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Fluoride Concentration in Selected Water Sources of Ngamiland and Boteti Districts: Risk of Dental Fluorosis

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ABSTRACT

Fluoride is well-known for its role in preventing dental issues and promoting strong teeth and bones. It is commonly found in water, tea, and fluoridated toothpaste. The World Health Organisation recommends fluoride concentrations between 0.5 mg/L to 1.50 mg/L in water. Excessive fluoride intake can lead to dental fluorosis which affects tooth enamel. This study aimed to investigate fluoride levels in different water sources within selected villages of Ngamiland and Central Boteti districts and assess dental fluorosis prevalence among the residents. Our objectives were to measure fluoride concentrations in various water sources, evaluate the impact of pH and salinity on fluoride levels, and determine the link between fluoride concentration and dental fluorosis prevalence. Water samples were analyzed for fluoride concentration, pH, and salinity using ion chromatograph, pH meter, and conductivity meter, respectively. Interviews were conducted in Maun, Tsau, Toteng, and Motopi regarding dental fluorosis prevalence. Results showed that groundwater in Motopi and Tsau had fluoride concentrations ranging from 2.81 – 17.05 mg/L, while Toteng tap and standpipe water had fluoride concentrations of 0.78 and 0.83 mg/L. Maun tap and standpipe water, as well as Motopi surface water, yielded fluoride concentrations ranging from 0.16 – 0.37 mg/L. Salinity and pH showed no significant relationship with fluoride concentration, with correlation coefficients of 0.09 and 0.46, respectively. In conclusion, Tsau boreholes had the highest fluoride concentration, linked to dental fluorosis in individuals aged 30 years and above. Maun tap and standpipe water, alongside Motopi tap and surface water, exhibited low fluoride concentrations, while Toteng tap, and standpipe water revealed appropriate fluoride levels. The study revealed that Salinity and pH do not influence fluoride concentration in water.

Keywords: Dental Fluorosis Risk, Groundwater Management, Surface Water Management, Ngamiland and Central Boteti Districts

INTRODUCTION

Fluoride, an anion of fluorine, is the 13th most abundant element in the earth's crust, with the chemical formula F^-. Water is a major source of fluoride and other sources of fluoride are tea, seafood that contains bones or shells, medicinal supplements, and fluoridated toothpastes (Al Hayek et al, 2018). Fluoride is mostly recognised for its role in preventing dental caries and building strong teeth and bones. Although fluoride is important in building strong teeth and bones, an excessive or low fluoride intake can lead to health implications. The World Health Organisation (WHO) states that the appropriate level of fluoride in drinking water should be between 0.50 mg/L to 1.50 mg/L (WHO, 2006). Fluoride concentration that is greater than 1.50 mg/L is associated with dental fluorosis, and chronic exposure to fluoride levels exceeding 4.00 mg/L is associated with skeletal fluorosis (Everett, 2011).

Dental fluorosis is a dental health condition that results in decolourization of teeth from excessive exposure to fluoride during tooth development. It is characterized by changes in the appearance of tooth enamel, ranging from subtle white streaks or spots to more severe brown discoloration and enamel pitting (Niazi and Pepper, 2023). Dental fluorosis affects children during the critical period of tooth formation, typically up to the age of eight (Everett, 2011). The severity of dental fluorosis is dose-dependent and influenced by the extent of time an individual is exposed to excessive fluoride within the critical window of development and genetic factors (Niazi and Pepper, 2023). It can manifest in varying degrees, mild cases show white streaks, lines, or small spots on enamel.

Skeletal fluorosis is a condition that affects bones in the body caused by exposure to high fluoride levels. It causes joint pain and stiffness, decreasing mobility, structural changes in the spine, and potential neurological complications (Everett, 2011). When fluoride intake is low, the protective benefits of fluoride on dental health are reduced. The main consequence of low fluoride intake is an increased risk of tooth decay; tooth enamel may be weaker and more susceptible to acid attacks from bacteria leading to cavities and dental problems.

Groundwater has been observed to have high levels of fluoride than surface water. This is because groundwater comes into contact with rocks and minerals that contain fluoride, leading to the dissolution of fluoride in the water. Some surface water sources are constantly replenished by groundwater which can increase the concentration of fluoride but other surface water sources get replenished by rainfall. Treated water contains a small amount of fluoride or contains an appropriate amount of fluoride, whereby the water from underground or rivers are purified.

Therefore, the aim of this study was to investigate the fluoride levels in various water sources in the selected villages of Ngamiland and Boteti districts and assess the prevalence of dental fluorosis among the residents.

MATERIALS AND METHODS

Study site

The study was conducted in the selected villages of Ngamiland District, which are Tsau, Toteng, Maun, and a village in Central Boteti District, which is Motopi as shown in the map in Figure 1.

Sampling and data collection

The water samples were collected from different water sources in the study sites. A total of twenty-two 500 ml plastic sampling bottles were used to collect water from different water sources in the study sites. Each sample had a duplicate and both were labelled then put into a cooler box as a carrier. The coordinates of every sampling site were taken and recorded in the GPS device. The water samples were transported to Okavango Research Institute (ORI) laboratory and were kept in a refrigerator at 16°C to prevent changes in fluoride concentration. An interview was conducted at the study sites with the key informants, including Nurses from public clinics and chiefs, to inquire about the prevalence of Dental fluorosis in these locations.

Sample analysis

A pH meter was used to measure the pH level of water samples. A pH meter was first calibrated in three 50 ml bottles that contained buffers at a pH of 4.01, 7.00 and 10.01 respectively and the pH level of each sample were determined. A conductivity meter was used to determine the salinity of water samples, the conductivity meter was first calibrated in a 50 ml calibration standard containing 0.01 mol/L potassium chloride (KCl) and the salinity of each sample was determined. An Ion chromatograph was used to determine the concentration of fluoride. The manual injection method was carried out. Firstly, the ion chromatograph was blanked with 25µL of distilled water to ensure that the chromatograph system is clean and free of any residual contaminants or previous samples before injecting the samples. Then, 25µL of each water sample was injected with a syringe in an injection port and the ion chromatograph ran the analysis for 13 minutes at a flow rate of 1.2 ml/min and the column pressure at 46 psi. After 13 minutes elapsed, the fluoride concentration of the water sample was determined.

Figure 1. A map of study sites in Ngamiland and Central Boteti district (Google maps, 2023).

Water samples from the study sites were analyzed for fluoride, pH, and salinity, with the results presented in Figures 2-7. Mean (1) and standard deviation (2) were calculated to assess the variability of fluoride concentrations (Ali and Bhaskar, 2016). In this section, the fluoride concentration of tap water and surface water was analyzed and presented in a bar graph (Figure 2). The safe levels for fluoride range from 0.50 to 1.50 mg/L (WHO, 2006). Similarly, Figure 3 presents the fluoride concentration of groundwater in a bar graph, also with the same safe levels.

Figure 4 illustrates the pH levels of each sample, analyzed and presented in a bar graph with safe levels ranging from 6.5 to 9.5 (WHO, 2007). Pearson's correlation coefficient (3) was used to examine the relationship between pH and fluoride, a graph depicts the relationship in Figure 5. The saline content of each sample was presented in a bar graph in Figure 6, and the relationship between salinity and fluoride was examined using Pearson's correlation coefficient (3), a graph shows the relationship in Figure 7. The formulas for mean, standard deviation, and Pearson's correlation coefficient were applied to analyze the data:

Mean:

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n} \quad (1)$$

Standard Deviation:

$$s = \sqrt{\frac{\sum(x_i - \bar{x})^2}{n-1}} \quad (2)$$

Pearson's Correlation Coefficient:

$$r = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum(x_i - \bar{x})^2 \sum(y_i - \bar{y})^2}} \quad (3)$$

These calculations provided insights into the central tendency, variability, and relationships between the measured variables. In Figure 2, Toteng standpipe and tapwater fall within the fluoride safe level with fluoride concentration of 0.83 ± 0.1 mg/L and 0.78 ± 0.03 mg/L. While tapwater and standpipe in Maun, tap water and surface water in Motopi fall below the minimum fluoride safe level.

In Figure 3, the fluoride concentrations of all groundwater samples in Tsau and Motopi exceeds the maximum safe level. Tsau groundwater C has the highest fluoride concentration of 17.05 ± 0.59 mg/L, followed by Motopi ground water with 5.56 ± 0.10 mg/L, Tsau groundwater B with 5.00 ± 0.24 mg/L and Tsau groundwater A with 2.81 ± 0.49 mg/L.

The pH of all water samples depicted in bar graph in Figure 4 falls within the WHO pH safe level. Motopi groundwater has the highest pH level of 9.09 and Maun tap water B has the lowest pH level of 7.24.

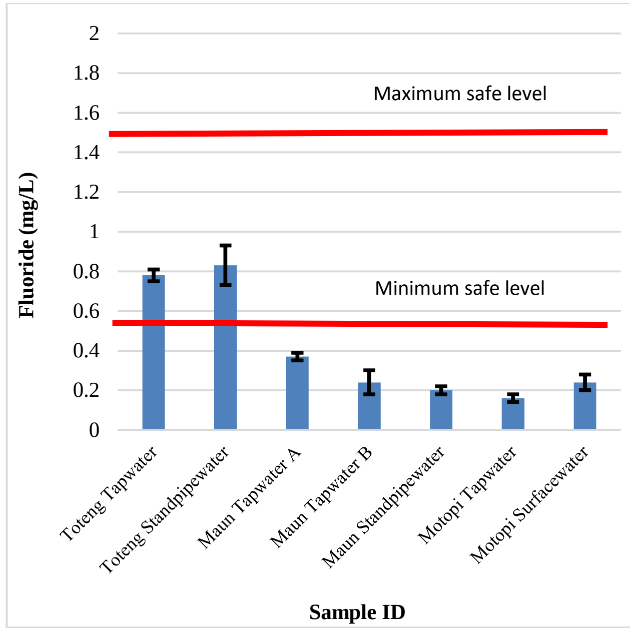

Figure 2. Fluoride concentration of tapwater in Maun, Motopi and Toteng, surface water in Motopi and standpipe water in Toteng and Maun.

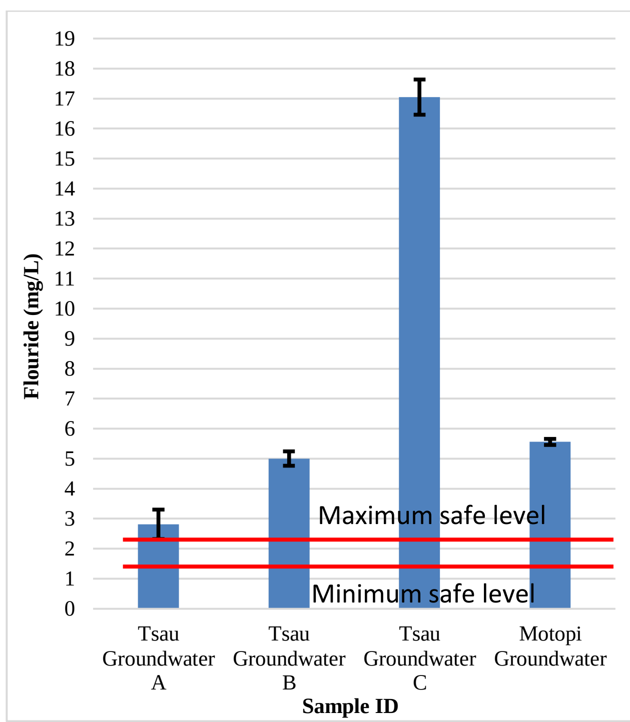

Figure 3. Fluoride concentration of groundwater in Tsau and Motopi.

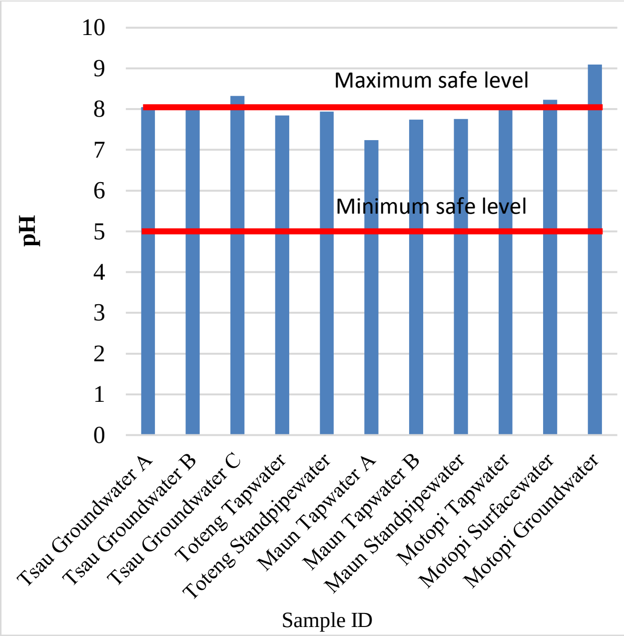

Figure 4. The pH level of different water sources in Maun, Toteng, Tsau and Motopi.

A scatter graph below shows no correlation between the pH and fluoride concentration and the correlation coefficient is 0.21. This low R^2 value indicates a weak linear relationship between fluoride concentration and pH. The equation y=5.0867x−37.843 represents a positive linear relationship between fluoride concentration and pH.

The saline content of Tsau groundwater A, Tsau ground water B and Motopi groundwater exceeds the safe salinity limit of 1600 µS/cm while other water samples are within the safe saline limit. Tsau groundwater A has the highest saline content of 14800 µS/cm (Figure 6).

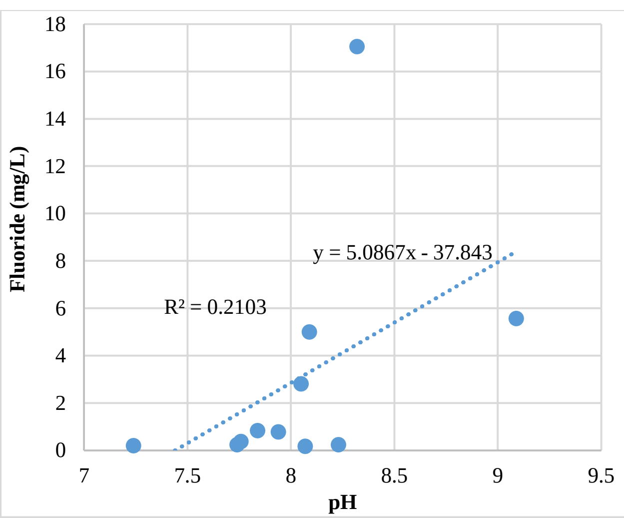

Figure 5. A relationship between the fluoride concentration and pH of various water sources.

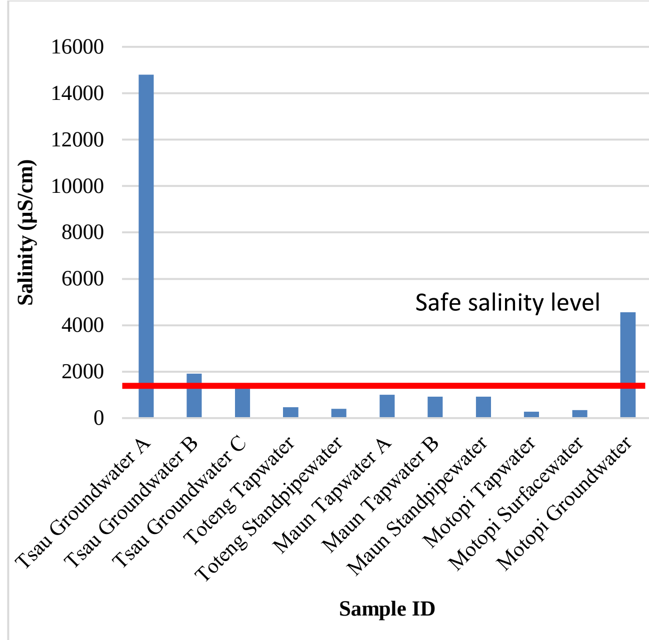

Figure 6. The saline content of different water sources in Maun, Toteng, Tsau and Motopi.

Another scatter graph shows no correlation between salinity and fluoride and the correlation coefficient is 0.003 (Figure 7). This low R^2 value suggests that there is almost no linear relationship between salinity and fluoride concentration, therefore salinity does not have an impact on fluoride concentration variation.

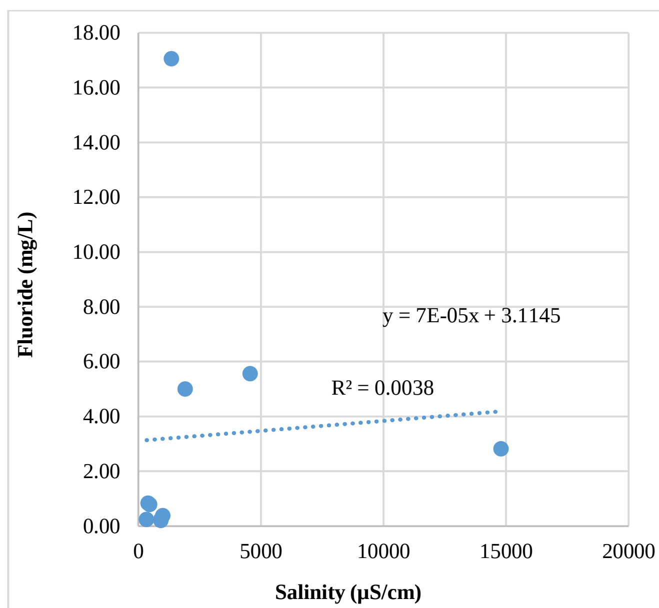

Figure 7. A relationship between salinity and fluoride concentration of various water sources.

Interview findings

- 80% of the key informants said that there is no prevalence of Dental fluorosis in Ngamiland and Central Boteti districts except in Tsau.
- 70% of the key informants said that water causes dental fluorosis.
- 71% of the key informants said that people who are 30 years and above have dental fluorosis while 29% said that people who are 29 years and below have dental fluorosis.

RESULTS AND DISCUSSION

Comparative analysis of fluoride concentrations in Maun and Motopi water sources: Tap water, Standpipe water and surface water

In Toteng, the fluoride concentrations in both tap water (0.78 ± 0.03 mg/L) and standpipe water (0.83 ± 0.1 mg/L) are within the World Health Organization (WHO) safe range of 0.50 – 1.50 mg/L, making them safe for consumption. However, in Maun and Motopi, the fluoride levels in tap water, standpipe water, and surface water are below the WHO safe level, with concentrations ranging from 0.16 ± 0.02 mg/L to 0.37 ± 0.02 mg/L. This low fluoride level can lead to weakened teeth and an increased risk of dental cavities. Differences in fluoride concentrations among various water sources in Maun and Motopi are attributed to the water coming from different boreholes (Azani-Aghdash et al., 2013).

Comparative analysis of fluoride concentrations in Tsau and Motopi ground water

The fluoride concentrations in groundwater from Tsau and Motopi are above the WHO safe level, posing a risk of dental and skeletal fluorosis. Tsau groundwater C has the highest fluoride concentration (17.05 ± 0.59 mg/L), followed by Motopi groundwater (5.56 ± 0.10 mg/L), Tsau groundwater B (5.00 ± 0.24 mg/L), and Tsau groundwater A (2.81 ± 0.49 mg/L). The high fluoride levels in Tsau and Motopi are likely due to the water coming into contact with fluoride-containing rocks and minerals. Long-term consumption of such high-fluoride water can cause dental and skeletal fluorosis, where bones become weak and bend (Brindha and Elango, 2011).

pH levels of various water sources in Maun, Toteng, Tsau and Motopi and the relationship between pH-fluoride concentration

The pH levels of water samples from Maun, Toteng, Tsau, and Motopi fall within the WHO safe range of 6.5 to 9.5, making them safe for human consumption. A scatter graph and Pearson correlation coefficient (0.21) indicate no significant correlation between pH and fluoride levels (Liu et al., 2022).

Saline content of various water sources in Maun, Toteng, Tsau and Motopi and the relationship between salinity-fluoride concentrations

In Tsau and Motopi, groundwater salinity exceeds the safe limit of 1600 μS/cm, making it unsuitable for drinking. However, other water samples fall within the safe salinity limit. A scatter graph and Pearson correlation coefficient (0.003) show no significant correlation between salinity and fluoride levels, indicating that salinity does not affect fluoride concentration (Ahmed et al., 2019).

Perception of key informants on the prevalence and causes of Dental fluorosis among different age groups

Interviews with nurses and chiefs revealed that 80% reported no prevalence of dental fluorosis in Ngamiland and Central Boteti districts, except in Tsau. Some villages near the Makgadikgadi salt pan, like Rakops, Mokoboxane, and Mopipi, have reported cases of dental fluorosis. Key informants attribute dental fluorosis to high fluoride levels in water and note that 71% of affected individuals are aged 30 and above, while 29% are aged 5 to 19. Dental fluorosis was more prevalent between 1978 and 1984, before water treatment facilities were established.

CONCLUSION

Tsau and Motopi groundwaters have high fluoride levels, exceeding WHO limits and posing a risk of dental fluorosis, particularly among individuals aged 30 and above. In contrast, Maun and Motopi's tap/standpipe and river waters have fluoride levels below the WHO minimum, risking dental cavities, while Toteng's water is within the safe range. Understanding fluoride content in drinking water is essential for public health, as excessive fluoride can cause dental and skeletal fluorosis, while insufficient levels can lead to cavities.

DECLARATIONS

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Data availability

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

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Authors' contribution

The first author provided assistance and supervision for the project, and revised the manuscript. The second author conducted the experiments, analyzed the data, and authored the manuscript. The third author contributed to the laboratory work.

Competing interests

The authors declare no competing interests in this research and publication.

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