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# Chemical Water Quality of Bottled Drinking Water Brands Marketed in Mwanza City, Tanzania

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## Abstract

*Water is a useful resource for domestic, industrial and agricultural purposes and its importance to man cannot be overemphasized due to its essentiality in body metabolism and proper functioning of cells. The present study was carried out to determine the physico-chemical quality of bottled drinking water brands available in retail shops in Mwanza city (Tanzania), and compare with drinking water standards. The results show that water type for different bottled water brands when classified according to TDS ranged from very low concentrations (brands A and B) to low concentrations (brands C, D, E, and F). Based on the classification criteria of total hardness, most brands were considered to have soft water except for brand E which had moderately hard water. The dominant component to all bottled water brands was $SO_4^{2-}$ accounted 48% to 90% of the total major ions, whereas $Cl^-$ accounted for 8% to 25%. Somewhat high contributions up to 20% was observed for $Ca^{2+}$, while $Mg^{2+}$ was below 9%, and $Fe^{2+}$ and $NO_3^-$ were below 6%. Brand D has exceptionally high levels for $Cl^-$, $NO_3^-$, and $Mg^{2+}$ ions. When compared with Tanzania Bureau of Standards (TBS) and World Health Organization (WHO) guidelines for drinking water, analysed parameters in all brands were within TBS and WHO limit values for drinking water. The study therefore concludes that the analysed bottled water brands are safe for human consumption. However, it recommends other water quality parameters such as microbiological and heavy metal be studied in future.*

**Keywords:** Packaged drinking water, quality parameters, TBS and WHO standards, Tanzania.

## Introduction

Water is a useful resource for domestic, industrial and agricultural purposes and its importance to man cannot be overemphasized due to its essentiality in body metabolism and proper functioning of cells[1]. Though, water is abundant in nature occupying 71% of the earth surface[2], only 1% is accessible for human consumption[3]. Access to adequate supply of safe drinking water for all is one of the primary goals of the World Health Organization[4]. In Tanzania, only 54% of the population has access to improved water supplies and 24% have access to adequate sanitation[5]. Bottled water is one of the reliable healthy drinking water in any parts of the world including Tanzania having undergone through series of treatments. Therefore, bottled water is widely accepted as potable and thereby free from physical, chemical and microbiological contaminants that could cause adverse health effects in humans when consumed.

In Africa, scarcity and water pollution constitute a major challenge for sustainable water resources management[6]. Despite the World Health Organization's guidelines[4] for drinking water quality, water pollution in various sources has been increasing over recent decades in most countries[7-9]. On local scale in Tanzania, people depended on tap water, surface water, and groundwater which unfortunately are polluted[10-12]. In addition, bottled water was widely accepted as potable and healthy drinking water; thereby free from contaminants that could cause adverse human health effects. In recent year, different brands of bottled water have been produced using series of treatments and packaging. Though in Tanzania is mandatory to register brands of bottled water for quality production[13-14], there are influxes of replica brands into the markets which has been posing threat to people's health[15-16]. Bottled water remains the highest consumable commodity especially for the middle and high income social classes in urban areas, and since is processed from various sources, is important to examine it quality. Therefore the aim of this paper is to assess the physico-chemical quality parameters of brands of bottled water consumed in Mwanza city, Tanzania. A comparison among brands and with the prescribed Tanzania and World Health Organization drinking water standards was also assessed.

## Material and Methods

**Study area**: The present study was conducted in Mwanza city (Latitude 2° 31' 0.01"S and Longitude 32° 53' 60"E) that is located on the shores of Lake Victoria in Northern Tanzania. The population of the city is current estimated to be 0.8 million people and 86% of its residents including industries and agricultural activities depend on Lake Victoria as the major source of water[17]. However, other water sources including groundwater (boreholes and wells) and bottled water of various brands are available for drinking and other domestic purposes.

**Sampling and analysis:** This study was limited to assessing six bottled mineral water brands available in retail shops in Mwanza city that were purchased once a week for one month from the public markets. To keep the brand names anonymous, bottled water samples were given alphabetical code from A to F and this convention used throughout the text. Out of the 6 brands, 5 brands (excluding A) had most important parameters (pH, $Na^+$, $K^+$, $Mg^{2+}$, $Ca^{2+}$, $Cl^-$, $SO_4^{2-}$, and $NO_3^-$) on their bottle labels. Brands D had in addition to the named parameters, TDS and $HCO_3^-$, brand E had TDS, and F had Fe levels of the water labelled on their bottles. One brand (A) reported generalized information on pH, $Na^+$, $Mg^{2+}$, $Cl^-$ and $NO_3^-$ parameters on its label. Three brands A, C, and E are tapped from Lake Victoria, snow of Mt. Kilimanjaro and boreholes respectively while the sources for other brands B, D and F were not indicated on the labels.

From each brand, two samples were analyzed for the physico-chemical 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 method 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, and iron by phenanthroline spectrophotometry method. It should be noted that other important parameters like $Na^+$, $K^+$ and microbiological due to laboratory technical problem during study period.

## Results and Discussion

**Classification of bottled Water brands:** Different hydro-chemical classification systems can be used to classify water types. In the present study, the European Union (EU) mineral water directive[18] was used to classify the water according to TDS and total hardness. The classification systems used to identify the chemical similarities and/or differences between bottled water brands. The criteria for the chemical composition of mineral water according to the EU mineral water directives are given table 1. The criteria show a distinction based TDS and a further specification based on some characterizing cations and anions.

Table 2 shows classification of brands of bottled water in accordance with EU mineral water directive (TDS). For the case of brands A and B fall in the class "very low mineral concentration" (with TDS<50 mg/l), brands C, D, E and F fall in class "low mineral concentration" (with TDS between 50-500 mg/l). The classified brands of bottled water for this study based on total hardness are also shown in table 2. Five of the brands A, B, C, D and F with hardness between 0-50 mg/l are considered soft water; brand E with hardness between 50-100 mg/l is considered moderately hard water. Total hardness in water is caused by dissolved calcium and to a lesser extent magnesium and total hardness.

**EC, TDS and Turbidity:** The chemical content of bottled water is determined by the composition of the source it is abstracted from. For example, similar types of rock may lead to different types of mineral water. The chemical content depends on the availability of mineralizing agents, such as $CO_2$ concentration, redox conditions and the type of adsorption complexes[19]. Levels of EC, TDS and turbidity in bottled water brands and their comparison to TBS and WHO limit values are presented in table 3. The ranges for these parameters were: 17.4–280 S/cm for EC with a median of 185.5 S/cm; 7.8-126 mg/l for TDS with a median of 83.5 mg/l; and 0.0-1.0 NTU for turbidity with median of 0.5 NTU. There is a variation between EC and TDS values of the bottled water brands; this depends on the origin of the water and the treatment or purification method applied during bottling process. Electrical conductivity in water is usually used as a measure of ionic concentrations. The low EC of brand A is due to its low ionic concentration and higher in brand D is due to high ionic concentrations, and this also can be applied in TDS because they are related. Turbidity in all brands is very low because bottled water brands are highly flirted during processing.

**Concentration of Major constituents:** Table 4 shows the analytical results of major constituents found in bottled water brands together with the corresponding standards values used in this study. The pH of all brands was around neutral ranging from 7.3 to 7.6 with a median of 7.4; this may have been done in processing as recommended for drinking water. The concentration ranges for the major constituents (in mg/l) are: 16-79 for alkalinity with a median of 42; 20-66.5 for total hardness with a median of 37; 3.4-14 for $Ca^{2+}$ with a median of 9; 0.1-8.9 for $Mg^{2+}$ with a median of 2.9; 0.18-0.2 for $Fe^{2+}$ with a median of 0.2; 2.5-48.2 for $Cl^-$ with a median of 10; 5.9-87.7 for $SO_4^{2-}$ with a median of 23.9; and 0.1-3.5 for $NO_3^-$ with a median of 0.3. Brand E has higher concentration of $Ca^{2+}$ and $Cl^-$, brand C has the higher value of $Mg^{2+}$ (after brand E) as from its source of snow the higher value can be because of presence of magnesium-rich minerals such as olivine and pyroxene in the volcano environment. Of all brands $Ca^{2+}$ concentration was higher than of $Mg^{2+}$ this means that hardness of water come mostly from $Ca^{2+}$ concentration. $Fe^{2+}$ concentration in all brands was low, this can be due to methods of processing that ensure the smaller concentration of $Fe^{2+}$. Generally, the results show that the bottled water brands are quite different in characteristics. The observed variations in the chemical constituents might be resulting from the origins, residence time, atmospheric conditions and purification or treatment process employed by the manufacturers. In fact all the constituents in all brands are within the recommended TBS and WHO standard limits for drinking water.

**Contribution of major ions:** The average concentrations in bottled water brands of proportions of major ions are shown in figure 1. It is clearly that $SO_4^{2-}$ was the major component to all bottled water brands and the lowest $SO_4^{2-}$ level was observed in brand B. Brand D has exceptionally high levels for most ions such $Cl^-$, $NO_3^-$, and $Mg^{2+}$. The percentage attributions of the analysed major ions concentrations to each of the six bottled water brands are given in figure 2. The dominant component, $SO_4^{2-}$, accounted for a range of about 48% to 90% of total ions in all the brands, whereas the respective percentages contribution of $Cl^-$ ranged from 8% to 25%. Somewhat high percentage contributions up to 20% was observed for $Ca^{2+}$, while $Mg^{2+}$ was below 9%, and $Fe^{2+}$ and $NO_3^-$ were below 6%. The contributing source of $SO_4^{2-}$ in the bottled water brands could be from oxidation of sulphate containing ores such as gypsum whereas the observed $Cl^-$ concentration in the bottled drinking water may come from water that entrapped in the sediments or from solutions of halite (chlorination process). The $NO_3^-$ is undoubtedly from natural occurring sources in addition to agricultural, industrial and domestic sources.

**Table-1**
**Classification based on EU mineral water directive**

| Water type | Criterion |
|---|---|
| Very low mineral concentration | Mineral content (TDS) < 50 mg/l |
| Low mineral concentration | TDS 50-500 mg/l |
| Intermediate mineral concentration | TDS 500-1500 mg/l |
| High mineral concentration | TDS > 1500 mg/l |
| Containing sulphate | Sulphate > 200 mg/l |
| Containing chloride | Chloride > 200 mg/l |
| Containing calcium | Calcium > 150 mg/l |
| Containing magnesium | Magnesium > 50 mg/l |
| Containing iron | Bivalent iron > 1 mg/l |

**Table-2**
**Classification of bottled drinking water brands based on TDS and total hardness**

| Brand code | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| TDS | 8 | 37 | 113 | 126 | 122 | 54 |
| EU Class | Very low conc. | Very low conc. | Low conc. | Low conc. | Low conc. | Low conc. |
| Total Hardness | 21.3 | 20 | 44 | 44 | 67 | 30 |
| Water class | Soft water | Soft water | Soft water | Soft water | Moderately hard water | Soft water |

Conc. = Concentration

**Table-3**
**Chemical and physical parameters for the bottled drinking water brands and their comparison to the TBS and WHO limit values**

| Brand code | EC (s/cm) | TDS (mg/l) | Turbidity (NTU) |
|---|---|---|---|
| A | 17.4 | 7.8 | 1.0 |
| B | 82.3 | 37.0 | 0.0 |
| C | 251.0 | 113.0 | 0.0 |
| D | 280.0 | 126.0 | 1.0 |
| E | 270.0 | 121.5 | 0.0 |
| F | 120.0 | 54.0 | 1.0 |
| Mean | 170.1 | 76.6 | 0.5 |
| SD | 111.5 | 50.2 | 0.5 |
| Minimum | 17.4 | 7.8 | 0.0 |
| Maximum | 280.0 | 126.0 | 1.0 |
| Median | 185.5 | 83.5 | 0.5 |
| TBS | – | – | 5-25 |
| WHO | – | 500 | 5 |

**Correlation between various constituents:** The correlation matrix for various water quality parameters in the bottled water brands during the survey is given in table 5. Most constituents exhibit strong correlations suggesting that they may originate predominantly from the same sources. Higher correlation (r > 0.80) was observed for alkalinity and pH, EC and hardness, between hardness and TDS, $Mg^{2+}$; $Fe^{2+}$ and $Ca^{2+}$, and also between $Mg^{2+}$ and $SO_4^{2-}$. As for the pH a strong correlation coefficient with EC (r = 0.69) and EC and TDS (r = 1.0) was found as shown in table 5, meaning that these constituents share the same source of high concentration of the major ions. High pH represents the major process controlling concentrations of the element in solution. Increase pH tends to increase concentration of $Mg^{2+}$ and $Fe^{2+}$ in solution, solubility of silicates mineral decrease solubility of calcium carbonate. High correlations among constituents with $Ca^{2+}$ and $SO_4^{2-}$ suggest the dissolution of gypsum, besides; carbonate mineral weathering might be playing a role in the hydrochemistry of $Ca^{2+}$ and water hardness.

**Table-4**
**Concentrations of major constituents of bottled drinking water brands and their comparison to TBS and WHO limit values, The units are in mg/l except for pH**

| Brand code | pH | Alkalinity | Hardness | $Ca^{2+}$ | $Mg^{2+}$ | $Fe^{2+}$ | $Cl^-$ | $SO_4^{2-}$ | $NO_3^-$ |
|---|---|---|---|---|---|---|---|---|---|
| A | 7.4 | 32.0 | 21.3 | 8.5 | 0.1 | 0.20 | 2.5 | 28.5 | 0.2 |
| B | 7.3 | 16.0 | 20.0 | 3.4 | 2.8 | 0.18 | 7.8 | 18.6 | 0.1 |
| C | 7.6 | 79.0 | 44.0 | 9.4 | 5.0 | 0.19 | 10.1 | 28.5 | 3.5 |
| D | 7.4 | 42.0 | 66.5 | 12.0 | 8.9 | 0.20 | 24.8 | 87.7 | 2.8 |
| E | 7.5 | 48.0 | 44.0 | 14.0 | 2.2 | 0.22 | 48.2 | 5.9 | 0.3 |
| F | 7.4 | 42.0 | 30.0 | 7.2 | 2.9 | 0.20 | 9.9 | 19.2 | 0.1 |
| Mean | 7.4 | 43.2 | 37.6 | 9.1 | 3.6 | 0.02 | 17.2 | 31.4 | 1.2 |
| SD | 0.1 | 20.8 | 17.6 | 3.7 | 3.0 | 0.01 | 16.9 | 28.8 | 1.5 |
| Minimum | 7.3 | 16.0 | 20.0 | 3.4 | 0.1 | 0.18 | 2.5 | 5.9 | 0.1 |
| Maximum | 7.6 | 79.0 | 66.5 | 14.0 | 8.9 | 0.22 | 48.2 | 87.7 | 3.5 |
| Median | 7.4 | 42.0 | 37.0 | 9.0 | 2.9 | 0.20 | 10.0 | 23.9 | 0.3 |
| TBS | 6.5-9.2 | – | 75-300 | 50-100 | 500-1000 | 0.3-1.0 | 200 | 200-800 | 10-25 |
| WHO | 6.5-8.0 | – | – | – | – | 0.3 | 250 | 250 | 50 |

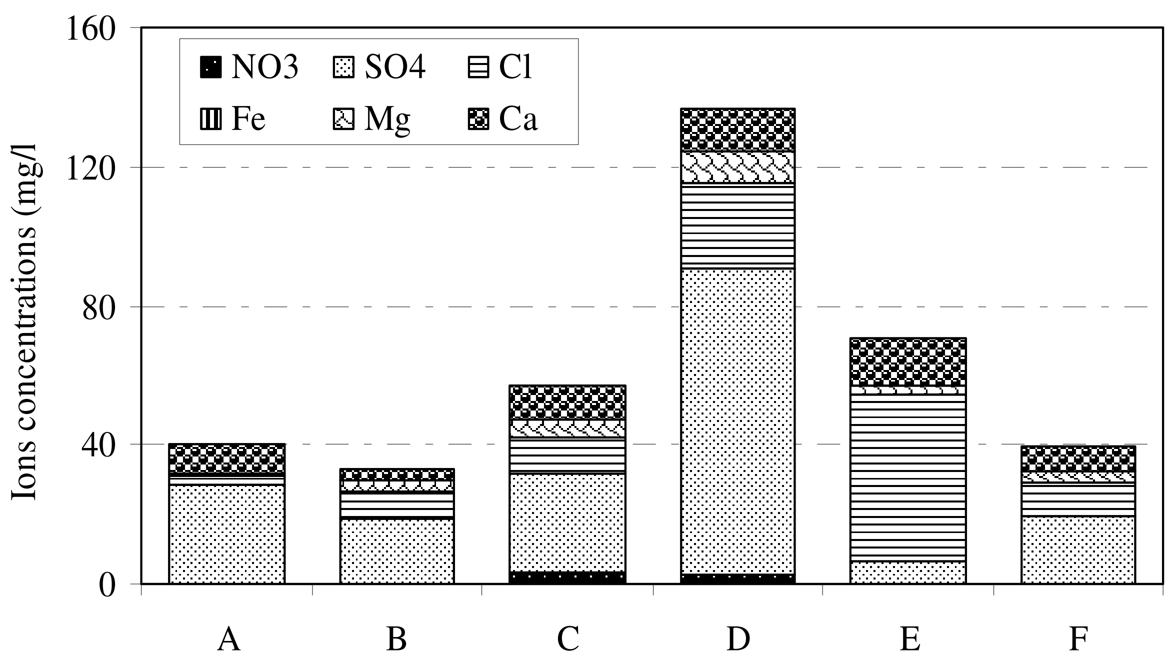


**Figure-1**
**Average concentrations of proportion of ionic constituents in difference bottled water brands**

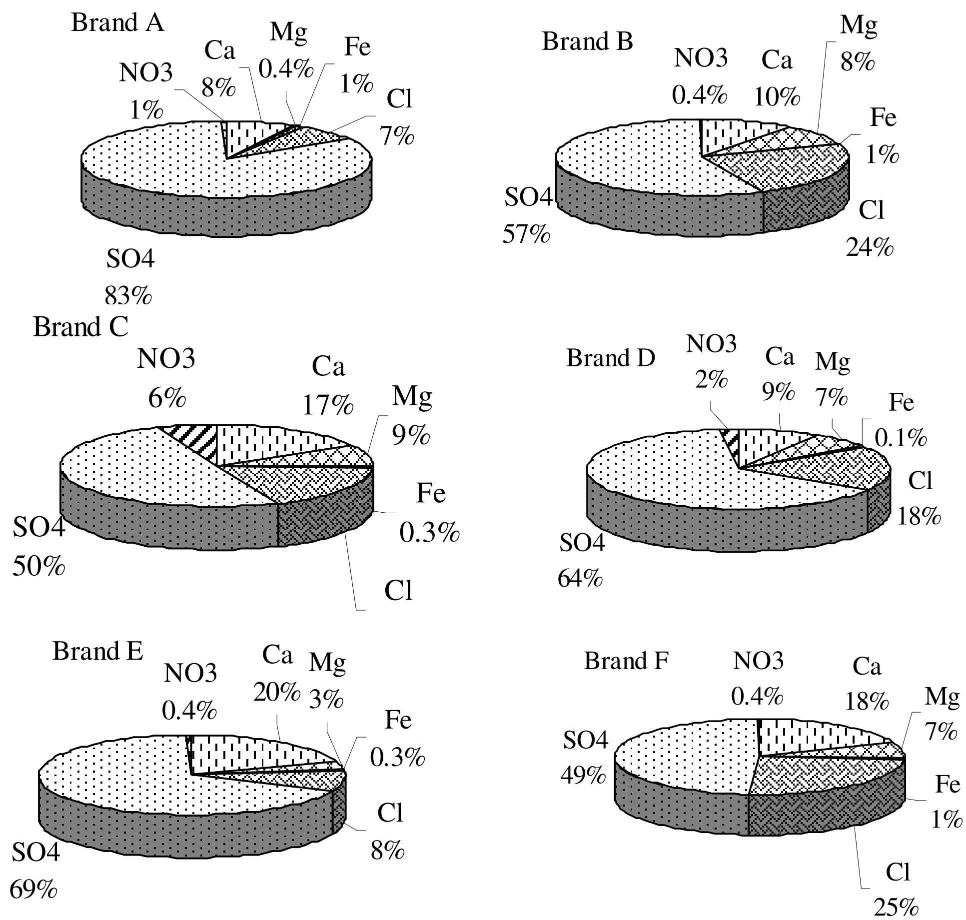


**Figure-2**
**Percent attributions of major ions concentrations to bottled drinking water brands**

**Table-5**
**Correlation matrix for water quality paramters in the bottled drinking water brands**

| | pH | EC | Alkalinity | Hardness | TDS | Turbidity | Ca | Mg | Fe | Cl | $SO_4$ | $NO_3$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **pH** | 1.00 | | | | | | | | | | | |
| **EC** | **0.69** | 1.00 | | | | | | | | | | |
| **Alkalinity** | **0.95** | **0.64** | 1.00 | | | | | | | | | |
| **Hardness** | **0.54** | **0.89** | 0.49 | 1.00 | | | | | | | | |
| **TDS** | **0.69** | **1.00** | **0.64** | **0.89** | 1.00 | | | | | | | |
| **Turbidity** | -0.21 | -0.30 | -0.24 | 0.10 | -0.30 | 1.00 | | | | | | |
| **Ca** | **0.72** | **0.73** | **0.50** | **0.74** | **0.73** | 0.04 | 1.00 | | | | | |
| **Mg** | 0.22 | **0.71** | 0.31 | **0.86** | **0.71** | 0.12 | 0.30 | 1.00 | | | | |
| **Fe** | 0.49 | 0.40 | 0.20 | 0.36 | 0.40 | 0.14 | **0.85** | -0.13 | 1.00 | | | |
| **Cl** | 0.42 | **0.72** | 0.18 | 0.56 | **0.72** | -0.31 | **0.79** | 0.19 | **0.78** | 1.00 | | |
| **$SO_4$** | -0.02 | 0.35 | 0.03 | **0.71** | 0.35 | **0.52** | 0.25 | **0.83** | -0.12 | -0.04 | 1.00 | |
| **$NO_3$** | **0.59** | **0.66** | **0.73** | **0.72** | **0.66** | -0.09 | 0.34 | **0.78** | -0.19 | 0.00 | **0.61** | 1.00 |

Correlation coefficients that is larger than 0.50 are indicated in bold

## Conclusion

This study gives an insight of major quality constituents of six bottled water brands currently sold in Mwanza retail shops. The results showed that the brands of bottled water analyzed are safe for human consumption. The measured constituents in the brands are within standards limits set by TBS and WHO for drinking water. However, the physicochemical quality of the brands studied was variable, which possibly depends on many factors such as natural environment, source water composition and type of treatment/purification technique(s) applied during the production. Additional changes in the water chemistries may also occur during storage and transportation, especially when bottles are exposed to direct sunlight. The number and type of parameters reported on the labels of bottled water showed a lack of homogeneity. Basic parameters (major ions) were usually indicated, whereas, for some brands generalized parameters were observed. In general, the concentration of species measured in this study was comparable to or slightly lower than values reported on the labels. This study has also shown that bottled water is not necessarily safer than tap water, and consumers should be aware. Long-term consumption of waters low in minerals (e.g. calcium, magnesium and fluoride) may be responsible for important health problems. The study recommends regular need for a nationwide survey about the quality of waters including tap and river waters as well as groundwater. Additionally, the analysis and labelling of other parameters such as microbiological and arsenic for Tanzanian bottled drinking water brands is needed to protect public health.

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