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Organoleptic and palatability properties of drinking water sources and its health implications in Ethiopia: a retrospective study during 2010-2016

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Abstract

Background: This retrospective study aimed to investigate the physicochemical properties of drinking water sources in Ethiopia and compare the water quality with the health-based target. For this purpose, the water quality database of Ethiopian Public Health Institute (EPHI) from 2010 to 2016 was used.

Methods: The concentration and other properties of the water samples were analyzed according to the Standard Methods of Water and Wastewater analysis. Quality control and quality assurance were applied in all stages following our laboratory standard operation procedures (SOPs).

Results: The concentration of the selected parameters varied based on the type of water sources. The mean concentration of turbidity was higher in spring water (21.3 NTU) compared to tap (12.6 NTU) and well (3.9 NTU) water sources. The mean concentration of total dissolved solids (TDS), electrical conductivity (EC), sodium (Na^+), and sulfate (SO_4^{-2}) was found to be higher in spring water sources than tap and well water sources. Comparably, the concentration of hardness, calcium, and magnesium was found to be higher in well water sources than spring and tap water sources. The bivariate analysis indicated that out of 845 analyzed water samples, more than 50% of the samples from Oromia region had turbidity, pH, TDS, hardness, Ca^{++}, K^+, and Na^+ within an acceptable limit. In addition, the logistic regression analysis showed that water quality parameters were strongly associated with the type of water sources and regional administration at $P<0.05$.

Conclusion: More than 80% of the samples analyzed from drinking water sources were in agreement with WHO guidelines and national standards. However, the remaining 20% specifically, pH (25%), calcium (20%), hardness (18.1%), TDS (15.5%), and turbidity (13.3%) analyzed from improved water sources did not comply with these recommendations. Due to objectionable or unpleasant taste, people may force to look for alternative unprotected water sources that lead to health concerns.

Keywords: Drinking water, Water quality, Water sources, Taste, Physicochemical properties, Retrospective study, Ethiopia, Logistic models

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Introduction

Drinking water quality parameters are often the most important tools for measuring access to improved water sources. The drinking water with an acceptable quality shows the water safety in terms of its physical, chemical and bacteriological parameters (1). Some of the attributes, including color, turbidity, odor, hardness, etc, are substantially influenced by the acceptability of drinking water (2). Consumers' perceptions of quality also have a great value in their drinking water safety. Consumers can have different opinion towards aesthetic values of drinking water quality based on taste, odor, and appearance. Having a good knowledge of the factors that influence public perception can help improve water management, consumer services, the acceptance of water reuse and risk communication, among other areas (3). Therefore, consumer perceptions and aesthetic criteria need to be considered in assessment of drinking water supplies even if they may not adversely affect human health (1).

In developing water supply units, regulations and standards, both aesthetic criteria and health-related guideline values should be given a prior attention. This is attributed to the fact that one complements the other (4). In assessing the quality of drinking water, consumers rely principally upon their senses. A water source with poor microbial and physicochemical properties could hamper the aesthetic value of the water (5). Any complication on the aesthetic value of the water could also make the consumer to have a less preference for consumption of the developed water source, otherwise, it would lead consumers to consume acceptable but potentially unsafe alternative water sources (6).

According to the previous studies, environmental pollution, mainly of water sources, in underdeveloped countries have been suffering the impact of pollution due to disordered economic growth associated with the exploitation of natural resources (7). Similarly, stone mining around water sources in Ethiopia is very common. The quality of any water sources is subjected to both natural influences and human activities. In the absence of anthropogenic impact, water quality would be determined by natural origins, including weathering, natural leaching of organic matter and nutrients, and hydrological factors (8,9). According to Ethiopian Ministry of Health National Drinking Water Quality Monitoring and Surveillance Strategy, possible sources of pollutants to drinking water sources that threat the public health, include open field defecation, animal wastes, economic-related activities (agricultural, industrial and businesses) and even wastes from residential areas as well as transportation systems (10).

In the rural and urban areas of Ethiopia, spring water, surface water (streams, ponds, and rivers), groundwater and rainwaters are the main sources of drinking water. According to Ethiopian Demographic and Health Survey 2016, 97% of the urban households and 57% of rural households have access to an improved source of drinking water. The most common source of improved drinking water sources in urban households is water piped into the household's residence (63%), water piped into a public tap/standpipe (13%), and water piped to a neighbor (12%). By disparity, rural households obtain their drinking water majorly from public taps/standpipes (19%), protected springs (14%), and tube wells and boreholes (13%) (11). Water in a distribution system could not have a similar condition across the distribution system until it reaches the distribution system. A constituent of water can be altered and also violate the health-related guideline value. To ascertain this, continuous quality monitoring of the water source at a different time and space will help to assure the desired goal. In this regard, the Environmental Health Laboratory of Ethiopian Public Health Institute (EPHI) is a spearhead in assisting the monitoring activities in the country. Data from the continuous water monitoring service were used in this retrospective study. The prime objective was to fill the void in the availability of studies that focused on organoleptic and palatability properties of drinking water sources in Ethiopia.

Materials and Methods

Country description

Ethiopia found in the Horn of Africa and located between 30N and 150N of the equator and 330E and 480E longitudes. The country is surrounded by Sudan to the west, Kenya to the south, Somalia to the southeast, Djibouti to the east, and Eritrea to the north and northeast. The total area of the country is about 1 127 127 km^2. In this country, there is great geographical variation, with a topography ranging from 4550 m above sea level to 110 m below sea level (12). Such variations have its own influences on spatial and temporal distributions of water sources availability in the country.

As indicated in Figure 1, Ethiopia is composed of nine administrative regions (Afar, Amhara, Benshangul-Gumuz, Gambella, Harari, Oromia, Somali, Tigray and the Southern Nations, Nationalities and Peoples Region (SNNPR)) and two city administration (Addis Ababa and Dire Dawa). Each regional state is subdivided into zones, woredas (districts), and Kebele.

In each woreda, there is a Water, Mining, and Energy Office which is responsible for water supply development and management and ensuring quality along with Woreda Water, Sanitation, and Hygiene Committee (WASHCO). The WASHCO always is organized from Health Office, Education Office, Woman Affair Office and Finance and Development Office. In addition, to ensure the water supply system through regular maintenance and follow up, each water supply scheme has its own WASHCO that is gathered from the community.

Sample collection and analysis

The water samples were collected by the environmental health professionals using plastic bottles. The concentration and other properties of the water samples were analyzed according to the *Standard Methods of Water and Wastewater analysis* (13). Quality control and quality assurance were applied in all stages of sample preparation, preservation and analysis according to the National Environmental Public Health laboratory's standard operation procedures (SOPs).

Figure 1. Map of Ethiopia with the nine regional states and two city administrations.

Data analysis

This retrospective study of physicochemical properties was conducted using the water quality database of EPHI. The physicochemical water quality data during seven years (2010 to 2016) were used. The data were stored in an Excel worksheet and transferred to SPSS version 20 for further statistical analysis. The physicochemical data of a total of 845 water samples from different sources (395 well, 242 spring, and 208 tap) were analyzed. The concentration physicochemical properties of the water samples were compared with Ethiopian drinking water standards and World Health Organization (WHO) guidelines (6,14). In addition to descriptive analysis, bivariate (chi-square test) and multivariate (logistic regression analysis) analyses were also conducted to determine the association of water quality parameters with each type of water source and regional administration.

Results

Descriptive physicochemical characteristics of water samples

Water samples examined during 2010 to 2016 in our laboratory were used for this study. Amongst all water samples, 46.7% were well water, 28.6% were spring water and 24.6% were tap water as shown in Figure 2.

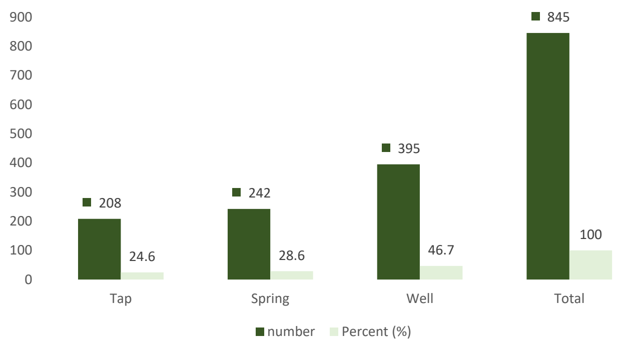

Figure 2. The number and proportion of water source types considered for retrospective analysis, brought to EPHI laboratory during 2010-2016.

The mean, minimum and maximum concentrations of the selected physicochemical parameters along with the type of water sources at the national level are presented in Table 1. The concentration of the selected palatability and aesthetic parameters varied with the type of water sources. The mean concentration of turbidity in Nephelometer Turbidity Unit (NTU) was higher in spring water samples (21.3 NTU) compared to tap (12.6 NTU) and well water samples (3.9 NTU). The maximum turbidity level was also recorded in spring water samples (919 NTU). In addition, the mean concentration of total dissolved solids (TDS), electrical conductivity (EC), sodium (Na^+), and sulfate (SO_4^{-2}) was found to be higher in spring water samples than tap and well water samples. Comparably, the concentration of hardness, calcium, and magnesium was found to be higher in well water samples than spring and tap water samples.

The number or frequency and proportion of palatability parameters in drinking water samples are summarized in Table 2. More than 90% of magnesium, potassium, sodium, chloride, and sulfate were within the ranges of the Ethiopian standards and WHO guidelines. About 12% and 13% of the water samples had a pH value less than 6.5 and above 8.5, respectively. In addition, approximately, 13% of the water samples reportedly had a turbidity level above 5 NTU.

Bivariate analysis

The status of palatability of drinking water in different water sources in Ethiopia is presented in Table 3. The results show that the palatability parameters within the recommended limits of the national standards and WHO guidelines were significantly associated with the type of water sources ($P=0.001$).

The number of water samples that were in the acceptable level was higher in well water sources for turbidity (354), pH (309), calcium (314), potassium (373), sodium (354),

Table 1. Mean distribution of water quality parameters by the type of water sources, retrospective data during 2010-2016

Water source type	Parameter	Turbidity (NTU)	TDS at 105°C	EC	pH	Hardness	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	SO_4^{2-}
Spring	Number	242	242	242	242	242	242	242	242	242	242	242
	Mean	21.25	854.33	1291.75	7.16	200.79	228.11	16.88	49.10	17.37	108.37	77.40
	Minimum	0	0	3.6	0	0	0	0	0	0	0	0
	Maximum	919	43326	63600	10.8	2450	17375	920	721.44	189.7	9497.06	2216.8
Tap	Number	208	208	208	208	208	208	208	208	208	208	208
	Mean	12.62	500.16	664.22	7.11	219.33	32.81	22.77	51.52	20.65	12.85	44.78
	Minimum	0	1.4	2.1	2.05	0	0	0	0	0	0	0
	Maximum	472	3420	7300	9	1500	353.6	288.75	292.58	189.7	92	1199.4
Well	Number	395	395	395	395	395	395	395	395	395	395	395
	Mean	3.92	571.07	766.71	7.43	267.37	96.94	7.02	70.22	126.57	74.92	91.06
	Minimum	0	0	0	3	0	0.014	0	0	0	0	0
	Maximum	201	7664	10650	9.41	3000	3000	462	801.6	41830	2500	2216

Table 2. Percentage of water quality parameters in drinking water sources, retrospective data during 2010-2016

Parameter	Range	N	%
Turbidity, NTU	0-5	733	86.7
	>5	112	13.3
pH	<6.5	102	12.1
	6.5-8.5	626	74.1
	>8.5	117	13.8
EC, µS/cm	0-1000	144	17
	>1000	701	83
TDS, mg/L	0-1000	716	84.7
	>1000	129	15.3
Hardness, mg/L	0-300	692	81.9
	>300	153	18.1
Calcium, mg/L	0-75	674	79.8
	>75	171	20.2
Magnesium, mg/L	0-50	766	90.7
	>50	79	9.3
Potassium, mg/L	0-1.5	773	91.5
	>1.5	72	8.5
Sodium, mg/L	0-200	774	91.6
	>200	71	8.4
Chloride, mg/L	0-250	812	96.1
	>250	33	3.9
Sulfate, mg/L	0-250	772	91.4
	>250	73	8.6

and chloride (369) compared with spring and tap water sources (Table 3).

Table 4 presents the status of palatability of drinking water sources in different regions of Ethiopia. The proportion of palatability parameters that complied with the recommended limits of the national standards and WHO guidelines was significantly associated with regions ($P = 0.001$).

Among a total of 845 water samples, more than 50% of turbidity, pH, TDS, total hardness, calcium, potassium, and sodium were in the range of acceptable ranges in Oromia. Next, the water samples of Addis Ababa were within the tolerable limit of both national standards and WHO guidelines compared to those of the rest regions in all parameters.

Multivariate analysis of the selected physicochemical parameters of water samples

Table 5-8 present adjusted odds ratios ($P < 0.001$) that were obtained from multivariate logistic regression model by considering the variable as acceptable and unacceptable limit of standards as outcome variables. The results show

Table 3. Distribution of water quality parameters in drinking water sources by the type of water sources, retrospective data during 2010-2016

Parameters	Ranges	Water Sources			Total	Chi-square	*P* value
		Spring	Tap	Well			
Turbidity, NTU	0-5	183	196	354	733	39.028	0.001
	>5	59	12	41	112		
	Total	242	208	395	845		
pH	<6.5	45	33	24	102	63.188	0.001
	6.5-8.5	146	171	309	626		
	>8.5	51	4	62	117		
	Total	242	208	395	845		
EC, µS	0-1000	65	23	56	144	24.061	0.001
	>1000	177	185	339	701		
	Total	242	208	395	845		
Total dissolved solid, mg/L	0-1000	206	173	337	716	0.524	0.770
	>1000	36	35	58	129		
	Total	242	208	395	845		
Hardness, mg/L	0-300	207	167	318	692	3.041	0.219
	>300	35	41	77	153		
	Total	242	208	395	845		
Calcium, mg/L	0-75	205	155	314	674	7.231	0.027
	>75	37	53	81	171		
	Total	242	208	395	845		
Magnesium, mg/L	0-50	224	182	360	766	3.591	0.166
	>50	18	26	35	79		
	Total	242	208	395	845		
Potassium, mg/L	0-1.5	218	182	373	773	9.244	0.01
	>1.5	24	26	22	72		
	Total	242	208	395	845		
Sodium, mg/L	0-200	214	206	354	774	20.125	0.001
	>200	28	2	41	71		
	Total	242	208	395	845		
Chloride, mg/L	0-250	235	208	369	812	16.657	0.001
	>250	7	0	26	33		
	Total	242	208	395	845		
Sulfate, mg/L	0-250	223	192	357	772	0.908	0.635
	>250	19	16	38	73		
	Total	242	208	395	845		

Table 4. Distribution of water quality parameters in drinking water sources by regional state, retrospective data during 2010-2016

Parameter	Region									χ2	*P* value
	A. A	Amhara	DD	Gambella	Oromia	SNNPR	Somalia	Tigray	A. A		
Turbidity, NTU	0-5	25.8%	7.5%	1.8%	1.8%	51.4%	3.8%	5.5%	2.5%	442.981	0.001
	>5	2.7%	0.0%	0.0%	0.0%	27.7%	0.0%	0.0%	69.6%		
	Total	192	55	13	13	408	28	40	96		
pH	<6.5	10.8%	4.9%	2.9%	2.9%	64.7%	2.9%	1.0%	9.8%	486.688	0.001
	6.5-8.5	28.6%	7.3%	1.6%	1.6%	50.2%	4.0%	5.9%	0.8%		
	>8.5	1.7%	3.4%	0.0%	0.0%	23.9%	0.0%	1.7%	69.2%		
	Total	192	55	13	13	408	28	40	96		
EC, µS/cm	0-1000	17.4%	2.8%	0.7%	0.7%	11.1%	0.0%	0.7%	66.7%	536.260	0.001
	>1000	23.8%	7.3%	1.7%	1.7%	55.9%	4.0%	5.6%	0.0%		
	Total	192	55	13	13	408	28	40	96		
TDS, mg/L	0-1000	26.4%	6.7%	1.3%	1.3%	47.8%	3.6%	1.4%	11.6%	145.223	0.001
	>1000	2.3%	5.4%	3.1%	3.1%	51.2%	1.6%	23.3%	10.1%		
	Total	192	55	13	13	408	28	40	96		
Hardness, mg/L	0-300	27.2%	6.8%	1.0%	1.0%	45.5%	3.8%	1.4%	13.3%	155.722	0.001
	>300	2.6%	5.2%	3.9%	3.9%	60.8%	1.3%	19.6%	2.6%		
	Total	192	55	13	13	408	28	40	96		
Calcium, mg/L	0-75	26.0%	6.8%	1.0%	1.0%	45.8%	3.9%	1.6%	13.8%	118.919	0.001
	>75	9.9%	5.3%	3.5%	3.5%	57.9%	1.2%	17.0%	1.8%		
	Total	192	55	13	13	408	28	40	96		
Magnesium, mg/L	0-50	25.1%	6.4%	1.3%	1.3%	48.2%	3.4%	2.6%	11.7%	105.004	0.001
	>50	0.0%	7.6%	3.8%	3.8%	49.4%	2.5%	25.3%	7.6%		
	Total	192	55	13	13	408	28	40	96		
Potassium, mg/L	0-1.5	24.8%	7.1%	1.7%	1.7%	47.7%	3.6%	5.2%	8.2%	114.652	0.001
	>1.5	0.0%	0.0%	0.0%	0.0%	54.2%	0.0%	0.0%	45.8%		
	Total	192	55	13	13	408	28	40	96		
Sodium, mg/L	0-200	24.8%	6.6%	1.4%	1.4%	47.3%	3.4%	2.7%	12.4%	109.558	0.001
	>200	0.0%	5.6%	2.8%	2.8%	59.2%	2.8%	26.8%	0.0%		
	Total	192	55	13	13	408	28	40	96		
Chloride, mg/L	0-250	23.6%	6.8%	1.4%	1.4%	49.3%	3.2%	3.2%	11.2%	127.551	0.001
	>250	0.0%	0.0%	6.1%	6.1%	24.2%	6.1%	42.4%	15.2%		
	Total	192	55	13	13	408	28	40	96		
Sulfate, mg/L	0-250	24.9%	6.7%	1.4%	1.4%	48.3%	3.4%	2.1%	11.8%	155.564	0.001
	>250	0.0%	4.1%	2.7%	2.7%	47.9%	2.7%	32.9%	6.8%		
	Total	192	55	13	13	408	28	40	96		

that the type of water sources (spring, tap, and well) and region were both statistically significant at a 5% level of significance ($P<0.5$). According to this association, the safety of drinking water samples was determined. As a result, the above-mentioned palatability parameters were considered in the multivariate logistic regression model as explanatory variables.

The odd ratios shown in these tables were used to compare whether the probability of an event is the same for the two groups. In this study, it helped to test the following hypotheses.

H0: there is no association between the type of water supply sources and their special distribution with palatability of drinking water when $P>0.05$.

H1: there is an association between the type of water supply sources and their special distribution with palatability of drinking water when $P<0.05$.

The *P* values for hardness, TDS, and calcium by region were less than 5% level of significance, indicating that there was an association between region and these parameters in drinking water. As a result, the odds of having water supplies within the acceptable limit of hardness, TDS, and calcium were less likely in drinking water supplies analyzed from Amhara, Dire Dawa, Gambella, Oromia, SNNPR, Somalia, and Tigray compared to those from Addis Ababa (Tables 5-7). In other way, Addis Ababa water supply sources were more likely to be in acceptable limit of these parameters compared to all regions of Ethiopia. At a 5% level of significance, almost all of the *P* values in analyzed water supply sources and palatability parameters were less than 0.05, indicating that there was an association between the type of water supply sources (spring, tap, and well) and palatability parameters (hardness, calcium, magnesium, TDS, sodium, potassium, and sulfate) (Table 8). As a result, the odds of having acceptable limits of hardness, calcium, magnesium, TDS, sodium, potassium, and sulfate were more likely in spring water sources compared to tap and well water sources except for sodium (1.520), which had good quality in well water sources compared to spring and tap water sources (Table 8).

At a 5% level of significance, there was no association between the type of water sources and region with turbidity, pH, and EC.

Table 5. Logistic regression of hardness by region, retrospective data during 2010-2016

Region	Adjusted odds ratio	*P* value
Addis Ababa	1	0.001
Amhara	0.079	0.001
Dire Dawa	0.015	0.001
Gambella	0.015	0.001
Oromia	0.051	0.001
SNNPR	0.143	0.03
Somalia	0.004	0.001
Tigray	0.269	0.07

Table 6. Logistic regression of TDS by region, retrospective data during 2010-2016

Region	Adjusted odds ratio	*P* value
Addis Ababa	1	0.001
Amhara	0.063	0.001
Dire Dawa	0.021	0.001
Gambella	0.021	0.001
Oromia	0.054	0.001
SNNPR	0.100	0.01
Somalia	0.002	0.001
Tigray	0.051	0.001

Table 7. Logistic regression of calcium by region, retrospective data during 2010-2016

Region	Adjusted odds ratio	*P* value
Addis Ababa	1	0.001
Amhara	0.313	0.01
Dire Dawa	0.071	0.001
Gambella	0.071	0.001
Oromia	0.214	0.001
SNNPR	0.656	0.5
Somalia	0.020	0.001
Tigray	1.659	0.4

Table 8. Logistic regression of palatability parameters in drinking water sources, retrospective data during 2010-2016

Parameter	Water sources	Adjusted odds ratio	*P* value
Hardness	Spring	1	0.001
	Tap	0.350	0.001
	Well	0.814	0.4
Calcium	Spring	1	0.001
	Tap	0.348	0.001
	Well	0.851	0.05
Magnesium	Spring	1	0.001
	Tap	0.179	0.001
	Well	0.852	0.6
TDS	Spring	1	0.001
	Tap	0.338	0.001
	Well	1.113	0.6
Sodium	Spring	1	0.01
	Tap	9.387	0.001
	Well	1.520	0.1
Potassium	Spring	1	0.001
	Tap	0.144	0.001
	Well	0.998	0.9
Sulfate	Spring	1	0.01
	Tap	0.373	0.01
	Well	0.897	0.7

Discussion

The mean concentration of the selected palatability parameters in this study varied according to the type of water sources. Most of the parameters including turbidity, TDS, EC, Na+, Cl-, and SO_4^{-2} were found to be higher in spring water samples compared to well and tap water samples. Mostly spring water is subjected to anthropogenic-induced factors due to its subsurface nature compared to groundwater that originates below the water table. Especially parameters like turbidity and chloride are signs of physical degradation of water sources by human and animal pressures along with open defecation and overgrazing near to the water sources. Turbidity is mostly related to rain. Studies conducted in Ethiopia reported high levels of turbidity in rainy season compared to the dry season (15-17).

According to Ethiopian national standards, pH of the water should be between 6.5 and 8.5 to avoid such a bad water taste. This pH range has also been recommended by WHO guidelines for drinking water quality. However, about 25% of water samples (12% and 14% below and above the recommended boundaries, respectively) in this study didn't comply with this recommendation (Table 2), which is consistent with a similar study conducted by Alemu et al (18). So, a pH value below 6 leads to toxic nature and a pH greater than 9 turns the water taste to a bitter taste (19). As a result, it would affect the user's perceptions and may make them to change their drinking water sources.

On the other hand, parameters like hardness, calcium, and magnesium were found to be higher in well water samples than tap and spring water samples. Nationally, calcium concentration (20%) in the water samples was not found in agreement with Ethiopian national standards. In addition, the level of hardness in the water samples that did not meet the national standards was estimated about 18.1% (Table 2). Since calcium and magnesium are well known to occur naturally in groundwater because of its channel through mineral deposits and rock layers that result in its total hardness (20), the results of the present study are in agreement with such facts. Another study conducted by Sisay et al in the south western part of Ethiopia indicated a similar scenario of hardness levels comparing with the type of water sources (21). Health-based guideline value for hardness is not proposed yet, but it has economic implications due to detergent consumption and scale formation during boiling. Even though the public acceptance level for hardness varies from community to community and person to person, hardness above 500 mg/L is classified as unacceptable (22). This unacceptable taste may make the public to look for other unprotected water sources, which consequently may threat the public health.

In addition, when the concentration of calcium exceeds the acceptable limit or national standards (greater than 75 mg/L), it will have its own effect on water quality. The taste threshold for the calcium ion is in the range of 100–300 mg/L as set by WHO but it depends on the other anions in the water (23). Due to the high content of calcium and carbonates as the most dissolved ions in hard water, hardness is usually expressed as calcium carbonate ($CaCO_3$). However, calcium is one of the essential elements that is required by human beings particularly for infants and under five years. It is crucial for bone formation and development. The basis for skeletal well-being is founded so early in life, and osteoporosis prevention begins by optimizing obtains in bone mineral throughout childhood and adolescence (19,24).

In the present study, a chi-square test and row percentage were used to determine the significant association of drinking water palatability with the type of water sources and administrative regions. Since the chi-square can provide information on the significance of any observed differences and determine the exact categories account for any differences found (25). Based on this analysis, the type of water sources has a direct relationship with water quality. The acceptable level of turbidity (354), pH (309), calcium (314), potassium (373), sodium (354), and chloride (369) was found to be higher in well water samples than in tap and spring water samples ($P = 0.001$) (Table 3). In addition, the region has a direct association with quality of water supply in the country ($P = 0.001$). Among a total of 845 water samples, more than 50% of turbidity, pH, TDS, total hardness, calcium, potassium, and sodium were in the range of acceptable limits in Oromia. After Oromia, Addis Ababa water samples were within the acceptable limits of recommended standards than the rest administrative regions in all parameters.

Furthermore, a logistic regression analysis was conducted to determine the significance level of water quality parameters with spatial distribution by region and type of water sources. In a developing country, water sources vulnerability has typically been assessed using largely qualitative methods and expressed as relative measures of risk (26). The Ethiopian scenario was not different and water quality data have usually summarized in a descriptive manner. However, determining the likelihood that different water sources contain elevated concentrations of contaminants can help water resources managers protect drinking water supplies. Based on this analysis, *P* values for hardness, TDS, and calcium by region were less than 5% level of significance ($P < 0.05$) indicating that there was an association between region and these parameters in drinking water. It is furtherly interpreted as the odds of having water supplies within an acceptable limit of hardness, TDS, and calcium were less likely in drinking water supplies in Amhara, Dire Dawa, Gambella, Oromia, SNNPR, Somalia, and Tigray compared to water sources in Addis Ababa, an administration city (Table 5-7). In addition, at $P < 0.05$, almost all the *P* values in analyzed water supply sources and palatability parameters were less than 0.05, it shows that there was an association between the type of water sources (spring, tap, and well) and palatability parameters (hardness, calcium, magnesium, TDS, sodium, potassium, and sulfate) (Table 8). This implies that the odds of having acceptable limit of hardness, calcium, magnesium, TDS, sodium, potassium, and sulfate were more likely in spring water sources compared to tap and well water sources except for sodium (1.520), which has a good quality in well water sources compared to spring and tap water sources (Table 8). But, at 5% level of significance, there was no association between the type of water supply sources and region with turbidity, pH, and EC.

In general, this study showed that more than 80% of all parameters analyzed from improved water sources (spring, tap, and well) were found within the national standards and WHO guidelines. These findings are in agreement with the previous study summarized from the same water quality database (18). However, the remaining 20% of water quality parameters collected from improved water sources which failed to meet both national standards and WHO guidelines along with above 35% of overall Ethiopian population relied on unprotected water sources reported by Ethiopian Demographic and Health Survey (11), that could threat the public health from drinking water supply. Unaccepted palatability parameters have equal influences and threat water supply sources even if they have not a track record on health concerns. Due to bad taste of drinking water, people will force to get alternative water sources that may be unprotected sources especially in rural area and dry places where water is not easily accessible. Other studies showed that high concentration of organoleptic parameters including turbidity, and salts of calcium, sodium, magnesium, and sulfate are the main influencing factors for objectionable water taste and influence community acceptability (27,28).

Conclusion

This retrospective study investigated the water quality status of improved water sources at a national level through cost-effective approaches i.e. analyzing water quality databases. The descriptive analysis showed that the mean concentration of the selected parameters in this study varied according to the type of water sources. Parameters like turbidity, TDS, EC, Na^+, Cl^-, and SO_4^{-2} were found to be higher in spring water samples compared to well and tap water samples. Contrarily, hardness, calcium, and magnesium were found to be higher in well water samples than tap and spring water samples.

Based on bivariate analysis, at *P* value of 0.000, the palatability parameters within the recommended limits of the national standards and WHO guidelines were significantly associated with the type of water sources and administrative regions. Among a total of 845 water samples, more than 50% of turbidity, pH, TDS, total hardness, calcium, potassium, and sodium were in the range of acceptable limits in Oromia. Next, Addis Ababa water samples were within the acceptable limits of recommended standards than the rest administrative regions in all parameters. The logistic regression analysis indicated that water quality was strongly associated with special distribution and type of water sources. This implies that the odds of having the acceptable limits of hardness, calcium, magnesium, TDS, sodium, potassium, and sulfate were more likely in spring water sources and Addis Ababa (an administration city) compared to tap and well water supply sources and other regions.

In general, more than 80% of all parameters analyzed from improved water sources were in agreement with WHO guidelines and national standards. However, the remaining 20% specifically, pH (25%), calcium (20%), hardness (18.1%), TDS (15.5%), and turbidity (13.3%) analyzed from improved water sources did not comply with these recommendations. Due to unpleasant taste, people will force to look alternative unprotected water sources that lead to health concerns. This calls to enhance the awareness and knowledge of the community on such water quality and water authority should put into consideration these water quality parameters during the development of water supply schemes.

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Ethics approval
Not applicable.

Competing interests
The authors declared that they have no conflicts of interest.

Author contribution
SD has participated in data analysis and manuscript preparation. AW and KT have participated in the manuscript preparation. And GT has participated in data analysis.

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