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ORIGINAL RESEARCH

Evaluation of fluoride concentrations in bottled drinking water in the western region of Saudi Arabia

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Abstract

Background: Fluoride levels in bottled water from local sources in the western region of Saudi Arabia pose a significant public health concern due to discrepancies between actual and labeled concentrations. This study examined fluoride concentrations in commercially available bottled water, focusing on differences between measured and labeled values and variations among sources. **Methods**: This cross-sectional study was conducted from September 2024 to February 2025, during which water samples were collected from both local and international sources in the western region of Saudi Arabia. The ion-selective electrode method was used for fluoride analysis. Sample preparation included shaking each bottle for homogeneity and extracting a 10 mL aliquot for analysis. Fluoride concentrations ranging from 0.1 to 3.0 mg/L were used to create a standard calibration curve. **Results**: A total of 110 brands were analyzed: 49 (44.5%) from wells, 30 (27.3%) were desalinated, 15 (13.6%) from springs, 11 (10%) from natural sources, and 5 (4.5%) from nurseries. Most samples were from Saudi Arabia (n = 90, 81.8%), and 20 samples (18.2%) were from international sources. The fluoride concentrations ranged from 0.000 to 1.460 ppm, with an average of 0.928 ppm. Significant discrepancies were found between the measured and labeled fluoride levels and among the different water sources ($p < 0.001$). The spring water had the highest concentration at approximately 1.4 ppm, whereas the nursery water had the lowest fluoride concentration of approximately 0.7 ppm. Saudi bottled waters had fluoride levels ranging from 0.70 to 1.50 ppm, which were significantly higher than those from the USA (0.1–0.3 ppm; $p = 0.008$) and Europe (0.2–0.5 ppm; $p = 0.003$). **Conclusions**: This study revealed significant differences in fluoride levels, with Saudi bottled waters generally having higher concentrations than international brands.

Keywords

Fluoride; Bottled water; Drinking water; Water resources; Saudi Arabia

1. Introduction

Fluoride, the ionic form of fluorine, is a mineral that occurs naturally in a variety of foods, and is also available as a dietary supplement. It exists in trace levels within water, soil, and plants. For most people, the main sources of fluoride are drinking water that has been fluoridated, beverages and foods made with such water, and dental care products containing fluoride [1].

Fluoride's beneficial properties in preventing dental caries and enhancing enamel mineralization is very well documented in the literature [2]. For instance, a Cochrane Review that assessed 20 prospective observational studies found that children who consumed water with fluoride experienced a 35% reduction in the instances of decayed, missing, and filled primary teeth, and a 26% decrease in similar issues with permanent teeth, compared with those who consumed water without fluoride [3].

According to the Saudi Health Ministry, dental caries remains a major public health concern, particularly among young people. In the Kingdom of Saudi Arabia, tooth decay affected 96% and 93.7% of children aged six and twelve, respectively [4]. Based on Saudi studies, a significant proportion of youngsters develop dental caries, which are frequently ascribed to poor food habits and inadequate oral hygiene [5, 6]. As a result, preventative strategies, such as diet modification, meticulous oral hygiene assessments, and fluoride therapy, including water fluoridation, may be beneficial. However, high fluoride exposure during tooth development has been linked to fluorosis, with varying prevalence rates across different Saudi regions [7]. A recent national survey in Saudi Arabia indicated that, despite widespread usage of fluoride-containing goods, 78% of Saudis were unaware that high fluoride exposure during childhood leads to fluorosis [8].

Excessive fluoride exposure can lead to negative health outcomes in vulnerable groups, particularly children and pregnant women. These groups face increased risks dental and skeletal

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fluorosis, as well as thyroid dysfunction [9, 10]. Fluoride levels exceeding 1.5 mg/L might be linked to increased risk of hypothyroidism [11]. In addition, enamel fluorosis can occur when fluoride exposure surpasses 0.1 mg/kg body weight daily during tooth development [12]. More severe skeletal fluorosis, which leads to joint pain and skeletal deformities, is associated with chronic exposure to fluoride levels above 10 mg/L. Acute fluoride toxicity occurs with estimated does between 5–10 mg/kg [13]. Understanding these impacts is crucial for public health, especially in regions like Saudi Arabia, where bottled water serves as a primary source of hydration.

To mitigate these risks, regulatory bodies worldwide have established guidelines for fluoride levels in drinking water to protect public health. For instance, the World Health Organization advises that the fluoride level in drinking water should remain below 1.5 mg/L to reduce the risk of developmental issues associated with high fluoride intake [14]. The Public Health Service in the United States initially advised that fluoride levels in water should range from 0.7 mg/L in hotter areas, where children are likely to increase water consumption, to 1.2 mg/L in areas with cooler areas to aid in preventing dental caries. However, this recommendation was updated to a consistent level of 0.7 mg/L to effectively reduce cavities while also lowering the risk of dental fluorosis [15].

A recent study carried out in the central area of Saudi Arabia analyzed 36 underground water samples and reported variable fluoride levels in drinking water, ranging from 0.63 to 2.00 mg/L. Notably, 11 out of 36 of these samples (30.55%) surpassed the WHO's advised limit for safe drinking water, set at 1.5 mg/L [16]. However, the fluoride concentrations in bottled water can vary significantly, influenced by several factors, including the source of the water, local geology, and the treatment processes utilized by various bottling companies [17].

A systematic review conducted from 2008 to 2012 revealed that 45.5% of studies worldwide identified significant discrepancies in labeling bottled water [18], underscoring the potential public health risks associated with such inaccuracies. Furthermore, a study conducted in Almadinah Almunawwarah, Saudi Arabia indicated that numerous bottled water brands contained fluoride levels that exceeded those stated on their labels [19]. These findings underscore the need for stringent quality assurance procedures and transparent labeling to safeguard consumers, especially because many people rely on bottled water as their primary source of hydration. A discrepancy between labeled and actual fluoride levels could lead to unintended overconsumption, posing health risks, particularly concerning groups at higher risk, such as children and pregnant mothers, who are more vulnerable to the negative impacts of excessive fluoride consumption [11].

Therefore, this study aimed to evaluate fluoride levels in bottled drinking water from various retail outlets in the western region of Saudi Arabia by comparing labeled and actual measured concentrations. Additionally, it assessed fluoride levels across different brands and sources, including both local and international products.

2. Methods

2.1 Sample collection and fluoride assessment

This cross-sectional research assessed fluoride levels in the most regularly purchased bottled drinking water in Saudi Arabia's western region, from September 2024 to February 2025. The study included a systematic collection of bottled water samples (n = 110) from multiple retail locations. A data extraction form was used to collect information from the water bottle labels, such as the source of the water, its country of origin, and the labelled fluoride levels. Furthermore, actual fluoride levels were measured for comparison. To ascertain that the analysis was consistent, three bottles of each brand were purchased and stored in a refrigerator to maintain sample integrity.

Fluoride level was measured immediately after the addition of Total Ionic Strength Adjustment Buffer (TISAB) using a fluoride ion-selective electrode (Orion 9609BN, Thermo Fisher Scientific, Waltham, MA, USA) and an analyzer (Orion 920A, Thermo Fisher Scientific, Waltham, MA, USA). The detection range of the electrode was from 0.0 to 10 mg/L, with a limit of quantification set at 0.05 mg/L, allowing for sensitive detection of fluoride in bottled water. Calibration procedures involved preparing standard solutions of fluoride at concentrations ranging from 0.01 to 3.0 mg/L. Sample preparation included shaking each bottle for homogeneity and extracting a 10 mL aliquot for analysis. Each water sample was analyzed in duplicate, and the average fluoride content was recorded. For reliability, 10% of the bottled water samples were randomly chosen and re-analyzed.

2.2 Statistical analyses

Data analysis was conducted using Statistical Package for the Social Sciences version 30 (IBM Corp, Armonk, NY, USA). Descriptive statistics, such as frequencies and percentages, were presented. The Kolmogorov-Smirnov and Shapiro-Wilk tests were used to assess the normality of the data, which helped to determine whether to use parametric or non-parametric tests.

The Wilcoxon signed-rank test was used to assess differences between the measured mean fluoride concentration (ppm F = mg F/L) and the labeled fluoride concentration. In addition, the independent-samples Kruskal-Wallis test was used to identify significant variations in measured fluoride concentrations across different water sources and between Saudi and international brands. The Bonferroni correction was applied to adjust all significance values for multiple comparisons, maintaining a significance threshold of 0.05.

Furthermore, a one-way analysis of variance (ANOVA) was performed to compare the mean measured fluoride concentrations across different Saudi cities, as it effectively assesses differences among three or more independent groups. To ensure the validity of our ANOVA results, the variants Levene's test was used. If significant differences were detected in ANOVA (at $p < 0.05$), *post hoc* analysis, such as Tukey's Honestly Significant Difference, was performed to identify differences.

3. Results

The analysis included a total of 110 bottled water brands, distributed among various sources as follows: 49 samples (44.5%) were from wells, 30 samples (27.3%) were desalinated, 15 samples (13.6%) were from springs, 11 samples (10%) were from natural sources, and five samples (4.5%) were from nurseries. This distribution indicates that well water was the most common source among the sampled brands (Table 1).

TABLE 1. Distribution of water sources by frequency and percentage.

Water source	Frequency (n)	Percent (%)
Well	49	44.5
Desalinated	30	27.3
Spring	15	13.6
Natural	11	10.0
Nursery	5	4.5
Total	110	100.0

Each water source is represented by both a numerical count (n) and a percentage (%).

The frequency and percentage of bottled drinking water sources based on the country of origin are presented in Table 2. The majority of the samples originated from Saudi Arabia (n = 90, 81.8%), with Jeddah representing the highest frequency with 37 samples (33.6%), followed by Riyadh with 19 samples (17.3%), and Al Qassim contributed 10 samples (9.1%). Other regions in Saudi Arabia included Makkah (six samples, 5.5%), Al Madinah (four samples, 3.6%), Jazan (four samples, 3.6%), and Najran (four samples, 3.6%). Smaller samples came from Al Qunfudhah and Al Jouf, each with two samples (1.8%), and Al-Kharj and Hail, each with one sample (0.9%).

In addition to the Saudi sources, 20 (18.2%) samples were obtained from international locations. Specifically, there were four samples (3.6%) from France, while Spain, the United Kingdom, Austria, Bahrain, the United States, and Italy each had two samples (1.8%). Moreover, Armenia, Kuwait, Norway, and Romania each had one sample (0.9%).

The accuracy of the labeled fluoride levels was also assessed, revealing a minimum fluoride concentration of 0.000 ppm and a maximum of 1.460 ppm, with a mean of 0.928 ppm (standard deviation (SD) $\pm$ 0.417). In total, 98 samples were evaluated for their labeled fluoride concentrations, and 12 brands were found to be unlabeled. Among these labeled samples, the fluoride levels varied between 0.000 ppm and 1.500 ppm, with an average labeled concentration of 0.889 ppm (SD $\pm$ 0.280).

Fig. 1 presents the labeled and measured fluoride levels (in ppm) for various water samples from different brands. This underscores the notable differences between the labeled fluoride concentrations and the actual measured levels. Although many of the labeled concentrations were below 1.0 ppm, several measured concentrations exceeded this threshold, indicating that actual fluoride levels were often higher than those reported. Notably, 60% of the water brands (n = 66) had fluoride concentrations exceeding 1.0 ppm.

TABLE 2. Distribution of bottled drinking water by country of origin.

Country of origin	Frequency (n)	Percent (%)
Saudi Arabia		
Jeddah	37	33.6
Riyadh	19	17.3
Al Qassim	10	9.1
Makkah	6	5.5
AL Madinah	4	3.6
Jazan	4	3.6
Najran	4	3.6
Al Qunfudhah	2	1.8
Aljouf	2	1.8
AlKharj	1	0.9
Hail	1	0.9
International		
France	4	3.6
Spain	2	1.8
United Kingdom	2	1.8
Austria	2	1.8
Bahrain	2	1.8
USA	2	1.8
Italy	2	1.8
Armenia	1	0.9
Kuwait	1	0.9
Norway	1	0.9
Romania	1	0.9
Total	110	100

The values for each country of origin are presented as both a numerical count (n) and a percentage (%).

The normality of the measured fluoride concentrations was assessed using the Kolmogorov-Smirnov and Shapiro-Wilk tests. The results indicated a significant deviation from normality, with the Kolmogorov-Smirnov statistic being 0.21 (df = 110, $p < 0.001$) and the Shapiro-Wilk statistic being 0.78 (df = 110, $p < 0.001$). These findings suggest that the data did not follow a normal distribution; therefore, non-parametric statistical tests were used for this sample.

A Wilcoxon signed-rank test for related samples was conducted to assess the difference between the measured average fluoride concentration (ppm F = mg F/L) and the concentration indicated on the label. The results revealed a statistically significant difference between the measured and labeled fluoride concentrations ($p < 0.001$).

The Kruskal-Wallis Test for independent samples indicated notable variations in fluoride levels across different water sources, with a p-value of less than 0.001. Dunn's pairwise comparisons indicated significant differences between natural and well water ($p = 0.002$), and natural and desalinated water (p

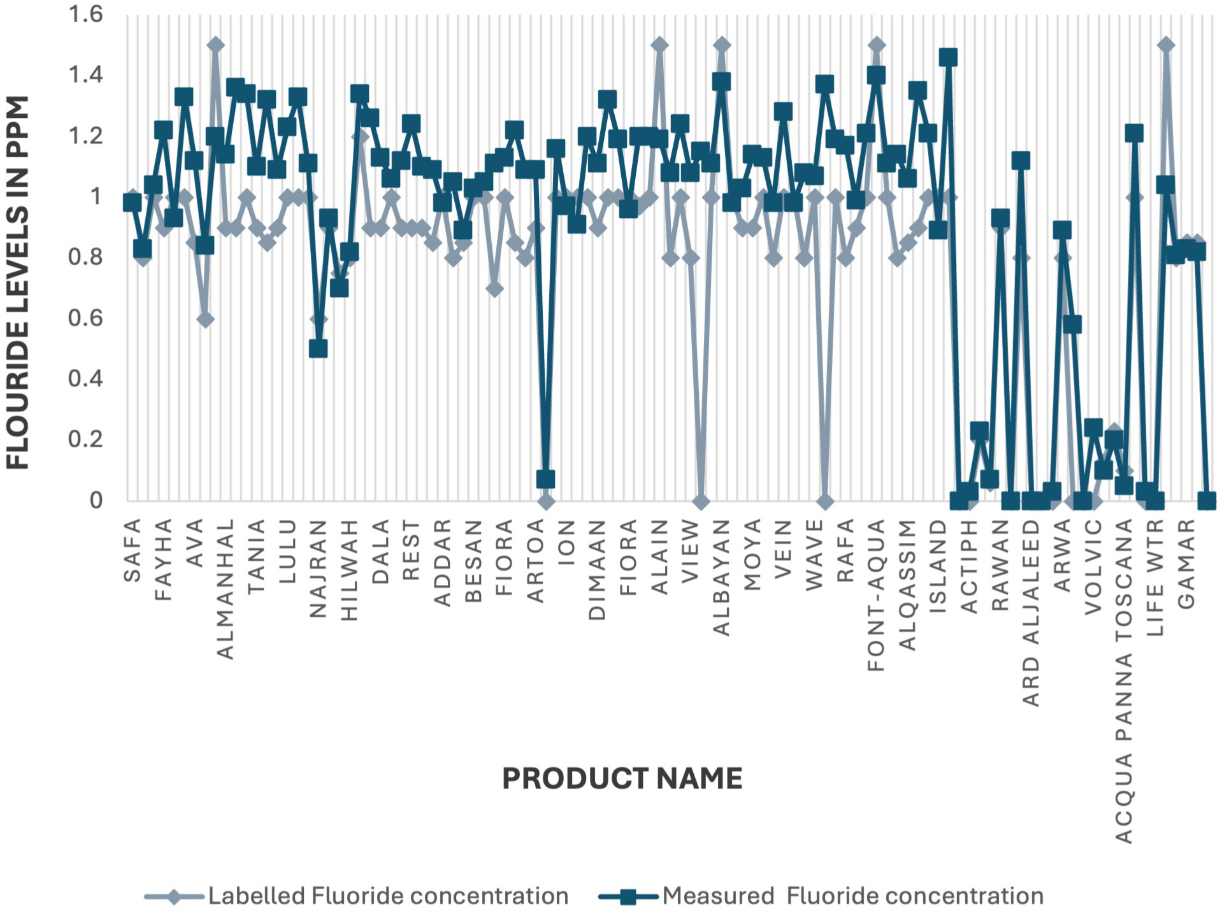

FIGURE 1. Comparison between labeled and measured fluoride levels in water samples (ppm).

< 0.001). Significant differences were also found between the nursery and desalinated water ($p = 0.002$) and between spring and desalinated water ($p = 0.007$). However, no significant differences were noted for the natural, nursery, and spring water.

Analysis of fluoride levels across various water sources revealed distinct differences, as shown in Fig. 2. Spring water exhibited the highest level of approximately 1.5 ppm, followed by well and desalinated water at approximately 1.3 ppm. Natural water registered a fluoride level of approximately 1.2 ppm. Finally, the nursery water had the lowest fluoride concentration of approximately 0.8 ppm.

When comparing Saudi and international brands, significant differences in fluoride levels were noted, particularly between specific Saudi brands and their international counterparts. Bottled water from Saudi Arabia typically contained fluoride concentrations ranging from 0.70 to 1.50 ppm, while bottled water from the USA ranged from 0.10 to 0.30 ppm ($p = 0.008$). This finding suggests that Saudi bottled waters generally contain higher fluoride levels, likely due to the natural mineral content of local water sources. In contrast, some international brands, particularly from Europe, reported fluoride levels ranging from 0.30 to 0.50 ppm for French bottled water ($p = 0.003$) and 0.20 to 0.40 ppm for Spanish brands, both of which are still lower than those found in leading Saudi brands.

A one-way ANOVA was conducted to compare fluoride concentrations among various Saudi water brands, focusing on Jeddah and other cities, such as Riyadh, Al Qassim, Makkah, and Al Madinah. The mean fluoride concentration of concentrations was as follows: Jeddah (1.12 ppm), Riyadh (1.10 ppm), Al Qassim (1.10 ppm), Makkah (1.00 ppm), and Al Madinah (1.06 ppm). Levene's test verified that the variances were homogeneous ($p = 0.14$). The ANOVA results indicated no significant differences in fluoride concentrations between the groups ($F = 1.63$, $p = 0.12$). Subsequent *post hoc* analyses indicated that there were no significant differences between pairs, as all p-values were greater than 0.05.

These findings suggest that the fluoride levels in the western cities were comparable to those in other cities. This is further supported by Fig. 3, which illustrates the mean fluoride levels across various Saudi brands, showing that Western region cities' levels closely aligned with those of other regions.

4. Discussion

This study investigated the fluoride levels in bottled drinking water sourced from various retail outlets in the Western region of Saudi Arabia and revealed substantial discrepancies between the measured and labeled fluoride concentrations. Statistical analysis confirmed a significant difference between the two ($p < 0.001$). The results indicated that the actual fluoride levels frequently surpassed those reported on the labels. This discrepancy highlights the necessity for enhanced transparency and accuracy in labeling practices, as consumers may inadvertently ingest higher levels of fluoride than expected.

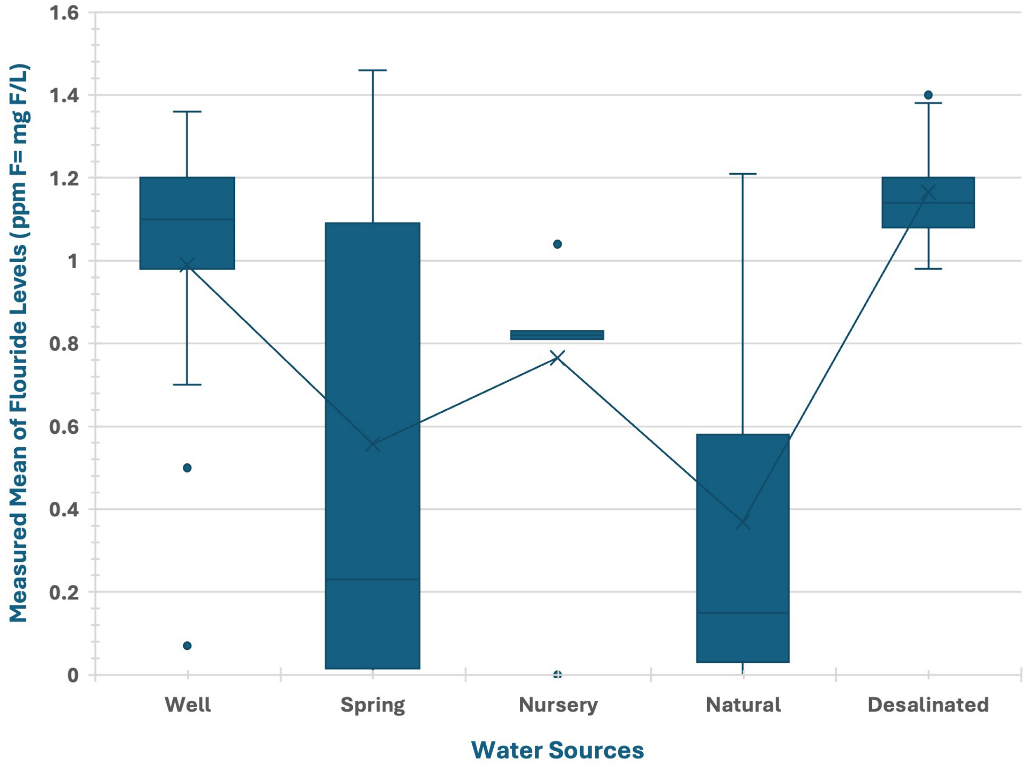

FIGURE 2. Fluoride levels by water source as determined by the independent-samples Kruskal-Wallis test.

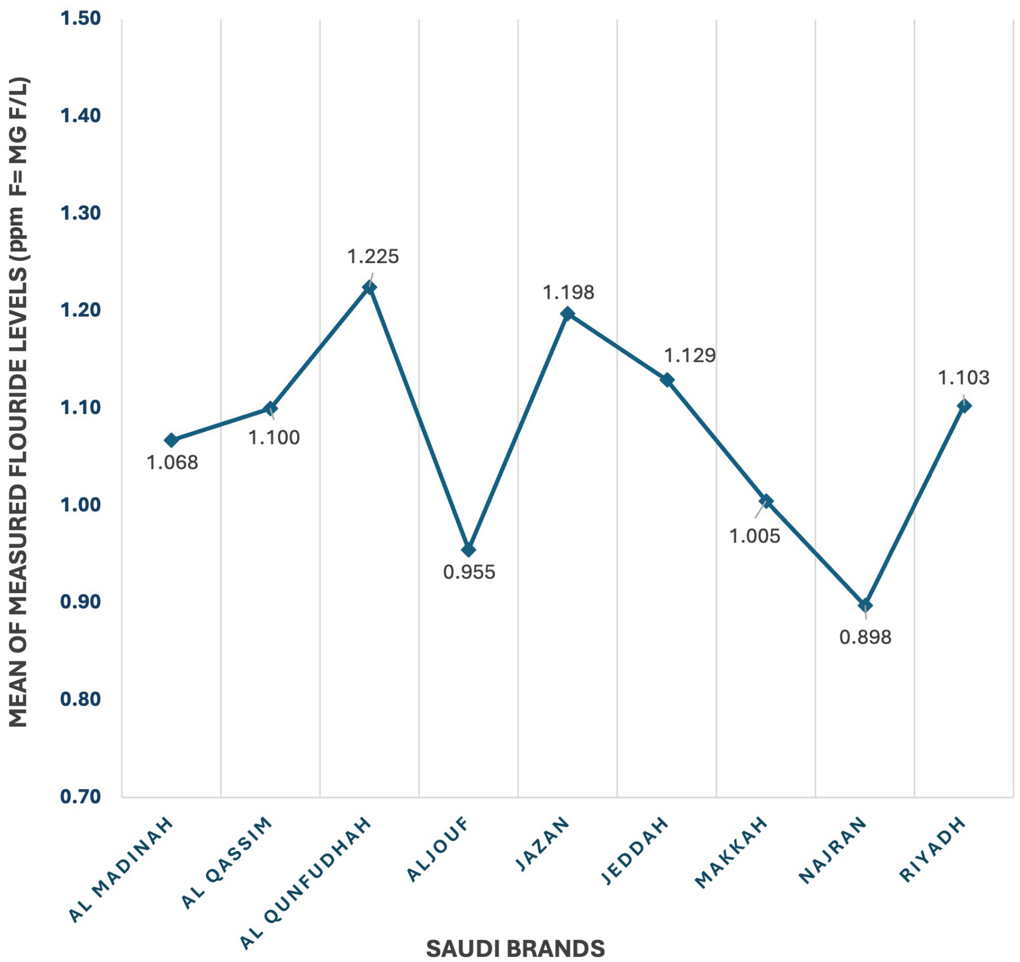

FIGURE 3. Means plot of measured fluoride concentration in bottled water from Saudi brands.

In the current study, 60% (n = 66) of the water brands showed measured fluoride levels greater than 1.0 ppm but less than 1.50 mg/L. Conversely, the U.S. Public Health Service advises that the fluoride level in drinking water should range from 0.05 to 0.7 mg/L [20], while the World Health Organization sets the acceptable fluoride Levels should range from 1 to 1.5 mg/L [14]. These recommendations are designed to enhance the dental health benefits of fluoride while reducing the risk of dental fluorosis, which can occur due to excessive fluoride intake [21]. Similarly, a recent study on bottled water in Almadinah Almunawwarah, Saudi Arabia, found that the fluoride levels indicated on labels ranged from 0.75 to 1.49 ppm, whereas laboratory tests revealed actual levels ranging from 0.03 to 1.86 ppm, highlighting significant discrepancies. Furthermore, nearly 82% of the bottled water brands assessed were found to have fluoride levels surpassing those listed on their packaging [19].

The findings of this study highlighted the variability in fluoride content among different water sources. Groundwater sources, such as wells and springs tend to have higher fluoride concentrations due to the natural mineral content of the aquifers from which they are extracted. Conversely, desalinated water typically exhibits lower fluoride levels because the desalination process often removes minerals, including fluoride. This observation is consistent with a study conducted in Saudi Arabia that found fluoride levels varying across different regions, with groundwater typically exhibiting higher fluoride concentrations (an average of 1.33 ppm) than desalinated water [22]. In addition, several studies in India indicated that fluoride levels in groundwater sources ranged between 0.2 to 2.0 ppm [23, 24]. These findings emphasize the importance of considering the water source when assessing fluoride exposure and suggest a potential need for targeted interventions in areas that predominantly rely on well water for drinking.

This study also revealed significant differences in fluoride concentrations between local Saudi brands and their international counterparts. Saudi bottled waters' average fluoride levels ranged from 0.70 to 1.50 ppm, which was significantly higher than those from the USA, which ranged from 0.1 to 0.3 ppm. This may reflect regional geological variations that affect the mineral content of water sources. Similarly, research in the United Arab Emirates revealed that 48% of brands did not include fluoride labeling, and some samples showed significant discrepancies. For instance, one brand contained 4.50 mg/L of fluoride, while its label indicated only 0.2 mg/L [25]. In addition, the examination of bottled water in the Baninah region of Benghazi, Libya, uncovered notable differences in fluoride levels across various brands. These concentrations ranged from 0.1 mg/L to as much as 3.0 mg/L, exceeding the recommended limit of 1.5 mg/L. One particular brand showed fluoride levels of 2.5 mg/L, prompting concerns about the potential dangers of fluoride toxicity and dental fluorosis, particularly among susceptible groups [26].

Moreover, the examination of bottled water in the Baninah region of Benghazi showed considerable differences in fluoride concentrations across various brands, with measurements ranging from 0.1 mg/L to as high as 3.0 mg/L, also exceeding the recommended threshold of 1.5 mg/L. One particular brand recorded a fluoride level of 2.5 mg/L [26]. However, a study conducted in Iran revealed that fluoride concentrations in bottled water were consistently lower than the values stated on the labels, with measured averages spanned from 0.18 to 0.35 mg/L, in contrast to the labeled values, which were between 0.7 and 1.2 mg/L [27].

Excessive fluoride in water sources can cause a range of health problems, including dental fluorosis, which manifests as tooth discoloration and mottling due to excessive fluoride exposure during childhood [24]. A study conducted in Saudi Arabia reported fluoride levels in bottled drinking water ranging from 0.03 to 3.8 ppm in 63 water samples. High fluoride levels (>0.81 ppm) have been observed among individuals who consumed well water. Among the 1150 patients examined, the prevalence of dental fluorosis was 20.43% [28]. These findings are interesting as they signal a relationship between fluoride exposure from various water sources, particularly well water, and the prevalence of dental fluorosis in Saudia Arabia. Therefore, there is a need for further research examining the association between water sources and dental fluorosis.

In addition, long-term high fluoride consumption has been linked to skeletal fluorosis, a condition marked by joint discomfort and bone degradation [29]. In studies conducted in China, India, Ethiopia, and other endemic countries, water fluoride concentrations varied from 1 to 5 mg/L, and were associated with skeletal fluorosis prevalence rates ranging from 6.1% to 72.4% [30–32]. Additionally, a systematic review found a linear dose-response relationship with a relative risk of 2.05 overall and 2.73 when utilising water as the fluoride source [33].

Other research has suggested potential associations between fluoride exposure and thyroid dysfunction [11, 34], as well as neurological effects, including studies that have found links between prenatal fluoride exposure and reduced IQ (Intelligence Quotient) scores in their children [35]. Furthermore, chronic fluoride toxicity has been associated with cardiovascular effects [36]. Although fluoride is beneficial for preventing dental cavities, these findings highlight the fine line between therapeutic and harmful levels. This emphasizes the importance of informed consumer choices and effective regulatory measures to minimize health risks linked to high fluoride intake.

Although there are risks associated with high fluoride exposure, maintaining appropriate fluoride levels is crucial for reducing dental caries. A recent study conducted in the Northeast of England revealed that children between the ages of five and twelve years residing in regions with water fluoridation had a 28% and 21% lower likelihood, respectively, of developing caries in their permanent teeth compared with those living in regions without fluoridation. Furthermore, the study indicated that fluoridated water could potentially result in a 59% reduction in hospital admissions for caries among children and adolescents (0–19 years old) [29].

This study assessed a comprehensive sample of 90 bottled water products from local brands across Saudi Arabia. A comparison of fluoride levels across different cities showed no significant differences (p = 0.12), suggesting consistent fluoride concentrations among the major regions. This uniformity may offer reassurance to consumers, suggesting that fluoride intake from bottled water remains relatively stable across various locations. However, contrasting findings from other studies have revealed considerable fluctuations in fluoride content of bottled water products from various regions in Saudi Arabia. This might be due to differences in geographical region, sample size, selection, storage and preparation, as well as using different methods for measuring fluoride levels. For instance, an investigation into bottled water quality identified significant variability in fluoride concentrations between brands, with some exceeding the limits recommended by health authorities. Specifically, fluoride levels in bottled water were found to range from 0.03 to 1.86 ppm, indicating that not all brands maintain consistent fluoride concentrations [19].

Overall, our findings highlight the critical public health implications of fluoride exposure from bottled water in Saudi Arabia. The significant discrepancies between the measured and labeled concentrations, along with the higher fluoride levels observed in local brands, underscore the need for enhanced consumer awareness and stringent regulatory measures to ensure accurate labeling and safe consumption. Accurate label information is essential for consumers, health professionals, and regulatory authorities when making decisions about fluoride intake. Mislabeling can have serious consequences: if fluoride levels are lower than reported, consumers may not receive sufficient intake for effective caries prevention [37]. Conversely, if fluoride levels are higher than reported, the risk of dental and skeletal fluorosis will increase [3].

This study had several limitations. First, although a substantial sample of 110 bottled water products was analyzed, the study focused exclusively on local brands in the western region of Saudi Arabia, which may not accurately represent fluoride levels in imported brands or those from other regional sources. Additionally, the geographic scope was limited to cities, potentially overlooking variations in fluoride concentrations in rural or less densely populated areas. Fluoride measurements were conducted at a single time point and did not account for seasonal fluctuations or temporal changes in water quality. Lastly, the study did not assess other potential sources of fluoride exposure, such as dental products or food, which could contribute to a more comprehensive understanding of total fluoride intake and its associated health effects.

5. Recommendations

The Saudi Food and Drug Authority (SFDA) regulates food and beverage safety, including bottled water, and monitors labelling and health regulations to encourage fluoride awareness. The Ministry of Health also plays an important role in public health education, notably in terms of oral health. Effective coordination among various regulatory entities, healthcare experts, and community organizations is critical for raising consumer awareness regarding fluoride in bottled water.

To support these efforts, several recommendations are proposed: continuously monitoring fluoride levels in public water supplies is necessary to ensure that they remain within safe limits; public education on the potential risks associated with high fluoride exposure, especially among young children, should be prioritized; alternative water sources or treatment options must be considered in communities with persistently high fluoride levels to mitigate exposure and associated health risks. Together, these efforts seek to protect public health from fluoride consumption.

6. Conclusions

This study identified substantial discrepancies between the measured and labeled fluoride concentrations in bottled water from the western region of Saudi Arabia, with actual levels often exceeding those reported. Spring and well water sources generally exhibited higher fluoride concentrations than other types. Additionally, Saudi bottled water tends to contain more fluoride than international brands, raising concerns about the potential health risks associated with excessive exposure. While fluoride levels appear consistent across major cities in Saudi Arabia, there remains an urgent need for accurate labeling and improved consumer awareness to mitigate the risks of dental fluorosis and other fluoride-related health concerns.

AVAILABILITY OF DATA AND MATERIALS

The data and materials used in this study can be obtained from the corresponding author upon reasonable request.

AUTHOR CONTRIBUTIONS

AMA—conceptualized and designed the study, conducted the data collection and analysis, interpreted the results, and wrote the manuscript. Additionally, the author is responsible for the overall accuracy and integrity of the work presented.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This laboratory study involved the analysis of commercially available bottled water and did not require ethical approval as it did not involve human subjects. Informed consent is not applicable to this research. All bottled water samples were purchased from retail outlets and were handled in accordance with standard laboratory practices.

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CONFLICT OF INTEREST

The author declares no conflict of interest.

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