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Assessment of Some Selected Physicochemical and Bacteriological Quality of Water Supply in Kiltu Kara Town, Western Ethiopia

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ABSTRACT
Background and Objective: Potable drinking water is essential for health and a fundamental human right. Safe drinking water is crucial for preventing waterborne diseases and promoting overall well-being. This study aimed to assess the physicochemical and bacteriological quality of drinking water supplied to the Kiltu Kara Town, Western Ethiopia Community. **Materials and Methods:** As 21 water samples from 7 sampling sites were collected and 63 replicate samples were analyzed for 12 physicochemical and 2 bacteriological parameters using a DR/2400 Portable Spectrophotometer and a Micro Bacteriological Laboratory Incubator, following standard methods. The analyzed parameters included temperature, total dissolved solids, color, electrical conductivity, turbidity, pH, nitrate, sulfate, phosphate, chloride, manganese, and iron. Bacteriological indicators analyzed include the determination of fecal coliform (FC) and total coliform (TC) counts. Data analysis, including correlation computation and One-way Analysis of Variance (ANOVA), was performed using SPSS software (version 22) with a 0.05 significance level. **Results:** The most physicochemical parameters met the values set by the Ethiopian compulsory standard and the World Health Organization guideline. However, fecal coliforms and total coliforms levels exceeded the acceptable limit of 0 CFU/100 mL, ranging from 1 to 5.44 CFU/100 mL and 3.44 to 7.78 CFU/100 mL, respectively. Manganese concentrations ranged from 0.6 to 1.12 mg/L, surpassing the Ethiopian compulsory standard and the World Health Organization guideline limits of 0.5 and 0.4 mg/L, respectively. The pH of the water samples varied between 6.5 and 8.5, except at one sampling site (R6), where the pH was below the recommended standards. **Conclusion:** The drinking water quality in Kiltu Kara Town is primarily affected by bacteriological contamination and elevated manganese levels. The water samples were found to be safe for consumption after treatment for microbial contamination and manganese reduction. This study recommends appropriate interventions, including infrastructure improvement and community awareness, to enhance the safety of drinking water at Kiltu Kara Town, Western Ethiopia.

KEYWORDS
Water supply, drinking water quality, physicochemical parameters, bacteriological parameters

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INTRODUCTION

Water is the Earth's most abundant substance, crucial for all life forms. It is essential for drinking, cooking, agriculture, transportation, and recreation. Water makes up two-thirds of the human body and is vital to the global economy, acting as a solvent, cooling agent, and transportation medium. It also absorbs industrial and domestic wastes[1]. Pure drinking water is essential for life and public health. Access to clean water is essential for preserving health and dignity. Safe drinking water is a fundamental human right for every individual, regardless of age or gender. Monitoring water quality is vital to safeguard against health risks[2], especially in developing countries where water contamination leads to waterborne diseases.

Having safe water is essential in breaking the cycle of poverty since it improves people's health, strength to work, to work, and ability to go to school. Safe drinking water meets the World Health Organization guidelines for microbial, chemical, and physical standards. However, nearly a billion people lack access to clean water, with many facing waterborne diseases due to contaminated sources. Pathogens and chemicals easily contaminate water, posing health risks[3]. Access to safe drinking water is a global concern and these issues are serious in developing countries like Ethiopia[4].

The health and well-being of the population are directly affected by water supply and sanitation coverage. Recent data reveals that waterborne diseases account for around 4 billion cases of illness worldwide and cause 3.4 million deaths annually, with 88% of these deaths associated with unsafe drinking water and poor sanitation[5]. Achieving Sustainable Development Goal 6 requires ensuring access to clean drinking water, improving sanitation, and reducing waterborne diseases.

Water contamination can result from industrial discharges, agricultural runoff, untreated sewage, household waste, mining activities, deforestation, landfill leachate, airborne pollutants, and naturally occurring substances like arsenic and fluoride. Drinking water can be contaminated at the source, in distribution lines, and at the household level[6]. The primary sources of water contamination include waste from inadequate sanitation, agricultural runoff, and other activities that enter water distribution systems. The quality of drinking water is evaluated by monitoring fecal indicator bacteria, such as fecal and total coliforms from genera like Escherichia, Klebsiella, and Enterobacter. These bacteria serve as indicators of water quality, though various pathogens can contaminate different environmental media. Besides bacteriological quality, the chemical quality of water is also important due to its potential toxicity at high concentrations.

However, no prior research has been conducted in the study area concerning the physico-chemical and bacteriological quality of drinking water from various sources. But, few similar studies have been carried out in several rural and urban regions of the country. Studies on the quality of drinking water from the source to household taps water distribution systems in Jimma Zone, Southwest Ethiopia[7], Nekemte Town[8], and Adama Town[9] in Ethiopia show high contamination levels of water sources by indicator bacteria like total coliforms, fecal coliforms, and fecal *Streptococci.* All these findings provide convincing evidence that water quality problems are widespread both with small-scale and large-scale water distribution systems in Ethiopia.

Increasing population, pollution, and environmental damage contribute to increased chemical and microbial contamination of drinking water sources. Despite various efforts to ensure safe drinking water, waterborne diseases continue to be a major concern. As a result, drinking water quality has become a global health issue, mainly due to pathogens and toxic chemical contamination. Hence, this study aimed to assess the quality of drinking water supply from deep wells, reservoirs, and public taps in Kiltu Kara Town, Western Ethiopia.

MATERIALS AND METHODS

Description of the study area and study period: The study was conducted at Kiltu Kara Town in Kiltu Kara District located in West Wallaga Zone, Oromia Regional State, Ethiopia. Astronomically the town is located between 9°35'N-9°50'N Latitude and 35°10'E-35°25'E Longitude. Kiltu Kara Town is found at a distance of 565 km from Addis Ababa, the capital city of Ethiopia, and 123 km from Gimbi Town, the Zonal Capital City of West Wallaga Zone. The town is bounded by the Kiltu Kara peasant association in the East, Guyo Sach Kebele in the West, Guyo Lalisa Kebele in the North and Wato Dale Kebele in the South direction. Kiltu Kara Town was divided in to two administrative kebeles; Kiltu Kara 01 kebele and Kiltu Kara 02 kebele.

According to the population and housing census report of 2007, the total population of Kiltu Kara Town was 5256 of which 2965 were male and 2291 were female. The total population of Kiltu Kara 01 kebele administration was 1514 male and 1244 female and the total was 2758, the total population of Kiltu Kara 02 kebele was 1451 male and 1047 female and the total was 2498. Currently, the total population in Kiltu Kara Town is estimated to be 11817 (5940 male and 5877 female). Generally, the town lies within an altitudinal range of 1400-1800 m above mean sea level (Kiltu Kara Town). The annual average temperature of the town ranges from a minimum of 16°C to a maximum of 22°C and the town receives annual rainfall which varies from 1500 to 1800 mm for about six months from May to October which is better for agricultural activities. Groundwater from deep aquifers is the main source for drinking water supply in the district. People also use rivers and streams nearby for cattle watering, washing clothes, and bathing.

Study design: The laboratory-based cross-sectional study design was employed to assess the status of the physicochemical and microbiological quality of the drinking water supply in Kiltu Kara Town from the source, the reservoir (treatment), household taps, and public taps from November to December, 2021. Water samples were collected using sterilized bottles for physicochemical parameters analysis, and ice cold box containing ice freezer packs for bacteriological parameters analysis. The collected water samples were transported to Nekemte City Water Supply and Sewerage Service Enterprise Laboratory for lab analysis. The laboratory analyses were conducted following standard processes and procedures for drinking water quality testing. Total coliform and fecal coliform counts were carried out by membrane ltration technique.

Materials

Apparatus: For this study apparatuses such as DR/2400 Portable Spectrophotometer (HACH Company, Cat., No. 59400-45), pH meter (CT-6021A) waterproof, Thermometer, Conductivity meter (Wagtech, Serial No. 2402181), Conductivity/TDS meter model Model-1601, Portable Turbidity Meter (WZS-200), Laboratory Incubator (DNP-9052A), WhatMan filter paper, pipette, membrane filtration, millipore, petri dish, burner, measuring cylinder, beakers of different sizes, vacuum pump, ice cold box, and plastic bottles were used.

Chemicals and reagents: All chemicals used for laboratory analysis were analytical-grade reagents. In all dilutions and cleaning steps, deionized water was used. For cleaning of microorganisms in membrane filtration, methanol and ethanol were used. Containers were washed up with double distilled water and then rinsed with the sample being analyzed before their actual usage. Chemicals and reagents used in this study were deionized water, buffer solutions (pH 4.01±0.02, 7.00±0.02 and 10.01±0.02 at 25°C), potassium chloride (0.01 M KCl), nitraver 5 nitrate reagent, sulfaver 4 reagent, phosver 3 phosphate, mercuric thiocyanate solution, ferric ion solution, buffer-citrate type, sodium periodate, ferrover iron reagent powder pillows and Membrane Lauryl Sulphate Broth.

Sample size, sampling technique and preservation of samples: Kiltu Kara Town drinking water supply relies on ground water as a source which is abstracted from deep well water. In the town, there is one functional deep well with depth of 72 m. Seven sampling sites, one from the source, two from reservoirs, two from private, and two from public taps were selected to collect water samples. A total of 21 water samples were collected from the seven sites, by taking three times from each site within 20 days interval for two months from November to December, 2021. Triplicate laboratory samples were prepared from each sample in the laboratory for laboratory analyses. The water sample was collected following the standard procedure as described in American Public Health Association guidelines. The samples from sampling sites were collected using 1 L and 100 mL polyethylene bottles for physicochemical and microbiological analyses, respectively. The plastics bottles were previous sterilized by steam sterilizer, washed and rinsed several times with the water being collected or filled to avoid any contamination. The collected water samples were labeled at the field using appropriate codes and temporary stored in ice packed cooler, and then transported to the laboratory. The samples were stored in a refrigerator at about 4°C prior to laboratory analysis.

Water samples analysis procedures: All the analytical procedures used in the physicochemical and bacteriological analysis of the water samples were executed according to the standard method of water and wastewater analysis prescribed in the American Public Health Association guidelines. The water samples were analyzed in the Nekemte City water supply and sewerage service enterprise laboratory. The analyses were conducted by using standard methods of classical laboratory methods model of DR/2400 Spectrophotometer and Microbiological Incubator.

Assessment of physicochemical parameters of water samples: The assessment of the physicochemical parameters of water samples was conducted by using standard methods of laboratory procedures prescribed by American Public Health Association guidelines. Details of the analytical methods and procedures used for each selected physical and chemical parameter are discussed below.

Physical parameters measurements: Certain physical parameters, such as temperature, pH, and electrical conductivity (EC), were measured in the field at the time of collection due to their instability. This was done following the standard methods and procedures for water and wastewater examination outlined in the American Public Health Association Guidelines[7,8].

Temperature measurements: The temperature of water samples was measured in the field using a thermometer calibrated to 0 to 100°C. The thermometer was immersed in the water sample until the liquid column in the thermometer stopped moving for 3 min and the reading was recorded.

Color measurements: The color of the water samples was measured by HACH's DR/2400 Portable Spectrophotometer and Platinum-Cobalt Standard Method. First, the water samples were filtered with 0.45 μm membrane filter paper to remove any solid particles. The HACH DR/2400 Spectrophotometer instrument was prepared and made ready for measurement. After zeroing the instrument with the Platinum-Cobalt standard, the filtered water samples were poured into a clean cuvette. Then the samples were filled to 10 mL sample cuvette inserted into the instrument, and then the results were recorded in mg/L PtCo.

Electric conductivity (EC) measurements: The EC was measured using a digital portable conductivity meter. Before measuring, the probe was rinsed with distilled water and the purity of distilled water was checked. Then the probe was immersed in a beaker containing a water sample and moved up and down taped on the beaker to be free the electrodes from any bubbles. Then data was recorded for each sample.

Total dissolved solids (TDS) measurements: The TDS was measured using a combined portable microprocessor-based conductivity/TDS meter model Model-1601.

Turbidity measurements: The turbidity of water was measured by a microprocessor portable turbidity meter instrument by zeroing with deionized water by the Turbidity Meter Method.

pH of water measurements: The pH water sample was measured by using a portable pH meter after calibrating the instrument by buffer solution standards at pH 4, 7, and 10.

Chemical parameters measurements: Some chemical parameters of the drinking water supply determined in this study were measured using a portable DR/2400 Spectrophotometer, following the procedures, chemicals, and reagents outlined in the American Public Health Association's guidelines for water and wastewater analysis[7,8].

Nitrate (NO_3^-) measurements: A content of one NitraVer 5 Nitrate reagent powder pillow was added to 10 mL sample water in the first sample cell shaken vigorously for 1 min, and allowed to stand for 5 min for amber color development. The second sample cell was filled with about 10 mL of sample water. This was used as a blank to calibrate the instrument to 0.0 mg/L NO_3^-. Then, the sample prepared in the first sample cell was inserted into the spectrophotometer; a direct reading of the concentration of NO_3^- was recorded.

Sulphate (SO_4^{2-}) measurements: In one sample cell, one SulfaVer 4 Reagent Powder Pillow was mixed with a 10 mL water sample. The mixture was allowed to react for 5 min and swirled vigorously to dissolve the powder. A white turbidity was formed. The blank, in the other sample cell, was inserted into the cell holder to make the reading on the instrument zero. Then, the prepared sample in the first sample cell was allowed for analysis.

Phosphate (PO_4^{3-}) measurements: In one sample cell, one PhosVer 3 phosphate Powder Pillow reagent has mixed with a 10 mL water sample and it was immediately caped and inverted to mix (this is the prepared sample) and allowed to stand for a 2 min reaction period. In the other sample cell, about 10 mL of sample water was filled (this is the blank). The blank, in the second sample cell, was inserted into the cell holder to make the reading on the instrument zero (0.00 mg/L PO_4^{3-}). Then, the prepared sample in the first sample cell was allowed for analysis and the results appeared in mg/L PO_4^{3-}.

Chlorides (Cl) measurements: Chloride was analyzed by the Mercuric Thiocyanate Method after selecting program number 70 from the instrument. Two round sample cells were filled with sample and deionized water separately; 2.0 mL of Mercuric Thiocyanate Solution and 1.0 mL of Ferric Ion Solution were pipetted into each sample cell. The mixture was swirled vigorously to mix and allowed to react for 2 min. The blank (with deionized water), was inserted into the cell holder to make the reading on the instrument zero. Then, the prepared sample was inserted into the instrument and allowed to read and the result appeared in mg/L Cl^-.

Total iron (Fe) measurements: Iron was determined by the FerroVer method. A content of one ferrover iron reagent powder pillow was added to 10 mL sample water in the first sample cell shaken vigorously and allowed to stand for 3 min reaction period. In the second sample cell, about 10 mL of sample water was filled. This was used as a blank to calibrate the instrument to 0.0 mg/L Fe. Then, the sample prepared in the first sample cell was inserted into the spectrophotometer; a direct reading of the concentration of Fe was recorded.

Manganese (Mn) measurements: Manganese was measured by the periodate oxidation method. In the first sample cell, one buffer powder pillow, citrate type for manganese, and one sodium periodate powder pillow were mixed with a 10 mL water sample. The mixture was swirled vigorously to dissolve the powder and allowed to react for 2 min. A violet color was developed. The blank, in the second sample cell of 10 mL was inserted into the cell holder to make the reading on the instrument zero. Then, the prepared sample in the first sample cell was allowed for analysis.

Bacteriological parameters measurements: The samples were analyzed for total coliform count (TC) and fecal coliform count (FC) using the membrane filter techniques as outlined in the American Public Health Association guidelines[7,8]. As 100 mL of water sample was placed on the surface of the sterile filter membrane with pore size 0.45 μm after vigorous shaking and placed on the funnel unit of the membrane filter support assembly. The filtration was facilitated by applying a vacuum pump and the assembly was rinsed by sterile dilute water as outlined in American public health association guideline. Up on completion of the filtration process, the bacteria that remained on the filter papers were placed on Petri dishes containing Eosin Methylene Blue (EMB) agar. The EMB agar contains lactose, sucrose, and dyes; eosin and methylene blue as indicators. Finally, the cultures were incubated in a Micro Bacteriological Laboratory Incubator at 37°C for 24 hrs and at 44.5°C for 48 hrs for total coliforms and fecal coliforms, respectively. Upon completion of the incubation period, colonies were observed and the number of colonies formed on the media was counted and recorded as Colony-Forming Units (CFU) per 100 mL of a sample. Both total and fecal coliform counts were analyzed by filtration method.

Quality control/quality assurance: Before the actual data collection time, a pretest was done in the laboratory by calibrating laboratory equipment, checking the expiry date of chemicals and reagents, and preparation of new standards for each test. For microbiological analysis certified microbiological test kits were used and proper sterilization protocols were followed. In addition, more numbers of techniques were undertaken to ensure that the data generated were reliable[9,10].

Statistical data analysis: The primary data collected were first entered into a Microsoft Excel spreadsheet (version 2010) software application to present descriptive data in frequency, table, graphs, and charts. Results were analyzed using Statistical Package for Social Sciences (SPSS version 22) to compute the mean values of the physicochemical and microbiological data. The one-way ANOVA was used to identify if there were any significant differences between samples amongst the drinking water sampling sites; water from wells, reservoirs, private tap water or public tap water with a 0.05 significance level. The mean values were compared against the national and international standards (CES and WHO) drinking water standards.

RESULTS AND DISCUSSION

Physicochemical and bacteriological water quality analysis: The physical and chemical parameters of water samples collected from seven different water supplies in Kiltu Kara Town during the study period are presented in Table 1 and 2. The results of the bacteriological parameters analyzed are summarized in Table 3. The results of the one-way ANOVA for the physicochemical and bacteriological parameters of the study sites, along with the Pearson correlation values for the physicochemical and bacteriological parameters of the Kiltu Kara Town water samples, are presented in Table 4 and 5, respectively.

Physical quality of drinking water: Tests under this category were carried out to examine the deep well drinking water sample for temperature, dissolved solids (TDS), color, electrical conductivity (EC), turbidity, and hydrogen power (pH) and are tabulated in Table 2.

Table 1: Mean concentrations of physical parameters of Kiltu Kara Town drinking water samples

	Sampling station									
	R1		R2		R3		R4		Standards	
Parameters	Mean	Std	Mean	Std	Mean	Std	Mean	Std	WHO	CES
Temp. (°C)	21.27	0.44	21.51	0.57	21.79	0.65	21.86	0.52	<40	25
TDS (mg/L)	80.11	0.19	85.11	1.34	80.89	0.84	86.56	0.2	500	1000
Color (PtCo)	6	0.58	3.33	1.15	2.33	0.58	10.22	2.22	15	22
EC (µS/cm)	117.67	1.67	124.78	3.67	119	2.67	127.11	2.01	400	500
Turb. (NTU)	0.5	0.07	0.39	0.09	0.45	0.14	1.25	0.57	5	5
pH units	6.66	0.05	6.65	0.24	6.55	0.17	6.56	0.25	6.5-8.5	6.5-8.5
			R5		R6		R7		Standards	
Parameters			Mean	Std	Mean	Std	Mean	Std	WHO	CES
Temp. (°C)			22.47	0.1	22.47	0.25	22.23	0.14	<40	25
TDS (mg/L)			85.78	0.39	84.67	1	88.78	2.34	500	1000
Color (PtCo)			6.33	1	4.22	0.39	9.22	1.65	15	22
EC (µS/cm)			126	1.53	124.45	0.39	130.2	1.84	400	500
Turb. (NTU)			0.47	0.06	0.32	0.02	0.87	0.45	5	5
pH units			6.91	0.43	5.88	0.37	6.75	0.37	6.5-8.5	6.5-8.5

R1: Source, R2: First tanker, R3: Second tanker, R4: Private tap (home tap, 01 Kebele), R5: Public tap/Bono (01 Kebele), R6: Private tap (home tap, 02 Kebele), R7: Public tap/Bono (02 Kebele), Std: Standard deviation, Temp.: Temperature, TDS: Total dissolved solids, EC: Electrical conductivity and Turb.: Turbidity

Table 2: Mean concentrations of some selected chemical parameters of Kiltu Kara town Deep Well drinking water samples

	Sampling station									
	R1		R2		R3		R4		Standards	
Parameters	Mean	Std	Mean	Std	Mean	Std	Mean	Std	WHO	CES
NO_3^- (mg/L)	1.53	0.22	1.32	0.15	0.9	0.25	1.1	0.09	50	50
SO_4^{2-} (mg/L)	3.11	0.19	4.89	1.84	3.78	0.69	5.67	2.18	250	250
PO_4^{3-} (mg/L)	0.56	0.01	1.28	0.45	1.58	0.4	1.87	0.53	5	
Cl^- (mg/L)	1.54	0.1	1.51	0.3	1.43	0.04	1.42	0.12	250	250
Mn (mg/L)	0.75	0.2	0.87	0.22	0.6	0.12	1.12	0.32	0.4	0.5
Fe (mg/L)	0.18	0.04	0.18	0.03	0.15	0.03	0.26	0.07	0.3	0.3
			R5		R6		R7		Standards	
Parameters			Mean	Std	Mean	Std	Mean	Std	WHO	CES
NO_3^- (mg/L)			0.99	0.15	0.8	0.07	0.98	0.32	50	50
SO_4^{2-} (mg/L)			6.56	2.83	7.11	3.02	6.44	3.15	250	250
PO_4^{3-} (mg/L)			0.86	0.05	0.79	0.03	0.64	0.02	5	
Cl^- (mg/L)			0.99	0.15	0.84	0.19	0.7	0.13	250	250
Mn (mg/L)			0.81	0.27	0.36	0.05	1.04	0.57	0.4	0.5
Fe (mg/L)			0.17	0.06	0.08	0.02	0.13	0.03	0.3	0.3

R1: Source, R2: First tanker, R3: Second tanker, R4: Private tap (household tap, 01 Kebele), R5: Public tap/Bono (01 Kebele), R6: Private tap (household tap, 02 kebele), R7: Public tap/Bono (02 Kebele) and Sdt: Standard deviation

Table 3: Mean concentrations of microbiological parameters of Kiltu Kara Town deep well-drinking water samples

	Sampling station									
	R1		R2		R3		R4		Standards	
Parameters (CFU/100 mL)	Mean	Std	Mean	Std	Mean	Std	Mean	Std	WHO	CES
FC	3	1	5.44	0.51	2	1	3.11	1.17	0	0
TC	5.33	2.34	7.78	0.19	4.45	2.34	6.44	2.34	0	0
			R5		R6		R7		Standards	
Parameters (CFU/100 mL)			Mean	Std	Mean	Std	Mean	Std	WHO	CES
FC			1	0	3	0	3.67	0.58	0	0
TC			3.44	1.26	5.22	0.51	5	0.88	0	0

R1: Source, R2: First tanker, R3: Second tanker, R4: Private tap (household tap, 01 Kebele), R5: Public tap/Bono (01 Kebele), R6: Private tap (household tap, 02 kebele), R7: Public tap/Bono (02 Kebele), Sdt: Standard deviation, FC: Faecal coli form count, TC: Total coli form counts and CFU: Colony forming units

Temperature: Temperature significantly affects drinking water quality by influencing physical, chemical, and biological processes. It impacts microbial growth, chemical reactions, dissolved oxygen levels, and the efficiency of water treatment. Monitoring and managing temperature variations in water sources is crucial to maintaining a safe and reliable drinking water supply. The study data revealed that the highest mean temperature of 22.47°C was recorded from R5 and R6, while the lowest mean temperature of 21.27°C was measured from R1 (Table 1). The measured mean values of temperature for this study were lower than 40 and 25°C set by World Health Organization guidelines and Ethiopian compulsory standard, respectively. The recorded temperature values were higher than 16.65°C studied in Jimma City, Southwest Ethiopia[7] and lower than 24.42°C recorded in Jimma Zone, Southwest Ethiopia[11] and 28.49°C recorded in Wondo Genet Campus, Southeast of Shashemene, Ethiopia[12] conducted on similar drinking water quality parameters from source to household tap connection of water sources.

Total Dissolved Solids (TDS): The mean concentration for TDS of deep well water samples of the current study was found to be in the range of 80.11 to 88.78 mg/L from R1 and R7 (Table 2) water samples, respectively. These results are less than the Ethiopian compulsory standard and World Health Organization guideline values of 500 and 1000 mg/L, respectively. The deep well water source is potable in terms of TDS according to this study result. This result is also lower as compared to the study result reported in Wondo Genet Campus, Ethiopia[12] in which the average concentration of TDS is 118.56 mg/L and the study result reported in Jimma Zone, Southwest Ethiopia[11] in which the average concentration of TDS is 524.73 mg/L and also in Shambu Town, Ethiopia[10] with recorded TDS value ranging from 62.73 to 154 mg/L in drinking water samples. The mean total dissolved solid values show a significant difference ($p \leq 0.05$) among the selected sites of the deep well drinking water samples (Table 4).

Color of water: Drinking water is typically colorless and clear. Any color may signal impurities, pollutants, or minerals. Clean and safe water should be free from color and particulate matter. Most people can detect colors above 15 true color units (TCU), though local preferences may vary. Dissolved organic matter, such as humic and fulvic acids, is the main cause of discoloration. Color values of the deep well drinking water source from all sample sites range from 2.33 PtCo (R3) to 10.22 PtCo (R4). The measured mean value of color in this study was lower than the value set by the Ethiopian compulsory standard and World Health Organization guideline which is 15 PtCo. This might be due to the natural filtration ability of the soil and non-environmental contact or absence of material and chemical inlet as the water drawn from deep wells, isolated from surface water sources, is less likely to contain organic material or pollutants that cause higher color values. The level of color positively correlated with turbidity and total suspended solid. It was also affected by the same factors that affect turbidity and total suspended solids. Color affects the aesthetic quality of drinking water and indicates contamination. While color itself is not usually a health risk, it can signal the presence of other substances that may impact water quality. Therefore, monitoring and treatment are essential to ensure the water meets safety standards for consumption.

Electrical conductivity (EC): Electrical conductivity (EC) in drinking water measures its ability to conduct electricity, influenced by dissolved salts and minerals. Higher EC indicates more ions, while lower EC suggests purer water. The EC is a useful indicator of water quality but doesn’t specify the types of dissolved substances. Water with an EC between 100 and 500 μS/cm is generally considered acceptable. The EC reflects the movement of ions in solution and helps assess water purity. In the current study, EC values recorded from R1 and R7 water samples range from 117.67 to 130.2 μS/cm. The mean concentration of EC was lower than 400 and 500 μS/cm set by World Health Organization Guidelines and Ethiopian Compulsory Standard, respectively.

Table 4: One way ANOVA results of physicochemical and bacteriological parameters of the study sites

Parameters	Sum of squares	df	Mean square	F	Sig.	Significance
Temperature						
Between groups	3.931	6	0.655	3.525	0.02	Significant
Within groups	2.602	14	0.186			
Total	6.532	20				
TDS						
Between groups	170.499	6	28.417	21.56	0.00	Significant
Within groups	18.451	14	1.318			
Total	188.951	20				
Color						
Between groups	156.028	6	26.005	16.9	0.00	Significant
Within groups	21.549	14	1.539			
Total	177.577	20				
EC						
Between groups	354.149	6	59.025	12.42	0.00	Significant
Within groups	66.533	14	4.752			
Total	420.681	20				
Turbidity						
Between groups	1.989	6	0.331	4.162	0.01	Significant
Within groups	1.115	14	0.08			
Total	3.104	20				
pH						
Between groups	0.372	6	0.062	0.722	0.64	Insignificant
Within groups	1.203	14	0.086			
Total	1.576	20				
NO_3^-						
Between groups	1.188	6	0.198	5.076	0.01	Significant
Within groups	0.546	14	0.039			
Total	1.734	20				
SO_4^{2-}						
Between groups	40.657	6	6.776	1.327	0.31	Insignificant
Within groups	71.516	14	5.108			
Total	112.173	20				
PO_4^{3-}						
Between Groups	4.509	6	0.751	8.236	0.00	Significant
Within groups	1.277	14	0.091			
Total	5.786	20				
Cl^-						
Between groups	2.233	6	0.372	13.67	0.00	Significant
Within groups	0.381	14	0.027			
Total	2.614	20				
Mn						
Between groups	1.204	6	0.201	2.328	0.09	Insignificant
Within groups	1.206	14	0.086			
Total	2.41	20				
Fe						
Between groups	0.057	6	0.009	5.847	0.00	Significant
Within groups	0.023	14	0.002			
Total	0.079	20				
FC						
Between groups	34.259	6	5.71	10.1	0.00	Significant
Within groups	7.919	14	0.566			
Total	42.177	20				
TC						
Between groups	35.051	6	5.842	2.144	0.11	Insignificant
Within groups	38.145	14	2.725			
Total	73.196	20				

FC: Faecal coli form count, TC: Total coli form counts and df: Degree of freedom

The measured value is within the range of 80 to 248.96 μS/cm which is similar to the recorded value in Shambu Town, Ethiopia[10], and lower than the average concentration of 366.93 μS/cm recorded in Jimma Zone[11] and 192.14 μS/cm Wondo Genet Campus, Ethiopia[12]. Thus the result revealed low electrical conductivity implying the reduced level of ionic species in the deep well water and the water is safe for drinking purposes in terms of EC. The mean value of EC shows significance difference ($p \leq 0.05$) among the sampling sites of the study area.

Turbidity: Turbidity in drinking water is the cloudiness caused by suspended particles like dirt, silt, and microorganisms. High turbidity can harbor pathogens and hinder disinfection. Clear water typically has turbidity below 1 NTU, though local standards may vary. It affects water quality and other chemical and bacteriological parameters. In the current study, turbidity ranged from 0.32 NTU at site R6 to 1.25 NTU at site R4. These measurements showed significant variations amongst water at all sample sites. Since the town was located at a low altitude, the distribution systems would not be contaminated by organic matter. On the other hand, there are no factories in the town which can pollute the well water.

Turbidity from all water samples complies with both World Health Organization guidelines and the Ethiopian compulsory standard set value of 5 NTU. High turbidity values affect the clarity of water and reduce the depth to which light can penetrate. It has also been an indication of poor filtration process of water supplies. Particulate matter can protect microorganisms from the effect of disinfection and can stimulate bacterial growth.

High turbidity can interfere with disinfection and provide a medium for microbial growth. The recorded mean value of turbidity in this study was lower than the ranges from 1.26 to 4.23 NTU reported in Shambu Town[10], and 1.87 NTU reported at Jimma Zone, Southwest Ethiopia[11] and 0.7 to 1.4 NTU reported at Wondo Genet Campus[12] in the similar drinking water samples. From the statistical values, the measured mean value of turbidity showed significant difference ($p \leq 0.05$) among the sampling sites (Table 4).

pH: The pH value of the water samples ranged from 5.88 to 6.91 and the highest value was recorded at R5 and the lowest value was recorded at R6. In this study, except R6, all water sources met national standards and the International World Health Organization Guideline which set the pH of drinking water between 6.5 and 8.5. The slightly lower pH recorded for water samples may be due to the marshy surrounding of the area that enhances microbiological activities that release acidic leachates into the source water. A slightly lower pH value may not pose a health risk but it may indicate the presence of harmful substances. Hence, regular monitoring of the water's pH and other parameters is essential to ensure it remains safe for drinking purposes.

The pH mean values of deep well water samples of the present study were lower than 7.96 to 8.63 in Shambu Town, Ethiopia[10], 7.53 to 7.94 recorded in Jimma Southwest, Ethiopia[11], and 6.52 to 6.83 in Wondo Genet Campus, Ethiopia[12] of similar drinking water samples. The measured mean value of pH in this study revealed an insignificant difference ($p \geq 0.05$) among the sampling sites.

Chemical drinking water quality parameters: Several chemical contaminants have been linked to negative health effects in humans due to long-term exposure to drinking water. These contaminants include both organic and inorganic chemicals, as well as certain pesticides. Some of these substances are toxic to humans or impact the aesthetic qualities of the water. The parameters analyzed were Nitrate (NO^{-}_{3}), Sulphate (SO_4^{2-}), Phosphate (PO_4^{3-}), Chloride(Cl^-), Manganese (Mn), and Total Iron (Fe).

Nitrate (NO_3^-): The nitrate (NO_3^-) content of drinking water is an important parameter that indicates the accumulation of nitrate due to leaching from nearby agricultural fields and pollution of water by organic matter due to microbial activity. The measured nitrate concentration results in Table 2 showed that the value ranged from 0.8 to 1.53 mg/L for R6 and R1, respectively. The Ethiopian compulsory standard and World Health Organization guideline level for nitrate is 50 mg/L. The present study indicated that the nitrate content is much lower than the Ethiopian compulsory standard and World Health Organization guideline, thus the deep well water samples in this study are safe in terms of nitrate concentrations.

Nitrate, nitrite, and ammonia, which are of great interest due to their nutrient values, were very low in all samples. The nitrate mean concentration values of deep well water samples of the present study were lower than the values which range from 2.46 to 2.56 mg/L recorded in Jimma Southwest, Ethiopia[7] and 1.42 to 4.97 mg/L recorded in Wondo Genet Campus, Ethiopia[12] and within the ranges 0.3 to 28 mg/L recorded in Shambu Town, Ethiopia[10], respectively of similar drinking water samples. The recorded nitrate concentration during the sampling period across the sampling sites indicated significant difference ($p \leq 0.05$) among the sites of the studied deep well drinking water supply.

Sulphate (SO_4^{2-}): Sulfate is not naturally harmful at low concentrations, but excessive exposure can have several health impacts, depending on the form in which it is encountered and the level of exposure. Its health effects include gastrointestinal distress, respiratory problems, and long-term environmental and metabolic impacts. Drinking well water from the sampling areas generally had low SO_4^{2-} concentrations ranging from 3.11 mg/L (R1) to 7.11 mg/L (R6), Table 2. All the values are very much lower than the acceptable maximum limits of 250 mg/L set by the Ethiopian compulsory standard and World Health Organization guidelines. When compared to other studies, the sulfate content of the deep well water samples of the study area were higher than that of the study conducted in Wondo Genet Campus, Ethiopia[12] with the reported value which ranges from 0 to 3 mg/L and lower than the value of 3.6 mg/L recorded at Shambu Town, Ethiopia[10]. The recorded values for sulfates among the sites reveal insignificant differences ($p \geq 0.05$) along sampling sites as in Table 3 and 4.

Phosphate (PO_4^{3-}): Determining the concentration of phosphate (PO_4^{3-}) in drinking water is essential for ensuring water quality, as excessive phosphate levels can contribute to eutrophication and may be a sign of pollution. No amount of phosphate in water was believed to have effects on human health. Phosphate has no significant adverse effect on human health. The level of phosphate in all the water samples is lower than the permissible limit of 5 mg/L set by the Ethiopian compulsory standard and World Health Organization guidelines. The recorded concentration ranged from 0.56 mg/L (R1) to 1.87 mg/L (R4). The phosphate concentration was slightly higher than 0.24 to 0.86 mg/L reported in Shambu Town[10] and similar to 1.21 mg/L in Jimma Zone, Southwest Ethiopia[12] in similar studies. The values show a significant difference ($p \leq 0.05$) among the sampling sites of the current study. Therefore, the level of PO_4^{3-} in the study area is found to be good both for drinking and domestic uses.

Chloride (Cl^-): Chloride is normally the most dominant anion in water and it imparts a salty taste to the water. Ethiopian compulsory standard and World Health Organization guideline value for chloride concentration in drinking water was 250 mg/L whereas, the study result ranged from 0.7 to 1.54 mg/L from R7 and R1, respectively which is much far lower than the maximum acceptable concentration limit. Compared to other similar study results, the measured mean values of chloride were lower than 51.3 to 54.1 mg/L recorded in Jimma, Southwest Ethiopia[7], and 3 to 4.4 mg/L in Wondo Genet Campus, Ethiopia[12]. The recorded chloride concentration during the sampling period across all the sampling sites shows a significant difference ($p \leq 0.05$) among the sites of the studied deep well drinking water supply.

Manganese (Mn): Manganese is often found with iron in groundwater. Excessive manganese concentrations in drinking water, especially from deep well sources, can pose significant health risks, including neurological damage and cognitive impairments. Concentrations of manganese (Mn) set below 0.4 mg/L by the World Health Organization and 0.5 mg/L by the Ethiopian compulsory standard. At this level, Mn does not cause black stains or deposits of hydrated manganese oxides. The study found manganese concentrations ranging from 0.36 to 1.12 mg/L in all water sources, exceeding the recommended levels and potentially causing manganese-related issues. The lowest Mn concentration was recorded at R6 which is within the recommended standard guidelines and in all the rest sampling sites found above Ethiopian compulsory standard and World Health Organization guidelines. Excess manganese in drinking water can cause an unpleasant taste, staining, and health issues, particularly neurological effects in infants and children. The recommended limit is 0.05 mg/L (50 mg/L)[13]. While manganese is essential in small amounts, high levels can interfere with iron use in blood regeneration and cause symptoms like irritability, headaches, and weakness. Large doses may lead to psychological issues such as impulsivity, hallucinations, and aggressiveness.

In this study, the manganese content of deep well water samples ranged from below detectable levels to 1.24 mg/L, consistent with the findings reported in Shambu Town, Ethiopia[10], for similar drinking water sources. The measured manganese value in all sites shows an insignificant difference ($p \geq 0.05$) among the sampling sites of the studied deep-well drinking water source.

Total Iron (Fe): The concentration of Total Iron (Fe) in drinking water is an important factor because excessive iron levels can have both aesthetic and health-related impacts. In this study, the mean concentration of iron in the water ranges from 0.08 to 0.26 mg/L, which is lower than the maximum acceptable concentration level set by the World Health Organization and Ethiopian compulsory standards, both of which are 0.3 mg/L. The highest iron content was observed from R4 whereas the least was seen from R6. The higher values of iron in R4 may be caused by precipitation of reddish color at the distribution line or faucets. In this study, the mean concentration of iron in the water samples ranges from 0.08 to 0.26 mg/L, consistent with the findings reported, which range from 0.016 to 0.31 mg/L, in Shambu Town, Ethiopia[10], for similar drinking water sources.

Iron is an essential trace element for human health, playing a crucial role in various metabolic processes, such as oxygen and electron transport, as well as DNA synthesis[14]. It can also promote the growth of iron bacteria in water and also make the water unacceptable for the users[15]. From the statistical results ($p \leq 0.05$) the iron mean value of this study shows significance differences among sampling sites.

Biological water quality parameters: For water to be considered safe, it must be free of harmful bacterial contaminants. The most important measure of water quality is the amount of bacteria it contains. While detecting all types of bacteria in a sample is challenging, certain microorganisms can act as indicators of contamination. The most important of these are coliform bacteria (including fecal coliform and total coliform), as they are more resilient, longer-lasting, and easier to detect compared to other pathogens[11]. In this study, the results of the microbiological analysis indicated that the deep well water sources of the present study were found to be positive for fecal and total coliform counts (Table 3). Fecal and total coliform counts per 100 mL are used to classify the risk of microbial contamination, with counts between 0 and 10 indicating a low risk[16]. In the present study, microbial contamination was found to pose a low risk to human health. The average fecal coliform counts ranged from 1 to 5.44 CFU/100 mL, while the total coliform counts ranged from 3.44 to 7.78 CFU/100 mL. The lowest fecal coliform count was observed in samples from the R5 site, while the highest was found in samples from the R2 site. When compared with the maximum permissible limit of Ethiopian compulsory standard and World Health Organization guideline value of 0 CFU/100 mL, both fecal and total coliform counts in this study were above the maximum acceptable limit standards.

Table 5: Pearson correlations of physicochemical and bacteriological parameters of the Kiltu Kara town water samples

	Temp.	TDS	Color	EC	Turb.	pH	NO_3^-	SO_4^{2-}	PO_4^{3-}	Cl^-	Mn	Fe	FC	TC
Temp.	1													
TDS	0.369	1												
Color	0.083	0.600**	1											
EC	0.216	0.931**	0.551**	1										
Turb.	-0.194	0.355	0.761**	0.397	1									
pH	-0.071	0.113	-0.02	0.313	0.103	1								
NO_3^-	-0.418	-0.32	0.03	-0.31	-0.155	-0.3	1							
SO_4^{2-}	0.236	0.413	0.127	0.601**	0.22	0.550**	-0.4	1						
PO_4^{3-}	-0.395	0.066	0.046	0.164	0.457*	-0.08	-0.23	0.095	1					
Cl^-	-0.718**	-0.512*	-0.28	-0.456*	-0.018	-0.25	0.513*	-0.38	0.529*	1				
Mn	-0.357	0.357	0.539*	0.412	0.745**	0.356	0.061	0.204	0.312	0.118	1			
Fe	-0.4	0.084	0.441*	0.046	0.437*	-0.34	0.283	-0.3	0.476*	0.457*	0.43	1		
FC	-0.518*	0.184	0.036	0.244	0.235	0.023	0.259	0.069	0.163	0.172	0.307	0.053	1	
TC	-0.651**	0.096	0.091	0.239	0.392	0.172	0.214	0.21	0.436*	0.319	0.423	0.243	0.855**	1

**Correlation is significant at the 0.01 level (2-tailed) and *Correlation is significant at the 0.05 level (2-tailed)

The recorded fecal and total coliform count values during the sampling period across the sampling sites show significant differences and insignificant differences at ($p \leq 0.05$), respectively among the sampled sites' deep well drinking water supply. Similar findings of the study conducted in Dire Dawa Administrative Council[17] reported the water samples were positive for indicator bacteria (fecal and total coliform counts). The bacteriological results from this study showed that most of the bacteriological parameters measured (fecal coliform and total coliform) were not in agreement with the standard values set out by the World Health Organization and the Compulsory Ethiopian Standard. Hence, regular bacteriological assessment of water supply sources is essential for drinking water quality parameters.

The one-way ANOVA analysis revealed significant variations in most physicochemical and bacteriological parameters across the study sites. Parameters such as temperature, TDS, color, EC, turbidity, NO , PO_4^{3-}, Cl , Fe, and FC showed statistically significant differences ($p<0.05$), indicating variability influenced by site-specific factors. In contrast, pH, SO_4^{2-}, Mn, and TC exhibited no significant differences ($p>0.05$). This suggests that certain parameters remain consistent across sites, while others are influenced by localized environmental or anthropogenic factors (Table 4).

Pearson correlation matrix of physicochemical and bacteriological parameters: The correlation between water quality parameters greatly facilitates the task of rapid monitoring of water quality. The interactions within and between the physicochemical and bacteriological parameters of the sampling sites of the present study were further verified by Pearson correlation. Table 5 shows the Pearson correlation coefficient matrix between the measured physicochemical and bacteriological parameters of deep well water samples of Kiltu Kara Town.

From the Pearson correlation coefficient matrix in Table 5, it is observed that the correlation of TDS with EC is very high positive correlation ($r = 0.931$), color with TDS, EC and turbidity, respectively ($r = 0.6$, $r = 0.551$ and $r = 0.761$), SO_4^{2-} with EC and pH, respectively ($r = 0.601$ and $r = 0.55$), Mn with turbidity ($r = 0.745$), TC with FC ($r = 0.855$) are pairs strongly positively correlated and temperature with Cl^- and TC, respectively ($r = -0.718$ and $r = -0.651$) are pairs negatively correlated significantly at 99% confidence level. Whereas color with Mn and Fe, respectively ($r = 0.539$ and $r = 0.441$), turbidity with PO_4^{3-} and Fe, respectively ($r = 0.457$ and $r = 0.437$), Cl^- with NO_3^- and Fe, respectively ($r = 0.513$ and $r = 0.457$), PO_4^- with Cl^-, Fe and TC, respectively ($r = 0.529$, $r = 0.476$ and $r = 0.436$) phosphate are paired positively correlated and Cl^- with TDS and EC, respectively ($r = -0.513$ and $r = -0.456$), temperature with FC ($r =-0.518$) are pairs negatively correlated significantly at 95% confidence level.

Overall, most of the remaining physicochemical and bacteriological parameters exhibit weak correlations with each other across the sampling sites. This suggests that an increase in one parameter tends to result in an increase in the other when there is a strong positive correlation and vice versa[18]. The significant positive correlations observed at the 99% confidence level among the studied water quality parameters suggest that the water samples may originate from similar sources.

CONCLUSION

In this study, water samples from seven sites in Kiltu Kara Town were analyzed for physicochemical and bacteriological parameters. Most values met the Compulsory Ethiopian Standard (CES) and WHO guidelines, except for fecal coliforms (1 to 5.44 CFU/100 mL), total coliforms (3.44 to 7.78 CFU/100 mL), manganese (0.6 to 1.12 mg/L), and pH (5.88 in R6). Elevated manganese levels could cause metallic taste and health issues like headaches and irritability, while low pH may damage plumbing. After treatment, the deep well water at all sites was deemed safe for drinking and other uses. It is recommended that improving water treatment processes to reduce manganese levels and adjust pH, along with regular monitoring to ensure coliform contamination is minimized.

SIGNIFICANCE STATEMENT

This study evaluates the physicochemical and bacteriological quality of drinking water in Kiltu Kara Town, Western Ethiopia, providing critical insights into water safety for the community. The findings highlight that while most parameters met the standards set by the Ethiopian compulsory standard and World Health Organization guideline, there were significant concerns related to bacteriological contamination (fecal coliforms and total coliforms) and elevated manganese levels. These issues indicate potential health risks, emphasizing the need for improvements in the water treatment process. The study underlines the importance of infrastructure development and public awareness to ensure safe provision of potable water, safeguarding public health in the town. Furthermore, the findings offer valuable data to address water quality challenges in developing countries for global stakeholders.

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