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Comparative assessment of physico-chemical quality of bottled and tap water in Dar es Salaam, Tanzania

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ABSTRACT

Samples of various brands of bottled water sold in Dar es Salaam, Tanzania were analyzed for physico-chemical water quality parameters. For comparison purposes, tap water was similarly examined. The results showed great variations in physico-chemical quality of bottled water, with some samples exceeding the Tanzania Drinking Water Quality Standards for nitrate, pH and lead. Significant discrepancies were observed between the labelled and measured values for all the investigated parameters except for pH. Mean concentration values of TDS and nitrate in tap water were found to be significantly lower than those of bottled water. On the whole, this study suggests that bottled water offers little advantage over tap water except in terms of turbidity and colour.

Keywords: Drinking water, Mineral water, Water quality, contaminants, ground water.

INTRODUCTION

Bottled water obtained from boreholes and springs often found in mountain areas has been drunk in countries where the quality of rural or urban water supplies is suspect (Pip, 2000; Ferrier, 2001; Feru, 2004). Ferrier (2001), reports that bottled water is the most dynamic market of all the food and beverage industry with numerous bottled water companies competing on this market. Many consumers choose bottled water because they believe that it contains fewer contaminants and is a healthier choice, or because they dislike the taste of chlorinated tap water (Pip, 2000). Bottled water is perceived as pure and safe, although that may not necessarily be the case.

Even when quality of bottled water is good at the source, it may deteriorate through subsequent handling, transportation, and storage. Growth of microorganisms may occur via agencies such as introduced flakes of human skin, particularly with non-ozonated, non-carbonated waters (Kassenga, 2007). Bottling and packaging can contribute a variety of inadvertent chemical contaminants. Leaching of volatile and semi-volatile organic compounds from packaging materials into the water has been reported to increase with length of storage time, temperature, and exposure to sunlight (Pip, 2000).

Given the extensive consumption of bottled water, the question naturally arises of the long-term impact of waters of various chemical compositions on human health. It is reported that elements such as magnesium and calcium have been linked with reduced frequency of sudden death and osteoporosis, respectively, and both may exert protective effects against gastric cancer (Pip, 2000). High concentrations of sulphate in drinking water have been associated with gastro-intestinal effects such as decreased transit time. Nitrate is a common contaminant in

groundwater and has been implicated in gastric cancer mortality and other disorders. Through conversion to nitrite, nitrate is the causative agent of methemoglobinemia (blue-baby disease**)** in infants. Copper is an essential element in human nutrition, but it may reach high levels in tap water through contact with copper fittings. Guidelines for copper in drinking water are primarily aesthetic; at high concentrations taste of the water may be affected. Lead may cause devastating effects to the human health. Lead exposure is most serious for young children, because their growing bodies absorb lead more easily than adults and they are more susceptible to its harmful effects. Even low level lead exposure may harm the intellectual development, behaviour, size and hearing of infants.

In Dar es Salaam city, many people prefer bottled water because it is the only source of water they can trust in the face of the prevalence of many waterborne diseases, especially cholera, typhoid and bacillary dysentery. These diseases have become endemic in the city, prompting many residents to take precautionary measures against drinking water with questionable quality. Tap water in Dar es Salaam city is generally not considered safe for drinking purposes due to inadequate treatment and post-treatment contamination in the distribution system. Even water supply utility companies consider tap water in Dar es Salaam city unsafe for direct consumption (Kassenga, 2007). Presumably in recognition of the fact that tap water is prone to contamination, public health authorities and even utility companies themselves advocate boiling of tap water before drinking, as a precaution against contracting waterborne diseases.

Other sources of water such as shallow wells, dug wells, and open ditches are also considered to be unsafe for drinking purposes. This situation has caused the business of bottled water to flourish in the City. Since concentration levels of residual chlorine in water distribution systems are generally low (< 0.1 mg/L) (Kassenga, 2007), it is unlikely that taste imparted to tap water by chlorine is an important reason for preferring bottled water over tap water as is the case in developed countries (Pip, 2000; Ferrier, 2001).

Whether bottled water is better than tap water and whether this justifies its higher cost, is debatable. A study carried out in New York to compare popular brands of bottled water showed that they were in no way superior to New York tap water (Ferrier, 2001). Their only advantage was their being safe in areas where tap water may be contaminated. However, for low-income people bottled water is very expensive, and boiling local water renders it safe at a much lower cost (Latham, 1997). The price of bottled water is reported to be 500-1000 times higher than that of tap water (Ferrier, 2001). In Dar es Salaam, however, bottled water, sold at between US$0.20-0.40 per litre, costs between 87 and 174 times more than tap water, which costs 0.23 US cents (US$2.30 $\times$ 10^{-3}) per litre (Kassenga, 2007). Cheaper brands (< US$0.20 per litre) available in the market are normally packaged in plastic bags. However, in most cases water quality of cheaper brands packaged in plastic bags is questionable because production of counterfeits can easily be done at household level using simple packing and sealing technologies (Kassenga, 2007).

There is a bewildering array of bottled water brands offered for sale in Dar es Salaam city, which includes various domestic and a few imported spring and mineral waters, and tap water treated by ozonation, filtration and reverse osmosis. To compound the confusion, labelling is extremely variable. Label designs can feature attractive and enticing pictures of blue mountains or glaciers that may bear no relationship to the actual source of water. Description of the product often contains terms that imply purity such as “glacial”, “crystal”, “natural” or “pure”. Terms such as “sweet water” are also used to entice consumers. Some of the bottled water products in Tanzania are labelled “glacial” although it is obvious that sources of water for these products are not glaciers. Labels of some brands contain ambiguous information. For example, some brands of bottled water are referred to as “natural spring water” while in their specifications labels, methods used to treat the water are provided, which is in contradiction with proper use of the term “natural”. To boost the market for their products, some manufacturers put on their products health claims that do not have any

scientific backing. For example, one manufacturer claims that its product contains "all vital minerals to support metabolism". Notably, the water source is not always identified on the product label. Similarly, the chemical composition of the water may not be provided at all, or may be provided for only highly selected parameters. It is worth noting that most of the consumers in Tanzania are either ignorant or oblivious of the information provided on the labels and may not be able to make an informed choice before purchasing the products.

At the time of conducting the current study, there were about 38 brands of bottled drinking water available in Tanzania, which were registered by Tanzania Bureau of Standard (TBS). Some bottled water brands available in Dar as salaam are locally processed and bottled. The rest are obtained from Zanzibar (an island part of Tanzania) and Kenya. All bottled drinking water produced or offered for sale within Tanzania is required to comply with the regulations and principles specified by Tanzania Drinking Water Quality Standards Part 1 Sections 8 of 1999, established by Tanzania Bureau of Standards (TBS) (1999).

The objective of the study for which the current paper was prepared was to examine the physical and chemical quality of bottled water available in Dar es Salaam, Tanzania at outlet places. The assessment of the quality of the bottled water was done in terms of total dissolved solids, chloride, sulphate, nitrate, pH, lead, and copper with a view to determining how the measured values for these parameters correlated with the labelled product specifications. The study also compared the quality of tap and bottled water to find out if consumption of expensive bottled water is really justified.

MATERIALS AND METHODS

Study area

Dar es Salaam city was selected as the study area because it is the largest business centre in Tanzania, where about 30% of the total urban population is living. Dar es Salaam probably has the highest number of bottled water consumers than any other urban centre in Tanzania since about 57% of all bottled water companies are located in the City.

Sampling

Bottled water

Thirteen (13) different bottled water brands were selected, representing 42% of the total number (38) of bottled drinking water brands registered in Tanzania. The selection of brands was based on responses of their packagers and back suppliers. During initial screening, packagers and back suppliers were contacted and asked to provide information on their brands. Only those who responded positively and agreed to cooperate during the rest of the study were included. Samples of the selected bottled water brands were randomly purchased all over the City from retail shops, supermarkets, street vendors, and distribution centres. All the samples were taken to the laboratory and analysed immediately after being purchased without storage. The selected brands are hereinafter referred to as A, B, C, D, E, F, G, H, I, J, K, L and M. Physico–chemical information displayed on the label of the bottle was also collected during the study. The sampling process of bottled water was done randomly as specified by the Tanzania Standard for Drinking Water (TBS, 1999). The packaging materials for the sampled bottled waters were 330 ml - 1.5 l capacity plastic bottles and 250 ml capacity plastic bags.

A total of ten bottles for each of the identified brands were sampled and analyzed in the two months study period. Sampling was done three times at an interval of two weeks. For brands packaged in different sizes each of the available sizes was sampled and analyzed accordingly.

Consumer tap water

Sampling of tap water was done according to the WHO Guidelines for Drinking Water Quality Standards (WHO, 2004). Accordingly, external nozzles were removed from the tap, which was then allowed to run for about 5 min to clear the stagnant water in the service pipe. The tap was turned on again and then allowed to fill sampling bottles from a slow stream of water. Extreme care was taken to remove and replace the bottled cap in an aseptic manner. Samples from buildings were taken from a tap directly connected to the mains and not from those supplied from cistern.

Tap water samples were also taken both from fixed points, such as pumping stations

and tanks, and from random locations throughout the distribution system, including points near its extremities. Selected sampling points were those established in 2004 by Dar Es Salaam Water and Sanitation Authority (DAWASA). The number of sampling points established was 61 for those areas with piped water supply.

Analytical procedures

The parameters analyzed during this study include total dissolved solids (TDS), chloride, sulphate, nitrate, pH, lead, copper, turbidity and colour. Analysis of total dissolved solids (TDS), chloride, sulphate, nitrate, pH was done using methods specified in the Standard Methods of Water and Wastewater Examinations (APHA/AWWA/ WEF, 1998) and WHO Guidelines for Drinking Water Standard Methods (WHO, 1997). Lead and copper were analysed using an atomic Absorption Hydride System (HC 3000) from GBS Scientific Equipment (Arlington Heights, IL). The detection limit of this method is 0.5 ppb. Turbidity was measured by Nepherometric method using the Hach Turbidimeter Model 2100 (Hach Co., Loveland, CO) and colour was analysed by Platinum-Cobalt Standard Method using a portable spectrophotometer (DR 2010; Hach Co., Loveland, CO). Blanks and calibration checks were run to ensure that the analytical methods were accurate and reliable.

Statistical analysis

Statistical analysis tests, including ANOVA, were used to determine the variations of chemical constituents (TDS, chloride, sulphate, nitrate, pH, lead, copper, turbidity and colour) among bottled water brands. The *t*-test was used to determine the differences between chemical qualities of bottled water with that of tap water. The results were considered statistically significant if $p<0.05$.

RESULTS

According to the information displayed on labels, water for nine (9) of the brands surveyed is sourced from groundwater whereas that for the rest (4) is obtained from "natural spring" sources. However, the product labels did not specify whether the packaged groundwater was obtained from shallow or deep wells. All brands indicated expiration dates except for one brand. The most frequently listed parameter on the label was Cl, which was found on 11 brands. Other listed parameters were Na and sulphate (6 each), TDS and total hardness, nitrite, Al and Mn (1 each), Ca, pH and Mg (10 each), Fr and K (5 each), ammonia, bicarbonate and iron (2 each), and nitrate (9). Two brands provided no chemical data at all.

The quality of bottled water for the surveyed brands and the measured parameters is shown in Table 1.

Statistical analysis results for parameters of interest analysed for the sampled bottled water brands are presented in Table 2.

Water quality of tap water for the parameters analysed is presented in Table 3 along side with TDWQS for comparison purposes. It is apparent from table 3 that all observed parameter values are significantly lower than those specified by TDWQS.

Concentrations of the chemical constituents analysed are presented together with the labelled values for the bottled water products sampled in figure 1, for the purpose of comparing them.

DISCUSSION

The inconsistence in water quality information displayed on labels observed in this study has also been reported by Pip (2000) based on a survey of drinking bottled water conducted in Manitoba, Canada, which showed great variations in the amounts of information presented on the labels.

Pearson correlation coefficients showed significant positive correlations between TDS and chloride ($r^2=0.46$, $p=0.0001$) and between TDS and nitrate ($r^2=0.69$, $p=0.0002$). This observation affirms the fact that chloride and nitrate are indeed amongst the principal inorganic chemical constituents of TDS (Sawyer and McCathy, 1987). However, a weak positive correlation was observed between TDS and sulphate ($r^2=0.17$, $p=0.001$). This observation suggests that sulphate was not one of the principal inorganic constituents of TDS.

Although few parameters were found to exceed the recommended Tanzania Drinking Water Quality Standards, the results indicate

Table 1: Chemical laboratory analysis results for bottled and tap water.

Brand/Tap water	Mean and standard deviation values for water quality parameters				
	TDS (mg/L)	**Cl^- (mg/L)**	**SO_4^{2-} (mg/L)**	**NO_3^- (mg/L)**	**pH**
A	68.9 ± 0.07	30.0 ± 1.71	35.6± 1.54	0.4±0.03	7.0± 0.17
B	37.4± 3.18	36.1 ± 1.62	2.6± 1.18	3.5±0.66	7.1± 0.46
C	174.4± 2.45	73.0± 6.22	44.3± 5.42	2.7± 0.48	7.7± 0.44
D	306.1± 0.32	60.8± 8.02	1.6± 0.14	12.7± 0.17	7.6± 0.22
E	101.2± 2.00	53.0± 2.92	1.7± 0.14	3.2± 0.24	7.4± 0.26
F	125.5± 2.93	70.0 ± 1.04	20.7± 1.15	1.1± 0.29	7.3± 0.18
G	173.8± 10.64	36.7± 3.02	24.8± 3.73	1.0± 0.06	7.5± 0.36
H	174.1± 0.18	32.4± 1.03	1.6± 0.04	0.4 ± 0.04	7.5± 0.43
I	88.1± 0.76	35.0± 4.12	BDL	2.8± 0.08	7.2± 0.32
J	138.1± 0.79	24.0 ± 1.62	1.6± 0.15	0.1± 0.00	6.8± 0.45
K	248.3± 8.63	36.2±1.91	4.3± 0.53	7.0± 0.56	8.7± 0.13
L	136.9± 0.63	25.1± 2.04	3.3± 0.18	3.8± 0.08	7.3± 0.24
M	151.7± 0.66	77.0± 1.54	114.0 ± 0.14	3.9± 0.40	6.8± 0.17
TDWQS	***≤1000***	***≤250***	***≤400***	***≤10***	***6.5 to 8.5***

TDWQS: Tanzania Drinking Water Quality Standards, BDL = below detection limit, NM = not measured. Note: Number of samples per brand for each parameter, $n = 10$.

Table 2: Summary of statistics of water chemistry parameters for the tested bottled water samples.

Parameter	Mean ± SE	Coefficient of variation (%)	Minimum	Maximum
TDS (mg/L)	148.1 ± 69.58	47.0	26.0	307.0
Chloride (mg/L)	45.3 ± 18.41	40.6	22.0	80.0
Nitrate (mg/L)	3.3 ± 3.33	100.6	0.04	14.9
Sulphate (mg/L)	13.0 ± 15.34	118.4	1.5	54.0
pH	7.4 ± 0.52	7.0	6.5	8.9

Number of samples, $n = 130$

Table 3: Summary of analytical results for tap water.

Parameter	Mean ± SE	Tanzania Drinking Water Quality Standards (TDWQS)
Turbidity (NTU)	14.3 ± 12.54	≤ 25
Colour (mg-pt/L)	18.0 ± 5.93	≤ 50
TDS (mg/L)	85.1±11.54	≤ 1000
Chloride (mg/L)	62.5 ± 17.13	≤ 250
Nitrate (mg/L)	1.6 ± 0.62	≤ 10
pH	7.1±0.55	6.5 to 8.5

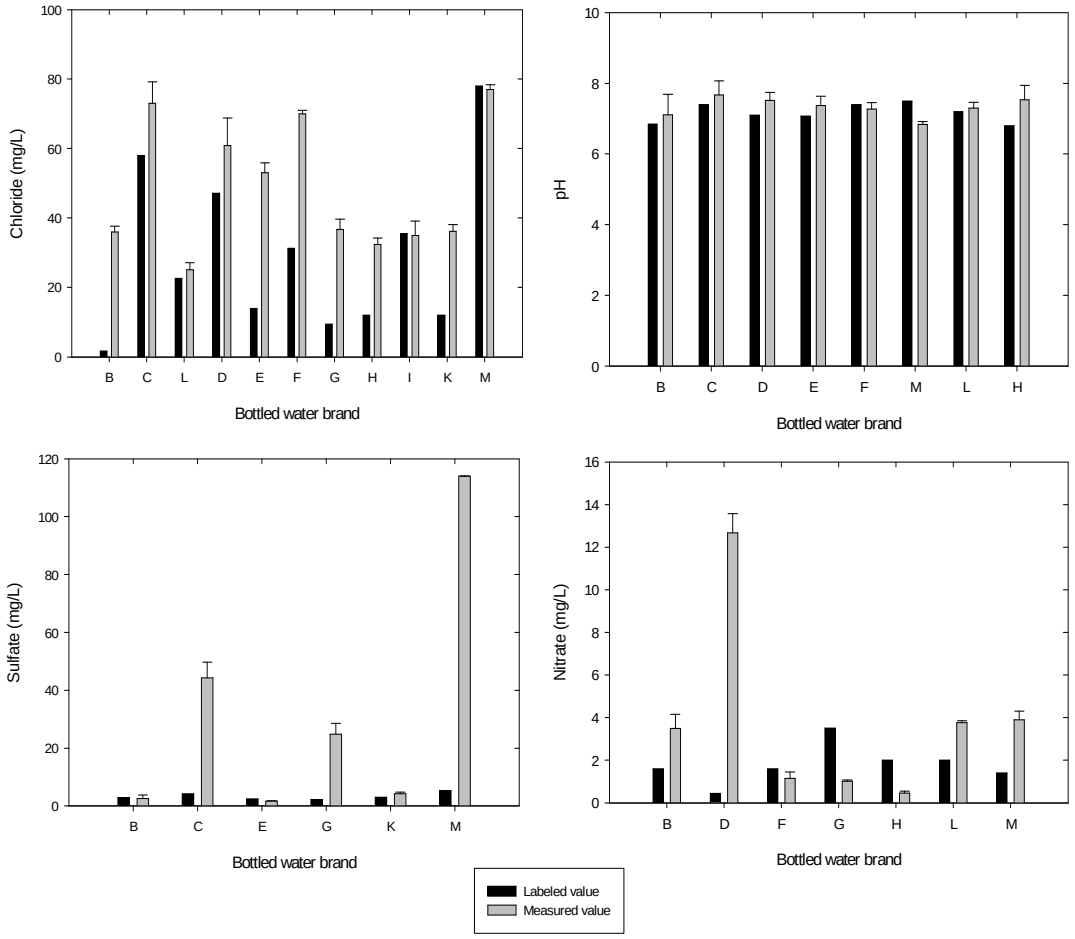

Figure 1: Comparison of measured and labelled values for selected parameters. Histograms represent means of results from analysis of ten samples and labelled values. Error bars indicate the range of results of measured parameters for individual brands.

that the quality of bottled water was generally good (Table 1). The mean chloride concentrations observed for all bottled water brands were found to lie within the recommended maximum Tanzania Standard Guideline value of 250 mg/l. Brand K had a mean pH value of 8.7 ± 0.13, which falls outside the Tanzania Drinking Water Quality Standard recommended range of 6.5 to 8.5. Unlike for all the other surveyed brands, no information on pH was displayed on the label of this brand (K). For nitrate (Table 1), Brand D exceeded the Tanzania Drinking Water Quality Standard of 10 mg/l. It is noteworthy that nitrate has been implicated in gastric cancer, mortality and other disorders (Yang et al., 1998). Only Brand D and K qualified to be categorized as "mineral water" according to the Tanzania Drinking Water Quality Standard, which specifies that mineral water should have a TDS value of more than 250 mg/l. This specification is in line with the definition of mineral water given by Chappelle (2005). According to this definition, bottled water can only qualify as mineral water if it is obtained from a protected underground formation, has a TDS content greater than 250 mg/l and contains no added minerals (Chappelle, 2005).

Although Brand H was labelled as mineral water it had a TDS concentration of 174.1 ± 0.18 mg/l, which is significantly below the recommended value of 250 mg/l. Interestingly, although Brand H was labelled as "natural mineral water" no TDS value was displayed on the label. Generally, the

designation "mineral water" was not always correctly applied, nor was this label found on waters observed to have high TDS (Brands D and K). Brand D exceeded the Tanzania Drinking Water Quality Standard of 50 µg/l for lead, and the rest were below the detection limit of 0.1 µg/l. Copper concentration levels were inconsequential for both bottled and tap water compared to the Tanzania Drinking Water Quality Standard limit of 1 mg/l, with the highest sample concentration being only 53 µg/l.

The concentrations of most of the chemical constituents analysed were higher than the labelled values for most of the bottled water products (Figure 1). A comparison of measured and displayed values using the *t*-test showed that measured values averaged significantly higher for chloride ($p=0.02$), sulphate ($p=0.03$) and nitrate ($p=0.01$) than the labelled values. However, the labelled pH values were statistically not different from the observed values ($p=0.121$). The labelled quality specifications are normally for water as obtained at the source, but the source may vary in quality over time. These discrepancies between the labelled and observed concentrations of the bottled water constituents probably also signify that post packaging conditions, especially temperature, affect the constituent concentrations of water in the bottle during distribution to the consumers considering that temperatures in Dar es Salaam may be as high as 33 ºC.

In 61.5% of the brands surveyed the sum of the concentrations for the parameters listed on the label exceeded the measured TDS value. It is noteworthy that variations in concentrations of water constituents within the same brand were not substantial, with 88.5% of the brands having coefficient of variation values for the parameters measured of less than 10%.

ANOVA tests showed statistically significant brand differences for most of the measured parameters ($p<<0.05$), which is in close concurrence with the findings reported by Pip (2000). These statistical analysis results show that the constituents of the thirteen bottled water brands available in Dar es Salaam markets were not uniform (Table 2). These variations may be interpreted in terms of type of treatment processes involved, the type of water source and variations in water quality at the source. Likewise, the results indicate that the quality of water in the bottles for the 13 brands are significantly different, meaning that the bottled water brands available in the city differ in quality. The long-term health effect of consuming bottled water with significant variations in water quality is a subject of future research.

With respect to treatment, three of the water brands were ozonated only, one was treated using both ozonation and reverse osmosis, whereas another was filtered and sterilised. The rest of the surveyed brands (8) did not indicate on the labels the methods used for treatment of water. The ozonated and the non-ozonated water brands exhibited statistically significant differences with respect to nitrate-N ($p<<0.05$), with a tendency for higher nitrate – N concentrations to occur in the ozonated water brand samples, which is in contrast with the observations made by (Pip, 2000).

The Tanzania Bureau of Standards (TBS) requires the quality and types of packaging materials used for bottled water to be the same as those for packaging food products. The TBS specifications stipulate that bottled drinking water must be packaged in hermetically sealed sterilized retail containers suitable for preventing possible contaminations. Plastic is the most commonly used type of packaging material for bottled drinking water in Tanzania. The types of plastic material used include polyester-terephthalate (PET) and high-density polyethylene (HDPE) for bottles and low-density polyethylene (LDPE) for plastic bags. Most of the caps used are made from HDPE. The Tanzania Drinking Water Specifications TZS 574 (Part 1, Section 7.2) stipulates that bottled drinking water must be packaged in various units and up to 2 l containers and stored away from direct sunlight (TBS, 1999). Bottled water available in Dar es Salaam is packaged in bottles with capacities ranging from 250 ml to 5 l. Plastic bags normally have a capacity to carry 250 ml of water. It was observed that for some brands water was packaged in bottles, which exceed the TBS specifications. Leaking is a common problem due to defective sealing of the bottles contrary to the specifications given by TBS. A study on microbiological quality of packaged drinking water sold in Dar es Salaam showed that

plastic-bagged water had higher rate of contamination than bottled water because the former is more susceptible to puncturing and consequently contamination of the water inside than the latter (Kassenga, 2007).

The mean TDS concentration in tap water (Table 3) was found to be 85.1 ± 11.54 mg/l (n=61), which is lower than that of bottled water (148.1 ± 69.58 mg/l) (Table 2). Mean nitrate concentration in tap water (Table 3) was 1.6 ± 0.55 mg/l (n=61) whereas that of bottled water was 3.3 ± 3.33 mg/l (Table 2). Therefore, bottled water offers no quality advantage over tap water with respect to TDS and nitrate.

Nitrate is generally encountered in water impacted by intensive livestock production, fertiliser application, or onsite excreta disposal facilities, especially pit latrines and septic tank systems. Pit latrines and septic tank effluents are probably the important sources of nitrate in groundwater since over 85% of the Dar es Salaam residents use these systems (Mato, 2002; Chaggu, 2004). Nitrate concentration levels in groundwater in some places have been reported to exceed the Tanzanian Drinking Water Quality Standards (10 mg/l) (Mato, 2002). The fact that 69.2% of the brands in this study were sourced from groundwater may partly explain the observed higher nitrate concentration in bottled water compared to tap water, which is obtained from surface sources. Nitrate concentrations in bottled water obtained from groundwater were found to be significantly higher compared to bottled water from spring sources (p=0.009).

However, the mean chloride concentration in bottled water (45.3 ± 18.41 mg/l) was observed to be lower than that of tap water (62.5 ± 17.13 mg/l; n=61). The largest difference between bottled water and tap water was in terms of turbidity and colour. Bottled water was observed to be free from turbidity and colour, as one would expect. On the other hand, tap water was found to have mean turbidity and colour of 14.3 ± 12.51 NTU and 18.0 ± 5.93 mg-pt/l (n=61), respectively (Table 3). Nonetheless, these values are below the Tanzania Drinking Water Quality Standards recommended maximum acceptable levels of 25 NTU for turbidity and 50 mg-pt/l for colour. In view of this, bottled water offers a slight advantage over tap water with respect to turbidity. It is noteworthy that in some places in Dar es Salaam city turbidity makes tap water objectionable for drinking to most consumers. There was no significant difference in pH values between bottled water and tap water (p=0.355). One sample of brand D contained lead concentrations of 5.3 µg/l, which is slightly higher than the Tanzanian Drinking Water Quality Standards recommended maximum value of 5 µg/l. On the other hand, lead was below the detection limit of 10 µg/l in tap water.

According to Kassenga (2007), microbiological analysis showed that total and faecal coliform bacteria were present in 4.6% and 3.6%, respectively of the bottled water samples analysed (Kassenga, 2007). The degree and rate of contamination suggest a need to be cautious and vigilant to avert the possibility of an outbreak of waterborne diseases from these types of drinking water.

Conclusion

Based on this study, bottled water does not have any quality advantage over tap water except in terms of turbidity and colour. This little quality advantage of bottled water over tap water is further weakened by the fact that, in this study, most of the samples of both bottled and tap water met the Tanzania Drinking Water Quality Standards for the investigated parameters. This study has also revealed the need for more stringent control of the bottled water market, particularly with regard to labelling and monitoring of the quality. This is meant to enable consumers to make an informed decision when purchasing bottled water and ensure that packagers do not make false claims on the labels of their products and thus mislead the consumers.

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