Concentration of Heavy Metals in Drinking Water from Urban Areas of the Tigray Region, Northern Ethiopia

Gebrekidan Mebrahtu*and Samuel Zerabruk
Department of Chemistry, College of Natural and Computational Sciences, P. O.Box 2035, Mekelle University, Ethiopia (*geb_meb@yahoo.com and samizer2005@yahoo.com)

ABSTRACT

The study was undertaken to assess the status of drinking water quality in the urban areas of the Tigray region, northern Ethiopia. A total of 106 drinking water samples were collected from 16 densely populated urban areas of the region, viz.: Alamata, Korem, Maichew, Adigudom, Abyi-Adi, Hagereselam, Zalambessa, Adigrat, Edagahamus, Firewoini, Wukro, Mekelle, Indaselassie, Axum, Adwa, and Enticho. All the samples were analyzed for six physicochemical parameters such as temperature, conductivity, total dissolved solids (TDS), salinity, pH, and turbidity and ten heavy metals,viz., As, Cd, Co, Cu, Cr, Fe, Mn, Ni, Pb, and Zn using standard procedures. The results were compared with other national and international standards. Among the analyzed samples, regarding physicochemical parameters, 84.01 % for electrical conductivity, 47.17 % for TDS and 31.13% for turbidity show concentrations higher than the WHO (2008) recommended values. More than 93.4% of the samples were within the United States Environmental Protection Agency (US EPA) admissible pH limit (6.5-8.5) and all the samples analyzed were within the EU (1998) admissible pH limit (6.5-9.5). All samples contain manganese and copper within the WHO (2008) maximum admissible limit, but arsenic (40.3 %), cadmium (7.46 %), chromium (64.18 %), iron (37.31 %), nickel (7 %), and lead (29.85 %) crossed the maximum admissible and desirable limits recommended by WHO (2008). The maximum admissible limit of cobalt in drinking water is not mentioned by WHO, but all the samples analyzed were found to comply the New Zealand (1000 µg/L) and US EPA (100 µg/L) maximum admissible limits. Although no guideline is set by WHO (2008) for Zinc level in drinking water, of the samples analyzed, 94.02% comply the New Zealand standard and 97.01% comply all the maximum admissible limits referred in the present study. In general, the results of the present study have shown that some of the physico-chemical parameters have shown values higher than the WHO (2008) recommended maximum admissible limits. This is an indication of pollution hazards and weak drinking water treatment practices in the areas, which in turn have important human health implications. This study, therefore, recommends the government and other responsible authorities to take appropriate corrective measures.

Key words: Drinking water quality, Heavy metals, Maximum admissible limit, World health organization, Tigray

1. INTRODUCTION

Safe drinking water is a human birthright – as much a birthright as clean air. As a matter of fact, in most of the African and Asian countries, even in relatively advanced countries such as India; safe drinking water is not easily available. Of the 6 billion people on earth, more than one billion lack accesses to safe drinking water and, about 2.5 billion do not have access to adequate sanitation services (TWAS, 2002). In addition to these shortcomings, various types of waterborne diseases kill on an average more than 6 million children each year i.e. about 20,000 children a day (TWAS, 2002). Water covers 70 percent of the globe's surface, but most is saltwater. Freshwater covers only 3 percent of the earth's surface and much of it lies frozen in the Antarctic and Greenland polar ice. Freshwater that is available for human consumption comes from rivers, lakes and subsurface aquifers. These sources account for only one percent of all water on the earth. Six billion people depend on this supply and a significant portion of the world's population is facing water shortages (Fig.1). Today 31 countries representing 2.8 billion people, including China, India, Kenya, Ethiopia, Nigeria and Peru confront chronic water problems. Within a generation, the world's population will climb to an estimated 8 billion people. Yet, the amount of water will remain the same (Bishnoi and Arora, 2007). The challenge is as clear and compelling as pristine water cascading down a mountain stream: We must find new and equitable ways of saving, using and recycling the water that we have (Atalay et al., 2008).

Besides the shortage, drinking water may be contaminated by different contaminants which have an impact on the health and economic status of the consumers (Anonymous, 1992). Contaminants such as bacteria, viruses, heavy metals, nitrates and salt have found their way into water supplies due to inadequate treatment and disposal of waste (human and livestock), industrial discharges, and over-use of limited water resources (Singh and Mosley, 2003). Even if no sources of anthropogenic contamination exist, natural sources are also equally potential to contribute higher levels of metals and other chemicals that can harm human health. This is highlighted recently in Bangladesh where natural levels of arsenic in groundwater were found to be causing harmful effects on the population (Anawara et al., 2002).

In Ethiopia, the dominant source of drinking water used to supply major urban and rural communities is from wells and springs. Although there are no systematic and comprehensive water quality assessment programs in the country, there are increasing indications of water contamination problems in some parts of the country. The major causes of this contamination could be soil erosion, domestic waste from urban and rural areas and industrial wastes.

So far, no sufficient study has been conducted on heavy metal contamination of drinking water of the Tigray region. For this reason, due emphasis is given to the analysis of these contaminants. Heavy metals normally occurring in nature are not harmful to our environment because they are only present in very small amounts (Sanayei et al., 2009). However, if the levels of these metals are higher than the recommended limits, their roles change to a negative dimension. Human beings can be exposed to heavy metal ions through direct and indirect sources like food, drinking water, exposure to industrial activities and traffic (Ghaedi et al., 2005). Drinking water is one of the important sources for heavy metals for humans. Concentration of the heavy metal ions in drinking water are generally at µg/l (ppb).

The main goal of this paper is to determine the levels/concentration of some of the physicochemical parameters and heavy metals (As, Cd, Co, Cu, Cr, Fe, Mn, Ni, Pb, and Zn) in drinking water in different parts of the Tigray region, Northern Ethiopia and, to compare the values with the national and international organization (like WHO) recommended drinking water standards (Table.1).

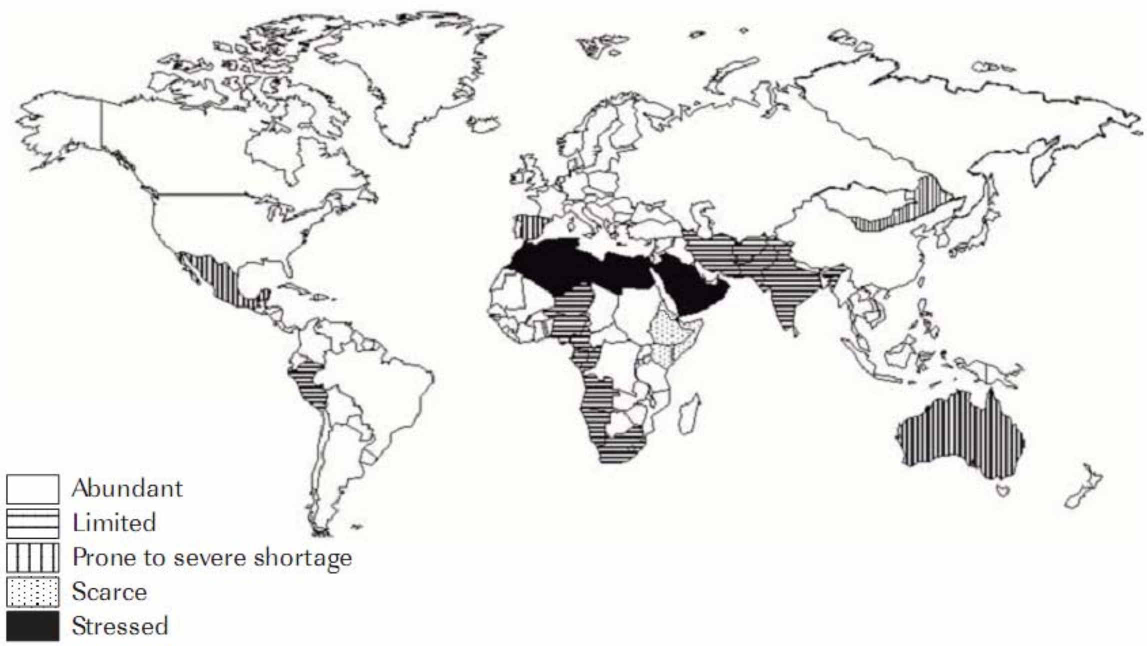

Figure 1. Water availability in different region of the world (TWAS, 2002).

2. DESCRIPTION OF THE STUDY AREA

The study was carried out in Tigray National Regional state (Fig. 2). The towns included in the study were Mekelle, Adigudom, Abiyi-Addi, Hagereselam, Adigrat, Enticho, Adwa, Axum, Firewoini,Edagahamus, Inda-Selassie, Korem, Alamata, Maychew, Wukro, Quiha, and Zalambessa,. The region has six administrative zones namely; Western,North west,Eastern, Central, South Estern and Southern. With an estimated area of 50,078.64 square kilometers, this region has an estimated density of 86.15 people per square kilometer. The region has diversified agro-ecological zones and niches each with distinct soil, geology, vegetation cover and other natural resources. The climate of the region is generally sub-tropical with an extended dry period of nine to ten months and a maximum effective rainy season of 50-60 days. Considering the rainfall, atmospheric temperature and evapo-transpiration, more than 90% of the region is categorized as semi-arid.

According to the CSA, as of 2004, 53.99% of the total population had access to safe drinking water, of whom 42.68% were rural inhabitants and 97.28% were urban.

Table 1. Drinking water contaminants and maximum admissible limit set by different national and international organizations. *(For health risk and aesthetic value)*

	EC (µS/cm)	*TDS (mg/L)*	*pH*	*Turbidity (NTU)*	*Heavy Metals (µg/L)*									
					As	*Cd*	*Co*	*Cr*	*Cu*	*Fe*	*Mn*	*Ni*	*Pb*	*Zn*
USEPA, 2008	NM*	500	6.5 - 8.5	0.5- 1	10	5	100	100	1300	300	50	100	15	5000
EU, 1998	2500	NM	6.5 – 9.5	NM	10	5	NM	50	2000	200	50	20	10	NM
WHO, 2008	250	NGL**	NGL**	NGL[a]	10	3	NM	50	2000	NGL***	400	70	10	NGL**
Iranian, 1997	NM	500	6.5 - 8.5	25	50	10	NM	50	1000	1000	500	NM	50	NM
Australian, 1996	NM	500[c]	6.5 - 8.5	5.0	7	2	NM	50[c]	2000	300[c]	500	20	10	3000[b]
Indian, 2005	NG	1500	6.5 – 9.2	10	50	10	NM	50[c]	1500	300	100	20	100	5000
New Zealand, 2008	NM	1000	7.0 – 8.5	2.5	10	4	1000	50	2000	200	400	80	10	1500

*NM = Not mentioned,

** NGL= No Guideline, because it occurs in drinking-water at concentrations well below those at which toxic effects may occur,

*** No Guideline, because it is not of health concern at concentrations normally observed in drinking water, but may affect the acceptability of water at concentration above 300 µg/L,

NGL[a] No Guideline but desirable less than 5 NTU,

[b] based on quality (Aesthetic) not safety (Health risk),

[c] Chromium as Cr^{+6} not total Cr.

3. METHODOLOGY

3.1. Drinking Water Sampling

A total of 106 ground drinking water samples were collected from sixteen densely populated urban areas of the region: Alamata, Korem, Maichew, Adigudom, Abyi-Adi, Hagereselam, Zalambessa, Adigrat, Edagahamus, Firewoini, Wukro, Mekelle, Indasilase, Axum, Adwa, and Enticho (Fig. 2). All the samples are taken from chlorine treated ground water sources. The drinking water samples were collected in prewashed (with detergent, dilute HNO_3, doubly deionized distilled water respectively) double caped polyethylene bottles from February to May 2010. In the field, the sampling bottles and caps were rinsed three times with the water to be sampled prior to sampling. Most of the samples were obtained directly from the tap after allowing the water to run for at least 5 min so as to stabilise the variation in EC and Temperature (Reimann et al., 2003). Then, the samples were acidified to 1% with nitric acid and were stored in 500 mL double caped polyethylene bottles. The samples were subsequently stored at 4 ^{0}C for as short a time as possible before analysis to minimize changes of the physicochemical characteristics of the metals (Tuzen and Soylak, 2006). As this study is supposed to reflect the quality of the water 'as drunk', the samples were not filtered (Reiman et al., 1996).

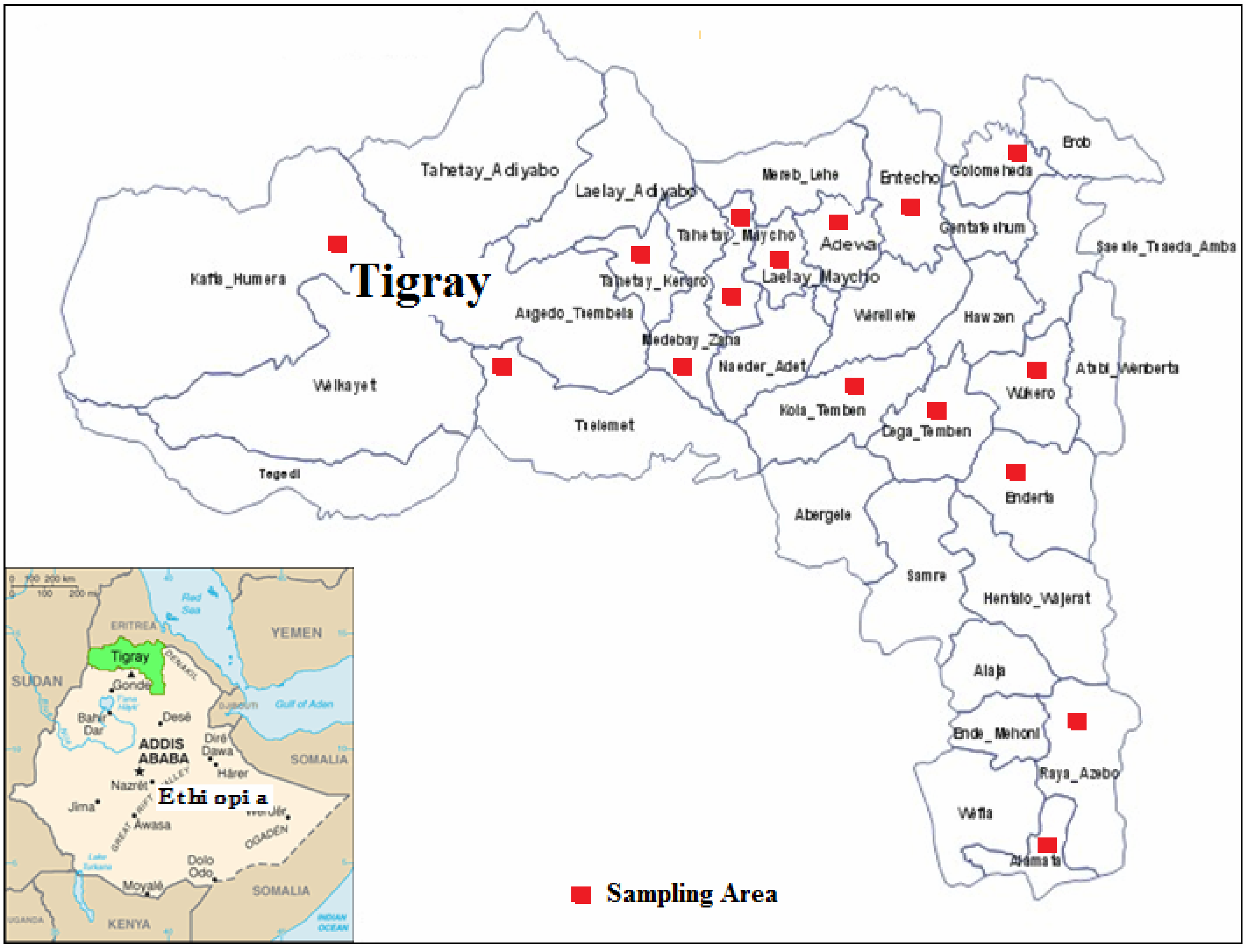

Figure 2. Location of the sampling areas in Tigray region, Northern Ethiopia.

3.2. Sample Analysis

Physical parameters like temperature, conductivity, total dissolved solids and salinity of the samples were measured at the sampling sites using Jenway 4150, portable conductivity meter. pH was also recorded at the sampling sites using Hach, HQ11d Portable pH Meter. Turbidity of the samples was measured at aquatic chemistry laboratory of Mekelle University using Hach, 2100Q Turbidimeter. Heavy metals (As, Cd, Co, Cu, Cr, Fe, Mn, Ni, Pb and Zn) analysis was done at analytical laboratory of Ezana Mining Development P.L.C. using AA240FC, Varian instruments, Fast Sequential AAS Australia with instrument working condition mentioned in table 2. Analytical grade chemicals (HNO_3, Sigma chemicals, Australia and standard heavy metal solutions, Varian instruments, Australia) after preserving at 4 ^{o}C for short period of time.

Table 2. Instrument working conditions.

Element	***As***	***Cd***	***Co***	***Cu***	***Cr***	***Fe***	***Mn***	***Ni***	***Pb***	***Zn***
Lamp current (mA)	10	4	7	4	7	5	5	4	5	5
Fuel	C_2H_2	C_2H_2	C_2H_2	C_2H_2	C_2H_2	C_2H_2	C_2H_2	C_2H_2	C_2H_2	C_2H_2
Support	N_2O	Air	Air	Air	N_2O	Air	Air	Air	N_2O	Air
Wave length (nm)	197.7	228.8	240.7	324.7	357.9	248.3	275.9	232.0	217.0	213.9
Slit width (nm)	0.5	0.5	0.2	0.5	0.2	0.2	0.2	0.2	1.0	1.0

Note: Flame used was reducing (red cone) for As, Cr and oxidizing for others.

4. RESULTS AND DISCUSSION

The range and the average value, $\bar{X}$ ± 1SD, of the physical parameters including temperature, conductivity, TDS, salinity, pH and turbidity of the drinking water samples are given in Table 3. Temperature of the samples was in the range of 11.8 to 27.7 ^{o}C, with minimum value (11.8) from Hagereselam and maximum from Alamata. Electrical conductivity (EC) which is a measure of water's ability to conduct an electric current is related to the amount of dissolved minerals in water, but it does not give an indication of which element is present but higher value of EC is a good indicator of the presence of contaminants such as sodium, potassium, chloride or sulphate (Orebiyi et al., 2010). Analysis of the results show that all the samples from Alamata, Korem, Maichew, and Abiyi-Addi (15.09% of the samples) have EC value less than the WHO (2008) (Table 1) maximum admissible limit; while the rest of the samples (84.01%) have EC values more than the limit. The range of EC of the samples was from 44.1 to 2130 µS/cm, with minimum (44.1) from Abiyi-Addi and maximum (2130) from Mekelle Drinking water samples. Very high values of EC with mean value of 1035, 1663.09 and 1793.6 t µS/cm was recorded for samples collected from Indasilase, Mekelle and Axum respectively.

Table 3. Level of some physical parameters for drinking water samples from urban areas of Tigray region, Ethiopia.

Sampling location	***Temperature (^{0}C)***		***Conductivity, (µS/cm)***		***TDS (mg/L)***		***Salinity (g/L)***		***pH***		***Turbidity, NTU***	
	$\bar{X}$ ± SD	***Range***	***$\bar{X}$ ± SD***	***Range***	***$\bar{X}$ ± SD***	***Range***	***$\bar{X}$± SD***	***Range***	***$\bar{X}$ ± SD***	***Range***	***$\bar{X}$ ± SD***	***Range***
Alamata	26.17 ± 1.46	24.80-27.7	151.33 ± 6.66	147 - 159	76.33± 3.21	74 - 80	0.50± 0.00	0.5	7.43 ± 0.41	7.02 – 7.85	7.92 ± 0.98	6.80 – 8.55
Korem	21.10 ± 1.87	19.00-22.6	87.37 ± 2.32	84.70 – 89.00	44.00± 1.00	43.00 – 45.00	0.50± 0.00	0.5	7.48 ± 0.50	6.92 – 7.92	4.61 ± 0.50	4.12 – 5.14
Maichew	21.77 ± 0.68	21 - 22.3	107.20 ± .32	105.7 – 108.2	53.67± 0.58	53 - 54	0.50± 0.00	0.5	8.48 ± 0.14	8.32 – 8.61	7.01 ± 1.06	5.92 – 8.03
Adigudom	22.50 ± 1.09	21.7 - 23.7	261.33 ± 0.58	261 - 262	134.67± 3.51	131 - 138	0.50± 0.00	0.5	7.99 ± 0.49	7.61 – 8.55	6.21 ± 0.59	5.73 – 6.87
Abyi- Adi	23.74 ± 2.33	19.7 - 25.7	50.2 ± 4.43	44.1 – 55.9	25.8± 3.11	21 - 29	0.5± 0.00	0.5	7.97 ± 0.53	7.34 – 8.54	3.94 ± 0.55	3.41 – 4.81
Hagereselam	14.67 ± 3.00	11.8 - 17.8	586 ± 18.73	571 - 607	349.67± 13.87	338 - 365	0.5± 0.00	0.5	8.19 ± 0.74	7.66 – 9.04	3.34 ± 0.62	2.63 – 3.79
Zalambessa	16.37 ± 0.25	16.1 - 16.6	503 ± 6.08	499 - 510	305.33± 8.50	299 - 315	0.5± 0.00	0.5	7.54 ± 0.11	7.47 – 7.67	7.58 ± 2.00	5.56 – 9.78
Adigrat	17.30 ± 2.61	13.6 - 20	768.33± 122.10	532 - 1013	469.33± 25.78	422 - 516	0.58± 0.06	0.5 – 0.7	7.67 ± 0.41	7.19 – 8.63	4.31 ± 2.61	1.11 – 8.83
Edagahamus	15.40 ± 1.98	14 – 16.8	115.25 ± 8.13	109.50 – 121.00	71.40± 9.90	64.4 – 78.4	0.4± 0.00	0.4	7.79 ± 0.37	7.52 – 8.05	1.81 ± 1.48	0.77 – 2.867
Firewoini	15.95 ± 2.33	14.– 17.6	425.50 ± 9.19	419 - 432	257.50± 6.36	253 - 262	0.50± 0.00	0.5	8.2± 0.06	8.24-8.32	6.17 ± 2.95	8.32
Wukro	17.21 ± 2.019	14.3 – 20.00	735.50 ± 166.20	567 - 997	439.5± 100.19	339 - 597	0.56± 0.07	0.5 – 0.7	7.81± 0.58	7.04 – 8.82	3.86 ± 0.52	2.98 – 4.71
Mekelle	17.78 ±1.64	14.6 – 21.2	1663.09 ± 240.21	1172 - 2130	999.72± 145.24	698 - 1288	0.90± 0.09	0.7 – 1.1	7.86 ± 0.24	7.44 – 8.36	7.09 ± 5.17	0.504 – 27.42
IndaSelassie	16.94 ± 1.68	14.6 – 19.1	1035 ± 104.41	860 - 1170	665.4± 163.32	515 - 1095	0.66± 0.05	0.6 – 0.7	7.42 ± 0.24	7.08 – 7.72	3.13 ± 2.11	0.31 – 7.16
Axum	16.9 ± 1.20	15 – 18.9	1793.67 ± 146.84	1493 - 2050	1004.75± 293.46	435 - 1593	0.88± 0.18	0.6 – 1.3	6.99 ± 0.14	6.80 – 7.35	2.79 ± 1.09	1.42 – 5.26
Adwa	19.83 ± 1.03	18.4 – 21.6	366.80 ± 3.26	362 - 371	219.50± 2.22	217 - 224	0.40± 0.00	0.4	7.63 ± 0.22	7.13 – 7.89	2.52 ± 0.53	1.52 – 3.14
Enticho	20.98 ± 0.71	20.1 – 21.7	817.25 ± 127.58	675 - 979	487± 87.78	405 - 592	0.58± 0.15	0.4 – 0.7	7.63 ± 0.27	7.31 – 7.93	1.99 ± 0.62	0.99 – 2.31

According to WHO (2008), there is no health based limit for TDS in drinking water, as TDS occurs in drinking water at concentrations well below toxic effects may occur, but the palatability of water with TDS level of less than 500 mg/L is generally considered to be good. Drinking water becomes significantly and increasingly unpalatable at TDS Levels greater than about 1000 mg/L. TDS greater than 1200 mg/L may be objectionable to consumers and could have impacts for those who need to limit their daily salt intake e.g. Severely hypertensive, diabetic, and renal dialysis patients (London et al., 2005). Of the samples analyzed 47.17% were found to contain TDS value of greater than 500 mg/L, these were mainly from Axum, Mekelle, and Indasilase with Mean TDS value of 1004.75, 999.72 and 665.4 mg/L respectively. Highest TDS value (1593 mg/L) was recorded in drinking water sample from Axum and lowest (21 mg/L) from Abyi-Adi.

According to the salinity classification of Rabinove et al., 1958, (Table 4), more than 94.33% of the samples were found to be non-saline and only 5.67% were slightly saline. pH of the samples was between 6.8 (Axum) and 9.04 (Hagereselam) with more than 89% of the samples' pH laying in the alkaline range. There is no guideline value by WHO for pH but 93.4% of the samples analyzed were within the US EPA admissible limit (6.5-8.5) and all the samples analyzed were within the (EU, 1998) admissible limit (6.5-9.5).

Table 4. Classification of the drinking water samples on the basis of salinity (Rabinove et al., 1958).

S. No	Description of the drinking water	Salinity (g/L)	No of Samples	Percentage
1	Non Saline	< 1	100	94.33%
2	Slightly Saline	1 - 3	6	5.67%
3	Moderately Saline	3 - 10	0	0.00%
4	Very Saline	> 10	0	0.00%

Turbidity is a measure of cloudiness of water. It has no health effects. However, turbidity can interfere with disinfection and provide a medium for microbial growth. High turbidity may indicate the presence of disease causing organisms. These organisms include bacteria, viruses, and parasites that can cause symptoms such as nausea, cramps, diarrhea, and associated headaches (Akoto and Adiyiah, 2007). 31.13% of the samples have turbidity value greater than 5 NTU (Nephelometric Turbidity Units), which is the WHO (2008) maximum desirable limit in drinking water (Table 1) and these were mainly from Mekelle, Adigrat, Zalambessa, Adigudom, Maichew and Alamata. Turbidity value as high as 27.42 NTU was observed in a sample from Mekelle and the lowest, 0.31 from Indaselassie.

Guidelines for the presence of heavy metals in drinking water have been set by different international organizations like US EPA, WHO, European Union commission (Momodu and Anyakora, 2010). Many national organizations like Bureau of Indian Standards (BIS) have also set their own drinking water standards (Table 1). As specified by these organizations there are maximum admissible limits for heavy metals in drinking water.

The concentrations of heavy metals: As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, and Zn in the drinking water samples analyzed are presented in tables 5 and 6. Highest heavy metal concentration was found for Zinc (3886 µg/L) in water sample from Axum. Levels of Iron and Zinc were above the detection limit in all the samples. Copper was the only heavy metal that was below the detection limit in any of the samples.

Table 5. Concentration of heavy metals As, Cd, Co, Cr and Cu (µg/L) in drinking water samples from urban areas of Tigray region, Ethiopia

Sampling location	**As**		**Cd**		**Co**		**Cr**		**Cu**	
	$\bar{X}$ ± SD	**Range**	**$\bar{X}$ ± SD**	**Range**	**$\bar{X}$ ± SD**	**Range**	**$\bar{X}$ ± SD**	**Range**	**$\bar{X}$ ± SD**	**Range**
Alamata	BDL*	-	BDL	-	BDL	-	108 ± 10	99 – 117	BDL	-
Korem	BDL	-	BDL	-	BDL	-	97± 6	93 – 101	BDL	-
Maichew	BDL	-	BDL	-	BDL	-	98 ± 7	93 – 103	BDL	-
Adigudom	BDL	-	BDL	-	BDL	-	104 ± 8	99 – 110	BDL	-
Abyi- Adi	BDL	-	BDL	-	BDL	-	98 ± 2	96 – 101	BDL	-
Hagereselam	620 ± 84	560 – 680	BDL	-	BDL	-	104 ± 4	101 – 108	BDL	-
Zalambessa	740 ± 239	571 – 910	BDL	-	BDL	-	120 ± 12	111 – 128	BDL	-
Adigrat	BDL	-	BDL	-	BDL	-	121 ± 11	106 – 136	BDL	-
Edagahamus	BDL	-	BDL	-	8 ± 2	6 – 10	116 ± 17	104 – 128	BDL	-
Firewoini	BDL	-	BDL	-	BDL	-	107 ± 20	92 – 121	BDL	-
Wukro	BDL	-	BDL	-	BDL	-	116 ± 7	106 – 125	BDL	-
Mekelle	395 ± 60	330 – 460	17 ± 2	14 – 21	18 ± 7	11 – 30	146 ± 9	131 – 158	BDL	-
Indasilase	603 ± 240	390– 1060	BDL	-	16 ± 8	8 – 29	BDL	-	BDL	-
Axum	520 ± 154	320 – 760	BDL	-	27 ± 6	19 – 36	BDL	-	BDL	-
Adwa	630 ± 170	450 – 790	BDL	-	23 ± 2	22 – 26	BDL	-	BDL	-
Enticho	725 ± 190	590 – 860	BDL	-	17 ± 7	12 – 22	BDL	-	BDL	-

**BDL*= below detection limit of the method.

Chromium was detected in 12 of the sampling areas followed by arsenic, nickel and lead which were detected in 7 of the sampling sites. Cobalt and manganese were also detected in 6 of the sampling areas while cadmium was detected in only one sampling area.

The Arsenic concentration is found to be a major threat in Hagereselam, Zalambessa, Mekelle, Indasilase, Axum, Adwa and Enticho with highest concentration measured 680, 910, 460, 1060, 760, 790 and 860 µg/L respectively. More than 40.3% of the samples analyzed, were found to contain arsenic level above the WHO recommended value of 10 µg/L (Table. 1).

Cadmium occurs mostly in association with zinc and gets into water from corrosion of zinc coated ("galvanized") pipes and fittings (danamark.com 2008). At higher concentrations, it is known to have a toxic potential. The main sources of cadmium are industrial activities; the metal is widely used in electroplating, pigments, plastics, stabilizers and battery industries (Nassef et al., 2006). Cadmium is highly toxic and responsible for several cases of poisoning through food. Small quantities of cadmium cause adverse changes in the arteries of human kidney. It replaces zinc biochemically and causes high blood pressures, kidney damage etc (Rajappa et al., 2010). It interferes with enzymes and causes a painful disease called Itai-itai. In the present study, cadmium is detected in water only from Mekelle area, where Cd value is above the WHO (2008) recommended value (3µg/L) in 7.46% of the samples analyzed with mean concentration of 17 µg/L and varies from 14 to 21 µg/L.

Cobalt concentration was found to be below the detection limit in ten of the sampling areas (Alamata, Korem, Maichew, Adigudom, Abyi- Adi, Hagereselam, Zalambessa, Adigrat, Firewoini, Wukro). In the other areas, cobalt concentration ranges from 8 to 36 µg/L with the maximum (36 µg/L) in drinking water sampled from Axum and minimum (8 µg/L) from Indasilase. Though the maximum admissible limit, MAL of cobalt is not mentioned by WHO (2008), all the samples analyzed comply the New Zealand (1000 µg/L) and US EPA (100 µg/L) maximum admissible limits of cobalt in drinking water (Table 1).

Chromium is an essential micronutrient for animals and plants, and is considered as a biological and pollution significant element. Generally the natural content of chromium in drinking water is very low ranging from 10 to 50 µg/L except for the regions with substantial chromium deposits (Jayana et al., 2009). Chromium in excess amounts can be toxic especially in the hexavalent form. Sub chronic and chronic exposure to chromic acid can cause dermatitis and ulceration of the skin. Long-term exposure can cause kidney, liver, circulatory and nerve tissue damages. Chromium often accumulates in aquatic life, adding to the danger of eating fish that may have been exposed to high level of chromium (Hanaa et al., 2000; Pandey et al., 2010). In this study, chromium was not detected in only four of the sampling areas (Indasilase, Axum, Adwa, and Enticho). In the other areas, Chromium level varies from 92 µg/L in Firewoini to 158 µg/L in Mekelle, which are above the WHO (2008) maximum admissible limit of Cr in drinking water (50 µg/L). Of all the samples analyzed, 64.18% contain chromium level above WHO (2008) maximum admissible limit with the highest level of chromium recorded for samples from Mekelle (mean concentration, 146 µg/L).

Contamination of drinking water with high level of copper may lead to chronic anemia (Acharya et al., 2008). In this study, copper is the only metal that was not detected in all the sampling areas presumably due to the low cupper related industrial and mining activities in the sampling areas. Since the WHO (2008) maximum admissible limit of copper in drinking water was well above the method detection limit; there was no health related risk due to the presence of copper in drinking water of the study areas.

Table 6. Concentration of heavy metals, Fe, Mn, Ni, Pb and Zn (µg/L) in drinking water samples from urban areas of Tigray region, Ethiopia.

Sampling location	*Fe*		*Mn*		*Ni*		*Pb*		*Zn*	
	$\bar{X}$ ± *SD*	*Range*	$\bar{X}$ ± *SD*	*Range*	$\bar{X}$ ± *SD*	*Range*	$\bar{X}$ ± *SD*	*Range*	$\bar{X}$ ± *SD*	*Range*
Alamata	311± 15	298 – 324	BDL*	-	BDL	-	BDL	-	78 ± 2	76 - 80
Korem	282 ± 21	267 – 297	BDL	-	BDL	-	BDL	-	145 ± 6	141 – 149
Maichew	411 ± 21	396 – 426	BDL	-	50 ± 2	49 – 52	72 ± 6	68 – 76	321 ± 36	296 – 347
Adigudom	140 ± 9	133 – 146	BDL	-	BDL	-	BDL	-	531 ± 53	493 – 569
Abyi- Adi	432 ± 60	397 – 501	BDL	-	242 ± 212	34 – 459	53 ± 18	41 – 66	617 ± 117	534 – 700
Hagereselam	449 ± 205	304 – 594	BDL	-	BDL	-	BDL	-	497 ± 136	401 – 593
Zalambessa	121 ± 21	106 – 136	BDL	-	BDL	-	BDL	-	306 ± 112	226 – 385
Adigrat	723 ± 740	104 – 1872	76 ± 62	24 – 156	44 ± 11	31 – 63	83 ± 46	5 – 136	457 ± 297	71 – 1050
Edagahamus	274 ± 32	251 – 297	BDL	-	37 ± 8	31 – 42	124 ± 78	69 – 179	157 ± 53	119 – 195
Firewoini	548 ± 454	226 – 869	200 ± 21	185 – 215	46 ± 11	38 – 54	BDL	-	428 ± 250	251 – 605
Wukro	193 ± 72	130 – 304	BDL	-	40 ± 6	34 – 50	59 ± 20	45 – 94	404 ± 321	80 – 904
Mekelle	379 ± 234	97 – 919	34 ± 4	31 - 38	37 ± 6	33 – 41	69 ± 26	69 – 106	246 ± 186	80 – 583
IndaSelassie	212 ± 66	134 – 307	28 ± 4	25 – 31	BDL	-	700 ± 916	52 – 1347	2499 ± 3739	439 – 5055
Axum	218 ± 91	140 – 434	78 ± 41	21 – 124	BDL	-	BDL	-	1338 ± 1456	401 – 3886
Adwa	271 ± 66	221 – 345	48 ± 27	25 – 77	BDL	-	BDL	-	267 ± 360	45 – 683
Enticho	429 ± 70	379 – 479	BDL	-	BDL	-	BDL	-	609 ± 242	437 – 780

BDL= below detection limit of the method.

Iron is the fourth most abundant element by mass in the earth's crust. In water, it occurs mainly in ferrous or ferric state (Ghulman et al., 2008). Iron in surface water generally present is ferric state. It is an essential and non-conservative trace element found in significant concentration in drinking water because of its abundance in the earth's crust. Usually, iron occurring in ground water is in the form of ferric hydroxide, in concentration less than 500 µg/L (Oyeku and Eludoyin, 2010).

The shortage of iron causes disease called "anemia" and prolonged consumption of drinking water with high concentration of iron may lead to liver disease called as haermosiderosis (Rajappa et al., 2010; Bhaskar et al., 2010). In the areas studied, iron content varies from 97 µg/L in sample taken from Mekelle to 1872 µg/L from Zalambessa. About 62.69% of the samples comply the desirable concentration of iron in drinking water (300ug/L) set by WHO (2008), whereas 37.31% of the samples have shown iron concentration above the limit. No guideline is set by WHO (2008) for iron content in drinking water because it is not of health concern at concentrations normally observed in drinking water.

Manganese level varies from below detection in samples from Alamata, Korem, Maichew, Adigudom, Abyi-Adi, Hagereselam, Zalambessa, Edagahamus, Wukro, and Enticho to 215 µg/L from Firewoini. WHOs' (2008) MAL for manganese is 400 µg/L and none of the drinking water samples analyzed show above the limit.

The WHO (2008) MAL for Ni in drinking water is 70µg/L. In this study, Nickel was detected in seven of the sampling areas with concentration range 31 µg/L in water samples from Adigrat and Edagahamus to 459 µg/L from Abyi-Addi. Of the 106 samples analyzed less than 3% contain Nickel concentration above the WHO (2008) maximum admissible limit (70 µg/L).

Lead is the most significant of all the heavy metals because it is toxic, very common (Gregoriaadou et al., 2001) and harmful even in small amounts. Lead enters the human body in many ways. It can be inhaled in dust from lead paints, or waste gases from leaded gasoline. It is found in trace amounts in various foods, notably in fish, which are heavily subjected to industrial pollution. Some old homes may have lead water pipes, which can then contaminate drinking water. Most of the lead we take is removed from our bodies in urine; however, as exposure to lead is cumulative over time, there is still risk of buildup, particularly in children. Studies on lead are numerous because of its hazardous effects. High concentration of lead in the body can cause death or permanent damage to the central nervous system, the brain, and kidneys (Hanaa et al., 2000). In this study, maximum level of Pb (1347 µg/L) was found in drinking water sampled from Indasilase and a minimum of BDL in drinking water samples from Alamata, Korem, Adigudom, Hagereselam, Zalambessa, Firewoini, Axum, Adwa and Enticho. More than 70.15% of the samples (Table 6) analyzed contain lead concentration within the WHO (2008) MAL of lead in drinking water (10µg/L).

Zinc is one of the important trace elements that play a vital role in the physiological and metabolic process of many organisms. Nevertheless, higher concentrations of zinc can be toxic to the organism (Rajkovic et al., 2008). It plays an important role in protein synthesis and is a metal which shows fairly low concentration in surface water due to its restricted mobility from the place of rock weathering or from the natural sources (Rajappa et al., 2010). In this study, a minimum of 45 μg/L and maximum of 5055 μg/L zinc concentration were recorded in water samples from Adwa and Indaselassie respectvely. Although no guideline is set by WHO (2008) for zinc level in drinking water, of the samples analyzed 94.02% comply the New Zealand standard (1500 μg/L) and 97.01% of the samples comply the maximum admissible limit set by USEPA (2008), EU (1998), Iranian (1997), Australian (1996) and Indian (2005) standards, table 1.

Table 7. Percentage of samples which comply with WHO, maximum admissible limit of different drinking water parameters.

	Drinking water Parameters with MAL set by WHO (2008)							
	EC	***As***	***Cd***	***Cr***	***Cu***	***Mn***	***Ni***	***Pb***
Percent of samples within WHO, 2008 MAL.	15.09%	59.70%	92.54%	35.82%	100%	100%	93%	70.15%

5. CONCLUSION

The main goal of this paper was to assess the status of drinking water quality in urban areas of the Tigray region, northern Ethiopia, with special emphasis on trace heavy metals. A total of 106 drinking water samples were collected from 16 densely populated urban areas of the region. All the samples were analyzed for six physicochemical parameters (T, EC, TDS, salinity, pH, and turbidity) and ten heavy metals (As, Cd, Co, Cu, Cr, Fe, Mn, Ni, Pb, and Zn) using standard procedures. The results show that values of electrical conductivity (EC), total dissolved solid (TDS), turbidity and concentrations of some heavy metals (As, Cd, Cr, Fe, Ni and Pb) in some of samples, mainly from Adigrat, Edagahamus, Firewoini, Wukro, Mekelle, Axum and Indasilase are higher than the MAL set by WHO, 2008. This is an indication of pollution hazards and weak drinking water treatment practices in these areas which, in turn, have implications on the health of the people.

During the sampling periods, severe drinking water shortage and weak drinking water storage practices (especially small service giving enterprises like hotels, restaurants and cafeteria) have also been observed. In some areas, very old metal tankers which may stay for over six months without cleaning were used to store drinking water and in other areas mainly in households, tankers made from plastic and clay without covers and necessary cleanups were used to store drinking water. All this together enhance the risk on human health.

This study, therefore, recommends the government and other responsible authorities to: (1) introduce relevant drinking water treatment techniques which can reduce the current levels of heavy metals, (2) Prevent any kind of waste disposal into rivers, canals or any reservoirs that supply domestic drinking water (3) educate the people to have better drinking water storage practices, and (4) support further study to be conducted on other physical, chemical and biological parameters of significant health concern and on identification of potential sources of the contaminants including heavy metal contaminants.

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