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Spatiotemporal variability of drinking water quality and the associated health risks in southwestern towns of Ethiopia

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Abstract The failure to provide safe drinking water services to all people is the greatest development setback of the twenty-first century including Ethiopia. Potential pollutants from various sources are deteriorating drinking water quality in different seasons, and associated health risks were not clearly known. We determined seasonal and spatial variations of urban drinking water characteristics and associated health risks in Agaro, Jimma, and Metu towns, Southwest Ethiopia. Seventy-two samples were collected during dry and rainy seasons of 2014 and 2015. The majority (87.4%) of physicochemical parameters was found within the recommended limits. However, free residual chlorine in Jimma and Agaro town water sources was lower than the recommended limit and negatively correlated with total and fecal coliform counts ($r = -0.585$ and -0.638). Statistically significant differences were observed at pH, turbidity, and total coliform between dry and rainy seasons ($p < 0.05$). A Kruskal-Wallis H test revealed a statistically significant difference in electrical conductivity, total hardness, fluoride, iron, and fecal coliform across the study towns ($p < 0.05$). The Agaro town water source was the highest in fluoride concentration (3.15 mg/l). The daily exposure level for high fluoride concentration in Agaro town was estimated between 0.19 and 0.41 mg/kg day, and the average cumulative hazard index of fluoride was > 3.13 for all age groups. Water quality variations were observed in all conventional water treatment systems in the rainy season, and further research should focus on its optimization to safeguard the public.

Keywords Health risks · Season · Water source · Water quality · Towns · Ethiopia

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Introduction

Global efforts were exerted to reduce by half the proportion of people without sustainable access to safe drinking water by 2015. However, 663 million people were using unimproved drinking water sources, and sub-Saharan Africa, including Ethiopia, accounts nearly half of the burden (United Nations 2015).

The government of Ethiopia was striving to enhance all national efforts towards the efficient, equitable, and optimum utilization of the available water resources of Ethiopia to access a universal coverage in drinking water (FMoWR 2008). Meanwhile, national coverage for improved water sources reached 82.4% urban and 66.3% rural, and in Oromia region 90.0% urban and 65.9% rural as reported by the Ministry of Finance

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and Economic Development (MoFED 2014). On the contrary, diarrhea was the second largest single cause of under-5child mortality (88/1000 live births), and morbidity due to diarrhea accounts 31%, mainly due to lack of quality water sources (CSA 2011). Although, acute watery diarrhea (AWD) was becoming a major health problem both in urban and rural settings of Ethiopia (OCHA 2016). In addition, the concentration of physicochemical characteristics in drinking water has its own health and esthetic effects on the consumers when it varies from permissible limits. In the Rift Valley of Ethiopia, fluoride concentration was up to 11.6 mg/l in public water sources and prevalence of dental fluorosis was 83.2% (Kloos and Haimanot 1999). The failure to provide safe drinking water services to all people is the greatest development setback in the twenty-first century including Ethiopia. Drinking water quality is degrading due to large-scale application of agrochemicals, direct pollution by untreated sewage, and infiltration of effluent from sewage treatment plants and storage pits (Lu et al. 2011; Pathak 2012). However, the efficiency of conventional water treatment systems to remove potential pollutants from the above sources in different seasons was not clearly known (Chen et al. 2008).

Conventional water treatment and bore hole are the dominant drinking water sources for urban settings of Ethiopia. However, studies are very limited, and even the existing studies focused on springs and wells (Sofonias and Tsegaye 2006; Abera et al. 2011). In addition, seasonal and local variability of physicochemical and bacteriological characteristics of urban drinking water and associated health risks in the study area and all parts of the country was not studied (Dagnew et al. 2010).

Despite the alarming rate of water pollution and the huge disease burden associated with unsafe water supply, very little effort has been done to investigate the quality of drinking water sources and their seasonal variations in the urban water supply systems and associated health risks in developing countries where Ethiopia is the case in point. Thus, the focus of this research is to assess seasonal and spatial variations and the associated health risks in drinking water sources in southwestern towns of Ethiopia. Additionally, we predicted and estimated the potential human health risks associated with drinking water quality parameters for concentrations above the World Health Organization (WHO) permissible limits.

Methods and materials

Study design and area

The study towns were selected due to availability of the common conventional water treatment methods existing in Ethiopia. A longitudinal study was conducted to examine seasonal and spatial variations of municipal drinking water quality in 2014 and 2015 in Agaro, Jimma, and Metu towns of Oromia region, Southwest Ethiopia (Fig. 1).

Based on the Central Statistical Agency of Ethiopia (CSA) projection for 2015, the total population for Agaro, Jimma, and Metu was 32,928, 184,925, and 37,227, respectively (CSA 2007). Surface water source has been used for many years in Jimma and Metu towns with rapid and slow sand filter for treatment, respectively. Jimma is the capital town of Jimma zone, and its water supply was a conventional treatment plant from Giligel Gibe River and has served for about 20 years and renovated in 2014. Metu is the capital town of the Illuababora zone of Oromia region, which has slow sand filter treatment plant from Sore River, which has served the town about 32 years and is being upgraded to conventional water treatment. Agro town is one of the town administrations in the Jimma zone of Oromia region and has been served by groundwater exploration through bore holes.

Sampling

A total of 72 (28, 24, and 20 water samples) was collected from Agaro, Jimma, and Metu towns, respectively. Water samples were taken four times from 18 sampling locations (Table 1) during the dry (January to February) and rainy seasons (July–August) from 08:00 a.m. to 12:00 p.m. The sampling was carried out scrupulously following standard methods (American Public Health Association (APHA) 1999). Samples were collected aseptically with a sterile 2-l polyethylene (PET) bottle for physicochemical analysis and 250 ml sterilized glass bottles for bacteriological analysis. The chlorinated water sample was collected using glass bottles autoclaved after adding 0.1 ml sodium thiosulfate (Cheesbrough 2006).

Water samples were taken from the sources and household taps. The tap was turned on at maximum flow rate, and the water allowed to flow for 2 min. The tap was disinfected for a minute using a 70%

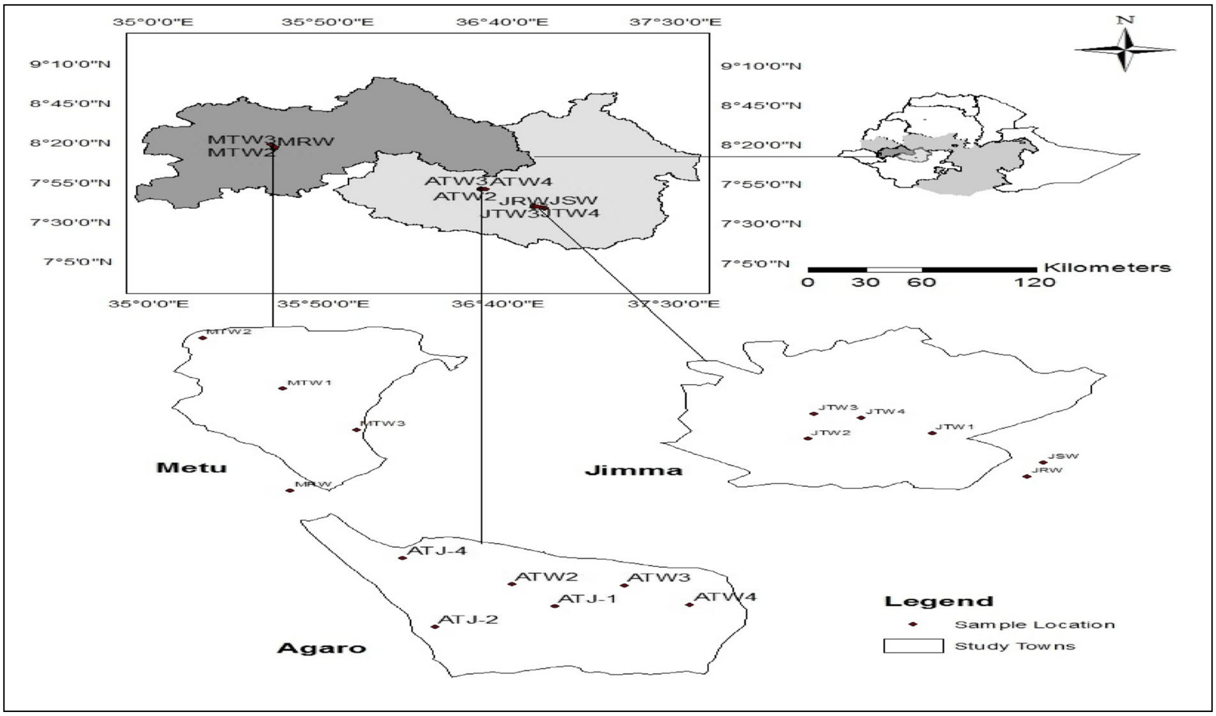

Fig. 1 Map of the study area and sampling locations in Jimma, Agaro, and Metu towns, Southwest Ethiopia, 2016

alcohol and allowed to flow at a medium rate for 1 min. A previously sterilized glass and clean PET bottles were opened for collecting water samples by holding the bottle steady under the water jet. Samples at treatment units were taken according to surface water sampling procedure by dipping the sampling container to 20 cm of the water body. The samples were sealed, labeled, and transported in the icebox to Environmental Health Science and Technology Laboratory, Jimma University within 8 h of sample collection.

Physicochemical analysis

Temperature, electrical conductivity (EC), dissolved oxygen (DO), and pH were determined using a calibrated and pre-tested portable digital multi-parameter probe, specifically Hatch PHC 101 probe, Hatch Loo, US PAT 691 2050 probe, and Hatch CDC 401 probe, respectively. Similarly, turbidity was determined by Hanna LP turbidity meter (Hanna, LP 2000). Total alkalinity (TA) was determined by a visual titration method using methyl orange and phenolphthalein indicator. Total hardness (TH) was measured by ethylenediamine tetraacetic acid (EDTA) titration method using Eriochrome Black T (EBT) indicator based on standard methods (American Public Health Association (APHA) 1999). Fluoride (F) was determined by alizarin photometric method and (METTLER TOLEDO n.d.) fluoride ion selective electrode for double checking. Nitrate (NO_3) was measured using HACH LANGE DR 5000 spectrophotometer, and iron (Fe) was determined by phenanthroline method. Free residual chlorine and total residual chlorine were determined by the planitest diethyl paraphenylene diamine (DPD) method.

Bacteriological analysis

Total coliform (TC) and fecal coliform (FC) were determined using membrane filtration (MF) technique within 8 h of sample collection. Hundred milliliters of water samples were filtered through 0.45-μm membrane filter, under vacuum. The filters were then layered to 2 ml prepared (35.6 mg/l proportion) membrane lauryl sulfate broth (AVONCHEM, Limited) with absorbent pad and incubated at 37 °C and 44 (± 0.5) °C for 24 h, respectively. After 24 h of incubation, the plates were examined for development of yellow colonies and expressed in colony-forming unit (CFU) per 100 ml

Table 1 Water sample labels and details of sampling locations in Agaro, Jimma, and Metu towns, Southwest Ethiopia, 2016

S. no.	Sample labels	Latitude	Longitude	Source
1	ATJ-1	37-232886	8-58442	Borehole
2	ATJ-2	37-232530	8-58492	Borehole
3	ATJ-4	37-232227	8-59542	Borehole
4	ATW1	37-233655	8-58428	Tap water
5	ATW2	36-34518	7-51295	Tap water
6	ATW3	36-35265	7-51291	Tap water
7	ATW4	36-35470	7-51158	Tap water
8	JFW	36-52279	7-39099	Filtered water
9	JClW	36-52396	7-39324	Chlorinated water
10	JTW1	36-51181	7-40198	Tap water
11	JTW2	36-49473	7-40101	Tap water
12	JTW3	36-49520	7-40503	Tap water
13	JTW4	36-50263	7-40444	Tap water
14	MFW	36-584214	9-19165	Filtered water
15	MClW	36-585216	9-19167	Chlorinated water
16	MTW1	35-34299	8-174818	Tap water
17	MTW2	35-33297	8-19109	Tap water
18	MTW3	35-34537	8-19132	Tap water

of water sample (Bartram and Ballance 1996). A laboratory-grade chemicals and reagents were used for laboratory analysis, and blank test was also carried out as a standard for quality checking.

Exposure assessment

The cumulative daily dose and health risk for all age groups exposed to high fluoride concentration were estimated using the average water consumption and body weight for each category. Exposure frequency was assumed to be 365 days per year. Exposure duration was 1, 4, 18, 25, and 35 years for infants, children, adolescents, adults, and old ages, respectively. We used an average body weight of 8.4 kg for 1-year infants, 17.2 kg for the 2 to 5-year-old group, and 58.2 kg for 18 to 34 years old in a similar fashion (Erdal and Buchanan 2005). Quantitative risk assessment model was used for determining acceptability of risk of fluoride by age categories using the estimated daily intake (EDI) and hazard index (HI) model developed by the US Environmental Protection Agency (EPA) (USEPA 1992) for water samples with fluoride concentration above the WHO limits.

$$\mathrm{EDI} = \frac{\mathrm{C} \times \mathrm{IR} \times \mathrm{EF} \times \mathrm{ED} \times \mathrm{AF} \times \mathrm{CF}}{\mathrm{BW} \times \mathrm{AT}} \quad (1)$$

where EDI is the estimated daily intake (milligram per kilogram per day), C is the concentration in a specific medium (milligrams per liter), IR is the ingestion or intake rate (milligrams per day), EF is the exposure frequency (days per year), ED is the exposure duration (years), AF is the absorption factor (unit less), CF is the conversion factor (10^{-6} kg/mg), BW is the body weight (kilograms), and AT is the averaging time (days). The average values for each variable were taken from literature (Wondimu 2014) and guideline values (USEPA 1992).

Risk characterization

The HI was calculated by dividing the cumulative dose (EDI) by the safe dose or reference dose (RfD). The RfD is an estimate of the daily exposure to children and adults that is likely to be without appreciable risk during a lifetime. The RfD for fluoride is 0.06 mg/kg day and is based on the no observed adverse effect level (NOAEL) of 0.06 mg/kg day cited in Erdal and Buchanan (2005).

$$HI = \frac{EDI}{RfD} \quad (2)$$

Statistical analysis

Physicochemical and bacteriological quality of water samples was compared with the WHO drinking water guideline values. The obtained data were statistically analyzed using STTISTICA8 computer software. A Mann-Whitney *U* test was used to assess seasonal differences in water quality, and a Kruskal-Wallis *H* test was used to determine water quality differences among towns. Exposure and risk were predicted using a prediction model developed by USEPA 1992. Spearman's rank-order correlation was applied to determine relationships between coliform bacteria and physicochemical parameters. Statistical significance was accepted at $p < 0.05$.

Results and discussion

pH

The majority of water source pH was found within the recommended limits of WHO drinking water guideline value of 6.5 to 8 in both seasons (WHO 2011) (Table 2). The minimum and maximum pH values were 6.3 ± 0.22 and 7.54 ± 0.19 during the rainy and dry seasons in Jimma town water source. The lowest pH observed during the rainy season due to the use of excess amount of alum ($Al_2{\cdot}(SO_4)_3$) as a coagulant to remove high turbidity as reported in other studies in Nigeria (Badejo et al. 2015). However, the use of excess alum for turbidity removal has the disadvantage of increasing the corrosive behavior of the water (Świderska-Bróż and Rak 2009).

A Mann-Whitney *U* test revealed a statistical significant difference in the mean pH score during dry and rainy seasons ($p = 0.000$). This may be explained by the amount of chemical used for coagulation in the rainy season that would reduce the pH (Świderska-Bróż and Rak 2009). However, a Kruskal-Wallis *H* test revealed that there were no statistical significant differences in mean pH across the towns, H (2, N = 36) = 1.486, $p = 0.475$. pH values more than 8 are not suitable for effective disinfection, while values less than 6.5 enhance corrosion in water pipes and household plumbing systems (WHO 2011). Therefore, cautious attention should be given to pH at all stages of water treatment and distribution to ensure satisfactory quality in terms of disinfection and to minimize the corrosion of water distribution pipes. The pH range of other water sources was consistent with previous studies done in Jimma area and Bahir Dar city (Deneke 2007; Milkiyas et al. 2011) (Fig. 2).

Turbidity

Mean values of turbidity in all water sources in the dry and rainy seasons were found in the range between 3.75 ± 0.34 and 5.15 ± 1.46. The highest turbidity was observed in Jimma town water source in the rainy seasons, and the lowest was in Metu town water source in the dry seasons (Table 2 and Fig. 3). A Mann-Whitney *U* test revealed a statistical significant difference in turbidity between dry and rainy seasons ($p = 0.008$), but no significant differences observed across the towns. Turbidity of 0.5 NTU is recommended for effective disinfection, and up to 5 NTU is considered acceptable to the consumers in WHO drinking water guidelines' water supply (WHO 2011). A slight increment of turbidity observed in Jimma water source during the rainy season may be due to high runoff in the rainy season and inefficient water treatment. However, further investigation is required to identify the reasons for turbidity rainy season maxima. This finding was consistent with the study reported in Bahirdar city (Milkiyas et al. 2011). But, it is not consistent with the previous rapid assessment report that stated that turbidity was a major water quality problem due to poor sanitary conditions of water supplies in almost all parts of Ethiopia (Dagnew et al. 2010).

Dissolved oxygen

The DO level in the study water sources was in the range of 4 to 6 mg/l; however, no health-based guideline value was recommended by WHO (2011). Dissolved oxygen levels from groundwater sources are found relatively lower in Agaro town, but higher than a study finding on groundwater samples of 2.1 to 4.8 mg/l in India (Shah et al. 2013). The highest level of DO was observed in surface water than groundwater samples in the rainy seasons, which is consistent with the

Table 2 Mean physicochemical characteristics of drinking water sources at dry and rainy seasons in Jimma, Agaro, and Metu towns, 2016

Parameters	Jimma (24 samples)		Agaro (28 samples)		Metu (20 samples)		WHO limit[a]
	Dry (12)	Rainy (12)	Dry (14)	Rainy (14)	Dry (10)	Rainy (10)	
T (°C)	23.82 ± 0.5	20.76 ± 0.9	26.52 ± 1.43	22.41 ± 1.25	24.44 ± 0.95	22.00 ± 1.06	25–30
pH	7.54 ± 0.19	6.3 ± 0.22	7.39 ± 0.2	7.23 ± 0.19	7.19 ± 0.24	7.21 ± 0.14	6.5–8
Turbidity	4.13 ± 0.85	5.15 ± 1.46	3.84 ± 0.82	4.25 ± 0.35	3.75 ± 0.34	4.30 ± 0.47	5.0
DO	6.74 ± 0.46	7.50 ± 0.56	5.34 ± 2.26	5.7 ± 1.74	6.22 ± 1.32	7.56 ± 0.64	6.0
EC	182.63 ± 5.99	105.78 ± 13.24	635.43 ± 11.7	624.14 ± 12.8	261.0 ± 5.4	264.50 ± 10.2	1000.0
TH	50.2 ± 1.1	24.36 ± 1.04	121.00 ± 52.05	141.4 ± 16.6	63.00 ± 10.3	64.00 ± 10.8	100.0
TA	16.3 ± 8.86	16.20 ± 8.96	142.00 ± 21.89	121.4 ± 3.58	60.00 ± 17.2	54.00 ± 17.96	200.0
NO_3	0.85 ± 0.11	0.85 ± 0.1	0.0 ± 00	0.0 ± 0.0	0.36 ± 0.27	0.51 ± 0.2	50.0
Fe	0.11 ± 0.01	0.76 ± 0.6	0.17 ± 0.19	0.21 ± 0.28	0.79 ± 0.25	0.52 ± 0.24	0.3
F	0.15 ± 0.06	0.15 ± 0.06	3.33 ± 3.24	3.44 ± 2.96	0.06 ± 0.06	0.05 ± 0.08	1.5

NB: DO, TH, TA, Fe, NO_3, and fluoride measurements are in milligrams per liter, EC in microsiemens per centimeter, and turbidity in nephelometric turbidity unit (NTU)

[a] WHO limit = World Health Organization drinking water guideline standard value

study done in India (Kumar Das et al. 2014); this is because surface water applies Henry's law (Sander 2015). A Mann-Whitney U test revealed a statistical significant difference in mean DO between dry and rainy seasons ($p = 0.007$), but no significant differences observed across the towns, H (2, N = 36) = 5.458, p = 0.065. Depletion of dissolved oxygen in water supplies can encourage the microbial reduction of nitrate to nitrite and sulfate to sulfide. It can also cause an increase in the concentration of ferrous iron in solution and would result in undesirable health risks for the consumers and odor and color changes at the tap when the water is aerated (WHO 2011).

Electrical conductivity

The highest EC found in Agaro groundwater sources indicates the existence of high concentration of dissolved ions (Chapman 1996). Electrical conductivity of all water sources in the study area was found below the permissible limits of WHO drinking water guideline values of 1000 μS/cm (WHO 2011). A Kruskal-Wallis H test revealed a statistically significant difference in mean EC across the towns (H (2, N = 36) = 30.91, p = 0.000). Agaro town groundwater sources were the highest in the EC, which is similar to the study conducted in Ethiopia (Dagnew et al. 2010) and a study done in

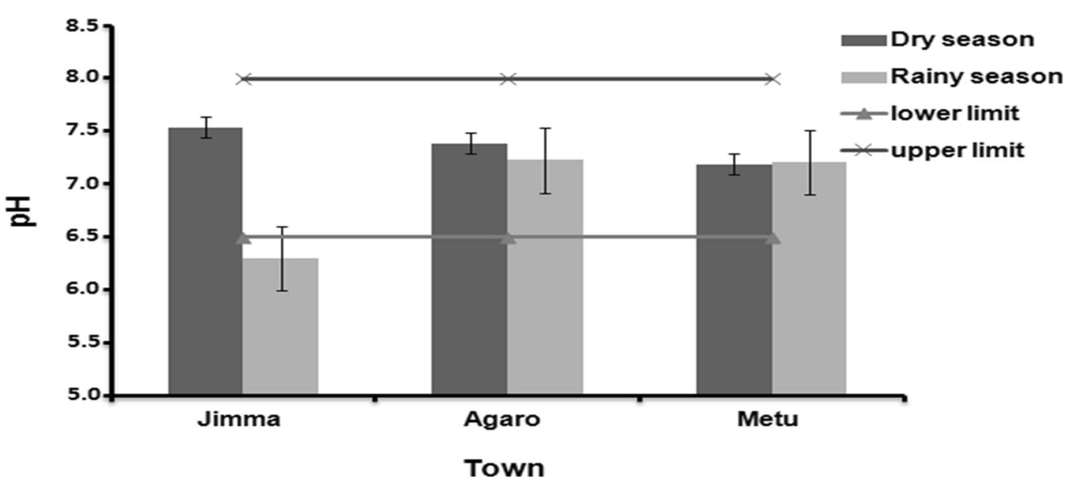

Fig. 2 Mean values of pH in drinking water sources during dry and rainy seasons in Jimma, Agaro, and Metu towns, 2016

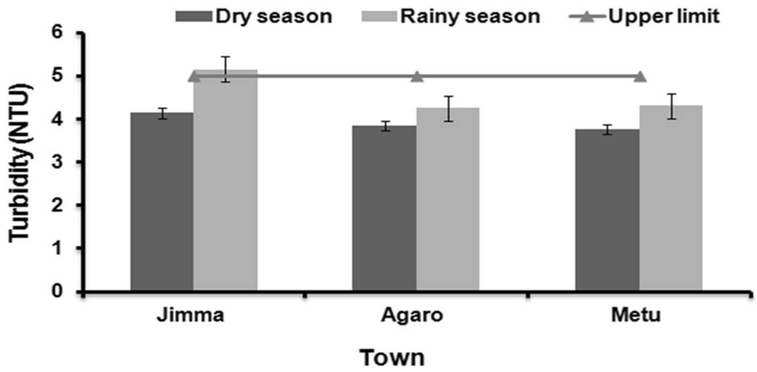

Fig. 3 Mean values of turbidity in drinking water sources during dry and rainy seasons in Jimma, Agaro, and Metu towns, 2016

Turkey (Soylak et al. 2002). The highest EC found in Agaro groundwater sources indicates the existence of high concentration of dissolved ions (Chapman 1996).

Total hardness

The study indicated a meaningful variation in total hardness across the towns. The minimum and maximum amount of TH was 24.36 ± 1.04 mg/l in Jimma and 141.4 ± 16.6 mg/l in Agaro water source (Table 2). The hardness category of water sources was soft, moderately hard, and hard in Jimma, Metu, and Agaro towns, respectively (Duguma et al. 2012). Hardness is one of the very important properties of groundwater from a utility point of view. Even though there is no health-based guideline value, the community may be wasting money for soap consumption and suffering from the effects of scale deposition in water boiling materials which consume much fuel and corrosion on plumbing systems that causes taste problems. Public acceptability of the degree of hardness may vary considerably from one community to another. However, hardness value above 500 mg/l is generally unacceptable (Asadullah et al. 2013). A Kruskal-Wallis H test revealed a statistically significant difference in TH across the towns (H (2, N = 36) = 9.02, p = 0.011). But, no significant variation was observed between dry and rainy seasons.

Fluoride

The highest fluoride concentration was found in Agaro town groundwater sources (3.33 ± 3.24 and 3.44 ± 2.96 mg/l) in the dry and rainy seasons, respectively. Whereas, it was below the recommended WHO guideline values of 1.5 mg/l in Jimma and Metu town water sources (WHO 2011) (Table 2). In Agaro town, borehole (ATJ-4) had the highest amount of fluoride (10.03 mg/l), which would be responsible for high fluoride concentration in the town water supply. This finding showed that groundwater sources beyond the Rift Valley area also contain high amount of fluoride from geological sources. The finding is consistent with the study done in the Rift Valley areas of Ethiopia, which was 11.6 mg/l in groundwater samples (Reimann et al. 2003). In the other study conducted in the Rift Valley area, fluoride concentration was found above 5.0 mg/l in shallow wells and boreholes; river and springs had levels below 1.5 mg/l (Kloos and Haimanot 1999). This finding showed that the concentration of fluoride in the Agaro town water source was even higher than some part of Rift Valley area groundwater sources. The high level of fluoride concentration may expose the community from mild dental fluorosis to crippling skeletal fluorosis as the level and period of exposure increases. A Kruskal-Wallis H test revealed a statistically significant difference in fluoride concentration among towns (H (2, N = 36) = 28.57, p = 0.000).

Iron

Iron concentration in the Metu water source was above the WHO recommended limits of 0.3 mg/l (WHO 2011). A Kruskal-Wallis H test revealed a statistically significant difference among the towns (H (2, N = 36) = 11.75703, p = 0.003). The possible reason for high iron content in the Metu water sample would be the infiltration of adjacent groundwater with iron content of 3 mg/l. People using water sources with high concentration of iron were suffering from taste, color, corrosion of plumbing systems, and liver diseases; however, less concentration would be highly susceptible to anemia as cited in Kumar Das et al. (2014).

Bacteriological quality

The study revealed that both TC and FC in all town water sources were above the recommended limits of WHO drinking water guideline values (0/100 ml) in the rainy season (Figs. 4, 5, and 6). This may be due to high runoff, rising of the water table, leaching during the rainy season, and failure of the treatment plant (Elisante and Muzuka 2016). However, FC count from Jimma town water source was within the WHO limit in the dry season. A Mann-Whitney U test showed a statistically significant difference of TC during dry and rainy seasons, $p = 0.001$. A Kruskal-Wallis H test revealed a statistically significant difference in FC among the towns with H (2, $N = 36$) = 11.75, $p = 0.003$. A highly significant difference was also observed in both TC and FC between Agaro to Jimma town water sources, $R = 25.679$, $p = 0.003$, and Agaro to Metu, $R = 16.209$, $p = 0.089$, and Jimma to Metu, $R = 12.042$, $p = 1.00$.

More than 10 CFU/100 ml FC was detected in Agaro groundwater source. The high FC count may be attributed to the failure of the treatment process due to malfunctioning of automatic chlorination devices and manual application of chlorine (Haydar et al. 2009). In addition, free residual chlorine was not detected in water source of Agaro town throughout the study periods and in Jimma town during the rainy season. However, it was found in the recommended limits (0.5 mg/l) in Metu and Jimma (dry season) water sources (WHO 2011). Lack of regular water quality monitoring may be the possible explanation for the poor bacteriological quality of water sources in the study area. A study done in Pakistan also indicated that water treatments with non-functional chlorination equipments contain more TC and FC in the distribution system (Haydar et al. 2009). This finding is consistent with the previous studies conducted in the Jimma zone, on spring water and hand-dug well bacterial loads of non-chlorinated water sources (Kifle and Gadisa 2006; Abera et al. 2011). A Kruskal-Wallis test revealed a statistically significant difference in free residual chlorine among towns (H (2, $N = 36$) = 17.78, $p = 0.0001$). The Spearman rank-order correlation indicated that free residual chlorine was negatively correlated with FC and TC (− 0.692 and − 0.599, respectively). Generally, the risk category of the water sources was in fair classification and needs higher action (WHO 2011).

Exposure level estimated from daily intake of fluoride

The estimated average daily intake of fluoride for age less than 1 year was 0.19 ± 0.002 mg/kg day, 0.37 ± 0.003 and 0.31 ± 0.003 mg/kg day for children 1–5 and 6–18 years, respectively. For age groups, including and greater than 35 years, the estimated daily intake was 0.41 ± 0.004 mg/kg day (Table 3) which was higher than the recommended EDI values of 0.06 mg/kg day in all age categories (USEPA 2008).

Risk characterization

In Agaro town, the mean HI values for children less than 1 year and 1–5 and 6–18 years old were found as 3.13, 6.1, and 5.16, respectively. All age groups were under

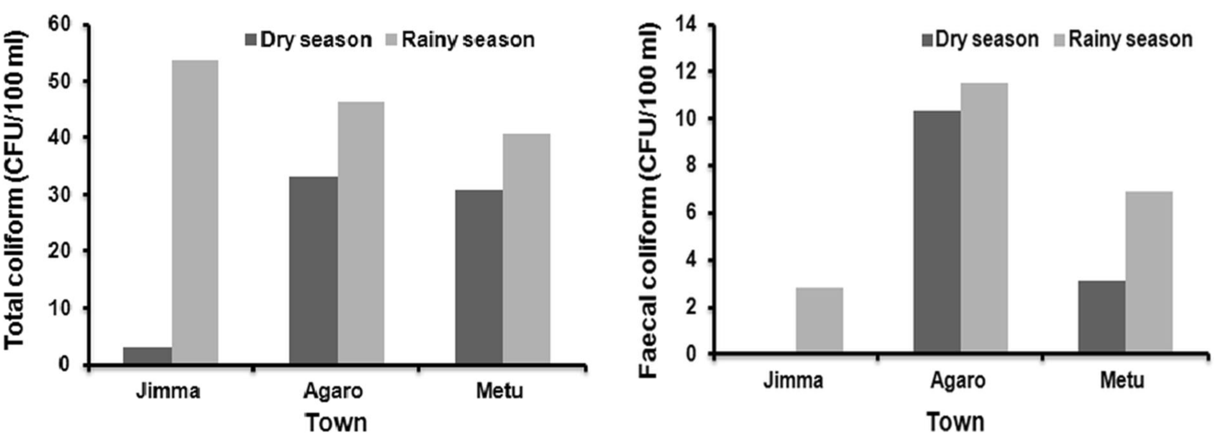

Fig. 4 Mean of total coliform and fecal coliform in drinking water sources during dry and rainy seasons in Agaro, Jimma, and Metu towns, 2016

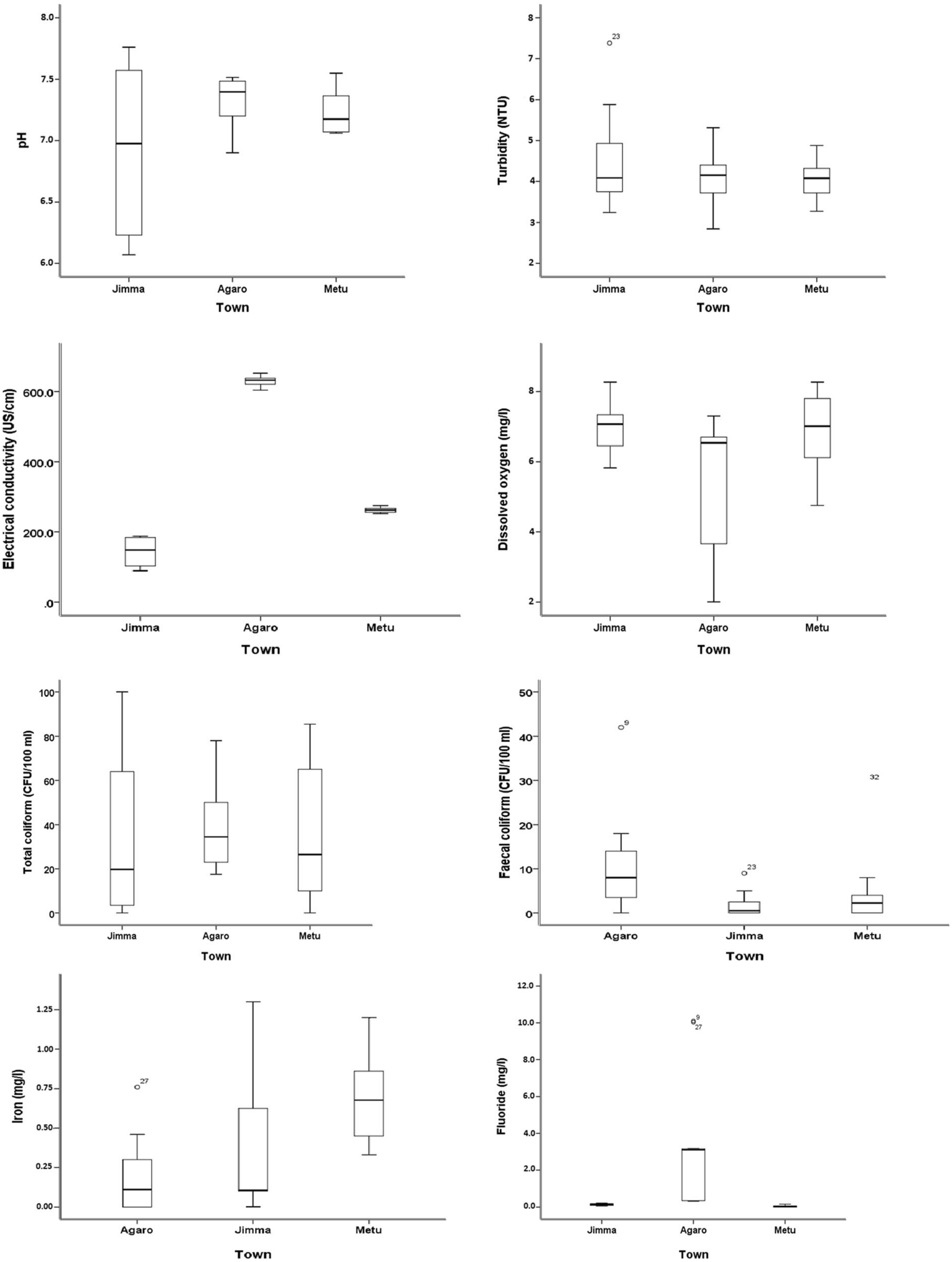

Fig. 5 Box and whisker plots of some parameters' spatial variations in Jimma, Agaro, and Metu towns, 2016

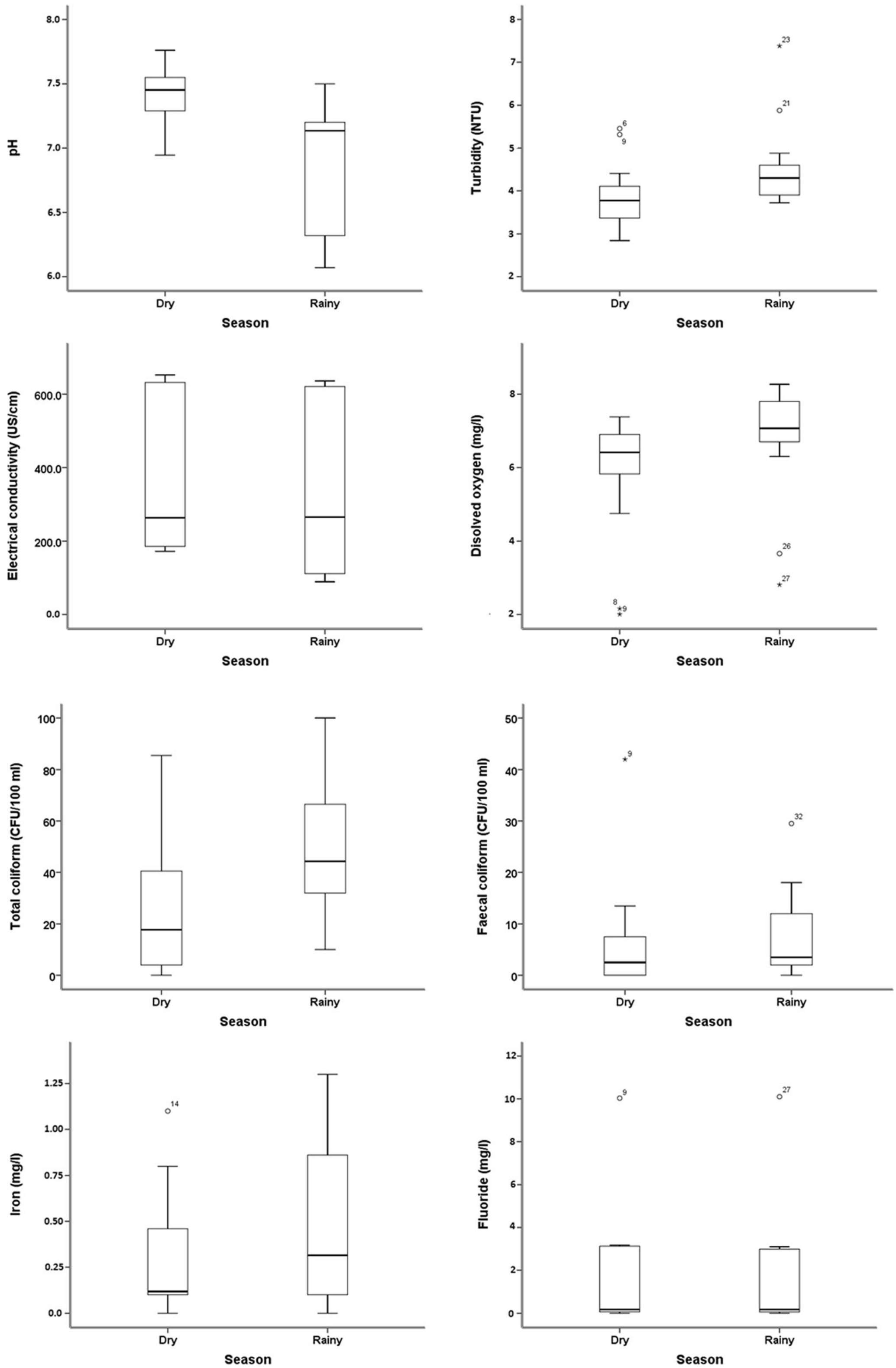

Fig. 6 Box and whisker plots of some parameters' seasonal variations in Jimma, Agaro, and Metu towns, 2016

Table 3 The estimated daily intake (EDI) by age groups in high fluoride concentration water sources in Agaro town, 2016

Age (years)	Fluoride estimated daily intake (EDI; mg/kg day)			
	Min	Max	Mean	SD
< 1	0.186	0.189	0.19	0.002
1–5	0.364	0.369	0.37	0.003
6–18	0.308	0.31	0.31	0.003
19–34	0.43	0.436	0.43	0.004
> 35	0.396	0.401	0.41	0.004

Min minimum, *Max* maximum, *SD* standard deviation

severe fluorosis risk. It is consistent with other studies; HI value ranging from 3 to 5 is regarded as a fluoride risk of adverse health effect (Zabin et al. 2008). Based on this analysis, HI value indicated that the risk of fluoride exposure was lethal for children, young, and adults. Therefore, urgent action may be needed to tackle the high concentration of fluoride problems in Agaro town (Table 4).

Conclusions

The majority of physicochemical and microbiological parameters in all water sources were in line with the WHO permissible limits in the dry season. A significant seasonal variation was observed in temperature, pH, turbidity, DO, and TC. While, spatial variations were observed in EC, TH, fluoride, iron, FC, and free residual chlorine across the towns.

Bacteriological quality of Agaro water source was in the medium-risk category in both seasons. Free residual chlorine was very minimal and below detectable level in Jimma and Agaro water sources and needs strict monitoring and regular checkup for removal of bacteriological indicator bacteria.

Table 4 Cumulative hazard index (HI) based on age categories calculated from EDI and RfD in Agaro town, 2016

Age (years)	Cumulative HI (mg/kg/day)			
	Min	Max	Mean	SD
< 1	3.11	3.14	3.13	0.03
1–5	6.07	6.14	6.1	0.05
6–18	5.13	5.19	5.16	0.05
19–34	7.17	7.26	7.22	0.06
> 35	6.6	6.68	6.64	0.06

Min minimum, *Max* maximum, *SD* standard deviation

Fluoride concentration in the Agaro town water source was higher than the WHO recommended guideline values. Borehole (ATJ-4) was the source of high fluoride. The estimated daily intake and risk characterization all revealed that fluorosis is a great concern to all age groups in Agaro town. Therefore, looking for an alternative source or treatment of the sources is a solution to avoid high fluoride concentration problems.

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