Assessment of Drinking Water Quality from Source to Point of Use in Merawi Town, Amhara National Regional State, Ethiopia

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Abstract

This research focused on evaluating drinking water quality from source to point of use in Merawi town, which is located in Amhara National Regional State, Ethiopia. Water samples were collected in both the dry season (from March to April) and the wet season (from mid-July to mid-August) of 2021. A total of 50 water samples were collected from 25 purposively selected sampling points and eleven physicochemical parameters (pH, temperature, turbidity, EC, TDS, total hardness, Ca^{2+}, Mg^{2+}, NO_3, NO_2^- and Cl^-) and bacteriological parameters (total coliform and faecal coliform) were tested using standard procedures. Sanitary inspections were also conducted in order to identify the possible causes of contamination. The results show that except turbidity and temperature all the selected physicochemical parameters were within the acceptable limits of WHO and Ethiopian standards. The maximum turbidity values of 14.27NTU was recorded in the wet season at the point of use while the highest temperature value of 25.63^{O}C was recorded in the dry season at the point of disinfection. Bacteriological test results show that all the samples had positive total coliform counts in both seasons whereas only 28% and 12% of the samples had zero faecal coliform counts in the dry and wet seasons, respectively. The sanitary inspection results indicate that uncovered collection chamber, wrong way of disinfection, incidence of cross-contamination, change in water flow due to intermittent water supply, presence of older pipe material and dead-end layout system are the possible causes of contamination. In order to provide safe drinking water to the residents of the town, there is an urgent need to establish buffer zone to the water source area, maintain the collection chamber cover, develop proper drainage network and improve the chlorination system.

Keywords: Water quality, Physicochemical, Merawi, Turbidity, Faecal coliform, Total coliform

1. Introduction

Access to clean water and sanitation services remains a critical issue in developing countries, with a large proportion of the population lacking these basic necessities (Rahut *et al.,* 2022). Poor water quality contributes significantly to global mortality rates, surpassing deaths from violence, including war, with around 26% of all deaths attributed to waterborne diseases caused by pathogenic microorganisms (Turk & Rozman, 2022). Inadequate water supply management in developing countries, where water is often provided intermittently due to cost-saving measures or shortages, can lead to low water pressure issues that allow contaminated water to enter the system through various points of weakness, such as breakdowns and leaks, further exacerbating the health risks associated with poor water quality (Aboah & Miyittah, 2022). Addressing these issues requires a multifaceted approach, including improving access to basic WASH facilities, enhancing awareness, subsidizing facilities for disadvantaged households, and promoting education on the benefits of proper sanitation and hygiene practices (Bijekar *et al.,* 2022).

Water quality parameters play a crucial role in assessing the suitability of water bodies for various purposes, including drinking water. Various studies have explored innovative approaches to monitor and predict water quality parameters effectively. For instance, Guo et al. developed a method combining spectral images and deep learning techniques to accurately detect multiple water quality parameters with high precision (Guo *et al.,* 2023). Additionally, Ahmed et al. investigated a hybrid remote sensing and deep learning approach for forecasting water quality parameters, demonstrating the efficiency of deep learning models in estimating parameter concentrations based on satellite imagery (Ahmed *et al.,* 2022). Furthermore, Zhao et al. proposed an automatic near-surface water quality monitoring system utilizing machine learning algorithms to achieve high-performance retrieval results of key parameters like chemical oxygen demand and dissolved oxygen (Zhang *et al.,* 2023). These studies collectively highlight the importance of advanced technologies in assessing and managing water quality for safe drinking purposes. Physical characteristic of drinking water quality mostly categorized as; temperature, color, odor, taste, turbidity, etc.(Shah, 2017). Chemical aspects of drinking water quality mainly classified as pH, electrical conductivity, free residual chlorine, total dissolved solids, total hardness (TH), major cations like calcium (Ca^{2+}) and magnesium (Mg^{2+}), major anions include chloride (Cl^-), nitrate (NO_3^-) and nitrite (NO_2^-) (Shah, 2017). The test group frequency for the inspection of physicochemical characteristics shall be approved at least two times per year, one is in the wet period and the other is in the dry period.

Ethiopia faces challenges in providing its people with adequate drinking water supply, sanitation and hygiene, which are crucial indicators of poverty in developing nations (Azanaw *et al.,* 2023; Berihun *et al.,* 2023; Desye *et al.,* 2023; Gizaw *et al.,* 2022; Tamene *et al.,* 2022). The effort of delivering safe and adequate drinking water to the population has faced several challenges due to high population growth, poor sanitation, and contamination of water with domestic waste and industrial effluents. The problem is far more serious in rural areas and small towns of Ethiopia where open defecation and free grazing of animals are common. Merawi town in Amhara Regional State, Ethiopia, where this study was conducted, is a good case in point. Residents of the town get their drinking water from a spring source. However, because of rapid population growth, residential areas of the town have expanded and encroached to the water source which has no buffer zone to protect it from potential contamination. On the top of this, the town has neither sewerage system nor proper solid waste management system. As a result, there are frequent reports from the town residents regarding poor drinking water quality and incidence of water related diseases. This necessitates assessment and regular monitoring of water quality of the town with the objective of identifying possible risks for contamination and developing control measures.

Regardless of the water quality issues in Merawi town, there have been no previous studies to address the problem. Therefore, this study aimed to evaluate drinking water quality of the town from source to point of use in the dry and wet season and identify possible causes of contamination.

2. Material and Methods

2.1 Description of the Study Area

Merawi town, where this study was conducted, is located in North Gojjam zone, Amhara National Regional State, Ethiopia about 30 kilometers from the regional capital Bahir Dar and approximately 525km from the national capital Addis Ababa. Its geographical location is at latitude and longitude coordinates of 11°24'31''N to 37° 9'39''E with an altitude of about 1900 meters above sea level. Based on the latest projections from the central Statistical agency of Ethiopia, the town is estimated to have a total population of 35,541 (CSA, 2007). However, as of 2020, the population of the town was reported to be 50,229, of whom 22,891 were male and 27,338 were female (Merawi town administrative statistical data 2020).

Piped water services in the town started in 1974. At present, water supply system of the town consists of two spring sources, a collection chamber close to the sources, two reinforced concrete distribution reservoirs (350m^3 and 500m^3), ten functional public taps, transmission line and branched type distribution pipe network, and house connections or private taps. Disinfection (chlorination) is carried out at the collection chamber and the treated water from the collection chamber is pumped to the two reservoirs from which it is distributed to the town by gravity.

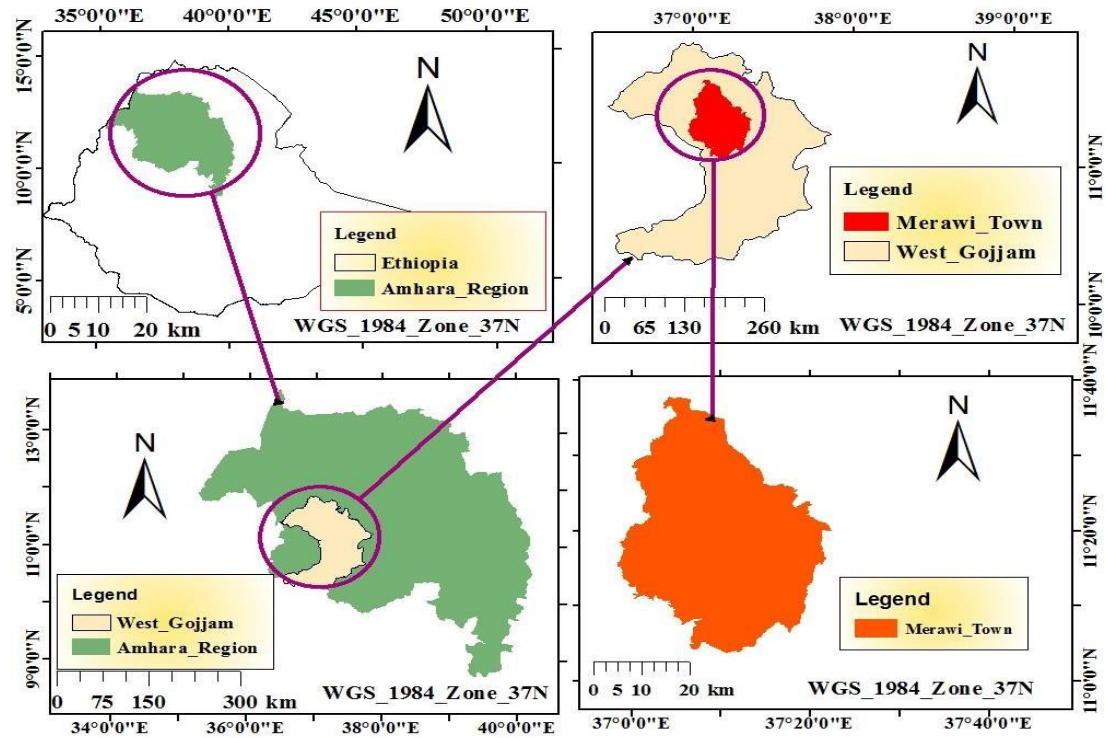

Figure 1. Location map of the study area

2.2 Methods of Data Collection

A total of 50 water samples were collected from 25 sampling points in the dry season (March to April 2021) and wet season (mid-July to mid-August 2021). The sampling points were purposively selected based on the population they serve, their year of construction (both new and old) and their location in the distribution system so as to assess water quality of the town in the entire system. Samples were collected from the two spring sources, the collection chamber (point of disinfection), the two reservoirs, 5 public taps, 10 private taps, and 5 institutions such as health centers and schools. Table 1 shows the list of sampling points with their geographical coordinates and year of installation while Figure 2 shows their location in the water distribution system. The water quality parameters to be tested were also selected purposively. The selected parameters include 11 physicochemical parameters (pH, temperature, turbidity, EC, TDS, total hardness, Ca^{2+}, Mg^{2+}, NO_3, NO_2^-, and Cl^-) and two bacteriological parameters (total coliform and faecal coliform).

Table 1. List of sampling points with their geographical coordinate and year of installation

Sampling site code	Sampling site description	Northing (m)	Easting (m)	year of installation
SP-I	Spring_1	298340	1262484.72	1974

SP-II	Spring_2	298308	1262520.17	2004
DP	Disinfection point	298410	1262705.78	2004
DR_I	Distribution reservoir-I	300329	1263706.52	2004
DR_II	Distribution reservoir-II	298858	1259720.65	2010
K1-S1	Private tap	299528	1263081.67	1974
K1-S2	Private tap	300186	1263134.68	2010
K1-S3	Private tap	299623	1262379.3	2004
K1-S4	Public tap	299240	1262364.6	1974
K1-S5	Public tap	299183	1262802.77	1997
K1-S6	Fentanesh bar and Restaurant	299041	1262539.28	2004
K2-S1	Private tap	299040	1262769.04	2004
K2-S2	Private tap	298807	1263137.74	2011
K2-S3	Public tap	299064	1263275.81	2010
K2-S4	Preparatory school	298857	1262492.79	1975
K2-S5	Health center	298791	1262737.41	2004
K3-S1	Private tap	299228	1261825.91	2004
K3-S2	Private tap	298724	1261022.46	2010
K3-S3	Public tap	298299	1261615.28	1994
K3-S4	Hospital	298376	1261809.7	2008
K3-S5	Chefe bar and Restaurant	298011	1262266.08	2008
K4-S1	Private tap	297970	1261293.51	2007
K4-S2	Private tap	297525	1261278.5	2010
K4-S3	Private tap	297870	1262917.84	2007
K4-S4	Public tap	297635	1262014.96	2010

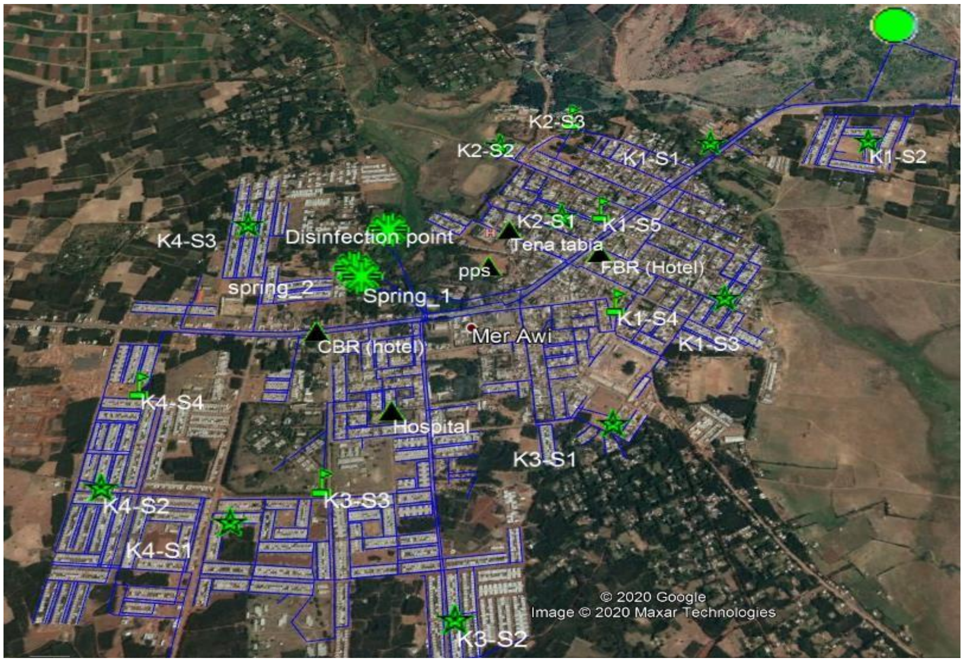

Figure 2. Location of sampling points in the distribution system

2.3 Sampling techniques and test analysis

Water samples for the physicochemical and bacteriological analyses were collected following international sampling procedures outlined in the standard methods for the examination of water and wastewater guidelines (Phiri *et al.,* 2023). All water samples were collected in two-liter polyethylene bottles individually, and before the collection, bottles were washed carefully to avoid any probable contamination. The pH, temperature, TDS, and EC were measured onsite through aqua-prove AP700 tools. The remaining parameters were tested using standard methods in the Water Quality Lab of Bihar Dar Institute of Technology, Bahir Dar University after transporting the samples in icebox under low temperature condition. Bacteriological tests were undertaken within a maximum of 6 hours after collection to avoid the growth and the death of microorganisms in the sample.

2.4 Data Analysis

After collecting the data, statistical analysis was carried out to reduce the range of uncertainty. MS Excel 2016 and IBM SPSS software were used to perform the graphical and statistical analysis of the collected data. Furthermore, spatial and seasonal variations of the results were analyzed. Finally, the results were compared with world health organization and Ethiopian standards.

3. Result and Discussion

3.1 Physicochemical Water Quality Results

Statistical results of the physicochemical water quality parameter tests are shown in Table 2. The results indicate that except for temperature and turbidity, all the selected physicochemical parameters were within the acceptable limit of Ethiopian and WHO standards.

Table 2: Statistical analysis of water quality in dry and wet seasons

Season	Statistics	Temp. (°c)	PH	EC (µs/cm)	TDS (mg/l)	Turbidity (NTU)	T.H (mg/l)
Dry	Mean	24.08	7.34	253.56	165.62	0.83	109.05
	Maximum	25.63	7.39	274.67	178.53	0.98	117.53
	Minimum	23.17	7.23	220.00	142.67	**0.65**	96.73
	Std. Deviation	0.63	0.03	18.79	11.58	0.10	8.99
Wet	Mean	21.34	7.72	270.47	175.37	4.75	86.12
	Maximum	22.43	7.91	288.33	187.33	**14.27**	106.93
	Minimum	19.67	7.63	212.33	137.33	1.16	69.27
	Std. Deviation	0.70	0.08	17.36	11.35	3.60	19.08

Season	Statistics	Ca^{2+} (mg/l)	Mg^{2+} (mg/l)	NO_3 (mg/l)	NO_2^- (mg/l)	CL^-(mg/l)
Dry	Mean	20.77	13.60	3.54	0.06	4.25
	Maximum	25.73	15.33	4.23	0.15	5.83
	Minimum	14.13	12.00	2.95	0.00	2.57
	Std. Deviation	4.04	1.18	0.48	0.07	1.17
Wet	Mean	16.09	10.93	4.41	0.03	4.74
	Maximum	18.13	15.00	4.86	0.05	6.40
	Minimum	11.47	6.67	4.19	0.01	2.60
	Std. Deviation	2.65	3.72	0.27	0.01	1.49

Temperature: The slightly above standard temperature observed in the study area is most likely due to the warm climate of the area and poor installation of transmission and distribution pipes. During the sanitary inspection, pipes of different lengths could be seen above ground exposed for direct sunlight which contributes to the temperature increase of the water.

Turbidity: The most desirable limit of turbidity in drinking water is below 5NTU (WHO, 2011). In this study, turbidity values in all samples varied from a minimum of 0.65NTU in the dry season to to a maximum of 14.27NTU in wet season (Table 2). In the dry season, all samples had turbidity values with within the WHO standard whereas in the wet season 7 out of the 25 samples (28%) had turbidity values exceeding the 5NTU (**Figure 3**). The spring sources, the collection chamber and the reservoirs had turbidity values within WHO standard in both the dry and wet seasons. All the samples that had turbidity values exceeding the WHO standard in the wet season were taken from points of use (public or private customer taps). This indicates the presence of water contamination in the distribution network due to intrusion of urban runoff into the distribution pipes and fittings. From the sanitary inspection that was conducted in this study, it can be deduced that the main cause of such contamination is the passing of pipes in drainage ditches and insufficient depth of pipes during installation. The intermittent nature of the water distribution in the town also contributes to such contamination by creating low pressure in the pipes and allow infiltration from the surrounding when pipes are dry or have little water.

3.2 Bacteriological Water Quality Results

Total coliform and E.coli tests were performed for all the 50 samples collected from the 25 sampling point in both the dry and wet seasons. In addition, free residual chlorine test was conducted for the samples collected during the dry season. **Table 3** presents the bacteriological and residual chlorine test results along with risk level of each sampling point as obtained through the sanitary inspection. The results indicate that there is a very high level of bacteriological contamination at the water sources. Since these sources are protected springs, which are considered as improved sources, this level of bacteriological contamination would not be expected. The potential causes of this contamination, as revealed through the sanitary inspection, were unavailability of buffer zones; presence of freely grazing animals, and presence residential houses close to the springs. The high level of bacteriological contamination at sources requires proper disinfection of water before distribution.

At the disinfection point (collection chamber), there was significant concentration of free residual chlorine at the time of survey during the dry season and that had reduced the coliform count to more or less an acceptable value. However, the concentration of free residual chlorine in most part of the distribution system was far below the WHO recommended value of 0.2 mg/L. As a result, only 7 of the 25 samples (28%) were found to be free from faecal contamination in the dry season whereas in the wet season, there were only 3 samples with zero faecal coliform count (12%). Overall, 80% of the samples were found to be faecally contaminated. This pauses significant public health risk unless customers are aware of the situation and use some form of household water treatment to protect themselves from waterborne diseases.

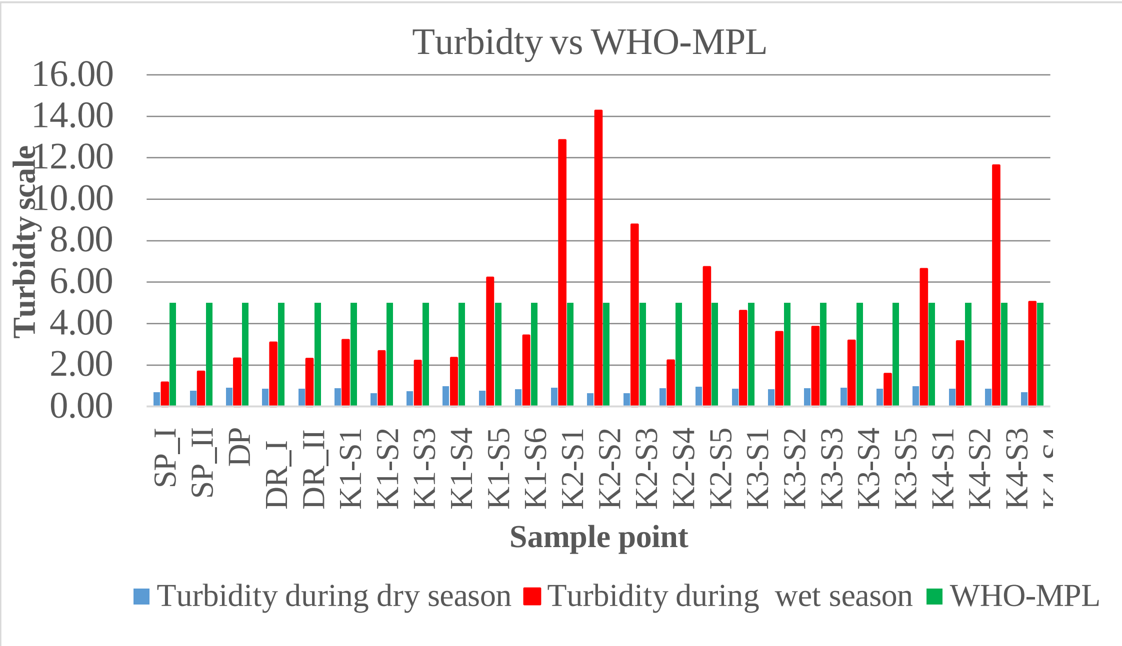

Figure 3. Turbidity during dry and wet seasons as compared with the WHO maximum permissible limits

Where, SP-Spring, DP=Disinfection point, DR=Distribution Reservoir K1-S1=Keble 1 site 1…. Kn-Sn=Kebel (n) site (n), n=1,2,3,4,5,6,

Table 3. Bacteriological test result on dry and wet seasons for all sampling stations

Sampling point	Sanitary inspection risk	Free residual chlorine (mg/L)	Dry seasons		Wet seasons	
			TC (CFU)	FC (CFU)	TC (CFU)	FC (CFU)
Spring I	Very high	…….	TNTC	42	TNTC	79
Spring II	Very high	……	TNTC	48	TNTC	86
DP	Very high	0.68	5	0	10	3
DR_I	Medium	0.25	10	3	13	4
DR_II	Low	0.23	9	1	18	4
K1-S1	Very high	0.00	21	2	25	13
K1-S2	Medium	0.21	18	0	20	0
K1-S3	High	0.05	17	4	21	3
K1-S4	Very high	0.04	22	6	30	11

K1-S5	High	0.00	28	4	27	5
K1-S6	Medium	0.06	19	0	22	1
K2-S1	Very high	0.00	TNTC	28	200	26
K2-S2	Medium	0.00	17	4	26	3
K2-S3	Low	0.24	7	0	31	0
K2-S4	High	0.03	32	4	36	7
K2-S5	Medium	0.07	86	7	46	9
K3-S1	Medium	0.02	42	8	40	2
K3-S2	Low	0.03	13	0	20	0
K3-S3	Medium	0.12	26	5	41	4
K3-S4	High	0.11	30	2	29	7
K3-S5	Medium	0.09	38	3	38	4
K4-S1	Very high	0.13	42	5	52	12
K4-S2	Medium	0.06	28	0	67	6
K4-S3	Medium	0.00	42	6	74	8
K4-S4	Low	0.18	26	0	35	2

Where, K1-S1=Keble 1 site 1…. Kn-Sn=Kebel (n) site (n), n=1, 2, 3,4,5,6, TNTC= Too numerous to count, CFU=Colony forming unit, DP=Disinfection point, DR=Distribution reservoir.

3.2.1 Spatial variation of bacteriological test results

A comparison of bacteriological test results at disinfection point, distribution reservoir and customer taps (tap water) are shown in **Figure 4**. It can be clearly seen from the figure that bacteriological quality of the water deteriorates as it goes from the point of disinfection to the reservoirs and to the customers taps. Water quality deterioration in the distribution network is a common problem in developing countries mainly because of intermittent nature of the water distribution, poor pipe installation and poor leakage control and pipe break maintenance practices.

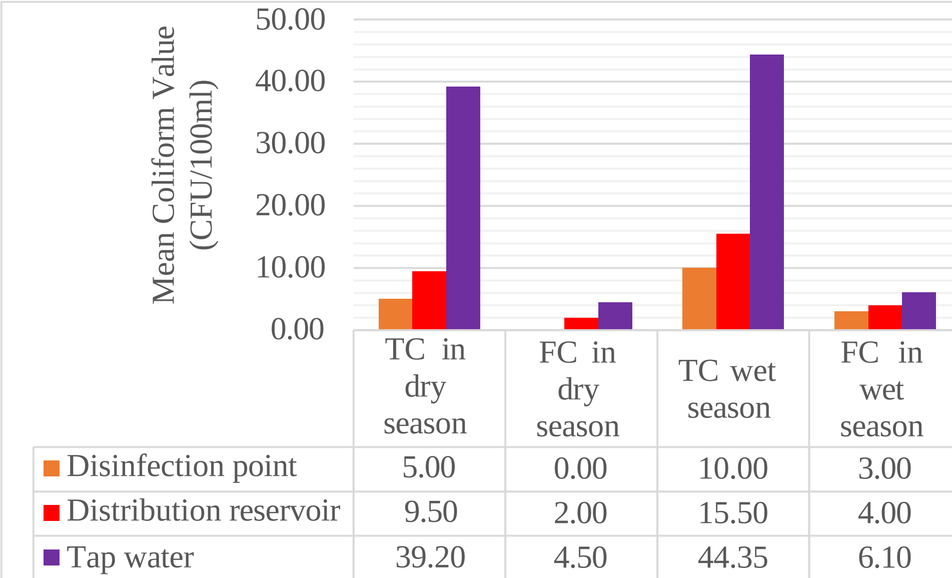

Figure 4. Spatial variation of bacteriological water quality in dry and wet seasons

3.2.2 Seasonal variation of biological test results

Although bacteriological water quality is a year-round public health concern in water supply systems of developing countries, the problem gets worse during the wet (rainy) season. The findings of this study also clear show this fact (Figure 5). The increase in both total and faecal coliform during the wet season is mainly because of intrusion of agricultural and urban runoff and sewage to the spring sources and loose pipes and fittings of the distribution network.

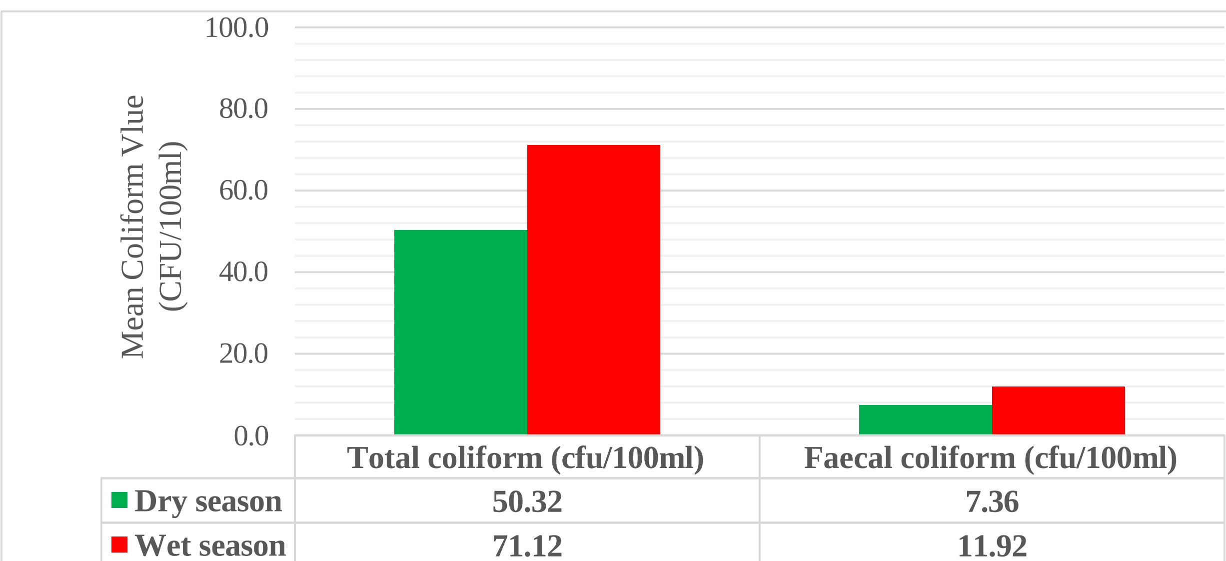

Figure 5. Mean value of the biological parameters in all seasons

3.3 Sanitary Inspection Results

A cross-sectional sanitary assessment was carried out in each spring, distribution reservoir, public tap and private tap (household connection) to identify the risk of contamination. The sanitary inspection showed that the spring sources have very high health risk score and the entire system had from low health risk to very high health-risk-score (Table 4).

As part of the sanitary inspection, overall status of the water supply system was assessed by field observation and discussions with operators and other relevant staff (lab assistants, town water sector, maintenance workers). As the result, the following hazards or possible causes of contamination were identified.

- Some drinking water pipes, most of which are old, passed through drainage systems and there was a high risk of contamination (Figure 6a).
- The capping of the spring was very poor; and because of this surface runoff was entering into the spring water source during the wet season (Figure 6c). Some people even were using the overflow side of the spring for bathing and swimming (Figure 6d).
- The collection chamber did not have a cover and it was near to pollution sources. Therefore, runoff can easily enter the collection chamber especially during rainy season.
- Disinfection (chlorination) was applied at collection chamber but it was added only at the inlet and there was no proper mixing and no enough contact time for the chlorine to kill or inactivate pathogens (Figure 6b). This wrong chlorination could be one of the reasons for the detection of faecal contamination at the reservoirs and beyond in the distribution network.

Table 4. Sanitary risk level and risk-priority matrix

Sanitary risk level	0 to 2	3 to 5	6 to 8	9 to 10
Protected spring (n=2)	0	0	0	2 (100%)
Disinfection point (n=1)	0	0	0	1 (100%)
Distribution reservoir (n=2)	0	2 (100%)	0.	0
Tab water (n=20)	3 (15%)	9 (45%)	4 (20%)	4 (20%)
Risk level	Low	Intermediate risk	High risk	Very high risk

(a) (b)

(c) (d)

Figure 6 (a) Drinking water pipeline passing through drainage ditch, (b) Wrong disinfection practice with uncovered collection chamber, (c) poor spring capping with the cracked slab & (d) people using overflow side of the spring for bathing and swimming.

4. Conclusion and Recommendations

This study focused on the assessment of physicochemical and bacteriological water quality from source to point of use of Merawi town, Amhara National Regional State, Ethiopia. Water samples were collected from 25 purposively selected sampling points in the dry and wet seasons and eleven physicochemical parameters (pH, temperature, turbidity, EC, TDS, total hardness, Ca^{2+}, Mg^{2+}, NO_3, NO_2^-, and Cl^-) and two bacteriological parameters (total coliform and faecal coliform) were tested. Results were compared with national and international standards and spatial and temporal (seasonal) variations of the results were analyzed. Furthermore, sanitary inspection was conducted to identify the potential risks of contamination.

The results indicated that except turbidity and temperature all physicochemical parameters were within acceptable limits of Ethiopian and WHO standards. Considering the intensive agriculture around the spring sources that heavily uses urea fertilizer and different herbicides and pesticides, it was encouraging to know the water supplied in Merawi town is of good quality from chemical parameters point of view. However, care should be taken to protect the water sources from agriculture-induced contamination in the future.

The bacteriological water quality results indicated that faecal contamination was a serious concern in the entire water supply system of the town. The spring sources were found to have very high level of faecal contamination. Although disinfection (chlorination) was applied at the collection chamber, faecal contamination could be detected at the reservoirs probably because of inefficiency of the chlorination. The faecal contamination level got even worse in the distribution network most likely due to regrowth of bacteria and intrusion of urban runoff and sewage into the pipes through loose fittings and pipe breaks. The level of faecal contamination and turbidity significantly increased in the wet season compared to the dry season putting higher risk on the public health.

A number of potential causes of contamination (or risks) were identified through the sanitary inspection. This included unavailability of buffer zones around the water sources, poor caping (cracked slabs) of the springs, collection chamber without cover, inappropriate way of disinfection, intermittent distribution of water, and passing of old drinking water pipes through drainage ditches. In order to ensure availability of safe and adequate drinking water for the residents and protect them from waterborne diseases, water utility of the town, in collaboration with all relevant stakeholders, should properly manage the risks identified in this study. A good alternative approach can be developing and implementing water safety plan of the town.

Acknowledgments

The authors are grateful to the Department of Water Supply and Sanitary Engineering, Bahir Dar Institute of Technology, Bahir Dar university, Ethiopia for providing the necessary facility to conduct the study. The authors also gratefully acknowledge the Merawi Water Utility and Health Office for providing the necessary data and other relevant information for the study.

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