Fluoride Contamination and Health Risk Assessment of Groundwater Resources of Jabalpur District

Shubhas kumar Shrivas[1], R. K. Bhatia[2], Dr. Shailza Verma[3]
[1]*Research Scholar, Department of Civil Engg. JEC Jabalpur (M.P)*
[2]*Professor, Department of Civil Engg. JEC Jabalpur (M.P)*

Abstract- **Water quality deterioration and supply of safe drinking water is a major concern throughout the world. Several types of health problems in Jabalpur district of Madhya Pradesh state are prevailing owing to groundwater as well as surface water quality problems such as high concentration of fluoride, chloride, salinity, TDS, etc. Groundwater with high fluoride concentration (>1.5 mg/L), according to WHO, is affecting more than 260 million people around the world. The objective of this work was to assess the groundwater quality of the district based on Fluoride Concentration, which is the leading factor to continuous deterioration in groundwater quality.**

EDI and HQ for the fluoride concentrations have been determined. Health risk assessment on the basis of fluoride concentrations in water, grains, fish and vegetables are calculated and examined. The study demonstrates that groundwater fluoride content of Jabalpur district is totally unsuitable for drinking purposes and is directly or indirectly influenced by geogenic factors and other pollution factors. About 70–75% of the samples analysed show high fluoride content. Remedies have been suggested to prevent further escalation of water quality problems that are needed imperatively for the sustainable development of water resources.

Index Terms-Ground Water, HQ, EDI, Health Risk Assessment, Fluoride Concentration, SPADNS.

I. INTRODUCTION

1.1 General

Our environment consists of physical, chemical, and biological substances, which interact so that the physical and chemical substances support the biological substances and allow them to experience sustainable growth. At the present level of human advancement, mankind is able to negatively and positively influence the balance of these substances, thereby affecting the health of the environment.

Discharges from human activity must be released to the air, the water or the soil. Each of these potential reservoirs can accept a limited amount of physical, chemical and biological substances without significant deterioration. Beyond this point of assimilation, the environment can be deteriorated to the point that sustainable biological growth cannot occur.

1.2 Water Quality

"Water quality" is a term used here to express the suitability of water to sustain various uses or processes. Any particular use will have certain requirements for the physical, chemical or biological characteristics of water; for example, limits on the concentrations of toxic substances for drinking water use, or restrictions on temperature and pH ranges for water supporting invertebrate communities. Consequently, water quality can be defined by a range of variables which limit water use. Although many uses have some common requirements for certain variables, each use will have its own demands and influences on water quality. Quantity and quality demands of different users will not always be compatible, and the activities of one user may restrict the activities of another, either by demanding water of a quality outside the range required by the other user or by lowering quality during use of the water. Efforts to improve or maintain a certain water quality often compromise between the quality and quantity demands of different users. There is increasing recognition that natural ecosystems have a legitimate place in the consideration of options for water quality management. This is both for their intrinsic value and because they are sensitive indicators of changes or deterioration in overall water quality, providing a useful addition to physical, chemical and other information.

1.3 Municipal Sources of Water Pollution

The non-industrial municipal sources of water are typically as follows:

- Dwellings
- Commercial establishments
- Institutions (schools, hospitals, prisons, etc)
- Governmental operations

Water quality

The quality of groundwater depends on the composition of the recharge water, the interactions between the water and the soil, soil-gas and rocks with which it comes into contact in the unsaturated zone, and the residence time and reactions that take place within the aquifer. Therefore, considerable variation can be found, even in the same general area, especially where rocks of different compositions and solubility occur.

The principal processes influencing water quality in aquifers are physical (dispersion/dilution, filtration and gas movement), geochemical (complexation, acid-base reactions, oxidation-reduction, precipitation- solution, and adsorption-desorption) and biochemical (microbial respiration and decay, cell synthesis).

II-LITERATURE REVIEW

Various researchers have been carried out their study for the same field, some of them are as:

"Groundwater quality analysis of quaternary aquifers in Jhajjar District, Haryana, India: Focus on groundwater fluoride and health implications", 2018, Ruchi Gupta, Anil Kumar Misra

Several types of health problems in Jhajjar district of Haryana state are prevailing owing to groundwater quality problems such as high concentration of fluoride, chloride, salinity, TDS, etc. The objective of this work was to assess the overall groundwater quality of the district based on Water Quality Index (WQI) and find out the factors leading to continuous deterioration in groundwater quality. The study demonstrates that groundwater quality of Jhajjar district is totally unsuitable for drinking purposes and is directly or indirectly influenced by geogenic factors. About 60–70% of the samples analysed show high fluoride content. Other parameters such as hardness, electrical conductivity, Total Dissolved Solids (TDS), and Chloride are also above the permissible limits. Hydro-geologically the study area belongs to Indo-Gangetic alluvial plains, which are dominated by clay-silt, clay and grey micaceous sand formations. Clay rich formations are rich in fluorine and other salts and their weathering is most probably causing the continuous escalation in the fluoride and salinity concentration in groundwater. Several in-situ and ex-situ measures have been suggested for remediation and to prevent further escalation of water quality problems that are needed imperatively for the sustainable development of water resources.

"Data on fluoride contents in ground water of Bushehr province", Iran Sina Dobaradaran, MaryamKhorsand, Abdolreza Hayati, Roya Moradzadeh, Mohammad Pouryousefi, MostafaAhmadi, 2018, Data in Brief17(2018)1158–1162

In this article, we measured the levels of fluoride in ground water. The samples were taken from ground-water in Bushehr's province, Iran. After the collection of samples, the concentration levels of fluoride were determined by the standard SPADNS method using spectrometer. The mean concentration levels of fluoride in water of all stations were higher than the WHO drinking water guide line. Microsoft Office Excel2016 was used for calculation of mean values. The mean concentration level of fluoride in statement were in therangeof1.52to3.64mgl-1.

"Determining the optimum locations for pumping low-fluoride groundwater to distribute to communities in a fluoridic area in the Upper East Region, Ghana", Laura Craig, James M. Thomas, Alexandra Lutz, David L. Decker, 2018

Groundwater is the primary source of water in the Upper East Region of Ghana and is generally considered a safe source of drinking water; but there are pockets where the groundwater contains high concentrations of fluoride due to the dissolution of minerals in the local granite. The goal of this study is to evaluate the hydrogeology and hydro geo-chemistry of an area where dental fluorosis endemic, in order to identify the optimum locations to pump and distribute low-fluoride groundwater. As expected, the data indicate that the higher elevation recharge areas with outcrops of Bongo granite have elevated concentrations of fluoride in the groundwater (up to 4.6 mg L−1), posing the highest risk of fluorosis in the nearby communities. The lower elevation areas, which are the farthest from the Bongo granitic, have the lowest groundwater fluoride (< 0.5 mg L−1) and the lowest risk of fluorosis. Groundwater flow models suggest that the steady decrease in fluoride is driven by dispersion, with the fluoride concentrations dropping to the World Health Organization's recommended drinking water limit of 1.5 mg L−1 at about 400–500 m from the source. The optimum locations to install boreholes (or use existing boreholes) for piping low fluoride groundwater to the higher fluoride areas, would be at or beyond this distance. Although the initial costs of developing such a water system would be substantial, this is a potentially viable option for providing low fluoride water to communities suffering from fluorosis.

III-RESEARCH METHODOLOGY

3.1 General

Fluoride is an inorganic, monatomic anion of fluorine and is the most electronegative element representing about 0.06 to 0.09 % of earth's crust in the form of minerals like topaz, fluorite, rock phosphate, mica hornblende, sellaite (MgF_2), fluorspar (CaF_2), sodium fluoride (NaF), cryolite (Na_3AlF_6) and fluorapatite [$3Ca_3(PO_4)_2CaF_2$]. Fluoride contaminated groundwater has been a major issue with concentrations existing as high as 4 mg/L and is considered as a serious problem throughout India and the world. Thus to differentiate the effects of fluoride concentration on human health, various limits have been determined.

3.2 Materials and methods

3.2.1 Description of the study area

Jabalpur is situated on the north bank of the Narmada River, one of the major holy rivers of Madhya Pradesh. Most of the inhabitants of the study area depend on groundwater for drinking purposes and various domestic needs. From the study area, 12 sampling stations were selected for collecting water samples from ground water resources such as bore well and open well. The study area lies between latitudes and longitudes of 23.1815° N, 79.9864° E. It is the 27th largest town in India (population wise), and the third largest in the state of Madhya Pradesh. The population pressure on the city is ever growing. The latest census puts it in the above 1 million categories. As per the 2011 census, the population of the metropolitan city of Jabalpur is 1.82 million.

The study area covered almost complete city area of Jabalpur.

3.2.2 Sampling Area

The locations of the groundwater sampling stations are represented in Figure 3.1 and its details are given in Table 3.1. Water samples were collected from open wells and tube wells (water supply wells) spaced almost 3.0 km apart, covering the entire study area.

Figure 3.1 Jabalpur City Map

Table 3.1: Details of ground water sampling stations in the study area.

Sr. No.	Sampling Station	Source of Water
S-1	Sanjeevani Nagar	Bore Well
S-2	Shastri Nagar	Open Well
S-3	Shakti Nagar	Bore Well
S-4	Yadav Colony	Bore Well
S-5	Bilhari	Bore Well
S-6	Cantt	Bore Well
S-7	Garha	Bore Well
S-8	Panagar	Bore Well
S-9	Amkhera	Bore Well
S-10	DamohNaka	Bore Well
S-11	Kanch Ghar	Bore Well
S-12	Ghamapur	Bore Well

Water Sample Collection:

The sampling and analyses were performed in July 2018. Totally 60 water samples were collected, 5 for each sampling station and analysed in the present study. The physical characteristics were measured in the location of sampling itself using calibrated digital equipment's.

Vegetables, grains and fish samples

Vegetables including potato (*Solanum tuberosum*), onion (*Allium cepa*), tomato (*Lycopersicumesculentum*), radish (Raphanussativus), and rice, wheat grains were collected from the eight farms in the study area. Eight high-consumed fish samples also were collected from various points of Jabalpur City.

3.3 Method Adopted for the Study

The SPADNS method has been adopted for the fluoride measurement study.

3.3.1 Principle

The SPADNS colorimetric method is based on the reaction between fluoride and a zirconium-dye lake. Fluoride reacts with the dye lake, dissociating a portion of it into a colourless complex anion, ZrF_6^{2-}, and the dye. As the amount of fluoride increases, the colour produced becomes progressively lighter.

The reaction rate between fluoride and zirconium ions is greatly influenced by the acidity of the reaction mixture. If the proportion of acid in the reagent is increased, the reaction can be made almost instantaneous. Under such conditions, however, the effect of various ions differs from that in the conventional alizarin methods. The selection of dye for this rapid fluoride method is governed largely by the resulting tolerance to these ions.

3.3.2 Interferences

Chlorine, colour and turbidity interfere and it has been removed by distillation. Interference caused by alkalinity, chloride, iron, phosphate and sulphate is not linear and so cannot be accounted for mathematically. For the interference alkalinity it has been neutralised with hydrochloric acid.

3.3.3 Apparatus

The two equipment's can be used for the study i.e.

- Spectrophotometer for measurement at 570 nm and capable of providing a light path of 1 cm or longer.
- Filter photometer providing a light path of at least 1 cm and equipped with a greenish-yellow filter having maximum transmittance at 550 to 580 nm.

For the study we used the Spectrophotometer as shown in figure 3.1

Figure 3.1 Spectrophotometer used for the study

Figure 3.2 Samples collected for the study

Reagents applied

SPADNS solution:

Dissolve 0.958 g of SPADNS, sodium 2-(parasulphophenylazo)-1, 8-dihydroxy-3, 6-naphthalene disulphonate, also called 4, 5-dihydroxy-3-(parasulpho-phenylazo)-2, 7-naphalene disulphonic acid trisodium salt, in distilled water and dilute to 500 ml. This solution is stable for at least one year if protected from direct sunlight.

Acid-zirconyl reagent:

Dissolve 130 mg zirconyl chloride octahydrate, ZrOCl 2.8H2O, in about 25 ml of distilled water. Add 350 ml of concentrated hydrochloric acid and dilute to 500 ml with distilled water.

Research Platform

The fluoride testing is carried out in the laboratory of water testing in "Regional Office, Madhya Pradesh Pollution Control Board"

3.3.4 Procedure Adopted for the Water Testing

1. Preparation of standard curve:
2. Sample pre-treatment:
3. Colour development:

For calculating the Fluoride content, the following formulae has been adopted:

$$\text{Fluoride} = \frac{A}{\text{ml Sample}} \times \frac{B}{C}\ \text{mg/l}$$

Where

A = F^- determined from plotted curve (µg)
B = final volume of diluted sample (ml)
C = volume of diluted sample used for colour development (ml).

3.3.5 Procedure Adopted for the Food Testing

There are many methods for fluoride measurement in different substances, but the most applicable methods that Environmental Protection Agency (EPA) has approved are sodium 2-(parasulfophenyl largo)-1,8-dihydroxy-3,6 naphtnalene disulfonate (SPADNS) for water and ISE for food.

IV-RESULT ANALYSIS

4.1 Results for Fluoride Level

The chemical analysis data of 11 groundwater and 1 surface water samples are presented in Table 3.1. The data shows deterioration in the groundwater quality as per the BIS standards. The fluoride concentration ranges between 0.53375 and 4.25 mg/L (average value), far exceeding the permissible limit of F^- as 1.5 mg/L.

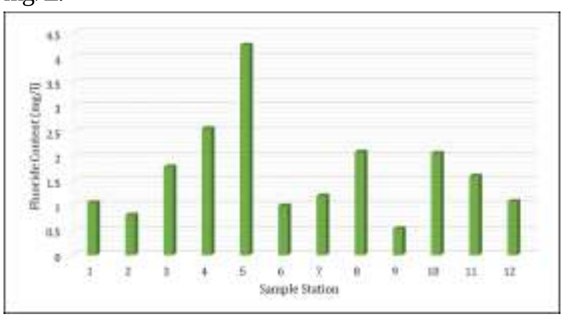

Figure 4.1 Fluoride content distribution (average Value) at each sampling station

The fluoride content in the ground water of the Jabalpur city varies from 0.533 to 4.22 mg/L during pre-monsoon season at the time of sampling. About 50% of the samples of the metropolitan city Jabalpur even exceed the maximum permissible limit of 1.5 mg/L during pre-monsoon season. As per the analysis a maximum value of 4.25 mg/L F is reported in Jabalpur.

4.2 Health Risk Assessment

Human health risk assessment for water contaminants estimate the nature and probability of adverse health effects for the population who receive the chemicals from drinking water. It provides a systematic approach for developing management strategies to supply safe drinking water.

The health risk assessment was determined by estimating the exposure doses of fluoride due to the consumption of drinking water, date, fish, and vegetables in terms of estimated daily intake (EDI) by following the generic equation

$$EDI = \frac{C}{BW} \times IR \qquad \text{……….} \ (4.1)$$

Where
BW: Body weight
EDI: Estimated daily intake (µg/kg/d)
IR is the intake rate of water, grain, fish, or vegetables (L/d, g/d and g/d), respectively; BW is the body weight (kg) that was assumed 70 kg for adults and 20 kg for children; and C is the concentration of fluoride (µg/L).

The water intake for children in spring and summer was assumed 0.8 and 1 L. These values for adults were 2.7 and 3 L, respectively. Intake rate of fish and vegetables are adapted from an integrated plan of nutritional condition.

Various methods have been evolved to estimate the potential health risks of pollutants and to categorize the carcinogenic and non-carcinogenic effects. Non-carcinogenic risk assessments are usually based on the use of the HQ, which is defined as the ratio of the estimated dose of a contaminant to the reference dose.

$$HQ = EDI/RfD \qquad \text{……….} \ (4.2)$$

This method is established by US-EPA at 1988. Reference dose (RfD) is an estimation of daily exposure that is expected to be without significant risk of harmful effects during the lifetime. Its value in Integrated Risk Information System (IRIS) is 60 µg/kg/day, which comprises both the EDI from ingestion of fluoride through drinking water (50 µg/kg/day) and dietary intake of fluoride (10 µg/kg/day).

When the HQ is greater than 1, the estimated potential exposure exceeds the RfD and a risk of fluorosis may be posed.

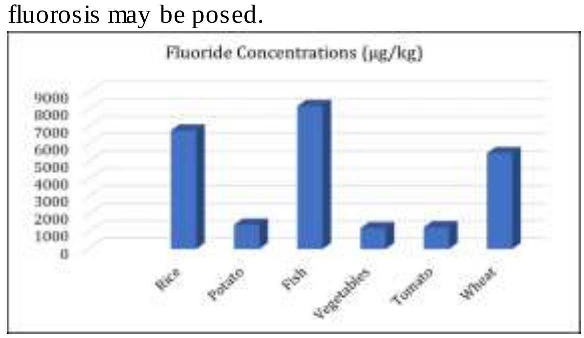

Figure 4.2 Fluoride Concentrations in different food constituents

Table 4.3 Total exposure dose and HQ index

In Table 4.2, fluoride amount and its exposure dose, in common vegetables, grains, and fish are presented. On the basis of these data fish with 8200 µg F-/kg and vegetables with 1200 µg F-/kg had maximum and minimum fluoride concentration and consequently the EDI level in grains, respectively.

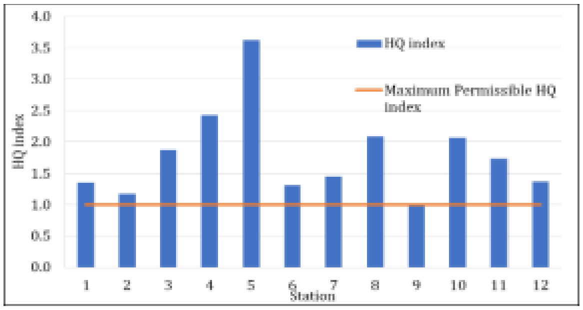

Figure 4.3 Variation in HQ index at all station

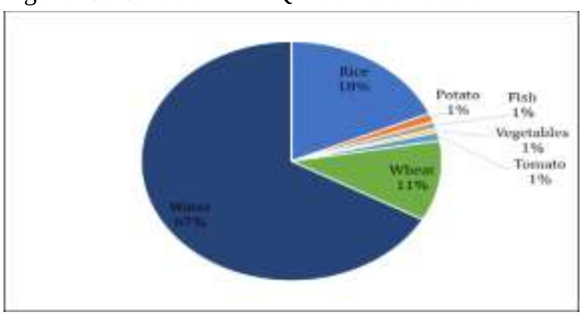

Figure 4.4 (a) Contribution percentage of the studied sources in total fluoride intake for adults

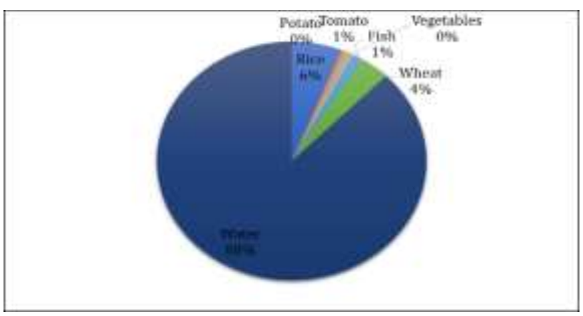

Figure 4.4 (b) Contribution percentage of the studied sources in total fluoride intake for children

Figure 4.4 (a) and (b) shows contribution percentage of each source in total fluoride intake for adult and children respectively. According to these figures, drinking water is the major contributor of fluoride ingestion, both in adults and children. For adults it is about 67% and for children it is about 88%.

4.3 Discussion

In this study, 48 drinking water samples were analyzed in Jabalpur region for fluoride concentrations, the description of sampling station is given in Table 3.1. The fluoride concentrations were varied from 0.533 to 4.25 mg/L for minimum and maximum value. Groundwater samples exhibit higher fluoride content compared with distribution/ surface water system samples. This is due to the fact of reactions of water with minerals in rock and soil which groundwater comes into contact. One-sample *T*-test also showed that there was significant difference between the fluoride concentrations in water supply system by the WHO guideline value.

Table 4.4 T Test value for all samples

	Fluoride Content
Mean	1.6705
Variance	1.0667
Observations	48
Hypothesized Mean Difference	1.5
df	47
t Stat	1.1438
P(T<=t) one-tail	0.1292
t Critical one-tail	1.6779
P(T<=t) two-tail	0.2584
t Critical two-tail	2.0117

EDI through consumption of rice and wheat in adults was higher than children. For EDI calculation, average body weight for children was considered 20 kg, while its value for adults was 70 kg. The most concentration of fluoride among grains belonged to rice. In this study, the fluoride amount of fish samples was also considerable. It may be due to higher fluoride concentration in water, where the fish in this study were harvested.

The results of shows that the daily fluoride intake from drinking water varies with the different locations, it is maximum in station 5 varies from 182.14 and 212.5 µg/kg/day for adults and children, respectively and minimum for station 9 i.e. 22.875 and 26.68 µg/kg/day for adults and children, respectively. In attention to the amount of water consumption that was considered is about 3 and 1 L for adults and children, respectively, it can be mentioned that as temperature of ambient air increased, water consumption and consequently fluoride intake from drinking water were increased.

The HQ values of fluoride for the two age groups are given in Table 4.3, which is maximum in station 5 i.e. about 3.6 times greater than 1 for both adults and children.

HQ values of present research indicated that health risks associated with fluoride exposure for children and adults are significant only from drinking water, grains, vegetables, and fish consumption and a potential risk of dental fluorosis would be exist.

It can be observed from the figure 4.4 that ~66% and 88% of the total fluoride intake for adults and children, respectively, is derived from drinking water. This proportion increased with increasing drinking water consumption due to climate temperature and raising fluoride content of water.

It can also be concluded that the drinking water was the principal source of fluoride ingestion. Therefore, this survey showed that in the study area, drinking water was the main contributor of fluoride ingested by the population.

V-CONCLUSION

The overall outcome of the study illustrates that Jabalpur district is facing severe water quality and scarcity problems. Large population is dependent on groundwater for domestic and irrigation activities, which is not suitable for use. The longer consumption of such contaminated water may cause serious health problems to the people.

The study demonstrates the following points:

1. Major source of fluoride and other salts in groundwater is the availability of salt rich geological formation in subsurface in Jabalpur district.
2. Generally long-term water–soil interaction in the subsurface leads to the release of fluoride and salt from rocks and then accumulated in the groundwater aquifers in the region.
3. The groundwater quality is almost unsuitable for domestic purposes as HQ level is more than 1 for the most of the parts of the region. The HQ values of fluoride for the two age groups is maximum in Bilhari area i.e. about 3.6 times greater than 1 for both adults and children. Bilhari is at high risk zone of the district.
4. Long term intake of fluoride above the permissible limit in drinking water is causing dental fluorosis diseases in the study areas.
5. EDI through consumption of rice and wheat in adults was higher than children.
6. The results of shows that the daily fluoride intake from drinking water varies with the different locations, it is maximum in station 5 i.e. Bilhari area. Sanjeenani Nagar, Shakti Nagar, Yadav Colony, Garha, Panagar, DamohNaka, Kanch Ghar, Ghamapur area shows high fluoride concentration while Shastrinagar, cantt and amkhera shows fluoride content in limit.

REFERENCES

[1] Abdullah M. Aldrees, Saad M. Al-Manea ,"Fluoride content of bottled drinking waters available in Riyadh, Saudi Arabia", 2010, , The Saudi Dental Journal (2010) 22, 189–193

[2] Dhanya Raj, E. Shaji; 2016, "Fluoride contamination in groundwater resources of Alleppey, southern India"

[3] Gayatri Singh, Babita Kumari, Geetgovind Sinam, Kriti, Navin Kumar, Shekhar Mallick, "Fluoride distribution and contamination in the water, soil and plants continuum and its remedial technologies, an Indian perspective- a review", 2018

[4] J. K. Bajaj, "food consumption in India and the world", cspindia.org

[5] Iran Sina Dobaradaran, MaryamKhorsand, Abdolreza Hayati, Roya Moradzadeh, Mohammad Pouryousefi, MostafaAhmadi, 2018, "Data on fluoride contents in ground water of Bushehr province", Data in Brief17(2018)1158–1162

[6] M. Changmai, M. Pasawan, M.K. Purkait, "A hybrid method for the removal of fluoride from drinking water: Parametric study and cost estimation", *Separation and Purification Technology* (2018), doi: https://doi.org/10.1016/j.seppur.2018.05.061

[7] Reza Ali Fallahzadeh, Mohammad Miri, Mahmoud Taghavi, Abdolmajid Gholizadeh, Ramin Anbarani, Ahmad Hosseini-Bandegharaei, Margherita Ferrante, Gea Oliveri Conti, "Spatial variation and probabilistic risk assessment of exposure to fluoride in drinking water", 2018,

[8] Ruchi Gupta, Anil Kumar Misra, "Groundwater quality analysis of quaternary aquifers in Jhajjar District, Haryana, India: Focus on groundwater fluoride and health implications", 2018

[9] Saurabh Levin, Sunderrajan Krishnan, Samuel Rajkumar, Nischal Halery, Pradeep Balkunde, "Monitoring of fluoride in water samples using a smartphone", 2016,

[10] Tarun Walia, Salem Abu Fanas , Madiha Akbar , Jamal Eddin , Mohamad Adnan, "Estimation of fluoride concentration in drinking water and common beverages in United Arab Emirates (UAE)", 2017", Chemical Geology 476 (2018) 481–492