Evaluation of heavy metals composition of drinking water distributed to Addis Ababa City, Addis Ababa, Ethiopia.

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Research

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Abstract

Background

Compromised drinking water quality due to accumulation of heavy metals is becoming a serious concern for many countries, including Ethiopia. Chronic exposure to heavy metals is associated with many human diseases. This study aimed at determining the levels of heavy metals in drinking water supplied to Addis Ababa city. There has been no such study done on drinking water supplied to the city

Methodology:

A community based cross-sectional study design was employed from April 2018 to December 2018. Inductively coupled plasma optical emission spectroscopy (ICP-OES) was used to measure the concentration of heavy metals in drinking water samples.

Result

The highest concentration of lead was recorded in water samples taken from Gefersa, Asko and Kolfie areas. Results of this study also showed that there was a statistically significant difference in the mean levels of lead in water samples taken from different treatment plants and their respective catchments (p-value < 0.01).

Conclusion

The mean lead level in water samples were higher than the maximum admissible limit set by the WHO in 2011. The mean level of cadmium concentration was higher than the maximum admissible limit of cadmium set by WHO in 2011 in water samples of the Gefersa surface water & catchment area. However, all values of heavy metals were lower than their respective maximum contaminant level set by USEPA in 2010.

1. Background

Water is essential for survival and our existence is intimately connected with the quality of water available to us [3]. Access to Safe and adequate drinking water should be considered as a human right. In fact, most countries of Africa and Asia have a problem of accessibility of safe drinking water. Groundwater and surface water are the two reservoirs mostly used by humans because of their accessibility. Fresh groundwater is more plentiful than fresh surface water, but we frequently use more surface water since it is easily accessible. Much of the total groundwater volume lies deep in the crust and is too saline for most uses (Fetter, 1988). Despite its immense role in human life, water is also a potential target for the transmission of a wide variety of human diseases. The pathogenesis of a broad range of human diseases such as; cholera, dysentery, typhoid fever, ring worms, skin irritation, and other illnesses is associated with the consumption and use of poor quality water supplies (Carter and Fernando, 1979).

Drinking water can be contaminated by different contaminants which can have a negative impact on the health and economic status of consumers. Contaminants such as bacteria, viruses, heavy metals, nitrates and salt might find their way into water supplies due to inadequate disposal and treatment of waste [4]. Heavy metals naturally found in the soil will infiltrate into surface and ground water. Anthropogenic activities such as mining, industrial and agricultural activity also contribute to heavy metal pollution in the water body due to improper waste water management and run off from fertilizer. However, most of the heavy metals dissolved in surface water and ground water are usually removed during water treatment process [5]. Studies indicate that multi-factorial mechanisms might be involved in metal-induced toxicity and it is evident that one of the prime mechanisms is metal-induced generation of reactive oxygen species [6]. The presence of high levels of heavy metals in drinking water has negative consequences on the health and wellbeing of human beings. Only a very small percentage (2.5%) of earth's total water coverage is clean and suitable for human consumption (Mendie, 2005).

Despite the importance of assuring the quality of drinking water, less attention has been given to water quality monitoring in Ethiopia. Additionally, there are limited studies in the area of water quality monitoring in the country (FMOH, 2007). Addis Ababa is the capital city of Ethiopia and the African continent. The city consists of so many governmental and non-governmental organization offices, several commercial and industrial companies as well as international organizations offices. The first modern water supply provision for Addis Ababa was introduced 15 years after the establishment of the city. During that time, the selected source was groundwater which served the city for almost 58 years. Then the first surface water development with treatment plant at Gefersa has been established in 1930 with the objective of meeting the increased demand of the population (PLAN, 2011). At present Addis Ababa City is supplied with surface water from the Legadadi, Dire and Gefersa reservoirs, and groundwater is pumped from Akaki well field located to the south of Addis Ababa and other wells and springs located within the city. The current total daily water production for the city is estimated to be 599,000m3. (AAWSA, 2018)

In a previous study conducted in Addis Ababa town, the total heavy metal levels in water samples taken from boreholes was higher when compared to that of water samples taken from springs from the same formation. This may be due to more residence time of the groundwater samples taken from boreholes. The movement of a particular metal into solution during weathering depends on the intensity of chemical weathering and the chemical strength of the particular water to dissolve theheavy metal. This is because of prolonged residence time and high degree of water-rock interaction [1]. Heavy metals are the primary toxic pollutants which affects the quality and safety of drinking water [7]. This study will provide baseline information for other researchers who are interested to conduct in-depth research on the safety and chemical content of drinking water distributed to the city.

2. Material And Methods

2.1 A community based cross sectional study was conducted from April 2018 to December 2018. A total of 12 drinking water samples (four from each of Gefersa, Akaki and Legedadi and their catchment areas) were collected from different parts of Addis Ababa town using a sterile glass container. For preservation purpose the samples were acidified with the addition of nitric acid and hydrochloric acid. After acidification, water samples were kept in a refrigerator at $4^{0}c$. Inductively coupled plasma- optical emission spectroscopy (ICP-OES) was used to measure the concentration of heavy metals in drinking water samples collected from different parts of Addis Ababa town.

2.2 ICP-OES principle: The concentrations of Pb, Cd, Cr and Mn were analyzed by using ICP-OES (Agilent 700 series, USA) in different water samples obtained from Addis Ababa area. The main gas supply argon was used as the plasma nebulizer and optics interface purge and also required to purge the poly-chromatic assembly with its purity (99.996%) and regulated with recommended flow rate of 0.7 to 0.32 L/min. The metals were prepared by using ISO 11885:2012 test method by using micro-wave digestion. Adding 8 ml concentrated nitric acid and 2 ml concentrated hydrogen peroxide in digestion tube including blank and the sample was digested in milestone start D microwave digester (Switzerland) with maximum temperature of 250 ^{0}C and pressure of 1200 psi for 15 minutes. Then the sample was diluted into 50 ml Erlenmeyer flask and made up to the mark with 2% nitric acid solution. Then it was filtered through 0.45 micro meter pore diameter membrane filter to avoid any possible contamination. The samples were analyzed using the ISO 11885:2014 test method. Standard solutions were prepared from 99.99% ICP grade standard. Five standard solutions were prepared (1ppm, 2ppm, 3ppm, 5ppm and 10ppm) by plotting calibration curve with recommended wavelength for each metal. The wavelength used was 214.439 for cadmium, 205.560 for chromium, 220.305 for lead and 257.610 for manganese. Due to its sensitivity and overall acceptability, the spectral interference was corrected and the prepared samples were run into the machine. After analysis in the machine the concentration of each metal was calculated by using the formula;

$$\text{Conc.(ppm or mg/L)} = \frac{(\text{conc.Of sample} - \text{conc.Of blank}) \text{ x extracted volume x dilution factor}}{\text{Amount of sample in ml}}$$

2.3 Data processing and analysis: All data were checked, cleared and fed into EPI Data and then exported to SPSS version 20. Descriptive analysis, independent sample t-test, and one-way ANOVA were used for statistical analyses. Continuous variables were expressed as mean ± SD, and $p \leq 0\ 05$ was considered as statistically significant.

2.4 Ethical Approval: Ethical clearance was obtained from Research and Ethics Committee of the Departmentof Biochemistry, Addis Ababa University, School of Medicine, letter reference No. DRERC 08/18 and protocol No.: M.Sc. 02/18.

3. Result And Discussion

Four water distribution centers and their catchment areas were included in our study as shown in Table 1. The distribution and their catchment areas are the main sources of drinking water to Addis Ababa city and they also represent river dam and ground water sources of drinking water that supply the city.

Table 1. Distribution of water samples based on catchment of actual main treatment plant.

Main treatment plant	Number of samples	%
Akaki deep-well system	4	33.33
Legedadi SWTP	4	33.33
Gefersa SWTP	4	33.33
Total	12	100

**SWTP= surface water treatment plant*

As shown in the table, equal numbers of samples were taken from the distribution centers that supply water to the city. The Gefersa and Legedadi river dams are sources of surface water but the Akaki deep-wells are alternate ground water sources that were dug to overcome water shortage of the city.

The mean lead concentration of the total water samples was 0.028 mg/l, which was higher than the maximum admissible limit (MAL) of lead by the WHO at 0.01mg/l [11], but lower than the USEPA MCL of 0.1mg/l [10]. Even though it is not statistically significant ($p>0.39$), the mean level of lead in surface water was higher than that of ground water. There was a statistically significant difference ($p<0.01$) in the mean level of lead among water samples taken from different treatment plants and their respective catchment areas (Table 2).

Though not statistically significant ($p>0.5$), the mean lead level of tap water samples (0.03 mg/l) is higher than that of water samples of major treatment plants (0.02 mg/l).

Table 2. Comparison of heavy metal levels in ground and surface water samples.

Parameter	Ground water samples	Surface water samples	p-value
Pb (mg/l)	0.02±0.01	0.03±0.02	0.39
Cd (mg/l)	BDL*	0.002±0.004	0.31
Cr (mg/l)	0.005 ±0.006	0.002±0.005	0.43
Mn (mg/l)	0.005 ±0.01	0.007 ±0.008	0.67

All values are expressed as mean ± Standard deviation. BDL(Below detectable limit).*

The mean level of cadmium in surface water samples of Addis Ababa town was 0.002 mg/l which is lower than the maximum admissible limit of Cadmium set by WHO at 0.003 mg/l [11] and the USEPA maximum contaminant level of Cadmium at 0.005 mg/l [10]. The mean level of Cadmium in water samples of the Gefersa surface water treatment plant and its catchment was higher than the maximum admissible limit of Cadmium by WHO at 0.003 mg/l [11] but aligns with the USEPA maximum contaminant level of cadmium in drinking water at 0.005 mg/l [10].The possible justification for high levels of cadmium may be due to the disposal of waste and industrial effluents containing Cadmium and Cadmium related compounds [12] and due to industrial activities such as electroplating, dye production, as well as plastic, stabilizer and battery industries [13].

Long-term exposure to cadmium is associated with renal dysfunction, obstructive lung disease and lung cancer. Cadmium may also be implicated in bone abnormalities such as osteomalacia and osteoporosis. Soon after ingestion Cadmium is first transported to the liver where it binds with many proteins to form complexes. These complexes then are transported to the kidneys, ultimately affecting the filtering mechanism (ATSDR,1999).

Table 3. Comparison of concentration of heavy metals in water samples taken from different treatment plants.

Parameter	Akaki deep-well& catchment area	Legedadi SWTP& catchment area	Gefersa SWTP& catchment area	ANOVA P-value
Pb (in mg/l)	0.02±0.02	0.01±0.01	0.05±0.01	0.01
Cd (in mg/l)	BDL	BDL	0.005±0.005	0.1
Cr (in mg/l)	0.005±0.005	BDL	0.005±0.003	0.27
Mn (in mg/l)	0.005±0.01	0.002±0.005	0.01±0.01	0.27

Values are expressed as mean ±Standard deviation. SWTP= Surface water treatment plant. BDL (Below detectable limit)

The mean level of Chromium in water samples of Addis Ababa town was 0.003 mg/l, which is below the maximum admissible limit of Chromium by WHO at 0.05mg/l [11] and the USEPA maximum contaminant level of Chromium at 0.1mg/l [10].The possible explanation for lower levels of Chromium might be due to limited availability of ophiolite rocks capable of generating Chromium and derivative compounds [14]. Low-level exposure to Cr can irritate the skin and cause ulceration. Long-term exposure can cause kidney and liver damage, and also circulatory and nerve defects (ATSDR, 1999).

The mean level of Manganese in water samples of Addis Ababa town was 0.007mg/l, which is below the maximum admissible limit of Manganese by WHO at 0.4 mg/l [11] and the USEPA maximum contaminant level of Manganese at 0.05 mg/l [10].The possible justification for lower levels of manganese may be due to dilution of dissolved manganese in surface and ground water sources [15], Oxidation of Manganese by Chlorine during the process of water treatment in treatment plants and other distribution systems [16] and the influence of water waves in surface waters and rainfall resulting in extensive dissolution of manganese ions [15]. Prolonged exposure of high levels of manganese negatively affects the central nervous system, visual reaction time, hand steadiness and eye-hand coordination (ATSDR, 1999)

Table 4. Comparison of concentration of lead between water samples of major treatment plant and tap water samples.

Parameter	Samples of treatment plants	Tap water samples	p- value
Pb (mg/l)	0.02±0.03	0.03±0.02	0.4
Cd (mg/l)	BDL	0.002±0.004	0.4
Cr (mg/l)	0.003±0.006	0.003±0.005	0.9
Mn (mg/l)	0.006±0.01	0.007±0.01	0.9

Values are expressed as mean ±Standard deviation.

Water is one of the natural resources that support the existence of human beings and other living organisms on earth(Musa *et al*, 2013).Water pollution is the leading worldwide cause of deaths and disease and it accounts for the deaths of more than 14,000 people daily (Larry,2006). Accumulation of heavy metals in living organism can be toxic and carcinogenic due to their non-biodegradable nature. So, water quality management and assessment with regard to levels of heavy metal is of prime importance. The overall water quality status and identification of source of origin of heavy metals are required for water quality management (Bodaghpour *etal.*, 2012). Heavy metals exhibit toxic effect by entering into food chains and the ecosystem where they pose adverse impact on both the living and nonliving components of the ecosystem.

The possible justification for high levels of lead may be due to the practice of mining and other anthropogenic activities in the area [8], composed manure deposited on the farms around the study area [2], junk auto spare parts which may contain lead residues [7] and mobilization of lead from sediments and leaching of lead from waste rocks and dumps in the area [9]. Lead is the most significant of all the heavy metals because it is toxic and very common and harmful even in small amounts. Lead is a potent toxic metal that is dangerous to the environment and can be a serious threat to human health. Acute lead poisoning is associated with seizure, coma and death, while long-term and low-level exposure leads to chronic poisoning which is commonly associated with diseases such as anemia, neurotoxicity, hemotoxicity, nephrotoxicity and toxic metabolic encephalopathy. Furthermore, lead toxicity causes brain damage and mental retardation especially in children (DEAT & DME 2003).

4. Conclusion

The mean levels of Lead in total water samples were higher than the Maximum admissible limit of lead by World Health Organization in 2011. Our results showed that surface water contained more heavy metals than ground water. Moreover, the Gefersa dam water contained more level of heavy metals compared to the rest analyzed water supplies. There was a statistically significant difference between the mean levels of lead in water samples of major treatment plants and their respective catchment areas. The mean level of Cadmium in GSWTP& catchment was higher than the maximum admissible limit of Cadmium by the WHO in 2011. The mean levels of each metal measured in this study were below the USEPA maximum contaminant limit of each respective metal.

5. Recommendation

It is recommended that developing reliable and sustainable drinking water treatment techniques and strategies are of prime importance to reduce the current levels of heavy metals. Designing and implementing safe and healthy waste handling and disposalstrategies in order to prevent potential contamination of drinking water sources. It is also recommended that routine environmental investigation including supervision of main distribution sources, checkup and maintenance of pipe-line breakages and evaluating the waste disposal techniques of major factories and industries is invaluable to alleviate heavy metal contamination of drinking water.

Declarations

Ethical approval was obtained before commencing of research from the concerned authorities and consent was first obtained from participants before sample collection.

Consent for publication: Not applicable

Data and material are available in the repository of the Library of Addis Ababa University.

Competing interests: The authors do not have any competing interest what so ever.

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Authors' contributions: All authors contributed equally in this work.

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Figures

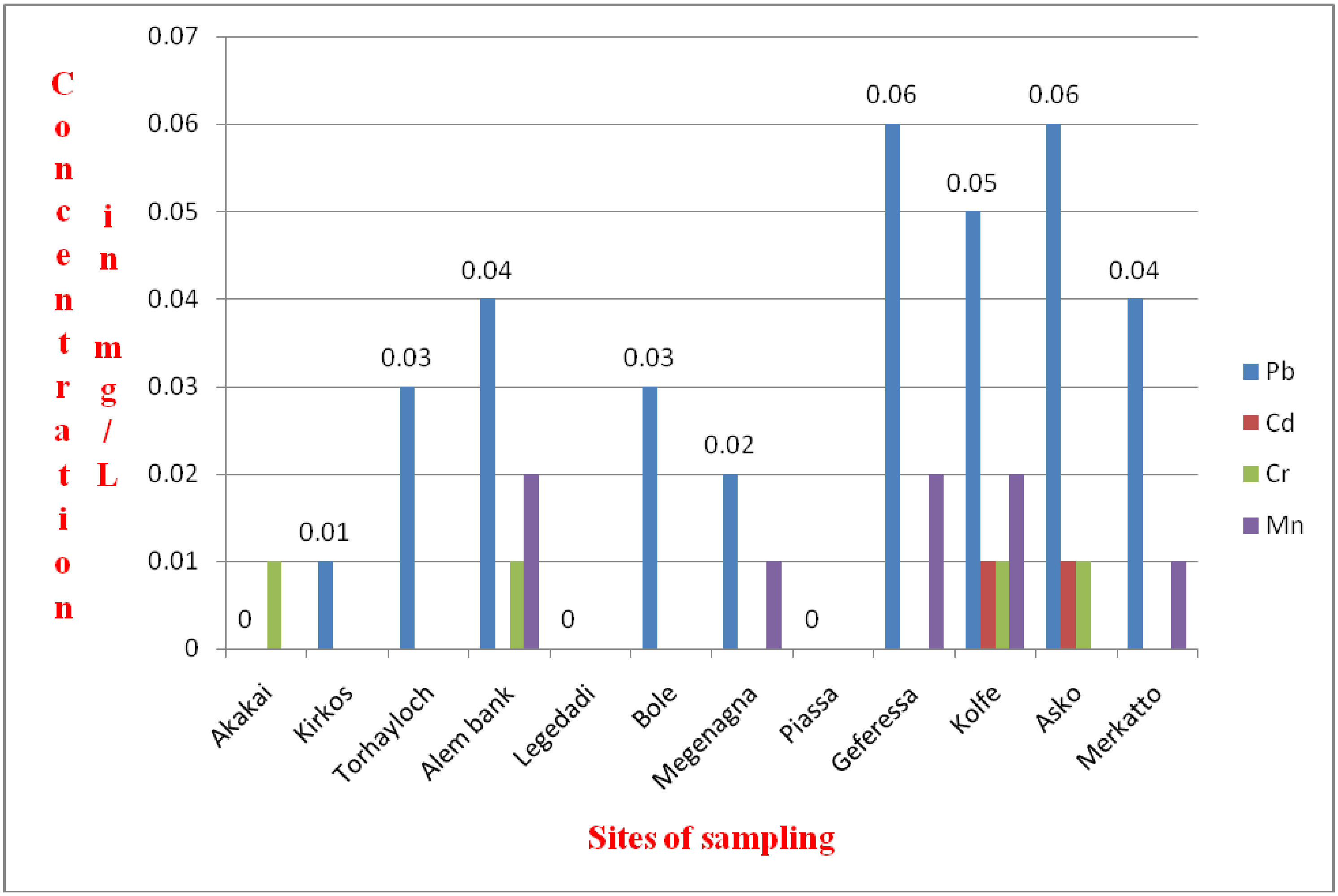

Figure 1

Bar chart showing concentration of heavy metals in different sampling sites in Addis Ababa, Ethiopia, 2018.