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Physico-chemicals and Heavy Metals Analysis of Drinking Water of Aksum University, Tigrai region, Ethiopia

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ABSTRACT

The quality of drinking water is a vital factor for human health and key to increase productivity of people. Unfortunately, most of the people in developing countries do not have access to safe drinking water. In Ethiopia, majority of population has suffered from a lack of access to safe drinking water, despite the country is blessed with abundant water resources. The community in Aksum University (AKU) has expressed concern about the quality (especially taste) of the drinking water. This has compelled the people to purchase bottled or packaged water, and thereby increasing the economic hardship on the community. Most people in AKU could not afford the cost, due to the high cost of the water, and have therefore used drinking water of the University. However, no report has been available regard to the quality parameters drinking water of AKU. Therefore, this study was designated to analyze some selected physico-chemical parameters and heavy metals to predict the quality status of drinking water of AKU. The results obtained were compared with the maximum permissible limits given by the Ethiopia Standard Agency (ESA) and World Health Organization (WHO). The result revealed that pH value was within recommended value. The levels of Ca, Cl^- F^-, SO_4^{2-}, NH_3-N, NO_2^--N, total dissolved solids, Ca hardness, Mg hardness, Co, Cr, Cu, Fe, Mn, Ni, Pb, and Zn were lower than the limits. On the other hand, the levels of total alkalinity, Mg, K, and Cd in drinking water of AKU were higher than the maximum permissible limits. Besides, according to WHO, drinking water of AKU was very hard. Therefore, an adequate treatment is required to decrease these parameters in the drinking water.

Keyword: *Aksum University, Drinking water, Quality of drinking water, Physico-chemical parameters, Heavy metals*

INTRODUCTION

The quality of drinking water is a vital factor for human health and key to increase productivity of people [1]. Supply of safe and adequate drinking water to everyone is important to the development of a given country [2]. So, every effort should be made to supply safe drinking water. Safe drinking water is required for all usual domestic purposes, including drinking, food preparation, and personal hygiene [3]. Unfortunately, most of the people in developing countries do not have access to safe drinking water [2]. As a result, almost 80 % of all illness is water-related in developing countries. Besides, worldwide, over 5 million people die each year from illnesses linked to unsafe drinking water [4]. In Ethiopia, majority of population has suffered from a lack of access to safe drinking water [5], despite the country is blessed with abundant water resources.

The quality of water is influenced by both natural and human activities. The important natural sources include the rocks and soil (sediment) through which water percolates or over which it flows. Human activities are including industrial sources, agricultural activities, and chemicals used in water treatment or from materials in contact with drinking water. Storage and distribution practices may also affect drinking water quality [3].

Some substances of health concern have effects on the taste of drinking water. According to WHO [3], some of the main physico-chemical parameters that are of a health concern include Al, Ca, Mg, K, F^-, PO_4^{3-}, SO_4^{2-}, NH_3-N, NO_2^-, pH, Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Electrical Conductivity (EC), total alkalinity, total hardness, Ca hardness ($CaCO_3$), and Mg hardness ($MgCO_3$), Dissolved Oxygen (DO), and heavy metals. The heavy metals in drinking water linked to human poisoning are including Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, and Zn. The heavy metals like Cd and Pb are toxic even in very small amounts. Heavy metals like Co, Cr, Cu, Fe, Mn, Ni, and Zn are required by human body in small amounts, but can also be toxic at large levels. Although individual heavy metal exhibits specific toxic effects on human beings, damage to kidney, liver, lung, blood cells, mental and central nervous systems, and other vital organs are general toxicity associated with Cd, Co, Cr, Cu, Fe, Ni, Mn, Pb, and Zn. Besides, a long-term exposure to some of them may cause cancer [6]. These toxicities can result from any of the heavy metal if it is present in excess amount in drinking water. So, it is imperative that the drinking water should be evaluated at regular time interval to ensure its good quality.

The community in Aksum University (AKU) has expressed concern about the quality (especially taste) of drinking water of the University. This has compelled the people to purchase bottled or packaged water and thereby increasing the economic hardship on the community. Most people in AKU could not afford the cost, due to the high cost of the water, and have therefore used drinking water of the University. However, no report has been available regard to the quality of drinking water of the University. Therefore, this study was designated to analyze some selected physico-chemical parameters and heavy metals to predict quality status of drinking water of AKU.

2. MATERIALS AND METHODS

2.1 Description of the Study area

The study was carried out at AKU main campus. AKU was established in 2007, and it is a public higher education institution and located at the western edge of Aksum town, Tigrai region, Ethiopia. It is situated at about 1035 km north of Addis Ababa, the capital city of Ethiopia. The university has made remarkable progress in diversifying programs and expanding campuses despite it is a young. AKU has offered both undergraduate and master's programs. It has also branch campuses in Shire and Humera tows, Tigrai region, Ethiopia. Over 15,000 students have been enrolled in regular (September-June), weekend, and summer (July and August) learning programs in main campus. AKU main campus is found between 14º 7′47″ North, Latitude and 38º42′57″ East, Longitude with the topographic elevation of 2,132 m.

2.2 Reagents and Standards

Nitric acid, HNO_3 (68 %, Brenntag NV, Deerlijk, Belgium) was used to treat glasswares, dilute standard solutions, and digest the sample. The standard stock solutions (Australian Chemical Reagents Pty Ltd, Australia) containing 1000 ppm of Mn, Ni, Co, Cr, Pb, Cd, Cu, Fe, and Zn were used as reference analytes for quantitative determination, calibration, and quality assurance. The standards and reagents used were of analytical grade.

2.3 Pretreatment of Materials

All materials used were cleaned with tap water using a laboratory detergent followed by soaking in 10 % v/v HNO_3 solution for 24 hr and rinsed thoroughly with deionized water, prior to use. The glasswares were then dried in an oven at 100 ºC for 6 hr.

2.4 Collection of the Sample

Standard methods [7] were followed for samples collection and preservation. The samples were collected three times a day (at 3-hr interval) for six consecutive days in 1 L polyethylene bottles, during the month of July, 2014. The bottles were thoroughly rinsed with appropriate amount of water sample at the site before sampling. The samples collected for the heavy metals analysis were immediately preserved to a pH value 1.5 with concentrated HNO_3 [7], and the bottles were sealed with paraffin wax. Subsequent to acidification, the samples were refrigerated at 4°C up to the time of analysis to minimize chemical alteration. The grab samples were then mixed to get composite sample.

2.5 Analysis of Physico-chemical Parameters

The physico-chemical parameters: Al, Ca, Mg, K, F^-, Cl^-, PO_4^{3-}, SO_4^{2-}, NH_3-N, NO_2^-, TDS, EC, total alkalinity, total hardness, Ca hardness ($CaCO_3$), and Mg hardness ($MgCO_3$) were analyzed using the standard procedure as described in the Palintest Photometer 7100 Operation Manual [8]. The analysis was carried out within 24 hr after sample collection [9], except chlorine determination which was done immediately after sampling. The water testing tablets (Wagtech International Ltd, UK) reagents were used for preparation of all solutions. The solutions were prepared by adding each test tablet to 20 mL of the water sample in a test tube. The tablets were then crushed to dissolve using stirring rods. The solutions were allowed to stand for about 10 min for full colors development; then, 10 mL of each clear solution was carefully decanted into a clean photometer cuvette. Concentrations of the physico-chemical parameters were then measured using Potalab photometer 7100 (Wagtech International Ltd, UK). Whereas DO was measured using photometer (Hach HQ40d multi parameter, Germany), and the pH was measured using pH meter (Hach HQ40d, Germany) where the respective electrodes were immersed into the sample till a steady reading was recorded. The chloride content was determined using argentometric method. The TSS was measured using gravimetric method [7]. For this, a filter paper was weighed and later wet with distilled water. The accurately measured portion of sample was poured through the filter paper and filtered out. The filter paper was then removed from filtration apparatus and transferred to an aluminum weighing dish as a support. Next, the dish was transferred into an oven for drying, to a constant weight, at 105 °C for about 1 h. The filter paper was allowed to cool at room temperature before being weighed. The following formula was used to calculate TSS.

$$\text{TSS (mg/L)} = \frac{(A - B) \times 1000}{\text{mL sample}}$$

Where A = the weight of the filter paper + residue after drying (mg), and B = the weight of the filter paper (mg). All parameters were performed three times to report the average value.

2.6 Digestion of the Sample for Heavy Metals Analysis

The digestion method was employed for the total metals concentrations as described by [7]. The three parameters (temperature, time, and volume of HNO_3) were optimized for the present study. The triplicate samples (each 50 mL) were gently heated with concentrated HNO_3 by adding a few boiling chips until light-coloured clear solutions were obtained. After cooling at room temperature, the solutions were filtrated through a filter paper (Whatman No. 42), and the filtrates were carefully transferred into 100 mL volumetric flasks and diluted to the mark using deionized water for analysis. The blank reagent was also digested in parallel with the sample, keeping all the digestion parameters the same.

2.7 Method Validation

The method validation was done in accordance with the standard procedure as described in the standard methods for the examination of water and wastewaters [7]. The Method Detection Limit (MDL) for each metal was estimated by digesting six blank reagents with the sample. The reproducibility of the method was checked by performing a triplicate digestion. The Percentage of Relative Standard Deviation (% RSD) for each heavy metal was then calculated. The calibration curves were constructed separately for the heavy metals to check calibration linearity, and the correlation coefficient (r^2) values were determined. Accuracy of the method was checked by evaluating the analytes recovery.

Table 1: Method validation results

	Heavy metals								
	Cd	**Co**	**Cr**	**Cu**	**Fe**	**Mn**	**Ni**	**Pb**	**Zn**
MDL	0.002	0.01	0.004	0.007	0.02	0.02	0.01	0.03	0.05
%RSD	16.67	13.33	12.50	7.69	10.70	3.51	18.18	14.28	1.63
%R	84	82	84	82	81	89	81	87	96
r^2	0.9952	0.9998	0.9986	0.9992	0.9978	0.9998	0.9991	0.9989	0.9954

As shown in Table 1, MDL for each metal was low enough to detect the presence of the heavy metals at a low level in the sample. The % RSD values were ranged 1.63 % to 18.18 %, which indicates that the analytical method was precise and reliable. The values of % R varied from 81 to 96 %, which is in the acceptable range. All correlation coefficient (r^2) values were greater than 0.995, which confirmed that there was very good correlation between concentrations and absorbance.

2.8 Analysis of the Selected Heavy Metals

Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, and Zn were selected to evaluate quality of drinking water of AKU due to their toxic effects on human beings if they are present above the recommended values. The Varian AA240FS Fast Sequential Atomic Absorption Spectrometer was used to determine concentrations of the heavy metals. The instrument was operated using optimized parameters (Table 2). The average values for three triplicate determinations were reported. Similarly, concentrations the heavy metals were determined in the spiked solutions.

Table 2: The Atomic Absorption Spectrometer operating conditions

	Heavy metals								
	Cd	**Co**	**Cr**	**Cu**	**Fe**	**Mn**	**Ni**	**Pb**	**Zn**
Wavelength (nm)	228.8	240.7	357.9	324.8	283.3	279.5	232.0	217.0	213.9
Slit (nm)	0.2	0.2	0.2	0.5	0.2	0.2	0.2	1.0	1.0
Lamp current (mA)	5.0	7.0	7.0	4.0	5.0	5.0	4.0	5.0	5.0

3. RESULTS AND DISCUSSION

3.1 Physico-chemical Parameters

The results (mean±SD) of physicochemical analysis of drinking water of AKU are presented in Table 3. pH is a term used to express the extent of acidity or alkalinity of water at a given temperature. The recommended pH value of drinking water is 6.5 to 8.5 [10]. The result obtained (pH=6.53 ± 0.01) was within acceptable range. Similar result was given by [12]. EC of water is usually used as a measure of total concentration of dissolved ions in water [13]. In the present study, the value of EC was 985±1.00 µS/cm at room temperature. TDS in drinking water of AKU (659.95±0.67 mg/L) was below the limit (1000 mg/L) given by [10]. Both EC and TDS levels in drinking water of AKU were higher than the reports of [12, 14, 15]. TSS content of water is directly related to its turbidity and depends on the amounts of suspended particle, soil, and silt [16]. It was not detected in drinking water of AKU. Total alkalinity is primarily caused by the CO_3^{2-} and HCO_3^- which may be resulted due to the weathering of rocks, waste discharge and microbial decomposition of organic matter in the water body [16]. Total alkalinity in drinking water of AKU (530.33±0.58 mg/L) was much greater than the recommended value of 200 mg/L as adopted by [10]. This value was also higher than reports given by [15, 17].

Table 3: Physicochemical characteristics of drinking water of AKU and comparison with guidelines

Parameter	Unit	Present study	[10]	[11]
pH		6.53 ± 0.01	6.5-8.5	
DO	mg/L	3.87±0.08	-	
TSS	mg/L	0.00±0.00	-	
TDS	mg/L	659.95±0.67	1000	
TA	mg/L	530.33±0.58	200	
EC	µS/cm	985±1.00	-	
NO_2^--N	mg/L	0.033±0.006	3	
NH_3-N	mg/L	0.58±0.01	1.5	
TH	mg/L	210.605±0.559	300	180
Ca hardness	mg/L	118.67±1.53	-	
Mg hardness	mg/L	91.67±1.53	-	
SO_4^{2-}	mg/L	35.33±0.58	250	
PO_4^{3-}	mg/L	7.27±0.86	-	
F^-	mg/L	0.553±0.006	1.5	
Cl^-	mg/L	53.96±0.15	250	
Al	mg/L	0.043±0.006	0.2	
Ca	mg/L	47.33±1.15	75	
Mg	mg/L	56.67±2.89	50	
K	mg/L	6.53±0.06	1.5	

[10] = maximum permissible limits given by Ethiopia Standard Agency; [11] = maximum permissible limit set by World Health Organization; EC=Electrical Conductivity; TH=Total Hardness, TA= Total Alkalinity; "-" = data unavailable

Hardness of water is caused by the presence of dissolved polyvalent metallic ions, predominantly Ca^{2+} and Mg^{2+} [11, 16]. Total hardness (210.605±0.559 ppm) of drinking water of AKU was lower than the maximum permissible limit (300 ppm) given by [10]. However, according to WHO [11], the present study area drinking water was very hard. The result was higher than the report of [17]. Dissolved polyvalent metallic ions from sedimentary rocks, seepage, and runoff from soils are the main natural sources of water hardness [11]. Hardness in water may affect its taste [18]. The concentration of Ca (47.33±1.15 mg/L) in drinking water of AKU was below the maximum allowable level (75 mg/L) given by [10]. Mg value (56.67±2.89 mg/L) obtained in the present study was slightly higher than the permissible limit (50 mg/L) as prescribed by [10]. Great amount of Mg imparts a repulsive taste to the potable water [19]. The main natural sources of Mg in water are sedimentary rocks, seepage and runoff from soils [11]. Even though Mg is an essential mineral and important to human health in several respects, its high amount intake can cause laxative effect [20], vomiting, diarrhea, muscle weakness, and breathlessness [13].

The concentration of K in drinking water of AKU (6.53±0.06 mg/L) was greater than the permissible limit of ESA (2013). Even though K is necessary for human body functions like heart protection [2], increased intake may cause diuretic and high blood pressure [21]. The concentration of Al (0.043±0.006) in drinking water of AKU was below the maximum permissible level (0.2 mg/L) given by [10].

The concentration of PO_4^{3-} in drinking water of AKU was 7.27±0.86 mg/L. The high PO_4^{3-} may occur in groundwater as a result of the agricultural runoff from the farmlands containing phosphate fertilizers [22]. The concentrations of F^- and Cl^- were 0.553±0.006 mg/L and 53.96±0.15 mg/L respectively. These values were below the maximum permissible limits (1.5 mg/L and 250 mg/L respectively) as prescribed by [10]. The SO_4^{2-} level in drinking water of AKU (35.33±0.58 mg/L) was below maximum permissible limit (250 mg/L) given by [10]. Both PO_4^{3-} and SO_4^{2-} amounts detected in the present study were higher than the values given by [14]. The concentration of NO_2^--N (0.033±0.006) in drinking water of AKU was found lower than tolerable limit (3 mg/L) of [10]. This result was comparable with that of reported by [14]. NH_3-N amount in the study area (0.58±0.01 mg/L) was below the maximum allowable level (1.5 mg/L) given by [10].

3.2 Concentrations of the Selected Heavy Metals

All analyzed heavy metals were detected and concentration of each metal (mean±SD) is given in Table 4.

Table 4: Concentrations of the heavy metals in drinking water of AKU and comparison with guidelines

	Concentration of heavy metal (ppm)								
	Cd	**Co**	**Cr**	**Cu**	**Fe**	**Mn**	**Ni**	**Pb**	**Zn**
Present study	0.006 ±0.001	0.015 ±0.002	0.008 ±0.001	0.013 ±0.001	0.243 ±0.026	0.228 ±0.008	0.022 ±0.004	0.007 ±0.001	0.492 ±0.008
[10]	0.003	-	0.05	2	0.3	0.5	-	0.01	5
[23]	0.003	-	0.05	2	-	0.5	0.02	0.01	3
[24]	0.005	-	0.05	2.0	0.2	0.05	0.02	0.01	-

[23] = maximum permissible limit set by World Health Organization; [24] = maximum permissible limit set by European Union; "-" = data unavailable

As shown in Table 4, the concentration of Cd in drinking water of AKU (0.006±0.001 mg/L) was found slightly above the prescribed maximum permissible limits [10, 23, 24]. Cadmium-containing solders in fittings, water heaters, water coolers, and taps are some of the major sources Cd contamination of drinking water [25]. Cd is contributed to the surface waters through paints, pigments, glass enamel, deterioration of the galvanized pipes etc. [26]. The level of Cd was in good agreement with other researchers' study [27, 28]; however, it was higher than that reported by [29]. The amount of Pb in drinking water of AKU was 0.007±0.001 mg/L. The maximum allowable value of Pb for drinking water is 0.01 mg/L [10, 23]. The result obtained was higher than that reported by [27, 28, 29]. Even low amounts of Cd and Pb are highly toxic to all organisms [30]. Cd can cause human diseases such as kidney and lung damage, pneumonitis, bone defects, osteomalacia, osteoporosis, fractures, and stomach irritation [31]. Chronic exposure to Pb may result birth defect, mental retardation, weight loss, male reproductive system damage, muscular weakness, paralysis, autism, psychosis, central nervous system damage, and blood pressure [32].

The concentration of Fe in drinking water of AKU (0.243±0.026) was found slightly above the maximum permissible limit set by [24] but below the standard given by [10]. Fe is an essential element, but its chronic exposure to Fe may lead to arthritis, heart failure, cirrhosis, diabetes, and tumors [32]. It also causes kidney and cardiovascular systems damage [33]. This study also revealed that the Mn concentration was above permitted limit set by [24] but below the standards set by [10, 23]. The levels of Fe and Mn were higher than the results reported by [27, 28, 29]. Mn is an essential nutrient that is required for various biochemical and physiological functions in all organisms; however, at elevated concentration, it becomes toxic [33] and can cause respiratory and reproductive tract damage, mental retardation, muscle damage, intelligence reduction in school-age children, and Parkinson's disease [34].

The concentration of Zn in drinking water of AKU was above maximum recommended level [10] but below the standard of [23]. This result was good agreement with results given by [27, 29]; however, it was lower than the result reported by [28]. Zn is one of the important trace elements for human health but excessive intake can cause adverse health effects [35] including irritability, muscular stiffness and pain, loss of appetite, and nausea [36].

The amount of Ni detected in this study was very slightly above the standards given by [23, 24]. The comparable to the results were given by [27, 29]. Ni toxicity may cause decrease body weight, damage the liver and heart, and reduction in cell growth, cancer and nervous system damage [33]. The amount of Co in drinking water of AKU was 0.015±0.002 mg/L. No guideline value has been given by WHO or any other organization for Co content in drinking water. The level of Co detected was comparable to the results reported by the other authors [27, 28, 29]. Chronic exposure to Co may cause lung disease, asthma, hypoxia, pneumonia, goiter, respiratory system disturbance, reduction in function of pulmonary tissues, and generation of oxidants and free radicals [37]. The concentrations of Cu and Cr detected in present study were found below the maximum permissible levels given by [10, 23, 24]. The amount of Cr was lower than the result given by the researchers [27, 29]. However, the content of Cu was higher than the result reported by other [28].

4. CONCLUSION

Some selected physico-chemical parameters and heavy metals were analyzed in drinking water of AKU, and the values obtained are compared with the maximum permissible limits given by the Ethiopia Standard Agency (ESA) and World Health Organization (WHO). The result showed that pH value was within recommended value and the levels of Ca, Cl^- F^-, SO_4^{2-}, NH_3-N, NO_2^--N, Total Dissolved Solids, Ca hardness, Mg hardness, Co, Cr, Cu, Fe, Mn, Ni, Pb, and Zn were lower than the limits. On the other hand, the levels of total alkalinity, Mg, K, and Cd in drinking water of AKU were higher than the maximum permissible limits. Besides, according to WHO, drinking water of AKU was very hard. Therefore, an adequate treatment is required to decrease these parameters in the drinking water.

Therefore, an adequate treatment is required to decrease these parameters in the drinking water.

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