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Physico-Chemical Analysis of the Bottled Drinking Water available in the Dhaka City of Bangladesh

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Abstract

Nowadays quality and suitability of water are of great concern because of various water borne disease and fatal unhealthy impacts on human health. Such concern is one of the reasons of opening of bottled water in Bangladesh. Public belief that bottled water is free from germs and unhealthy entities. As bottled water is marketed by various companies, it is essential to check whether these waters are really safe for public health or not. Convinced on it, the present study has investigated the physico-chemical properties of the bottled drinking water available in the Dhaka city of Bangladesh. The purpose of this study is to investigate the physico-chemical property of bottled drinking water currently available in Dhaka city, Bangladesh. Six different branded water samples were collected from market for this purpose. The investigated parameters were mainly- pH, Electrical conductivity (EC), Total dissolve solid (TDS), Dissolve oxygen (DO), and Total hardness (TH) accompanying with, Chloride (Cl^-), Nitrate (NO_3^-), Sulphate (SO_4^{2-}), Iron (Fe^{2+}), Calcium (Ca^{2+}) and Magnesium (Mg^{2+}) ions using standard analytical techniques available in the laboratory. It was observed that the concentration of like parameter is quite different from sample to sample. The parameter values found to be in the range of pH (6.11-6.83), EC (38.4-493.0 μS/cm), TDS (25.0-295.80 mg/L), DO (6.88-8.76 mg/L), TH (1.5-228.0 mg/L), Cl^- (0.24-2.69 mg/L), NO_3^- (0.11-2.98 mg/L), SO_4^{2-} (0.04-110 mg/L), Fe^{2+} (2.25-3.2 mg/L), Ca^{2+} (4.90-17.01 mg/L) and Mg^{2+} (0.25-7.27 mg/L. The findings are informing that except the pH, DO and Fe^{2+} values, all other parameter values are quite low and appeared within the World Health Organization (WHO) and Bangladesh Drinking Water Quality Standard (BDWQS) limit.

1. Introduction

Water is a useful resource for domestic, industrial and agricultural purposes and plays a vital role in body metabolism and proper functioning of the cells [1]. Despite this fact, water pollution and fresh water depletion are the two main environmental problems in the Asian region [2]. The economic burden of environmental degradation owing to water pollution is very huge in the Asia-Pacific region when it comes to restoring the quality of life and installing controls [3]. In the South Asian region, particularly Bangladesh, pollution of surface water has become a threat in urban areas especially in the Dhaka city. It is known that surface water of the country is mainly polluted from untreated industrial effluents, municipal waste water, runoff remaining pesticides, oil and lube spillage etc. [4-5].

According to the World Health Organization (WHO), 89% of the world population consumes drinking water from improved drinking water sources [6]. Improved drinking water sources include piped treated water connections, public standpipes and protected dug wells [7]. However, improved drinking water sources can still be contaminated by heavy metals from various sources [8]. Bottled drinking water consumption has been steadily growing in all parts of the world for the past 30 years, and it is now the most dynamic sector of the entire food and beverage industry. Globally, consumption has increased by an average of 12% per year, in spite of its high unit price compared with tap water [9]. Worldwide demand of drinking water is increasing because of increasing population. Drinking water must be free from chemicals and microbial contaminations because these are risk to human health. Good quality drinking water is essential for the well-being of all people. Therefore for the benefit of public health, it is important to analyze the physical and chemical properties including the trace element contents of natural water [10]. Moreover, water quality control is a crucial part of environmental pollution studies [11-12]. Thus investigations on the quality of drinking water and concurrently on the environmental pollution have been going on worldwide. But the real fact is that despite having the WHO's guidelines for drinking water quality [13], water pollution has been increasing in the most of the countries over recent decades [14-16].

Dhaka is the capital of Bangladesh and the center of the country. Most of the people of this city are highly dependent on the water supplied by the Water and Sanitation Authority (WASA) of the country. It is open secret that the quality of WASA water needs some treatment before drinking. Therefore, citizens boil WASA water to drink. Recently, bottled water is widely using by the citizens as healthy drinking water. Bottled waters are producing and marketing by various Governmental and private companies. Peoples/citizens are considering it potable. Therefore, bottled water should be free from contaminants as it was it couldn't cause any adverse effect on the human health. However, the companies are claiming that they are producing bottled waters through series of treatments and then packages in plastic/poly bottles.

The adverse effect to human health in associated with the selected metal (Ca, Mg and Fe) in the water samples has also been studied. A study was carried out to examine the relationship between the levels of magnesium in drinking-water and the risk of delivering a child of very low birth weight (birth weight less than 1500 g). There was a significant trend towards a decreased risk of having a child of very low birth weight with increasing magnesium levels in drinking-water [17]. It was hypothesized that magnesium supplementation can reduce smooth muscle contractibility and tone and that this effect can be clinically manifested by a reduction in blood pressure and a reduction in the incidence of premature delivery. A similar study was conducted on the relationship between the levels of calcium in drinking-water and the risk of delivering a child of very low birth weight by the same group in Taiwan, China. The results suggest that there is significant protective effect of calcium intake from drinking-water on the risk of delivering a very low birth weight baby [18].Chronic iron overload results primarily from a genetic disorder (hemochromatosis) characterized by increased iron absorption and from diseases that require frequent transfusions [19].

Although in Bangladesh it is mandatory to register brands of bottled water for quality production, there are influxes of replica brands into the markets which may be posing threat to the people's health. It is mentionable that bottled water becomes the highest consumable commodity especially for the middle and high income/social classes in the city areas. Since bottled waters are processing and producing from different water sources, is important to examine their quality. Convinced on it, the present study has attempted to investigate on the physico-chemical quality parameters of different branded bottled drinking waters usually consuming by the peoples of the Dhaka city, Bangladesh. Attempt also taken to compare the findings among the chosen brands as well as with the prescribed Bangladesh Drinking Water Quality Standards (BDWQS) and WHO standards.

2. Experimental details

2.1. *Sample collection and analysis*

Six different branded drinking water samples were collected randomly from different grocery stores of Dhaka city, Bangladesh. To keep the brand names anonymous, the samples were coded from A to F. Two bottles of water (2.0 L) of each brand were used to analyze the selected parameters- pH, Electrical Conductivity (EC), Total Dissolved Solid (TDS), Dissolved Oxygen (DO), Total Hardness (TH), Cl^-, SO_4^{-2}, NO_3^-, Fe^{2+}, Ca^{2+} and Mg^{2+}. For the determination of pH, EC and DO, pH meter (Orion 4 star), Electrical conductivity meter (EC 214, HANNA instruments) and DO meter (HQ 30d, HACH) was used. Chloride (Cl^-) was determined titrimetrically [20]. EDTA titration method was used for TH determination [21]. Sulphate (SO_4^{-2}) and Nitrate ($NO_3^{-)}$ were measured by using UV-VIS Spectrophotometer (Shimadzu 3401). The metals stands as ions (Fe^{2+}, Ca^{2+} and Mg^{2+}) were determined by Atomic Absorption spectrophotometer (Shimadzu AA-6800) using air/acetylene flame. All the samples were stored at room temperature (25 – 30^0C). The analyzed samples were within their 1-6 months of the date of production/manufacture.

2.2 S*tatistical analysis*

For carrying out statistical analysis of the obtained data's of the bottled waters, a correlation was developed between the parameters by applying Karl Pearson's coefficient of correlation. MS Excel was-used to find out the Mean, Standard deviation (SD) and Median of the data's.

3. Results and Discussion

3.1 Classification of bottled Water brands

Different hydro-chemical classification systems are available to classify water types. In the present case, the European Union (EU) mineral water directive [22] was used to classifying the investigated water by evaluating the obtained TDS and TH values. Classification systems also used to identifying the chemical similarities and/or differences among the water brands. The EU mineral water directives for the criteria of chemical composition are presented in the Table 1. From the Table, it is understandable that the criteria was formulated based on TDS accompanying with the concentration levels of cations and anions. Table 2 shows the classification of presently observed data's for bottled water arranged according to the EU mineral water directive. It may be seen that the coded brand E is falling in the "very low mineral concentration" class as the TDS value found to be 25 mg/L whereas the coded brands A, B, C, D and F are falling in the "low mineral concentration" class. On the other hand, coded brand A, B, D and E are falling into the soft water category as the observed TH values are within the concentration range of 0-50 mg/L. The brand C is considered to be moderately hard water and brand F is considered to be as hard water as their observed values are within the concentration ranges of 0-50 mg/L and 100 mg/L, respectively.

Table 1: Classification of water based on EU mineral water directive

Water type	Criterion
Very low mineral concentration	Mineral content (TDS) < 50 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 drinking water based on TDS and TH in mg/L (Present study)

Brand code	TDS	EU Class	TH	Water class
A	78	Low mineral concentration	46.0	Soft
B	72	Low mineral concentration	50.0	Soft
C	103	Low mineral concentration	76.4	Moderately hard
D	52	Low mineral concentration	1.5	Soft
E	25	Very low mineral concentration	2.0	Soft
F	296	Low mineral concentration	228.0	Hard

3.2 *Physical and Chemical properties study*

3.2.1 *pH*

It was mentioned earlier that the pH of the water samples were determined by Orion 4 star pH meter. The observed pH values including other data's are placed in Table 3. From the Table, it may be seen that the pH values appeared in between 6.11-6.80 with a median of 6.33. It signifies that all the water samples are slightly acidic. Table 4 represents the values of different parameters of drinking water of BDWQS and WHO. From the Table 3 and 4, it may be seen that only the water of the coded brand D stands in the recommended pH value of BDWQS and WHO whereas water of the coded brands A, B, C, E and F stands out of the range of recommended values, i.e., accepted values.

Table 3: Concentration of major constituent of bottled drinking water brand (Present Study)

Parameter	Brand Code						Mean	Min.	Max.	SD	Median
	A	B	C	D	E	F					
pH	6.11	6.47	6.17	6.83	6.44	6.29	6.38	6.11	6.80	0.27	6.33
EC, µS/cm	130.20	120.20	172.10	86.10	38.40	493.00	173.30	38.40	493.00	176.50	151.10
TDS, mg/L	78.00	72.10	103.20	51.60	25.00	295.80	104.30	25.00	295.80	105.40	90.60
DO, mg/L	7.28	6.88	7.47	8.76	7.75	7.76	7.65	6.88	8.76	0.69	7.56
TH, mg/L	46.00	50.00	76.40	1.50	2.00	228.00	67.06	1.50	228.00	90.04	58.65
Cl^-, mg/L	1.06	0.31	0.63	0.27	0.24	2.69	0.87	0.24	2.69	1.00	0.75
NO_3^-,mg/L	0.20	0.23	2.98	0.13	0.11	0.15	0.52	0.11	2.98	1.21	0.21
SO_4, mg/L	0.04	0.66	16.00	0.15	0.10	110.00	21.11	0.04	110.00	44.00	8.33
Fe^{2+}, mg/L	2.45	2.25	3.20	3.15	2.90	2.80	2.70	2.25	3.20	0.38	2.80
Ca^{2+}, mg/L	8.94	4.90	5.35	5.36	5.35	17.01	7.82	4.90	17.01	5.01	5.30
Mg^{2+},mg/L	0.30	1.94	2.03	0.25	0.27	7.27	1.96	0.25	7.27	2.92	1.97

3.2.2 *EC and TDS*

From the Table 3, it may be seen that the EC values of the bottled waters are appeared to be in the range of 38.4–493.0 µS/cm. The gap in between the lowest and the highest EC values is wide enough and the median is 173.3 µS/cm. It is recognized that EC is usually the measure of ionic concentrations present in a water sample. Therefore, it can be speculated that the sample coded E consists of low ionic concentrations whereas the sample coded F contains high ionic concentrations. Such a variation of ionic concentration may appear from the surrounding environment of water source. Usually, it depends on the availability of mineralizing agents, such as CO_2 concentration, metal redox conditions types of adsorbed complexes etc. [23]. On looking the obtained TDS values, it may be seen that the values are appeared in the range of 25.0-295.8 mg/L with the median 104.3 mg/L. The remarkable fact that the lowest EC valued sample E showed the lowest TDS value and the highest EC valued sample F showed the highest TDS value. Such coincidences among the EC and TDS values may be taken as the accuracy of the measurements.

3.2.3 *DO*

The dissolved Oxygen (DO) values for bottled drinking water samples ranged between 6.88- 8.76 mg/L. There were not significant differences for DO values among the brands. It was found that sample coded D contained the highest level (8.76 mg/L) and sample coded A contained the lowest (6.88mg/L) (Table-3). It is one of the most important parameter to indicate the water purity. According to the environmental quality standard (EQS), the following requirements for DO are prescribed as 6.0 mg/L for drinking purpose, 4.0 to 6.0mg/L for fish and livestock and 5.0mg/L for industrial application [24].

3.2.4 *TH*

Total hardness of water mainly represents the concentration of calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions, in the form of carbonate and bicarbonate. From the Table 3, it may be observed that the total hardness values of the bottled waters are found from 1.5 – 228 mg/L. The difference between the highest and lowest value is so significant and the median is 58.65. Among the samples, it was observed that F coded water sample contained highest amount of TH and the lowest amount was found in D coded sample. Water can be classified as soft (<75 mg/L), moderately hard (75-150 mg/L), hard (150-300 mg/L) and very hard (>300 mg/L) according to the concentration of calcium and magnesium [25]. It is an important criterion for determining the usability of water for domestic, drinking and many industrial applications [26]. Water having hardness below 300mg/L is considered portable, but beyond this limits cause gastro-intestinal irritation.

3.2.5 *Concentration of ionic constituents*

The concentration level of the ionic constituents present in the water samples are: 4.9-17.01 mg/L for Ca^{2+} with a median of 5.35; 0.25-7.27 mg/L for Mg^{2+} with a median of 1.97; 2.25-3.20 mg/L for Fe^{2+} with a median of 2.79; 0.24-2.69 mg/L for Cl^- with a median of 0.75; 0.04-110.0 mg/L for SO_4^{2-} with a median of 8.33; and 0.11-2.98 mg/L for NO_3^- with a median of 0.21(Table 3). Both calcium and magnesium are essential to human health. Inadequate intake of either nutrient can impair health which has been associated with increased risks of osteoporosis, colorectal cancer, hypertension and stroke, coronary artery disease, insulin resistance and obesity.

Table 4: Physico-chemical parameters of drinking water according to the BDWQS and WHO

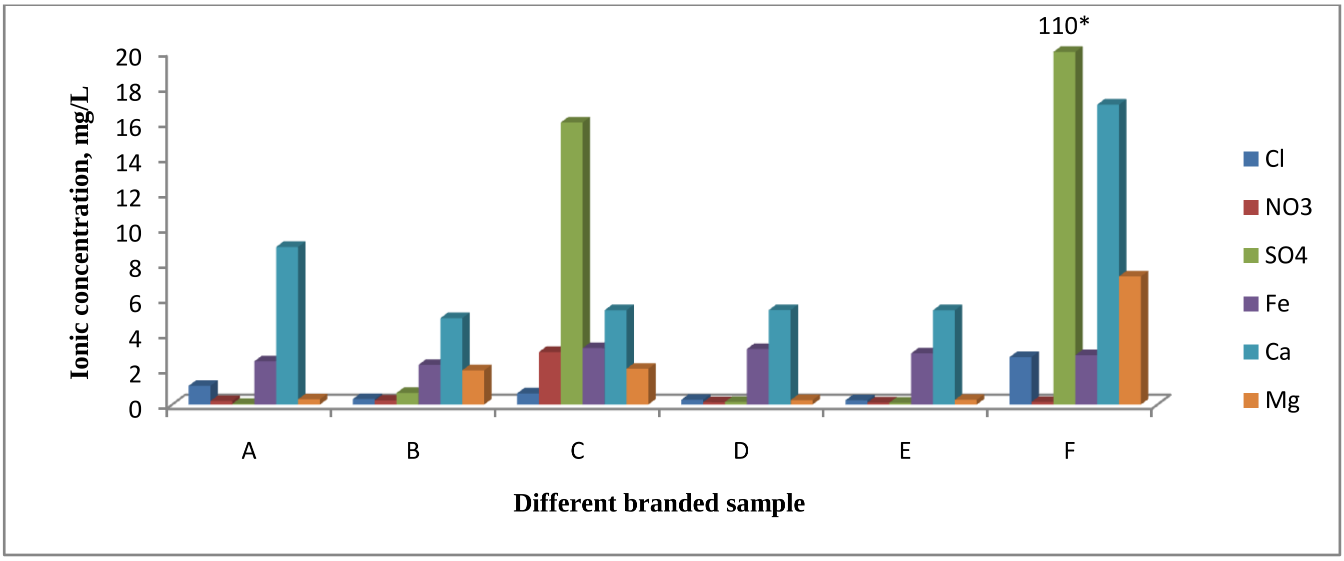
Parameter	Unit	BDWQS	WHO
pH	-	6.5 – 8.5	6.5 – 8.5
EC	µS/cm	-	-
TDS	mg/L	1000	1000
DO	mg/L	6	4 – 6
TH	mg/L	80	80 - 120
Cl^-	mg/L	150-600	400
NO_3^-	mg/L	10	50
SO_4	mg/L	400	500
Fe^{2+}	mg/L	0.3	0.3
Ca^{2+}	mg/L	150	200
Mg^{2+}	mg/L	50	50

BDWQS→ Bangladesh Drinking Water Quality Standard, **WHO** →World Health Organization

On the other hand, excessive intake of these constituents is responsible for different diseases like kidney stone, osmotic diarrhea etc. From Table 3, it may be seen that sample coded F has higher concentration of Ca^{2+} and Mg^{2+}, as from its source of water used for purification which has higher level of calcium and magnesium-rich minerals. It may be also found that Ca^{2+} concentration was higher than Mg^{2+}, among the brands; this means that hardness of water comes mostly from Ca^{2+} concentration. Fe^{2+}concentration were found at high levels in all brands according to WHO and BDWQS. This may be occurred due to methods of processing and source of water that ensure the higher concentration of Fe^{2+}. A report has been shown that uptake of iron supplements for extended periods without deleterious effects and an intake of 0.4–1 mg/kg of body weight per day is unlikely to cause adverse effects in healthy persons [27]. Cl^- and SO_4^{2-} is not of health concern at levels found in drinking-water, however, excessive Cl^- concentrations increase rates of corrosion of metals in the distribution system and when it exceeds over 600 mg/L, impair the portability of water. SO_4^{2-} is one of the least toxic anions. The presence of high concentration of SO_4^{2-}in the drinking water may lead to dehydration, stomach complaints, and possibly diarrhea. In general, the adverse effect on the taste is said to be minimal at levels lower than 250 mg/L for both Cl^- and SO_4^{2-}. NO_3^- in drinking water can also affect certain adults and small children. It was observed that sample coded C contains higher concentration (2.98 mg/L) of NO_3^- compared with the other samples, which is within the range of WHO and BDWQS (Table 4). Pregnant women can pass methemoglobin on to developing fetuses and low birth weights have been attributed to high nitrates in water. The observed variations in the chemical constituents can be described as the variation of the origins, residence time, atmospheric conditions and purification or treatment process employed by the manufacturers. In fact, it may be showed that the concentration of the ionic constituent present in the collected bottled water samples are within the recommended drinking water BDQWS and WHO (Table 4) standard limits except Fe^{2+} (>0.3 mg/L).

3.3 *Contribution of ions*

Figure 1 shows the average concentrations of ions present in the bottled water samples. From figure it was found that Cl^- was the major component present in all bottled water samples. It was also found that sample coded F contains exceptionally high levels of most ions like Cl^-, SO_4^{2-}, Ca^{2+} and Mg^{2+} compared with the other water samples. The percent attributions of the measured ions are presented in the figure 2. From figure it may be seen that Ca^{2+} was the dominating component in the A, B, D and E coded water samples within the range of around 48% - 69%, whereas $SO_4^{2-}$was dominated in the water samples coded C (53%) and F (79%). A particular fraction of Fe^{2+} was observed, in the range of around 2% - 34%. Somewhat higher proportion was found for Mg^{2+} (□ 19%), whereas NO_3^- and Cl^- was found under 10%. It may be think that the source of SO_4^{2-}comes from the oxidation of sulphate containing ores like gypsum and Cl^- arises from water that entrapped in the sediments or halite solution during chlorination. The NO_3^- is undoubtedly comes from natural occurring sources including agricultural, industrial and domestic sources. The contribution of Fe^{2+} in water is common in deeper wells where the water has been in contact with rock for a longer time. Ca^{2+} and Mg^{2+} is also comes from naturally occurring sources in drinking water.



* This value exceed the Y-axis value (0- 20 mg/L)

Figure 1: Concentration of ionic constituents in different branded bottled drinking water sample measurements

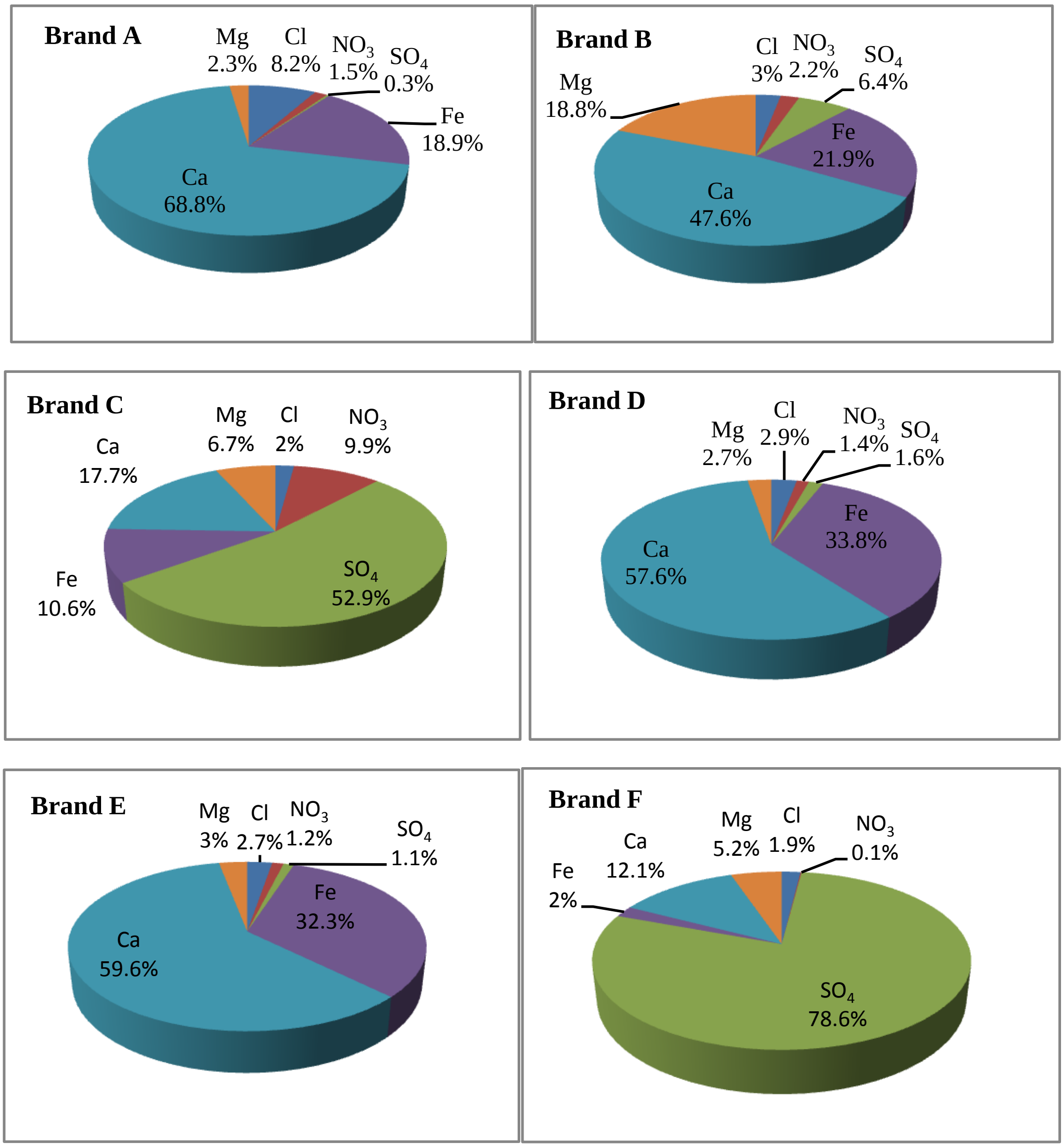


Figure 2: Percent attributions of different ions concentrations to bottled drinking water brand

3.4 *Correlation between various constituents*

Table 5 shows the Pearson's correlation between physicochemical characteristics of water samples and the metals ion (Ca^{2+}, Mg^{2+} and Fe^{2+}) concentration. According to Taylor [28], the correlation coefficient, $r \leq 0.35$ represent weak correlations, *r* value of 0.36-0.67 indicate moderate links, and *r* value of 0.68-1.00 signify strong relationships. Bottled water samples show strong positive correlation (r= 0.68-1.00) for pH and DO, between EC and TDS, TH , Cl^{-}, SO_4^{2-}, Ca^{2+}, and Mg^{2+}, between TDS and TH, Cl^{-}, SO_4^{2-}, Ca^{2+} and Mg^{2+}, between DO and Fe^{2+}, between TH and Cl^{-}, SO_4^{2-}, Ca^{2+}, and Mg^{2+}, between Cl^{-} and SO_4^{2-}, Ca^{2+}, and Mg^{2+}, between $SO_4^{2-}$and Ca^{2+}, and Mg^{2+} and also between Ca^{2+}, and Mg^{2+},while moderate correlation (r=0.36-0.67) exit between $NO_3^{-}$and Fe^{2+}, and weak correlation (r≤ 0.35) exits between pH and Fe^{2+},between EC and NO_3^{-}, between TDS and NO_3^{-}, Fe^{2+}, between DO and SO_4^{2-}, Ca^{2+}, between TH and NO_3^{-} and also between SO_4^{2-} and Fe^{2+} .

Table 5: Correlation matrix for water quality parameters in the bottled drinking water brands

	pH	EC	TDS	DO	TH	Cl	NO_3	SO_4	Fe	Ca	Mg
pH	1										
EC	-0.32	1									
TDS	-0.32	**0.99**	1								
DO	**0.68**	-0.03	-0.03	1							
TH	-0.41	**0.99**	**0.99**	-0.15	1						
Cl	-0.42	0.**96**	**0.96**	-0.04	**0.94**	1					
NO_3	-0.41	0.002	0.005	-0.13	0.05	-0.12	1				
SO_4	-0.24	**0.97**	**0.98**	0.06	**0.96**	**0.94**	-0.06	1			
Fe	0.25	-0.0006	0.0005	**0.73**	-0.05	-0.07	**0.50**	0.08	1		
Ca	-0.34	**0.93**	**0.93**	0.02	**0.90**	**0.98**	-0.25	**0.92**	-0.09	1	
Mg	-0.26	**0.97**	**0.97**	-0.10	**0.97**	**0.89**	0.004	**0.97**	-0.02	**0.85**	1

Correlation coefficients that is larger than 0.50 are indicated in bold

Conclusion

In this study, six brands of bottled water of the Dhaka City, Bangladesh, were assessed for the physical and chemical parameters. The results revealed that the physical parameters namely EC and TDS values of the bottled waters are within the permissible limit of WHO standards and BDWQS whereas the DO values and most of the pH values are on out of limit.TH and anions (Cl^{-}, SO_4^{2-} and NO_3^{-}) values are lower than that of the permissible limits of WHO and BDWQS. However, the chemistry of bottled water may change during transportation or storage, particularly when containers exposed to sunlight or kept for an extended period of time. Ca^{2+} and Mg^{2+} values are also exist within the permissible value but that of Fe^{2+} exceeds the permissible level of WHO and BDWQS. Although the drinking water is regarded as safe, bottled water has slightly high values of pH, DO and Fe^{2+} may be arises due to the water treatment process. This study presents baseline data for future reference especially for drinking water assessment. Analyses of other mineral ions (e.g. sodium and potassium), trace metals (e.g. arsenic, cadmium and lead), radionuclides (e.g. uranium and radon) and potentially carcinogenic substances are necessary for bottled water to maintain the safety of drinking water.

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