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Groundwater Contamination in Punjab Due to High Levels of Nitrate (NO_3^-) and Its Health Hazards: A Preliminary Report

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Abstract

Punjab is facing a crisis due to high levels of heavy metals and nitrate concentration in groundwater of several districts of Punjab. The highest level of NO_3 content of 2553 mg/l has been recorded in two villages of Patiala district. The concentration of NO_3 in groundwater of seven districts of Punjab has been studied. The maximum content values range from 78.20 in Pathankot to 2553 mg/l in Patiala district, which are much higher than the permissible limit allowed by Bureau of Indian Standards (45 mg/l) and World Health Organization (50 mg/l). The source of NO_3 in groundwater includes both geogenic and anthropogenic sources. Consumption of water with high NO_3 content can pose serious health hazard among the children (<5 years). The non-carcinogenic health risks of high NO_3 intake have been estimated using US-EPA model for both adults and children. The analysis presented in this study is based on Water Supply and Sanitation Department (DWSS) data collected in three phases during 2009 to 2016 and compiled and analyzed in April 2016 using Ion Chromatography and Spectrophotometer in DWSS Laboratory in SAS Nagar (Mohali), India.

Keywords: Groundwater, nitrate, daily intake, health hazards, hazard quotient

INTRODUCTION

The groundwater is a precious source of water for industrial and agricultural activities in the modern era of human development. Nonetheless, in developing countries, it is considered a significant source of drinking and potable water for rural as well urban populations. But continuous anthropogenic activities and industrial revolution in the past few decades had posed a severe threat on the quality and quantity of groundwater resources [1, 2].

Nitrate contaminant is found to be widespread in groundwater and surface water resources. Its occurrence in the hydrosphere is either due to the natural processes (atmospheric fixation, lightning storms) or by addition through anthropogenic activities (fertilizer applications, septic tanks) [3]. The groundwater contamination is contributed by various species like nitrate (NO_3), nitrite (NO_2), ammonia (NH_3) and organically bound forms of nitrogen (Org-N) [4]. The naturally occurring nitrate in groundwater shall not exceed 10 mg/l and the levels exceeding this natural limit are an indicator of nitrate contamination primarily through various anthropogenic activities [5]. There are two pathways in which nitrate may enter the human body, namely, endogenous and exogenous pathways, and its toxicity is attributed to nitrate reduction to nitrite in the oral cavity of human body

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[6]. The NO_3 in groundwater of India has been enlisted as an emerging parameter for groundwater safety and human health wellbeing.

Nitrate is considered as a harmless constituent of food and water in moderate amounts, hence a permissible limit of 50 mg/l as nitrate ion (or 11 mg/l as nitrate-nitrogen) in drinking water is specified by the World Health Organization (WHO) to protect against methemoglobinemia in bottle-fed babies [7]. The Environmental Protection Agency (EPA) has set the maximum contaminant level as 10 mg/l of nitrate as nitrogen in the United States [8], whereas in India, the acceptable limit set by the Bureau of Indian Standard (BIS) is 45 mg/l for nitrate in water [9]. It is assumed that ingestion of water having nitrate concentration up to 45 mg/l has no severe health impact in humans.

The State of Punjab adopted a chemical-based agriculture model to usher in the start of "Green Revolution" in India under the patronage of Punjab Agriculture University (PAU), Ludhiana during the early 1960s. The crop productivity in the state increased significantly with excessive application of a high dose of chemical fertilizers and pesticides in this area. Punjab is among the states using excessive chemical fertilizers in India, and the per hectare consumption is 243 kg/year, which is highest among other states in the country [10].

The Department of Water Supply and Sanitation (DWSS), Punjab is providing potable water to 14722 habitations through 8552 ground water and 917 canal-based water supply schemes [11]. The Department has formulated a monitoring protocol according to which all the ground water-based sources, i.e., tube-wells and hand-pumps are regularly being tested for basic chemical parameters, heavy metals including uranium once in a year whereas bacteriological parameters are tested twice in a year. Canal water generally does not contain chemical impurities. DWSS had formally hoisted the status of Annual Water Quality Report on Department's website in 2020. As on 1 April 2021, there are 1525 Quality Affected habitations in the State of Punjab (Figure 1), out of which 56 are marked for high levels of nitrate contamination.

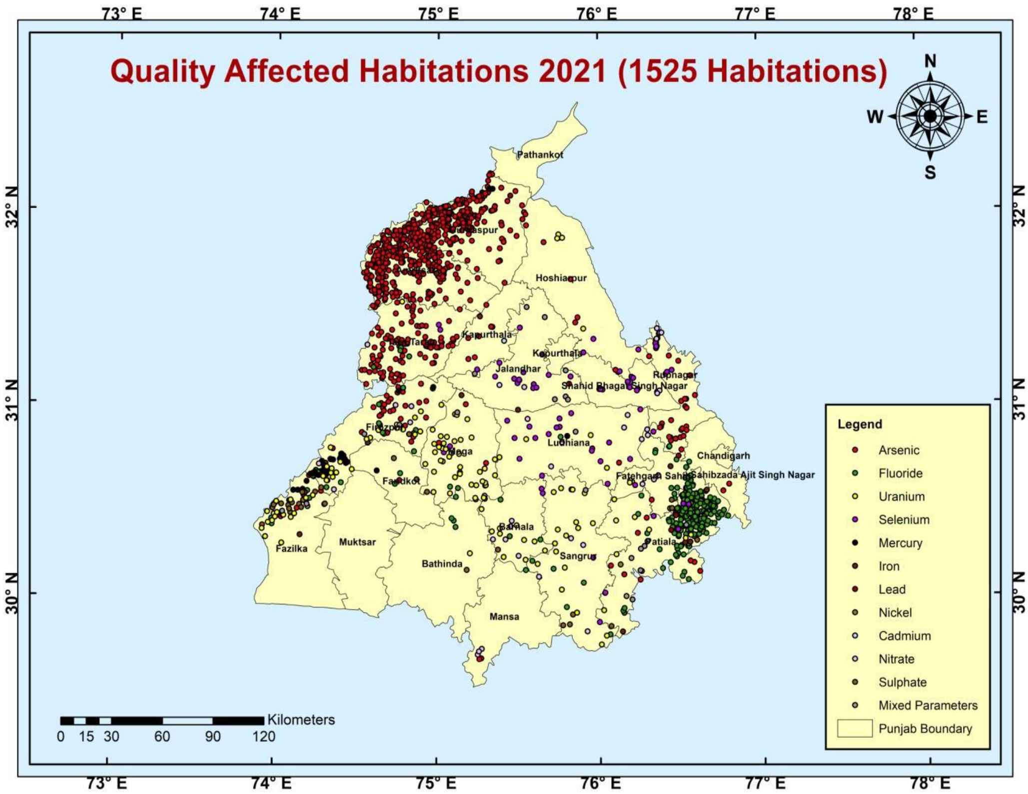

Figure 1. Groundwater quality affected habitations in Punjab listed for Mitigation.

Keeping in view the deteriorating water quality of ground water sources of Punjab, DWSS built its own State of Art Regional Advance Water Testing Laboratory at SAS Nagar in 2015 with sophisticated equipment, namely, Inductively Coupled Plasma Mass Spectrophotometer (ICP-MS) for Heavy Metals like Uranium and Arsenic and Ion Chromatograph (IC) for anions like Nitrate, Sulphate and Fluoride.

In this study, the author is presenting a comprehensive study of contamination of groundwater in the quality affected districts of Punjab due to presence of Nitrates in groundwater (Figure 2). The analysis presented in this study is based on DWSS data collected in three phases during 2009 to 2016 and compiled in April 2016 using Ion Chromatography and Spectrophotometer in DWSS Laboratory in SAS Nagar (Mohali).

MATERIALS AND METHODS

Punjab is situated in the northern part of India in between latitudes 29.30° North to 32.32° North and longitudes 73.55° East to 76.50° East. It is divided geographically into three regions, Malwa, Majha, and Doaba. The rivers Satluj and Beas are the primary freshwater sources in the region and form boundaries of three sub-regions. Punjab has common boundaries with the states of Himachal Pradesh and Haryana on the north and east, respectively, and Rajasthan in the south. Punjab also forms a common boundary with Pakistan on the western side.

The characteristics of soil affect the infiltration, percolation, and groundwater recharge capacity of the region. Higher recharge rate has higher groundwater contamination potential from surface contaminants. The groundwater level in various districts of Punjab is recorded beyond 60 mbgl (meter below ground level) [12]; this is due to the overexploitation in the absence of alternate sources. The groundwater level in Punjab has declined drastically in past few decades. Punjab faces a crisis due to high levels of groundwater contamination of heavy metals and nitrate.

SAMPLE COLLECTION AND ANALYSIS

Water samples were collected in 500 ml amber colored superior quality plastic bottles from the area of study by the field staff of DWSS. The cleaning of bottles was carried out by washing first with soap solution and then with distilled water. Next step was rinsing the bottles with deionized water and drying with a blower. Groundwater from the source was allowed to flow freely for 5–10 min before collection in plastic bottles. Samples were subject to filtration using the 0.2 µ filters on the spot. 2 ml of conc. HNO_3 was added to each sample and labelled using scotch tape. The samples were transported to Regional Testing Water Laboratory in SAS Nagar (Mohali) for storage on the same day. 100 ml of water sample was taken out from the bottle for testing and analysis of nitrate contamination of groundwater using state of the art instrumentation, for example, Ion Chromatography and Spectro-photograph [13]. The Merck-grade chemicals were used while preparing solvents and reagents/standards for all analytical works.

RESULTS AND DISCUSSION

In a recent study by Ahada and Suthar [14], groundwater nitrate contamination and its associated health risk assessment has been investigated in southern districts of Punjab falling in the Malwa belt. They estimated possible health hazards of high NO_3 intake using USEPA human health risk assessment model for both adult and children. Their study is confined to 14 districts of Malwa belt whereas our study covers seven districts spread over the whole of Punjab. They found hazard quotient ($HQ_{Nitrate}$) values >1 in most sampling locations of Malwa belt. Our results are in conformity with their study but our investigations show higher concentrations of nitrate in groundwater and, as a consequence, much higher values of hazard quotients for both adults and children.

Nitrate concentration in groundwater for seven districts, namely, Amritsar, Fazilka, Ferozepur, Patiala, Sangrur, Fatehgarh Sahib, and Pathankot has been investigated using data collected by field staff of DWSS (Figure 2). Representative data tables for only two districts, namely, Patiala and

Pathankot, have been included. Patiala district represents the highest contamination of Nitrates in groundwater (Table 1). It has 10 villages with nitrate content in the range of 642.20 to 2553 mg/l, which shows that the maximum nitrate content is 57 times the permissible limit allowed by BIS. Pathankot district with 87 habitations having nitrate content in the range 10.10 to 78.20 mg/l shows minimum statistical distribution as compared with other districts (Table 2). Amritsar district has highest number of villages (91) with groundwater Nitrate contamination in the range of 10.18 to 314.32 mg/l. An alarming situation exists in other five districts with nitrate content higher than the BIS permissible limit by an order of magnitude (Table 3). In our final report, we propose to study correlation of nitrate in groundwater with fluoride and other ions to develop a model for its spatial distribution in different regions of Punjab.

NON-CARCINOGENIC HEALTH RISK DUE TO INGESTION OF NITRATE

There are two routes for occupational exposure to nitrates, through inhalation and dermal contact. Industry workers employed in explosive and fertilizer factories may be exposed to nitrate through inhalation of dusts containing nitrate salts. For general public, considered under non-occupational category, the primary route of exposure is ingestion of water or foodstuffs that contain high levels of nitrates or nitrites. Inhalation exposures may also occur from use of some medicines consumed by inhaling or alternatively through dermal exposures if applied on the skin surface.

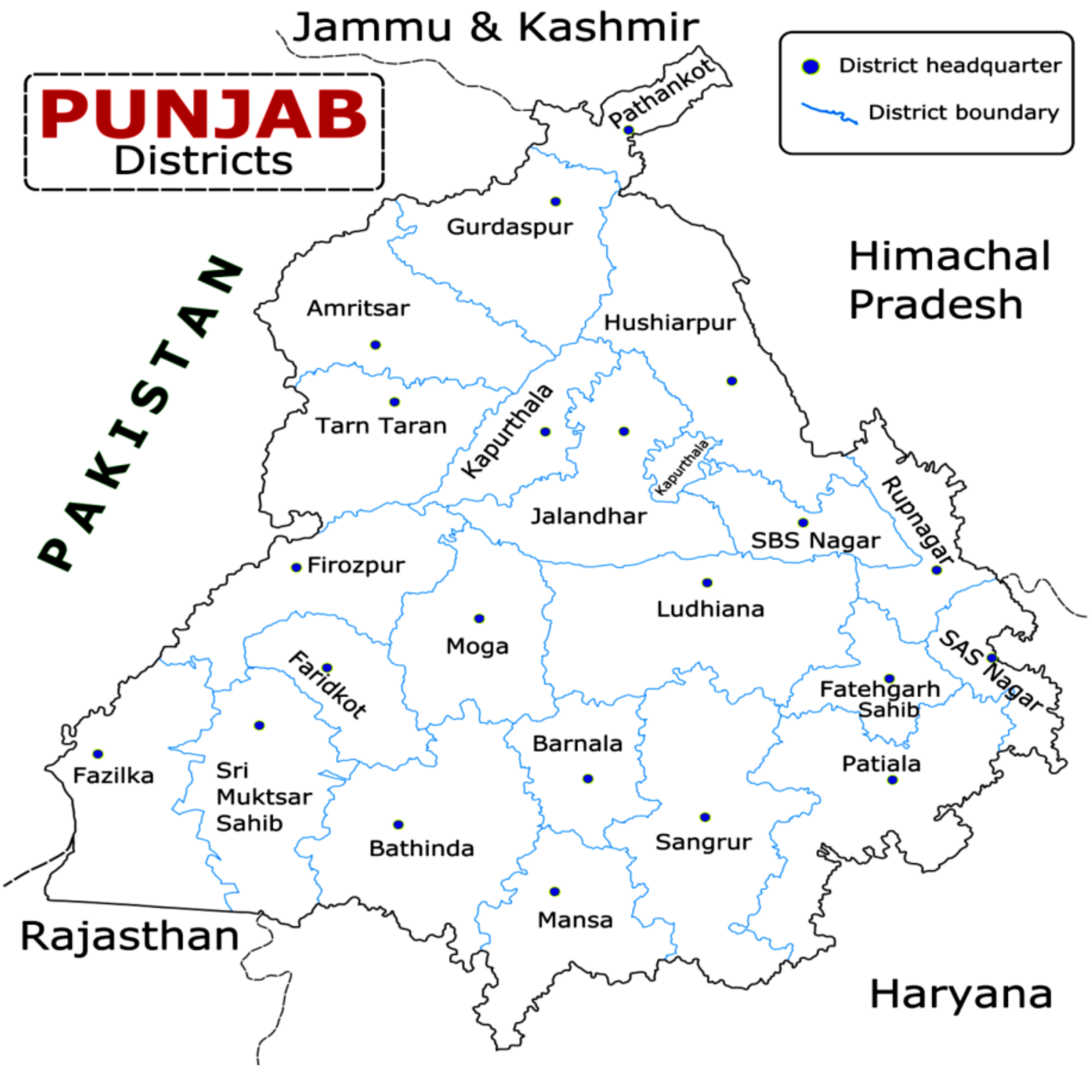

Figure 2. District Map of Punjab showing seven Districts (Amritsar, Fazilka, Ferozepur, Patiala, Sangrur, Fatehgarh Sahib, Pathankot) affected by high Nitrate contamination.

Table 1. Nitrate conc. in Groundwater (GW) of Patiala district.

S. No.	Villages Surveyed	Source of GW	Depth	Nitrate Conc. (mg/l)	DWSS Project
1	Sukhewal	Null	Null	2553.00	Phase 3
2	Bhilowal	Null	Null	2553.00	Phase 3
3	Kauli	Null	Null	2380.00	Phase 3
4	Chalaila	Null	Null	2160.00	Phase 3
5	Aman Vihar	Null	Null	2051.00	
6	Jassowal	Null	Null	1942.00	Phase 3
7	Jassowal	Null	Null	1942.00	Phase 3
8	Jagatpura	Null	Null	1876.00	Phase 3
9	Ranibpura	Null	Null	1672.00	Phase 3
10	Babarpur	Null	Null	642.20	Phase 3
11	Dera Rajputan	Handpump	Null	87.76	Phase 2
12	Jhansla	Tubewell	Null	78.57	Phase 3
13	Fatehpur Garhi	Tubewell	Null	78.57	Phase 3
14	Jai Nagar & Basti Amirpur	Null	Null	78.44	Phase 3
15	Safdarpur	Null	Null	78.44	Phase 3
16	Shergarh	Handpump	90 Mtr	34.63	Phase 2
17	Kheri Gandian	Tubewell	270 Mtr	18.80	Phase 2
18	Chatar Nagar	Null	Null	18.59	Phase 3
19	Dera Xen Retd.	Tubewell	150 Mtr	16.83	Phase 2
20	Chunagra	Tubewell	150 Mtr	16.83	Phase 2
21	Faridpur	Tubewell	Null	13.64	Phase 3
22	Rawas Brahmna	Tubewell	145 Mtr	13.00	Phase 2
23	Nalas Kalan	Tubewell	Null	12.01	Phase 3
24	Jhandi	Tubewell	200 Mtr	11.80	Phase 2
25	Faridpur	Tubewell	Null	11.78	Phase 2
26	Alampur	Hand pump	70 Mtr	11.50	Phase 2

Table 2. Nitrate conc. in Groundwater (GW) of Pathankot District.

S. No.	Villages Surveyed	Source of GW	Nitrate conc. (mg/l)	DWSS Project
1	Taragarh	Tubewell	78.20	Phase 2
2	Gugaran	Tubewell	72.40	Phase 2
3	Malarwan	Tubewell	72.40	Phase 2
4	Lahri	New Scheme	32.30	Phase 2
5	Gotran Lahri	Tubewell	25.90	Phase 2
6	Balawar	Tubewell	23.60	Phase 2
7	Taloor	Tubewell	21.70	Phase 2
8	Man Singhpur	Tubewell	21.70	Phase 2
9	Taloor Chhota	Tubewell	21.70	Phase 2
10	Narot Mehra	Tubewell	20.60	Phase 2
11	Chack Dhariwal	Tubewell	20.60	Phase 2
12	Farwal	Tubewell	20.60	Phase 2
13	Dera Baba Basant puri	Tubewell	20.60	Phase 2
14	Jammu Kiliary	Tubewell	18.10	Phase 2
15	Saili Bholi	Tubewell	18.10	Phase 2
16	Kailashpur	Tubewell	18.10	Phase 2
17	Nangal	Tubewell	17.80	Phase 2

S. No.	Villages Surveyed	Source of GW	Nitrate conc. (mg/l)	DWSS Project
18	Bhur	Tubewell	17.80	Phase 2
19	Chak Bhattian	Tubewell	17.80	Phase 2
20	Ghiala	Improvement	17.80	Phase 2
21	Chak Bharaian	Tubewell	17.40	Phase 2
22	Talwara Gujran	Tubewell	17.20	Phase 2
23	Beli Changan	Tubewell	17.20	Phase 2
24	Talwara Jatta	Tubewell	17.20	Phase 2
25	Mirzapur	Tubewell	16.10	Phase 2
26	Sarna	Tubewell	15.50	Phase 2
27	Jamalpur	Tubewell	15.50	Phase 2
28	Behlolpur	Tubewell	15.50	Phase 2
29	Abadie Sarna Nehar	Tubewell	15.50	Phase 2
30	Tirhari	Tubewell	15.30	Phase 2
31	Harijan Abadi Shahapur Kandi	Tubewell	15.30	Phase 2
32	Turhaty	Tubewell	15.30	Phase 2
33	Shahpur Kandi	Tubewell	15.30	Phase 2
34	Tikka Doong	Tubewell	14.40	Phase 2
35	Tilla Matti	Tubewell	14.40	Phase 2
36	Gura Kalan	Tubewell	13.80	Phase 2
37	Gandlan Lahri	Tubewell	13.80	Phase 2
38	Kale Chak	Tubewell	13.80	Phase 2
39	Moh. Mudde	Tubewell	13.80	Phase 2
40	Farakhpur	Tubewell	13.80	Phase 2
41	Nihalpur	Tubewell	13.40	Phase 2
42	Kahanpur	Tubewell	13.40	Phase 2
43	Jhanjeli	Tubewell	13.40	Phase 2
44	Haler	Tubewell	13.40	Phase 2
45	Gulpur	Tubewell	13.00	Phase 2
46	Abadgarh	Tubewell	12.60	Phase 2
47	Jaini Khalki	Tubewell	12.40	Phase 2
48	Man Nagal	Tubewell	12.20	Phase 2
49	Saraf Chak	Tubewell	12.20	Phase 2
50	Bhatoa	Tubewell	12.20	Phase 2
51	Nangal Farida	Tubewell	12.20	Phase 2
52	Baroonpur	Tubewell	12.20	Phase 2
53	Padian Lahri	Tubewell	12.00	Phase 2
54	Gosaipur	Tubewell	12.00	Phase 2
55	Tharyal	Tubewell	11.70	Phase 2
56	Mutfarka	Tubewell	11.70	Phase 2
57	Gura Khurad	Tubewell	11.70	Phase 2
58	Datyal	Tubewell	11.60	Phase 2
59	Madhopur Cantt	Tubewell	11.50	Phase 2
60	Bhoa	Tubewell	11.20	Phase 2
61	Targarh	Tubewell	11.20	Phase 2
62	Gobindsar	Tubewell	11.20	Phase 2
63	Sultanpur	Tubewell	11.20	Phase 2
64	Budhi Nagar	Tubewell	11.00	Phase 2

S. No.	Villages Surveyed	Source of GW	Nitrate conc. (mg/l)	DWSS Project
65	Bahadur Lahri	Tubewell	11.00	Phase 2
66	Maira Kalan	Handpump	10.90	Phase 2
67	Basroop	Tubewell	10.80	Phase 2
68	Bhadrali	Tubewell	10.80	Phase 2
69	Seonti old	Tubewell	10.70	Phase 3
70	Harizan Abadie	Tubewell	10.60	Phase 2
71	Lahri Brahmna	Tubewell	10.60	Phase 2
72	Napwal	Tubewell	10.60	Phase 2
73	Ghandran	Tubewell	10.60	Phase 2
74	Chak Chimna	Tubewell	10.60	Phase 2
75	Dhaki Saida	Tubewell	10.60	Phase 2
76	Darsopur	Tubewell	10.60	Phase 2
77	Aiman Changa	Tubewell	10.60	Phase 2
78	Lahri	Tubewell	10.60	Phase 2
79	Najo Chak	Tubewell	10.60	Phase 2
80	Lahri Sarmo	Improvement	10.40	Phase 2
81	Jaswal Lahri	Tubewell	10.30	Phase 2
82	Chak Paswal	Tubewell	10.30	Phase 2
83	Aima Gujjran	Tubewell	10.30	Phase 2
84	Samrala	Tubewell	10.30	Phase 2
85	Rajparura	Tubewell	10.30	Phase 2
86	Sukalgarh	Tubewell	10.30	Phase 2
87	Bharoli Khurd	Tubewell	10.10	Phase 2

Table 3. Nitrate Conc. in Groundwater and Hazard Quotients for Population of Punjab.

S. No.	Name of District	Nitrate Conc. (mg/l)	Chronic Daily Intake (CDI)		Hazard Quotient $HQ_{Nitrate}$	
			Adult	Children	Adult	Children
1	Amritsar	314.32	8.98	20.95	5.61	13.10
2	Fazilka	130.95	3.74	8.73	2.39	5.46
3	Ferozepur	152.92	4.37	10.19	2.73	6.37
4	Patiala	2553	72.94	170.20	45.59	106.38
5	Sangrur	211.79	6.05	14.12	3.78	8.82
6	Fatehgarh Sahib	184.00	5.26	12.27	3.29	7.67
7	Pathankot	78.20	2.23	8.34	1.40	5.21

The ingestion of contaminated groundwater can adversely affect the health of humans through varieties of exposures including direct ingestion, drinking water, dermal contact, washing, etc. [15]. The excess intake of NO_3 through drinking water can cause serious health hazards in human beings. To estimate the health hazards of high NO_3 dose in drinking water, the USEPA model was adopted. The exposure of NO_3 through ingestion with drinking water is calculated by following Eq. (1) [15, 16]:

$$CDI=C\times IR\times EF\times ED/BW\times AT \qquad (1)$$

Where, CDI (chronic daily intake) is the ingestion dose from drinking water (mg/kg/day), C is the concentration of NO_3 estimated in groundwater samples ($mg.l^{-1}$), IR is the average daily ingestion rate of drinking water (l/day), and the values of IR (2 l/day for adult and 1 l/day for children) were used for this model; EF is the exposure frequency (365 days/year), ED is the exposure duration (standard exposure duration in literature is suggested 30 years for adult and 12 years for children), BW is the body weight (70 kg for adult and 15 kg for children), and AT is the average exposure time which is 10,950 days (30 years) for adults and 4380 days (12 years) for children.

The present study focuses on the non-carcinogenic health risk of NO_3 mainly estimated by the hazard quotient ($HQ_{Nitrate}$) values, which is estimated through following Eq. (2) [17]:

$$HQ_{Nitrate}=CDI/RfD \tag{2}$$

Where, RfD is reference dose (1.6 mg/kg/day) for noncarcinogenic health risk [18]. The calculation of $HQ_{Nitrate}>1$ potentially known to cause health risks and values of $HQ_{Nitrate}<1$ is an acceptable level of noncarcinogenic risk in individuals due to ingestion of NO_3 contaminated groundwater.

The maximum concentration of nitrate in groundwater of seven districts has been summarized in Table 3. It shows a variation in the range of 78.20 to 2553 mg/l. Using Eq. (1), chronic daily intake values for both adults and children (<5 years) have been calculated. CDI values range from 2.23 to 72.94 mg/l for adults and 8.34 to 170.20 mg/l for children of Punjab. To calculate health hazards of nitrate, we take recourse to USEPA Model parameter Hazard Quotient as defined in Eq. (2) above.

Table 3 lists the $HQ_{Nitrate}$ values corresponding to maximum concentration of Nitrate in groundwater of seven districts of Punjab. The range of $HQ_{Nitrate}$ for adults shows a variation of 1.4 to 45.59 while this variation ranges from 5.21 to 106.38 for children. $HQ_{Nitrate}$ values have been found significantly higher than 1 in most of the habitations studied both for adults and children. The HQ values cross the limit of a century in Patiala district which must set the alarm bell ringing for the safety of children and youth of this district. BIS permissible limit set at 45 mg/l is safe for adults but not for the children. HQ values for adults and children corresponding to this limit are 0.8 and 3.0, respectively.

The ingestion of water with high NO_3 content can cause various health issues in affected population, for example, methemoglobinemia, neural effects, gastric and respiratory problems, etc. Infants (<6 months) compared to children are always at greater risk for NO_3 toxicity mainly due to their smaller body weight and lower metabolic activities [2]. Some studies have shown that there is a link between the large intake of nitrate and thyroid dysfunction, gastrointestinal cancer [19]. A study showed that women who used high nitrate drinking water in two states in the United States, had offspring with birth defects [20].

There is an urgent need to undertake epidemiological investigation of population affected by high nitrate levels in groundwater of Patiala and other districts.

CONCLUSION

1. Patiala District is found to be a ‘hot spot’ of nitrate contamination of groundwater.
2. Hazard Quotients for ingestion of nitrate contaminated groundwater is >1 for both adults and children in all the districts referred to in this study.
3. Correlation of nitrate with fluoride and other ionic contaminants is under investigation.

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