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Assessment of pathogenic and nonpathogenic contaminants and their relative risks: the case of Dilla town water sources, Ethiopia

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ABSTRACT

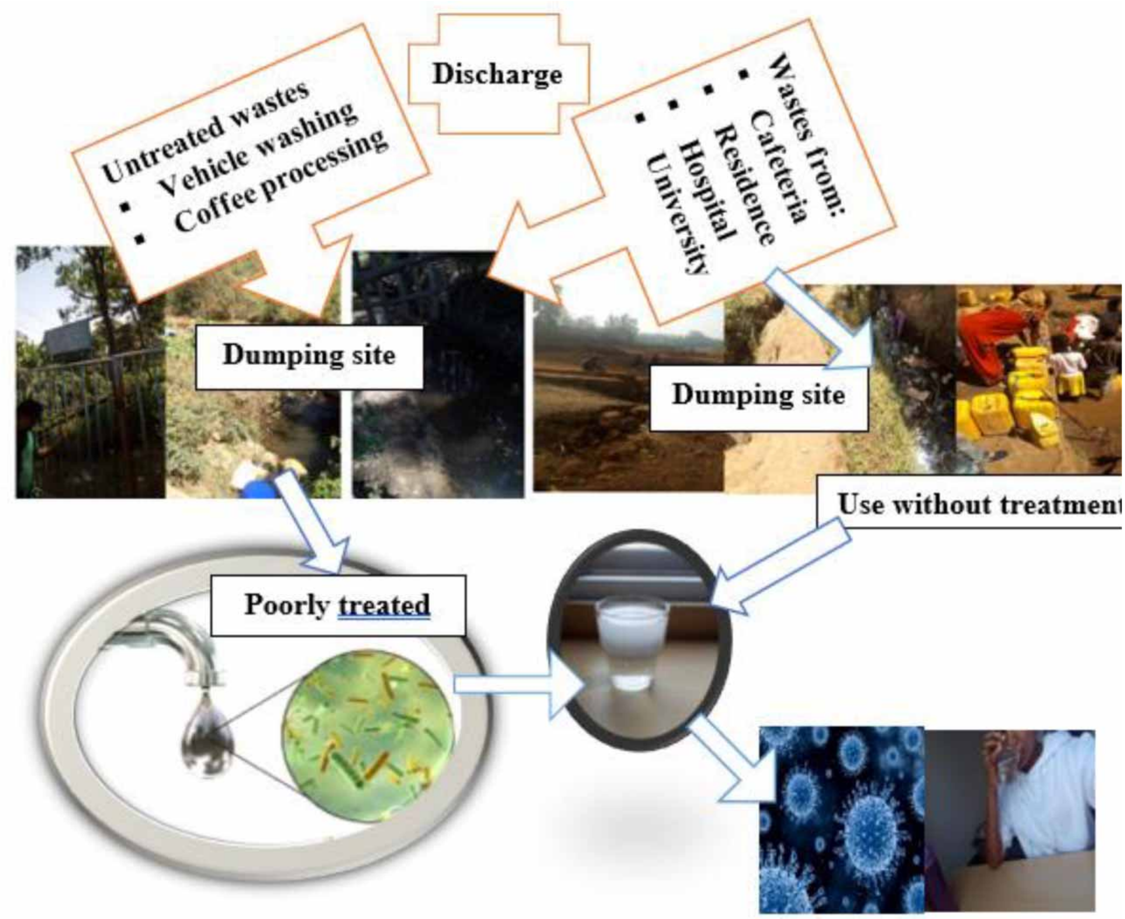
The state of positive health and wellbeing is impossible without safe water. This study was aimed to assess the quality of Dilla town water sources. A total of 108 water samples were collected from twelve sites and selected physical and chemical parameters were analyzed. Most of the physicochemical parameters were in the acceptable range for water quality of WHO and CES. Three sampling sites were contaminated by nitrate with concentration range 51.68–126.30 mg/L. The heavy metal analysis indicated that the levels of iron, zinc, manganese, and chromium in some of the sites exceed values of WHO standard concentrations in the range 0.506–5.773, 3.606–4.312, 0.194–0.588 and 0.053–0.098 mg/L respectively. While three heavy metals (mercury, arsenic and lead) were above the WHO limit in all the sites. The bacteriological analysis of all the water sources indicated microbial contamination, total count of the coliforms ranging from 3 to 80 MPN/100 mL. As per WHO criteria, some of the water sources were grouped in to high-risk. The cause of such contamination may be due to no treatment or poor processing system. Therefore, the need to Hygiene promotion programs, urgent and continuous monitoring is highly recommended.

Key words: contaminants, drinking water, health, pathogen, physicochemical

HIGHLIGHTS

- Electrical conductivity in four sites and temperature in five sites were beyond the WHO guideline.
- Highest nitrate level was determined in the water samples from untreated hand dug wells.
- The level of arsenic, mercury, and lead in all the sites were above the WHO and CES limit for drinking water.
- Microbial contamination was detected in all the water samples.

GRAPHICAL ABSTRACT



INTRODUCTION

Water is critical for sustainable development and indispensable for human development, health and wellbeing (Omari & Yeboah-Manu 2012). Since water is vital for our life, we expect it to be clean and safe. Even water that appears clear may not necessarily be safe or acceptable. The World Economic Forum (2018) ranked the water crisis in the top three global risks for two consecutive years. Failing to respond effectively to these challenges will have devastating global effects (World Health Organization 2018). However, water may become the source of human disease if it is exposed to bacteriological, chemical, and physical contaminants. Water also plays a significant role in the growth of pathogens: an estimation of 80–85% of the communicable disease is transmitted through water (Meride & Ayenew 2016; Lewoyehu 2021). Pathogenic contamination of water arguably represents the most significant risk to human health on a global scale, and there have been countless numbers of bacterial or food poisonings and disease outbreaks throughout history, deriving from poorly treated or untreated water (Levallois & Villanueva 2019).

Next to pathogenic contamination of drinking water, significant risks to human health also result from exposure to nonpathogenic, toxic contaminants that are often globally ubiquitous in waters from which drinking water is derived. Heavy metals have increasingly caused health concerns due to their hazardous bioaccumulation ability through the food chains even at low concentrations (Gall *et al.* 2015; Tang *et al.* 2018). Most of these non-degradable toxic elements, such as arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), nickel (Ni), lead (Pb), and zinc (Zn), are listed as priority pollutants to control by the US Environmental Protection Agency (EPA) (Cobbina *et al.* 2015; Huang *et al.* 2020). Drinking water that does not meet regulatory guidelines can cause serious diseases in humans, especially in children, who are more vulnerable to infection (Thangiah 2019; Rahman *et al.* 2021).

The need to determine the quality of public water supply has been intensified as a result of an increase in water pollution on a global scale caused by increasing population, urbanization and industrialization (Behailu *et al.* 2018; Haldar *et al.* 2022). In natural waters, the dissolved solids mainly consist of bicarbonates, carbonates, sulfates, chlorides, nitrates and phosphates of calcium, magnesium, sodium, and potassium with traces of iron, manganese and other minerals (Sarda & Sadgir 2015; Kumar *et al.* 2016). Since a country such as Ethiopia has limited technical and financial resources for regular water quality assessment and faces constraints in conducting a national monitoring program for all water sources, water quality also varies considerably from municipality to municipality (Alemu *et al.* 2015; Wolde *et al.* 2020).

Dilla town in Ethiopia is bounded by Legedara, Walame and Chichu rivers. However, the town is supplied with water by Legedara River and ground water from which eight boreholes are developed. There are also 36 public stand pipes used as water sources, which supply water for those households that do not have access to piped connections (Debela & Muhye 2017). A survey conducted in Dilla town (Debela & Muhye 2017) revealed that the town's water supply cannot fulfill the consumer demand. The basic factors for this imbalance are shortage of finance, electric power supply problem, obsolete supply system and lack of skilled workforce. According to the survey result the average per capita consumption was found to be less than the recommended standard. In the qualitative results of the study respondents mentioned that due to water shortages they incur additional costs and face health problems such as diarrhea as they are forced to use alternative sources of water of poor quality. Furthermore, according to a report by the Gedeo zone Health and Water Office the zonal water supply coverage including Dilla town in 2020 was less than 20% (Aregu *et al.* 2021).

The water demand and supply of the community are still not balanced, forcing the residents to use other alternatives such as untreated or poorly treated sources. The community also uses untreated water from hand dug wells and boreholes located in different areas of the town. Currently, there is no coordinated water quality monitoring program in Dilla town, where private wells are left entirely up to the owners. It is, therefore, necessary to do more on the assessment and monitoring of the usable water sources in Dilla town and other areas.

In Dilla town the problems of water quality and quantity are obvious but, despite the water quality only limited research mainly focused on the bacteriological quality has been conducted previously. Moreover, research findings in the private and hand-dug wells used by the community have not been reported yet. So, this study assessed the physicochemical, heavy metal and bacteriological quality of Dilla town water sources including the protected hand dug wells accessed by the residents. Water quality measurements include a variety of physical, chemical, and biological parameters, but researchers may be limited on some parameters. Hence, analyzing a large number of variables may become complex due to shortage of resources and time limitations.

In the present study, selected physicochemical parameters such as temperature, pH, turbidity, total hardness, electrical conductivity, alkalinity, major cations, major anions, and heavy metal analysis of different water samples were investigated. In addition, bacteriological analysis of the water samples was performed for microbial contaminants. The aim of the present study was to investigate the quality (pathogenic and physicochemical) of water sources used for drinking and household consumption. The findings in this study may be valuable to highlight the level of contamination of Dilla town water sources and invite the regulatory bodies to develop permanent water treatment strategies of all the water sources used by the community including of protected hand-dug wells.

MATERIALS AND METHODS

Description of the study area

The study was conducted in Dilla town, Gedeo zone, which is in the southern part of Ethiopia 365 km from Addis Ababa, the capital city of Ethiopia. The town is located at the latitude of 6°24′30″N, 38°18′30″E and an elevation of 1,570 m above sea level. The mean annual rainfall ranges from 250.1 to 1,400.1 mm and the mean annual temperature ranges between 23 °C and 30 °C. The total area of the study is estimated at about 1,210.89 km^2 with an estimated population of 97,516. The map of the study area is presented in Figure 1.

The specific sampling areas were identified and selected with the help of the Gedeo zone water, mining, and energy sector experts. Presently, the town is supplied with water by Legedara River and ground water from eight boreholes named Millennium, Chichu number 1, Chichu number 2, Chichu number 3, Hostel, Hiwot Birhan, Mengesha and Maremya Jerba. Two ground water sources, namely Mengesha and Maremya Jerba, were not functional at the time of sample collection.

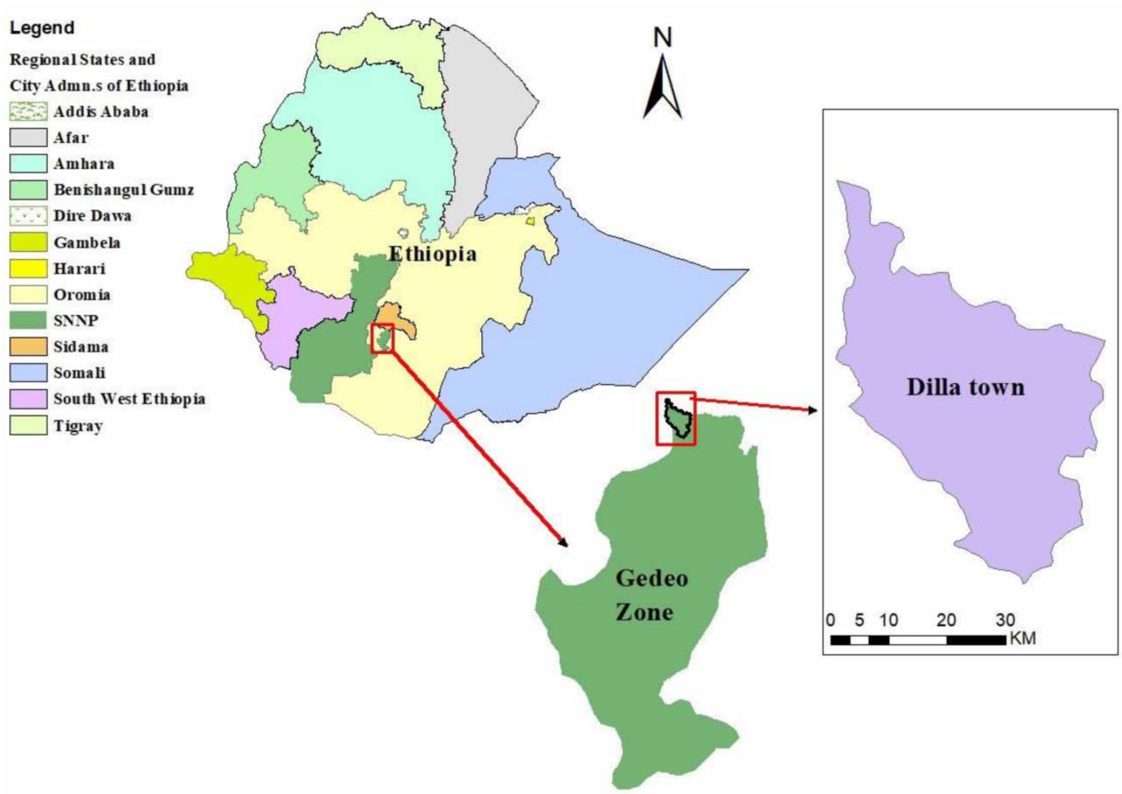


Figure 1 | Location of the study area.

Design of the study

A cross-sectional study design was used. This study included Dilla town ground and surface water sources that were functional at the time of sample collection. A purposive sampling technique was used to include all types of water sources including hand-dug wells currently used by the community. It is evident that the people who are most vulnerable to waterborne disease are those who use polluted drinking water from rivers, streams and hand dug wells.

Chemicals and reagents

Analytical grade chemicals and reagents were used throughout the analysis and used without any further purification. The chemicals and reagents were Sigma Aldrich products. Deionized water was used for all experimental activities.

Apparatus and instruments

Different laboratory apparatus and instruments such as inductively coupled plasma atomic emission spectrophotometer (ICP-AES) and UV-Vis spectrophotometer were employed during this analysis. All glass wares were washed with detergent, soaked overnight, again washed, rinsed with deionized water, and dried in an oven before using.

Sample collection and preparation

The study was conducted from January 2021 to July 2021. The sampling sites were represented by the local name of the sampling area. A total of 108 water samples were collected from 12 purposively selected sites, from ground water sources treated at the main reservoir (Hostel, Chichu, Hiwot Birhan, Millennium and Dilla University Main Campus), protected-hand dug wells (Baeta, Kalehiwot, Qoffi and Hasedila), surface water (Legedara treatment plant) and households (Kuteba and Menharya). A total of 36 water samples (100 ml of water specimen for each) were collected for bacteriological analysis. The samples were taken between 7:00 and 8:00 a.m. and transported for testing to the laboratory in an ice box within 2 hours. The analysis was begun immediately after the samples had arrived at the microbiology laboratory at Dilla University, Ethiopia. All the water samples were examined for total coliforms and fecal coliforms using the most probable number (MPN) method (Phyo *et al.* 2019). Standard biochemical (IMViC) test was also performed on the positive samples to identify the genus of bacteria. At the same time a total of 36 samples were also collected for physicochemical, major cation and anions analysis. For the heavy metal analysis, 36 water samples were collected and homogenized into 12 samples, preserved with concentrated nitric acid (HNO_3), stored in the dark at an ambient temperature until microwave acid digestion following USEPA (1994).

Experimental procedure

Physicochemical determination

The physicochemical parameters of the water samples such as temperature, pH, turbidity, total hardness, electrical conductivity, alkalinity, major cations, and major anions were analyzed. *In situ* analysis was performed for temperature, pH, turbidity, and conductivity at the sampling sites using properly calibrated potable thermometer, pH meter, nephelometer and conductivity meter respectively. The analytical standard methods applied for the determination of nitrate, ammonium, bicarbonate, and chloride ion concentrations were ES ISO 7890-3:2001, ES ISO 7150-1:2005, ISO 9963-2 and ES ISO 9297:2001, respectively. The metal cation analysis was performed using the analytical examination standard method ISO 11885.

Heavy metal analysis

Heavy and trace metals were analyzed according to ISO 11885 examination standards using ICP-AES. The digestion of 50 ml of water sample was performed with 4 ml HNO_3 65% and 1 ml HCl 35%. After digestion, all samples were filtered through 0.45 μm nylon filter and stored at 4 °C for heavy metal analysis. The concentrations of Fe, Mn, Ni, Co, Cu, Zn, Cd, Hg, Pb, As and Cr were measured using inductively coupled plasma-optical emission spectrometry in accordance with the standard method (ISO 11885).

Bacteriological analysis and characterization

The pathogen analysis and characterization were performed according to the method of Graham *et al.* (2000) with slight modification (Kawo *et al.* 2009; Phyo *et al.* 2019). The samples were inoculated in nutrient broth medium and then incubated at 44 °C for 48 hours to test for the presence of coliform bacteria in the sample. MacConkey agar was used for lactose fermentation for the presence of bromocresol purple. The inverted test tube was used for the detection of gas formation by Gram-negative coliform bacteria. The color change of media to yellow and observed gas in the test tube can be used to confirm that coliform bacteria are present in the samples. After incubation the number of positive tubes were recorded from each set and bacterial content was estimated using MPN index. It was also compared with the standard chart to find coliform count per 100 ml of water sample. Then, the positive samples were used to determine whether the coliform are of indicator bacteria of fecal origin (*Escherichia coli*). Undiluted water samples were directly plated on to xylose lysine deoxycholet (XLD) and MacConkey agar plates. The plates were incubated at 37 °C for 24 hours and then observed for growth condition. Prescence of fecal indicator *E. coli* was confirmed by the production of gas and color change in the media. For specification, the colonies were subcultured on other individual MacConkey agar plates from the primary plate and incubated at 37 °C for 24 hours. After the incubation a pure, heavy growth was found on the MacConkey agar plate. For further complete conformation a satisfactory differentiation within the coliform group was done by indole, methyl red, urease, Voges-Proskauer and sodium citrate, the biochemical (IMViC) tests which are commonly recommended for differential determination according to *Bergey's Manual of Systematic Bacteriology* (Vos *et al.* 2011) and World Health Organization (WHO) guidelines.

Data analysis

The obtained data were analyzed by using Origin statistical software (version 8.0) and the map of the study area was prepared by using Arc GIS software.

RESULTS AND DISCUSSION

The results of all physicochemical parameters, heavy metals, common cations, common anions and bacteriological analysis are presented below.

Determination of physicochemical parameters

The results of selected physicochemical parameters of water samples are shown in Table 1.

Table 1 | Physicochemical parameters of Dilla town water sources, 2021

Sites			Parameters			
	Temp. (°C)	pH	Turbidity (NTU)	Conduct. (μS/cm)	TDS (mg/L)	Total hardness (mg/L)
Hostel	25.0	7.3	1.27	386.00	257.33	19.56
Chichu	24.0	6.8	2.95	332.66	21.77	22.54
Hiwot Birhan	26.0	7.2	2.32	493.33	328.88	35.31
Millennium	26.0	7.0	0.33	219.66	146.44	23.69
Legedara	20.0	7.2	4.22	140.06	93.37	6.73
Baeta	25.5	6.4	3.98	361.00	240.66	12.96
Kalehiwot	25.3	7.5	0.66	591.66	394.44	34.93
Qoffi	24.5	6.5	4.48	280.66	187.10	7.34
Hasedila	25.0	6.8	1.47	208.00	138.66	5.94
Kuteba	25.0	6.9	1.30	411.00	274.00	20.54
Menharya	24.5	7.2	4.69	304.00	202.66	17.86
Campus	25.5	7.1	2.45	969.00	646.00	26.14
WHO limit[a]	12–25	6.5–8.5	5.00	400	500–1,000	500
CES limit[b]	–	6.5–8	5.00	500	500	300

[a]WHO limit represents WHO 2017 permissible limit for drinking water.
[b]CES (Compulsory Ethiopian Standard), 2013.

The results for the physicochemical parameters of the water samples were in the following ranges: temperature (20–26 °C), pH (6.4–7.5), turbidity (0.33–4.69 NTU), electrical conductivity (140–969 μs/cm), total dissolved solids (93–646 mg/L) and total hardness (6.73–35.00 mg/L). Hence, most of the parameters were within the permissible limit range of WHO and Compulsory Ethiopian Standard (CES) for drinking water specification except the electrical conductivity of four sites and temperature of five sampling sites. The electrical conductivity of the four sampling sites were above the WHO permissible limit of 400 μS/cm for drinking water. The levels of electrical conductivity for the four sites were 411.00, 493.33, 591.66 and 969.00 μs/cm for Kuteba, Hiwot Birhan, Kalehiwot and Campus water samples respectively. Moreover, the electrical conductivities of two sites were above the CES permissible limit of 500 μS/cm for drinking water. The temperature of five sampling sites were also beyond the WHO limit of 12–25 °C for drinking water.

The concentration of common cations and anions are presented in Table 2.

The test results for common cations and anions in Table 2 show that most of the parameters were in the acceptable range of the WHO drinking water quality guidelines except for nitrate in three sites and potassium in one site. The highest mean concentration of chloride ion was observed in Kalehiwot protected hand-dug well followed by ground water from Dilla university main campus. This may be due to discharge of sewage from waste disposal areas. Chloride does not pose a health hazard to humans other than palatability, but serves as an indicator of pollution by sewage (Sarda & Sadgir 2015). The highest concentration of potassium was also determined in Kalehiwot protected hand-dug well and the concentration was found to be 26.83 mg/L, which exceeds the WHO and CES permissible standards of 20 mg/L.

Nitrate

In the present study three sampling sites were highly contaminated by nitrate with values higher than the WHO and CES recommended value (50 mg/L). The nitrate concentrations were found to be 51.68 mg/L, 62.74 mg/L and 126.30 mg/L for Hasedila, Baeta church, and Kalehiwot church respectively. The highest nitrate concentration was observed in the untreated ground water source and protected hand-dug wells used by the community. Those sampling sites were located near waste disposal area where municipal wastes with different contaminants may be discharging and leaching. Domestic sewage, industrial waste and agricultural run-off contribute to nitrates contamination. High concentration of nitrate is useful in agriculture but their entry into the water increases algal growth and eutrophication (Sarda & Sadgir 2015). A study conducted in Malwa Punjab, India revealed high nitrate concentration in ground water ranging from 38.45 to 198.05 mg/L and the researcher

Table 2 | Common cations and anions concentration in Dilla town water sources, 2021

	Parameters (mg/L)								
Sites	**Ca**	**Mg**	**K**	**Na**	**NH_4-N**	**SO_4-S**	**NO_3-N**	**HCO_3**	**Cl**
Chichu	17.37	5.17	8.73	24.07	0.023	3.44	4.25	2.18	4.50
Hiwot Birhan	28.29	7.02	8.21	32.71	<0.007	1.18	4.21	3.43	<0.50
Millennium	18.92	4.77	8.99	64.16	<0.007	3.41	11.60	3.61	9.52
Legedara	5.70	1.04	5.83	10.22	<0.007	7.43	10.07	0.29	4.79
Hostel	15.02	4.54	9.56	36.86	<0.007	1.77	6.45	2.74	<0.50
Baeta	10.84	2.12	17.15	26.78	<0.007	3.86	62.74	0.67	24.69
Kalehiwot	27.54	7.39	26.83	27.95	<0.007	4.45	126.30	1.00	43.55
Qoffi	6.25	1.09	12.45	15.79	0.143	0.80	26.75	0.83	2.66
Hasedila	5.18	0.76	15.56	19.46	<0.007	0.98	51.68	0.54	17.01
Kuteba	15.69	4.85	9.46	39.52	<0.007	1.72	5.96	2.83	<0.50
Menharya	14.38	3.48	7.54	30.06	<0.007	5.42	9.22	1.92	<0.50
Campus	20.19	5.95	16.61	160.80	<0.007	22.83	4.25	7.35	25.86
WHO limit[a]	100	50	20	200	NM	250	50	125	250
CES limit[b]	75	50	20	200	1.5	250	50	125	250

[a]WHO limit represents WHO 2017 permissible limit for drinking water.
[b]CES (Compulsory Ethiopian Standard), 2013; NM, not mentioned.

suggested that consumption of nitrate contaminated water may pose a serious health hazard to residents. Hence, nitrate is listed as a noncarcinogenic chronic toxicant for humans (Ahada & Suthar 2018).

Another study conducted in India for water samples from drain water, tap water, surface water, and ground water indicated that high concentrations of sulfate and nitrate were obtained in the water samples and the concentration of nitrate ranged from 10 to 97 mg/L. Hence, consumption of water containing a high concentration of nitrates can cause blue baby disease at levels above 40 mg/L (Sharma & Kaur 2017). A critical review of drinking water standards and implementation by Tsaridou & Karabelas (2021) also revealed that in natural water excess nitrate is reported as the greatest health concern in addition to arsenic and fluoride.

The results for common cations and anions in the present study indicated that most of the parameters were highest in Kalehiwot protected hand dug well. As evidence, in the sampling site waste discharging from different source and human activities were observed. Hence, a large number of residents who do not have access to the piped connection are accessing water from this source. Therefore, it is necessary to pay special attention in the protected hand-dug wells, take control measures, and apply water quality monitoring techniques to ensure the safety of the consumers.

Heavy metal analysis

Heavy metal analysis was performed using acid digestion followed by ICP-AES method. A total of 11 heavy metals were analyzed for each water samples as depicted in Table 3.

The heavy metal analysis results in Table 3 show that the concentrations of Ni, Co, Cu and Cd were within the acceptable level of heavy metal concentration reported by WHO (Cotruvo 2017). However, the concentrations of iron, manganese, zinc, mercury, lead, arsenic, and chromium exceeded the acceptable level in the drinking water guideline (CES 2013; WHO 2017).

Iron

The concentration of iron in most of the sites was higher than the permissible limit of WHO and CES of 0.3 and 0.5 mg/L respectively. The highest concentration of iron was found in Hiwot Birhan and Chichu ground water sources with concentrations of 1.378 mg/L and 5.773 mg/L respectively. A sanitary survey in Dilla town reported by Kanno *et al.* (2020) also indicated that the highest concentration of iron was observed in Chichu borehole at about 0.7 mg/L. However, the concentration of iron in the present study is very much higher than the result reported in the previous survey. Iron is an essential and non-conservative trace element found in significant concentration in drinking water because of its abundance in the Earth's crust. Usually, iron occurring in ground

Table 3 | Heavy metal analysis results for Dilla town water sources, 2021

	Trace metals (mg/L)										
Sites	**Fe**	**Mn**	**Ni**	**Co**	**Cu**	**Zn**	**Cd**	**Hg**	**Pb**	**As**	**Cr**
Chichu	5.773	0.413	0.095	0.005	0.069	0.068	0.002	0.041	0.439	0.056	0.048
Hiwot Birhan	1.378	0.588	0.100	0.009	0.042	0.208	0.003	0.036	0.465	0.057	0.061
Millennium	0.808	0.540	0.109	0.001	0.091	0.089	0.001	0.030	0.412	0.046	0.044
Legedara	0.506	0.023	0.095	0.005	0.063	0.049	0.001	0.026	0.431	0.049	0.036
Hostel	0.443	0.066	0.098	0.008	0.070	0.037	0.002	0.041	0.453	0.060	0.061
Baeta	0.738	0.082	0.103	0.007	0.007	0.122	0.003	0.057	0.461	0.063	0.070
Kalehiwot	0.859	0.020	0.094	0.003	0.087	0.083	0.001	0.029	0.433	0.050	0.023
Qoffi	0.801	0.050	0.105	0.004	0.093	0.128	0.001	0.037	0.412	0.049	0.025
Hasedila	0.235	0.088	0.086	<0.002	0.079	3.606	<0.0001	0.037	0.398	0.045	0.053
Kuteba	0.412	0.029	0.082	<0.002	0.088	0.119	<0.0001	0.033	0.374	0.037	0.054
Menharya	0.314	0.194	0.094	0.004	0.061	0.145	0.001	0.030	0.424	0.049	0.029
Main Campus	0.704	0.024	0.093	0.003	0.014	4.312	0.002	0.047	0.432	0.058	0.098
WHO limit[a]	0.500	0.10	0.10	0.07	1.00	3.00	0.003	0.010	0.010	0.010	0.050
CES limit[b]	0.300	0.5	NM	NM	2.00	5.00	0.003	0.001	0.010	0.010	0.050

[a]WHO limit represents WHO 2017 permissible limit for drinking water.
[b]CES (Compulsory Ethiopian Standard), 2013; NM, not mentioned.

water is in the form of ferric hydroxide, in concentration less than 0.5 mg/L (Mebrahtu & Zerabruk 2011). The lack of iron in the body causes anemia and prolonged consumption of drinking water with high concentration of iron may lead to a liver disease known as hemosiderosis.

Manganese

The concentrations of manganese in four sites were beyond the WHO limit for drinking water and found to be 0.194, 0.413, 0.540 and 0.588 mg/L for Menharya, Chichu, Millennium and Hiwot Birhan ground water sources respectively. The results indicated that the concentrations of manganese in all four sites were higher than the accepted WHO value (0.1 mg/L).

Zinc

The highest concentrations of zinc were 3.606 and 4.312 mg/L in Hasedila and Dilla University main campus respectively, which is higher than the WHO permissible limit (3 mg/L).

Mercury

The concentration of mercury in all sites was higher than the WHO standard limit (0.01 mg/L) with maximum mercury concentration of 0.057 mg/L in Baeta church hand-dug protected well and the lowest mercury concentration of 0.026 mg/L was found in Legedara treatment plant surface water.

Lead

The concentration of lead in all sites was higher than the WHO standard limit (0.01 mg/L) with maximum lead concentration of 0.465 mg/L in Hiwot Birhan ground water source and lowest lead concentration of 0.374 mg/L in Kuteba household. Lead is toxic and harmful even in small amounts. High concentration of lead in the body can cause death or permanent damage to the central nervous system, brain and kidneys (Mebrahtu & Zerabruk 2011).

Arsenic

The concentration of arsenic in all sites was higher than the WHO standard limit (0.01 mg/L) with maximum arsenic concentration of 0.063 mg/L in Baeta church hand-dug protected well and lowest arsenic concentration of 0.037 mg/L in Kuteba.

Chromium

The concentrations of chromium were found to be 0.053, 0.054, 0.061, 0.061, 0.070 and 0.098 for Hasedila, Kuteba, Hiwot Birhan, Hostel, Baeta church and Dilla University main campus respectively. The concentration of chromium indicated that 50% of the sites contained chromium concentration higher than the WHO limit (0.01 mg/L). As reported by Sarda & Sadgir (2015), the dissolved solids in natural waters mainly consist of bicarbonates, carbonates, sulfates, chlorides, nitrates and phosphates of calcium, magnesium, sodium, and potassium with traces of iron, manganese and other minerals.

In the present study the water sources were an indication of chemical contamination with nitrate, iron, manganese, zinc, mercury, lead, arsenic and chromium in some sites. The level of contamination and reported relative risks are presented in Table 4.

Table 4 | Level of chemical contaminants and related health risk

Parameter	Present study	WHO	No. of contaminated sites	Percentage contaminated sites	Related risks
Nitrate	51.68–126.3	50	3	25	Blue baby disease
Iron	0.506–5.773	0.5	8	66.6	May lead to liver disease
Manganese	0.194–0.588	0.1	4	33.3	May cause anemia Reproductive issues
Zinc	3.606–4.312	3.00	2	16.6	Palatability
Mercury	0.026–0.057	0.01	All (12)	100	Lung damage, skin rashes, blood pressure and severe neurologic abnormalities
Lead	0.374–0.465	0.01	All (12)	100	Can cause death or permanent damage to the central nervous system, brain and kidneys
Arsenic	0.037–0.063	0.01	All (12)	100	Cancer causing
Chromium	0.053–0.098	0.01	6	50	Can damage liver and kidneys

The summary of the chemical contaminants in Dilla town water sources shows that the concentration of mercury, lead and arsenic in all water samples exceed the concentration set by national and international standards. Meanwhile, the concentration of chromium in six sites, manganese in four sites, iron in eight sites, zinc in two sites and nitrate in three sites also exceed the WHO and CES water quality standards. A study conducted in Ethiopia also reported that heavy metal concentrations exceed the maximum permissible limits recommended by the WHO. The results indicated that arsenic (40.3%), cadmium (7.46%), chromium (64.18%), iron (37.31%), nickel (7%) and lead (29.85%) were above the water quality standard (Mebrahtu & Zerabruk 2011).

Another study conducted in northern Ghana mining communities (Cobbina *et al.* 2015) also found levels of Hg, As, Pb, Zn, and Cd in water from Nangodi sampling site and levels of Hg, Pb, and Cd recorded in Tinga sampling site that exceeded the WHO stipulated limits. The researcher suggested that ingestion of water containing elevated levels of Hg, As, and Cd by residents in these mining communities may pose significant health risks. Continuous monitoring of the quality of drinking water sources in these two communities is recommended. However, a study conducted in the southwest coastal area of Bangladesh (Rahman *et al.* 2021) reported that the concentrations of arsenic (As), cadmium (Cd), lead (Pb), and zinc (Zn) in the water samples were lower than the WHO provisional guideline values. Exposure of humans to those heavy metals plays a role in damage to the kidneys and central nervous system (Saleh *et al.* 2022). The WHO drinking water report (WHO 2017) suggested that high concentrations of lead, arsenic, and other heavy metals can affect the nervous system and kidneys, and may cause reproductive disorders, skin lesions, endocrinal damage, and vascular diseases. Therefore, urgent assessment of Dilla town water sources is needed and a better monitoring program to protect the lives of the residents.

Bacteriological analysis

The bacteriological quality of the water samples was assessed using a modified most probable number (MPN) method and the result are presented in Table 5.

Table 5 | Bacteriological quality (MPN/100 ml) of Dilla town water sources, 2021

Sites	MPN/100 ml	Disease risk classification
Chichu	3	Low
Baeta	MTC	Very high
Main campus	4	Low
Millennium	MTC	Very high
Hostel	43	High
Kuteba	40	High
Legedara	40	High
Kalehiwot	80	High
Qoffi	36	High
Hiwot Birhan	51	High
Hasedila	60	High
Menharya	35	High
WHO	0	
CES	0	

MTC, too many to count; WHO, World Health Organization permissible limit; CES, Compulsory Ethiopian Standard.

The test results for the bacteriological analysis in Table 5 indicated that the pathogen concentration of 83.33% of the water samples was in the range of 3–80 MPN/100 ml and 16.67% were too many to count. However, WHO drinking water guideline and the Ethiopian drinking water quality standard are strict and set no detection of coliforms per 100 ml of water sample (Sitotaw & Nigus 2021). In the present study all the samples exceeded the WHO and CES permissible limit for drinking water quality. A study conducted in India using a similar method (MPN method) also reported bacterial contamination in bottled water ranging from 6 to 16 MPN/100 ml (Phyo *et al.* 2019). The analysis reported that 7 out of 19 (36.8%) water samples did not reach the standard of 0 MPN/100 ml of water as recommended by WHO guidelines. Another study conducted in Mpraeso, Ghana, western Africa focused on bacterial contamination of drinking water sources by MPN method showed that both total and fecal coliforms were detected in all water samples (ground and surface water sources) analyzed (Omari & Yeboah 2012).

The bacteriological test results in this study are also consistent with the study conducted in Ethiopia, Gedeo zone assessing tap water for hand washing facilities, which found that in Dilla town 27.5% had zero coliforms, 57.6% had positive fecal coliforms and 15% had too many to count (Aregu *et al.* 2021). Furthermore, the result of a sanitary survey conducted in Dilla town, Ethiopia focused on physicochemical and bacteriological quality also suggested that both surface and ground water sources were not safe in terms of bacteriological quality (Kanno *et al.* 2020).

According to the drinking water disease risk classification (CSA 2017), 16.67% of Dilla town water samples are low risk, 66.66% are high risk and 16.67% are very high risk. Other studies conducted in Ethiopia reported that 71.2% (Asfaw *et al.* 2016), 82.5% (Sitotaw *et al.* 2021) and 83.34% (Amenu *et al.* 2012) of the water samples were positive for bacteriological indicators in Jigjiga, Wegeda and Diredawa respectively. Water samples collected from protected sources in Wondogenet campus were also positive for total coliforms ranging from 1 to 4/100 ml while all the water samples were classified as low risk (Meride & Ayenew 2016). Similarly, water samples collected from drinking water storage tanks in Jimma town indicate that all the samples were positive for total and fecal coliforms with concentration ranging from 2.6 to 14.3 and 1.3 to 9.33 cfu/100 ml respectively (Chalchisa *et al.* 2018). In the present study all the water samples collected from protected drinking water storage tanks, households and protected hand dug wells were also positive for coliforms. However, the quality of drinking water may differ from area to area due to the differences in the sources of water contaminants and treatments.

Bacterial identification and biochemical testing

For species identification, the biochemical (IMViC) test as per WHO guideline was performed and the test results are presented in Table 6.

Table 6 | Biochemical characterization test result

Organism	MR	VP	Indole	Urease	Citrate
Escherichia coli	+	−	+	−	−
Klebsiella	+	−	−	+	+
Pseudomonas sp.	−	−	−	−	+
Proteus spp.	+	−	+	+	−
Staphylococcus aureus	+	+	−	+	+
Bacillus spp.	−	−	−	+	+
Enterobacter aerogenes	−	+	−	−	+

VP, Voges-Proskauer; MR, methyl red.

The biochemical test results for species identification implies that the leading isolated pathogens in this study were *E. coli*. Hence, the highest *E. coli* count in the samples might be an indication that the water sources are fecally contaminated, showing the presence of pathogenic bacteria. The presence of these bacteria in drinking water has a negative impact on public health. The water intended for human consumption must be free of pathogenic and chemical agents, pleasant to taste and potable for domestic purposes. Moreover, disease-causing pathogens were detected in the samples and this implies the use of this water without proper treatment is dangerous which leaves the health of the public at risk. This research has shown that the ground waters and municipal drinking water systems in Dilla town have a potential for the growth of bacterial pathogens. The causes of bacterial contamination in Dilla town are mainly insufficient water supply to the residents, human activities, poor waste disposal practice in the town, and lack of regular water treatment practices. This suggests that there should be urgent improvement to ensure the supplies of safe water for consumers. The suggested control measures might be:

1. Improving the piped water coverage and system of the town by investing additional resources.
2. Proper treatment of water sources such as regular chlorination, regular inspection of the distribution line, and good hygienic practice.
3. Raising awareness in the community still using untreated water, to practice in-home water treatment technologies such as chemical disinfection, proper filtration, boiling and heating to pasteurization to minimize the existing waterborne disease.

CONCLUSION

In the present study selected physicochemical parameters, heavy metals and bacteriological analysis of water samples collected from Dilla town water sources were performed. The results of most of the physicochemical parameters were in good agreement with the national and international standards of water quality. In the case of heavy metals, some of the parameters were higher than the WHO and CES recommended permissible limits. The bacteriological analysis of the water samples by MPN method also showed that none of the samples complied with the standard of MPN per 100 ml of water as recommended by WHO drinking water guidelines. Special attention should be given to the hand-dug wells, which are highly contaminated bacteriologically and chemically with chemicals such as nitrate, which may come from the disposal of municipal wastes near to the area. The present study on Dilla town water sources has indicated pollution hazards and inefficient drinking water treatment practice, which in turn have human health implications. This study, therefore, recommends the government and other responsible authorities to take appropriate corrective measures. This study also highlighted the need for further research, to determine the level of different parameters with a large number of samples. This may help to identify areas of potential toxicity and enhance drinking water quality consumed by the community.

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AUTHORS' CONTRIBUTIONS

Blen Weldegebreal and Wakshuma Yadesa designed the proposal, Blen Weldegebreal and Birtukan Getahun collected the samples, performed the experiments, and interpreted the data. Blen Weldegebreal drafted the manuscript. All authors read and approved the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Official letter of permission for this research work was obtained from Dilla University Energy and Environment Research Center. All the water samples were collected and tested with the standard procedure, and all confidentiality of the results was maintained.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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