International Journal of Environmental Monitoring and Protection
2014; 1(3): 56-61
Published online August 20, 2014 (http://www.openscienceonline.com/journal/ijemp)

Investigations of Dodoma municipal hard water: (Part 1): Review of hard water treatment processes and identification of contaminants

Morris F. Hiji*, Justin W. Ntalikwa

College of Earth Sciences, University of Dodoma, Dodoma, Tanzania

Email address

morris.frankh@gmail.com (M. F. Hiji), jntalikwa@yahoo.com (J. W. Ntalikwa)

To cite this article

Morris F. Hiji, Justin W. Ntalikwa. Investigations of Dodoma Municipal Hard Water: (Part 1): Review of Hard Water Treatment Processes and Identification of Contaminants. *International Journal of Environmental Monitoring and Protection.* Vol. 1, No. 3, 2014, pp. 56-61.

Abstract

In this work, a preliminary investigation of the quality of Dodoma municipal water as well as a review of potential methods for removing hardness from this water were undertaken. The water quality parameters such as pH, titratible residue, total hardness, carbonate hardness, calcium, magnesium, fluoride, nitrate, sulphate and iron ions were measured using standard procedures. The results were compared with allowable levels for drinking water. It was observed that the calcium ions spanned the range 105 -217 mg/L which is greater than the allowable range of 50-100 mg/L. The magnesium ions spanned the range of 31-217 mg/L which is lower than the permissible level of 500-1000 mg/L. The other parameters studied were observed to be within the permissible levels. It was concluded that the hardness of this water was due to calcium ions/salts which are introduced by underground rocks containing limestone and dolomite. The review of methods that can be used to remove this hardness suggested that grape and Moringa seeds and powder can be used as they are potential adsorbents and that they are easily available in Dodoma. These materials will therefore be amenable for investigation of removal of unwanted salts in part II of this work.

Keywords

Dodoma Municipality, Hard Water, Water Contaminants, Water Treatment Processes

1. Introduction

Water is a useful resource that is used in many applications such as domestic, industrial, agricultural and it also plays important role in body metabolism and proper functioning of cells. Although, water is abundant in nature occupying about 71% of the earth surface, only 1% is accessible for human consumption [1, 2]. Access to adequate supply of safe drinking water for all is one of the primary goals of the World Health Organization [3]. According to the United Nations (UN) more than 1 billion people cannot get clean and safe drinking water and that the dirty water contributes about 80 percent of diseases in the developing world, and kills 10 million people annually[4], [5].

A major cause of diarrheal-disease in developing countries is the consumption of unsafe water, along with poor hygiene and sanitation. Diarrheal disease is the second leading cause of death for children under the age of five globally: it contributes to 1.7 million deaths (or 18% of child deaths) per year for children under the age of five [6]. The global importance of safe drinking water is emphasized under Millennium Development Goal (MDG) number seven; target ten, which aims to halve the number of people without sustainable access to safe drinking water and sanitation by 2015. In Tanzania, there are 28,200 deaths per year attributable to diarrhea and the under five years, child mortality rate is 16.8% due to diarrhea [7]. Only 55% of Tanzanian population has access to improved drinking water and 24% have access to adequate sanitation. The access to improved water supplies is significantly higher in urban areas (81%) than in rural (46%) [8].

Dodoma region is positioned centrally in Tanzania with five districts, namely as Dodoma urban, Dodoma rural, Kongwa, Mpwawa and Kondoa. Dodoma urban is estimated to have a population of 513,267 people by the year 2014 [9]. The city drinking water is supplied by Dodoma Urban Water Supply and Sanitation Authority (DUWASA) at a rate of about 31,000 m^3/day [10]. This water comes from bore holes located at Nzakwe in the vicinity of Dodoma municipality. Many residents of Dodoma city complain about salt present in the water. The due effects are unpleasant taste, high consumption of soap during domestic washing, reduced life span of water meters, water taps, valves and pipes due to clogging and choking resulting from accumulation of salts deposits.

This calls for an immediate solution of treating the water to remove the salts as well as other contaminants and make it suitable for drinking and many other applications. This reflects, first identification of the dissolved salts and other contaminants, second looking for appropriate processes of removing the contaminants and thirdly implementing the processes. This first part of this work deals with the identification of the contaminants and review of the processes available for treatment of hard water and recommending the appropriate one/s. The implementation part will be reported in the second part of this work.

2. Literature Review

Water can be categorized into two groups as soft and hard water depending on the amount of calcium and magnesium contents. The water hardness measured as parts per million of calcium carbonate spans the following ranges for the groups: Soft water: 0-50 mg/L, moderate soft water: 50-100 mg/L, slightly Hard water: 100-150 mg/L, moderately hard: 150- 250 mg/L, hard water: 250 -350 mg/L and excessively hard water: > 350 mg/L [3, 11]. Since the water in Dodoma municipality is essentially hard water, the literature review will essentially be on hard water.

2.1. Hard Water

Hard water is usually defined as water which contains a high concentration of calcium and magnesium ions. Measurement of water hardness is given in terms of the calcium carbonate equivalent, which is an expression of the concentration of hardness ions in water in terms of other equivalent value of calcium carbonate. Water is considered to be hard if it has hardness of 100 mg/L or more as calcium carbonate [12]. Thus hard water essentially contains Ca^{2+} and Mg^{2+} ions. These ions do not pose any health threat, but they can be involved in reactions that leave insoluble mineral deposits. If there are mineral deposits on cooking dishes upon washing or rings of insoluble soap scum in bathtubs, these reflect signs of hard water from the municipal water supply. These deposits can make hard water unsuitable for different applications, and hence a variety of processes have been developed to "soften" hard water; i.e., remove the calcium and magnesium ions.

2.1.1. Sources of Hardness

The most common sources of hardness are minerals such as limestone ($CaCO_3$) which introduces calcium ions and dolomite ($CaMgCO_3$) which introduces magnesium ions into the water. Carbon dioxide reacts with water to form carbonic acid which at ordinary environmental pH exists mostly as bicarbonate ion. Microscopic marine organisms take this up as carbonate to form calcite skeletons which, over millions of years, have built up extensive limestone deposits. Ground waters, made slightly acidic by CO_2 (both that absorbed from the air and from the respiration of soil bacteria) dissolve the limestone, thereby releasing calcium and bicarbonate ions and making the ground water "hard". So as the ground water percolates through rocks containing limestone and dolomite, the extent of hardness increases. On other hand hardness of water has also been reported to be caused by other dissolved divalent ions such as strontium (Sr^{2+}), manganese (Mn^{2+}) and iron (Fe^{2+}) [13].

2.1.2. Types of Hardness

The hardness of water has been generally been known to be caused by a variety of divalent cations. These cations have a tendency to combine with anions (negatively charged ions) in the water to form stable salts. The type of anion found in these salts has therefore been used to distinguish between the two types of hardness-carbonate and non carbonate hardness (Table1).

Table 1. *Types of hard water [14], [15]*

Carbonate hardness compounds (temporary hardness)	Non carbonate hardness compounds (permanent hardness)
Calcium carbonate ($CaCO_3$)	Calcium sulfate ($CaSO_4$)
Magnesium carbonate ($MgCO_3$)	Magnesium sulfate ($MgSO_4$)
Magnesium bicarbonate ($Mg(HCO_3)_2$)	Calcium chloride ($CaCl_2$)
Magnesium hydroxide (Mg(OH)2)	Magnesium chloride ($MgCl_2$)
Calcium hydroxide ($Ca(OH)_2$)	

Table 1 shows that carbonate hardness is caused by Ca^{2+} and Mg^{2+} ions combined with anion (CO_3^{2-} or HCO_3^- or OH^-) to form a salt. In contrast, non-carbonate hardness forms when Ca^{2+} and Mg^{2+} combine with anything other than carbonate, bicarbonate, and hydroxide ions. Carbonate hardness is sometimes called temporary hardness because it can be removed by boiling the water. The heating of the water can result to decomposition of the salt into metal oxide, carbon dioxide and water and hence removing the hardness.

Non-carbonate hardness cannot be broken down by boiling the water, so it is also known as permanent hardness. In general, it is important to distinguish between the two types of hardness because the removal methods differ significantly. When measuring hardness, it is typically considered the total hardness which is the sum of all hardness compounds in water, expressed as a calcium carbonate equivalent. Total hardness includes both temporary and permanent hardness caused by calcium and magnesium compounds.

2.1.3. Hardness Problems

Hard water makes soap precipitate out of water and form a scum, such as the ring which forms around bathtubs. In addition to being unsightly, the reaction of hard water with soap results in excessive use of soaps and detergents. Fabrics washed in hard water loose their quality and texture very quickly and subsequently shortening their life. Hard water also causes taste problems in drinking water and this is one of the most widespread causes of customer complaints. Although there are no associated health effects, the extensive public relations difficulties resulting from test make it important to treat the water.

Hard water also causes blockage of the piping system, reduces the working life of valves, taps, pipe and pipe fittings. This is mainly associated by scaling and corrosion problems posed by hard water. Also hard water harms many industrial processes, so industries often require much softer water than is usually required by the general public. Excessively hard water will nearly always have to be softened in order to protect the water treatment plant equipment and piping systems. At a hardness of greater than 300 mg/L as calcium carbonate, scale will form on pipes as calcium carbonate precipitates out of the water. The scaling can damage equipment and should be avoided [16].

2.2. Other Ground Water Contaminants

Apart from ground water being contaminated with calcium and magnesium salts there are other several contaminants that can be present in this water. These depend on the anthropogenic activities in the area as well as the type of rocks on which the water percolates and rock surrounding the ground water. The ground water quality is however relatively uniform throughout an aquifer. Changes in quality occur slowly due to the fact that it is not exposed to the air and is not subjected to direct pollution as compared to surface water. Due to natural filtering action of the aquifer, the ground water is relatively free from microbes than surface water. In most cases contamination results either from improper well construction or poor waste disposal facilities in the vicinity of the well [17]. Hence depending on the geological set up and social activities in the area the ground water may be contaminated with microbes, chemical ions such as chlorides, frouride, nitrates, arsenic, phosphates, manganese, lead, selenium, uranium, etc. The allowable levels of drinking water contaminants are provided by TBS and WHO standards [18], [19].

2.3. Water Treatment Technologies

Water treatment technologies are normally aimed at removing unwanted contaminants from the water and rendering it suitable for drinking and many other applications. Many processes are available for this, the merits and demerits of these processes have been discussed in Table 2.

Table 2. *Advantages and disadvantages of Water Treatment technologies*

Serial no.	Method	Advantages	Disadvantages
Energy intensive methods			
1	Boiling	Kills 99% of all living things It can be a secondary method Can vaporize the water, temporary hard water can decompose to form insoluble and soluble substances	Unwanted mineral salts cannot be removed. Taste of water remain unpleasant It is energy intensive Minerals, metals and solids become more concentrated
2	Distillation	Kills 99% of all living things Leaves out precipitates of salts	It is expensive to boil and to cool the water Needs distillation still, condenser and reboiler
Chemicals methods			
1	Use of tablets of chlorine, bromine, iodine, silver, aluminum sulphate and ozone	The chemicals are potential for killing living organisms Some of the chemicals are effective as coagulants	Not effective for removal of water hardness Some of the chemicals are toxic at high concentration levels.
2	Ion exchange methods using synthetic material e.g. zeolite, etc	The materials are effective for removing hardness and other wide range of contaminants	The technology need regular replacement of the zeolites Slightly capital intensive The fate of zeolite residues is not clearly known
3	Ion Exchange methods using natural materials (e.g. activated carbon produced by using coconut shells, Grapefruit Seed Extract (GSE) and Moringa Seed powder	The non synthetic materials have potential effect for ion exchange between sodium from the material and calcium or magnesium in water. The materials are less expensive, locally available Some of the materials have antibacterial effects	The technologies are still at an infant stages and hence they are amenable for further investigations Toxicity levels of some of the materials are not well known.
Filtration methods			
1	Slow Sand	The major raw material is sand which is cheap : 1m^3 of sand can passes about 2lts/min of water Almost all contaminants can be removed	Cannot remove water harness Limited bacteria can be removed
2	Pressure Sand	The major raw material is sand which is cheap : 1m3 of	Cannot remove water harness

Serial no.	Method	Advantages	Disadvantages
		sand can pass about 40L/min of water A pump is needed for increasing the pressure of water A daily backwash is needed Almost all contaminants can be removed	Limited bacteria can be removed
3	Ceramic Filters eg colloidal-silver-saturated earthenware	Some of the raw materials are cheap, Potential for converting clean water to portable water	Cannot remove unwanted minerals and salts Some of the materials are very expensive
4	Paper or Cloth filters	The filter materials are disposable and need replacement Almost all contaminants can be removed	Cannot remove water hardness Not effective for killing bacteria and pathogens
5	Reverse Osmosis and ultra filtration	They use membrane technology which is effective for removal of unwanted salts from water They are modern technologies and potential for large scale applications	They are capital intensive Regular replacement of membranes and backwashing are needed
Light intensive methods			
1	Ultraviolet light	Effective for killing bacteria and other pathogens Potential for converting clean water to portable water	Cannot remove water hardness

3. Material and Methods

3.1. Purpose, Scope and Study Area

The research was conducted in Dodoma urban district in Dodoma region (Fig1). The purpose of the study was to identify the contaminants in Dodoma municipal drinking water and suggest methods that can be used to remove them and render the water suitable for drinking. The sampling sites were selected carefully so as to come up with results, which reflect the entire spectrum of the water quality profile in Dodoma municipality. This paper describes the tap water quality parameters of water supplied by DUWASA to Dodoma city residents for drinking and other domestic purposes. The main purpose of studying the quality of this water was to assess its quality in terms of physical and chemical characteristics and its suitability for drinking. The parameters analyzed include: pH, chloride, nitrate and total hardness. The results were then compared with the drinking water quality standards from Tanzania Bureau of Standards (TBS) and WHO. Finally, effects of the observed contaminants to human health were presented.

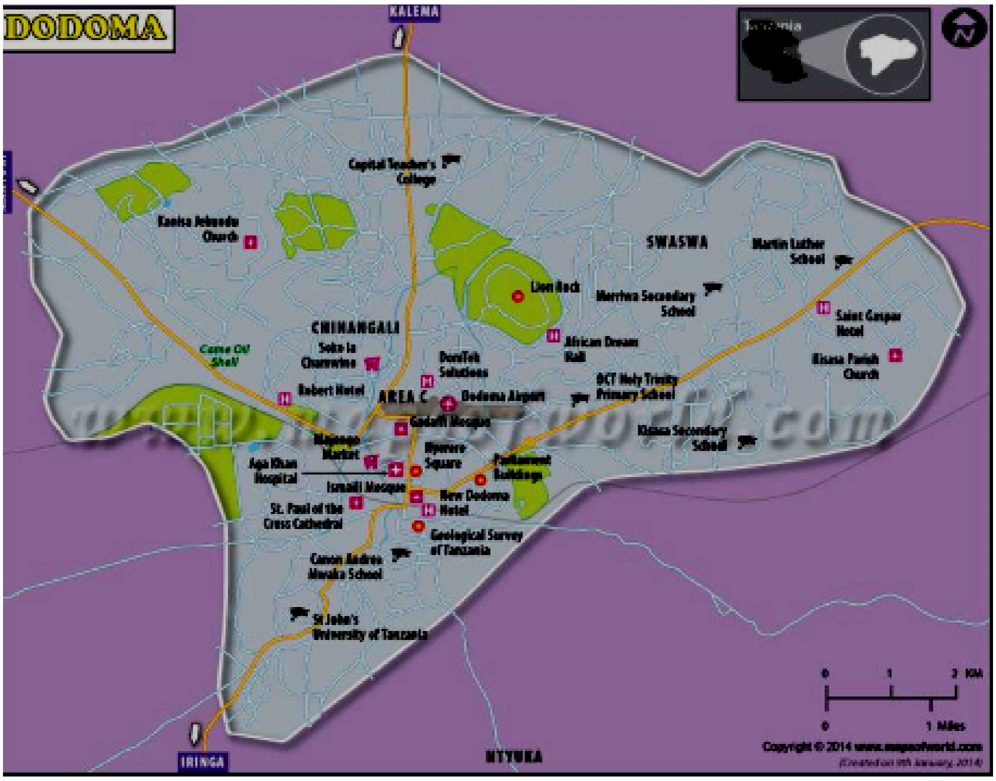

Fig. 1. Map of Dodoma region indicating the study and sampling areas

3.2. Materials

One liter of tap water from four different locations in Dodoma municipal was collected and kept in secure tight bottles. The four samples collected were designated as Sample A, B, C and D. The sampling exercise was done every week and it was carried out consecutively for a period of four months and the results were averaged. Great care was taken during sampling to prevent contamination of the samples being collected. The sample containers were rinsed with the water from the collection station. Physio-chemical parameters such as pH, electrical conductivity (EC), total dissolved solids (TDS) and turbidity were tested immediately at the collection source so as to avoid further microbial and chemical activities that might undergo in the sample. Other parameters were determined at Geological Survey of Tanzania (GST) and DUWASA laboratories.

3.3. Methods

All samples were analyzed for the physicochemical parameters immediately after sample collection. The parameters include pH, electrical conductivity (EC), total dissolved solids (TDS), turbidity, hardness and alkalinity, chloride (Cl^-), sulphate (SO_4^{2-}), nitrate (NO_3^-), Magnesium (Mg^{2+}), Calcium (Ca^{2+}), iron (Fe^{2+}). The pH was measured using a pH meter, EC by conductivity meter, turbidity by turbidity meter, and TDS was calculated by the relationship: TDS = 0.45 × EC. Alkalinity, hardness, calcium, magnesium, and chloride were determined by titration methods where by the volume of sample with indicator was titrated against the volume of reagent of known concentration (morality). Sulphate was determined by turbidimetric method; nitrate by colorimetric method; iron by phenanthroline spectrophotometer method and fluoride by calorimeter method.

4. Results and Discussion

Table 3. *Experimental results for DUWASA water compared with allowable TBS standards*

Group	No. Substance	Unit	Sample				TBS Standards	
			A	B	C	D	Lower limit	Upper Limit
Salinity And Hardness	1. pH	mg/L	6.9	7	6.9	7.7	6.5	9.2
	2. Total Filterable Residue		1354	1388	1143	436	500	2000
	3. Total Hardness		680	600	460	530	500	600
	4. Carbonate Hardness		108	360	460	396	75	300
	5. Calcium (Ca)		148	217.6	128	105.6	50	100
	6.Magnesium (Mg)		75.33	68.04	31.59	64.64	500	1000
Affecting Human Health	1. Fluoride (F)		0.22	0.43	0.89	1.02	1.5	4.0
	2. Nitrate (NO3)		75.3	12.0	0.443	8.854	10.0	75.0
Organoleptic	1. Colour true	mgPt/L	NIL	NIL	NIL	NIL	1.5	50
	2. Turbidity	NTU	7	NIL	NIL	NIL	5	25
Other ions	sulphate (SO42−),	mg/L	310	152	118	74	200	600
	Iron (Fe2+)		0.12	NIL	NIL	NIL	0.3	1.0

n.o- not objectionable; A-Chamwino sokoni; B-Dodoma hotel; C-Parliament building nearby; D-St John University

The experimental results of DUWASA water with their corresponding allowable TBS standards are presented in Table 3.

From Table 3 and Fig2, it can be clearly seen that the concentration of calcium at all points is higher than maximum allowable value of 100 mg/L. This is main source of hardness of Dodoma municipality hard water which leads to the peoples' complains of unpleasant taste, high consumption of soap during domestic washing and reduced life time of water utility equipment such as valves and meters due to accumulation of salt deposits. This hardness is permanently because it cannot be removed by boiling. It can also be seen from Table 3 that total carbonate hardness and total hardness are slightly above the permissible values and this therefore calls for treatment of the water to suit for domestic usage. Table 3 also indicates that the rest of the parameters that were studied for the Dodoma municipal water appear to be within the permissible levels and that magnesium ions appear to be on the lower side.

This preliminary investigation has shown that the main source of hardness in Dodoma Municipal water is calcium ions/salts and that magnesium ions/salts are on the lower when compared with permissible levels. Further studies are needed to identify the exactly the type of calcium salt that is responsible for the hardness and also method and technology to remove it. Grape and moringa seed powder are cheap and readily available in Dodoma and hence they are potential materials to be used in treatment of this water.

The part II of this research will involve identification of dissolved salts and establishment of appropriate method for water treatment and final part is development of economically viable technology to assist the majority. The research will thus make a useful contribution to Dodoma municipality residents to realize number seven, target ten of MDG's.

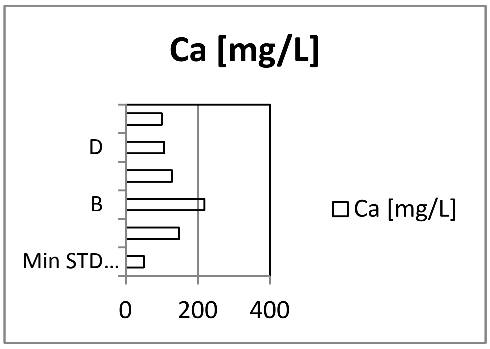

Fig.2. *Concentration of calcium in mg/L*

5. Conclusions and Recommendations

The physical and chemical parameters of Dodoma municipality tap water have been analyzed. Calcium is a major source of hard water which revealed with people complains. The type of hardness is permanent. The water has also revealed to have low levels of magnesium ions/salts. The other parameters (pH, titratable residues, fluoride, nitrate, sulphate and iron ions were observed to be within the allowable levels. The review of the methods that can be used to remove the hardness suggest that grape and moringa seed and powder can be used as they are potential adsorbents and that they are easily available in Dodoma. These materials will therefore be amenable for investigation of water treatment in part II of this work.

References

[1] Gleick P.H. (2006). The world's water, The Biennial Report on Fresh water Resources. Washington. Island Press.

[2] Lefort R. (2006). Down to the last drop, UNESCO Sources, No. 84 (7).

[3] WHO (2008). World Health Organization (WHO), Guidelines for drinking water quality, Geneva.

[4] http://www.gizmag.com/moringa-tree-seeds-purify-water/14427/ access on 25/10/2012

[5] McFeters, G.A. (1990). Drinking Water Microbiology, Springer Velag, New York

[6] (UNICEF, 2009). United Nations Children's Fund (UNICEF). Water, Sanitation and Hygiene Annual Report. UNICEF WASH Section, Programme Division, UNICEF New York

[7] http://tmarc.or.tz/fileadmin/documents/TMARC_Research/PUR_Assessment_Write_Up.pdf, accessed on 25/10/2012.

[8] URT (2009). United Republic of Tanzania (URT), Water Supply and Sanitation Act, Ministry of Water and Irrigation, Dar es Salaam.

[9] NBS (2002). Tanzania Bureau of Statistics (NBS). Ministry of Planning and Economic Empowerment. Dodoma region and districts projections, Vol. XII. Dar es Salaam.

[10] DUWASA (2010). A report prepared by Partners for Water and Sanitation following a visit to Dodoma Urban Water and Sanitation Authority (DUWASA).

[11] Mato, R.M.A (2002). Ground water pollution in urban Dar es salaam, Tanzania: Assessing vulnerability and protection priorities, Eindhoven University of Technology, Netherlands.

[12] Saurina, J. E. (2002). Determination of calcium and total hardness in natural waters using a potentiometric sensor array; Analytica Chimica Acta 464 (1): pp. 89-98.

[13] Hammarlund, D. and Aravena, R. (1997). Multi-component carbon isotope evidence of early Holocene environmental change and carbon-flow pathways from a hard-water lake in northern Sweden."Journal of Paleolimnology 18 (3): pp 219-233.

[14] Mihayo, I.Z. and Mkoma, S.L. (2012). Chemical Water Quality of Bottled drinking water brands marketed in Mwanza city, Tanzania. Research Journal of chemical sciences, 2(7): pp. 21-26

[15] Vander Aa N.G.F.M. (2003). Classification of mineral water types and comparison with drinking water standards, Environ. Geol., 44 (5),pp. 554-563 .

[16] Warren, R. and Ertel, K.D. (2006). The influence of hard water (calcium) and surfactants on irritant contact dermatitis; Contact Dermatitis 35 (6):pp. 337-343.

[17] EPA (2012). United States environmental Protection Agency (EPA). Water standards and Health Advisories, Washington DC.

[18] TBS (2005). Tanzania Bureau of Standards (TBS), National Environmental Standards Compendium: TZS 789. Drinking (potable) water – Specification, 74.

[19] WHO (2011). World Health Organization (WHO) Guidelines for Drinking-water Quality, Fourth Edition; Geneva