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Chemical quality and water quality indices of Fiche drinking water, Oromia, Ethiopia

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ABSTRACT

The problem of drinking water quality is common in developing countries. While a piped water supply is available in many parts of Fiche, Ethiopia, the water may be contaminated in the distribution system and thus continuous quality assessment is required to ensure safe drinking water for the community. Instrumental and spectrophotometric methods were used to analyze the chemical characteristics including dissolved oxygen, pH, temperature, chloride, fluoride, nitrate, nitrite, sulfate, ammonia, iron and manganese. The weighted arithmetic water quality index method was applied to assess the water's quality rating. The chemical characteristics of the tap water's annual range was; temperature between 19.4 and 20.0°C, pH between 6.8 and 7.6, DO between 4.5 and 6.1 mg/L, ammonia between 0.01 and 0.2 mg-NH_3/L, nitrate between 1.1 and 1.8 mg-NO_3^-/L, nitrite between 0.003 and 0.06 mg-NO_2^-/L, 2.0 and 19.1 mg-SO_4^{2-}/L, chloride between 10.07 and 30.0 mg-Cl^-/L, manganese between 0.003 and 0.003 mg-Mn/L, iron between 0.01 and 0.03 mg-Fe/L. The WQIs for the reservoir and tap water were 25.031 and 40.676, respectively, so the tap water is rated 'good' for drinking.

Key words: chemical quality, contamination, correlation, drinking water, WQI

HIGHLIGHTS

- Chloride ion may be carried by rainwater into the groundwater.
- Good quality water may lack the recommended fluorine content.
- The dissolved oxygen concentration is affected by water temperature.
- The sulfate ion concentration affects the water's taste and odor.
- Water distribution systems should be monitored frequently and in a timely manner.

1. INTRODUCTION

Water is fundamental to life. Its quality is crucial since it is directly linked with human welfare. Water's quality and suitability for consumption are measured by taste, odor, color, and content of organic and inorganic matter (Dissmeyer 2000) and microbial load (WHO 2017). Due to the chemical properties of water, it is easily contaminated from chemical and biological sources, and serves as a medium for several unwanted substances (Cantor 1997), which results in shortages of safe drinking water. Increasing anthropogenic activities requiring large amounts of clean and safe water expand the gap between supply and demand. Demand for clean water is one of the major sources of irritation of the majority of the population in developing countries where poor water quality is taken as one of the manifestations of poverty (Adetunde & Glover 2010).

The chemical content and physical properties of water are determined to a considerable extent by geological and environmental conditions (Dinka *et al.* 2015). Water released from natural and artificial sources may contain dissolved inorganic and organic substances that could cause health problems in the community. The medical impact of inorganic chemicals is greater than that of other contaminants in drinking water (Azrina *et al.* 2011). Such substances can affect the water's drinking quality, if their concentrations exceed the recommended limits set by the World Health Organization (WHO) (2017) and/or regulatory bodies. Many reports indicate that millions of people suffer from diseases related to water quality (Usman *et al.* 2016; Hejaz *et al.* 2020; Tariq *et al.* 2020). In developing countries like Ethiopia, about 80% of all diseases are directly linked to poor drinking water quality

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and unhygienic conditions (WHO 2006). Uncontrolled and continuous population growth and contamination of water sources with domestic wastes and industrial effluents have exacerbated the extent of pollution and challenged the effort to deliver safe and clean water to the population (de Troyer *et al.* 2016).

Several factors can affect the physicochemical quality of water. The major pollution sources are industrial wastes, improper sanitation, and agricultural and other activities (Tabor *et al.* 2011). In addition, structural instability also leads to breaks in distribution systems, and age and poor maintenance have their own impacts and play significant roles in water quality. Insufficient disinfection can also be a problem in distribution systems (Duressa *et al.* 2019). Since numerous developing countries are facing serious water scarcity and poor drinking water quality, regular quality assessment should be done at or in the source, distribution tanks, distribution systems, and taps to check that the water is safe for drinking.

Groundwater is the primary source of water for drinking, agricultural, and domestic purposes in Fiche, central Ethiopia. Because of rapid urbanization, increasing agricultural and industrial activity, and inadequate capacity to manage freshwater resources, industrial (mainly mining) and agro-chemicals – for example, herbicides, pesticides, inorganic fertilizers, etc – can leach into ground water sources with the help of irrigation and rainfall. The aim of this study was to determine the chemical parameters and calculate the drinking water quality using an arithmetic water quality index (WQI) in Fiche. Drinking water quality can be assessed within a particular region quickly and effectively using WQIs (Abdulwahid 2013; Bora & Goswami 2017) to reflect the combined effects of various water quality parameters (Horton 1965). Parameters including temperature, pH, chloride, fluoride, nitrate, nitrite, ammonia, iron and manganese were analyzed in each water sample, and the results compared with WHO guidelines.

2. RESEARCH METHODS

2.1. Study area

Fiche is the administrative capital of North Shewa Zone/Salale, Oromia, Ethiopia. The town has four kebeles and a total population of around 65,000. It is about 114 km north of Addis Ababa at latitude 9°48′N and longitude 38° 44′E (Figure 1). The town's average altitude is 2,738 m (8,983 ft.), and its drinking water sources are boreholes and springs. The water from these is pumped up into three large local reservoirs from which distribution systems

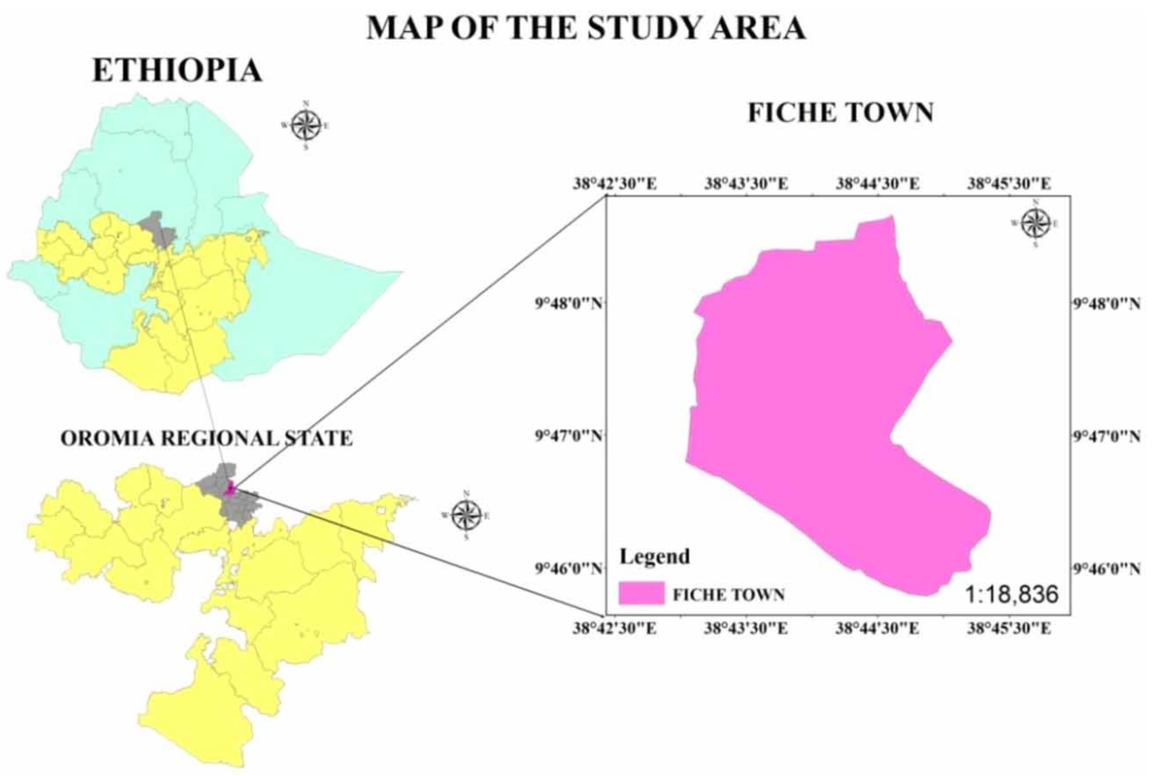

Figure 1 | Fiche, Ethiopia (GIS database).

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extend into the local community. There are no studies of the geology around Fiche and no information is available for the boreholes or springs. The average annual temperature in Fiche is 15.1 °C (59.2°F). The warmest month, on average, is May with an average temperature of 16.8 °C (62.2°F) and the coolest December, with an average of 13.3 °C (55.9°F). Average annual precipitation is 1,244.6 mm, the highest monthly precipitation on average occurs from June to August and the lowest in December (with 12.7 mm on average).

2.2. Sampling

Purposive sampling was used to select sampling points from reservoirs to distribution points (taps). All reservoirs were included and the taps were selected randomly and included hotels and water sellers. Some 110 drinking water samples, 55 each in winter and summer, were taken from taps, and 40 (20 each in winter and summer) from the reservoirs.

2.3. Data analysis

The data were analyzed using descriptive statistics. Analysis of variance (ANOVA) at 5% level of significance, was used to compare the water quality in the reservoirs and at distribution points. The weighted arithmetic water quality index (WQI) method was used to assess and rate the overall water quality. The analytical results from the water analyses were evaluated against recommended limits and standards set by WHO and Ethiopia, respectively. The relationships between chemical and physical parameters were analyzed to identify correlations. More general quality results like turbidity, electrical conductivity (EC), and total dissolved solids (TDS) were obtained from a previous report on the study area within the same time frame for correlation and WQI analysis (Sebsibe *et al.* 2021).

2.4. Water sample collection and preparation

Water samples were collected according to the WHO drinking water guidelines (WHO 2006), and American Public Health Association guideline (APHA 1998). The sampling bottles (500 mL) were washed with clean water before the samples were taken and the filled bottles were kept in an ice box and transferred immediately to Woliso Poly technic College for analysis.

2.5. Analytical methods/instruments

The samples' chemical characteristics were determined using the APHA standard methods (1998). The methods and instruments are noted in Table 1.

Table 1 | Water quality parameters and methods/instruments used

No	Parameters	Unit	Method used/instruments
1	Dissolved oxygen (DO)	mg/L	Dissolved oxygen Meter (DO600)
2	pH		pH/mV/temperature meter (PH-013)
3	Temperature	°C	pH/mV/temperature meter (PH-013)
4	Chloride (Cl^-)	mg-Cl/L	DR3900 spectrophotometer
5	Fluoride (F^-)	mg-F/L	DR3900 spectrophotometer
6	Nitrate (NO_3^-)	mg-NO_3^-/L	DR3900 spectrophotometer
7	Nitrite (NO_2^-)	mg-NO_2^-/L	DR3900 spectrophotometer
8	Sulfate (SO_4^{2-})	mg/L	DR3900 spectrophotometer
9	Ammonia (NH_3)	mg-NH_3/L	DR3900 spectrophotometer
10	Iron (Fe)	mg-Fe/L	DR3900 spectrophotometer
11	Manganese (Mn)	mg-Mn/L	DR3900 spectrophotometer

3. RESULTS AND DISCUSSION

3.1. Chemical parameters

The temperature was analyzed on site, and ranged between 19.4 and 20.0 °C. The pH was also determined on site. Water temperature affects chemical reaction rates and gas solubility, and thus the water's color and taste (Olajire & Imeokparia 2001; Milkiyas *et al.* 2011). All water temperatures recorded were close to the 20 °C recommended

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value for drinking water (Garoma *et al.* 2018). In the dry season the tap water pH range was between 6.7 and 7.5, and in the rainy season between 6.8 and 7.6. The pH ranges in the reservoir water samples in the rainy and dry seasons were 6.9 to 7.4 and 6.95 to 7.35, respectively (Tables 2 and 3). These values are entirely within the range – 6.5 to 7.8 – recommended by WHO and set by Ethiopia Standard Agency (ESA) (WHO 2006; ESA 2013).

The range of dissolved oxygen (DO) concentration was between 4.5 and 6.1 mg/L, with no statistical difference either between the tap and reservoir waters or across the seasons ($F = 0.42$, $p > 0.05$). Physical, chemical and biochemical activities all affect DO concentration in water. The DO range recorded is close to the WHO recommended value of 5 mg/L (Khanam & Singh 2014; WHO 2017).

Table 2 | Range and standard error of chemical concentrations in tap water in Fiche

Parameters	Dry season (tap water) Range	Rainy season (tap water) Range
pH	6.7–7.5	6.7–7.6
DO	4.7–5.5	4.5–6.1
Chloride	10.07–30.0	20.01–27.0
Nitrate	1.2–1.4	1.1–1.8
Nitrite	0.02–0.04	0.003–0.06
Sulfate	2.0–13.1	11.02–19.1
Ammonia	0.02–0.13	0.01–0.2
Iron	0.01–0.03	0.01–0.03
Manganese	0.003–0.02	0.002–0.03

Units: all in mg/L except pH.

Table 3 | Range and standard error of chemical concentrations in reservoir water in Fiche

Parameters	Dry season (tap water) Range	Rainy season (tap water) Range
pH	6.9–7.4	6.95–7.35
DO	4.8–5.6	4.6–5.45
Chloride	19.0–22.01	20.0–24.0
Nitrate	1.1–1.4	1.34–1.65
Nitrite	0.02–0.03	0.02–0.04
Sulfate	12.02–15.04	13.0–17.02
Ammonia	0.01–0.04	0.06–0.11
Iron	0.01–0.02	0.01–0.02
Manganese	0.003–0.007	0.007–0.019

Units: all in mg/L except pH.

The ammonia concentration ranged between 0.01 and 0.2 mg-NH_3/L across the year. While this is very low, the concentration difference between tap and reservoir water was significant in the dry season ($t = 12.85$, $p < 0.01$). There were also differences in ammonia concentration between seasons and locations ($F = 6.10$, $p < 0.01$). In particular, the post-hoc test after ANOVA showed considerable variation in the ammonia concentration in both tap and reservoir waters during the dry season ($F = 40.73$, $p < 0.01$), and in reservoir water between the dry and rainy seasons ($F = 25.66$, $p < 0.01$). Chlorinated drinking-water containing more than 0.2 mg –NH_3/L can cause problems (Weil & Quentin 1975), as up to 68% of the chlorine may react with the ammonia and become unavailable for disinfection. The ammonia concentration can be reduced naturally in the reservoir, but cement mortar used to coat water pipes can release considerable amounts of ammonia into the water, which may raise its the concentration at the tap (Wendlandt 1988). Frequent assessment of ammonia

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concentration is recommended in Fiche since the presence of more than 0.2 mg-NH_3/L can be an important indicator of fecal pollution.

The nitrate and nitrite concentrations of both tap and reservoir waters were between 1.1 and 1.8 mg-NO_3^-/L and 0.003 and 0.06 mg-NO_2^-/L, respectively. The nitrate concentration in the reservoirs varied between seasons ($t = -4.66$, $p < 0.05$), and was higher in the rainy season (mean difference = about 0.84). ANOVA showed the differences in the nitrate concentration ($F = 8.72$, $p < 0.01$). During the dry season the nitrite concentrations was higher in tap water than the reservoir sources ($t = 7.03$, $p < 0.01$), and the reservoir waters had different nitrite concentrations during the dry and rainy seasons ($t = -4.52$, $p < 0.01$). Nevertheless, the nitrate and nitrite concentrations recorded were significantly below the recommended limits of 50 mg/L in drinking water limit (WHO 2006; ESA 2013). It is noted that these findings are well below 0.3 to 7.0 mg-NO_3^-/L range found in Ziway (Bedane 2008), and Bahr Dar (9 to 30.1 mg-NO_3^-/L) (Kassahun 2008), both also in Ethiopia.

The sulfate ion concentration ranged between 2.0 and 19.1 mg-SO_4^{2-}/L (Tables 2 and 3). The lowest concentrations occurred in the dry season in tap water and the highest in reservoir water in the rainy season. There were large differences in sulfate concentration between sampling locations and seasons ($F = 100.92$, $p < 0.01$). The main difference was found when dry season tap water was compared with rainy season tap water ($t = -14.86$; $P < 0.01$) and dry season reservoir water ($t = -7.82$; $P < 0.01$). The main source of sulfate in the water is mineral dissolution. Sulfate in water causes noticeable taste changes. The taste threshold ranges from 250 mg/L for sodium sulfate to 1,000 mg/L for calcium sulfate (Al-Mezori & Harami 2013). High sulfate concentration can cause permanent hardness (Beyene 2015), but levels were below the WHO's maximum acceptable level for drinking water (400 mg/L) in both tap and reservoirs. A study in Nekemt (Ethiopia) also reported sulfate concentrations in the range 11 to 26 mg/L in line with this study (Duressa *et al.* 2019).

The chloride concentration was between 10.07 and 30.0 mg-Cl^-/L (Tables 2 and 3). Both the maximum and minimum were found in tap water in the dry season, and the tap water differed between the rainy and dry seasons ($p < 0.05$). Higher chloride concentrations during the rainy season may arise because of leaching from chemical fertilizers on agricultural soils, the chloride being carried into the groundwater which is the source for all reservoirs in Fiche. The chloride concentrations recorded are similar to those reported in Barwari Bala, Duhok, Kurdistan Region, Iraq (Ameen 2019). All chloride concentrations were within permissible limits (<250 mg/L) for drinking water (ESA 2013).

The annual manganese concentration range was between 0.003 and 0.003 mg-Mn/L, and the iron concentration was minimal (between 0.01 and 0.03 mg-Fe/L). Fluoride was not detected in any sample (Tables 2 and 3). It is noted, however, that fluoride concentrations below 1 mg/L in drinking water are said to be inadequate and cause dental caries (Behailu *et al.* 2017).

3.2. Correlation analysis

The correlation between the parameters was characterized as very strong in the range ± 0.8 to ± 1.00, strong ± 0.7 to ± 0.8, and moderate ± 0.5 to ± 0.7. In the reservoir, ammonia showed a very strong positive relationship with EC ($r = 0.81$) and TDS ($r = 0.82$). This may be due to intermolecular association between ammonia and water influencing the EC (Shcherbakov *et al.* 2009).

Ammonia in the reservoir showed a moderate positive correlation with turbidity ($r = 0.62$) and nitrate ($r = 67$). Other reports have shown that ammonia at concentrations exceeding about 0.5 mg/L can cause nitrification in the water distribution system, leading to many problems including corrosion (Rittmann *et al.* 2012; Zhang *et al.* 2019) which in turn affects turbidity. Other correlation coefficient values are given in Tables 4 and 5.

3.3. WQI analysis

The weighted arithmetic WQI method was applied to assess water quality. The WHO's maximum acceptable concentrations are presented in Table 6. In the weighted arithmetic WQI method, ranges are used to indicate water quality (Table 7).

The computed WQIs for reservoir (25.031) and tap water (40.676) indicated good physico-chemical quality. The results indicated that the reservoir water has higher quality than the tap water, perhaps indicating contamination arising in the pipe system. The WQI results are tabulated in Table 8.

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Table 4 | Cumulative correlation coefficient matrix of reservoir water physicochemical parameters

Parameters	DO	EC	pH	TDS	Temperature	Turbidity	Cl^-	NO_3^-	NO_2^-	SO_4^{2-}	NH_3	Fe
DO	1											
EC	0.36	1										
pH	0.46	0.37	1									
TDS	0.36	0.99***	0.37	1								
Temperature	−0.14	−0.08	−0.15	−0.08	1							
Turbidity	−0.04	0.25	−0.03	0.25	−0.02	1						
Cl^-	−0.05	−0.24	−0.28	−0.24	0.03	−0.33	1					
NO_3^-	−0.19	0.18	−0.17	0.18	−0.19	0.3	−0.24	1				
NO_2^-	0.36	0.06	0.06	0.06	−0.17	−0.21	0.25	−0.38	1			
SO_4^{2-}	0.1	0.28	0.12	0.28	−0.26	−0.15	0.26	−0.17	−0.17	1		
NH_3	−0.19	−0.04	−0.1	−0.04	−0.02	0.27	−0.43	0.67*	−0.51*	−0.62*	1	
Fe	−0.12	−0.03	0.23	−0.03	−0.16	−0.26	0.09	0.26	0.26	0.15	0.04	1
Mn	−0.17	0.13	−0.05	0.13	0.06	0.35	−0.52*	0.70**	− 0.58*	− 0.60*	0.93***	0.08

{*** very strong}, {** strong}, {* medium} correlation at 0.05 alpha level. Excluding pH, temperature (°C), EC (μS/cm) and turbidity (NTU); all units are mg/L.

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Table 5 | Cumulative correlation coefficient matrix of tap water physicochemical parameters

Parameters	DO	EC	pH	TDS	Temperature	Turbidity	Cl^-	NO_3^-	NO_2^-	SO_4^{2-}	NH_3	Fe
DO	1											
EC	0.38	1										
pH	0.26	−0.53*	1									
TDS	0.45	0.97***	−0.45	1								
Temperature	0.58*	0.07	0.53*	0.09	1							
Turbidity	0.29	0.42	−0.22	0.44	0.29	1						
Cl^-	0.81***	−0.05	0.24	0.01	0.48	0.4	1					
NO_3^-	−0.45	0.58*	−0.79**	0.52*	−0.57*	0.07	−0.61*	1				
NO_2^-	0.41	−0.4	0.48	−0.38	0.59*	−0.29	0.49	−0.7**	1			
SO_4^{2-}	−0.07	−0.18	−0.07	−0.22	0.41	0.55*	0.24	−0.3	0.3	1		
NH_3	0.16	0.81**	−0.28	0.82**	0.25	0.62*	−0.21	−0.4	−0.4	0.13	1	
Fe	0.11	0.44	−0.46	0.41	−0.35	−0.5*	−0.22	0.41	0	−0.56*	−0.04	1
Mn	−0.15	0.61*	−0.37	0.59*	−0.02	0.64	−0.29	−0.64*	−0.64*	0.05	0.82**	−0.25

{*** very strong}, {** strong}, {* medium} correlation at 0.05 alpha level. Excluding pH, temperature (°C), EC (μs/cm) and turbidity (NTU); all units are mg/L.

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Table 6 | Water quality parameter values (means) and WHO maximum acceptable concentrations (MACs)

Parameters	Tap	Reservoir	WHO
pH	7.19	7.20	6.5–8.5
DO	4.99	5.02	4–6
Chloride	21.55	21.11	250
Nitrate	6.18	5.94	50
Nitrite	0.12	0.10	3
Sulfate	10.39	14.38	250
Iron	0.01	0.01	0.3
Manganese	0.01	0.01	0.1

Table 7 | WQI ratings (Sierra-Porta 2020)

WQI	Water quality rating
0–25	Excellent
26–50	Good
51–75	Poor
76–100	Very poor
Above 100	Unsuitable for drinking

Table 8 | Calculated WQI values for tap and reservoir water

Parameters	si	1/si	Unit weight (wi = k/si)	Tap water qi	Reservoir water qi	Tap water qiwi	Reservoir water qiwi
DO	6	0.167	0.007	83.33	83.67	0.542	0.544
EC	800	0.001	0.00005	34.35	32.98	0.002	0.002
pH	8.5	0.118	0.005	84.71	84.71	0.389	0.389
TDS	1,000	0.001	0.00004	13.74	13.12	0.001	0.001
Turbidity	5.00	0.200	0.008	24.00	23.20	0.187	0.181
Cl^-	250	0.004	0.0002	8.62	8.40	0.001	0.001
NO_3^-	11	0.091	0.004	12.73	12.18	0.045	0.043
NO_2^-	1	1.000	0.039	4.00	3.00	0.156	0.117
SO_4^{2-}	250	0.004	0.0002	4.16	5.76	0.001	0.001
NH_3	0.10	10.000	0.390	90.00	50.00	35.100	19.500
Fe	0.3	3.333	0.130	3.33	3.33	0.433	0.433
Mn	0.1	10.000	0.390	10.00	10.00	3.900	3.900
$WQI = \frac{\sum qiwi}{\sum wi}$			$\Sigma wi = 1$			WQI = 40.676	WQI = 25.031

Where *si* is the standard value of the i^{th} parameter, *qi* the rate scale of quality, and *wi* the relative unit weight of the corresponding parameter.

4. CONCLUSIONS

The chemical characteristics of the water were within the WHO guideline levels and Ethiopian recommended values for drinking water. The overall analysis was assessed with WQI, which indicated that the water quality was good. Low concentrations of chloride, iron, manganese, ammonia, nitrate, nitrite and sulfate were recorded. No fluoride was detected, however, and artificial fluoridation has been recommended.

AUTHORS' CONTRIBUTIONS

All authors (Gezahegn Faye, Tsige Tekle, Berhanu Degaga and Israel Sebsibe) engaged in all activities of this research work starting from proposal writing to manuscript preparation.

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Official letter of permission for this research work was obtained from Salale University, Research and Publication Directorate. Water samples were collected and tested with the standard procedure, and all confidentiality of the results was maintained.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information. All required data for this work are incorporated in this manuscript.

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