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ORIGINAL ARTICLE

Groundwater quality analysis of quaternary aquifers in Jhajjar District, Haryana, India: Focus on groundwater fluoride and health implications

Ruchi Gupta, Anil Kumar Misra *

Department of Civil and Environmental Engineering, The NorthCap University, Sector 23A, Gurgaon, Haryana 122017, India

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Abstract 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. Hydrogeologically 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.

1. Introduction

Groundwater is the major source of water in India. About 80% of domestic water requirements in rural areas and 50% in urban areas are fulfilled by groundwater but owing to large population and over exploitation, water resources are depleting very rapidly [29]. In countries like India, where population exponentially increases [7], approximately 165 billion litres of water is required per day but the shortage of water resources leads to situation where 54% of India faces high to extremely high water stress conditions [27]. As per the Central Ground Water Board, the overall stage of groundwater development in the country is 62% [9]. Approximately 17% of the locations evaluated by CGWB are in the stage of over-exploitation, 3% critical, 10% semi-critical and 68% units are Safe. CGWB assesses the groundwater conditions based on stage of groundwater development for that area and is computed using the following formula:

* Corresponding author.
E-mail address: anilgeology@gmail.com (A.K. Misra).
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$$\text{Stage of groundwater development} = \frac{\text{Existing Gross Draft for all uses}}{\text{Net Annual Groundwater Availability}} \times 100$$

These values are more than 100% for the states of Delhi, Haryana, Punjab and Rajasthan; this signifies that the annual groundwater consumption is more than annual groundwater recharge in these states [8]. Besides depleting resource, another major issue with groundwater is declining quality in India. In 2015, World Resource Institute (WRI) measured water quality of India using India Water Tool (IWT 2.0) based on Bureau of Indian Standards (BIS) limits [6] and evaluated the IWT's 632 groundwater quality districts, and only 59 are found within BIS limits [27]. The previous reports and studies published also indicate the poor quality of groundwater throughout the country [10].

The quality of groundwater is contaminated mainly due to two reasons. One is addition of contaminants due to anthropogenic activities (called as anthropogenic contamination) and other is contamination due to the presence of natural minerals within the aquifer. There are several contaminates, such as Arsenic, fluoride, Chloride, Nitrate, Iron and Manganese, Uranium, Radon and Strontium, Chromium, and Selenium which are reported in groundwater due to geogenic contamination [9]. Amongst these, fluoride is the most widespread contamination in India [9]. The type of contamination is caused due to dissolution of soluble products of weathered rocks. The rocks are made up of minerals and chemical reactions such as weathering, dissolution, precipitation, ion exchange and various biological processes commonly take place below the surface release several ions and this cause natural contamination of groundwater. The degree of geogenic contamination in groundwater is highly dependent on the nature of the aquifers, climatic conditions, porosity of the soil and land use patterns [9,14,25,21].

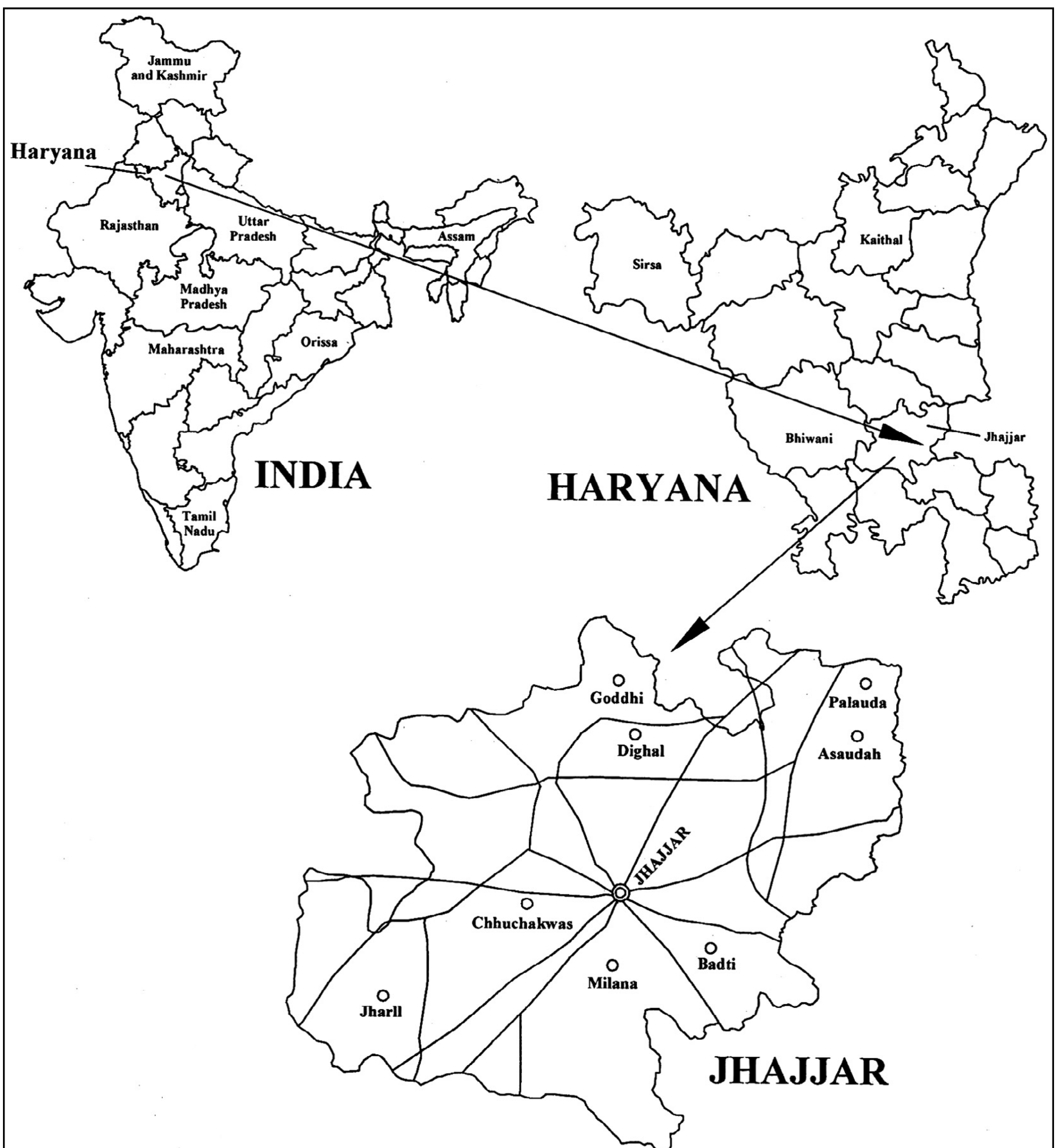

Figure 1 Location of Jhajjar district in Haryana, India.

The present study was carried out in Jhajjar district of Haryana state, being reported for poor groundwater quality by several researchers [33,34,10,15]. A Study carried out by Yadav et al. [34], shows that about 30–94.85% of the school going children are affected with dental fluorosis in different parts of the Jhajjar district. As per the report of Ministry of Drinking Water and Sanitation Data (2013), groundwater fluoride is the one major problem in habitation in Jhajjar district. The study determined the quality of groundwater through primary data collection and evaluated the groundwater quality based on groundwater quality index (GWQI). The district is chosen for the study as there is no literature found on GWQI of Jhajjar district.

In this study, weighted arithmetic index method, first developed by Brown et al. [5] was used for calculation of WQI. The method is applied by many researchers for estimating the groundwater quality index for the districts of MP, Rajasthan, Gujarat, Karnataka, etc. [12,13,3,24,26,28,30]. The water quality index of a region would help in understanding the quality of water by a single number. Most of the time, out of the several parameters analysed for a location, some are within the permissible limits but others are not, then the overall quality is unknown. WQI helps in simplifying the complex water quality data into simple number terms.

2. Materials and methods

2.1. Study area

Jhajjar is geographically situated between 28°22′ to 28°49′ N and 76°18′ to 76°59′ E with a total geographical area of approximately 1834 km^2 (Fig. 1). It is the recent formed district in Haryana state, carved out in 1970 from the Rohtak district. The district is divided into five blocks namely Jhajjar, Beri, Bahadurgarh, Matenhail and Salahwas [20]. Out of the five blocks of Jhajjar district, 3 blocks are falls under the critical category of groundwater stage development.

Jhajjar district is part of the Indo-Gangetic Plain. Majority of the area of the district is covered by Gangetic alluvial deposits of the quaternary period comprising gravel, sand, silt, clay and kankar in various proportions [23]. The study of borehole data generated by the ETO/CGWB indicates that clay group of formations dominate over the sand group in the district. The lithological correlation clearly indicates the presence of clay layer at the top of the surface [11]. Fig. 2 shows the geomorphological formations of the Jhajjar district, Haryana.

In present study, about 20 samples were collected from different locations of the district. These locations were chosen because a large number of inhabitants were collecting water from these sites for their daily needs. The geographical coordinates, Latitude and Longitude of each sample site (village/location name mentioned), were also taken (Table 1).

2.2. Collection and analysis of water samples

Twenty samples from hand pumps and borewells (used for the domestic water usages) were collected in the month of August 2015. Water samples were collected after running the water for about 3–5 min in pre-cleaned polyethylene bottles and analysed for pH, chloride (Cl) and fluoride (F), total hardness (TH), total dissolved solids (TDS) and electrical conductivity (EC). pH was measured by digital pH meter, fluoride with fluoride meter (make: HANNA, HI 98402), and TDS and Electrical conductivity were measured with digital EC-TDS analyser (make: Decibel, DB-1028). Chloride and Hardness were determined as per the standard procedures of American Public Health Association (APHA).

2.3. Calculation of Groundwater Quality Index (GWQI)

GWQI was calculated using weighted arithmetic index method. In the present study, parameters considered for calculating the GWQI are pH, Fluoride, Total Dissolved Solids, Total Hardness and Chloride. For determining GWQI, following steps were followed:

Step 1: Calculating the quality rating scale (Qi)
Qi = 100* [Measured value (Vm) – Ideal value (Vi)]/[Standard value (Vs) – Ideal value (Vi)]

Where,
Qi = Quality rating of ith parameter for a total of n water quality parameters
Vm - Measured value of the water samples for quality parameters estimated from analysis
Vi - Ideal value of that water quality parameter can be obtained from the standard tables
Ideal value is equal to zero for most parameters except for pH = 7 and F = 1.0 mg/L
Vs - Standard of the water quality parameter given by WHO

Step 2: Calculating the relative unit weight (Wi)
Wi is inversely proportional to standard value (Si) of the parameter, therefore relative unit weight (Wi) was calculated using following formula

Wi = K/Si

Where,
Wi - Relative unit weight of nth parameter
Si - Standard value for nth parameter
K = Proportionality constant = 1

Step 3: Calculating water quality index (WQI)
The overall WQI was calculated by using formula
$WQI = \sum Qi^{*} Wi / \sum Wi$

Where,
Qi = Quality rating
Wi = Relative weight

3. Results and discussion

Groundwater quality and soil salinity, both are deteriorating through time in Jhajjar district. The study area belongs to Indo-Gangetic Plain and previous studies in different parts of this plain have revealed that, in Ganga Plain the sodic nature of soil is owing to in-situ weathering of alkali alumino-silicates [4,16]. Moreover it is assumed that salt-rich geological formation has also contributed in the development of existing alluvial deposits [18,19,17]. The soil horizons in Indo-Gangetic Plain are dominated by clay layers with very low hydraulic conductivity [22]. This study indicates that subsurface lithological formation is rich in fluorine mineral and other salts that

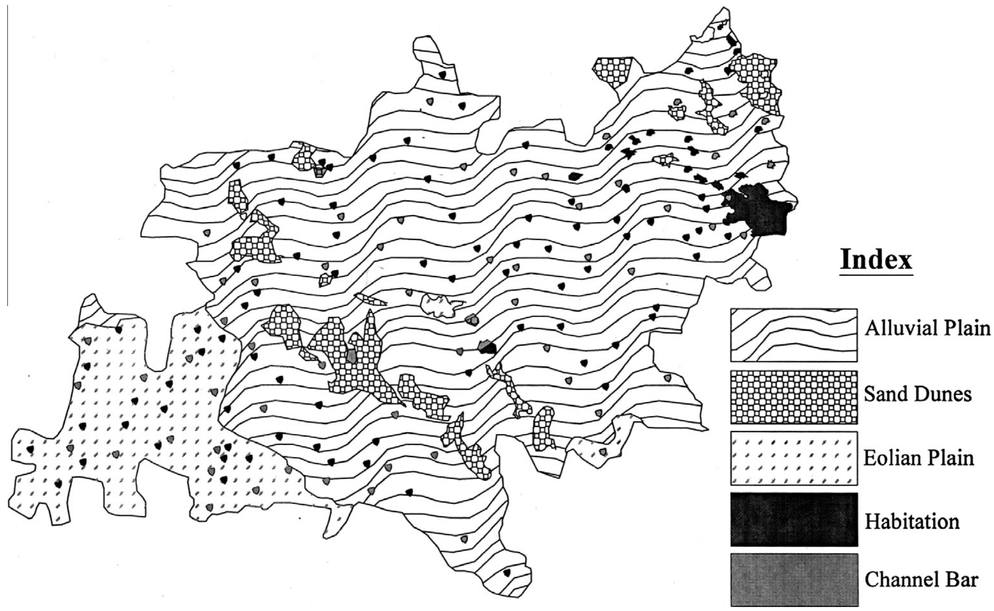

Figure 2 Geomorphological map of Jhajjar district, Haryana.

Table 1 Measured groundwater quality in the parts of Jhajjar district in 2015.

Sample no.	pH	Fluoride (mg/L)	Chloride (mg/L)	Total hardness (mg/L)	Total dissolved solids (mg/L)	Electrical conductivity μmhos/cm at 25 °C
Acceptable limit[a]	6.5–8.5	1.0	250.0	200.0	500.0	< 250
Permissible limit[a]	No relaxation	1.5	1000.0	600.0	2000.0	500
Rampura (1)	7.4	3.6	37.0	220.0	261.0	383.0
Jondhi (2)	6.5	0.3	246.9	720.0	821.0	1233.0
Kheri Sultanpur (3)	7.0	2.8	379.9	536.0	1580.0	2350.0
Gudha (4)	6.7	1.7	87.0	528.0	884.0	1255.0
Dhor (5)	7.3	2.0	18.0	272.0	198.0	273.0
Wazirpur (6)	7.5	2.8	29.0	508.0	319.0	467.0
Kheri Asra (7)	7.5	1.4	21.0	100.0	74.4	111.8
Dubaldhan Bidhan (8)	7.5	1.2	6.0	140.0	74.6	103.5
Palra (9)	6.0	1.1	61.0	172.0	147.0	209.5
Majra D (10)	7.4	2.7	180.9	148.0	761.0	1101.0
Khatiwas (11)	6.6	1.4	39.0	364.0	484.0	660.0
Kheri Khumar (12)	7.0	3.6	227.0	256.0	243.0	356.0
Bir Sunarwala (13)	7.0	9.3	2439.2	2740.0	3920.0	5640.0
Sekhupur Jat (14)	7.5	1.7	62.0	228.0	311.0	437.0
Kablana (15)	7.2	0.6	28.0	260.0	238.0	337.0
Dulhera (16)	6.9	1.5	98.0	504.0	444.0	651.0
Daboda Khurd (17)	7.6	1.9	27.0	256.0	182.0	272.0
Birdhana (18)	7.0	1.3	386.1	230.0	680.0	756.0
Baghpur (19)	7.9	3.8	52.5	178.0	371.0	476.0
Sikanderpur (20)	7.6	2.5	26.2	180.0	225.0	358.0
Average	7.1	2.1	212.5	427.0	610.9	871.5

[a] BIS standard drinking water specification (IS: 10,500:2012).

can directly or indirectly affect the groundwater quality in Jhajjar district.

The laboratory results indicated that in majority of the area concentration of fluoride, chloride, hardness in groundwater is above the permissible limit. The fluoride concentration was found in the range of 0.3–9.0 mg/L. In 60% of the samples fluoride was more than permissible limit of 1.5 mg/L. Hardness is another important parameter which is high in about 70% of the samples collected from the site. The results were in the range of 100–2740 mg/L. Chloride and TDS were higher than permissible limit at two locations. TDS were in the range of 74.6–3920 mg/L and Chloride was between 6 and 2439 mg/L. The electrical conductivity was also high in the samples ranging 100–5640 μmhos/cm, and the standard value prescribed by CGWB for domestic purposes is 500 μmhos/cm at temp 25 °C.

Table 2 Groundwater quality in the parts of Jhajjar district in 2013–14 [32].

Nearest to the sample site number	pH	Fluoride (mg/L)	Chloride (mg/L)	Total hardness (mg/L)	Total dissolved solids (mg/L)	Electrical conductivity µmhos/cm at 25°C [a]
Rampura (1)	7.9	1.6	80.0	115.0	510.0	797.0
Jondhi (2)	8.1	1.1	100.0	350.0	670.0	873.0
Kheri Sultanpur (3)	7.8	0.9	450.0	485.0	1341.0	1870.0
Gudha (4)	8.2	1.3	23.0	227.0	158.0	233.0
Dhor (5)	7.8	0.2	20.0	100.0	125.0	195.0
Wazirpur (6)	7.2	0.6	90.0	400.0	490.0	758.0
Kheri Asra (7)	7.1	0.3	110.0	50.0	330.0	431.0
Dubaldhan Bidhan (8)	7.4	3.2	55.0	270.0	636.0	793.0
Palra (9)	7.2	0.2	20.0	85.0	146.0	228.0
Majra D (10)	7.7	1.9	135.0	350.0	676.0	734.0
Khatiwas (11)	7.6	0.2	20.0	110.0	141.0	220.0
Kheri Khumar (12)	7.7	0.8	28.0	105.0	276.0	431.0
Bir Sunarwala (13)	7.4	3.3	290.0	1020.0	2020.0	2730.0
Sekhupur Jat (14)	7.3	0.3	21.0	180.0	230.0	359.0
Kablana (15)	7.6	0.2	80.0	520.0	240.0	375.0
Dulhera (16)	7.5	0.9	2230.0	2030.0	2810.0	4120.0
Daboda Khurd (17)	7.3	1.3	270.0	320.0	240.0	375.0
Birdhana (18)	8.1	1.7	165.0	230.0	635.0	784.0
Baghpur (19)	7.3	1.4	55.0	140.0	110.0	172.0
Sikanderpur (20)	7.7	0.8	42.0	120.0	318.0	497.0
Average	7.6	1.1	214.2	360.4	605.1	832.5

Reference: National Rural Drinking Water Programme, Ministry of Drinking Water and Sanitation, Government of India.
[a] Calculated.

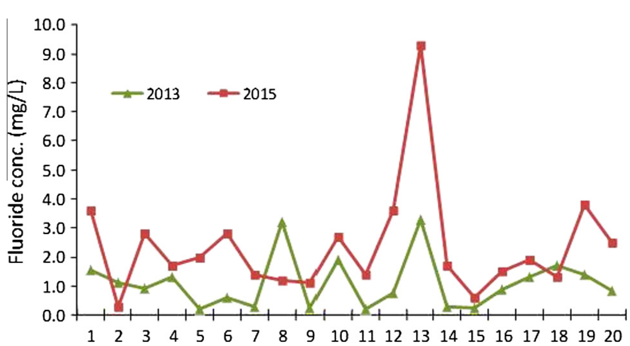

Figure 3a Fluoride concentration.

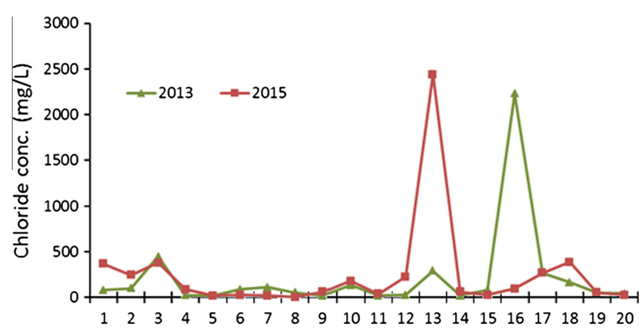

Figure 3b Chloride concentration.

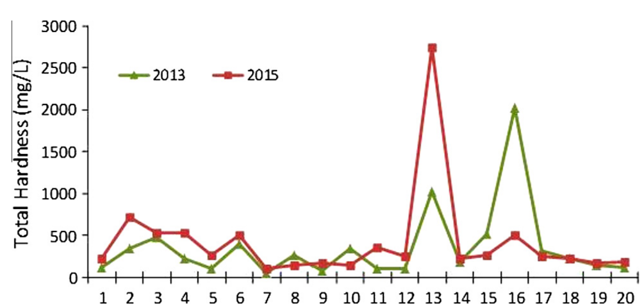

Figure 3c Total hardness.

The results obtained from primary research (Table 1) were compared and verified with studies carried out by National Rural Drinking Water Programme under the Ministry of Drinking Water and Sanitation for years 2013–14, 2014–15 and [9]. The data were taken only for those sites/villages (Table 2) which are most proximate to the sites sampled during 2015.

Study of groundwater quality data measured in 2015 (Table 1) and 2013 (Table 2) shows that there is escalation of contaminants in groundwater of Jhajjar district. Most of the samples analysed in 2015 were found above the level evaluated in previous years. Figs. 3a–3e show the change in concentration for the years 2013 and 2015. A significant level of increase in concentration has been seen for all the samples.

The escalation in groundwater for fluoride and salinity is geogenic, as most of the subsurface lithological formations are rich in fluorine and other salts and their weathering is increasing the fluoride and salinity in the groundwater. This could be one of the major reasons for the continuous increase in fluoride levels in aquifers of study area.

Since the quality of groundwater is not found satisfactory in the preliminary sampling as per the BIS standards, the groundwater quality index (GWQI) was determined to evaluate the overall quality of groundwater for the sampled sites.

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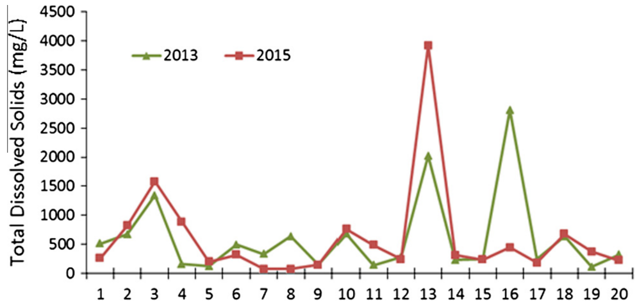

Figure 3d Total dissolved solids.

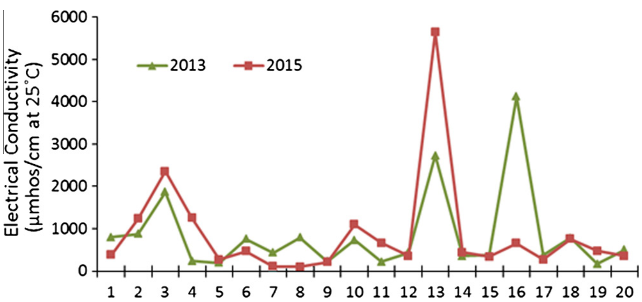

Figure 3e Electrical conductivity.

Table 3 Groundwater Quality (GWQ) scale for drinking water.

Water quality scale	Quality of groundwater
0–25	Excellent
26–50	Good
51–75	Poor
76–100	Very poor
100 and above	Unsuitable to drink

The GWQ scale used for in this study is given in Table 3. This scale has been used by several researchers for evaluating the groundwater quality for drinking purpose [13,1,31,2].

The result for GWQI is presented in Table 4. Out of the total samples collected from the district, one sample S-15 was extremely high for all parameters and it may bias the results of GWQI. Therefore in Table 4, the index was calculated as case 1 and case 2, where the case 1 means the GWQI for all the 20 samples and case 2 refers GWQI excluding results of sample no. 15.

As per the weighted arithmetic index method, the score obtained is 189 in Case 1 and 125 in Case 2, i.e. in both the cases, score is more than 100; therefore, as per the GWQ scale used in the study, the quality of water is unsuitable for drinking purpose.

The findings suggest that the cause of groundwater contamination in Jhajjar district is geogenic in nature. The district is comprised of Indo Gangetic alluvial plains. The geomorphology of Jhajjar district is featured with upper plain of old alluvium deposits spreading in north, north-east and north-central parts of the district, whereas the south and south-west part of the district has Aeolian sandy cover with some sand dunes. The geomorphology map of Jhajjar district (Fig. 2) also supports the hydrogeological conditions that can lead to the escalation of fluoride and salinity in the groundwater.

4. Conclusion and recommendation

The overall outcome of the study illustrates that Jhajjar 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:

- Major source of fluoride and other salts in groundwater is the availability of salt rich geological formation in subsurface in Jhajjar district.
- 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.
- The groundwater quality is totally unsuitable for domestic purposes as Water Quality Index is more than 100 for the region.
- Long term intake of fluoride above the permissible limit in drinking water is causing dental fluorosis diseases in the study areas.
- There is variation in the groundwater quality in shallow and deep aquifers, which can be attributed to the poor hydraulic conductivity between the shallow and deep aquifer systems in the region.

Table 4 Results of water quality index for Jhajjar district.

Parameters	Quality rating		Standard value (Si)	Unit weight (Wi)	Factor	
	Case 1 (Qi 1)	Case 2 (Qi 2)			Case 1 (Qi 1* Wi)	Case 2 (Qi 2* Wi)
pH	11.2	11.8	8.5	0.118	1.32	1.39
Fluoride	221.3	145.6	1.5[a]	0.667	147.54	97.05
Chloride	85.0	38.2	250	0.004	0.34	0.15
Hardness	213.5	152.6	200	0.005	1.06	0.76
Total dissolved solids	122.2	87.3	500	0.002	0.24	0.17
Total				0.795	150.51	99.52

Water quality index for case 1 = $\sum$ Qi 1* Wi/$\sum$ Wi = 189.25
Water quality index for case 2 = $\sum$ Qi 2* Wi/$\sum$ Wi = 125.16

[a] For fluoride, maximum permissible value is used.

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To improve the groundwater quality in the region, following remedial measures are recommended:

- *Treatment of contaminated water*: There are several technologies available for treatment of contaminated water. For example, ex-situ techniques are used for salinity and fluoride reduction; adsorption using materials such as activated alumina, red mud, and mud pots, membrane technology and precipitation and coagulation processes. The famous coagulation techniques are Nakuru, Nalgonda and Electrocoagulation.
- *Dilution of contaminated water with in-situ treatment*: Dilution is one of the simplest and low cost methods of reducing the contaminants in groundwater aquifers. By implementing different artificial recharge and rainwater harvesting techniques dilution of contaminants is possible, and moreover it will also reduce the impact of geogenic factors.
- *Water Conservation and management training*: Water conservation and management techniques have been proved worthwhile in improving the groundwater quality and preventing the water table depletion. Training related to construction of recharge structures at home (rooftop harvesting, vertical and horizontal shaft) may help in escalating the groundwater recharge.

References

[1] A. Ambica, Ground water quality characteristics study by using water quality index in Tambaram area, Chennai, Tamil Nadu, Middle-East J. Sci. Res. 20 (11) (2014) 1396–1401.
[2] K.M. Anwar, V. Aggarwal, Analysis of groundwater quality of Aligarh city, (India): using water quality index, Curr. World Environ. 9 (3) (2014) 851–857.
[3] I.N. Balan, M. Shivakumar, P.D.M. Kumar, An assessment of ground water quality using water quality index in Chennai, Tamil Nadu, India, Chronicles Young Sci. 3 (2) (2012) 146–150.
[4] G.P. Bhargava, I.P. Abrol, B.S. Kapoor, S.C. Goswami, Characteristics and genesis of some sodic soils in the Indo-Gangetic alluvial plains of Haryana and Uttar Pradesh, J. Indian Soc. Soil Sci. 29 (1) (1981) 61–70.
[5] R.M. Brown, N.J. McCleiland, R.A. Deininger, M.F. O'Connor, A water quality index – crossing the psychological barrier, in: S.H. Jenkis (Ed.), Proceeding International Conference on Water Pollution Research, Jerusalem, vol. 6, 1972, pp. 787–797.
[6] Bureau of Indian Standards: Drinking Water Specification (Second Revision), IS 10500, 2012.
[7] Census of India, 2011.
[8] Central Ground Water Board: Dynamic Ground Water Resources of India, March 2011.
[9] Central Ground Water Board: Concept Note on Geogenic Contamination of Groundwater in India, 2014.
[10] Central Ground Water Board: Ground Water Quality in Shallow Aquifers of India, 2010.
[11] CGWB, Ground Water Report "Jhajjar District, Haryana" Central Ground Water Borad, Ministry of Water Resources, Government of India, North Western Region, Chandigarh, 2007.
[12] N.K. Dhakad, D. Shinde, P. Choudhary, Water quality index of ground water (GWQI) of Jhabua town, M.P. (India), J. Environ. Res. Dev. 2 (3) (2008) 443–446.
[13] R.M. Chowdhury, S.Y. Muntasir, M.M. Hossain, Water quality index of water bodies along Faridpur-Barisal road in Bangladesh, Glob. Eng. Tech. Rev. 2 (3) (2012) 1–8.
[14] Geological Survey of India: Geology and Mineral Resources of Haryana, Publication No. 30: Part – XVIII (Second Revised Edition), 2012.
[15] Gulab, Impact of water logging and salinity on agriculture and socio-economic status in Rohtak and Jhajjar district, Int. J. Res. Appl. Sci. Eng. Technol. 2 (4) (2014) 491–497.
[16] B.S. Kapoor, H.B. Singh, S.C. Goswami, I.P. Abrol, G.P. Bhargava, D.K. Pal, Weathering of micaceous minerals in some salt affected soils, J. Indian Soc. Soil Sci. 29 (1981) 286–492.
[17] R. Kumar, Role of Himalayan Orogeny in the formation of salt affected soils of the Indian sub-continent, in: Proceedings of 16th World Congress of Soil Science, held at Montpellier, 1998. August 20–26, Symposium: 15 Reg No: 277.
[18] R. Kumar, S.K. Ghabru, R.L. Ahuja, N.T. Singh, H.S. Jassal, Clay minerals in the alkali soils of Ghaggar river basin of Satluj–Yamuna divide in North-West, Clay Res 12 (1993) 43–51.
[19] R. Kumar, S.K. Ghabru, R.L. Ahuja, N.T. Singh, H.S. Jassal, Elemental and mineralogical composition of the coarse fraction of the normal and alkali soils of the Satluj-Yamuna divide of North-West India, Clay Res 14 (1995) 29–48.
[20] Preparation of Sub-Regional Plan of Haryana Sub-Region of NCR-2021, Interim report-1.
[21] A.K. Misra, Influence of stone quarries on groundwater quality and health in Fatehpur Sikri, India, Int. J. Sustain. Built Environ. 2 (1) (2013) 73–88.
[22] A.K. Misra, A. Mishra, Escalation of salinity levels in Quaternary Aquifers of Ganga alluvial Plain, India, Environ. Geol. 53 (1) (2007) 47–56.
[23] A.K. Misra, A. Mishra, Groundwater quality monitoring in shallow and deep aquifers in Saidabad tahsil area, Mathura district, India, Environ. Monit. Assess. 117 (2006) 345–355.
[24] F.M. Al-Mohammed, A.A. Mutasher, Application of water quality index for evaluation of groundwater quality for drinking purpose in Dibdiba aquifer, Kerbala city, Iraq, J. Babylon Univ./Eng. Sci. 21 (5) (2013) 1647–1660.
[25] Proceedings of International Workshop on Mitigating Effects of Geogenic Contaminants, CSIR-NEERI, Nagpur, 2012.
[26] C. Sarala, P. Ravi Babu, Assessment of groundwater quality parameters in and around Jawahar Nagar, Hyderabad, Int. J. Sci. Res. Publ. 2 (10) (2012).
[27] T. Shiao, A. Maddocks, C. Carson, E. Loizeaux, 3 Maps Explain India's Growing Water Risks. <http://www.wri.org/blog/2015/02/3-maps-explain-india%E2%80%99s-growing-water-risks> (26 February 2015).
[28] D. Shinde, U. Ningwal, Water quality index for ground water (GWQI) of Dhar town, MP, India, Int. Res. J. Environ. Sci. 2 (11) (2013) 72–77.
[29] B. Singh, V.K. Garg, Fluoride quantification in groundwater of rural habitations of Faridabad, Haryana, India, Int. J. Environ. Prot. 2 (10) (2012) 8–17.
[30] P. Singh, A.K. Tiwari, P.K. Singh, Assessment of groundwater quality of Ranchi township area, Jharkhand, India by using water quality index method, Int. J. ChemTech Res. 7 (1) (2015) 73–79.
[31] S. Tyagi, P. Singh, B. Sharma, R. Singh, Assessment of water quality for drinking purpose in district Pauri of Uttarakhand, India, Appl. Ecol. Environ. Sci. 2 (4) (2014) 94–99.
[32] www.indiawater.gov.in/imisreports/nrdwpmain.aspx, Website of Ministry of Drinking Water and Sanitation.
[33] J.P. Yadav, S. Lata, Urinary fluoride levels and prevalence of dental fluorosis in children of Jhajjar district, Haryana, Indian J. Med. Sci. 57 (9) (2003) 394–399.
[34] J.P. Yadav, S. Lata, S.K. Kataria, S. Kumar, Fluoride distribution in groundwater and survey of dental fluorosis among school children in the villages of the Jhajjar District of Haryana, India, Environ. Geochem. Health 31 (4) (2009) 431–438.

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