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Characterization of Physicochemical and Bacteriological Quality of Drinking Water and Associated Health Risks in Haramaya District, Eastern Ethiopia

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Abstract

Access to safe drinking water is vital component of public health interventions. However, drinking water in Eastern Ethiopia, including those in Haramaya District is exposed to various contaminants and contributing to public health risks. This study aims to assess the physicochemical and bacteriological qualities of drinking water and the associated public health risks in Haramaya District using a cross-sectional study. Water samples were analyzed for pH (7.06 to 7.763), T°C (20.12 to 23.25°C), turbidity (0.04 to 4.82 NTU), EC (83.564 to 400.11 µS/cm), TDS (400.1 to 1000 mg/L), and FRC (0 to 0.303 mg/L), Cl^- (95. 133 to 198.133 mg/L), SO_4^{2-} (50.45 to 225.4 mg/L), TA (234.09 to 268.1 mg/L), TH (530.17 to 1800.1 mg/L), Ca (30.04 to 47.17 mg/L), Mg (5.66 to 8.85 mg/L), K (0.68 to 10.12 mg/L), Na (13.52 to 21.47 mg/L), Mn (0 to 0.15 mg/L), Fe (0 to 0.49 mg/L), Cu (0.05 to 0.95 mg/L), Zn (0.03 to 0.42 mg/L), TC (9 to 27.9 CFU/100 mL), and *E. coli* (0 to 4.4 CFU/100 mL). Heavy metals (Cd, Cr, Pb, and Ni) were below methods of detection limits, indicating that water sources were free from toxic heavy metal. Most physicochemical parameters met standard limits set by Ethiopian Standards (ES) and World Health Organization (WHO), but 75% of the water samples indicated a moderate health risk due to poor water handling practices and natural impacts in some extent. Therefore, there is a critical need of intervention for sustainable drinking water management to reduce public health risks.

Keywords: *Bacteriological Parameters; Drinking Water Quality; Water Sources; Water Quality Guidelines; Physicochemical Parameters; Health Risk*

Abbreviations

APHA: American Public Health Association; CFU: Colony Forming Unit; CSA: Central Statistical Agency; *E. coli*: *Escherichia coli*; EC: Electrical Conductivity; ES: Ethiopian Standards; FRC: Free Residual Chlorine; MV: Median Value; SE: Standard Error; TA: Total Alkalinity; TC: Total Coliform; T°C: Temperatures in Degree Centigrade; TDS: Total Dissolved Solids; WHO: World Health Organization

Introduction

Everyone has the fundamental human right to access clean drinking water. However, nearly 2 billion people worldwide do not have access to this basic resource [1,2]. This concern is especially severe in many developing nations, like Ethiopia, where environmental factors, outdated infrastructure, and socioeconomic problems hinder the provision of safe drinking water [1]. To be a drinking water is safe and acceptable, it must meet the standard limits set by the WHO and various organizations, tailored to the specific conditions of each country [3]. Drinking water should not pose any significant long-term health risks [4]. However, nearly 3.6 billion people were exposed to waterborne disease in the world [5,6].

Assessing drinking water to determine the level of contamination and potential health risks involves analyzing water quality in terms of physicochemical and bacteriological parameters. Bacteriological analysis aims to identify harmful bacteria, such as fecal coliforms (FC), total coliforms (TC), and other pathogenic bacteria, which indicate possible waterborne illnesses. Physicochemical parameters such as temperature, electrical conductivity (EC), turbidity, total dissolved solids (TDS), and others provide insight into the chemical composition and potential physical quality of water [4]. While physical degradation of water quality does not immediately harm health, it can signal potential chemical and microbiological contamination. For instance, excessive turbidity in water can promote the growth of bacteria and other dangerous microbes [3]. Different chemical parameters in drinking water such as fluoride (F^-), chloride (Cl^-), heavy metals or trace metals, hardness, sulfate (SO_4^{2-}) etc., can be pollutants if they exceed recommended limits and lead to various health complications [7]. Different chemical pollutants and other toxic elements leached from underground rock formations pose significant health risks [2].

Breathing difficulties and cancer are among the health risks that can arise from drinking water with excessive metal concentrations. Measuring and monitoring these metal concentrations in drinking water is crucial for human health and safety [8]. According to [9], the biological toxicity of trace elements like lead (Pb), cadmium (Cd), chromium (Cr), and copper (Cu) in drinking water can be extremely dangerous to human health. Liver disease, migraines, and neurological problems can also arise from these trace metals. Arsenic pollution can cause neurological, developmental, reproductive, respiratory, cardiovascular, gastrointestinal, hematological, hepatic, and carcinogenic effects [8].

Bacteriological contamination of drinking water is a significant concern in low-income countries, particularly in Africa [5]. Despite a significant progress on WASH sectors, only a few countries in sub-Saharan Africa have achieved access to clean water [10]. Ethiopia, despite its abundance of water resources, faces problem due to limited access to safe drinking water [11,12]. Among sub-Saharan nations, Ethiopia has one of the lowest access to clean drinking water [13]. Many drinking water sources in this country were exposed to various contaminants, posing a serious health risk [14]. Previous studies conducted in different parts of Ethiopia that have drawn attention to the increasing frequency of waterborne diseases [13,15-17]. Eastern Ethiopia, in particular, facing a critical health challenges due to the consumption of contaminated water [15]. This is especially true for the Haramaya District in Eastern Ethiopia, where communities are exposed to waterborne disease, significantly contributing to public health risks. Studies underscored the need for continuous water quality monitoring and evaluation to ensure the safety of drinking water sources.

Despite these concerns, there is limited information available on drinking water quality in terms of physicochemical and bacteriological aspects. This makes it challenging to implement effective water quality management and public health interventions. To tackle this challenge, it is crucial to provide a detailed assessments and analysis of water quality status and the associated health risks. The main objective of this study is to assess drinking water quality in terms of physicochemical and bacteriological parameters, as well as health risks associated with consuming of contaminated water in the Haramaya District, Eastern Ethiopia. The study aims to offer a clear understanding of water quality in this area and inform the local community about potential health risks from their drinking water sources.

Overall, the study seeks to offer evidence-based data from findings that can aware the community, local authorities, and other stakeholders about the status of drinking water quality in the present study area and this contributes to the effective implementation in protection of drinking water quality. The findings will serve as references for future studies and public health professionals to act on area of concerns.

Methodology

Study area description

The Haramaya District is situated in 507 km southeast of Addis Ababa, the capital city of Ethiopia, in the East Hareghe Zone of the Oromia Regional State in Eastern Ethiopia (Figure 1). It is located at an altitude ranging from 1400 to 2340 meters above sea level, with geographic coordinates between 9°06’0’’ to 9°28’0’’ latitude and 41°55’30’’ to 42°06’30’’ longitude. The annual rainfall in the area varies from 600 to 1260 mm, with temperatures ranging from 17°C to 25°C. According to the Central Statistical Agency (CSA), the District has a total population of 271,018, consisting of 138,282 males and 132,736 females [18]. Based on the [19] population projection, the district’s total population is estimated to be 423,131, with 214,661 males and 208,470 females. The predominant farming system in the area is mixed crop-livestock production, with khat (*Catha edulis*) being the main cash crop, and potatoes (*Solanum tuberosum*), tomatoes (*Solanum lycopersicum*), sorghum (*Sorghum bicolor*), and maize (*Zea mays*) as staple crops. There is potential groundwater in the area. The peoples obtain their drinking water from springs, reservoirs, boreholes or dug wells, and rivers [20].

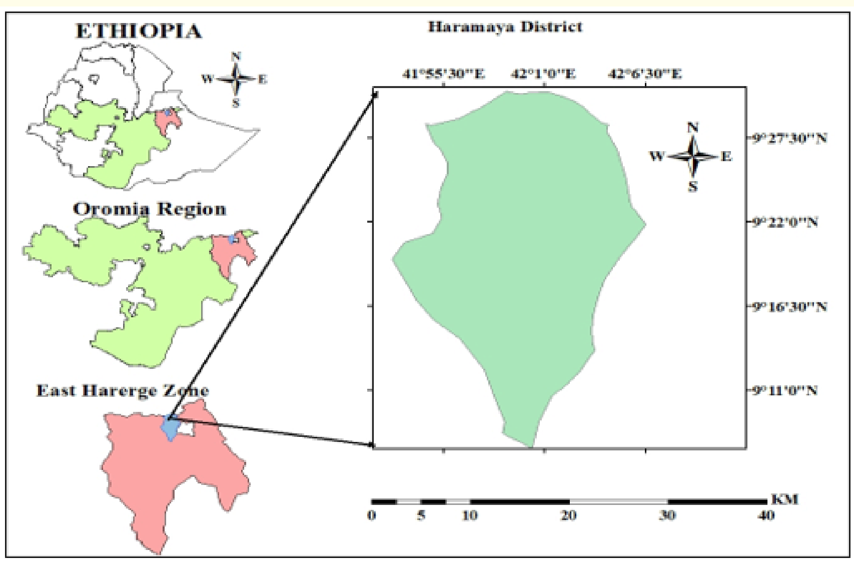

Figure 1: *Study area map.*

Research design

To assess the quality of drinking water and associated risks, a cross sectional study design was utilized.

Sampling

Water samples were collected from dug wells, springs, and reservoirs between December 2024 and April 2025, during the dry and partially dry season. Sterile polyethylene bottles that had been conditioned with 5% nitric acid and rinsed thoroughly with distilled water were used for sample collection. The samples were transported to Haramaya University Laboratory. Plastic bottles were utilized for water samples that analyzed for physicochemical parameters, while 250 mL glass bottles were used for analysis of bacteriological parameters. Sampling sites and water sources were purposively selected based on their capacity to serve large populations. For example, one spring in a rural area serves a significant number of people who must travel long distances to access water. This issue is also the same for water supply from dug wells in rural areas. In addition, two reservoirs serve a large urban community, and one of them was selected for the study. The study area is geographically almost similar, as well as in terms of water supply systems. Therefore, the researchers believe that the water quality status will be almost similar across the same water sources. As a result, the researchers expect that samples from 12 distinct water sources can represent the remaining sources.

Drinking water in Haramaya District predominantly originates from homogenous shallow volcanic aquifer systems with almost similar lithology and recharge mechanisms [21,22]. A study by [23] in Harar and Dire Dawa, Eastern Ethiopia, demonstrated that the spatial variability of major physicochemical parameters among groundwater sources was low due to comparable geological formations. According to [24,25] guidelines, if water sources share similar hydrological and land use conditions, the representative sampling is appropriate. The selected water sources of the present study cover major types of water sources within the district and there are very few water sources serving the population of the district. Therefore, the chosen 12 water sources are adequate to represent the water quality status in Haramaya District

To ensure sample integrity, all collected samples were preserved in insulated coolers with ice packs and transported to the laboratory within 6 hours of collection. For bacteriological analysis, samples were treated with sodium thiosulfate to neutralize any residual chlorine. Standardized laboratory protocols outlined in the [26] were followed for sample handling, solution preparation, instrument calibration, and sample digestion. Bacteriological data tests were conducted using established microbiological methods. Rigorous data accuracy control measures, such as field blanks, strip blanks and duplicate water sample tests were implemented. Detailed documentation of environmental conditions during sample collection was maintained to provide context for the results obtained.

Data analysis

The analytical processes of all physicochemical and bacteriological parameters were performed following quality assurance procedures recommended by [26]. Triplicate analysis was performed for each water sample and then the values were used for interpretation. AAS and other analysis instruments were calibrated using a series of certified standard solutions in their expected standard concentrations ranges. Calibration curves with $R^2 \geq 0.99$ were generated for verification of instruments during analysis. All sampling bottles and glassware were thoroughly washed with acid and rinsed with distilled water. Blanks were also included in laboratory analysis procedures to check for contamination. Sterility of media, membrane filters, and instruments was ensured by autoclaving, and blanks were run for the analysis of bacteriological parameters.

Physicochemical parameters

Temperature was measured with a digital thermometer (Thermo Scientific Traceable) immediately upon sample collection to capture *in situ* conditions. pH was tested with a calibrated pH meter (Hach HQ40d, Hach Company) using standard solutions (pH 4.00 and 7.00). Turbidity levels were quantified with a turbidity meter (Hach TL23, Thermo Scientific AQ4500) calibrated with standard solutions. A conductivity meter (Cyber Scan PC USA) calibrated with standard solutions was used to test electrical conductivity (EC). Total dissolved solids (TDS) were determined through gravimetric methods by drying well-homogenized samples at 105°C. Free residual chlorine (FRC) was analyzed using the iodometric method, which involves titration with a standard solution of sodium thiosulfate for precise quantification. Chloride (Cl^-) concentrations were determined via titrimetric methods using silver nitrate as the titrant and potassium chromate as an indicator. Sulfate (SO_4^{2-}) levels were quantified using a spectrophotometric method measuring the formation of a barium sulfate precipitate. Alkalinity and hardness were assessed through titration methods, with alkalinity determined using sulfuric acid as the titrant and hardness evaluated based on complexometric titration with EDTA.

An Atomic Absorption Spectrophotometer (AAS) was used to determine the concentrations of metals such as zinc (Zn), manganese (Mn), nickel (Ni), magnesium (Mg), cadmium (Cd), calcium (Ca), iron (Fe), copper (Cu), and lead (Pb). Calibration curves were generated using standard metal solutions for accurate quantification. A Flame Photometer (410) was used to determine the cations potassium (K) and sodium (Na). All analytical procedures followed the guidelines set forth by [26] for methodological rigor and data integrity.

The AAS instrumental detection limits presented in the table 1 were referenced from [27] and [28].

S. No	Metals	AAS detection limits (mg/L)	S. No	Metals	AAS detection limits (mg/L)
1	Cd	0.01		Zn	0.005
2	Ni	0.05		Mn	0.01
3	Pb	0.02		Mg	0.02
4	Cr	0.05		Ca	0.02
5	Cu	0.01		Fe	0.02

Table 1: *Detection limits of AAS for each metals.*

Bacteriological parameters

The critical water quality indicator bacteria like TC and FC particularly *Escherichia* coli (*E. coli*) were quantified. This was done following the standardized procedures outlined in the [26] guidelines for examining water and wastewater. The membrane filtration method provides a more selective method of identifying these indicator bacteria, and this method was used to determine the presence of TC and *E. coli.* A sterile membrane filter with 0.45-micron pore size was used to filter a known volume of water sample. After that, the filter was placed on selective culture media and left to incubate for a predetermined amount of time at an appropriate temperature. Following incubation, the quantities of colonies on the culture plate were measured and reported as colony-forming units per 100 mL of water sample (CFU/100 mL) and calculated as:

$$\text{CFU per 100 mL of water sample} = \left(\frac{\text{Number of colonies}}{\text{Volume of sample}}\right) * 100$$

Risk characterization

Characterizing the risks associated with drinking water contamination is crucial for understanding public health implications. The primary risks to human health associated with water quality are mostly microbiological in nature [24]. Different pathogenic bacteria can exist in water. However, coliform bacteria are used as a primary indicator of potential water contamination. Their presence in water indicates contamination of water by fecal materials [24]. In this study, risk levels were categorized based on the concentrations of coliform bacteria according to [24] guidelines.

E. coli	TC	Risk levels	WHO remark	Health implications
0	0	No risk	In conformity with guidelines	Acceptable water quality
0	1-10	Low risk	Not in conformity with guidelines	Potential for low-level exposure; low intervention needed
1-10	11-100	Intermediate risk	Not in conformity with guidelines	Significant risk of waterborne disease; moderate intervention needed
>10	>100	High risk	Not in conformity with guidelines	Severe contamination; high intervention (urgent action) needed

Table 2: *Risk levels of drinking water associated with coliforms.*

Source: [24].

Statistical analysis

The water quality data was analyzed using R software version 4.5.0. The analysis started with data preparation and integrity checks. Various statistical analyses, such as mean, median, standard deviation, standard errors, and range, were conducted for each parameter. Additionally, a correlation matrix was used to see the relationship among the water quality parameters to identify common possible sources influencing water quality. Furthermore, the normality of variables was assessed to determine appropriate statistical tests and predict whether pollution sources are heterogeneous or homogeneous. These results were then compared against WHO guidelines and ES to identify any exceedances. Charts were utilized for data visualization to assist in result interpretation. The findings were compiled into comprehensive tables and figures to clarify the relationship between water quality standards and public health implications.

Results and Discussion

Physicochemical quality of water

Analysis of physical parameters

The physical parameters of the drinking water across sampling sources in Haramaya District are summarized in the table 3.

Sample ID	T°C	Turbidity (NTU)	TDS (mg/L)	EC (µS/cm)
S1	22.63 ± 0.050	4.55 ± 0.006	950.2 ± 0.044	104.61 ± 0.015
S2	22.61 ± 0.038	4.82 ± 0.009	885.3 ± 0.015	109.86 ± 0.006
S3	22.47 ± 0.033	4.61 ± 0.006	800.2 ± 0.039	98.6362 ± 0.018
S4	22.78 ± 0.044	4.53 ± 0.006	895.3 ± 0.029	110.941 ± 0.005
S5	20.32 ± 0.012	1.12 ± 0.060	490.1 ± 0.058	87.1367 ± 0.075
S6	20.12 ± 0.012	0.08 ± 0.006	500.2 ± 0.045	83.5642 ± 0.009
S7	23.25 ± 0.024	3.21 ± 0.009	875.1 ± 0.058	128.574 ± 0.009
S8	22.28 ± 0.015	1.60 ± 0.058	1000 ± 0.012	139.561 ± 0.006
S9	21.71 ± 0.023	1.25 ± 0.029	960.1 ± 0.063	138.75 ± 0.087
S10	20.50 ± 0.115	0.06 ± 0.006	500.1 ± 0.049	327.167 ± 0.088
S11	20.60 ± 0.058	0.05 ± 0.006	500.1 ± 0.052	370.103 ± 0.058
S12	20.50 ± 0.058	0.04 ± 0.006	400.1 ± 0.055	400.11 ± 0.056

Max.	23.247	4.82	1000	400.11 ± 0.056
Min.	20.12	0.04	400.1	83.564 ± 0.009
MV	21.995	1.425	837.65	119.76
(29)	-	5	1000	-
(30)	15-35	0.3-25	200-2500	170-2700

Table 3: *Physical parameters of water samples.*

Note: SE: Standard Error; T°C: Temperatures in Degree Centigrade; MV: Median Value; WHO: World Health Organization; ES: Ethiopian Standard.

Result: As shown table 3, the temperature ranged from 20.12 ± 0.012 to 23.25 ± 0.024°C, with a median value of 21.995°C. The total dissolved solids (TDS) concentrations in the drinking water ranged from 400.1 ± 0.055 to 1000 ± 0.012 mg/L, with median value of 837.65 mg/L. The turbidity levels ranged from 0.04 ± 0.006 to 4.82 ± 0.009 NTU, with a median value of 1.425 NTU, indicating a significant variation among sampling sites. EC levels ranged from 83.564 ± 0.009 to 400.11 ± 0.056 µS/cm, with a median value of 119.76 µS/cm (Table 3).

Discussion: Temperature is very important parameter that can significantly influence the chemical, physical, and microbiological quality of drinking water [30]. The water temperature of the present study is higher than the mean value (16.65°C) reported by [31] in Jima Zone, Southwestern Ethiopia but lower than those reported by [32] in Wondogenet Campus, Southern Ethiopia, with a mean value of 28.49°C. This indicates that local climatic conditions and catchment characteristics may affect the water temperature. The findings of [33] in Southwestern Ethiopia, with a mean value of 22.22°C, are comparable to the water temperature in Haramaya District. The observed temperature in the drinking water in this study found within the recommended range (15 - 35°C) [30]. Therefore, the temperature does not significantly affect drinking water quality, contributing to health risks.

The TDS concentrations in the drinking water in Haramaya District exceeded those reported by [32] in the southern part of Ethiopia, which may be due to groundwater-rock interaction and local conditions of hydro geochemistry. However, the findings of this study remain within the standard limits set by [29] and [30]. Therefore, the TDS concentrations in the drinking water in Haramaya District are unlikely to have an adverse impact on water quality. The turbidity levels in drinking water sources of the Haramaya District showed that drinking water was at good quality, as they comply with [29] and [30] standards. However, three water sources showed low turbidity levels and below the [30] standards. It is important to note that turbidity levels below the standards can impact water quality, and contributing a suitable environment for microbial growth and allowing pathogens to persist in drinking water, leading to public health risks [2].

The presence of dissolved salts significantly affects EC of water [4]. In the Haramaya District, the EC levels in most of drinking water sources were below the [30] standard limit, except for those from three sources. Water samples from these three sources were in line with the WHO standard. A relatively similar study conducted by [32] at Wondo Genet Campus in Southern Ethiopia, reported a mean EC value of 192.14 µS/cm, which is higher than the EC levels demonstrated in the Haramaya District. This may due to variation in mineral content and salinity of water sources at different geological conditions.

Analysis of chemical parameters

Results: As indicated in table 4, the pH of drinking water ranged from 7.06 ± 0.006 to 7.76 ± 0.009, with a median value of 7.12. The sulfate (SO_4^{2-}) concentrations spanned from 50.45 ± 0.090 to 225.4 ± 0.039 mg/L, with a median value of 142.8 mg/L, the concentrations

Sample ID	pH ± SE	SO_4^{2-} (mg/L) ± SE	Cl^- (mg/L) ± SE	FRC (mg/L) ± SE	TA (mg/L) ± SE	TH (mg/L) ± SE
S1	7.19 ± 0.004	170.3 ± 0.073	148.12 ± 0.012	0 ± 0	237.1 ± 0.052	560.13 ± 0.015
S2	7.19 ± 0.004	160.2 ± 0.044	98.93 ± 0.015	0 ± 0	241.09 ± 0.048	580.13 ± 0.012
S3	7.11 ± 0.003	225.4 ± 0.039	148.10 ± 0.009	0 ± 0	239.14 ± 0.076	570.23 ± 0.015
S4	7.11 ± 0.003	210.2 ± 0.070	98.91 ± 0.009	0 ± 0	234.09 ± 0.046	530.17 ± 0.065
S5	7.09 ± 0.004	60.14 ± 0.072	97.09 ± 0.046	0 ± 0	236.08 ± 0.043	540.13 ± 0.088
S6	7.12 ± 0.005	170.1 ± 0.073	98.72 ± 0.012	0.213 ± 0.015	250.09 ± 0.047	590.20 ± 0.058
S7	7.11 ± 0.003	145.3 ± 0.050	197.41 ± 0.021	0 ± 0	255.1 ± 0.049	650.26 ± 0.02
S8	7.08 ± 0.005	140.3 ± 0.058	198.13 ± 0.467	0 ± 0	252.08 ± 0.042	600.26 ± 0.021
S9	7.06 ± 0.006	139.5 ± 0.023	197.23 ± 0.015	0 ± 0	251.49 ± 0.067	600.16 ± 0.082
S10	7.76 ± 0.009	50.58 ± 0.073	100.10 ± 0.058	0.22 ± 0.021	268.1 ± 0.058	1800.10 ± 0.058
S11	7.55 ± 0.009	80.59 ± 0.073	110.17 ± 0.089	0.25 ± 0.015	260.09 ± 0.045	1440.10 ± 0.06
S12	7.64 ± 0.021	50.45 ± 0.090	95.13 ± 0.089	0.30 ± 0.006	262.1 ± 0.049	1600.10 ± 0.054
MV	7.12	142.8	105.1	0	250.79	595.18
Max	7.76 ± 0.009	225.4 ± 0.039	198.133 ± 0.467	0.303 ± 0.006	268.1 ± 0.058	1800.1 ± 0.058
Min	7.06 ± 0.006	50.45 ± 0.090	95.133 ± 0.089	0	234.09 ± 0.046	530.17 ± 0.065
(29)	6.5-8.5	250	250	0.5	-	-
(30)	6.5-8.5	50 - 800	20-1000	0.1-5	20-200	100-1000

Table 4: *Chemicals concentrations in water samples.*

EC: Electrical Conductivity; FRC: Free Residual Chlorine; Cl^-: Chloride; SO_4^{2}: Sulfate; TA: Total Alkalinity; TH: Total Hardness; SE: Standard Error; MV: Median Value; ES: Ethiopian Standard; WHO: World health Organization.

of Cl^- ranged from 95.133 ± 0.089 to 198.133 ± 0.467 mg/L, with a median value of 105.1 mg/L. The concentrations of free residual chlorine (FRC) was generally low in the drinking water ranging from 0 - 0.303 ± 0.006 mg/L. The concentrations of total alkalinity (TA) ranged from 234.09 ± 0.046 to 268.1 ± 0.058 mg/L, with a median value of 250.79 mg/L. The concentrations of total hardness (TH) ranged from 530.17 ± 0.065 to 1800.1 ± 0.058 mg/L with a median value of 595.18 mg/L (Table 4), indicating spatial variability among sample point.

Discussion: The pH values of present study indicate that the drinking water in the study area was approximately neutral and found within the standard range (6.5-8.5) set by [29] and [30]. Comparing these findings with earlier studies by [31,33,34] in other regions of Ethiopia shows that the pH values in Haramaya District was in similar ranges to those reported. The pH values of drinking water sources in Haramaya District met the standard limits ensured the safety of water for consumption without significant health risks.

The findings regarding the SO_4^{2-} concentrations of drinking water in the Haramaya District offer valuable insights into the chemical composition and quality of water sources. Comparing the findings to established standards (50 - 800 mg/L) stipulated by [29] and [30] reveals that the SO_4^{2-} levels for present findings fall comfortably within these prescribed limits. The adherence to regulatory standards underscores the suitability of water for drinking, affirming that SO_4^{2-} concentrations exist at a level that would not pose a risk to human health.

The analysis of Cl^- concentrations in the drinking water of the Haramaya District provides a comprehensive overview of the variability in the Cl^- in the drinking water sources. The Cl^- concentrations in the water sources found well within prescribed limits set by [29] and [30] confirming the safety of water for consumption without significant risk to human health. Similar studies by [31,35,36] reported a mean Cl^- concentrations of 53.7 mg/L, 32.90 - 85.77 mg/L and 10.07-30.0 mg/L, in other regions of Ethiopia respectively, indicated that the Cl^- concentrations in the drinking water of the Haramaya District were notably higher.

Another water quality parameter analyzed in the case of the Haramaya District was FRC. A similar study in another region of Ethiopia by [34] reported mean FRC concentrations of 0.05 mg/L, underscoring lower FRC concentrations than present findings. It is noteworthy that, except for samples from four water sources, the FRC in the drinking water of the Haramaya District was below the standard limits set by [29] and [30] for drinking water, with it being not detectable in eight water sources. Majority of water sources were below the standard; however, four water sources were in line with WHO guidelines, assuring suitability for consumption without significant public health risks.

The concentrations of TA exceeded the recommended operational values of [30] of 20 - 200 mg/L. In contrast, a study by [37] in Addis Ababa indicated that the TA in spring, tap, and well water was below the WHO standard. Although WHO does not identify TA as a health-based water drinking quality parameter, elevated TA mainly affects taste. Similarly, a study by [38] in the Wolaita Zone of Southern Ethiopia showed that TA in spring, tap and well water exceeded the ES and WHO standard, underscoring the necessity of remedial action needed to make these water sources safe for drinking.

The concentrations TH indicating varying distribution of Ca and Mg in water sources. Except for samples from three water sources, the TH concentrations in the drinking water of Haramaya District were within the [30] standard limit. The finding indicated that most water sources meet the operational and aesthetic quality limit set by the WHO. While the TH levels in three sources exceeded the standard limits, the WHO reports no direct health risks associated with it. However, these sources can cause scaling effects, taste problems, and reduced soap efficiency. This highlights the necessity of water quality monitoring in those water sources through reducing the concentrations of ions that exacerbate hardness. In contrast, a study in the Wolaita Zone of Southern Ethiopia showed that the mean values of drinking water from different water sources were within acceptable standard limits [38].

Alkali and alkaline earth metals

Sample ID	Na^+ (mg/L) ± SE	K^+ (mg/L) ± SE	Ca^{2+} (mg/L) ± SE	Mg^{2+} (mg/L) ± SE
S1	20.41 ± 0.052	7.12 ± 0.060	32.58 ± 0.044	6.25 ± 0.032
S2	19.04 ± 0.043	6.23 ± 0.033	35.09 ± 0.046	6.68 ± 0.015
S3	18.34 ± 0.032	5.17 ± 0.037	33.57 ± 0.033	6.46 ± 0.029
S4	19.54 ± 0.015	6.77 ± 0.033	30.04 ± 0.040	5.66 ± 0.03
S5	15.13 ± 0.015	1.65 ± 0.025	31.68 ± 0.039	5.89 ± 0.046
S6	18.03 ± 0.033	4.77 ± 0.037	36.15 ± 0.029	6.90 ± 0.015
S7	18.54 ± 0.030	5.84 ± 0.030	38.26 ± 0.030	7.81 ± 0.023
S8	21.47 ± 0.037	10.1 ± 0.058	37.2 ± 0.056	7.45 ± 0.029
S9	20.56 ± 0.032	10.12 ± 0.062	37.12 ± 0.062	7.16 ± 0.032
S10	17.42 ± 0.044	1.37 ± 0.009	47.17 ± 0.021	8.49 ± 0.647
S11	17.76 ± 0.019	1.38 ± 0.006	39.67 ± 0.022	8.24 ± 0.03
S12	13.52 ± 0.012	0.68 ± 0.290	42.06 ± 0.019	8.85 ± 0.029
MV	18.44	5.505	36.64	7.03
Max	21.47 ± 0.037	10.12 ± 0.062	47.17 ± 0.021	8.85 ± 0.029
Min	13.52 ± 0.012	0.68 ± 0.290	30.04 ± 0.040	5.66 ± 0.03
[29]	200	1.5	75	50
[30]	100 - 400	0.2 - 50	30 - 500	0.1 - 1000

Table 5: *Metal concentrations of water samples.*

Na^+: Sodium; K^+: Potassium; Ca^{2+}: Calcium; Mg^{2+}: Magnesium; MV: Median Value.

Results: As presented in table 5, the concentrations of Na^+ ranged from 13.52 to 21.47 ± 0.037 mg/L, with a median value of 18.44 mg/L, K^+ concentrations varied from 0.68 ± 0.290 to 10.12 ± 0.062 mg/L, with a median value of 5.505 mg/L. Ca^{2+} concentrations ranged from 30.04 ± 0.040 to 47.17 ± 0.021 mg/L, with a median value of 36.64 mg/L. The concentrations of Mg^{2+} ranged from 5.66 ± 0.03 to 8.85 ± 0.029 mg/L, with a median value of 7.03 mg/L.

Discussion: The findings as indicated in table 5 showed that the concentrations of alkali and alkaline earth metals such as Na^+, K^+ Ca2+, and Mg^{2+} were within the standard limits set by [29] and [30] for drinking water. Specifically, the concentrations of Na^+ were below the allowable limit set by [30], but within the recommended limit of [29]. These findings highlight that the drinking water sources in Haramaya District contain appropriate mineral concentrations for safe consumption, thereby contributing for human health and well-being. Essential metals like Ca^{2+}, Mg^{2+}, Na^+, and K are crucial for various physiological functions in the body and are necessary for overall health [39,40]. Luckily, the concentrations of these metals observed in the present study area were within safe limits, indicating that drinking water sources in the district can be consumed without adverse health effects.

Heavy metal concentrations

Sample ID	Cd	Cr	Pb	Ni	Mn	Fe	Cu	Zn
	± SE	± SE	± SE	± SE	± SE	± SE	± SE	± SE
S1	Nd	Nd	Nd	Nd	Nd	0.448 ± 0.002	0.82 ± 0.006	0.13 ± 0.012
S2	Nd	Nd	Nd	Nd	Nd	0.443 ± 0.006	0.22 ± 0.006	0.09 ± 0.003
S3	Nd	Nd	Nd	Nd	0.15 ± 0.035	0.44 ± 0.001	0.25 ± 0.009	0.24 ± 0.031
S4	Nd	Nd	Nd	Nd	0.13 ± 0.012	0.445 ± 0.012	0.06 ± 0.015	0.34 ± 0.031
S5	Nd	Nd	Nd	Nd	0.13 ± 0.002	0.437 ± 0.002	0.25 ± 0.002	0.39 ± 0.009
S6	Nd	Nd	Nd	Nd	Nd	0.435 ± 0.001	0.12 ± 0.009	0.17 ± 0.013
S7	Nd	Nd	Nd	Nd	Nd	0.446 ± 0.002	0.11 ± 0.009	0.37 ± 0.017
S8	Nd	Nd	Nd	Nd	Nd	0.449 ± 0.008	0.95 ± 0.006	0.40 ± 0.029
S9	Nd	Nd	Nd	Nd	Nd	0.443 ± 0.015	0.93 ± 0.012	0.42 ± 0.012
S10	Nd	Nd	Nd	Nd	Nd	Nd	0.17 ± 0.009	0.03 ± 0.003
S11	Nd	Nd	Nd	Nd	Nd	Nd	0.15 ± 0.009	0.06 ± 0.003
S12	Nd	Nd	Nd	Nd	Nd	Nd	0.05 ± 0.015	0.044 ± 0.003
MV	-	-	-	-	0.13	0.43	0.195	0.205
Max	-	-	-	-	0.15 ± 0.035	0.49 ± 0.008	0.95 ± 0.006	0.42 ± 0.012
Min	-	-	-	-	0	0	0.05 ± 0.015	0.03 ± 0.003
[29]	-	-	-	-	0.1	0.3	2	5
[30]	$5*10^{-6}$ - 0.15	0.05 - 0.5	0.005 - 0.1	0.01 - 0.25	0.01 - 0.5	0.2 - 2.0	0.001 - 3.0	0.01 - 15

Table 6: *Concentrations of heavy metals (mg/L) in water samples.*

Nd: Below Methods of Detection Limit; Cd: Cadmium; Pb: Lead; Ni: Nickel; Mn: Manganese; Fe: Iron; Cu: Copper; Zn: Zinc; Cr: Chromium; MV: Median Value; SE: Standard Error.

Results: As presented in table 6, the concentrations of Mn ranged from 0 - 0.15 ± 0.035 mg/L, with a median value of 0.13 mg/L. Zn showed concentrations ranging from 0.03 ± 0.003 - 0.42 ± 0.012 mg/L, with a median value of 0.205 mg/L. Fe concentrations varied from 0 - 0.49 ± 0.008 mg/L, with a median value of 0.43 mg/L. Cu concentrations ranged from 0.05 ± 0.015 - 0.95 ± 0.006 mg/L, with a median value of 0.09 mg/L. However, Cd, Cr, Pb, and Ni were below the method detection limit of AAS for water samples (Table 1).

Discussion: Heavy metal concentrations were analyzed in drinking water sources of the Haramaya District were analyzed for heavy metals such as Zn, Fe, Cu, Mn, Cd, Cr, Pb, and Ni. The overall analysis of these metals indicated varying levels of concentrations in the water. Cu and Zn were found to be within the standard limits set by [29] and [30]. Cu is a crucial element for various enzymatic processes, while Zn plays a vital role in immune functions, protein synthesis, and wound healing [4]. The presence of these metals within acceptable limits indicates that the water is safe for consumption without contributing significant health risks. Except for three water sources, the concentration of Fe met the standard limits of [29] and [30]. Fe was not detected in those three water sources, indicating either a natural deficiency or potential issues with manmade problems. It is an essential nutrient necessary for oxygen transport in the circulatory systems [4]. Further investigations are needed to understand the reason behind the deficiency of Fe.

Furthermore, Mn was detected in only three water sources, with no Mn detected in the remaining samples. The present study indicated that Mn in most water sources were below method of detection limit. Moreover, the concentration of Cd, Cr, Pb, and Ni were below methods of detection limits in drinking water sources is a highly positive finding, indicating that the water sources were free from contamination from these poisonous metals. These metals are known for their toxicity and potential to cause severe health risks, including kidney damage, cancer, and neurological disorders [2]. Overall, the drinking water sources in the Haramaya District appear to be of good quality concerning poisonous metal concentrations.

Test of normality

Parameter	W Value	p-value	Normality Status
Ca (mg/L)	0.95918	0.7721	Normal
Cl (mg/L)	0.75775	0.003224	Not Normal
Cu	0.73308	0.00179	Not Normal
EC (µS/cm)	0.71617	0.001211	Not Normal
K (mg/L)	0.91262	0.2305	Normal
Mg (mg/L)	0.9651	0.8533	Normal
Na (mg/L)	0.93998	0.4978	Normal
pH	0.72051	0.001338	Not Normal
SO4 (mg/L)	0.91388	0.2392	Normal
Temperature	0.86345	0.05401	Normal
TA (mg/L)	0.93636	0.4525	Normal
TDS (mg/L)	0.82784	0.01976	Not Normal
TH (mg/L)	0.64996	0.0002895	Not Normal
Turbidity (NTU)	0.81853	0.01534	Not Normal
Zn	0.87357	0.07255	Normal

Table 7: *Normality tests of water quality parameters.*

Results: As indicated in table 7, several water quality parameters followed normal distributions, such as Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, SO_4^{-2}, TA, Zn, Temperature at p-values >0.05 in the Shapiro-Wilk test statistics, while Cl^{-}, Cu, EC, pH, TDS, TH, turbidity showing significant deviations from normal distribution at p-values >0.05. The findings of present study showed mixed distribution of data across water quality parameters.

Discussion: Several data including Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, SO_4^{-2}, TA, Zn, Temperature revealed p-values >0.05 in the Shapiro-Wilk test statistics (Table 7). This indicates that the distribution of parameters did not significantly deviate from normality. These distributions reflect the stable hydrogeochemical processes and relative uniformity of environmental influences across sampling sites, especially for naturally occurring ions that tend to follow predictable hydro-chemical conditions. However, Cl^{-}, Cu, EC, pH, TDS, TH, turbidity exhibited p-values less than 0.05, showing significant deviations from normal distribution. These conditions often arise from heterogeneous sources of pollution, intermittent contaminant events, or spatial-temporal variability in hydrogeochemical conditions. For instance, TDS and turbidity can exhibit skewed distribution due to seasonal fluctuations, runoff, or different human activities. In general, the mixed normality test results underscore the complex and variable nature of water quality dynamics in the present study area.

Correlation matrix (CM) of physicochemical parameters

	Ca^{2+}	Cl	Cu	EC	FRC	K^{+}	Mg^{2+}	Na^{+}	pH	SO^{2-}_4	T°C	TA	TDS	TH	Turb.	Zn
Ca^{2+}	1	-0.037	-0.153	0.784	0.703	-0.420	0.933	-0.303	0.811	-0.663	-0.441	0.966	-0.463	0.866	-0.657	-0.512
Cl	-0.037	1	0.691	-0.305	-0.527	0.729	0.052	0.629	-0.478	0.294	0.561	0.046	0.703	-0.383	0.186	0.623
Cu	-0.153	0.691	1	-0.300	-0.469	0.740	-0.158	0.675	-0.390	0.160	0.274	-0.140	0.635	-0.362	0.097	0.412
EC	0.784	-0.305	-0.300	1	0.822	-0.632	0.848	-0.514	0.927	-0.717	-0.501	0.797	-0.602	0.956	-0.611	-0.631
FRC	0.703	-0.527	-0.469	0.822	1	-0.711	0.731	-0.603	0.824	-0.598	-0.760	0.738	-0.827	0.839	-0.754	-0.719
K^{+}	-0.420	0.729	0.740	-0.632	-0.711	1	-0.402	0.887	-0.726	0.657	0.673	-0.374	0.919	-0.701	0.474	0.615
Mg^{2+}	0.933	0.052	-0.158	0.848	0.731	-0.402	1	-0.344	0.762	-0.642	-0.375	0.967	-0.440	0.832	-0.648	-0.473
Na^{+}	-0.303	0.629	0.675	-0.514	-0.603	0.887	-0.344	1	-0.535	0.640	0.645	-0.278	0.868	-0.537	0.466	0.393
pH	0.811	-0.478	-0.390	0.927	0.824	-0.726	0.762	-0.535	1	-0.700	-0.531	0.744	-0.660	0.984	-0.533	-0.790
SO^{2-}_4	-0.663	0.294	0.160	-0.717	-0.598	0.657	-0.642	0.640	-0.700	1	0.700	-0.649	0.686	-0.740	0.766	0.325
T	-0.441	0.561	0.274	-0.501	-0.760	0.673	-0.375	0.645	-0.531	0.700	1	-0.457	0.888	-0.563	0.872	0.382
TA	0.966	0.046	-0.140	0.797	0.738	-0.374	0.967	-0.278	0.744	-0.649	-0.457	1	-0.461	0.826	-0.739	-0.413
TDS	-0.463	0.703	0.635	-0.602	-0.827	0.919	-0.440	0.868	-0.660	0.686	0.888	-0.461	1	-0.669	0.721	0.536
TH	0.866	-0.383	-0.362	0.956	0.839	-0.701	0.832	-0.537	0.984	-0.740	-0.563	0.826	-0.669	1	-0.628	-0.692
Turb	-0.657	0.186	0.097	-0.611	-0.754	0.474	-0.648	0.466	-0.533	0.766	0.872	-0.739	0.721	-0.628	1	0.200
Zn	-0.512	0.623	0.412	-0.631	-0.719	0.615	-0.473	0.393	-0.790	0.325	0.382	-0.413	0.536	-0.692	0.200	1

Table 8: *Correlation matrix of physicochemical parameters.*

Results: As indicated in table 8, there is strong and moderate relationships among water quality parameters. EC showed strong positive (+ve) association with TH (r = 0.96), pH (r = 0.93), Ca^{2+} (r =0.78) Mg^{2+} (r = 0.848), TA (r = 0.797). TH has also strong correlation with pH (r= 0.98), Ca^{2+} (r = 0.87), Mg^{2+} (r =0.83) and FRC (r = 0.84). Major cations also indicated a significant association, such as Ca^{2+} strongly correlate with TA (r = 0.97) and Mg^{2+} (r =0.93), while K^{+} and Na^{+} exhibited strong +ve relationship (r = 0.89). TDS has a +ve association with K^{+} (R = 0.92), Na^{+} (r = 87) and turbidity (r =0.72). Strong negative association were indicated between FRC and TDS (r = -0.83), EC and SO_4^{2-} (r = -0.72), and pH with Zn (r =- 0.79). These associations of water quality parameters exhibit the interconnected nature of physical and chemical process that affects water quality across sample sites.

Discussion: The findings of the study exhibited a strong geochemical link among major anions and cations, indicating that the ionic compositions of the drinking water sources in Haramaya District are governed by water-rock interaction and the dissolution of minerals. For instance, Ca^{2+} exhibited a very strong positive correlation with Mg^{2+}, TA, TH, and EC, revealing that bicarbonate (HCO_3) and carbonate (CO_3) weathering are dominant hydrogeochemical processes. Similarly, the highly significant relationships between pH and EC, and TH with EC, indicate the role of dissolved ions in regulating buffering capacity and ionic strength (Table 8). The negative association between Mg^{2+} and Ca^{2+} with Cl^- or Na^+ suggests that the major sources of water hardness arise from lithogenic rather than human influenced salinity. The strong cluster of hardness causing variables such as Mg^{2+}, Ca^{2+}, TH, TA, and EC shows the existence of a uniform geochemical origin that is consistent with CO_3 aquifer systems.

Analysis of bacteriological parameters

Sample ID	x̄ ± SE of *E. coli*	x̄ ± SE of TC
S1	0	14.8 ± 0.86
S2	0	13.2 ± 0.374
S3	0	22.8 ± 0.374
S4	0	22.2 ± 0.374
S5	0	19.6 ± 0.927
S6	0	10.2 ± 0.374
S7	2.8 ± 0.37	23.6 ± 0.510
S8	4.4 ± 0.51	27.4 ± 0.510
S9	3 ± 0.32	26.2 ± 0.583
S10	0	13 ± 0.707
S11	0	10 ± 0.707
S12	0	9 ± 0.707
MV	3	17.2
Max	4.4 ± 0.51	27.4 ± 0.510
Min	0	9 ± 0.510
[29]	0	0
[30]	0	0

Table 9: *Coliform concentration (CFU/100 mL) in drinking water.*

TC: Total Coliform; E. Coli: Escherichia coli; MV: Median Value.

Results: As shown in table 9, total coliform (TC) counts varied from 9 ± 0.707 to 27.9 ± 0.510 CFU/100 mL, with a median value of 17.2 CFU/100 mL, while the concentration of *E. coli* ranged from 0 to 4.4 ± 0.51 CFU/100 mL.

Discussion: Drinking water must be free from pathogenic bacteria. Among the numerous pathogens, coliforms are primary indicators of possible water contamination. They are used to detect the presence of other pathogenic bacteria. High coliform counts in drinking water indicate a high risk of contamination [2]. The common groups of coliforms are TC, FC, *E. coli*. The TC bacteria represent various types coliforms found in the environment. Their presence may not always indicate fecal contamination, mainly in tropical regions. *E. coli,* on the other hand, is a reliable indicator of fecal contamination [2]. Its presence is a clear sign of contamination that can lead to waterborne diseases [11].

In the Haramaya District, the prevalence of TC and *E. coli* (Table 9) in drinking water sources exhibiting bacteriological contamination. The concentration of *E. coli* in three water sources raises concerns about potential contamination and health risks. While most water sources were free of fecal contamination, the presence of TC in all water sources is still concerning. The prevalence of waterborne diseases like diarrhea and typhoid fever is posing a serious public health challenges in Eastern Ethiopia [15,41], which corroborate our findings. Overall, the findings of the present study indicate that water sources failed to conform to the standard limits set by [29,30].

Risk characterization

The drinking water in Haramaya District is contaminated with coliform bacteria. The results of the coliform tests on each water sample in the current investigation indicates that the drinking water can contribute to a significant public health risk (Table 10).

Sample ID	*E. coli*	TC	Category of Risks	Remark	Health implication
S1	0	14.8 ± 0.86	Intermediate risk	Not in conformity with guidelines	Moderate intervention needed
S2	0	13.2 ± 0.374	Intermediate risk	“	Moderate intervention needed
S3	0	22.8 ± 0.374	Intermediate risk	“	Moderate intervention needed
S4	0	22.2 ± 0.374	Intermediate risk	“	Moderate intervention needed
S5	0	19.6 ± 0.927	Intermediate risk	“	Moderate intervention needed
S6	0	10.2 ± 0.374	Low risk	“	Low intervention needed
S7	2.8 ± 0.374	23.6 ± 0.510	Intermediate risk	“	Moderate intervention needed
S8	4.4 ± 0.510	27.4 ± 0.510	Intermediate risk	“	Moderate intervention needed
S9	3 ± 0.316	26.2 ± 0.583	Intermediate risk	“	Moderate intervention needed
S10	0	13 ± 0.707	Intermediate risk	“	Moderate intervention needed
S11	0	10 ± 0.707	Low risk	“	Low intervention needed
S12	0	9 ± 0.707	Low risk	“	Low intervention needed

Table 10: *Concentration of coliform bacteria and risk level category.*

Results: As indicated in table 10, the concentration of TC and *E. coli* detected in 12 water samples. *E. coli* was not detected in only three water samples ranged from 2.8 ± 0.374-4.4 ± 0.510, while TC was detected in all water samples ranged from 9 ± 0.707-27.4 ± 0.510. Based on concentration of coliforms, 9 sampling sites were classified as intermediate risks and 3 sites were under low risk category. All samples were not conforming to the guideline values. Therefore, moderate is recommended for intermediate risk sites, while minimal intervention is needed for low risk sites.

Discussions

Risk distribution: According to WHO, drinking water should be free from coliforms in 100 mL of potable water samples, as its presence indicates fecal contamination of drinking water and risk of waterborne disease. In present study, *E. coli* was detected in 3 water samples indicating non-compliance with WHO guidelines, exhibiting significant public health concerns in these sites. *E. coli* was not detected in most water samples; however, TC were detected in all samples indicating non-compliance with WHO guidelines. TC indicates the existence of inadequate protection of water sources. Therefore, the water handling practices in study area was very poor.

According to risk-based classifications, most of sampling sites fell within intermediate risk categories. Only few sources were under low risk categories. Based on WHO guidelines, water sources with intermediate risk is associated with an elevated likelihood of adverse public health outcomes. Therefore, these findings underscore the need for effective bacteriological control measures, strengthened protection off water sources, and routine monitoring of water quality. Moreover, adoption of water safety plan is very important developed by WHO.

Risk visualization

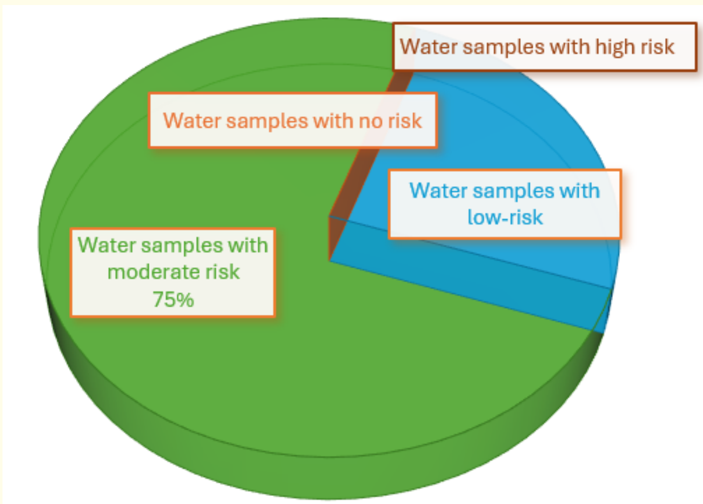

Figure 2: *Risk visualization of water samples.*

The findings indicated that none of the water samples were completely safe for consumption. Figure 2 shows that 25% of the samples had a low risk, suggesting minimal health concerns but still requiring basic treatment. The majority of water samples (75%) fell into the intermediate risk category, requiring moderate intervention. This is especially important for vulnerable populations such as children, the elderly, and individuals with compromised immune systems. In light of these findings, it is imperative to take swift and comprehensive action to tackle the problems. These actions may involve pollutant identification, implementing appropriate treatments like disinfection of contaminated water, educating the community to improve water handling practices, and ongoing monitoring of water resources. It is crucial to implement these recommendations to enhance overall water quality and reduce potential health risks in the study area.

Risk factors for water contamination

During site observations, researchers noted that drinking water sources in the study area were not protected from animal entry. Activities such as laundry and bathing near the drinking water sources, as well as the discharge of contaminated water into these sources

Figure 3: *Status of different water sources in rural areas of Haramaya district.*

were common practices (Figure 3). Additionally, the lack of latrine facilities contributing to open defecation practices, allowing animal and human waste to contaminate water sources. The findings by [42] in the Rural District of Shashemene in central Ethiopia support our findings. There is a similar challenge in the rural area of Haramaya District. Fecal material enters water sources through surface runoff during rainfall and infiltration into groundwater from contaminated environments contributing the growth of coliforms. A similar study by [15] indicated that drinking water in Eastern Ethiopia at HH level was significantly exposed FC bacteria where the unsafe surrounding environmental conditions were contributing significantly, corroborating the present findings. Therefore, improving water handling practices is crucial to enhance drinking water quality and reduce the risk of contamination.

Conclusion

Drinking water quality assessment in the Haramaya District has provided crucial insights into both physicochemical and bacteriological quality of drinking water. This study offers a comprehensive evaluation of drinking water quality in Haramaya District, Eastern Ethiopia, highlighting key areas for public health intervention and water management. The analysis of physicochemical quality revealed that most parameters, including T°C, TDS, turbidity, EC, SO_4^{2-}, Cl^-, FRC, Ca, Mg, K, Mn, Zn, Fe, and Cu were within acceptable limits of ES and WHO. However, TA and TH exceeded recommended limits in some samples, indicating potential water pollution issues related to water hardness and alkalinity that could affect domestic use. The concentration of Na^+ met the maximum limit set by ES but did not meet the standard set by WHO. Toxic heavy metals such as Cd, Cr, Pb, and Ni were below methods of detection limits, which is a positive outcome, indicating that water sources were free from harmful heavy metals.

The bacteriological quality analysis showed that water sources were contaminated with coliform bacteria especially TC and *E. coli*, with 75% of water samples posing a moderate health risk. The detection of *E. coli* suggests the potential presence of other pathogenic microorganisms that could pose serious health risks to the local population. While most physicochemical parameters met standard limits, the presence of coliforms indicates exposure to fecal pollution. This contamination poses a serious health risk, emphasizing the urgent need for effective water treatment and regular monitoring to ensure water quality.

Implementing a regular monitoring system will help promptly detect and address any deviations from standard limits. A public education campaign is also crucial to promote safe water handling practices. These combined efforts will greatly reduce health risks and improve the overall well-being of the community in the Haramaya District. Future research should focus on reflecting potential seasonal variations and longitudinal studies to observe changes in water quality over time and investigate potential sources of contamination. Addressing these water quality challenges in the Haramaya District is essential to protect community health and promote overall well-being. Collaborative efforts among local authorities, NGOs, and community members are necessary to ensure safe drinking water access for all individuals. In spite of the significant findings generated, the present study has some limitation such the absence of seasonal variation in water quality analysis, a relatively small sample size analyzed, and the water sampling covers small geographic scope. Therefore, future research should fill these gaps.

Data Availability

All relevant data is included in this manuscript.

Declaration of Interest Statement

The authors declare that they have no potentially conflicting financial interests or personal relationships that could have influenced the research work.

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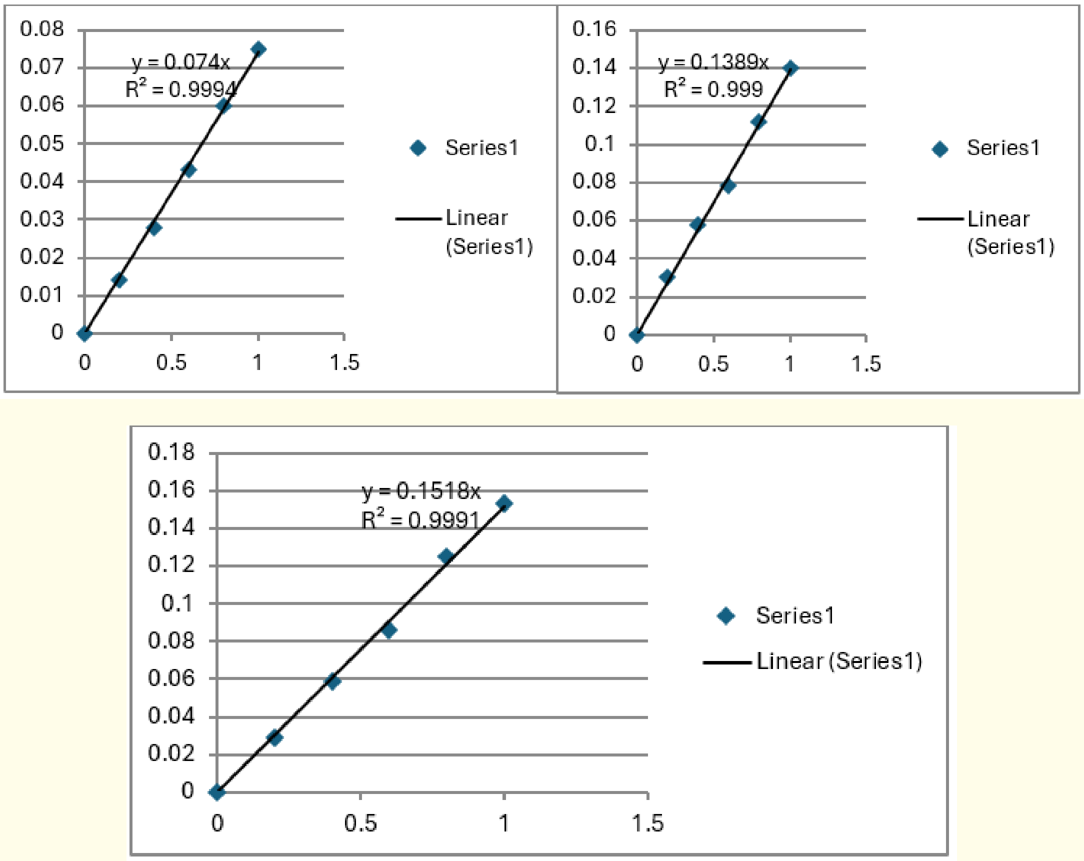
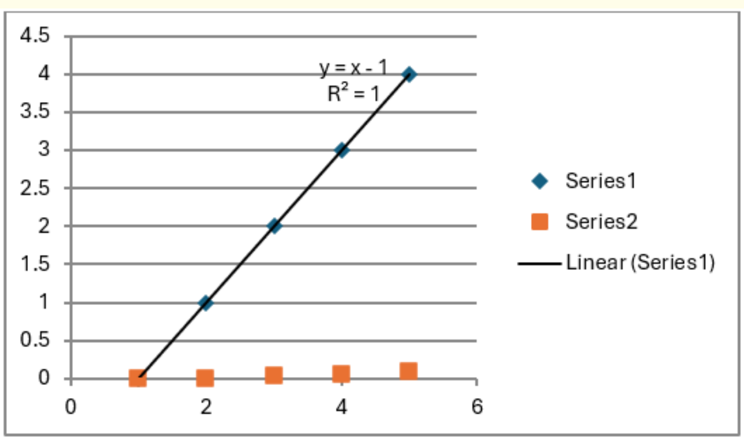
The author did not receive any funding for this study.

Appendix



Appendix Figure 1: *The calibration curves with R2 > 0. 99 generated for verification of instruments during analysis of heavy metals.*



Appendix Figure 2: *The calibration curves with R2 > 0. 99 generated for verification of instruments during analysis of* $SO4^{-2}$.

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