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Human Health Hazards of Fluoride Ions: A Case Study of Al-Busif Village Water Supply Station, Iraq

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Abstract

The current study aimed to assess the health risks of fluoride in drinking water from the Al-Busif Water Supply Station and the residential neighborhoods covered by its distribution pipeline network in the region of northern Iraq. One hundred water samples were collected from ten sites, including intake water, post-treatment water, and other sites distributed throughout residential neighborhoods. The study results indicated that fluoride ion concentrations were within the calculated safe limits for the city of Mosul, ranging between 0.173 ± 0.029 mgL^{-1} and 0.206 ± 0.05 mgL^{-1}. As for the results of the pollution indices Pollution Index (PI), Fluoride Pollution Index (FPI), and Human Health Risk (HHR), the average values of the PI ranged between 0.249 ± 0.016 and 0.292 ± 0.041, classifying the water as no pollution. The same applies to the results of the FPI, which ranged between 1.88 and 1.90 , classifying the water as low pollution water. As for the potential HHR of fluoride, the Hazard quotient (HQi) values were within safe limits (less than 1.0), as the highest risk Hazard quotient values were among male children (0.251) and female children (0.258). The study also found higher hazard quotient (HQi) values among breastfeeding women compared to adult females, reaching values of 0.180. The study recommended periodic monitoring of water quality and the development of efficient scientific programs to reduce the risks of probabilistic pollution in the future.

Keyword: Human health risk (HHR), pollution index (PI), fluoride pollution index (FPI), drinking water.

Introduction

The provision of safe and clean drinking water is a basic right for every human being worldwide in order to maintain their health, development, and well-being. Surface and groundwater are among the main sources of water for drinking, domestic uses, irrigation, livestock watering, etc., on our planet [1-5]. Currently, many countries around the world, particularly developing countries, are facing challenges related to the scarcity of safe water due to global developments. This is compounded by the challenges of global warming, which has led to changes in rainfall patterns, negatively impacting the quality and quantity of water and threatening the poorest segments of the population in these countries [5-7].

As for Iraq, these challenges have led to a decrease in the discharge of both the Tigris and Euphrates rivers and their tributaries. In addition to the construction of dams in upstream countries, which poses a threat to Iraqi water security, there is also the destruction of infrastructure, weak oversight, and the absence of deterrent laws against those who manipulate water resources. This has encouraged the discharge of all types of wastewater into water sources without treatment, which will contribute to the problem of a shortage of safe water, with the potential for many health and environmental effects, such as pollution with heavy metals, pesticides, nitrate ions and fluoride [8-10]. In general, the problem of water sources being contaminated with fluoride ions has become a concern for human and animal health, with more than 500 million people in 37 countries, particularly India, Africa, China, and South America, being exposed to the risks of fluoride. In India alone, about 66 million people suffer from problems caused by high levels of fluoride, ranging from the effect on tooth enamel to skeletal fluoride poisoning [2,11,12] as shown in Fig. 1.

Figure 1. **Images of skeletal and dental fluorosis due to high fluoride drinking water.**

Fluoride ion levels in drinking water sources in some areas of India, Ethiopia, Algeria (Ouargla region), Morocco (Angad Plain), Kenya, Norway, and Germany (Münster) reach: 70, 17.0, 7.3, 62.6, 6.6, 9.5, and 8.8 mgL^{-1} [13-16]. Finally, the current study of the health risks of fluoride ions in drinking water supplies in the Al-Bu Saif area, Mosul, Iraq, presents a comprehensive, multifaceted approach. It combines multiple indicators polution index, flouride polution index and fluoride risk index (PI, FPI, and FRI) to determine the degree of fluoride contamination, along with calculating the chronic daily intake (CDI) and the Hazard quotient (HQi) by age group to provide data on the risks to which these age groups may be exposed. Samples were also taken over different periods to provide a more accurate assessment of potential health risks for consumers and provide model data for future studies and health policies. Therefore, the current study aims to enrich the data on fluoride ions, which is one of the very limited studies in Iraq, by estimating their concentrations in drinking water and calculating pollution indicators.

Materials and Methods

Description of the Study Area

The Al-Busif area is located south of Mosul city, in northern Iraq. It is characterized by its location on the highlands overlooking the Tigris River, and its climate is hot and dry in the summer and relatively cool and rainy in the winter. It is therefore considered part of the semi-arid regions and its climate is affected by factors such as solar radiation, temperature, humidity, precipitation, and wind. The Tigris River passes through the eastern side of the study area, where a water supply station was built on the riverbank to supply the residential neighborhoods in the area with drinking water. The geology of the study area is characterized by the prevalence of the Fatha formation, which contains gypsum ($CaSO_4.2H_2O$) and anhydrite ($CaSO_4$), in addition to water-soluble evaporate salts, which cause depressions, increasing the possibility of ruptures in the water supply network pipes, especially in the areas where the pipes are connected. This is one of the most important causes of drinking water contamination. What increases the problem is that citizens connect water pumps directly to the pipe network, which leads to pressure fluctuations inside the pipes and consequently sewage leakage into them. Figure. 2 presents the aerial map of the study area, while Table 1 lists the coordinates of the sampling sites.

Table 1. **Coordinates of water sample collection sites in Al-Busif area.**

Sites	Longitude	Latitude	Uses
1	4315748	3628476	
2	4315739	3628442	
3	4315706	3628194	
4	4315770	3628176	
5	4316002	3627852	For drinking, washing dishes and clothes, bathing, etc.
6	4316128	3627789	
7	4315646	3627484	
8	4315751	3627380	
9	4315600	3627403	
10	4315847	3627364	

Figure 2. **Aerial map of Al-Busif drinking water supply station and its residential areas**

Methodology

In the current study, ten sites were selected for collecting water samples, including Tigris River water (raw water for the treatment plant and post-treatment water). Water samples were also collected from residential areas affiliated with the water supply station, at a rate of ten replicates per site, for the period from July 2024 to January 2025. One hundred water samples were collected using clean polyethylene bottles from the selected sites after the water tap was turned on for several minutes before filling. The water samples were then placed in a refrigerator and protected from light.

Fluoride ion concentrations were estimated in water samples by adding the LRR fluoride reagent to a known volume of the water sample, then measuring them using a HANNA Romanian fluoride meter after adjusting the device as indicated by Alzuhairy et al. [17]. pH, bicarbonate ions, sodium ions, and calcium ions were also measured according to the standard methods indicated by APHA [18].

Assessing of Water Fluoride Pollution Levels

The current study on the health risks of fluoride ions in drinking water in the Al-Bu Saif area presents a comprehensive, multifaceted approach. It utilizes multiple indices, (PI, FPI, and FRI) to determine the degree of fluoride contamination, along with calculating the (CDI) and (HQ_i) by age group to provide data on the risks to which these age groups may be exposed. It also utilizes sampling at different intervals to provide a more accurate assessment of potential health risks for consumers and provide model data for future studies and health policies. These indices are:

i. Pollution index of fluoride (PI)

The fluoride pollution index (PI) was calculated according to the following formula [19].

$$PI = \frac{F.\ concentraion\ (ppm)}{Standardlimit}$$

The standard limit for fluoride according to the World Health Organization is 1.5 mgL^{-1}, while the minimum, maximum, and optimal limits are 0.6, 0.8, and 0.7 mgL^{-1}, respectively, calculated based on the study area's temperature over five years, which is 28 °C [2,20,21].

ii. Fluoride pollution index (FPI)

This index was calculated from the following formula [19].

$$FPI = \frac{Wf + WHCO3 + W\frac{Na}{Ca} + WpH}{N.of\ parameters}$$

The weights Wi were found from the tables referred to by Taplur et al. [19] and Kumar [22] for each of the concentrations of bicarbonate ions, fluoride, the ratio of sodium to calcium ions and the pH values as shown in Table 2.

Table 2. **Average values of some chemical properties of the drinking water studied.**

Sites	Parameters		
	pH	HCO_3 (mgL^{-1})	Na/Ca
01St	7.135	184.5	2.5
02St	7.120	183.5	2.5
03St	7.138	183.0	2.5
04St	7.141	184.0	2.5
05St	7.168	183.0	2.5
06St	7.170	182.5	2.5
07St	7.166	182.5	2.5
08St	7.226	182.5	2.5
09St	7.263	182.5	2.5
10St	7.202	183.5	2.6

The drinking water status is then assessed according to the FPI as follows: 1-2: Low pollution water, 2-3: Moderate pollution water, 3-4: High pollution water [22].

iii. Human Health Risk Assessment (HHRA)

This model was used to assess the health risks of fluoride ions in drinking water, as indicated by the US Environmental Protection Agency (USEPA). This study is one of the very limited studies of water resources in Iraq, and it is considered a good means to assess the potential health risks related to exposure to fluoride ions. The CDI and HQ index for different age groups were calculated using the following formulas [23-25].

$$CDI = [Cf \times IR] / Bw$$
$$HQi = CDI / RfD$$

Where Cf: is fluoride ion concentration, IR denotes water intake rate for each age group ($Lday^{-1}$), Bw: shows weight rate for each age group (kg), CDI is: chronic daily intake ($mgkg^{-1}day^{-1}$), and RfD: is oral fluoride reference intake equal to 0.06 $mgkg^{-1}day^{-1}$ [2].

Results and Discussion

The results shown in Fig. 3 summarizes the mean fluoride concentrations across sites, whereas Table 3 provides replicate values and standard deviations and indicate that there were no clear fluctuations in the concentration of fluoride ions in the water before treatment (Tigris River water) and after treatment for the rest of the sites, because the water treatment processes are traditional and do not include a unit for removing ions from the water (which is limited to sedimentation, filtration, and then sterilizing the water with chlorine). The concentrations ranged between 0.13 to 0.29 mgL^{-1} and at rates between 0.173 ± 0.027 to 0.206 ± 0.047 mgL^{-1}. Thus, the studied water was less than the ideal limits calculated for the city of Mosul 0.6 mgL^{-1} according to the specifications of the USEPA [2,17].

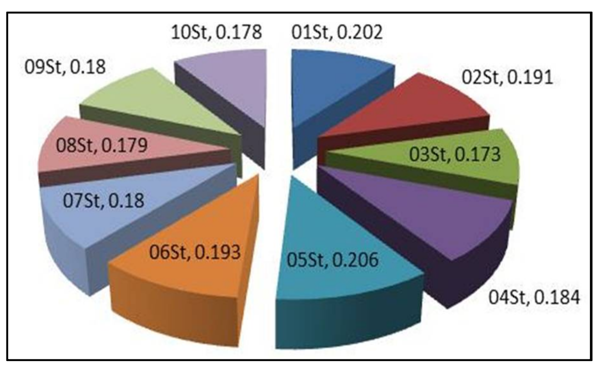

Figure 3. **Fluoride ion concentration rates in water before and after treatment for all studied sites**

Table 3. **Results of levels and standard deviation of fluoride ions for water before and after treatment for the studied sites (mgL^{-1}).**

Sites	Duplicate										
	1	2	3	4	5	6	7	8	9	10	± Sd
01St	0.23	0.17	0.17	0.22	0.19	0.21	0.18	0.23	0.25	0.17	0.030
02St	0.23	0.17	0.22	0.18	0.18	0.20	0.16	0.21	0.20	0.16	0.025
03St	0.18	0.17	0.14	0.18	0.18	0.20	0.12	0.21	0.19	0.16	0.027
04St	0.20	0.18	0.20	0.20	0.19	0.19	0.13	0.20	0.20	0.15	0.025
05St	0.20	0.26	0.27	0.18	0.19	0.19	0.14	0.21	0.27	0.15	0.047
06St	0.18	0.26	0.16	0.23	0.18	0.19	0.14	0.20	0.23	0.16	0.037
07St	0.16	0.15	0.15	0.19	0.19	0.18	0.15	0.21	0.26	0.16	0.035
08St	0.22	0.15	0.14	0.19	0.19	0.18	0.14	0.21	0.23	0.14	0.035
09St	0.20	0.19	0.14	0.18	0.18	0.18	0.13	0.21	0.23	0.16	0.031
10St	0.20	0.13	0.14	0.16	0.17	0.18	0.16	0.29	0.20	0.15	0.046

This decrease in the concentration of fluoride ions in the studied samples is likely due to the low solubility of fluoride compounds, calcite, and clay minerals in the Tigris River bed as well as the relatively low levels of dissolved solids and sodium ions, and the pH close to neutral, in contrast to the acidic conditions of the water that encourage the decomposition of fluoride-containing compounds, as in the following equation [1]:

$$Ca_{10}(PO_4)_6F_2 + 12H^+ \Rightarrow 10Ca^{+2} + 6H_2PO_4 + 2F$$

There is also the possibility that dissolved fluoride ions may combine with cations present in the water or may adsorb on the surfaces of particles of suspended materials in raw water (river water), which negatively affects the health of local consumers as it increases the risk of tooth decay [20,24].

When comparing our current results with studies conducted in Mosul city, we note that they are relatively close to the results reached by Mohhfer and Al-Saffawi [2], when they studied the concentrations of fluoride ions in Al-Dandan water supply station and its affiliated neighborhoods in the right side of Mosul city, which ranged between 0.288 to 0.310 mgL^{-1}, as is the case study of Alzuhairy et al. [17] on tap water in Alshurta and Alandalus quarters in Mosul city, whose rates fluctuated between 0.333 ± 0.045 to 0.380 ± 0.08 mgL^{-1}. Regarding the fluoride ion pollution indicators, fortunately, all of them were within the safe limits for consumers, as the PI values ranged between 0.230 to 0.328 and at a rate of 0.249 ± 0.016 to 0.292 ± 0.041 to classify the water quality as no pollution, as shown in Table 4. The same is the case with the fluoride PI values, which ranged between 1.88 to 1.90, to classify the water quality as low pollution water, as shown in Fig. 4.

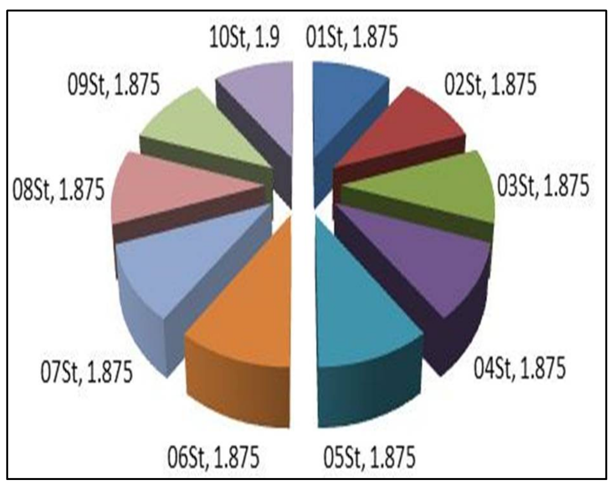

Figure 4. **Fluoride pollution index (FPI) valuesof drinking waterfor the study sites**

Table 4. **Results of the pollution index values for water before and after treatment for the studied sites.**

Sites	Season					
	Summer	Autumn	Winter	*Mean*	± *Sd*	*Status*
01St	0.280	0.277	0.310	0.289	0.018	NP
02St	0.285	0.260	0.273	0.273	0.013	NP
03St	0.240	0.240	0.267	0.249	0.016	NP
04St	0.283	0.243	0.263	0.263	0.020	NP
05St	0.328	0.247	0.300	0.292	0.041	NP
06St	0.298	0.243	0.283	0.275	0.028	NP
07St	0.230	0.247	0.300	0.259	0.037	NP
08St	0.248	0.243	0.277	0.256	0.018	NP
09St	0.255	0.237	0.287	0.260	0.025	NP
10St	0.228	0.243	0.303	0.258	0.040	NP

NP: No Pollution

As for the results of the hazard quotient values for fluoride ions HQi, fortunately, they were within the safe limits (less than 1.0) for all the age groups studied, as shown in Table 5., where the highest values were in male and female children, although they were relatively slightly higher in females, ranging between 0.211 to 0.246 and 0.216 to 0.258, where the lowest values were in female and male infants, ranging between 0.030 to 0.036 and 0.031 to 0.037, respectively, decreasing relatively with age, ranging in female adults between 0.140 to 0.164 and males between 0.106 to 0.122. As for breastfeeding women, the HQi values were higher compared to adult females, ranging between 0.156 to 0.180. These differences between the studied age groups are due to differences in body weight and daily consumption rate, which are reflected in CDI and is associated with a higher risk [19, 26].

Overall, the concentration of fluoride ions and many other water contaminants within globally recommended limits. Otherwise, consumers would have experienced other health problems, including, but not limited to, low blood calcium levels, which can cause abdominal pain, cramps, and irregular heartbeat. These damages are caused by hydrofluoric acid, which results from the interaction of fluoride with water, damaging body tissue cells. Electrolyte imbalances also occur, leading to hyperkalemia and consequently impaired heart function. In addition, enzyme systems are inhibited [27,28].

In general, Site-wise HQi values for each cohort are presented in Table 5, while Fig. 5 summarizes the average HQi pattern across cohorts. The data shows that the risk quotient values for the age groups studied are arranged in descending order as follows:

Children > Teenagers > Breastfeeding > Adults > Pregnant > Infants

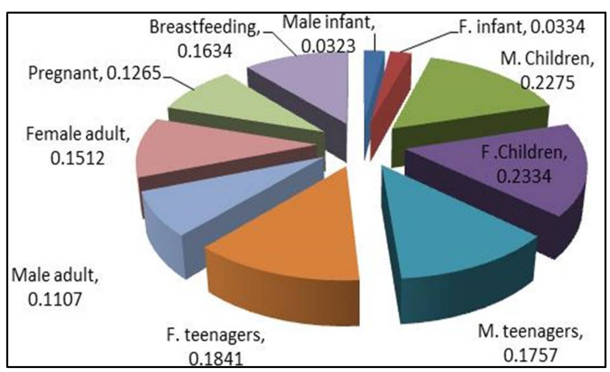

Figure 5. **Hazard quotient averages for fluoride ions in drinking water for different cohorts**

Table 5. **Results of the hazard quotient values of fluoride ions for different cohorts in drinking water in the study area.**

Cohort	Sites									
	St_1	St_2	St_3	St_4	St_5	St_6	St_7	St_8	St_9	St_{10}
M. infant	0.035	0.033	0.030	0.032	0.036	0.033	0.031	0.031	0.031	0.031
F. infant	0.036	0.034	0.031	0.033	0.037	0.035	0.032	0.032	0.032	0.032
M. children	0.246	0.233	0.211	0.224	0.251	0.235	0.220	0.218	0.220	0.217
F. children	0.253	0.239	0.216	0.230	0.258	0.241	0.225	0.224	0.225	0.223
M. teenagers	0.190	0.180	0.163	0.173	0.194	0.182	0.169	0.169	0.169	0.168
F. teenagers	0.199	0.188	0.171	0.181	0.203	0.190	0.178	0.177	0.178	0.176
M. adult	0.120	0.113	0.103	0.109	0.122	0.114	0.107	0.106	0.107	0.106
F. adult	0.164	0.155	0.140	0.149	0.167	0.156	0.146	0.145	0.146	0.144
Pregnant	0.137	0.129	0.117	0.125	0.140	0.131	0.122	0.121	0.122	0.121
Breastfeeding	0.177	0.167	0.151	0.161	0.180	0.169	0.158	0.157	0.158	0.156

Conclusion

The current study is one of the few studies in Nineveh Governorate and across Iraq, where the concentration of fluoride ions was estimated in one of the water supply stations and the residential neighborhoods covered by the distribution, with the water quality being evaluated using three indicators (HHR, FPI and PI), where the concentrations of fluoride ions were safe and much lower than the ideal limits calculated according to the climatic conditions of Iraq, which were indicated by the USEPA.All values of the PI and FPI indices were within the safe limits for drinking and home use, which did not exceed 0.328 and 1.90, respectively. The hazard quotient (HQ_i) values were lower than the internationally permissible limits for all age groups, which did not exceed 0.258, although male and female children, and then breastfeeding women, were the age groups most affected by fluoride risks, while infants, both male and female, werethe age groups least affected by fluoride risks.

Therefore, we recommend not adding fluoride compounds to the drinking water at the Al-Busif drinking water station, given that the amount of fluoride consumed varies from person to person. Local residents also obtain fluoride from other sources, such as toothpaste, eating fluoride-rich fish, drinking tea, spinach, lettuce, and others. Regular monitoring of drinking water quality should be undertaken to avoid future risks to citizens, especially infants, pregnant and lactating women. The data from this study should be used in water resource management. We also recommend developing scientific programs to monitor drinking water quality and taking appropriate action when necessary.

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Conflict of Interest

Authors declare that they have no conflicts of interest.

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