MJoSHT
Malaysian Journal of Science, Health & Technology
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Physico-Chemical Quality of Bottled Drinking Water Sold in Zomba City, Malawi

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Article Info
Article history:
Received: 6 March 2023
Accepted: 2 June 2023
Published:12 September 2023

Academic Editor: Ismatul Nurul Asyikin Ismail
Malaysian Journal of Science, Health & Technology

MJoSHT2022, Volume 9, Issue No. 2
eISSN: 2601-0003

https://doi.org/10.33102/mjosht.v9i2.354

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***Abstract*—The quality of drinking water is a key priority from a human health perspective. The present study was conducted to assess the physico-chemical quality of bottled drinking water marketed in Zomba City, Malawi. Seven bottled water brands were analyzed for pH, EC, TDS, K, Na, Ca, Mg, NO_3^-, F^-, Cl^- and total water hardness using standard methods. The results of the analysis were compared with Malawi Standard (MS) 560 for natural mineral water, MS 699 for bottled water other than natural mineral water, and the World Health Organization (WHO) guidelines for drinking water. The results showed that EC, TDS, Cl^-, NO_3^-, F^-, K, Na, Ca, and Mg in all the bottled water brands complied with MS 560, MS 699, and WHO guidelines for drinking water. Further, four bottled water brands had their mean pH below the minimum MS 560 and MS 699 value of 6.5. Comparison of the analyzed water quality parameters with the reported label values showed considerable variation in both exaggeration and undervaluing. This study has also shown that all brands had low fluoride content as compared to recommended levels by MS 560 and MS 699. The paper suggests the need for strict monitoring to check bottled water quality compliance.**

***Keywords*— Bottled water; physico-chemical quality; Zomba**

I. INTRODUCTION

Water is one of the renewable resources essential for sustaining all forms of life, food production, economic development, and general well-being [1]. Drinking water quality is a serious problem worldwide as it impacts human health [2]. It is reported that over one billion people globally lack access to safe drinking water [3], and millions of people in developing countries are suffering from communicable diseases emanating from drinking unsafe water [4]. The sixth goal of the Sustainable Development Goal (SDG) set by the United General Assembly in 2015 aims to ensure universal and equitable access to safe water and sanitation for all by 2030 through sustainable management of water resources [5]. Locally, in line with SDG 6, a number of policy frameworks have been set by different countries. For instance, the Malawi government implemented the Malawi Growth and Development Strategy (MGDS III) in 2017, of which one of the targets is to ensure safe drinking water and sanitation for all [6]. Despite these interventions by the government of Malawi,

Malawi is still among the countries with a high prevalence of water-related diseases [7].

Bottled water is viewed as one of the main ways drinkable water is distributed globally [8]. Over the decades, the consumption of bottled water has tremendously increased worldwide. The preference for bottled water is attributed to increasing health awareness among the public, as bottled water is perceived to be safe [9-10]. It is paramount that bottled drinking water should meet the same standard as tap water [11]. However, poor quality control during production and poor management in the supply chain can impede the quality of bottled drinking water at different stages of bottle filling at the source, during distribution, incorrect transportation, and storage [8,12].

Due to the increasing interest in bottled water from a sanitary point of view, a number of studies focusing on the composition and quality of bottled water have been conducted [13-21]. Some studies have revealed non-compliance and irregularities in the chemical composition of bottled drinking water. Additionally, dubious labelling of bottled drinking water has been reported [13,14]. However, there is a paucity of data on the quality and labelling of bottled water sold on the Malawian market. Zomba City is one of the highest consumers of bottled drinking water in Malawi. So, this study was carried out to characterize bottled water brands sold in Zomba city, Malawi, as well as to check compliance with respect to Malawi Standards and World Health Organisation drinking water guidelines and possible health implications associated with consumption of the bottled drinking water.

II. MATERIALS AND METHODS

A. *Description of the study area*

The study was conducted in Zomba city, located in the Southern region of Malawi (Figure 1). As of 2018, the district had a total population of 746,724, resulting in a population density of 316 persons per km^2. Almost four-fifths of all households (79.6%) have access to safe drinking water [22]. Communal taps, boreholes, and unprotected shallow wells are the main sources of individual water supply. It is worth noting that the Southern Region Water Board (SRWB) supplies tap water in the district, and bottled drinking water is supplied by private companies. Based on the water sources and treatment processes, the bottled drinking water under investigation is categorized into mineral, purified (still), and spring water.

B. *Sample Collection*

Sixty-three bottled water samples from seven commercial brands were randomly purchased from the supermarkets in Zomba city. For each brand, 9 separate samples were collected from those supermarkets. At the time of purchase, the bottled drinking water of 500 mL had a validity of one year, and all sampled bottled waters were within the safe period. Great care was taken during sample collection, preservation, and transportation to prevent cross-contamination and degradation of samples [23-24].

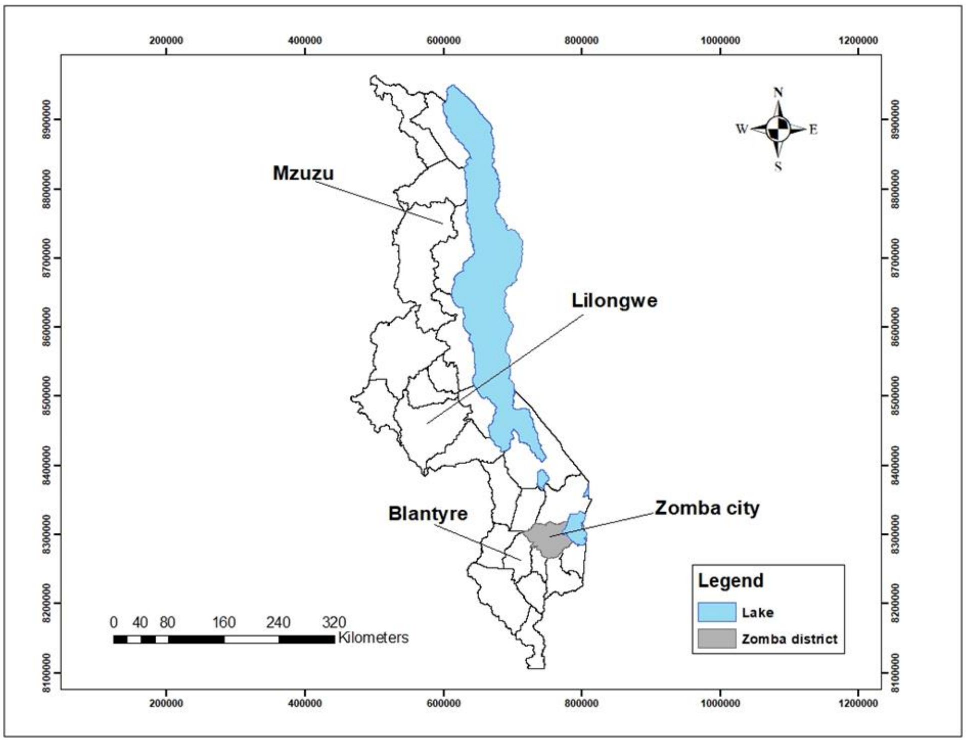

Fig.1 Map of Malawi showing the location of Zomba.

All reagents and chemicals used in the analyses were of analytical grade. Samples were acidified with nitric acid 70% supplied by Sigma Aldrich (to pH < 2) and stored for metal analysis. Samples for anions (unacidified) were kept at 4°C until laboratory analysis was conducted. The real names of the bottled water samples were not used for ethical considerations but rather coded B1 to B7.

Most of the brands used in this study were purified still water (B2, B3, B5, B6, and B7), while two brands (B1 and B4) had their water sources from spring and natural minerals, respectively. All bottles were made of Polyethylene Terephthalate (PET) with plastic screw caps.

C. Physico-Chemical Analyses

pH, electrical conductivity (EC), and total dissolved solids (TDS) were measured using Hanna model HI-991300N pH-EC-TDS waterproof pH/EC/TDS/Temperature meter (Hanna Instruments Limited). pH meter was calibrated with buffer solutions of pH 4 and pH 7 bought from Sigma Aldrich. Similarly, the conductivity meter was calibrated with 1413 μScm^{-1} standard solution bought from Sigma Aldrich. K, Na, Ca, and Mg were measured using Atomic Absorption Spectroscopy (AAS) by the Agilent Technologies 200 series AA model. Stock standard solutions of the measured elements (K, Na, Ca, and Mg) of concentration 1000 parts per million (ppm) from Stigma Aldrich were used to prepare calibration standards in the range of 5.0 to 10.0 ppm. Nitrate, chloride, and fluoride were measured using Ion Selective Electrodes (ISE) made by Cole Palmer on a Seven Multi-Mettle Toredo GmbH 8603 model meter made in Switzerland. A combined stock standard solution of anion (1000 ppm) from Sigma Aldrich was used to prepare standards of nitrate, chloride, and fluoride in the range of 1.0 to 10.0 ppm.

The total water hardness, as Ca^{2+} and Mg^{2+}, was calculated according to equation (1) [26-27].

$$\textit{Total Hardness} = 2.5\,[Ca] + 4.1\,[Mg], \qquad (1)$$

where [Ca] and [Mg] are the calcium and magnesium concentrations (in mg/L) measured in the water sample, while 2.5 and 4.1 are their molar mass ratios per 100 g $CaCO_3$.

D. Data Management and Statistical Analysis

To guarantee quality control and reliability of the data, for each brand, 9 samples were collected, and standard methods were used for all procedures for both sample collection and analysis. It should also be noted that sample analyses were conducted at an accredited institution. Using Microsoft Excel, descriptive statistics such as minimum, maximum, and mean were computed. Multivariate statistical analysis, mainly Hierarchical Cluster Analysis (HCA), was done using Statistical Package for the Social Sciences (SPSS version 20). The HCA was used for searching the natural grouping among bottled water brands from different sources. Correlation analysis (Pearson's correlation r, $p = 0.05$, and $p = 0.01$) was used to evaluate the statistical significance and degree of association between two water chemistry parameters.

III. RESULTS AND DISCUSSIONS

A. Physico-chemical Characteristics of Bottled Water

It is noteworthy that guideline values for drinking water have been adopted nationwide. This guideline value gives the concentration of a given parameter that does not lead to a significant health risk over a given time of consumption. Herein, we refer to the MS 560 (2004) for natural mineral water and MS 699 (2004) [28-29] for bottled water other than natural mineral water, as well as WHO guidelines (2017). Table 1 shows the mean results for the physico-chemical parameters.

pH, Electrical Conductivity (EC) and Total Dissolved Solids (TDS)

The pH ranged from 6.2 to 6.6 (Table 1). The MS 560 drinking water guideline for natural mineral water and MS 699 for non-mineral bottled water recommend a minimum value of 6.5. B2, B5, and B7 complied with the maximum MS 699 pH guideline value of 8.5. However, brands B1, B3, B4, and B6 registered pH values of 6.2, 6.3, 6.2, and 6.4, respectively (Table 1), below the minimum MS 560 and MS 699 set value of 6.5. According to WHO guidelines for drinking water, there is no health-based guideline value for pH. However, a pH of less than 5.5 in the oral environment leads to tooth enamel dissolution [30]. With regard to the present study, no bottled water poses such a threat. Additionally, a pH of less than 6.7 demineralises tooth dentine [31]. 100% of bottled waters herein were erosive to tooth dentine. A similar study conducted in Australia found that 81.0% of bottled waters were erosive to tooth dentine [32].

EC and TDS are parameters used to distinguish differences in mineral water. The chemical quantity of bottled water is influenced by its source. The chemical content depends on the readiness of mineralizing agents [33]. However, EC is not usually reported on the bottle label. Herein, EC has been computed due to the macro-composition of the mineral water. Electrical conductivity describes the ability of water to conduct an electric current and provides the degree of mineralization of water. MS 560 and MS 699 recommend maximum values of 400 μScm^{-1} and 1500 μScm^{-1}, respectively. With regard to the present study, EC (4.59 – 90.15 μScm-1) in all brands complied with both MS 560 and MS 699 drinking water guidelines (Table 1). For all brands, B2 registered the lowest EC. This is attributed to its low ionic concentration. Similarly, the highest EC value for B1 is attributed to its high ionic concentration, and the same is applicable to TDS because EC and TDS are linked. A similar study conducted in Bushehr city, Iran, reported EC values for commercial bottled drinking water that were below the Iranian National Regulation guidelines (INR) [20].

TDS shows how much salt is present in drinking water. TDS concentration in water varies in various geological locations depending on the solubility of minerals [34]. For instance, Kulmann et al. [35] note that phosphorus (P) is strongly adsorbed to iron, aluminum, and manganese oxides in weathered soils and reduces the P uptake by plants, and according to Liao et al., [36], labile carbon input has the possibility to alter soil organic carbon mineralization. TDS ranged from 2.28 mg/L to 44.90 mg/L (Table 1). In accordance with MS 560 and MS 699, all the bottled waters were within the permissible limit. From Table 1, it is evident that there is a variation between EC and TDS. The source of the water and treatment/purification method could explain this variation. A TDS value of less than 600 mg/L renders the palatability of water healthy. Nevertheless, a TDS value of greater than 1000 mg/L makes drinking water unpalatable [37]. In this regard, all the bottled waters herein are deemed palatable.

TABLE I. PHYSICO-CHEMICAL RESULTS (MEAN VALUES±SD)

	B1	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**
K (mg/L)	0.92±0.65	0.04±0.03	0.1±0.14	0.2±0.17	0.92±0.73	0.6±0.53	0.11±0.06
Na (mg/L)	10.25±4.58	0.93±0.63	3.12±0.36	5.02±2.20	5.94±2.00	3.9±2.20	1.43±0.60
Mg (mg/L)	7.91±3.76	0.69±0.02	0.97±0.84	1.59±0.70	1.84±1.15	1.47±0.82	0.69±0.33
Ca (mg/L)	89.34±98.24	14.21±15.84	15.99±19.10	19.57±20.94	28.39±30.01	18.74±21.45	12.15±13.25
pH	6.2±0.92	6.5±1.41	6.3±0.60	6.2±0.37	6.6±0.33	6.4±0.80	6.6±0.02
EC (μScm^{-1})	90.15±36.42	4.59±1.65	18.19±13.17	22.98±5.54	29.25±11.53	20.07±8.82	6.54±2.50
TDS (mg/L)	44.9±17.82	2.28±0.81	9.1±6.65	11.5±2.83	14.6±5.80	10.2±4.67	3.45±1.48
NO_3^- (mg/L)	4.3±1.01	0.98±0.11	0.85±0.21	2.36±0.16	1.03±0.23	0.58±0.32	0.82±0.36
F^- (mg/L)	0.29±0.16	0.02±0.01	0.09±0.07	0.09±0.06	0.15±0.09	0.11±0.05	0.04±0.02
Cl^- (mg/L)	34.8±14.23	20.45±7.08	16.25±2.25	15.62±0.00	21.86±0.03	20.12±1.49	20.54±5.24

Anions

Chloride ranged from 15.62 mg/L to 34.80 mg/L (Table 1). All bottled water brands complied with MS 560 and MS 699 drinking water guidelines of 150 mg/L and 200 mg/L, respectively. A similar study conducted by Chidya et al. [21] reported chloride values that were within the permissible limit set by MS 560 and MS 699 for bottled drinking water. The presence of chloride in natural water is limited. However, chloride emanates from agricultural runoff, rocks, wastewater from industries, and wastewater from treatment plants [38]. There is no drinking water guideline for chloride set by WHO because the levels existing in the drinking water industry pose no health concern.

However, it should be noted that chloride values in drinking water of greater than 250 mg/L change the taste of water [37]. Herein, chloride levels in all the bottled waters were below 250 mg/L, hence expected to give good taste.

Nitrate ranged from 0.58 mg/L to 4.30 mg/L (Table 1). It should be noted that MS 699 gives no drinking water guideline value for NO_3^-. MS 560 recommends a maximum nitrate value of 50 mg/L. With respect to the current study, all bottled waters complied with MS 560. High nitrate drinking water is associated with the risk of methemoglobinemia, especially for children [39]. The WHO [37] recommends NO_3^- guideline and short exposure taste threshold value of 50 mg/L to offer protection against methemoglobinemia and thyroid effects to children in the lactation period. Herein, all the bottled waters were within the permissible NO_3^- taste threshold value set by WHO. Our results agree with the work reported by Taiwo et al. in Nigeria [40].

Fluoride ranged from 0.022 mg/L to 0.29 mg/L (Table 1). MS 560 recommends a maximum fluoride value of 0.2 mg/L for natural mineral water. B4, being natural mineral water, complied with the MS560 drinking water guideline. MS 699 recommends a maximum fluoride value of 1.0 mg/L, and all the brands complied with this specification. Fluoride in water may occur naturally and from fluorine-rich minerals through water-rock interaction [41]. Fluoride concentration of 1.0 mg/L has a beneficial impact on the development of children's teeth. [42]. The WHO [37] recommends a guideline value of 1.5 mg/L fluoride in drinking water. As such, all bottled waters complied with the WHO specification. Our results are in agreement with those reported by Das et al. [11] and Fard et al. [20]. It should be noted that concentrations above 1.5 mg/L damage children's teeth, causing staining cavities, a condition referred to as dental fluorosis [42]. Artificial fluoridation (0.5-1.0 mg/L), such as the use of fluoridated toothpaste, is required for drinking waters with low fluoride content. Consequently, all bottled waters require artificial fluoridation as a result of their low fluoride concentration.

Cations

Potassium ranged from 0.04 mg/L to 0.92 mg/L (Table 1). MS 560 and MS 699 recommend potassium standard values of 12 mg/L and 50 mg/L, respectively. All brands complied with MS 560 and MS 699. Similar K concentrations (0.1 – 7.0 mg/L and 0.2-7.1 mg/L) have been reported by Kermanshahi et al. [14] in Iran and by Chidya et al. [21] in Malawi, respectively. The WHO has no fixed health guidelines for the amount of potassium consumed through drinking water that would be regarded as safe. However, people on low-potassium diets are more likely to suffer from strokes, high blood pressure and diabetes than those whose potassium intake is enough [42].

Sodium presence in bottled water may result from the treatment of reverse osmosis followed by sodium carbonate and sodium bicarbonate [43]. Sodium in drinking water is of health concern, especially to those people who have heart disease, hypertension, and kidney disease due to the inability to maintain the optimum body balance of sodium [44]. Sodium ranged from 0.93 mg/L to 10.25 mg/L (Table 1). All brands complied with MS 560 and MS 699 drinking water guidelines of 150 mg/L and 200 mg/L, respectively. Similar findings have been reported in Alkoms city [45]. The WHO recommends sodium consumption in drinking water of not more than 20 mg/L to people suffering from hypertension or those on a sodium-controlled diet [42]. In this regard, all brands are suitable for people having such health problems.

Calcium and magnesium are the major elements in rocks and soil, and their main sources are Ca- and Mg-bearing minerals [38]. Calcium is a constituent of bones and teeth and is essential for conducting myocardial system, heart and muscle contractility, and blood clotting. Water low in calcium is linked to a higher risk of fracture in children [46]. Calcium ranged from 12.15 mg/L to 89. 34 mg/L (Table 1). All brands complied with MS 560 and MS 699 calcium drinking water guidelines of 100 mg/L and 150 mg/L, respectively. Similar results have been reported in Bushehr city, Iran [20]. The WHO [37] recommends a taste threshold range of 100-300 mg/L for calcium.

Magnesium behaves as a natural antagonist of calcium. Magnesium ranged from 0.69 mg/L to 7.91 mg/L (Table 1). All brands complied with MS 560 and MS 699 drinking water guidelines of 50 mg/L and 70 mg/L, respectively. A laxative effect emanates from drinking water having high levels of magnesium and sulphate (>250 mg/L) [37]. With respect to our study, no brand possesses laxative effects.

Total hardness

Water hardness emanates from the presence of calcium and magnesium salts in water. When water is referred to as 'hard,' it implies that it has more minerals (Ca and Mg). Water hardness classification is given in Table 2. According to Table 2, B2, B3, B4, B6 and B7 are classified as soft. B5 is classified as moderately hard, and B1 is classified as very hard. The results of this study also agree with Loloei and Zolala [47] and Chidya et al. [21], who reported some of their bottled water samples as hard water. It should be noted that consumption of soft water (<50 mg/L) is harmful to the body because it robs off the body's minerals [48]. Loss of minerals is associated with osteoporosis, osteoarthritis, hypothyroidism, and high blood pressure. Brands B2, B3, and B7 may pose such health risks. Excess consumption of magnesium salts may cause a temporary adaptable change in bowel habits (diarrhea) but rarely causes hypermagnesaemia in people with normal kidney functions. Consequently, consumption of B1 may bring such health problems.

TABLE 2. CLASSIFICATION OF THE WATER HARDNESS COMPARED TO THE CURRENT STUDY (WHO, 2011; Lenntech, 2017).

Conc. Range (mg/L $CaCO_3$)	**Hardness Classification**	**Comparison with this study: Brand (Hardness, mg/L $CaCO_3$)**
<60	Soft	**B2** (38), **B3** (44), **B4** (55), **B6** (53), **B7** (33)
60-120	Moderately hard	**B5** (79)
120-180	Hard	-
>180	Very Hard	**B1** (256)

B. Analyzed Parameters Compared to Values on Bottle Labels

A comparison of the physico-chemical results with the claimed values on the bottled water labels is shown in Table 3. Four brands, B1, B3, B4, and B6, reported pH values slightly lower than claimed values on the bottle labels. All seven brands registered very low levels of TDS compared to claimed values. Despite the standard requirement by MS 560 and MS 699 for turbidity to be among the reported chemical composition of bottled water, all commercial bottled water brands in this study (100%, n = 7) did not report it. This is a serious breach of MS 560 and MS 699 specifications that demand accurate labelling of the chemical composition of bottled water products. Water brands B1 and B7 reported very low calcium values, while the actual analytical results were very high. Further, water brands B1 and B7 reported Mg, Cl-, NO_3^- and F^- values slightly higher than the claimed values on the bottle labels. Bottled water labelling errors were also noted for Na and K, where both undervaluing and exaggeration were recorded for water brand B1. The majority of the water brands (71 %, n = 7: B2, B3, B4, B5, B6) did not report exact concentrations of the chemical and physical parameters and instead opted to use less than symbol (<). This tendency was observed to be abused, for it is only recommended for TDS by MS 560. This might have been done deliberately to hide the actual composition of their brands. It was also observed that the majority (86 %, n = 7: B1, B2, B3, B5, B6, and B7) of the brands concealed information on sources of water used to produce their product and the type of treatment methods deployed during production.

The irregularities between the actual values reported and claimed labelled values on the bottled water may be attributed to either typographic errors or deliberate acts to hide the actual chemical composition of the bottled water products. Variation in the physico-chemical quality of the bottled water brands observed in this study possibly results from the treatment process, source water composition, changes in chemical and physical processes, for instance (co)precipitation emanating from exposure to light and storage of the bottles [21]. Dubious labelling and variation in the chemical composition of bottled drinking water have also been reported in Iran, Libya, Tanzania, and Italy [14,33,49,50].

C. Multivariate Analysis

Correlation analysis was used to describe the degree of relation between two water parameters. Correlation is defined as the ratio of the covariance of two variables to the product of the standard deviations [18]. 'Pearson r correlations' was used, and the results of the analyzed water quality parameters are given in Table 4. A number of parameters show strong correlations, signifying that they may come from the same source. The Pearson r correlation with a pre-established significance level of 1% (0.01) gave high significant correlation coefficient between Na and Mg (r = 0.906), Na and Ca (r = 0.904), Na and F- (r = 0.978), Mg and Ca (r = 0.997), Mg and NO3- (r = 0.916), Mg and F- (r = 0.945), Ca and NO3- (r = 0.901), and Ca and F- (r = 0.948). EC vindicates dissolved mineral solids. Higher EC values show that dissolved solids are present in higher content in the water [51]. Herein, EC and TDS had a strong correlation (r = 1.00), as shown in Table 4. This indicates that these constituents share the same source of high concentrations of major ions. Inorganic salts such as calcium, potassium, magnesium, sodium, and chloride make up TDS. TDS and EC correlate strongly with the following: Na (r = 0.953), Mg (r = 0.989), Ca (r = 0.987), NO3- (r = 0.899), and F- (r = 0.981).

TABLE 3. PHYSICO-CHEMICAL RESULTS REPORTED COMPARED TO CLAIMED VALUES.

Brand	Item	pH	TDS	Turb	Ca	Mg	Na	K	CL^-	NO^-_3	F^-
B1	CL	7.10	400	NA	0.30	2.30	12.50	0.00	36	1.54	0.00
	AL	6.2	44.9	0.61	89.34	7.91	10.2	0.92	34.80	4.30	0.29
B2	CL	6.5 - 8.5	<1000	NA	<150	<70	<200	<50	<200	NA	none
	AL	6.5	2.28	0.51	14.21	0.69	0.93	0.04	20.45	0.98	0.02
B3	CL	6.5 - 8.5	<1000	NA	<100	<50	<150	<12	<150	0	none
	AL	6.3	9.10	0.36	15.99	0.97	3.12	0.10	16.25	0.85	0.09
B4	CL	6.5 - 8.5	<1000	NA	<100	<50	<150	<12	<150	<50	<0.2
	AL	6.2	11.5	0.21	19.57	1.59	5.02	0.20	16.25	2.36	0.09
B5	CL	6.5 - 8.5	<1000	NA	<150	<70	<200	<50	<200	NA	none
	AL	6.6	14.60	0.16	28.39	1.84	5.94	0.92	21.86	1.03	0.15
B6	CL	6.5-8.5	<100	NA	<150	<70	200	<50	<200	NA	<1.0
	AL	6.4	10.2	0.72	18.74	1.47	3.90	0.60	20.12	0.58	0.11
B7	CL	6.8	5	NA	2.84	0.031	NA	NA	0.19	NA	0.002
	AL	6.6	3.45	0.41	12.15	0.69	1.43	0.11	20.54	0.82	0.04

TABLE 4. CORRELATION MATRIX FOR THE PHYSICO-CHEMICAL WATER QUALITY PARAMETERS

	K	Na	Mg	Ca	pH	EC	TDS	NO_3^-	F^-	Cl^-
K	1									
Na	.824*	1								
Mg	0.678	.906**	1							
Ca	0.697	.904**	.997**	1						
pH	-0.134	-0.631	-0.638	-0.602	1					
EC	0.732	.953**	.989**	.987**	-0.664	1				
TDS	0.733	.953**	.989**	.987**	-0.663	1.000**	1			
NO_3^-	0.452	.840*	.916**	.901**	-0.754	.899**	.899**	1		
F^-	.828*	.978**	.945**	.948**	-0.610	.981**	.981**	.817*	1	
Cl^-	-0.235	0.095	-0.094	-0.137	-0.396	-0.063	-0.064	0.265	-0.094	1

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

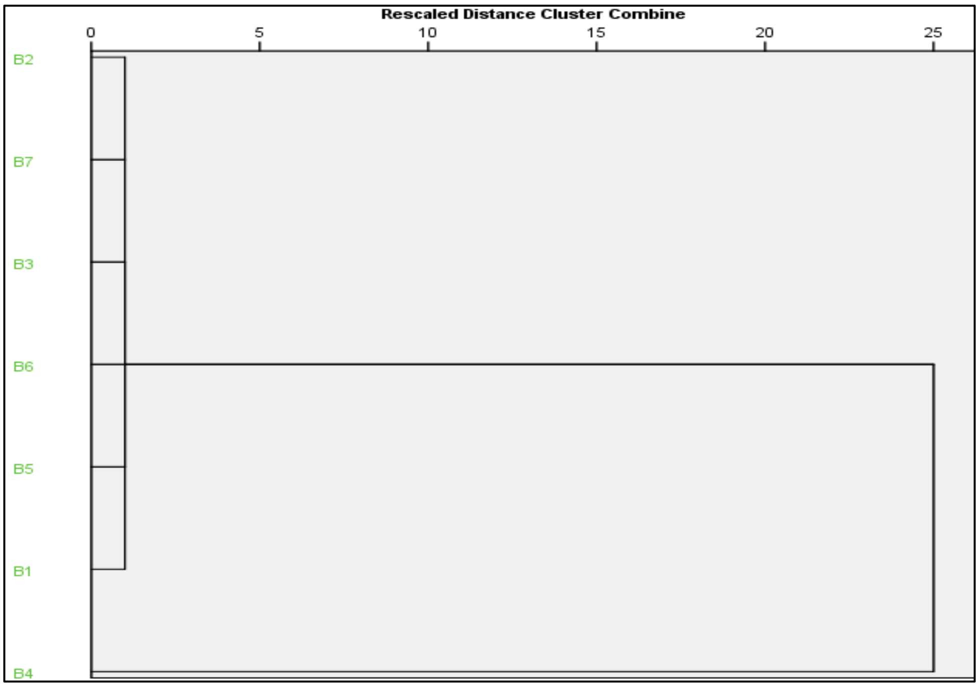

Fig. 2 Hierarchical cluster analysis dendrogram showing clusters of 7 bottled water brands with respect to their chemical composition

Hierarchical cluster analysis (HCA) was used to establish if the investigated bottled water brands can be grouped into statistically distinct clusters. Generally, HCA is applied to water chemistry data to check clusters of samples having similar physical and chemical characteristics. Ward's technique was used as an amalgamation to obtain the hierarchical associations. The results of the HCA are presented as a dendrogram in Figure 2. The dendrogram classifies the 7 brands into two major clusters based on the similarity of the measured water parameters. Cluster 1 is composed of 6 brands, mainly B1, B2, B3, B5, B6 and B7. From the results, it is evident that B4 had a unique chemical composition supported by its water source, the natural mineral water.

IV. CONCLUSIONS

This study investigated the physico-chemical characteristics of bottled drinking water marketed in Zomba city, Malawi. Compliance with Malawi Standards and World Health Organization drinking water guidelines and possible health concerns were investigated. The study highlighted how some bottled waters do not respect the drinking water guidelines for natural mineral water and non-mineral bottled water recommended by the Malawi Standards. Our results suggest that it is worth making an effort to analyze a wide range of elements and come up with comparable databases on water chemistry countrywide. Depending on the water sources, incorrect transportation, and storage, it is expected for water brands to give different concentration ranges for many elements. The study covered a good number of bottled water brands marketed in Zomba city. As such, all bottled waters marketed in the city should be monitored for quality control. Furthermore, the study recommends the inclusion of other parameters on the bottle label, such as NO_3^- (only B1 and B4 had NO_3^- on the label). Fluoridation should be considered for all brands with low fluoride concentrations.

CONFLICT OF INTEREST

The authors have no conflict of interest to declare.

ACKNOWLEDGEMENT

The authors acknowledge the technical support offered by the Department of Chemistry and Chemical Engineering of the University of Malawi.

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