
1	Men	F	2.0E-01	1.2E+00	1.8E-01	2.3E-01	3.1E-01	7.7E-01	3.0E-01	3.3E-01
		No2	1.3E-02	1.3E-01	1.0E-02	1.5E-02	1.2E-02	8.4E-02	1.1E-02	1.4E-02
		Fe	2.9E-03	1.4E-02	2.7E-03	3.2E-03	3.3E-02	2.0E-01	2.9E-02	3.7E-02
		Cr	6.7E-01	2.2E+00	6.2E-01	7.1E-01	9.3E-01	2.7E+00	8.8E-01	9.8E-01
		As	3.4E-01	1.1E+00	1.2E+00	1.6E+00	2.4E-01	1.37 + 00	4.2E-01	5.2E-01
		NO3	1.6E+00	7.8E+00	1.5E+00	1.8E+00	1.8E-01	2.2E+00	1.4E-01	2.3E-01
2	Women	F	2.3E-01	1.2E+00	2.0E-01	2.5E-01	3.6E-01	1.7E+00	3.3E-01	4.0E-01
		NO2	1.4E-02	4.7E-02	1.3E-02	1.5E-02	1.6E-02	1.9E-01	1.2E-02	1.9E-02
		Fe	3.3E-03	1.9E-02	2.9E-03	3.6E-03	3.6E-02	1.9E-01	3.3E-02	4.0E-02
		Cr	7.5E-01	3.0E+00	6.9E-01	8.1E-01	1.1E+00	7.2E+00	9.3E-01	1.2E+00
		As	3.8E-01	9.0E+00	1.1E+00	1.5E+00	2.6E-01	1.1E+00	4.7E-01	7.0E-01
		NO3	1.8E+00	7.7E+00	1.7E+00	2.0E+00	1.8E-01	5.7E-01	1.7E-01	1.9E-01
3	Children	F	3.0E-01	1.8E-01	3.0E-01	3.1E-01	4.9E-01	2.4E-01	4.9E-01	4.9E-01
		No2	5.9E-02	9.8E-02	5.7E-02	6.1E-02	1.8E-02	3.7E-02	1.8E-02	1.9E-02
		Fe	4.3E-03	3.5E-03	4.3E-03	4.4E-03	4.9E-02	1.3E-01	4.6E-02	5.1E-02
		Cr	1.0E+00	6.0E-01	9.9E-01	1.0E+00	1.4E+00	4.1E-01	1.4E+00	1.4E+00
		As	5.3E-01	5.7E-01	1.9E+00	2.0E+00	3.6E-01	1.1E+00	6.8E-01	7.6E-01
		NO3	2.5E+00	2.0E+00	2.4E+00	2.5E+00	2.6E-01	6.5E-01	2.5E-01	2.7E-01

Table 7
Hazard Quotient of drinking water quality parameters (Sebeta-Hawas district).

No	Group	WQP	Dry Season				Wet Season			
			Mean	Std. D	LB	UB	Mean	Std. D	LB	UB
1	Men	F	4.5E-01	1.8E+00	4.2E-01	4.9E-01	4.9E-01	1.5E+00	4.6E-01	5.2E-01
		NO_2	1.7E-04	1.3E-03	1.5E-04	2.0E-04	9.0E-05	8.0E-04	7.4E-05	1.1E-04
		Fe	3.5E-03	2.5E-02	3.0E-03	4.0E-03	1.3E-02	5.5E-02	1.2E-02	1.4E-02
		Cr	7.0E-01	5.3E+00	6.0E-01	8.1E-01	8.9E-01	2.2E+00	8.5E-01	9.3E-01
		As	9.24E-03	2.2E-03	1.5E-01	1.8E-01	1.4E-03	4.3E-03	1.3E-03	1.4E-03
		NO_3	4.2E-01	4.1E+00	3.4E-01	5.0E-01	3.0E-01	1.3E+00	2.7E-01	3.2E-01
2	Women	F	4.9E-01	1.5E+00	4.6E-01	5.2E-01	5.5E-01	1.7E+00	5.2E-01	5.8E-01
		NO_2	2.1E-01	1.4E+00	1.8E-01	2.4E-01	1.9E-01	3.7E+00	1.2E-01	2.6E-01
		Fe	1.3E-02	5.5E-02	1.2E-02	1.4E-02	1.6E-02	1.9E-01	1.2E-02	1.9E-02
		Cr	8.9E-01	.2E+00	8.5E-01	9.3E-01	1.0E+00	6.2E+00	9.3E-01	1.2E+00
		As	1.36E-03	4.3E-03	1.3E-03	1.4E-03	1.4E-03	2.4E-03	1.4E-03	1.6E-03
		NO_3	3.0E-01	1.3E+00	2.7E-01	3.2E-01	3.3E-01	8.2E-01	3.2E-01	3.5E-01
3	Children	F	3.2E+00	1.5E+00	3.1E+00	3.2E+00	7.5E-01	4.1E-01	7.5E-01	7.6E-01
		NO_2	6.2E-03	6.1E-03	6.0E-03	6.3E-03	3.1E-01	1.1E+00	2.9E-01	3.3E-01
		Fe	5.1E-03	1.3E-02	4.9E-03	5.4E-03	1.9E-02	2.3E-02	1.9E-02	2.0E-02
		Cr	2.2E-01	3.9E-01	2.1E-01	2.2E-01	1.4E+00	1.6E+00	1.4E+00	1.4E+00
		As	1.42E-02	4.0E-03	2.5E-03	2.6E-03	2.0E-03	2.0E-03	2.0E-03	2.0E-03
		NO_3	5.9E-01	1.2E+00	5.7E-01	6.1E-01	4.6E-01	6.9E-01	4.5E-01	4.7E-01

to women during the dry season. Only chromium poses a non-cancer risk to children during the rainy season. Therefore, NO_3 is the non-cancer risk for children in both seasons and women and children in the dry season when compared to chromium.

Fig. 2's Hazard Index (HI) values for the six water quality parameters such as F, NO_2, Fe, Cr(VI), NO_3 and As demonstrated that, with the exception of the seasonal average for the men group, HI for non-cancer hazards was higher than one (HI > 1). This value exceeds the permissible limit of HI for the total non-cancer risk.

Generally, the non-cancer risks of NO_3, Chromium, and Fluoride were identified in this study and the discussion points are presented as follows.

a) Nitrate

The Men's HQs were 1.6E+00 while women's HQs were 1.8E+00.1.6E+00 for Children on average during the dry season, 2.5E+00 for Children, and 1.3E+00 for Women. One of the public health concerns in short-term exposure, methemoglobinaemia is the most common health effect on babies. In addition, researchers found that there was a risk of childhood central nervous system, stomach, brain and colon cancers, glioma and birth defects [55,56]. Nitrate speeds up the production of chloropicrin which is a disinfection byproduct responsible for mutagenesis in bacterial experiment; however some of the hazards of nitrate as a cause of cancer remain controversial [57]. Watershed-based publication found that children had higher non-cancer risks as a result of drinking nitrate-contaminated groundwater [58], which is similar to the findings of this investigation. Children, babies, and teenagers are

Table 8
Seasonal Hazard Quotient of drinking water quality parameters.

S/N	Categories	Parameters	Dry Season				Wet Season			
			Mean	Std.D	LB	UB	Mean	Std.D	LB	UB
1	Men	F	3.3E-01	1.1E+00	3.1E-01	3.6E-01	4.1E-01	1.4E+00	3.8E-01	4.4E-01
		NO_2	5.8E-06	2.5E-04	8.3E-07	1.1E-05	9.0E-02	1.7E+00	5.7E-02	1.2E-01
		Fe	7.6E-07	6.0E-05	−4.2E-07	1.9E-06	2.0E-02	2.5E-01	1.5E-02	2.5E-02
		Cr	7.2E-01	4.9E+00	6.3E-01	8.2E-01	9.4E-01	3.1E+00	8.8E-01	1.0E+00
		As	2.6E-05	8.0E-05	2.8E-04	3.0E-04	1.8E-02	2.0E-01	2.9E-01	3.8E-01
		NO_3	6.3E-04	2.1E-02	2.1E-04	1.0E-03	2.5E-01	1.3E+00	2.2E-01	2.7E-01
2	Women	F	3.6E-01	1.2E+00	3.4E-01	3.9E-01	4.6E-01	2.3E+00	4.1E-01	5.0E-01
		NO_2	9.6E-03	5.9E-02	8.4E-03	1.1E-02	1.1E-01	2.3E+00	6.2E-02	1.5E-01
		Fe	1.3E-05	8.3E-05	1.1E-05	1.5E-05	2.4E-02	8.8E-02	2.2E-02	2.6E-02
		Cr	7.8E-01	6.4E+00	6.5E-01	9.1E-01	1.0E+00	1.9E+00	9.8E-01	1.1E+00
		As	7.2E-02	3.5E-01	6.3E-01	1.2E+00	2.0E-02	2.0E-01	2.9E-01	3.8E-01
		NO_3	1.3E+00	1.7E+01	9.3E-01	1.6E+00	2.5E-01	8.6E-01	2.4E-01	2.7E-01
3	Children	F	5.0E-01	3.4E-01	4.9E-01	5.1E-01	6.1E-01	3.6E-01	6.1E-01	6.2E-01
		NO_2	1.2E-02	2.4E-02	1.2E-02	1.3E-02	1.7E-01	7.8E-01	1.5E-01	1.8E-01
		Fe	5.1E-03	9.6E-03	4.9E-03	5.3E-03	3.5E-02	9.5E-02	3.3E-02	3.7E-02
		Cr	1.0E+00	1.2E+00	9.9E-01	1.0E+00	1.4E+00	1.2E+00	1.4E+00	1.4E+00
		As	9.6E-02	5.3E-02	1.1E+00	1.2E+00	3.2E-02	1.0E-01	4.4E-01	5.0E-01
		NO_3	1.6E+00	1.9E+00	1.5E+00	1.6E+00	3.6E-01	6.7E-01	3.5E-01	3.8E-01

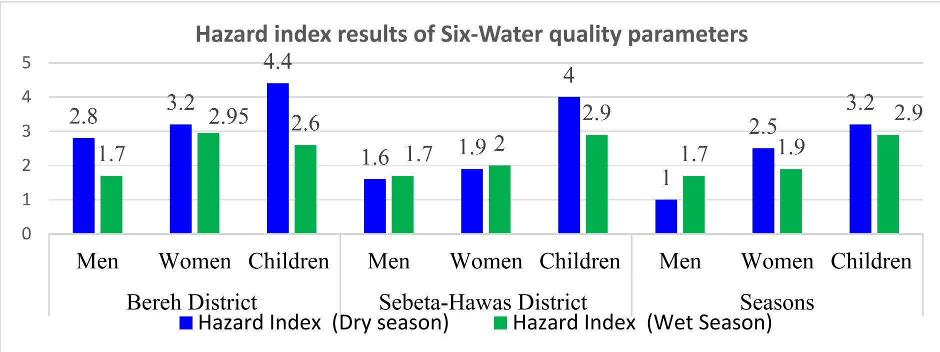

Fig. 2. Hazard Index results of Six-Water Quality paramters

therefore more vulnerable to the risk because they fall within vulnerable age categories in the population. Even though there is minimal difference in risks between the dry and rainy seasons, there is evidence that nitrate contamination of drinking water occurs in both seasons for a variety of reasons. Because washout effects speed up the accumulation of pollutants from ground surfaces and pull them down to groundwater sources, nitrate concentrations were higher during the wet season. Nitrate concentration of groundwater increased throughout the dry season and decreased in the rainy season due to the diluting effects of significant precipitation [59,60].

According to studies conducted in the Awash basin in general and the upper Awash sub-basin in particular, increased concentrations of nitrate were linked to untreated industrial waste, geogenic processes, urban sewage, and fertilizers [49]. Its concentration expected to be raised due to the effects of climate change, poor waste disposal, fertilizer application and population growth [61]. It is evident that nitrate non-cancer hazards are a global concern, extending to the targeted sub-basin. Despite acknowledging the presence of nitrate hazards in the sub-basin, the records from the Legedadi and Gefersa Dams, significant water sources supplying Addis Ababa, reveal compliance with WHO's acceptable guideline values for nitrate, nitrite, and ammonia levels [62]. Internationally, reports from Indonesia indicate risks associated with nitrate in drinking water, particularly for the sensitive population, with potential implications for infant methaemoglobinaemia and birth defects [63]. In Jordan, infants emerge as more susceptible to nitrate exposure in drinking water compared to children and adults [64]. The specific case of Kazerun, Iran, highlights the HQ for nitrate among children, with the HI for all three contaminants surpassing 1 in 56 % of cases, indicating a serious risk [65]. Furthermore, the health risk assessment of nitrate in bottled water in Iran reveals HQ values exceeding unity in 10 % of samples for both infants and children, signaling potential adverse non-carcinogenic health effects upon consumption [66]. These collective findings underscore the nuanced challenges associated with nitrate contamination, emphasizing the need for targeted interventions and ongoing monitoring to mitigate health risks in diverse geographical contexts.

b) Fluoride

Fluoride is harmful to human health when the concentration exceeds 1.5 mg/L [67]. Fluoride has been linked to specific non-cancer hazards that have been reported worldwide. In this study, children in the Sebeta-Hawas district during the dry season are at a non-cancer risk from fluoride (HQ = 3.2E+00) compared to adults. The non-carcinogenic risks for children in the study area's to the southern ranged from 0.75 to 8.44, 0.34 to 3.84 for women, and 0.27 to 3.01 for males [68]. These facts were also supported by articles from around the world [69]. Comparable risks are observed on the east and west coasts of Bangladesh and India, where children exhibit higher mean HQ ingestion values for fluoride, emphasizing the significant non-carcinogenic risk for children [70]. Türkiye's lentic ecosystem similarly identifies fluoride as a major health risk, particularly linked to daily water intake [71]. Kazerun, Iran, presents potential adverse health effects from fluoride intake, with HQ exceeding 1 across various age groups [66]. These findings collectively underscore the consistent health risks associated with fluoride exposure, emphasizing the need for targeted interventions. Fluorosis was caused by groundwater contaminated with fluoride, which harmed 200 million people in 25 different countries [72]. In eleven sub-Saharan African nations, dental fluorosis is common [67]. Skeletal fluorosis was prevalent in the Rift Valley of Ethiopia at 21.4 % [73] and dental fluorosis was estimated as high as 28 % as it is because of high concentration in the Rift Valley [74]. Fluoride is mostly obtained from thermal and fluoride-rich deep well fluids in this study area's in Akaki catchment. In addition, fluoride levels in the northwest of Addis Ababa City increased due to human activity and the urban environment [75]. This explains why there is a larger concentration of fluoride than in samples taken from the city's eastern region. Fluoride concentrations in the Sebeta-Hawas District range from 0.32 mg/l to 1.41 mg/l, with a mean of 0.67 mg/l (Table 4). The main geogenic sources of fluoride in groundwater are fluorite, fluorapatite, biotite, amphibole, micas, topaz, cryolite, muscovite, fluorspar and phosphate rock [67]. The presence of sodium bicarbonate-type water may create an influx of fluoride and a deficiency of calcium [72]. These findings are particularly applicable to the Ethiopian Rift Valley, where the heightened fluoride levels can be attributed to volcanic activity and geothermal temperatures within the rift system. As highlighted in the referenced article, the primary contributors to elevated fluoride levels in both groundwater and surface water in this study area are the utilization of phosphate fertilizers, improper disposal of sewage sludge, and the application of pesticides for agricultural purposes. This underscores the localized sources of fluoride contamination, emphasizing the significance of understanding and addressing specific contributors to effectively manage and mitigate fluoride-related concerns in the Ethiopian Rift Valley [69].

c) Chromium (Cr(VI)

Chromium is a potential non-cancer risk in both districts and the seasonal average for women and children in both districts during the rainy season as well as for children in the seasonal average during both seasons, according to Table 7, Tables 8 and 9. The Bereh HQ (1.1E+00) for women and the HQ (1.4E+00) for children, as well as the Sebeta-Hawas HQ (1.4E+00) for children and the Seasonal HQ (1.4E+00) for children.

3.2.2. *Cancer risk analysis*

a) Arsenic (As)

Table 9 shows that the cancer risk of arsenic has a significant impact on children in both seasons, and for all groups (Men, Women, and Children) in Bereh district in each season, the risk level is over 1 in 10,000 people, which is an unacceptable risk level with WHO standard. While the HQ value of arsenic was less than unity (HQ < 1), which is in an acceptable non-cancer risk level, the cancer risk of arsenic in the Sebeta-Hawas district during the dry season is within the permissible range (below 1 in 10,000 people). According to studies conducted in this sub-basin, soils that were irrigated with water from the Akai River have greater concentrations of arsenic [2]. Arsenic levels increased throughout the dry season and were higher above the WHO threshold [76]. Arsenic was also more mobile in

Table 9
Cancer risk of Arsenic contaminant of drinking water supply.

S/N	Category	Groups	Mean	Std.D	LB	UB
1	Dry Season	Men	2.35E-08	7.18E-08	2.21E-08	2.49E-08
		Women	3.22E-05	1.57E-04	2.92E-05	3.53E-05
		Children	1.29E-04	7.17E-05	1.28E-04	1.30E-04
2	Wet Season	Men	8.16E-06	8.51E-05	6.49E-06	9.83E-06
		Women	9.58E-06	7.96E-05	8.02E-06	1.11E-05
		Children	4.29E-05	1.37E-04	4.02E-05	4.56E-05
3	Bereh district in the dry season	Men	3.04E-04	1.00E-03	2.84E-04	3.23E-04
		Women	1.71E-04	4.06E-04	1.63E-04	1.79E-04
		Children	7.10E-04	7.65E-04	6.95E-04	7.25E-04
4	Bereh district in Wet Season	Men	1.10E-04	6.15E-04	9.75E-05	1.22E-04
		Women	1.16E-04	5.03E-04	1.06E-04	1.26E-04
		Children	4.90E-04	1.50E-03	4.60E-04	5.19E-04
5	Sebeta-Hawas in dry season	Men	4.16E-06	9.82E-06	3.97E-06	4.35E-06
		Women	6.11E-07	1.92E-06	5.73E-07	6.49E-07
		Children	1.92E-05	5.45E-06	1.91E-05	1.93E-05
6	Sebeta- Hawas in Wet Season	Men	6.11E-07	1.92E-06	5.73E-07	6.49E-07
		Women	6.45E-07	1.10E-06	6.23E-07	6.67E-07
		Children	2.74E-06	2.75E-06	2.69E-06	2.79E-06

Lake Koka at the sub-basin's outlet during the dry season than it was during the wet season [77]. The highest level of arsenic was found in the fish liver at this location, which may be related to water retrieved from the sub-basin [78]. Consistent with reviewed publications, 220 million people could be exposed to high levels of arsenic through their groundwater [79]. Arsenic exposures, both long-term and short-term, increase the likelihood of mutagenesis, carcinogenic, neoplasms, hyperkeratosis, abnormalities and disorders whereas the acute toxicity has an impact on the intestinal, circulatory, and central nervous systems, and death [9]. Evidences shown that anthropogenic and natural activities are the sources of arsenic for water supply contamination [76].

b) Chromium (Cr (VI))

Among the chromium species, Cr (VI) is justified as being a substance that causes cancer and significantly increases the burden of cancer worldwide. Cr (IV) had a higher cancer risk than the WHO-acceptable risk level for both the seasonal average (Table 10) and all sampling sites. From 1 in 1000 to 9.78 in 10,000, it was possible. Evidence suggests that the calculated cancer risk of Cr (VI) values was 2.8E-03 for adults and 6.3E-03 for children in a work done in the Awash River Basin, despite the lack of comparable suitable studies in the region [80]. The risk of Cr(IV) is a burden around the world [81]. It is responsible and suspected as the causes of DNA damage, stomach malignancies, skin tumors, lung cancer and impacts on immunological, gastrointestinal, liver, kidney systems and cancer mortality [11]. The average amount of total chromium in drinking water is less than 0.02 mg/L, however the cited research [82] reports amounts as high as 0.120 mg/L. The effluent from the Factory in the upper Awash River sub-basin included a large amount of Cr (VI) as well [83]. Chromium was also detected in Akaki River water which was used for irrigated vegetables [51]. Cr (IV) pollution of water is caused by both anthropogenic and natural processes. The three main factors that affect the presence of Cr(IV) in groundwater are the well's hydrologic characteristics, geochemical evolution, and geological settings [84] and four different types of sources, including arid alluvial basins, chromite ore, saline brines in evaporate basins, and serpentinite ultramafic terrains, all contribute to the presence of Cr(IV) in groundwater [85]. Consquently, agricultural fertilizers, the local geological formation, and non-point sources from solid and wastewater sources in urban, semi-urban, and rural locations are some examples of suggested sources in this study, despite the fact that the sampling sites were not near an industrially impacted area. Among the anthropogenic sources, phosphate fertilizer is one of the suspected source in the study area as this is the main source of pollutants from those chemical fertilizers [86]. In this case, chromium has been recognized as a public health-important water quality parameter in the study area, further research is needed to identify the source of chromium contamination of drinking water.

3.2.3. Microbial risks analysis

The risk of diarrheal diseases caused by the *E. coli* species, one of the pathogens that cause the majority of cases of diarrhea, especially in developing countries, has been the focus of the prediction of the risk of waterborne diseases in the Upper Awash sub-river basin. Five categories of *E. coli*, including enterotoxigenic, enteropathogenic, Shiga toxin producing, enteroinvasive, and enteroaggregative strains, are pathogenic strains of *E. coli* out of the total *E. coli* microorganisms [87]. In this study, harmful strains of *E. coli* were estimated to make up 8 % of the *E. coli* that was found in 60 water supply systems during wet and dry seasons [22]. As a result, Table 11's infection risk shows that all daily infection risks during the dry and the wet seasons, on a seasonal average, and in both Districts are higher than the tolerable risk of the 1 in 10, 000, 000 WHO threshold. While the seasonal average, Bereh District average, wet season risk of infections, and annual risk of infections were 6, 2, 9, and 8 in 10,000 respectively, exceeding the WHO's acceptable annual risk of infection criterion of 1 in 10,000. The Sebeta-Hawas District, however, had a 1 in 1000 annual risk of infection, which was higher than both this norm and another viewpoint of the samples [88]. Given that *E. coli* is a significant public health risk in low-income settings, the amount of these daily and yearly infection risks indicated that appropriate interventions must be taken to protect residents of the sub-basin. Studies in Ethiopia identified various enteropathogenic *E. coli* serotypes in infants and children with acute gastrointestinal symptoms, highlighting waterborne pathogen prevalence in the region [89]. In the southern Wondogenet District, 25 % of water points had fecal coliform bacteria, exceeding the 2016 national survey's 14 % [90]. *E. coli* serves as a prevalent etiological factor for diarrheal illnesses and a straightforward biological hazard indicator in water quality monitoring [41,91]. Regions like Karnataka, India, and San Cristóbal de Las Casas, Chiapas, Mexico, show exposure and infection risk inequalities based on water sources [92,93]. Southern Sindh and recreational water use posed health risks, highlighted by a beta-Poisson model [23,94]. Additionally, the biological hazard presented a risk of diarrheal disease brought on by *E. coli* spp. It is among the most prevalent etiological factors for diarrheal illnesses. It is a straightforward test to determine the biological hazard of water quality during monitoring and surveillance and serves as an indicator organism to construct risk-based management.

4. Conclusions

To quantify public health risks due to chemical and microbial water quality parameters among consumers of drinking water in the upper Awash River Sub-basin system has been done. Considering the local settings and other indications, five water quality parameters as Nitrite, Nitrate, Chromium, Iron, and Arsenic were analyzed for the chemical parameters and *E. coli* for the microbial risks. Accordingly, Nitrate, Chromium, and Fluoride have potential effects for the non-cancer risks and Chromium and Arsenic have effects for the carcinogenic risks. For Men (1.6E+00), Women (1.8E+00), and Children (2.5E+00) in the Bereh District, as well as for Women (1.3E+00) and Children (1.6E+00) for the seasonal average during the dry season, the values of HQ of nitrate were more than unity ($HQ > 1$). For women (1.1E+00) and children (1.4E+00) in the Bereh District and for children (1.4E+00) in the Sebeta-Hawas District during the wet season, and for children in both seasons for seasonal average risks, the values of HQ of Chromium were larger than unity ($HQ > 1$). Children in the Sebeta-Hawas District had fluoride HQ values (3.2E+00) that were more than unity ($HQ > 1$) during the dry

Table 10
Cancer risk of Chromium contaminant of drinking water supply.

No	Categories		Mean	Std.D	LB	UB
1	Dry Season	Men	1.08E-03	7.33E-03	9.39E-04	1.23E-03
		Women	1.17E-03	9.66E-03	9.81E-04	1.36E-03
		Child	4.55E-03	5.47E-03	4.44E-03	4.66E-03
2	Wet Season	Men	1.40E-03	4.68E-03	1.31E-03	1.50E-03
		Women	1.53E-03	2.91E-03	1.47E-03	1.59E-03
		Child	6.39E-03	5.44E-03	6.28E-03	6.50E-03
3	Bereh Woreda in the dry season	Men	1.00E-03	3.32E-03	9.35E-04	1.07E-03
		Women	1.12E-03	4.57E-03	1.03E-03	1.21E-03
		Child	4.52E-03	2.71E-03	4.47E-03	4.58E-03
4	Bereh District in Wet Season	Men	1.39E-03	3.99E-03	1.31E-03	1.47E-03
		Women	1.61E-03	1.08E-02	1.40E-03	1.83E-03
		Child	6.39E-03	1.83E-03	6.35E-03	6.42E-03
5	Sebeta-Hawas District in dry season	Men	1.05E-03	7.94E-03	8.99E-04	1.21E-03
		Women	1.33E-03	3.26E-03	1.27E-03	1.40E-03
		Child	9.78E-04	1.75E-03	9.44E-04	1.01E-03
6	Sebeta- Hawas in Wet Season	Men	1.33E-03	3.26E-03	1.27E-03	1.40E-03
		Women	1.57E-03	9.28E-03	1.39E-03	1.76E-03
		Child	6.27E-03	7.35E-03	6.12E-03	6.41E-03

Table 11
E.coli daily and annual risks of infection.

S/N	Descriptive	Mean	Std. Deviation	95 % CI for Mean	
				Lowe Limit	Upper Limit
A	**Daily infection risk**				
1	Dry season daily risk	2.31E-06	2.58E-06	2.26E-06	2.36E-06
3	Wet season daily risk	2.79E-06	4.25E-06	2.71E-06	2.87E-06
5	Seasonal average daily risk	2.52E-06	3.02E-06	2.46E-06	2.58E-06
7	Bereh District daily risk	2.34E-06	3.02E-06	2.28E-06	2.40E-06
9	Sebet-Hawas District daily risk	2.81E-06	2.98E-06	2.75E-06	2.87E-06
B	**Annual infection risk**				
2	Dry season annual risk	6.36E-04	7.09E-04	6.22E-04	6.50E-04
4	Wet season annual risk	2.51E-04	3.82E-04	2.44E-04	2.59E-04
6	Season average annual risk	9.20E-04	1.10E-03	8.98E-04	9.41E-04
8	Bereh District annual risk	8.54E-04	1.10E-03	8.32E-04	8.75E-04
10	Sebeta-Hawas District annual risk	1.03E-03	1.09E-03	1.00E-03	1.05E-03

season. Chromium and arsenic have cancer risks that are higher than the permissible risk levels. Moreover, except seasonal average for the men, the Hazard Index (HI) of six water quality parameters was higher than unity (HI > 1) which exceeded the total non-cancer risk level. In, arsenic may have a substantial impact on women (3.22E-05) and children (1.29E-04) during the dry season, children (4.29E-05) in wet season and in Bereh District, all other groups during the dry season. Both the seasonal average provided by WHO and the permitted risk level for all sample sites are exceeded by the cancer risk associated with chromium. Although it is below 1 in 10,000, the cancer risk in Sebeta-Hawas during the dry season is tolerable. It varies from 1 in 1000 to 9.78 in 10,000. All the daily and annual risks of infection due to *E. coli* were higher than the tolerable risks.

Therefore, in light of these water quality worries of carcinogenic, non-cancer and infectious risks, immediate public awareness campaigns, enhancement of treatment processes at the source and point of use levels, remediation for contaminated sources supported by continuous monitoring, health programs, and community engagement initiatives are recommended. Furthermore, responsible organizations should develop proper policies, enforcement of regulatory measures, integrated watershed management and establish long-term sustainable water treatment technologies for urban, semi-urban, and rural settlements in the upper awash sub-basin.

Data availability statement

Data will be made available on request.

CRediT authorship contribution statement

Tesfa Aklilu: Writing – original draft, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Geremew Sahilu:** Writing – review & editing, Conceptualization. **Argaw Ambelu:** Writing – review & editing, Supervision.

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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