

## Assessment of physicochemical parameters and levels of heavy metals concentrations in drinking water of Asmara city, Eritrea III

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### Abstract

This study, the first of its kind in Eritrea, is aimed at the assessment of the safety and quality status of the drinking water in Asmara city, Eritrea. A total of 88 water samples were collected from the reservoirs of surface water, treatment stations and consumer taps. The assessment was carried out in terms of physicochemical parameters with annual averages for consumer taps: pH 6.98-7.09, hardness 108.46-118.42 ppm and conductivity 282.73-330.23  $\mu\text{S}/\text{cm}$ , which were found to be within the permissible international standard guidelines, while the turbidity parameter 7.50-836 NTU was slightly above the standard WHO values (5.00 NTU). All mean annual concentration levels of the heavy metals for consumer taps were below WHO (standard value). Atomic Absorption Flame spectrometry and Inductively Coupled Plasma Spectrometry determinations are: Cr 0.026 ppm, Cu 0.008 ppm, Fe 0.334 ppm, Mn 0.262 ppm and Zn 0.410 ppm. The assessment affirmed the nonexistence of VOCs pollutants analyzed via GC-MS. Statistical analysis of the seasonal variations within these physicochemical parameters reveal that the total mean values of the dry season for hardness ( $U=0$ ,  $p=0.002$ ) and conductivity ( $U=2$ ,  $p=0.009$ ) were significantly higher than the rainy season values for both Mainefhi and Toker sources. Whereas for pH ( $U=15$ ,  $p=0.699$ ) and turbidity ( $U=8$ ,  $p=0.121$ ) were found to be with no significant variation. This water can be said of safe quality measured against WHO standards. However, there is a need for improvement in the water treatment processes.

**Key words:** Asmara, Drinking water, Physico-chemical parameters, Heavy metals, Mean concentration.

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## Introduction

Access to a safe and reliable supply of drinking water is essential for the wellbeing of all human beings. However, the availability of fresh water is getting scarce let alone its quality, which becomes a major issue in our world. Though water is important to life, it is one of the most poorly managed resources in the world (Fakayode, 2005). Besides the shortage, the pollution of water by different agents is also a threat to human health and economic growth. These critical drinking water problems are more pronounced in the underdeveloped and some developing countries.

Water intended for human consumption must conform to standard magnitude of physicochemical parameters such as pH, hardness, conductivity and turbidity. It must also abide to certain permissible levels of heavy metals (Hanaa et al., 2000; Maigari et al., 2014). Actually specific drinking water standards are not given or not mentioned for all the four parameters by WHO. On the other hand, USEPA has quoted the pH acceptable value, which is normally, considered as a "Secondary Maximum Contaminant Level" where the regulations are based on aesthetic considerations. The EU regulations document also has given standards for conductivity only (Table 1) (WHO, 2011; USEPA, 2012; EU, 1998). Moreover, drinking water must be free from disease producing micro-organisms (Lamikaran, 1999; Shittu et al., 2008, Zerabruk et al., 2015).

**Table 1: Some drinking water international standard values for physicochemical parameters and heavy metals in the study**

	pH	Hardness (mg/l)	Conductivity ( $\mu$ S/cm)	Turbidity (FTU)	Heavy Metals (mg/L)								
					Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
WHO	NG <sup>a</sup>	NG <sup>b</sup>	NM	NG <sup>c</sup>	0.003	NA	0.05	2.0	NG <sup>f</sup>	NG <sup>f</sup>	0.07	10	NA
USEPA	6.5 - 8.5	NM	NM	NG <sup>d</sup>	0.005	NA	0.1	1.3	0.3	0.05	0.1	15	5.0
EU	6.5 - 9.5	NM	2500	NA <sup>e</sup>	0.005	NA	0.05	2.0	0.2	0.05	0.02	10	NA

NA = Not available; NG = Not given; NM = Not mentioned

<sup>a</sup> Not of health concern at levels found in drinking-water, but desirable: 6.5-8.5

<sup>b</sup> Not of health concern at levels found in drinking-water, but desirable: 150-500 mg/l.

<sup>c</sup> Desirable: Less than 5 NTU.

<sup>d</sup> At no time can it go above 5 NTU.

<sup>e</sup> Acceptable to consumers and no abnormal change.

<sup>f</sup> Not given Because it occurs in drinking-water at concentrations well below those at which toxic effects may occur.

Levels of Toxic chemicals cause either acute or chronic health effects. The levels of chemicals in drinking water, however, are seldom high enough to cause acute health effects. They are more likely to cause chronic health effects that occur long after exposure to small amounts of a chemical. Examples of chronic health effects include cancer, birth defects, organ damage, disorders of the nervous system, and damage to the immune system (USGAO, 2000). Pb, Zn, Cu, Mn, Co, Ni, Cd, Cr, and Mo are toxigenic and carcinogenic agents consistently found as contaminants in human drinking water supplies in many areas around the world (Groopman et al., 1985).

Volatile organic compounds VOCs, both BTEX and PAHs, are both termed as traffic related indoor and outdoor air pollutants (Dareen and Younis, 2013; Mohamed and Younis, 2015). Some have been widely recognized as a human carcinogen (IARC, 2012) and others possess high toxicity, especially to central nervous system in humans (Northampton, 2014). Natural water surfaces could adsorb these air pollutants and hence affect the quality standard of these waters (Westrick, 1990; Lanchote et al., 2000; Polkowska et al., 2000; Mottaleb et al., 2004)

Eritrea is one of the developing countries, in Sub-Saharan Africa, facing most of the common challenges in providing water services to its citizens. The country is semi-arid and is not endowed with rich water resources. The natural availability of water across the country is variable, and rainfall displays strong seasonality. River and stream flow in Eritrea is also seasonal or is very low for most of the year except during the short rainy months. (Zeraebruk et al., 2014)

The drinking water supply system in Asmara city, the capital of the state of Eritrea, has been seen to provide unsatisfactory services due to a combination of various reasons such as, low service coverage, intermittent mode of water distribution, and long period of cut-offs. The problems were related to limited and scarce water sources, aging infrastructure and substantial leakage losses together with inefficient system of planning and water management. Some of the water supply infrastructure facilities currently in use for supplying water to the capital were built during the colonial period (Zeraebruk et al., 2014)

The major source of drinking water supply for Asmara is surface water from rainfall collected during the rainy months of summer. The runoff created from the rainfall over the drainage areas is collected into dam reservoirs located around the city and such sources are apparently open and prone to pollutants. The main sources are Mai Nefhi reservoir, located in the south and Toker dam located in the north of the city.

The current investigation is a continuation of our previous published investigation on the bacteriological assessment of the drinking water of Asmara (Zeraebruk et al., 2015). The main aim of the current research study, which is the first of its kind in Eritrea, is to authenticate the physicochemical parameters of drinking water in Asmara, and also the determination of the concentration levels of some heavy metals, namely, cadmium (Cd), cobalt (Co), copper (Cu), chromium (Cr), iron (Fe), manganese (Mn), nickel (Ni), lead (Pb), and zinc (Zn). Findings were compared with the international recommended drinking water standards (Table 1) to assure the safety and quality of this water.

## Materials and Methods

### Description of Sample Collection Site

Samples were collected from the Asmara water supply system. Asmara is the capital of the state of Eritrea and the administrative centre of the Central Region known as Administration of Maekel Zone. The current population of Asmara is around 620,000 (from Database of Administration of Maekel Zone, July 2015). Asmara is located at coordinates of 15.33°N, 38.93°E and an elevation of 2,325 meters above sea level in the central highlands of Eritrea

(Figure 1). Asmara gets an average of about 500 millimeters of precipitation annually in the months of June to September (Ministry of Land Water and Environment, 2007). Administration of Maekel Zone is divided into 16 sub-zones and 13 of them are part of the city proper (Asmara). For this study, data had been collected from the nine sub zones of Asmara city that are supplied drinking water from the main reservoirs of Mainefhi and Toker.

Asmara city has been experiencing serious water stress conditions due to limited available water resources, unreliable rainy seasons due to climate change, growth in population, and aging infrastructure in recent years. To manage this situation, the Asmara Water Supply and Sewerage Department (AWSDD) implemented a water rationing system with scheduled services, where water is distributed only on some days each week and for some hours only. However, the shortage of water coupled with lack of proper management of the rationing system has resulted in the interruption of water supply for extended periods in some areas and supply through water tanker trucks to sectors that were facing difficulties of distribution. (Zeraebruk et al., 2014).



**Figure1. Map of Eritrea.**

### Sampling procedure

A total of 88 water samples were collected from different parts of Asmara drinking water supply for the two seasons, 52 during the rainy season months of July and August and 36 during the dry season months of February and March. Out of the total sampled, 16 were from the two untreated water reservoirs of Mainefhi and Toker, 12 from treated water at the two treatment stations attached to the reservoirs and 60 from taps of consumers supplied from the two reservoirs. Random sampling was adopted for the study.

The water samples used for the physicochemical tests of pH, conductivity and turbidity were collected in pre-sterilized screw capped Borosilicate glass bottles of 250 ml capacity aseptically, according to APHA and WHO guidelines (APHA, 1998; WHO, 2006). For samples collected from consumer taps, five drops of 10% sodium thiosulphate solution was added to the bottles before sterilization in order to neutralize the residual free chlorine. The samples were then transported to the laboratory in a cold box and the analyses carried out within 2 to 6 hours of collection.

Samples of drinking water for the analyses of metals and hardness, done in Khartoum, Sudan, were collected in prewashed polyethylene bottles of 0.5 liter capacity. For preservation, the samples were acidified in situ to  $\text{pH} < 2$  with concentrated Nitric acid ( $\text{HNO}_3$ ) in the proportion of 1.5 ml of concentrated  $\text{HNO}_3$  per 1 liter of sample water (APHA, 1998). These water samples were then carefully packed and transported to Khartoum and analyses performed within two weeks of arrival in Khartoum.

## **Determination of Physicochemical Parameters**

### **Determination of pH and Conductivity**

The pH and conductivity parameters were determined by electrochemical methods; with the adoption of the *WTW-pH/Cond 340i* instrument, following the instructions recorded in the Instruction Manual (WTW, 2007; Radiometer Analytical SAS, 2004) provided by the manufacturer. Measurements in triplicate runs for both parameters were taken at  $20^\circ\text{C}$ .

### **Determination of Turbidity**

Turbidity was determined by adoption of *Palintest Photometer 7500* instrument. The measurement runs were performed according to the instructions described in the Instruction Booklet of the manufacturer (Palintest Instruments, 2009). Values were in Formazin Turbidity Units (FTU) based on the fact that FTU is equivalent to Nephelometric Turbidity Units (*NTU*) as recommended by the manufacturer.

### **Determination of Hardness**

Determination of hardness was performed by the method described in Vogel (1989). The titration involved water sample against EDTA using Eriochrome black T as indicator. An average value for triplicate determinations was recorded.

## **Determination of the concentration levels of heavy metals**

### **Analytical Instruments**

The analytical instrument used for the determination of heavy metals in the water samples was a Flame Atomic Absorption Spectrometer (F-AAS), a Japan made *Shimadzu AA-7000* model. The fuel used for analysis with F-AAS was a mixture of air and acetylene ( $\text{C}_2\text{H}_2$ ). An Inductively Coupled Plasma – Atomic Emission Spectrometer (ICP-AES), ICP-OES Varian, Vista-MPX-CCD model was used for the determination of elements in water samples from the reservoirs. An assessment for the presence of volatile organic compounds (VOCs) in the water samples from the reservoirs was also performed with the application of GC-MS (Gas Chromatography – Mass Spectrometer), a Japan made *Shimadzu IR Prestige-21* model.

### Preparation of samples and standards

Out of the 88 collected samples a total of 44 water samples were analyzed for metals, that is, half of them for the rainy season and similar number for the dry season. Regarding the location of samples, 22 were from the Mainefhi reservoir and supply line (i.e., treatment station and consumers) and the same number from Toker reservoir and supply line. These were, in each supply line, six from the reservoirs, four from the treatment stations and twelve from consumer taps. As the water samples were already acidified in situ with HNO<sub>3</sub> for preservation, the only procedure done for their preparation for analysis was to filter water from the samples into a 50 ml volumetric flask.

For each of the heavy metals, three and sometime four standard solutions were prepared from known standard stock solutions of 1000 mg/l (manufactured by *AccuStandard*, USA and *Sherlab S.A.*, Spain) by serial dilution. A calibration curve was prepared with these standards and then the analysis of the samples for the heavy metals carried out.

### Detection of Volatile Organic Compounds

**Reagents:** Hexane (n-hexane, 99% HPLC grade) from *Sharlab S.L.*, Spain; C<sub>18</sub> SPE cartridges from *Alltech Associates Inc.*; methanol (HPLC grade) from *DUKSON Pure Chemicals*, Korea;

### Experimental procedures:

Water samples from both Mainefhi and Toker reservoirs were both examined for the presence or absence of VOCs pollutants (BTEX and PAHs). Water sample (200 ml) was filtered through a 0.45 µm filter membrane. Hexane (30 ml) was, then, added to the filtrate. The mixture was shaken for 30 minutes and the upper layer (hexane layer) was collected. The aqueous layer was re-extracted with 25 ml portion of hexane. The ethereal extracts were combined and then passed through SPE columns using C<sub>18</sub> adsorbent cartridges. Elution was carried out with two portions of methanol (2 ml) and the eluate was then passed through a dryer containing sodium sulphate to eliminate any traces of moisture (Mottaleb et al., 2004).

### GC-MS Operating Conditions

Aliquots were injected, according to manufacturer instructions, into the gas chromatograph/mass spectrometer (GC-MS) [GC-MS QP2010Ultra *Schimidzu*, Japan, Serial No. 020525101565SA], for analysis. Two types of capillary columns have been tested for their resolution efficiency: the DB-5-nonpolar column (30 m X 0.25mm X 0.25µm) and RTX-50-medium polar column (30m X 0.25mm X 0.25µm). The GC/MS-Operating Conditions were as follows: Injection temperature was 180°C, Split ratio-1. Column pressure 47.7. Column oven temp. 35°C. Injection mode: Split less. Total Flow 50 ml/min, Column Flow 1.00 ml and Purge Flow 3.00 ml/min. The oven temperature program: Initial: 35°C initial (hold time 2 min); raised to 70°C at a rate of 5°C/min (hold time 1 min); raised to 75°C at a rate 5°C/min (hold time 1min) and finally raised to a constant temperature of 180°C at a rate of 20°C/min. The ion source is operated at 70eV. Ion source temp.: 200°C. Interface temp.: 250°C.

### Statistical Analysis

*SPSS*, *PASW Statistics 18* was used for data analysis. Comparisons and significance tests were run with *Kruskal-Wallis H* and *Mann-Whitney U* (2-tailed) tests. Differences were considered significant if calculated *p*-values were < 0.05.

## Results and discussion

It is noteworthy, at first, to mention that most environmentalists, tourists and expatriates who visited Eritrea observed true nature in its utmost reality and described Eritrea as a typical environmentally clean natural habitat and virgin land. The small scale and scattered traditional farming pursued predominantly in the central highlands of the country is dependent primarily on rainfall. Soil pollution due to pesticide residues is not expected on the site of study, as there is little usage of pesticides and synthetic fertilizers. Industrial activity is meager, except for quite a few micro-industrial enterprises established in the capital city of Asmara. Traffic related pollutants that may eventually reach the surface water are also not expected, as the number of vehicles is not excessive. Accordingly, it is predicted that if there is any water pollution in the country, it could be attributed mainly to natural factors or agents.

In the present research work, the assessment of the safety and quality status of Asmara drinking water is based on determination of the four main physicochemical parameters of pH, hardness, conductivity and turbidity, in addition to the concentration levels of nine heavy metals of different kinds and ranges of health risk effects, namely: Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb and Zn.

It could be noticed, in Table 2, that the mean annual values obtained for the physicochemical parameters are, generally, within the acceptable range of the permissible levels of WHO, USEPA and EU standards (Table 1). It could also be observed that the source water from the reservoirs is of neutral and slightly alkaline nature as it is evident from the pH values, 7.80 minima and 8.17 maxima, obtained from Mainefhi and Toker reservoirs, respectively. These pH values reflect that the water in the reservoirs has little pollution. It was claimed that the pH of surface waters is an important indicator of its quality and the extent of pollution in the watershed area. Normally, unpolluted waters show a pH of about 7.00 and 8.00 (WHO, 2008). These values also agree with the findings (pH=8.1) of Abdel Daim et al. (2010) in the Gedarif dams of Al Saraf (Sudan) and Dalassa (pH=7.3) and with that of Zamxaka et al. (2004) (pH=7.5-8.3) in the dams of rural communities of Eastern Cape Province, South Africa.

**Table 2. Mean annual values of physicochemical parameters in the drinking water of Asmara**

Parameter	Sampling Locations and values in means with standard deviations ( $\bar{x} \pm SD$ )					
	Mainefhi dam			Toker dam		
	Reservoir	Treatment st.	Consumer tap	Reservoir	Treatment st.	Consumer tap
Ph	7.80 $\pm$ 0.48	6.77 $\pm$ 0.29	6.98 $\pm$ 0.37	8.17 $\pm$ 0.25	6.62 $\pm$ 0.37	7.09 $\pm$ 0.22
Hardness (mg/l)	118.52 $\pm$ 1.16	120.42 $\pm$ 0.58	118.42 $\pm$ 1.58	114.82 $\pm$ 1.58	114.82 $\pm$ 1.58	108.46 $\pm$ 3.62
Conduct. ( $\mu$ S/cm)	301.63 $\pm$ 44.80	342.00 $\pm$ 41.27	330.23 $\pm$ 43.08	269.00 $\pm$ 21.42	284.50 $\pm$ 58.61	282.73 $\pm$ 42.41
Turbidity (FTU) <sup>a</sup>	24.75 $\pm$ 17.98	3.67 $\pm$ 2.25	7.50 $\pm$ 7.06	7.75 $\pm$ 3.45	11.00 $\pm$ 5.02	8.36 $\pm$ 7.31

a = FTU (Formazin Turbidity Units) is equivalent to NTU (Nephelometric Turbidity Units)

The decreased pH values in the consumer tap waters might be attributed to the pH adjustment measures that are practiced during the water treatment processes. Moreover, the pH values also show that Toker water source is slightly more alkaline than that of Mainefhi water source. This is

presumably due to the higher Ca concentration level 35.6 mg/l, determined by ICP, in the former reservoir compared to that for the latter reservoir 33.1 mg/l. Moreover, it was reported that increased calcium carbonate  $\text{CaCO}_3$  and other bicarbonates  $\text{Ca}(\text{HCO}_3)_2$  levels in the water, enhance combination with both hydrogen and hydroxyl ions to increase the buffering capacity of the water and thereby increase its alkalinity (Kemker, 2013).

The mean annual values for hardness, 118.5 mg/l and 114.8 mg/l for samples from Mainefhi and Toker reservoirs, respectively, are both below the desirable drinking water standards indicated by WHO 150.0-500.0 mg/l (Table 1). Some reported studies of surface water have found very low mean values for the water hardness parameter: Kusti (Sudan) with a range of 55.0-59.0 mg/l (Ibrahim et al., 2015), in Kontagora (Nigeria) with 56.0 mg/l for dry and 49.0 mg/l for rainy seasons (Ibrahim et al., 2009) and in Bhopal (India), Choudhary et al. (2011). Some of these reported values are compatible to that found in the present study. It has been claimed that hardness is not considered of health concern at levels found in drinking water (WHO, 2011). Generally, increased water hardness is attributed to increased amounts of dissolved chlorides or sulphates of calcium and magnesium, although positively charged divalent ions, such as Fe, Sr and Mn can also contribute to water hardness (Meena et al., 2012). However, there is not much difference in hardness between the values of the water from the two reservoirs and the consumer taps of each respective source of Mainefhi or Toker.

The mean annual values for conductivity measurements found in the current study for all locations are much lower than the standard drinking water guideline value of 2,500  $\mu\text{S}/\text{cm}$  quoted by EU guidelines. It could also be noticed that generally conductivity values for Mainefhi are slightly higher than those of Toker, due to the increased water hardness of the former reservoir. Parameters such as conductivity, water hardness, total dissolved salts and availability of high levels of ions which have divalent cations are all inter-related (Heston, 2015; Xylem Inc., 2011). Likewise, conductivity values of samples from consumer taps, 330.23  $\mu\text{S}/\text{cm}$  and 282.73  $\mu\text{S}/\text{cm}$ , supplied from Mainefhi and Toker reservoirs respectively, are also higher than the values from their respective supplying reservoirs, 301.63  $\mu\text{S}/\text{cm}$  and 269.0  $\mu\text{S}/\text{cm}$  for Mainefhi and Toker reservoirs respectively. Difference in the conductivity could, apparently, be attributed to the reverse leakage and dissolution of minerals from the surrounding soil into the water running through the old and rusted metal water pipes of the Asmara water supply distribution system.

On the other hand, Choudhary et al. (2011) in a study of three reservoirs found comparable results to the current findings of conductivity in the range 222 – 385  $\mu\text{S}/\text{cm}$ . Contrary to other studies on the conductivity of dam waters in Ethiopia (Tessema et al., 2014) and Sudan (Abdel Daim et al., 2010), which had reported higher conductivity values of 399  $\mu\text{S}/\text{cm}$  and 702  $\mu\text{S}/\text{cm}$ , respectively.

The mean annual value of turbidity of the raw water of Mainefhi reservoir is more than three folds higher than that of Toker reservoir. The difference could, obviously, be attributed to differences of soil types through which these waters flow over. Mainefhi area is predominantly characterized by clayey and silty type of soil, while Toker water passes through more of sandy soils, which are expected to act as filters.

A number of published studies have reported high values for the mean annual turbidity of surface water that exceed Tessema et al. (2014), Mwangi (2014) and Chigor et al. (2011) also recorded high turbidity mean values of surface water in studies of reservoirs and dams, which were 24.6 NTU, 4.8 – 27.2 NTU, and 57.5 – 295.4 NTU, respectively. Similarly, the present study revealed



that All the mean annual values of turbidity, except that of the treatment station at Mainefhi (3.67 FTU), are above the desired value indicated by WHO and USEPA (Table1). It could also be observed that there is slight elevation in the value of turbidity in the consumer taps, which could also be the result of entry of pollutants into the old distribution pipes. According to WHO (2011), turbidity in distribution systems can occur because of the disturbance of sediments and biofilms but is also from the ingress of dirty water from outside the system.

The turbidity mean values of Mainefhi treatment station water 3.67 FTU is within the desirable standard. On the other hand, the water turbidity for Toker treatment station 11.0 FTU is more than double the desirable standard (Table 1). This could, apparently, be related to inefficiencies in the treatment processes. Turbidity can seriously interfere with the efficiency of disinfection by providing protection for organisms, and much of water treatment should be directed at removal of particulate matter before disinfection (WHO, 2011).

**Table 3. Mean seasonal values of physicochemical parameters in the drinking water of Asmara**

Parameter	Sampling Locations and values in means with standard deviations ( $\bar{x} \pm SD$ )											
	Mainefhi dam						Toker dam					
	Reservoir		Treatment st.		Consumer tap		Reservoir		Treatment st.		Consumer tap	
	R.S.	D.S.	R.S.	D.S.	R.S.	D.S.	R.S.	D.S.	R.S.	D.S.	R.S.	D.S.
pH	7.89 ± 0.45	7.65 ± 0.59	7.03 ± 0.03	6.51 ± 0.14	6.85 ± 0.34	7.17 ± 0.35	8.28 ± 0.04	7.98 ± 0.36	6.82 ± 0.19	6.42 ± 0.44	7.16 ± 0.20	6.98 ± 0.21
Hardness (mg/l)	111.5 ± 1.16	125.5 ± 1.16	108.7 ± 1.16	132.1 ± 0.00	108.1 ± 2.00	128.7 ± 1.16	110.1 ± 2.00	119.5 ± 1.16	85.5 ± 1.16	130.7 ± 5.78	93.4 ± 4.17	123.5 ± 3.06
Conduct. (µS/cm)	269.6 ± 4.93	355.0 ± 11.79	305.7 ± 15.50	378.3 ± 7.57	318.2 ± 19.35	348.3 ± 60.97	254.2 ± 2.49	293.7 ± 11.55	232.3 ± 4.73	336.7 ± 20.03	256.9 ± 31.81	321.5 ± 21.12
Turbidity (FTU) <sup>a</sup>	35.20 ± 14.04	7.33 ± 3.05	4.67 ± 3.06	2.67 ± 0.55	6.78 ± 7.39	8.58 ± 6.69	9.20 ± 3.63	5.33 ± 1.15	14.67 ± 4.16	7.33 ± 2.31	9.78 ± 7.91	6.25 ± 5.99

R.S. = Rainy season; D.S. = Dry season

a = FTU (Formazin Turbidity Units) is equivalent to NTU (Nephelometric Turbidity Units)

Table 3 shows the seasonal mean values for the physicochemical parameters. All the mean values for pH are within the recommended and desirable international drinking water standards (Table 1). On the other hand, seasonal comparison shows slight difference between the values of the rainy and dry seasons, but which is not statistically significant with Mann-Whitney results of,  $U=15$ ,  $p=0.699$ . The dry season mean values for hardness for all locations are significantly higher than their corresponding rainy season mean values ( $U=0$ ,  $p=0.002$ ). The reason for such a difference could be due to the higher evapo-transpiration and no entry of rainwater into the reservoirs during the dry season months, thus resulting in an increase in the concentration of mineral salts. For conductivity seasonal mean values of the dry season results are significantly higher ( $U=2$ ,  $p=0.009$ ) than the rainy season values. The reason could be similar to that of hardness as conductivity is related to the increased levels of dissolved minerals during the summer or dry season.

Turbidity seasonal mean values are higher for the rainy season than for the dry season, except for consumer taps supplied from Mainefhi source. This is natural as the water is supposed to be more turbid due to the entry of rainfall runoffs during these months. The statistical analysis for

turbidity for the seasonal variation of the values has shown no significant difference with Mann-Whitney test results,  $U=8$ ,  $p=0.121$ .

Table 4 shows the mean annual concentration levels of the heavy metals. Only five out of the nine studied heavy metals, namely, Cr, Cu, Fe, Mn and Zn were above the detection limit of the F-AAS analysis. Out of these, Cu was detected in only three locations, namely, consumer taps supplied from Mainefhi and the reservoir and treatment station of Toker. The other four metals were detected in all the locations.

**Table 4. Mean annual concentration levels ( $\mu\text{g/l}$ ) of detected heavy metals in Asmara drinking water**

Heavy metal	Sampling Locations and values in means with standard deviations ( $\bar{x} \pm \text{SD}$ )					
	Mainefhi dam			Toker dam		
	Reservoir	Treatment station	Consumer tap	Reservoir	Treatment station	Consumer tap
Chromium	29 $\pm$ 32	24 $\pm$ 27	25 $\pm$ 32	17 $\pm$ 29	27 $\pm$ 31	27 $\pm$ 31
Copper	BD	BD	16 $\pm$ 53	11 $\pm$ 18	11 $\pm$ 14	BD
Iron	242 $\pm$ 102	148 $\pm$ 40	268 $\pm$ 183	163 $\pm$ 147	478 $\pm$ 75	400 $\pm$ 236
Manganese	65 $\pm$ 15	56 $\pm$ 55	182 $\pm$ 231	96 $\pm$ 49	632 $\pm$ 278	351 $\pm$ 118
Zinc	16 $\pm$ 16	46 $\pm$ 68	696 $\pm$ 855	16 $\pm$ 21	382 $\pm$ 717	123 $\pm$ 175

BD = Below limit of detection; SD = standard deviation

No mean annual concentration of the heavy metals was above WHO standard. The latest WHO (2011) guideline limit for drinking water has not given values for Fe and Mn, mentioning that they were "Not of health concern at levels found in drinking-water" but "may affect acceptability of drinking-water". All annual concentration values for Cr were above USEPA and below EU guideline limits. Other annual mean values above USEPA guidelines were: Fe for Toker treatment station and consumer taps supplied from it with values of 478  $\mu\text{g/l}$  and 400  $\mu\text{g/l}$ , respectively and Mn for Toker treatment station and consumer taps provided from it, with 632  $\mu\text{g/l}$  and 351  $\mu\text{g/l}$ , respectively. Compared to EU guideline standards, concentration values of Fe for Mainefhi and Toker reservoirs and their respective consumer taps and concentration value of Toker treatment station had higher levels. The annual concentration values of both Cu and Zn were below USEPA and that of Cu was below EU standard guidelines. EU has not given guideline values for Zn. The current levels of Fe, Mn and some of the minerals studied in this work are compared with some reported levels (McFarland and Dozier, 2001; Muangi, 2014; Seelig et al., 2013; Yahaya et al., 2012).

Table 5 shows, the mean seasonal levels of the heavy metals. It could be observed that iron and manganese again have noticeable levels for both seasons. Zinc also has values above detection limits for all locations, except for the rainy season of the reservoirs of both Mainefhi and Toker. Chromium, as well, has values for all locations but for only the dry season. Copper, on the other hand, has high levels for all four locations, the reservoir and consumer taps of Mainefhi as well as the reservoir and treatment station of Toker. The mean seasonal concentration levels of Cr, Fe and Zn were higher during the dry season than in the rainy season for all locations of both water source reservoirs. The *Kruskal-Wallis H test* indicated a significant difference in the mean seasonal concentrations of Cr and Zn with *p-values* of 0.000 and 0.006, respectively, but not for Fe ( $p = 0.105$ ). It could also be noticed that the Mn concentration level, in the rainy season were higher than those obtained for the dry season values. The difference was not significant with

*Kruskal-Wallis H test* ( $p = 0.882$ ). The current results obtained for Cr, and Fe are also compatible with those obtained in previous published reports on surface waters (Muangi, 2014).

**Table 5. Mean seasonal concentration values ( $\mu\text{g/l}$ ) of detected heavy metals in Asmara drinking water**

Heavy metal	Sampling Locations and values in means with standard deviations ( $\bar{x} \pm \text{SD}$ )											
	Mainefhi dam						Toker dam					
	Reservoir		Treatment st.		Consumer tap		Reservoir		Treatment st.		Consumer tap	
	R.S.	D.S.	R.S.	D.S.	R.S.	D.S.	R.S.	D.S.	R.S.	D.S.	R.S.	D.S.
Chromium	BD	58 $\pm$ 9	BD	47 $\pm$ 3	BD	51 $\pm$ 27	BD	35 $\pm$ 34	BD	53 $\pm$ 6	BD	53 $\pm$ 20
Copper	BD	11 $\pm$ 12	BD	BD	BD	34 $\pm$ 73	BD	25 $\pm$ 17	BD	21 $\pm$ 12	11 $\pm$ 4	BD
Iron	150 $\pm$ 8	333 $\pm$ 24	115 $\pm$ 6	181 $\pm$ 16	237 $\pm$ 101	298 $\pm$ 248	66 $\pm$ 96	267 $\pm$ 105	479 $\pm$ 22	476 $\pm$ 128	292 $\pm$ 78	508 $\pm$ 298
Manganese	78 $\pm$ 10	53 $\pm$ 4	87 $\pm$ 72	25 $\pm$ 1	237 $\pm$ 238	128 $\pm$ 232	140 $\pm$ 18	52 $\pm$ 4	868 $\pm$ 0	395 $\pm$ 97	325 $\pm$ 94	377 $\pm$ 142
Zinc	BD	30 $\pm$ 3	4 $\pm$ 5	89 $\pm$ 82	195 $\pm$ 371	1196 $\pm$ 933	BD	32 $\pm$ 19	14 $\pm$ 19	751 $\pm$ 998	92 $\pm$ 152	154 $\pm$ 204

BD = Below detection limit; D.S. = Dry season; R.S. = Rainy season; SD = standard deviation

Laboratory attempts that have been performed have revealed the non-existence of contamination due to VOCs (BTEXs and PAHs pollutants) in Asmara City water reservoirs. This is in agreement to our previously mentioned assumption that Asmara ambient air is void of traffic related air pollutants.

The study results showed that the physicochemical parameters were generally within the permissible levels of the international drinking water guidelines of WHO, USEPA and EU, although turbidity levels were slightly higher than the desired level of both WHO and USEPA standards. For heavy metals also, the results were within the international standard limits with the exception of Cr, Fe and Mn, which were above or equal to the permissible maximum concentration levels of USEPA and/or EU. It should be noticed, however, that Cr concentration level is below the WHO standards and guideline levels for Fe and Mn are not given by WHO as they are not considered health hazards in concentrations they are normally present in water. This water, therefore, can be said to be of safe quality measured against WHO standards. However, there is a need for improvement in the water treatment process, especially in the effective removal of turbidity, and reducing the levels of Cr, Fe and Mn to the acceptable levels. Turbidity, although not a health risk, can seriously interfere with the efficiency of disinfection during water treatment.

In addition, this study contributes towards understanding of the quality status of the Asmara water supply system, especially regarding the concentration of heavy metals, and can be used by concerned parties to improve the water quality status by introducing advanced treatment and distribution practices and a better management structure.

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