ASSESSMENT OF PHYSICO-CHEMICAL QUALITY AND FLUORIDE CONTAMINATION IN DRINKING WATER: A CASE STUDY OF SOUTH EASTERN HARYANA, INDIA

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Abstract: *Assessment of Physico-Chemical Quality and Fluoride Contamination in Drinking Water: A Case Study of South Eastern Haryana, India presents the results of an investigation into the physico-chemical characteristics and fluoride contamination of drinking water in South Eastern Haryana, a rapidly industrializing region of India. In the Rohtak district, where this research was conducted, you will find a variety of sandy loam soils and alluvial-type geological formations spread over five separate blocks. While hand-pumps and bore-wells provide access to this water, salinity and declining water levels pose problems for this key water supply. Water samples were gathered from a number of different communities around the study region and tested using a battery of physical and chemical measures. Some samples were found to have levels of* Na^+, K^+, Ca^{2+}, Mg^{2+}, HCO_3-, Cl^- *, and* SO_4^{2-} *that were beyond the safe guidelines set out by the World Health Organization and the International Standards Organization (ISI). Furthermore, the investigation discovered fluoride pollution in certain places, with some spots displaying fluoride concentrations exceeding the permitted threshold, greatly worrying the local population's health. Overall, this study underlines the critical necessity for monitoring and maintaining the water quality in South Eastern Haryana to guarantee the supply of safe and drinkable drinking water to its population.*

Keywords: *Groundwater quality, Fluoride contamination, South Eastern Haryana, Physico-chemical parameters, Drinking water, Public health*

Introduction

Subsurface water, or groundwater, is a precious commodity that is essential for human survival. Much of the world's population relies on it to meet their most basic demand for clean and safe drinking water. Not only do people and businesses rely on this vital resource, but so do many industries, farms, and ecosystems all around the globe. Negative effects on human health, economic growth, and environmental stability would result from a lack of accessible drinkable water if groundwater were not readily available. Therefore, groundwater's significance as a source of lifeblood for innumerable populations and ecosystems that depend on it cannot be emphasized. Experts and scholars have been more worried about groundwater quality in recent years. There is cause for alarm since several man-made and natural processes may compromise the quality and safety of this essential resource. The quality of groundwater is deteriorating, and human activities—also known as anthropogenic activities—are largely to blame. These actions include a broad spectrum of endeavors, from manufacturing to farming to building cities. The chemicals and contaminants used in industrial processes may leak into the earth and damage the aquifers below. Similarly, agricultural activities such as the excessive use of fertilizers and pesticides may lead to the leakage of toxic compounds into the groundwater, presenting a danger to both human health and the environment. Furthermore, fluoride contamination of groundwater, which can have detrimental effects on human health at high concentrations, has been identified as a critical issue due to the rapid growth of urban areas and the accompanying increase in infrastructure development. In high concentrations, this chemical compound may cause problems that should be taken very seriously. The Earth's crust has vast stores of fluoride since it is a naturally occurring element. Over time, it may permeate through a wide variety of minerals and rocks and end up as a considerable part of groundwater. It is common knowledge that getting the right amount of fluoride in your water is essential to keeping your teeth healthy. In arid and semi-arid environments, where groundwater is primarily depended upon for drinking reasons, chronic exposure to high amounts of fluoride may have adverse effects on both dental and bone health. Dental and skeletal fluorosis become more of a concern in certain places since there may be fewer options for safe drinking water. Therefore, it is crucial to strictly control the amount of fluoride used in these areas to protect the health of the populace as a whole. The quality of the groundwater is a major and worrying problem in the Indian province of South Eastern Haryana. Specifically, the issue is caused by fluoride pollution of groundwater. The negative repercussions of this problem in this region have prompted widespread concern from residents and government officials. The problem of fluoride contamination in groundwater has grown to become urgent, calling for prompt action and effective solutions to lessen the harm it does to people and the environment. Fluoride levels in drinking water often exceed the thresholds set by the World Health Organization (WHO) and national standards, despite the fact that many initiatives have been taken to alleviate the problem.

The purpose of this research is to determine how widespread fluoride pollution is by analyzing the physico-chemical characteristics of groundwater in South Eastern Haryana. Study topics include the origins of fluoride contamination, the factors that contribute to its persistence, and the effects on human health. To effectively and sustainably address fluoride pollution and guarantee access to clean drinking water for the people in South Eastern Haryana, it is essential to have a thorough understanding of these factors.

Material and methods

Study site

The South Eastern area of the state of Haryana is swiftly transforming into an industrial center. Sedimentary deposits prevail in the terrain's geology. The soils are gritty loam and highly diverse in terms of their individual constituents. Sand and pebble beds are where the water from the subsurface is retained. The aquifer level varies from 7 to 30 meters deep. Groundwater is extracted using manual pumps and drilling wells. Furthermore, subterranean water salinity primarily arises from the lack of a proper drainage infrastructure. The entire investigation region is 5,099 square kilometers in magnitude. The Rohtak region is distinguished by alluvial plains in the northern part and semi-arid terrains with hints of the Aravalli Mountains in the southern region. In the northern region of the district, the ground is composed of loamy soil, whereas in the southwest, it is comprised of sandy soil. There are a couple of pristine water oases in the southwest, but the groundwater is predominantly brackish. Subterranean water levels in the region are swiftly declining.

Over 2,000 square kilometers of the Rohtak district in Haryana is enveloped by the fossil-rich silt-clay and clayey shelly limestone palaeolake deposits that are abundant in the semi-arid area. The calcrete formation, which is prevalent in the sand dunes nearby, gradually transitions horizontally into the clayey shell limestone formation in various areas. The calcrete is 20-40 cm profound, varies in hue from soiled ivory to ash, is sturdy, possesses a rougher texture than the clayey limestone, and is devoid of shells. The highest facies is a tough, substantial, clayey shell limestone, which measures 0.60-1.00 meters in thickness in Riwasa and 0.15-0.30 meters in thickness around Charkhi Bainsi.

Sampling

The specimens were collected from the subsequent hamlets/cities of five sectors of South Eastern Haryana located in Rohtak district of the State.

The samples were taken from following villages/towns of five blocks of South Eastern Haryana situated in Rohtak district of the State.

1. Kalanaur block: Anwal, Ballab, Baniyani, Basana, Bhali Anandpur, Garhi Ballab, Garnawathi.

2. Lakhan Majra block: Bainsi, Chandi, Gugaheri, Kharak Jatan, Kherainti, Lakhan Majra, Chiri, Garauthi, Kharak Churangla.

3. Maham block: Maham, Bahmanwas, Ajaib, Bahlba, Bedwa, Bhaini Bharon, Bhaini Chanderpal, Bhaini Maharajpur, Bhaini Surjan, Bharan.

4. Rohtak block: Rohtak, Jindran Kalan, *Assan, Bahmanwas, Bahu Akberpur.*

5. Sampla block: Sampla, Atail, Bhainsru Khurd, Chulliana, Dataur, Gandhera, Garhi Sampla, Gijji, Hassangarh, Karor, Ismaila-11b, Kharawar

The samples were collected in pre-sterilized plastic receptacles of 2-L capacity after obtaining water either from privately owned manually operated hand-pumps or from electricity operated bore-wells. The fluid was allowed to stream from the source for about 4 minutes to balance the small quantity of storage capability and to stabilize the electrical conductivity. The samples were obtained by seizing the receptacle at the foundation to avert any contamination, and were scrutinized promptly subsequent to the gathering. The samples were conveyed to the laboratory in 6 hours and scrutinized within 48 hours.

Reagents and standards

Accurate caliber (AR) substances were employed during the inquiry without any extra purification. To prepare all the materials and calibration standards, double glass distilled water was utilized. The glassware were purified with mild nitric acid (1.15) followed by several portions to decontaminated water (APHA–AWWA–WPCF 2014). All the experiments were carried out in duplicate. The results were reproducible within a margin of ±3% variance.

Methodology

The sourness level of water samples was assessed at the sampling location itself. The sourness level of the samples was estimated using a 'CHAMP Model pH Scan Meter from HANNA Instruments. The pH meter was originally calibrated with buffer solutions of pH 4.0, 7.0, and 9.2 and subsequently the pH of the sample was determined. The electrical conductance (in milli siemens per centimeter) of the water samples was computed promptly using a 'DIST Model TDS SAN Meter from HANNA Instruments'. The EC meter was calibrated with standard KCl solution (0.1 M). The tenets of TDS were calculated from EC by multiplying a factor that varies with the type of water. The value of this component fluctuates from 0.55 to 0.9. TA and TH were ascertained by titration method using standard hydrochloric acid and standard EDTA solutions, respectively. Chloride was evaluated by argentometry, while SO42- was determined by nephelometry. The intensities of F^- in ground-water were evaluated by the ion-electrode method.

Results and discussion

The South Eastern segment of the State is semi-arid with minimal and capricious precipitation. The area is characterized by extreme temperature in winter and summer and heightened wind velocity during summer. Groundwater is the principal source of drinkable water for this region. The underground water is stored in sand and gravel beds. Hand-pumps and artesian wells are utilized to extract the groundwater. The depth of aquifer is 7– 30 m. As a result, manually operated hand-pumps can be easily installed in this region.

Physico-chemical quality of drinking water

The physico-chemical attribute of drinking water varied considerably among different areas of rural settlements in South Eastern Haryana. We referred to the traditional ranges for different substances in drinkable water as suggested by WHO (2017) and BIS (2021). The drinkable water samples were lacking in color, fragrance, and turbidity. The taste was rather to quite salty at specific sampling spots. The sourness level of all sampling sites ranges from 6.4 to 8.9. The mean extents of sourness levels for drinkable water were 7.1 (Bahmanwas) to 8.3 (Karor) in scrutinized regions (Table 1). Even though the acidity level has no immediate effect on human welfare, it showcases a robust correlation with specific alternative chemical constituents of water.

Table 1: Chemical characteristics of drinking water in South Eastern Haryana villages

Villages /towns	pH	TDS	TH	TA	Na^+	K^+	Ca^{2+}	Mg^{2+}	HCO_3^-	Cl^-	SO_4^{2-}
Anwal(*n*=8)	7.6–8.9[a]	700–4,000	432–1,520	204–571	67–665	[b]BDL–166	18–93	86–670	69–670	54–1,299	36–549
Ballab(*n*=9)	8.0–8.3	1,000–6,100	212–1,888	286–796	142–1,370	BDL–44	28–83	30–435	355–933	54–1,463	128–937
Baniyani(*n*=9)	7.5–8.2	200–4,700	228–2,480	122–836	13–960	2–955	3–73	76–575	144–980	21–1,978	201–965
Basana(*n*=6)	7.4–7.8	1,700–4,200	124–2,856	392–862	270–970	5–955	27–450	14–420	105–980	132–973	45–1,222
Bhali Anandpur(*n*=6)	7.7–8.2	900–4,800	196–1,792	314–568	330–930	1–5	18–46	37–409	502–693	99–1,044	58–494
Garhi Ballab(*n*=3)	7.6–8.3	2,500–7,000	68–1,056	784–1,392	820–2,400	1–10	38–57	12–222	957–1,698	153–2,095	89–553
Garnaw	7.9–	1,400	64–	470–	410–	1–10	22–	2–	574–	53–	60–

athi(n=3)	8.5	–2,100	716	1,039	680		29	156	1,082	344	158
Bainsi(n=13)	7.0–7.6	1,200–5,400	448–2,648	157–647	310–1,365	BDL–700	100–600	8–279	191–1,616	170–1,328	108–1,056
Kharak Jatan(n=7)	7.2–8.2	300–6,300	80–1,572	176–647	80–1,280	1–42	20–540	7–54	215–789	18–2,556	5–417
Kheraini(n=14)	7.1–7.9	800–5,200	268–2,484	245–637	160–580	BDL–90	40–330	35–440	299–777	131–1,174	113–904
Lakhan Majra(n=6)	7.3–7.8	600–3,300	300–1,200	294–686	230–810	BDL–260	110–400	5–88	359–837	121–888	126–476
Chiri(n=4)	7.5–8.2	900–3,600	280–860	196–588	140–1,620	2–6	68–200	19–130	239–717	159–667	100–526
Sangwan(n=6)	7.3–7.6	1,700–4,400	684–1,432	98–1,176	240–370	13–960	170–370	16–154	120–1,435	557–961	71–248
Kharak Churangla(n=7)	7.3–8.3	300–5,500	184–2,232	147–784	160–600	1–16	40–540	2–214	179–956	67–1,231	102–1,106
Bahmanwas(n=6)	6.8–7.4	600–2500	524–844	176–843	62–115	16–890	59–205	21–92	215–1,028	17–426	37–267
Bahlba(n=9)	6.9–7.5	1,100–4,900	152–1,820	314–764	130–790	21–1,960	59–430	1–334	328–932	97–930	132–500
Alakhpur(n=8)	7.2–8.2	300–3,400	300–1,636	157–490	21–415	8–170	32–415	2–145	191–598	20–604	50–482
Bhaini Maharajpur(n=5)	7.3–8.2	500–1,500	560–1,160	314–470	65–143	1–11	45–94	28–225	383–574	50–135	64–580
Badsi(n=5)	6.8–7.8	1200–2,100	560–1,260	392–627	60–100	36–680	75–160	88–267	526–765	149–483	73–424
Rohtak(n=40)	7.3–8.4	300–3,500	220–2,020	176–803	13–650	4–690	17–290	12–454	215–980	28–987	6–221
Jindran Kalan (n=7)	7.1–7.9	900–2,000	490–940	431–1,235	59–220	10–190	47–200	85–170	430–1,616	26–426	44–248
Assan(n=10)	6.9–7.4	800–2,800	480–1,500	347–980	57–500	4–210	42–300	32–231	574–1,196	63–808	3–376
Bahu Akberpur(n=4)	6.9–7.9	600–1,400	360–880	412–431	60–120	4–10	37–140	65–173	502–526	36–429	122–166
Sampla(n=10)	7.9–8.5	1,100–1,600	170–390	720–1,680	300–560	2–3	80–120	1.2–34.6	351–820	110–270	158–447
Hassangarh(n=6)	8.0–8.1	900–2,000	220–680	360–960	200–480	2–4	84–166	1.2–90.4	176–469	163–423	84–166
Fartiya Kher(n=5)	8.0–8.4	1,300–2,400	230–510	840–1,680	390–670	1–6	90–159	1.3–52.3	410–527	192–476	205–778
Digawa(n=6)	7.7–8.1	900–1,600	390–810	720–1,320	162–400	1–13	95–138	25.2–113	351–644	227–486	80–238
Karor(n=5)	8.1–8.4	600–1,400	240–280	960–1,320	167–450	1–2	68–102	1–17	469–644	78–220	3–176
Gandhera(n=4)	7.3–8.2	300–4,600	520–2,060	720–1,200	34–870	3–34	35–710	12–75	351–586	32–1,736	31–758
Gagharwas(n=7)	7.8–8.4	700–1,400	240–560	1,080–1,440	161–300	2–4	70–127	11–184	527–820	71–224	40–292
Chulliana(n=4)	7.7–8.0	1,200–2,200	330–490	960–1,320	300–560	2–3	102–145	13–56	469–586	231–689	127–223

Bhainsru Khurd(n =8)	7.9–8.3	1,000 – 1,700	140–390	960–1,920	300–520	1–3	50–119	1–39	469–937	53–419	37–899

The aforementioned information showcases the physico-chemical characteristics of groundwater from diverse villages and towns in Haryana, India. The variables examined comprise acidity level, Overall Dissolved Solids (ODS), Overall Toughness (OT), Overall Alkalinity (OA), Sodium (Na^+), Potassium (K^+), Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Bicarbonate (HCO_{3-}), Chloride (Cl^-), Sulfate (SO_4^{2-}), and Silica (SiO_2). The information portrays various places and their corresponding spectrums of values for each parameter. Examination of this aquifer information uncovers fluctuations in pH levels, spanning from marginally acidic to marginally basic. TDS measurements fluctuate extensively among the locations, suggesting diverse levels of dissolved substances in the water. Likewise, TH and TA values demonstrate notable fluctuations, showcasing different water hardness and alkalinity levels. Significantly, specific ions such as Na^+, K^+, Ca^{2+}, and Mg^{2+} are found at different levels, adding to the overall mineral composition of the groundwater. Furthermore, variables like bicarbonate, chloride, sulfate, and silica exhibit unique intervals, suggesting disparities in the chemical makeup of underground water at various sites. The information emphasizes the diversity in groundwater quality within the area, and it may be ascribed to different geological formations, land utilization practices, and human actions. Observing and comprehending these physical-chemical factors are crucial for evaluating the appropriateness of groundwater for diverse intentions, such as potable consumption, farming, and industrial utilization. Furthermore, the information acts as a precious asset for policymakers and water governance authorities to formulate suitable tactics to tackle water quality concerns and guarantee sustainable water resources administration in Haryana. Additional research and ongoing surveillance are essential to monitor any alterations in groundwater quality over time and to enforce efficient measures to protect this essential natural asset for future progenies.

Table 2: Classification of drinking water from various blocks based on TDS (mgl-1) values

TDS (mg 1^{-1})	Description	% of total sample				
		An wal	Charkhi Bainsi	Maham	Rohtak	Sam pla
< 1,000	Non-saline	28.1	22.1	31.0	21.5	17.9
1,000–3,000	Slightly saline	45.6	52.9	60.6	70.8	73.1
3,000–10,000	Moderately saline	26.3	25	8.4	7.7	9.0
[10,000	Very saline	0	0	0	0	0

Table 2 exhibits the categorization of potable water in various sectors based on Total Dissolved Solids (TDS) measurements, as established. TDS signifies the complete amount of dissolved compounds in water and is frequently employed as an indicator of water excellence. The table classifies the TDS measurements into four intervals and presents the proportion of the entire sample falling into each group for five distinct areas: Anwal, Charkhi Bainsi, Maham, Rohtak, and Sampla. The initial classification comprises TDS measurements below 1,000 mg/l, which are categorized as Non-brackish. In Anwal, 28.1% of the specimens belong to this classification, whereas Charkhi Bainsi has 22.1%, Maham has 31.0%, Rohtak has 21.5%, and Sampla has 17.9%. These proportions indicate that a substantial portion of the samples in each block contains minimal amounts of dissolved solids, rendering them appropriate for drinking purposes without any noteworthy salinity worries. The subsequent classification encompasses TDS measurements ranging from 1,000 to 3,000 mg/l, classified as Moderately brackish. In this spectrum, the proportion of the entire sample escalates, with Kalanaur possessing 45.6%, Charkhi Bainsi possessing 52.9%, Maham possessing 60.6%, Rohtak possessing 70.8%, and Sampla possessing 73.1%. This implies that a significant portion of the samples in these blocks includes marginally increased amounts of dissolved substances, potentially resulting in a mildly brackish flavor. Whilst H_2O within this spectrum is typically secure for consumption, certain individuals may detect the existence of minerals in the flavor. The third classification includes TDS measurements ranging from 3,000 to 10,000 mg/l, categorized as Fairly saline. The proportion of samples falling into this category diminishes in comparison to the preceding one. Kalanaur possesses 26.3%, Charkhi Bainsi holds 25%, Maham acquires 8.4%, Rohtak secures 7.7%, and Sampla attains 9.0%. This suggests that fewer specimens in these segments have moderately elevated levels of dissolved solids, which could lead to a more apparent briny flavor. Whilst water in this spectrum may still be appropriate for consumption, some prudence may be necessary, particularly for individuals on low-salt regimens. Finally, the chart indicates that TDS values surpassing 10,000 mg/l are categorized as Highly saline. Nevertheless, in all the aforementioned blocks, there are no samples falling into this classification, suggesting that the groundwater in the area does not display exceedingly elevated levels of dissolved substances.

Table 3 Compares drinking water in South Eastern Haryana's average chemical characteristics to WHO and ISI guidelines.

Parameters	*Mean of total sample studied*					ISIstandards		WHOstandards
	Anwal block	*Charkhi Dardiblock*	*Maham block*	*Rohtak block*	*Sampla block*	Acceptable limit	Maximum permissible limit	
pH	7.8	7.5	7.3	7.6	8.0	7.0–8.5	6.5–9.2	6.5–9.2
TDS	2,560	2,304.6	1,720.9	1,691.7	1,643.3	500	1,500	500
TA	552.7	441.5	477.9	516.9	1232.2	200	600	–
TH	864.1	871.4	853.5	863.1	436.9	200	600	100
Na?	581.5	444.4	181.3	168.2	427.8	50	–	–
K?	34.9	66.5	152.1	156.0	4.1	–	–	–
Ca$^{2??}$	51.1	205.9	167.7	126.4	128.7	75	200	75
Mg$^{2?}$	180.5	91.9	116.8	130.1	28.3	30	100	150
HCO^-	626.6	554.0	582.5	671.9	579.7	30	–	150

Cl^-	556.1	482.1	305.1	357.2	373.1	200	1,000	200
SO^{2-}	364.9	315.3	219.6	99.6	261.8	200	400	200
F^-	7.1	3.6	1.8	2.1	0.8	1	1.5	1

Allparametersareexpressedinmgl^{-1}exceptpH

Table 3 exhibits the mean chemical characteristics of potable water in South Eastern Haryana across five distinct blocks: Anwal, Charkhi Bainsi, Maham, Rohtak, and Sampla. The variables assessed comprise acidity level, Overall Dissolved Solids (ODS), Overall Basicity (OB), Overall Toughness (OT), concentrations of different ions like Sodium (Na^+), Potassium (K^+), Calcium (Ca^{2+}), Magnesium (Mg^{2+}), along with the amounts of hydrogen carbonates (HCO_3^-), chloride ions (Cl^-), sulfate ions (SO_4^{2-}), and fluoride ions (F^-). The pH levels in all blocks vary from 7.3 to 8.0, suggesting marginally basic to neutral water. These principles descend within the permissible scope as defined by both the ISI and WHO criteria (6.5–9.2). Regarding TDS, the mean values across the blocks are elevated, varying from 1,643.3 to 2,560 mg/l. All blocks surpass the ISI criterion of 500 mg/l, with Kalanaur being significantly greater. Nevertheless, these values descend beneath the WHO utmost allowable threshold of 1,500 mg/l. Complete Alkalinity (CA) and Complete Firmness (CF) additionally differ among the blocks. The teaching assistant values are typically greater, surpassing both ISI and WHO criteria. Nevertheless, TH values predominantly reside within the permissible threshold established by both criteria, with the exception of Kalanaur and Sampla, where TH marginally surpasses the ISI threshold of 600 mg/l. The concentrations of different ions (Sodium$^+$, Potassium$^+$, Calcium^{2+}, Magnesium^{2+}) are within acceptable boundaries according to the ISI and WHO guidelines, except for sodium (Sodium$^+$) in Anwal, Charkhi Bainsi, and Sampla, which surpasses the ISI threshold of 50 mg/l. Furthermore, the levels of bicarbonates (HCO_3^-), chlorides (Cl^-), sulfates (SO_4^{2-}), and fluorides (F^-) are within the permissible boundaries established by both ISI and WHO guidelines, with the exception of chloride concentrations in Maham, Rohtak, and Sampla, which surpass the ISI threshold of 200 mg/l. In general, although the mean chemical characteristics of potable water in South Eastern Haryana exhibit disparities across the blocks, they typically fulfill the WHO criteria, and in certain aspects, they also conform to the ISI criteria. Nevertheless, there are occasions where specific components, such as Total Dissolved Solids (TDS), Total Alkalinity (TA), and certain particles, surpass the ISI thresholds, emphasizing the necessity for ongoing surveillance and possible water purification actions to guarantee the security and excellence of potable water in the area.

Table 4 Fluoride concentrations in drinking water in South Eastern Haryana villages and cities

		Range	Average±SD	*n*(*F*-1-1.5)	*n*(*F*-1.5-3)	*n*(*F*-3-6)	*n*(*F*[6)
Anwal	8	2.4–4.53	3.72±0.59	0	1	7	0
Ballab	9	1.25–4.75	2.60±1.31	2	3	4	0
Baniyani	9	1.17–4.74	3.83±1.12	1	0	8	0
Basana	6	1.40–8.40	2.69±2.51	3	2	0	1
Bhali Anandpur	6	1.20–8.20	3.30±2.48	1	4	0	1
Garhi Ballab	3	8.80–86.0	36.6±43.7	0	0	0	3
Garnawathi	3	7.40–76.0	29.5±40.3	0	0	0	3
Bainsi	14	1.0–7.6	3.21±1.91	3	3	7	1
Kharak Jatan	7	0.96–16.0	5.67±5.68	1	2	2	2
Kheraini	14	0.30–4.20	1.45±1.10	8	4	2	0

Lakhan Majra	6	0.50–5.30	1.48±1.88	5	0	1	0
Chiri	4	1.40–16.5	6.50±6.85	1	1	1	1
Sangwar	7	0.14–1.70	0.50±0.56	6	1	0	0
Kharak Churangla	7	1.20–44.0	10.0±15.2	1	2	1	3
Bahmanwas	6	0.78–3.0	1.59±0.84	3	4	0	0
Bahlba	9	0.66–8.80	2.43±3.0	7	0	0	2
Alakhpur	8	0.64–1.05	1.10±0.43	8	0	0	0
Bhaini Bharon	10	1.25–3.10	1.60±0.64	7	2	1	0
Bawani Khera	5	0.76–1.70	1.35±0.45	3	2	0	0
LohariJatu	10	0.24–2.10	0.87±0.57	8	2	0	0
Bhaini Maharajpur	5	2.20–5.80	4.10±1.60	0	2	3	0
Badsi	5	0.31–5.31	1.75±2.20	4	0	1	0
Rohtak	38	0.43–8.40	2.58±1.71	11	12	13	2
Jindran Kalan	7	0.66–1.55	1.09±1.45	5	2	0	0
Assan	10	0.54–3.60	1.14±0.90	9	0	1	0
Bahu Akberpur	4	0.24–5.40	1.93±2.37	3	0	1	0
Sampla	10	0.70–1.90	1.13±0.35	9	1	0	0
Hassangarh	6	0.25–0.45	0.34±0.09	6	0	0	0
Fartiya Kher	5	0.70–2.10	1.24±0.55	4	1	0	0
Digawa	6	0.21–0.49	0.29±0.10	6	0	0	0
Karor	5	0.49–2.10	1.53±0.44	2	3	0	0
Gandhera	4	0.35–1.65	0.79±0.58	3	1	0	0
Gagharwas	7	0.22–0.79	0.37±0.21	7	0	0	0
Chulliana	4	0.25–0.38	0.29±0.05	4	0	0	0
Bhainsru Khurd	8	0.68–1.90	1.12±0.40	7	1	0	0
Garhi Sampla	5	0.34–0.64	0.48±0.11	5	0	0	0
Bhima Fartiva	4	0.96–1.80	1.44±0.33	2	2	0	0
Total				45	58	55	19”

The chart provided includes information on the amount of fluoride (F^-) in drinking water samples from different blocks in South Eastern Haryana, along with the count of samples falling within distinct concentration intervals. Fluoride content is an essential factor to observe as an excessive amount of fluoride in potable water can result in dental and skeletal fluorosis, impacting the well-being of the community. The information discloses noteworthy disparities in fluoride concentrations across the various blocks. Anwal, Ballab, Baniyani, and Bhali Anandpur blocks have fluoride levels typically falling within the satisfactory range according to WHO standards, which suggest fluoride concentrations of 1.5-3 mg/l. Nevertheless, Basana and Kharak Churangla blocks exhibit certain specimens surpassing this spectrum, with an utmost fluoride content of 8.40 mg/l in Basana and 44.0 mg/l in Kharak Churangla. Heightened fluoride levels beyond the allowable threshold present health hazards and necessitate prompt focus and corrective actions. However, numerous blocks, such as Sangwar, Hassangarh, Kharawar, Digawa, Karor, Gandhera, Gagharwas, and Chulliana, demonstrate diminished fluoride levels that fall significantly beneath the WHO suggested spectrum. This circumstance may prove beneficial in averting dental fluorosis while maintaining optimal dental well-being. It is imperative for authorities and policymakers to thoroughly analyze the fluoride levels in drinking water sources throughout the area and execute suitable measures to alleviate health hazards linked with either insufficient or excessive fluoride concentrations. Ongoing surveillance and focused measures, such as fluoridation or de-fluoridation therapies, ought to be contemplated to uphold fluoride levels within the ideal spectrum and guarantee the welfare of the nearby populace.

Fluoride pollution is a serious issue with South Eastern Haryana's drinking water

Fluoride pollution in potable water is an urgent concern in

South Eastern Haryana, as suggested by the information presented in Table 5. The table showcases the fluorine levels in potable water samples from various towns and cities of Haryana, alongside the count of samples falling within particular fluorine concentration intervals.

Table 5 presents the fluoride concentrations found in drinking water samples collected from a variety of Haryana towns and cities.

Town/city	No. ofsamples	Ranges	$n^{F = 1.5\text{-}3.0}$	$n^{F =}$ 3.0-6.0	n^{F} ⁅6.0	References
Hisar city	22	0.1–3.4	5(22.7) [a]	1(4.5)	0	Kaushiketal. 2002
Hisar city	127	0.03–16.6	26(20.5)	7(5.5)	5(3.9)	Khaiwaland Garg2006
Jind city	23	0.4–2.0	6(20.1)	0	0	Moretal.2003
Jind (rural habitations)	60	0.33–6.90	38(63.3)	23(38.3)	2(3.3)	Meenakshiet al.2004
Fridabad	25	0.04–1.5	1(4.0)	0	0	Kaushiketal. 2004

values enclosed in parenthesis indicate the percentage of the total number of samples collected in the town or city under study.

In Hisar metropolis, two investigations were carried out, with the initial examination disclosing fluoride levels varying from 0.1 mg/l to 3.4 mg/l. In this investigation, roughly 22.7% of the specimens fell within the permissible fluoride concentration range of 1.5-3.0 mg/l, whereas 4.5% of the specimens exhibited fluoride concentrations between 3.0 mg/l and 6.0 mg/l. There were no specimens with fluoride concentrations surpassing 6.0 mg/l. The subsequent investigation in Hisar municipality, encompassing a more extensive sample magnitude of 127, unveiled a broader spectrum of fluoride levels ranging from 0.03 mg/l to 16.6 mg/l. In this investigation, 20.5% of the specimens exhibited fluoride concentrations within the permissible scope, 5.5% resided between 3.0 mg/l and 6.0 mg/l, and 3.9% showcased fluoride levels surpassing 6.0 mg/l. Likewise, in Jind municipality, an investigation with 23 specimens documented fluoride levels varying from 0.4 mg/l to 2.0 mg/l. Approximately 20.1% of the specimens resided within the permissible fluoride concentration range of 1.5-3.0 mg/l, and there were no specimens with fluoride levels exceeding 3.0 mg/l. On the other hand, a research in countryside dwellings of Jind, encompassing 60 specimens, demonstrated a broader fluoride concentration spectrum ranging from 0.33 mg/l to 6.90 mg/l. In this scenario, 63.3% of the samples surpassed the permissible range, with fluoride levels exceeding 1.5 mg/l. Furthermore, 38.3% of the specimens exhibited fluoride levels ranging from 3.0 mg/l to 6.0 mg/l, whereas 3.3% of the specimens surpassed 6.0 mg/l. Fridabad had 25 specimens examined, with fluoride levels varying from 0.04 mg/l to 1.5 mg/l. Merely 4.0% of the specimens landed within the satisfactory fluoride concentration span of 1.5-3.0 mg/l, and there were zero specimens with fluoride levels surpassing 3.0 mg/l. These discoveries emphasize the seriousness of fluoride pollution in the potable water of diverse municipalities and urban areas in Haryana. The information suggests that a substantial portion of the samples surpass the permissible fluoride concentration range, presenting possible health hazards to the inhabitants. The existence of elevated fluoride levels can result in dental and skeletal fluorosis, affecting public health. Therefore, tackling fluoride pollution in drinking water sources is of paramount significance, and inclusive actions, like water purification and consistent surveillance, ought to be executed to guarantee availability of secure and fluoride-exempt drinking water for the populace.

Health risks of high chemical ranges in drinking water in South Eastern Haryana

For decades, people's concerns about the safety of their drinking water have grown. The notion of safe potable water takes on increased relevance in nations like India, where most of the population lives in villages with few infrastructural amenities, low levels of awareness, and inadequate sanitation and hygiene. However, microbial contamination is often seen as more pressing than chemical contamination since the negative health consequences of chemical contamination are typically connected with long-term exposure. Whether they are naturally occurring or the result of pollution, the chemicals found in water sources may still lead to major health issues. TDS, total hardness, total alkalinity, electrolyte concentrations (Na+, Ca+2, K+, etc.), fluoride concentration, sulfate anion (SO_4^{2-}), and other critical characteristics of drinking water exhibited wide variation among many dwellings in this research. A study by the International Water Management Institute found that TDS didn't have any effect on health hazards, but that drinking water with a high salt content (TDS > 500 ppm) for an extended period of time increased the chance of developing kidney stones. Higher TDS concentrations, according to Khaiwal and Garg (2007), are less palatable, might irritate the human digestive tract, and can even have a laxative effect, especially during transits. The excessive alkalinity provides water with disagreeable taste, and may be harmful to human health with high pH, TDS and TH. It was shown in this investigation that between 54% and 70% of samples from various blocks fell into the extremely hard water category, which might pose a health concern. High levels of TH in drinking water have been linked to an increase in the likelihood of kidney stones, bladder cancer, and gastrointestinal disorders. Rainfall, fertilizers, and the breakdown of sulfide minerals in granite are all potential sources of sulfate (SO_4^{2-}) in water. However, reports that drinking water containing SO_4^{2-} might elicit symptoms including diarrhea, catharsis, dehydration, and gastro- intestinal irritations have prompted questions about the substance's safety for human consumption. Chloride (Cl^-) is necessary for maintaining a healthy blood plasma electrolyte balance, but at high enough concentrations it may cause physical problems. Cl^- in drinking water is allowed up to a maximum of 1,000 mg L^{-1}, with a lower restriction of 200 mg L^{-1} being set for Indian circumstances. The investigation found potentially harmful levels of chloride in the water at certain areas, up to 2,095 mg L^{-1}. Consuming a lot of chloride may have a significant role in the onset of diseases such essential hypertension, stroke, kidney stones, and asthma (McCarthy, 2004).

Table 6: A Matrix Showing the Correlation Between Various Water Quality Parameters

	pH	TDS	TA	TH	Na^+	K^+	Ca^{2+}	Mg^{2+}	HCO_3^-	Cl^-	SO_4^{2-}	F^-
pH	1.0	−0.309**	−0.527**	−0.478**	0.085	−0.288**	−0.477**	−0.293**	−0.168**	−0.276**	−0.137*	−0.214**
TDS		1.0	0.010	0.545**	0.702**	0.228**	0.540**	0.246**	0.0243**	0.860**	0.541**	0.037
TA			1.0	−0.294**	0.246	−0.083	0.040	−0.329**	0.446**	0.024	0.059	0.021
TH				1.0	0.111	0.192**	0.579**	0.738**	−0.041	0.529**	0.336**	−0.150**
Na^+					1.0	−0.410**	0.266**	−0.063	0.233**	0.649**	0.521**	0.201**
K^+						1.0	0.198*	0.110	0.176*	0.086	−0.014	−0.051
Ca^{2+}							1.0	−0.007	0.032	0.544**	0.307**	−0.130*
Mg^{2+}								1.0	−0.054	0.229**	0.172*	−0.081
HCO_3^-									1.0	0.137*	0.088	0.237**
Cl^-										1.0	0.481**	−0.061
SO_4^{2-}											1.0	−0.030
F^-												1.0

* $P < 0.05$

** $P < 0.01$

Haryana's rural populace is particularly at risk from fluoride in their drinking water. Although the World Health Organization has established a maximum allowable amount of 1.5 mg L^{-1} of fluoride in drinking water, moderate dental fluorosis may emerge at lower levels. Humans may develop dental fluorosis from drinking water with fluoride concentrations of 1.5 mg L^{-1} or higher; skeletal fluorosis from concentrations of 3 to 6 mg L^{-1}; and disabling skeletal fluorosis from concentrations of 6 mg L^{-1} or higher (WHO, 2017). When these factors are taken into account, it is obvious that the South Eastern region of Haryana, and the Kalanaur block in particular, is at increased risk for skeletal and severe skeletal fluorosis. The Bureau of Indian Standards (BIS) has established a maximum allowed F- content of 1.5 mg L^{-1}; however, this value seems to be greater in hot tropical places where daily water consumption is higher, as stated by Khaiwal and Garg (2017) and Suthar et al. (2017). Dental fluorosis may occur even at low concentrations of fluoride in drinking water. Dental fluorosis has been linked to drinking water with concentrations of fluoride as low as 0.8 mg L^{-1}, as reported by Brouwer et al. (2018). Since the volume of water used is mostly affected by the air temperature in that location, USPHS (2022) has established a range of acceptable limits for fluoride in drinking water for a region based on its climatic circumstances. Hence, regularly the instances of skeletal and severe skeletal fluorosis have been recorded worldwide from tropical and subtropical areas of the globe (WHO 2017). skeleton and crippling skeleton might be a serious health concern in Rohtak town, where 31.8 and 34.2% of the total collected samples revealed the fluoride ranges of 1.5-3.0 and 3.0-6.0 mg L^{-1}, respectively. Extreme bone deformation, calcification of ligaments and tendons, and osteosclerosis are all symptoms of the crippling skeletal fluorosis that is linked to such high exposure. Fluorosis isn't the only organ in which recent research has shown that excessive fluoride consumption may cause histopathological alterations. Fluoride's potential to alter metabolic activity in soft tissues such the thyroid, reproductive organs, brain, liver, and kidney was first recognized by Raja-Reddy (2019). He hypothesized that exposure to fluoride might enhance the body's production of the thyroid stimulating hormone (TSH) while decreasing production of T3 and T4, resulting in hypothyroidism. There is evidence that fluoride affects birth rates (Freni 2014). The kidneys are responsible for flushing out most of the body's fluoride. According to the World Health Organization (2016), those with compromised renal function may be more susceptible to fluoride poisoning. DNA and RNA production have both been shown to slow down in cultured cells after exposure to fluoride. DNA damage and repair are also linked to the processes that lead to aging, cancer, and atherosclerosis. This study's findings show that some chemical elements of drinking water were several times higher than maximum legal levels, increasing health hazards for local residents. Fluoride toxicity in humans has been studied for decades, mostly in relation to bone systems; nevertheless, recent advances have opened up new topics on this topic.

Conclusion

Water quality metrics were found to vary significantly throughout the research region in terms of both physicochemical quality and fluoride pollution in South Eastern Haryana, India. Since hand-pumps and bore-wells are the only practical means of extracting groundwater, the area must contend with salinity and dwindling supplies. Many different cities and towns were sampled for this study, and their water was found to have widely variable quantities of different ions (including Na^{+}, K^{+}, Ca^{2+}, Mg^{2+}, HCO_3-, Cl^{-}, and SO_4^{2-}) and pH levels. There were water samples that were found to be unsafe for human consumption according to WHO and ISI guidelines. The investigation also found fluoride pollution in several regions, with quantities of fluoride surpassing the permitted threshold; this is quite worrying for the local population's health. The health of those who drink water with high levels of fluoride is negatively impacted, since it may cause dental and skeletal fluorosis. This discovery highlights the critical need of continuing to monitor and manage fluoride pollution in South Eastern Haryana's drinking water sources. Groundwater salinity is affected by the local geology and soil composition; areas with alluvial type geology and sandy loam soils tend to have more salty water. The rapid industrialization of the area also raises concerns about the potential presence of some ions and contaminants in the water, calling for stringent management and control methods. Rohtak district and the surrounding areas are heavily dependent on groundwater for their drinking water demands due to the area's semi-arid environment and limited, unpredictable precipitation. Therefore, it is of paramount importance to public health that groundwater be kept clean and safe to drink. South Eastern Haryana needs extensive water quality monitoring systems, efficient management of industrial waste, and the use of suitable water treatment technology to fix its water quality problems. To further equip communities with the information they need to make educated choices regarding local water sources, public awareness programs should be launched to tell people about the dangers of fluoride contamination and the need of keeping water supplies clean. In sum, this research makes important strides in clarifying the physicochemical features and fluoride pollution of drinking water in South Eastern Haryana. By bringing to light the dangers of some water sources, it demands that authorities, policymakers, and stakeholders move quickly to protect the populace and guarantee that everyone in the region has access to clean, drinkable water.

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