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AMBIENT TEMPERATURE IN THE DETERMINATION OF THE UPPER OPTIMUM FLUORIDE LEVEL FOR COMMUNAL POTABLE WATER SUPPLIES IN THE KINGDOM OF SAUDI ARABIA

AbdelRahman M Ramadan,[a,*] Ali S Al-Sharif,[b] Suha H Al-Shareef[c]

Al-Madinah Al-Munawarah, Kingdom of Saudi Arabia

ABSTRACT: Although fluoride plays an essential role in preventive dentistry because of its cariostatic potential, the excessive consumption of fluoride may result in the adverse health effects of dental, skeletal, and non-skeletal fluorosis. The aims of the present study were (i) to determine the permissible fluoride level relative to air temperature in sixteen cities representing the thirteen administrative regions of the Kingdom of Saudi Arabia, and (ii) to aid the different authorities in adjusting the fluoride level in their regions to the appropriate levels in order to prevent the occurrence of adverse health effects in humans. The annual mean maximum temperatures (AMMTs) were obtained from the website of the General Authority of Meteorology and Environmental Protection, the Saudi National Portal, that has maintained records of the monthly ambient temperature measurements for the last twenty-two years (January 1995–December 2017). The optimal fluoride level for each administrative region was calculated by the Galagan and Vermillion formula that is used universally to estimate the permissible fluoride level and the allowable water consumption as a function of ambient temperature. The optimal fluoride level in the potable water for the sixteen cities, representing the 13 administrative regions in Saudi Arabia, was calculated to be 0.32–0.42 ppm. The fluoride content of water in Saudi Arabia was found to vary considerably, being high in certain areas, adequate in others, and occasionally being low and needing supplementation. Of the sixteen cities representing the 13 administrative regions, the cities of Al Qassem, Al Riyadh, Hail, and Najran reported levels of 1.11, 1.01, 1.02, and 0.64 ppm, respectively and were found to have an unacceptable level of risk for the occurrence of dental fluorosis.

Keywords: Ambient temperature; Fluorosis; Kingdom of Saudi Arabia; Upper permissible fluoride level.

INTRODUCTION

Water is essential for life and its significance as a community resource is widely acknowledged. However, on a global scale, 30% of the world's people (2.1 billion) are without access to treated water.[1,2]

The Kingdom of Saudi Arabia (KSA), a Middle East county positioned between the Red Sea and the Persian Gulf, has a total area of about 2 million km^2. The KSA[3,4] has an estimated total population of about 32.6 million and has been growing at an average growth rate of 3.4% over the past 40 years.[3] Most of the population lives in five urban centres: El Riyadh with a population of 5.2 million, Jeddah with 3.4 million, Makkah with 1.5 million, the Eastern area (Dammam, Al-Khobar, Dhahran) with 1.3 million, and Madinah with 1.1 million.[5]

The climate of the KSA could be characterised as a desert environment with an average annual rainfall of less than 100 mm across the country.[3,4] Almost the whole

[a]Associate Professor, Department of Preventive Dentistry, College of Dentistry, Taibah University, Al-Madinah Al-Munawarah, Kingdom of Saudi Arabia; [b]Teaching Assistant, Department of Prosthetic Dentistry College of Dentistry, Taibah University, Al-Madinah; [c]Dental Student, College of Dentistry, Taibah University, Al-Madinah Al-Munawarah, Kingdom of Saudi Arabia. For correspondence: AbdelRahman M Ramadan, Associate Professor, Department of Preventive Dentistry, College of Dentistry, Taibah University, Al-Madinah Al-Munawarah, Kingdom of Saudi Arabia. E-mail: dramaramadan@gmail.com

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of the KSA is arid, although there is rainfall in the North and along the mountain range to the West, especially in the far Southwest, which receives the monsoon rains in summer. In the KSA the varied topography and its features produce a diverse climate varying from one region to another. The climate in the KSA is usually continental, hot in summer and cold in winter, and the rainfall occurs mostly in winter. The Western and South-western heights present a moderate climate while the heartland regions have a hot dry summer and a cold dry winter.[3,6]

The modernisation of the KSA has resulted in an ever growing water consumption in the domestic, agricultural, and industrial sectors.[7] However, the KSA does not have any permanent surface water resources. Flash floods occur, which sometimes run for short durations, and result in temporal and spatial changes in the rainfall patterns. The water from these flash floods is secured in 260 irrigation dams and amass an estimated 0.6 billion m^3 of water annually.[4,7] The flash floods are not a dependable source for domestic water, and therefore Saudi Arabia relies on two primary sources to satisfy the water demand: groundwater aquifers and seawater desalination. Currently, the industrial and domestic demands are met from a combination of groundwater and seawater desalination while the agricultural demand depends entirely on groundwater.[8-10]

In the KSA, groundwater is considered to be the primary reliable natural water source and accounts for an estimated 3.85 billion m^3/year, and is acquired from both renewable and non-renewable aquifers.[4] The second source for potable water is desalinated water and the KSA is considered to be the leading global producer of desalinated water which is obtained from 30 desalination plants located on the Red Sea and the Persian Gulf.[7]

Fluoride, from a dental public health perspective, is a double-edged sword. When the fluoride intake is at an optimal level it decreases the incidence of dental caries and maintains the integrity of oral tissues but when fluoride is consumed in excess, during the critical period of tooth development up to the age of approximately 8 years, it can cause the adverse effect of dental fluorosis, and excess consumption at any age may result in skeletal and non-skeletal fluorosis. The United States Environmental Protection Agency (USEPA)[11,12] lists fluoride as one of 16 inorganic chemical pollutants in drinking water in the National Primary Drinking Water Regulations and as a priority hazardous substance with the US Agency for Toxic Substances and Disease Registry.[13]

It has been advocated that 0.5–1 ppm is an appropriate upper acceptable fluoride level. The prevalence and severity of fluorosis, for a given fluoride level, increase with higher altitude above sea level, impaired nutritional status, and higher mean daily temperature.[14-18] The single most important source of fluoride for causing dental fluorosis is, undeniably, the potable water.[19-21] Although the global dental caries prevalence is reported to have significantly diminished in recent years due to the widespread use of fluoride, dental fluorosis, nevertheless, continues to be an unsettled global public health concern, particularly in some countries.

During the first half of the 20th century, observational studies in the United States demonstrated an inverse association between the average number of decayed teeth in a population and the fluoride level in the potable water supply. However, subsequent

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studies demonstrated that the occurrence of dental caries was insignificantly reduced beyond a certain level, while there was a significant increase in dental fluorosis prevalence. These studies were essential for estimating the optimum fluoride level that provides a maximum benefit in caries reduction with the minimum risk of developing dental fluorosis and demonstrating the complex association between dental fluorosis and the fluoride level in potable water.[16,22-26]

Temperature is one of the most critical climatic parameters, and has a serious impact on the socio-economic condition of a region. The climate in Saudi Arabia is principally a desert climate typified by high temperatures during the day and low temperatures by night. Nonetheless, two significant differences in the Saudi-Arabian climate can be felt between its coastal regions and its heartland.[27]

Acquaintance with the upper acceptable fluoride level of the potable water of a population is essential in all dental fluorosis studies. Galagan and Vermillion developed a formula to establish the upper acceptable fluoride level, which correlates with the fluid consumption and the average temperature of the environment.[28] However, it must be emphasised that this formula is based on the temperate climate differences in the United States of America (USA). It is of utmost importance to adjust a community's supplies potable water fluoride levels to thwart an unwarranted fluoride intake. The optimal level of fluoride in drinking water is commonly calculated by using the Galagan and Vermillion equation which allows the calculation of the water intake as a function of the temperature of the geographic location.

The optimal fluoride in drinking water has been calculated, based on the annual mean maximum temperature (AMMT), and found to fluctuate between 0.7 and 1.2 ppm, depending on the climate of the country.[29] Subsequent studies in Sudan, Pakistan, Chile, and Sri Lanka have used a modified version of the equation to ascertain the upper acceptable fluoride level in potable water in these countries.[15, 30-32]

Despite the therapeutic and preventive attempts employed by the Saudi authorities in response to the high prevalence of dental caries among children, the Saudi Arabian Standards Organization (SASO) adopted, in 2007, the MOH suggestions concerning fluoridating the primary drinking water networks of the major cities.[33] Saudi Arabia, however, still has some risk of dental fluorosis as potable well water is still drunk as the primary water source in remote parts of the country.[34,35] Dental fluorosis is of dental public health interest in various regions of the KSA, and, on this basis, numerous studies on dental fluorosis and fluoride levels in the KSA have demonstrated variable prevalence rates of dental fluorosis. The prevalence of dental fluorosis, among people aged 6 to 74 years in ten administrative regions, varied from a low of 7.7% among 6 to 7 year-olds to a high of 37.5% among the 20 to 29 year-olds.[35] A significant difference was found between the rural and urban residents ($p<0.01$). The researchers concluded that 24.6% of the Saudi population has some form of fluorosis (from questionable to severe fluorosis) but that the prevalence of severe fluorosis was not a huge country-wide problem.[34–41]

The aim of the current study was to obtain an epidemiological estimate of an appropriate fluoride level range in potable water, under the local conditions in the

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KSA. This estimate could assist the National Health Authorities in the decision-making process on this issue.

MATERIALS AND METHODS

Using the search terms "fluorosis, climate, water, potable and Saudi" in the search engines of MEDLINE and PubMed, HINARI (Health Internetwork, WHO), and Google Scholar, the scientific literature was searched for clinical, experimental, and review reports and the articles obtained from these databases were reviewed.

A cross-sectional study design was used for this research. The optimal fluoride level in potable water in the KSA was determined to take into consideration the regional differences in the ambient temperature across the country.

Ethical approval for this study was obtained from the Taibah University College of Dentistry, Research Ethics Committee (TUCDREC), Taibah University, Al Madinah Al Munawarah, Saudi Arabia. City, KSA, despite the data used being open access, and available online from the public domain.

The monthly maximum ambient temperature data were obtained from the websites of the General Authority of Meteorology and Environmental Protection (http://www.pme.gov.sa, https://www.saudi.gov.sa, http://www.climatetemp.info/saudi_arabia/) for the thirteen Saudi administrative regions.[42]

The optimal fluoride level for the KSA was determined by using the original and modified Galagan and Vermillion formulae.[15,28-31] When the original metric units of the Galagan and Vermillion formula were substituted with the units of the International System of Units (SI), the formula to assess the optimal upper level of fluoride (ppm) in potable water became:

$$\text{Optimal upper permissible fluoride level (ppm, mg/L)} = \frac{0.022}{(0.0104 + 0.000724 \times \text{AMMT °C})} \quad \text{........ Equation 1}$$

Where AMMT = Annual mean maximum temperature in °C

The Galagan and Vermillion formula was recommended for American children who consumed almost 44% of their fluid intake from cow's milk, which contains almost insignificant quantities of fluoride According to original Galagan and Vermillion formula,[28] 0.62 ppm is suggested as the upper acceptable fluoride level in potable water in the KSA. However, under the conditions existing in the KSA, practically all the fluid intake by the population is from potable water. To establish the optimal upper level of fluoride in potable water for the KSA, a modification of Galagan and Vermillion original formula is appropriate. The modified equation has been previously used in Pakistan, Chile, and Sudan with a correction factor of 0.44–1.

The optimal upper permissible fluoride level using the modified equation is shown in Equation 2.

$$\text{Optimal upper permissible fluoride level (ppm, mg/L)} = \frac{0.022 \times 0.56}{(0.0104 + 0.000724 \times \text{AMMT °C})} \quad \text{........ Equation 2}$$

Where AMMT = Annual mean maximum temperature in °C

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It was assumed that the drinking habits of Saudi Arabians are generally similar to the countries where the modified equation was applied earlier.[15,28-31]

RESULTS

The relationship between the levels of water fluoride, caries, and fluorosis was investigated by observing the data on fluoride concentrations in potable water of 16 cities of the KSA in which the fluorosis levels and the ambient temperature were also known.

To determine the optimal level of fluoride in potable water for the KSA from the original and modified equation of Galagan and Vermillion,[15,30–32] the AMMTs recorded during the period between January 1995 and December 2017 were obtained from the General Authority of Meteorology and Environmental Protection.

The annual mean maximum temperature (AMMT) were obtained for 16 cities which were representative of the 13 regions (Table and Figure 1). The cities studied were: Dhahran, Abha, Al Ahsa, Dammam, Jizan, Tabuk, Arar, Al Gassim, Riyadh, Mecca, Al Madinah Al Munawarah, Jeddah, Najran, Hail, Sakakah, and Al Bahah. The mean of the AMMT was 32.91ºC and the range was 26.33ºC (Abha) to 38.78ºC (Mecca).

Table. Optimal fluoride level (upper permissible level, ppm, mg/L) according to the average annual maximum air temperature (AMMT, °C)

No.	City	AMMT (°C)	Original optimal fluoride level (ppm)	Modified optimal fluoride level (ppm)
1	Dhahran	34.1	0.63	0.35
2	Abha	26.3	0.75	0.42
3	Al Ahsa	35.7	0.61	0.34
4	Dammam	34.4	0.62	0.35
5	Jizan	35.2	0.61	0.34
6	Tabuk	30.1	0.68	0.38
7	Arar	30.4	0.68	0.38
8	Al Gassim	33.8	0.63	0.35
9	Riyadh	33.3	0.64	0.36
10	Mecca	38.8	0.57	0.32
11	Madinah	35.5	0.61	0.34
12	Jeddah	34.9	0.62	0.35
13	Najran	34.0	0.63	0.35
14	Hail	30.3	0.68	0.38
15	Sakakah	29.8	0.69	0.39
16	Al Bahah	29.9	0.69	0.38

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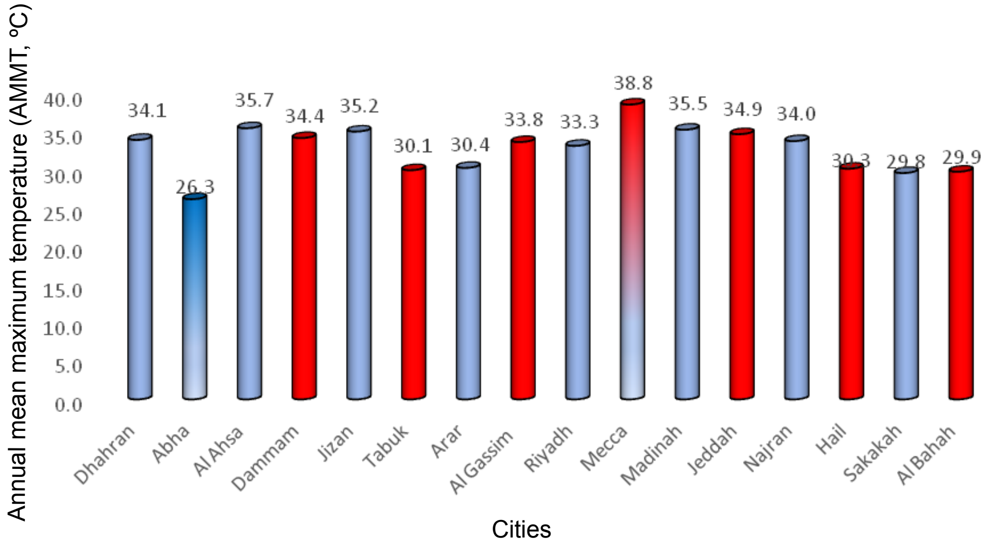

Figure 1. Annual mean maximum temperature (ºC) during January 1995–December 2017 in the sixteen cities in the thirteen administrative regions.

Using the original formula of Galagan and Vermillion, the range of the upper acceptable fluoride level in potable water in the KSA was determined to be 0.57–0.75 ppm (mean 0.65 ppm). However, with the modified version of the equation, using the 0.56 correction factor and the same values for the AMMT in the KSA, the range of the recommended upper acceptable fluoride level in potable water was 0.32–0.42 ppm (mean 0.36 ppm, Table and Figure 2).

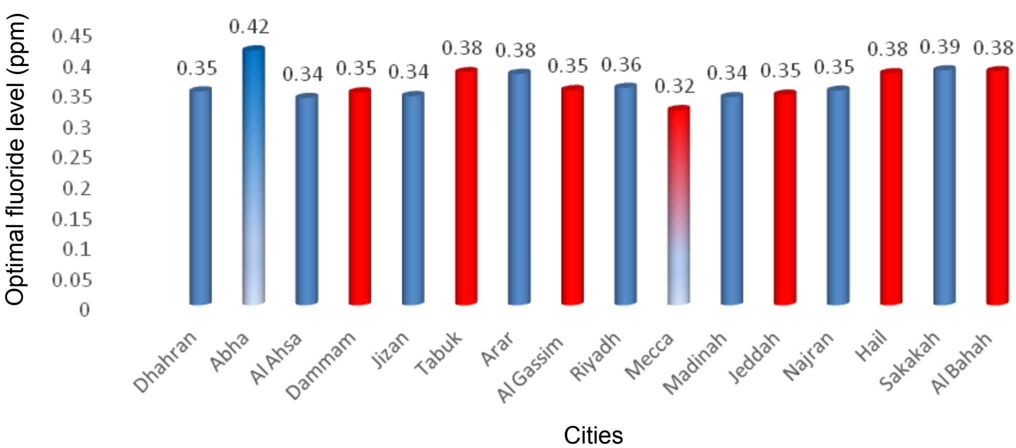

Figure 2. Optimal fluoride level (ppm) in the sixteen cities of the thirteen administrative regions as calculated with the modified version of the Galagan and Vermillion equation using the correction factor of 0.56.

The AMMT, optimal fluoride level with the modified equation, and the water consumption per capita in the 16 cities studied in the 13 administrative regions of the KSA are shown in Figure 3.

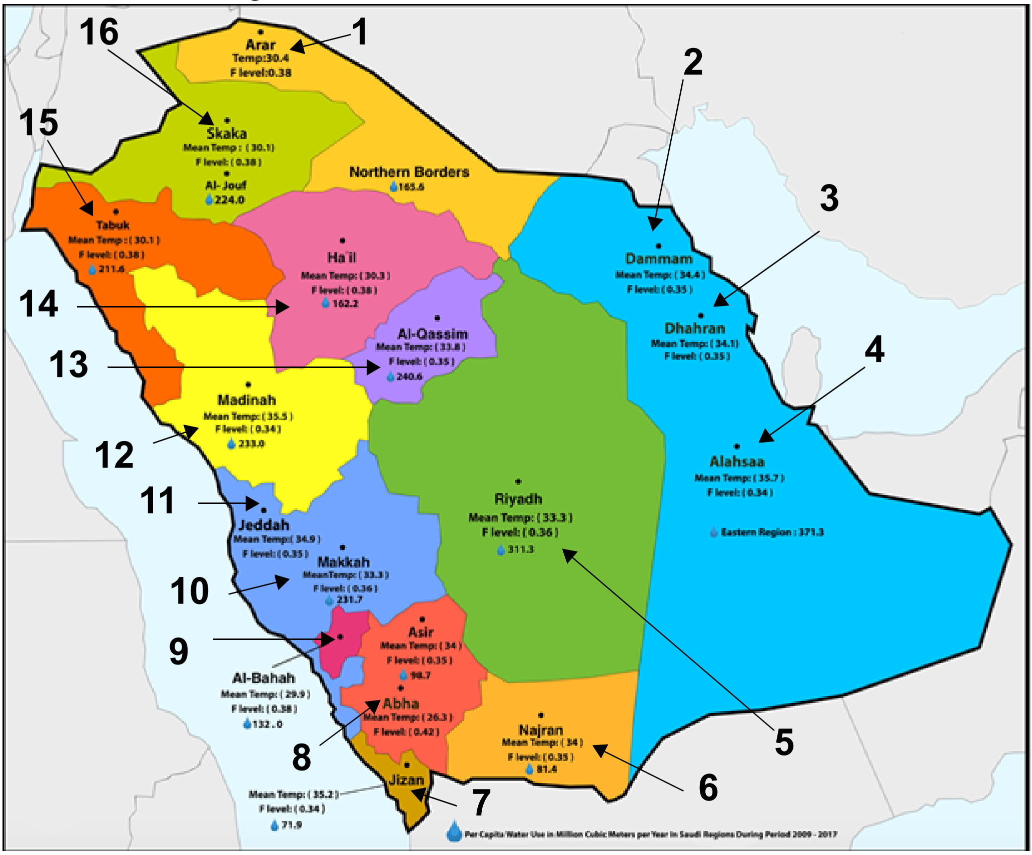

Figure 3. Map of the Kingdom of Saudi Arabia showing the annual mean maximum temperature (AMMT, ºC), the optimal fluoride level (ppm), and water consumption (L per capita per year) in the sixteen cities of the thirteen administrative regions under study.

No.	City	AMMT (ºC)	Modified optimal F level (ppm)	Water intake (L/yr)
1	Arar	30.4	0.38	165.6
2	Damman	34.4	0.35	
3	Dhahran	34.1	0.35	371.3
4	Al Ahsa	35.7	0.34	
5	Riyadh	33.3	0.36	311.3
6	Najran	34.0	0.35	81.4
7	Jizan	35.2	0.34	71.9
8	Abha	26.3	0.42	98.7
9	Al Bahab	29.9	0.38	132.0
10	Mecca	38.8	0.32	231.7
11	Jeddah	34.9	0.35	
12	Madinah	35.5	0.34	233.0
13	Al Gassim	33.8	0.35	240.6
14	Hail	30.3	0.38	162.2
15	Tabuk	30.1	0.38	211.6
16	Sakakah	29.8	0.39	224.0

The range of the optimal fluoride level in potable water when calculated on the basis of the original equation was 0.57–0.75 ppm. When the modified equation was used the range was 0.32–0.42 ppm. For the hottest city in the KSA (Mecca, AMMT 38.8ºC), the optimal fluoride level in potable water was 0.57 ppm obtained with the original formula, and 0.32 ppm with the modified equation. For the coldest city in the KSA (Abha, AMMT 26.3ºC) the value obtained for the optimal fluoride level with the original formula was 0.75 ppm while 0.42 ppm was obtained with the modified equation.

DISCUSSION

This research was designed to determine the optimal fluoride level in potable water in relation to the climate in various regions. The results demonstrated a wide variation in the optimal fluoride levels between the various regions due to the differences in their annual mean maximum temperature.

Climate is a significant factor in determining the optimal fluoride level in potable water. In the hot climates of the tropics and subtropics, undesirable health effects may follow the use of potable water containing fluoride, even when the level is less than the World Health Organization (WHO) recommended upper limit of 1.5 mg/L. Water consumption in countries with hot climates is usually significantly higher than in temperate countries. Therefore, a temperature correction is required to reduce the health risks from water consumption due to the accumulation of excess fluoride in the body.

The findings of this study are vital to the KSA in deciding the optimal fluoride levels in the potable water. However, the original and modified Galagan and Vermillion formulae are based on certain assumptions about drinking consumption behaviours, and reliable conclusions cannot be drawn without conducting a large scale study aimed at particular communities. These modified equations may also be needed in site-specific cases based on the subsurface geological, geographical, hydrogeochemical, and land-use conditions.[43]

In the KSA a water fluoridation project is in place in the major cities although the fluoride level is naturally above the acceptable upper level in the potable water and dental fluorosis is present in the Al Riyadh, Hail, Al Qaseem, Al Jouf, Al Madinah Al Munawarah, Makkah, Dammam, Tabuk, Abha, and Jizan regions.[33] The published studies have reported the number of dental fluorosis cases for a number of specific regions or cities raising the possibility of respondent bias.[34,35,38-41,44-52]

Al Shammary et al. reported that the prevalence of dental fluorosis among different age groups varied greatly.[38] In the 5–6 year-old age group, the prevalence of dental fluorosis was approximately 8%.[38] Among the 20–29 year-olds, the dental fluorosis rate was much higher, approximately 38%.[38] The authors concluded that, generally, the prevalence of dental fluorosis for the KSA was approximately 25%,[38] which is markedly lower than the prevalence of dental fluorosis reported in Hail of approximately 75%.[34] Al Shammary et al. stressed the need to determine the fluoride level of potable water. Their study also described significant differences in the dental fluorosis prevalence between those residing in an urban area and those living in a rural situation. In contrast, Dosari et al. did not describe the global prevalence of dental fluorosis but documented that it is roughly 40% more rampant in maxillary

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incisors and the permanent dentition. The high prevalence in these teeth justifies an interest being taken in the aesthetic aspects of dental fluorosis. Studies have described people's aesthetic perceptions as a result of having dental fluorosis, which may involve having or developing low self-esteem.[53]

The fluoride levels in drinking water found in our study varied widely in different parts of the country, being highest in the Northern region and in Hail where the fluoride concentration was above 2.5 ppm in some wells.[54] The fluoride levels were very low in desalinated water and at government water distribution points, which have reported less than 0.14 ppm in most of the sources. However, levels of 0.09 ppm and 0.56 ppm have also been reported.[54,55]

In 2017, the World Health Organization (WHO) stated that in temperate climate conditions the permissible upper level of fluoride in potable water is 1.5 ppm. However, in hot climates where water intake is high, the fluoride levels should be decreased.[56] Potable water is an indispensable communal asset which is essential for life, and whose significance is generally appreciated.

In the 1984 WHO publication, *Fluorine and fluorides*, it is noted that, from a public health perspective, the cariostatic effect of fluoride depends partly on the incorporation of fluoride in developing teeth and partly on post-eruptive exposure of enamel to adequate levels of fluoride in the oral environment and that both requirements can be satisfied by an optimal fluoride concentration in the household drinking water of 0.7–1.2 mg/L, depending on climatic conditions.[57] This implies a recommendation that in countries with a warmer climate the optimal fluoride levels in potable water should remain below 1.0 ppm, while in colder climates it could be up to 1.2 ppm.[57] The distinction between the levels is based on the assumption that perspiration is higher in a hotter climate than in a colder climate, and accordingly water consumption is higher. This recommendation was further endorsed in 2004 when the WHO stated that dental fluorosis could occur at lower fluoride levels in warmer countries due to the higher consumption of potable water.[58] The WHO generally recommended a range between 0.5–1.0 ppm as the optimal fluoride level.[29] Even though the effect of temperature has been given ample consideration in deciding the optimum fluoride levels for drinking water in the past, the US Public Health Service recently amended its temperature-based optimal fluoride concentration (0.7–1.2 ppm) in community water supplies to a fixed value of 0.7 ppm.[29] The US Public Health Service reports claimed that recent data do not defend a definite association between water consumption and outside air temperature and thus suggestions based on the outside temperature are not relevant for the USA due to the extensive use of air conditioning and the sedentary lifestyle of the US population.[59]

Globally, however, approximately 30% of the world's population (2.1 of 7.8 billion) are without safe water.[1,60] The evaluation of the quality of the potable water remains an essential consideration as fluoride, when present at high levels, has the capacity to induce dental fluorosis, skeletal fluorosis, and non-skeletal fluorosis including developmental neurotoxicity.[1] The institution of harmless fluoride levels in potable water is a fundamental criterion for safeguarding health.[61]

In the fluorotic zones of tropical countries, the incidence of high fluoride levels in the potable water sources is an obstacle in the way of delivering safe water to the

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community, particularly in rural areas where groundwater continues to be only supply of potable water. Dental fluorosis may occur when the teeth are exposed to fluoride while they are still developing, up to the age of approximately 8 years, and it has been demonstrated that a significant upsurge in the prevalence of dental fluorosis occurs with elevated fluoride levels in potable water, an increased age, and an increased duration of residency in a high-fluoride area.[30,62]

The WHO suggests, that each country calculates its optimal fluoride level in potable water based on its climatic conditions, water intake, dietary habits of the population, and other possible fluoride sources such as dental products.[58] The risk of fluorosis can be increased with the regular consumption of some fluoride-containing food (e.g., tuna fish) and beverages (e.g., tea), and with the inadvertent ingestion of fluoridated toothpaste.[63] Although some areas in the People's Republic of China have had endemic fluorosis due to food contamination with fluoride from burning powdered coal and high-fluoride clay briquettes indoors without a flue, drinking water is usually the single largest contributor to fluoride intake and contains fluoride in a free ionic state which is easily absorbed. With relatively high fluoride levels in the potable water in the rural areas of the KSA, potable-water has become gradually more important as a major source of fluoride. Waugh et al. reported that the fluoride content of black tea infusions, made from 54 brands of black tea bags available in the Republic of Ireland, had a range of 1.6 to 6.1 ppm, with a mean value of 3.3 ppm.[64] They considered that an implication of their study was that tea should not be consumed by infants or children in order to prevent the risk of cardiotoxicity, neurotoxicity, dental fluorosis, abnormal bone metabolism, endocrine dysfunction, hepatotoxicity, and nephrotoxicity.[64]

Galagan and Vermillion [28] observed that different levels of dental fluorosis occur at equivalent fluoride levels in various temperature zones. Galagan and Vermillion further amassed figures on children's drinking habits in different temperature settings to formulate an ideal fluoride level between 0.7 and 1.2 ppm for a mean maximum temperature between 50 and 90ºF.

Galagan and Vermillion's[28] original formula was used as the basis for the calculations which considered the daily water intake under various temperature conditions in the late 1950s. This equation was recommended for calculating the optimal drinking water fluoride level for children in the USA, who were assumed to consume 44% of their total fluid intake from milk which had insignificant fluoride levels.[65] Since then, the Galagan and Vermillion equation has been unanimously applied globally to calculate the optimum fluoride level in potable water.[28] The equation permits water intake estimations to be made as a function of temperature. However, these guidelines cannot be applied universally, particularly in hot tropical countries.[15]

In Austria, the Galagan and Vermillion equation deemed a fluoride level between 0.7–1 ppm which may be ideal for Austria,[66] but would be considered to be too high for Sudan, Bophuthatswana, and Namibia,[15,66,67] where fluorosis has been observed at the level of 0.5 ppm. The upper limit of fluoride in the potable water has been set at 0.6 ppm for Senegal.[69] In Sri Lanka, the suggested upper limit of fluoride in the potable water is 0.6–0.8 ppm,[70] while in Chile the suggested optimal fluoride level in the potable water level is 0.5–0.6 ppm.[31] Similarly, an optimal fluoride level of 0.34

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ppm has been advocated for the fluorotic zones in India.[70] In 2004, the WHO recommended a range between 0.5–1.0 ppm as the optimal fluoride level in potable water.[29]

Under the current Saudi conditions, practically all the fluid consumption in the KSA comes from potable water and beverages and the application of the modified Galagan and Vermillion formula with a correction factor of 0.56 is appropriate. The modified equation gives an upper acceptable potable water fluoride level range for the KSA of 0.32–0.35 ppm.

LIMITATIONS OF THE STUDY

The study was unable to determine or to consider individual variations and lifestyles. There are people who work in air-conditioned rooms and so may consume less water compared to those working outdoors. Similarly, the nature of job might also affect the consumption of water and ultimately the fluoride intake. Finally, there is a wide variation of weather conditions in the various regions of the KSA which may affect the fluoride intake and should be taken into consideration

CONCLUSIONS

According to the results of this study, the optimum fluoride level for potable water in 16 different cities of the KSA varies from 0.32–0.42 ppm. This level is much lower than the water fluoride levels currently recommended by the WHO and the US Public Health Service to prevent dental caries of 0.7–1.2 mg/L and 0.7 mg/L, respectively.

A thorough analysis of all the sources of fluoride must be available for each community before a criterion for the upper acceptable water fluoride levels can be determined. Currently, there is no benchmark for establishing a common upper acceptable fluoride level in potable water. The establishment of the upper acceptable fluoride levels in potable water is crucial for populations but the significant heterogeneousness present across the thirteen administrative regions of the KSA, makes the delineation of a clear yardstick and general recommendations exceptionally challenging. Each administrative region has to calculate its own upper acceptable fluoride level in its potable water. Using Deans' guidelines and the correction for the temperature in the KSA, the suggested upper acceptable fluoride level in potable water in the KSA can be determined to be between 0.32 and 0.42 ppm with an average of 0.36 ppm.

In preparing recommendations for the optimal potable water fluoride level in the KSA, consideration needs to be given to the current increase in the use of fluoridated toothpastes and other secondary fluoride sources, the overall exposure to different ingestible forms of fluoride, the climatic circumstances, the population dietary habits, and other possible sources of fluoride exposure. Therefore, further dose-response studies are necessary in order to appraise the optimum fluoride levels in potable water for the endemic fluorosis areas of the KSA.

RECOMMENDATIONS

(i) As dental fluorosis is a public health problem in the KSA, authorities at several levels of government will need to consider defluoridation of water, especially when there are no substitute safe water sources available.

(ii) A well-designed comprehensive epidemiological study and a database of the fluoride content in groundwater needs to be started in the KSA to substantiate and evaluate dental fluorosis and to gauge the risk factors associated with the condition in the KSA.

(iii) An epidemiological study, including the creation of a database of the fluoride content of potable water, is needed before official recommendations can be made to establish the optimal fluoride levels for the general public in the KSA. In order to recommend an upper acceptable intake of fluoride for the KSA, the study will need to take into consideration the factors of age, nutritional status, geographical altitude and location, and weather.

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Not applicable.

CONFLICT OF INTEREST

The authors declare that they have no competing interests.

REFERENCES

1 World Health Organization (WHO) and the United Nations Children's Fund (UNICEF) Joint Monitoring Programme For Water Supply, Sanitation and Hygiene (JMP). Progress on drinking water, sanitation and hygiene: 2017: update SDG baselines. Geneva, Switzerland: World Health Organization (WHO) and the United Nations Children's Fund (UNICEF); 2017. Available from: https://washdata.org/reports?text=&page=2

2 Peres MA, Cury JA. Drinking water quality and fluoride concentration. Rev Saúde Pública 2011;45(5):1-10.

3 Saudi Open Data. Population statistics, Weather conditions. Saudi Open Data. [cited 2019 Mar 17]. Available from: http://www.data.gov.sa/en/group/weather-conditions.

4 Al-Zahrani KH, Baig MB. Water in the Kingdom of Saudi Arabia: sustainable management options. J Anim Plant Sci 2011;21:601-4.

5 General Authority for Statistics, Kingdom of Saudi Arabia. Population. General Authority for Statistics. 2018. [cited 2019 Mar 10]. Available from: https://www.stats.gov.sa/en/852.

6 Almazroui M. Temperature variability over Saudi Arabia and its association with global climate indices. JKAU Met Env Arid L Agric Sci 2012;23:85-108.

7 Ouda OKM, Shawesh A, Al-Olabi T, Younes F. Al-Waked R. Review of domestic water conservation practices in Saudi Arabia. Appl Water Sci 2013;3, 689-99.

8 Alhassan AA, McCluskey A, Alfaris A, Strzepek K. Scenario based regional water supply and demand model: Saudi Arabia as a case study. Int J Environ Sci Dev 2016;7;46-51.

9 Odhiambo GO. Water scarcity in the Arabian Peninsula and socio-economic implications. Appl Water Sci 2017;7:2479-92.

10 Energy & Environmental Services. Saudi Arabia: Water consumption by region 2017. Statistic. 2017. [cited 2018 Nov 3]. Available from: https://www.statista.com/statistics/627146/saudi-arabia-water-consumption-by-region/.

11 United States Environmental Protection Agency, (US EPA). Fluoride: Dose-response analysis for non-cancer effects. Dental fluorosis: Evaluations of key studies. Health and Ecological Criteria Division. Washington, DC, USA: Division Office of Water, US EPA; 2008. Available from: https://nepis.epa.gov/Exe/ZyPDF.cgi/P100N4KD.PDF?Dockey=P100N4KD.PDF

12 United States Environmental Protection Agency (EPA). Ground water and drinking water: National primary drinking water regulations. [cited 2020 July 25]. Available from: https://

[Now published in full after the initial publication as an Epub ahead of print on Aug 3, 2020, at www.fluorideresearch.online/epub/files/095.pdf]

www.epa.gov/ground-water-and-drinking-water/national-primary-drinking-water-regulations#Inorganic.

13 Yousefi M, Ghoochani M, Mahvi AH. Health risk assessment to fluoride in drinking water of rural residents living in the Poldasht city, Northwest of Iran. Ecotoxicol Environ Saf 2018;148:426-30.

14 Ramadan AM, Ghandour IA. Dental fluorosis in two communities in Khartoum State, Sudan, with potable water fluoride levels of 1.36 and 0.45 mg/L. Fluoride 2016;49:509-20.

15 Ramadan AM, Hilmi YA. The influence of climate on the determination of the upper permissible fluoride level in potable water in Sudan. Fluoride 2014;47:170-80.

16 Burt BA, Eklund SA. Measuring dental fluorosis. In: Burt BA, Eklund SA, editors. Dentistry, dental practice and the community. 6th ed. St. Louis, Missouri, USA: Elsevier Saunders, 2005.

17 Fejerskov O, Manji F, Baelum V, Moller IJ. Dental fluorosis. Copenhagan, Denmark; Munksgaard; 1988.

18 Galagan JD, Vermilion RJ. Determining optimum fluoride concentrations. Public Health Rep 1957;72:491-3.

19 World Health Organization (WHO). Fluoride in drinking-water. Background document for development of WHO guidelines for drinking-water quality. Geneva, Switzerland: World Health Organization; 2004.

20 Kanduti D, Sterbenk P, Artnik B. Fluoride: A review of use and effects on health. Mater Sociomed 2016;28:133-7.

21 Denbesten P. Li W. Chronic fluoride toxicity: Dental fluorosis. Monogr Oral Sci 20*11;* **22:** 81-96.

22 Dean HT, Elvove E. Studies on the minimal threshold of the dental sign of chronic endemic fluorosis (mottled enamel). Public Health Rep 1935;50:1719-29.

23 Dean HT. The investigation of physiological effects by the epidemiological method. In: Moulton FR, editor. Fluorine and dental health. Washington, DC, USA: American Association for the Advancement of Science; 1942. pp. 23-31.

24 Dean HT, Elvove E. Some epidemiological aspects of chronic endemic dental fluorosis. Am J Public Health Nations Health 1936;26(6):567-75.

25 Dean HT, Arnold FJ, Elvove E. Domestic water and dental caries: V. Additional studies of the relation of fluoride domestic waters to dental caries experience in 4,425 white children, aged 12 to 14 Years, of 13 cities in 4 States. Public Health Rep1942;57:1155-79.

26 Dean HT. Classification of mottled enamel diagnosis. J Am Dent Assoc 1934;21:1421-6.

27 weatheronline.co.uk. Climate of the world: Saudi-Arabia. [cited 2019 Feb 1]. Available from: https://www.weatheronline.co.uk/reports/climate/Saudi-Arabia.htm.

28 Galagan DJ, Vermillion JR. Determining optimum fluoride concentrations. Public Health Rep 1957;72:491-3.

29 World Health Organization (WHO). Fluorides and oral health: Report of a WHO expert committee on oral health status and fluoride use [meeting held in Geneva from 22 to 28 November 1993]. World Health Organization technical report series 846. Geneva, Switzerland: World Health Organization; 1994.

30 Khan AA, Whelton H, O'Mullane D. Determining the optimal concentration of fluoride in drinking water in Pakistan. Community Dent Oral Epidemiol 2004;32:166-72.

31 Villa AE, Guerrero S, Villalobos J. Estimation of optimal concentration of fluoride in drinking water under conditions prevailing in Chile. Community Dent Oral Epidemiol 1998;26:249-55.

32 Ranasinghe N, Kruger E, Tennant M. Determination of the optimum level of fluoride for drinking water in different climatic zones of Sri Lanka based on the ambient temperature. Sri Lanka Dental Journal 2018;48(2):78-87.

33 MoH. MOH news - MOH recommends more fluoride in drinking water networks. 2007. [cited 2018 Oct 18]. Available from: https://www.moh.gov.sa/en/Ministry/MediaCenter/News/Pages/NEWS-2007-11-26-001.aspx.

34 Alhobeira HA, Siddiqui AA, Mian RI. Prevalence and severity of dental fluorosis in Hail, Saudi Arabia. J Int Oral Heal. 2015;7:1-4.

35 Khan N, Al-Zarea B, Al-Mansour M. Dental caries, hygiene, fluorosis and oral health knowledge of primary school teachers of Riyadh, Saudi Arabia. Saudi Dent J 2001;13:128-32.

36 Akpata ES, Fakiha Z, Khan N. Dental fluorosis in 12–15-year old rural children exposed to fluorides from well drinking water in Hail region of Saudi Arabia. Community Dent Oral Epidemiol 1997;25:324-7.

37 Aldosari AM, Akpata ES, Khan N. Associations among dental caries experience, fluorosis, and fluoride exposure from drinking water sources in Saudi Arabia. J Public Health Dent 2010;70:220-6.

38 Al-Shammery AR, Guile EE, El Backly M. The prevalence of dental fluorosis in Saudi Arabia. Saudi Dent J 1997;9:58-61.

39 Almas K, Shakir ZF, Afzal M. Prevalence and severity of dental fluorosis in Al-Qaseem province, Kingdom of Saudi Arabia. Odontostomatol Trop 1999;22:44-7.

40 Bhayat A, Ahmad MS. Oral health status of 12-year-old male schoolchildren in Medina, Saudi Arabia. East Mediterr Health J 2014;20:732-7.

41 Al-Banyan RA, Echeverri EA, Narendran S, Keene HJ. Oral health survey of 5–12-year-old children of National Guard employees in Riyadh, Saudi Arabia. Int J Paediatr Dent 2000;10: 39-45.

42 The General Authority of Meteorology and Environmental Protection. Protection. The General Authority of Meteorology and Environmental Protection and E Saudi - National Portal. [cited 2018 Nov 30]. Available from: https://www.saudi.gov.sa/wps/portal/snp/pages/agencies/agencydetails/organization-AC040/?entityId=AC040&gadCode=organization-AC040.

43 Biglari H, Chavoshani A, Javan N, Mahvi AH. Geochemical study of groundwater conditions with special emphasis on fluoride concentration, Iran. Desalin Water Treat 2016;57:22392-9.

44 Alhababy A, Al-Rajab A. Groundwater quality assessment in Jazan region, Saudi Arabia. Curr. World Environ 2015;10:22-8.

45 Elsherbini MS, Alsughier Z, Elmoazen RA, Habibullah MA, Habibullah MA. Prevalence and severity of dental fluorosis among primary school children in AlRass, Saudi Arabia. Int J Med Health Res 2018;4:45-9.

46 Al Anazi AH, Al Saab FA, Alatallah SS, Alfahaid SF, Alharbi AS, Almutairi BS et al. Fluoride level in drinking water and prevalence of dental fluorosis and dental caries among the school children?: A descriptive cross-sectional study. Asian Pacific J Health Sci 2017;4:155-9.

47 Alabdulaaly AI, Al-Zarah AI, Khan MA. Occurrence of fluoride in ground waters of Saudi Arabia. Appl Water Sci 2013;3:589-95.

48 Aldosari AM, Akpata ES, Khan N, Wyne AH, Al-Meheithif A. Fluoride levels in drinking water in the Central Province of Saudi Arabia. Ann Saudi Med 2003;23:20-3.

49 Al Zuhair N, Khounganian R. Comparative study between the chemical composition of potable water and Zamzam water and its effect on tooth structure in Saudi Arabia. Afaq Dental Journal 2006;11:36-7.

50 Siddiqui AA, Al Hobeira H, Mirza AJ, Alshammari AK, Alshammari BA, Alsalwah NM. Dental fluorosis in Saudi Arabia: A review of current literature. Ann Int Med Dent 2017;3:44-50.

51 Khan SQ, Moheet IA, Farooq I, Farooqi FA, ArRejaie AS, Al Abbad MHA, Khabeer A. Prevalence of dental fluorosis in school going children of Dammam, Saudi Arabia. J Dent Allied Sci 2015;4(2):69-72.

52 Al-Turki AI. Assessment of well drinking water quality in Hael Region of North Central Saudi Arabia. J Agric Vet Sci Qassim Univ 2009;2:101-10.

53 Claudino D, Traebert J. Malocclusion, dental aesthetic self-perception and quality of life in a 18 to 21 year-old population: a cross section study. BMC Oral Health 2013;13:3.

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54 Aldosari AM, Akpata ES, Khan N. Associations among dental caries experience, fluorosis, and fluoride exposure from drinking water sources in Saudi Arabia. J Public Health Dent 2010;70(3):220-6

55 Al Anazi AH, Al Saab FA, Alatallah SS, Alfahaid SF, Alharbi AS. Fluoride level in drinking water and prevalence of dental fluorosis and dental caries among the school children?: A descriptive cross-sectional study. Asian Pacific J Health Sci 2017;4:155-9.

56 World Health Organization. Guidelines for drinking-water quality. Fourth edition incorporating the first addendum. Geneva: World Health Organization; 2017.

57 International Program on Chemical Safety. Environmental health criteria 36. Fluorine and fluorides. Geneva: World Health Organization [published under the joint sponsorship of the United Nations Environmental Programme, the International Labour Organization, and the World Health Organization; 1984.

58 World Health Organization. Guidelines for drinking water quality. Third edition. Volume 1 Recommendations. Geneva: World Health Organization; 2004.

59 U.S. Department of Health and Human Services Federal Panel on Community Water Fluoridation. Public Health Service recommendation for fluoride concentration in drinking water for the prevention of dental caries. Public Health Reports 2015;130:318-31.

60 Ullah R, Zafar MS, Shahani N. Potential fluoride toxicity from oral medicaments: A review. Iran J Basic Med Sci 2017;20:841-8.

61 Frazão P, Peres MA, Cury JA. Drinking water quality and fluoride concentration. Rev Saúde Pública 2011;45(5).

62 Ibrahim YE, Affan AA, Bjorvatn K. Prevalence of dental fluorosis in Sudanese children from two villages with 0.25 and 2.56 ppm fluoride in the drinking water. Int J Paediatr Dent 1995;5:223-9.

63 Kanduti D, Sterbenk P, Artnik B. Fluoride: A review of use and effects on health. Mater Sociomed 2016;28(2):133-7.

64 Waugh DT, Potter W, Limeback H, Godfrey M. Risk assessment of fluoride intake from tea in the Republic of Ireland and its implications for public health and water fluoridation. Int J Environ Res Public Health 2016;13.

65 Dirks OB. The benefits of water fluoridation. Caries Res 1974;8:2-15.

66 Nell A, Sperr W. Analysis of the fluoride content of drinking water in Austria. Wien Klin Wochenschr 1994;106:608-14.

67 Zietsman S. Spatial variation of fluorosis and fluoride content of water in an endemic area in Bophuthatswana. J Dent Assoc S Afr 1991;46:11-5.

68 Wanke H, Ueland JS, Hipondoka M. Spatial analysis of fluoride concentrations in drinking water and population at risk in Namibia. Water SA 2017;43(3):413-22.

69 Brouwer ID, De Bruin A, Dirks OB, Hautvast JGAJ. Unsuitability of World Health Organisation guidelines for fluoride concentrations in drinking water in Senegal. Lancet 1988;331:223-5.

70 Warnakulasuriya KA, Balasuriya S, Perera PA, Peiris LC. Determining optimal levels of fluoride in drinking water for hot, dry climates: a case study in Sri Lanka. Community Dent Oral Epidemiol 1992;20:364-7.

71 Chandra S, Sharma R, Thergaonkar VP, Chaturvedi SK. Determination of optimal fluoride concentration in drinking water in an area in India with dental fluorosis. Community Dent Oral Epidemiol 1980;8:92-6.

72 Viswanathan G, Jaswanth A, Gopalakrishnan S, Siva ilango S, Aditya G. Determining the optimal fluoride concentration in drinking water for fluoride endemic regions in South India. Sci Total Environ 2009;407(20):5298-307.