STM JOURNALS

Research & Reviews: A Journal of Toxicology
ISSN: 2231-3834(Online), ISSN: 2349-1264(Print)
Volume 9, Issue 3
www.stmjournals.com

Groundwater Contamination due to Heavy Metals and other Pollutants in Amritsar District of Punjab

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Abstract
Punjab is facing a crisis situation due to high levels of uranium (U) and heavy metals in underground water table of Punjab. Department of Water Supply and Sanitation (DWSS), Punjab report on water quality monitoring and mitigation presents a deplorable situation about the current water quality scenario in Punjab. Out of total 874 habitations covered under this survey, 378 are found to be quality affected due to high contamination of arsenic, iron, aluminium, magnesium, nitrates and other basic parameters. Arsenic contamination dominates the scenario in Amritsar district with iron at number two in the list of heavy metal contaminants of groundwater. In addition to arsenic and iron, aluminium, magnesium, nitrate and fluoride are other pollutants of groundwater found above the permissible limits. The present report is based on the data collected by the Punjab Water Supply and Sanitation Department (PWSSD), Mohali, Punjab, India. Inductively coupled plasma mass spectroscopy (ICPMS) has been used to measure the heavy metal contents of the ground water samples of Amritsar district of Punjab (India).

Keywords: *Groundwater, heavy metals, World Health Organization, acceptable limit, fluoride, nitrate*

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INTRODUCTION
Heavy metals, namely, arsenic (As), cadmium (Cd), zinc (Zn), copper (Cu), nickel (Ni), Lead (Pb), mercury (Hg), iron (Fe), selenium (Se), and chromium (Cr) are detected in high concentrations in mine drainage waters and in industrial wastewaters, which originate from metal plating, mining activities, smelting, battery manufacturing, tanneries, petroleum refining, paint manufacturing, pesticides, pigment manufacturing, printing, photographic industries, etc. [1, 2]. Groundwater can be contaminated either geogenically or anthropogenically with the heavy metals such as As, Cd, Hg, Fe, Pb, and Se, etc. [3]. Nowadays, pollution due to heavy metal contaminants is one of the most important environmental concerns due to their high toxicities and adverse impacts on human health. According to the report published by the World Health Organization (WHO) [4], drinking of contaminated water is responsible for 80% of all the diseases and deaths in the developing countries. Drinking water with a high concentration of heavy metals has the potential of causing critical diseases such as cancer [5].

Punjab is facing a crisis situation due to heavy metals contamination in the underground water table and recent reports concerning high toxicity of heavy metals in the groundwater of Punjab are alarming. The report concludes that toxic metals have poisoned the subsoil groundwater in Punjab to an extent that cancer and heart diseases among adults are rampant. The report published on February 7, 2018 states that Punjab accounts for 88 percent of total habitations (villages or cluster of houses) in India that are adversely affected with the presence of heavy metals in groundwater [6–8].

Punjab Water Supply and Sanitation Department (PWSSD) has collected groundwater samples from more than 50% habitations of Punjab and analysed it for heavy metal contamination in its sophisticated laboratory set up in Mohali (Punjab), using state of art instrumentation including ICPMS (inductively coupled plasma mass spectrometry) and ion chromatography mass spectrometry (IC-MS) [9]. PWSSD Report presented an analysis of groundwater collected from 15384 homes with heavy metal contamination found in 2080 habitations. The analysis presented in this paper is also based on PWSSD data collected in three phases during 2009 to 2016 and compiled in April 2016 [10].

WORLD HEALTH ORGANIZATION GUIDELINES AND INDIAN STANDARDS FOR WATER

The primary aim of the WHO guidelines for drinking water quality (GDWQ) is the protection of public health. After a series of expert meetings held in Geneva during 1956, International Standards for Drinking-Water were first published in 1958. The International Standards for Drinking-Water were revised in 1963, 1971 and 1984. This process continued and more revisions were carried out in 1993, 1995, 2004 and 2011. We have adopted 1993 edition of GDWQ for this study [11].

These guidelines were prepared to be used as a basis for the development of national standards that will ensure the safety of drinking water supplies through the process of elimination, or reduction of constituents in drinking water that are known to be hazardous to health to a bare minimum level. The guideline values recommended are not mandatory limits but can be adopted for use in the development of risk management strategies based on national or regional standards in the context of local or national environmental, social, economic and cultural conditions.

The Bureau of Indian Standards (BIS) has adopted WHO Guidelines and Standards for most of the heavy metals under the heading "General Parameters Concerning Substances Undesirable in Excessive Amounts (Table 1)" [12]. It includes all metals listed in PWSSD analysis except Arsenic.

THE STUDY AREA

Location

Amritsar district [13] is located in northern part of Punjab state and lies between 31°28′30″ to 32°03′15" north latitude and 74°29′3″ to 75°24′15″ east longitude (Figure 1). Total area of the district is 2647 sq km. Upper Bari Doab is the major canal in the area which gives rise to the various branches as Lahore branch, Kasur branch, etc. Gurdaspur and Tarn Taran are adjoining districts of Amritsar. In fact, Tarn Taran is recently carved out of Amritsar district.

Geomorphology and Soil Types

Amritsar district [13] area is occupied by Indo-Gangatic alluvium. Amritsar district falls in between Ravi River and Beas River. Ravi River flows in north-west of the district and forms international border with Pakistan. Beas River flows in the eastern part of the district. Soils in the western part of the district are coarse loamy, calcareous soils, where as in the central part of the district soils are fine loamy, calcareous and are well drained.

DISCUSSION OF RESULTS

Aluminium Contamination

Aluminium is the most abundant metallic element and constitutes about 8% of Earth's crust. It occurs naturally in the environment as silicates, oxides and hydroxides, combined with other elements, such as sodium and fluoride, and as complexes with organic matter [14].

The concentration of aluminium in natural waters can vary significantly depending on various physicochemical and mineralogical factors. Dissolved aluminium concentrations in waters with near-neutral pH values usually range from 0.001 to 0.05 mg/l but rise to 0.5–1 mg/l in more acidic waters or water rich in organic matter. At the extreme acidity of waters affected by acid mine drainage, dissolved aluminium concentrations of up to 90 mg/l have been measured [15].

At an average adult intake of aluminium from food of 5 mg/day and a drinking water aluminium concentration of 0.1 mg/l, the contribution of drinking water to the total oral exposure to aluminium will be about 4%. Aluminium can form complexes with deoxyribonucleic acid (DNA) and cross-link chromosomal proteins and DNA, but it has not been shown to be mutagenic in bacteria or induce mutation or transformation in mammalian cells in vitro. There is no indication that aluminium is carcinogenic.

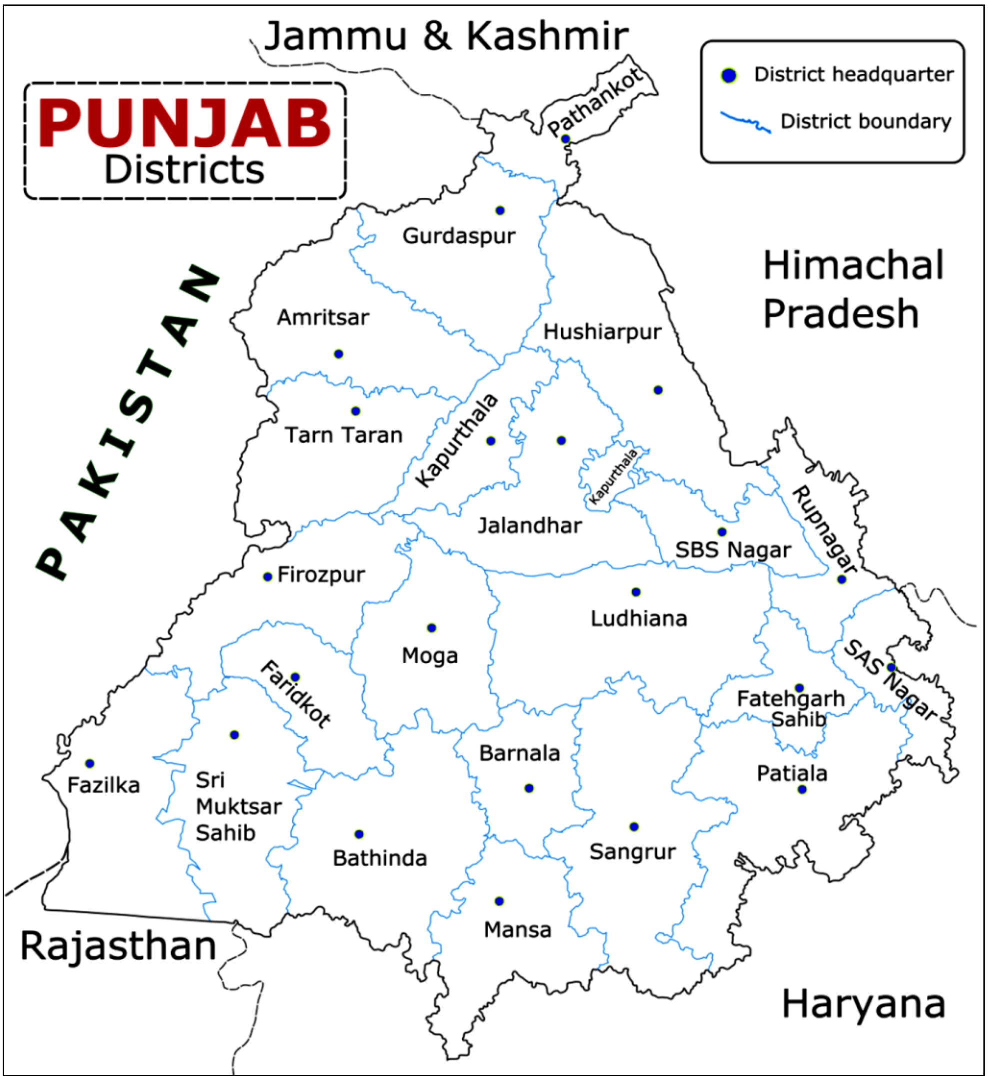

Fig. 1: *District Map of Punjab Showing District of Amritsar.*

There is little indication that aluminium is acutely toxic by oral exposure despite its widespread occurrence in foods, drinking water and many antacid preparations. On the whole, the positive relationship between aluminium in drinking water and AD (Alzheimer disease), which was demonstrated in several epidemiological studies, cannot be totally dismissed. The findings of Virk and Eslick [16] demonstrate that aluminium levels are significantly elevated in brain, serum, and CSF of patients with AD. These findings suggest that elevated aluminium levels, particularly in serum, may serve as an early marker of AD and/or play a role in the development of the disease. These results substantially clarify the existing evidence examining the link between chronic aluminium exposure and the development of AD.

Aluminium content values are listed in Table 2 ranging from 2.795 to 0.193 mg/l. There are more than 100 habitations in Amritsar district with aluminium values higher than the acceptable limit of 0.03 mg/l. We have listed 47 villages in Table 1 with values equal or more than the permissible limit of 0.2 mg/l [12]. In its 2010 assessment of aluminium in drinking water, the WHO has calculated a non-regulatory health-based value of 0.9 mg/l but has highlighted the importance of not exceeding the practicable levels of 0.1–0.2 mg/l [17]. Canada has proposed a maximum acceptable concentration (MAC) of 2.9 mg/l for total aluminium in drinking water. An operational guidance (OG) value of 0.050 mg/l is proposed for total aluminium to optimize water treatment and distribution systems [18].

Table 1: *Iron Contamination (>2 mg/l) of Groundwater in Amritsar District Acceptable limit 1.0 mg/l (ppm).*

Sr. No.	Villages Surveyed	Source of Groundwater	Depth (m)	Iron (mg/l)
1	Bagrian	Handpump	80	14.585
2	Abadi Guru Nanakpura	Handpump	80	10.150
3	Gaziwal Miani	Handpump	80	9.500
4	Nassoke	Handpump	NULL	9.390
5	Shahzada	Handpump	NULL	9.390
6	Gaggar	Handpump	NULL	9.390
7	Abadi Bathungarh	Handpump	132	6.887
8	Bandala	Tubewell	122	6.341
9	Butt	Tubewell	122	6.341
10	Abadi Bachan Singh Wala	Handpump	80	5.750
11	Abadi Bhagwan Sar	Handpump	80	5.750
12	Abadi Sukhe Wala	Handpump	80	5.750
13	Khasi	Handpump	80	5.700
14	Nanoke	Handpump	NULL	5.570
15	Harar Near Bhure Gill	Handpump	240	5.337
16	Rakh Nag	Handpump	80	5.180
17	Wadha Chack	Handpump	122	5.024
18	Padiana	Handpump	80	5.000
19	Talwandi Nahar	Raw Water of RO	NULL	4.950
20	Phirvaria	Raw Water of RO	61	4.640
21	Kot Kesar Singh	Raw Water of RO	61	4.640
22	Kotla Sadar	Raw Water of RO	61	4.640
23	Gorey Nangal	Raw Water of RO	NULL	4.630
24	Abadi Rakhe Shah	Handpump	80	4.234
25	Sahliwal	Handpump	122	4.068
26	Bhure Gill	Raw Water of RO	64	3.805
27	Urdhan	Raw Water of RO	61	3.155
28	Dial Pura	Raw Water of RO	61	3.155
29	Chung	Raw Water of RO	NULL	2.875
30	Abadi Joga Singh Wala	Handpump	80	2.820
31	Abadi Nandwala Nawan Pind	Handpump	80	2.820
32	Abadi Dera Baba Diyal Singh	Handpump	260	2.817
33	Rakh Manawala	Handpump	80	2.720
34	Nikki Ajaib Wali	Handpump	80	2.690
35	Abad Gur Teg Bahadur Nagar	Handpump	75	2.624
36	Abadi Jasso Nangal	Handpump	75	2.624
37	Abadi Jhiri Nangal	Handpump	75	2.624
38	Abadi Miran Chak	Handpump	80	2.620
39	Chung	Tubewell	130	2.510
40	Hailar	Handpump	150	2.324
41	Chicha Naudh Singh	Handpump	80	2.280
42	Nanoke	Raw Water of RO	64	2.270
43	Makam	Raw Water of RO	61	2.265
44	Chak Sikander	Raw Water of RO	NULL	2.260
45	Nizampura	Raw water of RO	NULL	2.260
46	Loharka	Tubewell	NULL	2.260
47	Ibban Khurd	Tubewell	130	2.080
48	Kotla Angran	Handpump	90	2.040
49	Pandher Khurd	Handpump	80	2.030
50	Abadi Near Shahid Waryam Singh	Handpump	80	2.030

Table 2: *Aluminium Content in Groundwater of Amritsar District (Acceptable limit 0.03 mg/l).*

Sr. No	Villages Surveyed	Source of Ground water	Depth (m)	Aluminium Conc. (mg/l)
1	Thathi	Null	NULL	2.795
2	Thathi	Null	NULL	2.335
3	Malakpur	Null	NULL	2.039
4	Malakpur	Null	NULL	2.022
5	Manawala	Null	NULL	1.97
6	Chung	Tubewell	130	1.925
7	Manawala	Null	NULL	1.813
8	Abadi Guru Nanakpura	Handpump	80	1.78
9	Jathaul	Tubewell	130	1.005
10	Abadi Teja Singh Wala	Handpump	75	0.601
11	Abadi Khu Guru Arjan Dev Ji	Handpump	75	0.601
12	Abadi Surjan Singh Wala	Handpump	75	0.601
13	Abadi Dakhla Khu	Handpump	75	0.601
14	Abadi Dera Baba Diyal Singh	Handpump	75	0.601
15	Boharwala	Treated Water of RO	NULL	0.44
16	Dhulka	Null	NULL	0.35
17	Dulo Nangal	Null	NULL	0.322
18	Bhangwan	Null	NULL	0.297
19	Nikki Ajaib Wali	Null	NULL	0.289
20	Majjupura	Null	NULL	0.286
21	Sangat Pura	Null	NULL	0.286
22	Taragarh Ram Pura	Null	NULL	0.276
23	Naag Khurd	Tubewell	180	0.272
24	Bhittey Wad	Tubewell	122	0.271
25	Rasulpur Kalan	Tubewell	150	0.268
26	Bhaini Ram Dial	Null	NULL	0.266
27	Buey Nangali	Null	NULL	0.257
28	Mallu Nangal	Null	NULL	0.256
29	Channa	Handpump	65	0.254
30	Jagiana	Handpump	65	0.254
31	Khanwal	Handpump	65	0.254
32	Jassar	Null	NULL	0.248
33	Lola Dashmesh Nagar	Null	NULL	0.233
34	Chak Sikander	Null	NULL	0.232
35	Nizampura	Null	NULL	0.232
36	Loharka	Null	NULL	0.232
37	Malowal	Tubewell	145	0.231
38	Mehmudpur	Null	NULL	0.220
39	Jhanjoti	Null	NULL	0.220
40	Lalla Afghana	Null	NULL	0.209
41	Dudrai	Null	NULL	0.209
42	Dhariwal	Null	NULL	0.209
43	Lohgarh	Null	NULL	0.208
44	Khajala Urf Kohala	Null	NULL	0.206
45	Saido Lehal	Null	NULL	0.206
46	Jhande	Null	NULL	0.205
47	Bhure Gill	Treated Water of RO	NULL	0.200
48	Machhi Nangal	Null	NULL	0.195
49	Qila	Null	NULL	0.193
50	Sapari Wind	Null	NULL	0.193

Iron Contamination

Iron contamination above the acceptable limit (1.0 mg/l) is recorded in 70 villages [19]. A list of 50 villages is provided in Table 1 with highest value of 14.585 mg/l recorded in Bagrian village of Amritsar district and an average value of 4.536 mg/l. There is hardly any epidemiological investigation to study the health hazard effects of iron in groundwater on the human population in Punjab. Normally, iron deficiency in human body leads to anemia and fatigue. But an overload of iron in the body produces toxic effects leading to *hemochromatosis*, a severe disease that can damage body organs. Health risk assessment due to heavy metals in soil has been made by Manpreet et al. [20] for Jammu district of Jammu and Kashmir state of India. Ahmad et al. [21] have reported spatial variation and health risks of heavy metal contaminated drinking water from Sumra basin in Bangladesh. Wongsasuluk et al. [22] have reported a systematic investigation of carcinogenic and non-carcinogenic effects of heavy metals on an agricultural area of Thailand. Human health risk assessment has been made for all heavy metals including arsenic.

Magnesium Contamination

Dietary sources of magnesium are more varied; dairy products, vegetables, grain, fruits and nuts are important contributors. Low magnesium status has been implicated in hypertension, coronary heart disease, type 2 diabetes mellitus and metabolic syndrome. Oral magnesium supplementation improves insulin sensitivity and metabolic control in type 2 diabetes mellitus.

Drinking water in which both magnesium and sulfate are present in high concentrations can have a laxative effect, although data suggest that consumers adapt to these levels as exposures continue. Laxative effects have also been associated with excess intake of magnesium taken in the form of supplements, but not with magnesium in diet. Available data suggest that magnesium deprivation can increase calcium imbalance and lead to an abnormal redistribution of tissue calcium, such that there may be increased risk of soft tissue (including aorta) calcification, despite concurrent bone degradation [23].

Table 3: *Magnesium Content in Groundwater of Amritsar District (Acceptable limit 30 ppm).*

Sr. No.	Villages Surveyed	Source of Ground water	Depth (m)	Magnesium (ppm)
1	Bath	Raw Water of RO	NULL	48.91
2	Khatrai Khurd	Raw Water of RO	NULL	48.91
3	Khatrai Kalan	Raw Water of RO	NULL	48.91
4	Bhure Gill	Raw Water of RO	64	46.23
5	Boharwala	Raw Water of RO	61	45.38
6	Urdhan	Raw Water of RO	61	43.85
7	Dial Pura	Raw Water of RO	61	43.85
8	Abusaid	Raw Water of RO	58	38.89
9	Hetampura	RO Treated Water	NULL	38.49
10	Nanoke	Raw Water of RO	64	37.05
11	Makam	Raw Water of RO	61	34.33
12	Dalam	Raw Water of RO	NULL	32.95
			Average	42.31

Table 3 lists 12 villages of Amritsar district with magnesium values higher than the acceptable limit of 30 ppm. All the samples were collected from villages with RO (Reverse Osmosis Plants) facility but only raw water of tubewell was analysed for magnesium contamination. The average value of 42.31 ppm is not so high considering the health hazards of magnesium which are found to be mild in nature. It will be of interest to study the source of magnesium in the groundwater of Amritsar district.

Fluoride Contamination

Fluoride is one of the important micronutrient in humans which is required for strong teeth and bones. The Bureau of Indian Standards (BIS) [12] has set an acceptable limit of fluoride in drinking water to be 1.0 mg/l, with the maximum permissible limit up to 1.5 mg/l.

Fluoride contamination is widespread, intensive and alarming in India as 14.5% of total fluoride deposits on the earth’s crust are found in India. Of the 85 million tons of fluoride deposits on the earth’s crust, 12 million are found in India [24]. Hence, it is natural that fluoride contamination is widespread, intensive and alarming in India. Our investigations have revealed that out of 2500 habitations surveyed in Punjab state, 80% are affected by fluoride contamination. The highest fluoride contamination is recorded in Patiala and Fatehgarh Sahib districts of Punjab [25].

Groundwater with fluoride concentration above the permissible limit set by WHO i.e., 1.5 mg/l (ppm), have been recorded in several parts of the world. In 1984, WHO estimated that more than 260 million people living all over the world consume water with fluoride concentration above 1 mg/l [26]. The risk of fluorosis is higher in these places. The intensity of fluorosis problem is very serious in the two heavily populated countries of the world namely India and China [27]. In most cases, fluoride in groundwater is contributed by the host rocks which are naturally rich in fluoride. Because of rock water interaction, long residence time and evaporate-transpiration, the concentration of fluoride increases. Overall, the natural concentration of fluoride in groundwater depends on the geological, chemical and physical characteristics of the aquifer, the porosity and acidity of the soil and rocks, the surrounding temperature, the action of other chemical elements, depth of the aquifer and intensity of weathering [28].

Intake of fluoride higher than the optimum level is the main reason for dental and skeletal fluorosis. In India 62 million people including 6 million children are estimated to have serious health problems due to consumption of fluoride contaminated water [29]. Exposure to very high fluoride over a prolonged period of time results in acute to chronic skeletal fluorosis. Of the 32 states in India, 17 have been identified as endemic areas with 6 million people affected by skeletal fluorosis. In Amritsar district (Table 4), only nine villages are having high fluoride contamination in groundwater with average value of 1.96 mg/l, which is almost twice the acceptable limit. Hence the epidemiological effects of fluoride overdose to population are not very alarming.

Table 4: *Fluoride Content in Groundwater of Amritsar District (Acceptable limit 1.0 mg/l).*

Sr. No.	Villages Surveyed	Source of Groundwater	Depth (m)	Fluoride (mg/l)
1	Bathu Chak	Tubewell	150	4.77
2	Sialka	Tubewell	150	3.92
3	Timmowala	Tubewell	122	1.93
4	Dialpura Purbian	Tubewell	122	1.36
5	Hetampura	RO Treated Water	120	1.30
6	Talwandi Nahar	RO Raw Water	120	1.12
7	Phirvaria	Raw Water of RO	61	1.08
8	Kot Kesar Singh	Raw Water of RO	61	1.08
9	Kotla Sadar	Raw Water of RO	61	1.08
			Average	1.96

Nitrate Contamination

The nitrate ion (NO^{3-}) is the stable form of combined nitrogen for oxygenated systems. Nitrate can reach both surface water and groundwater as a consequence of agricultural activity (including excess application of inorganic nitrogenous fertilizers and manures), from wastewater treatment and from oxidation of nitrogenous waste products in human and animal excreta, including septic tanks [30].

The nitrate concentration in surface water is normally low (0–18 mg/l) but can reach high levels as a result of agricultural runoff, refuse dump runoff or contamination with human or animal wastes. The natural nitrate concentration in groundwater under aerobic conditions is a few milligrams per liter and depends strongly on soil type and on the geological situation. As a result of agricultural activities, the nitrate concentration can easily reach several hundred milligrams per liter [31]. For example, concentrations of up to 1500 mg/l were found in groundwater in an agricultural area of India [32].

The toxicity of nitrate to humans is mainly attributable to its reduction to nitrite which may lead to the condition, called methaemoglobinaemia, causes cyanosis and, at higher concentrations, asphyxia. Several reviews of epidemiological studies have been published; most of these studies are geographical correlation studies relating estimated nitrate intake to gastric cancer risk.

It is recommended that water should not be used for bottle-fed infants when nitrate levels are above 100 mg/l, but that it may be used if medical authorities are vigilant for signs of methaemoglobinaemia when the nitrate concentration is between 50 and 100 mg/l, particularly where a high rate of gastrointestinal infection is present in infants and children in the population.

Table 5 lists 19 villages of Amritsar district with nitrate values varying between 314.32 and 45.48 ppm, with an average value of 81.36 ppm. The source of high nitrate in groundwater is the use of nitrogen-based fertilizers in soil. Only two villages, Bathu Chak and Sialka, show values higher than the permissible limit of 100 ppm. There is a need to monitor nitrate contamination in both soil and groundwater on a regular basis without harming the agricultural activity in the district.

Table 5: *Nitrate Content of Groundwater of Amritsar District (Acceptable limit 45 ppm).*

Sr. No.	Villages Surveyed	Source of Ground water	Depth (m)	Nitrate (ppm)
1	Bathu Chak	Tubewell	150	314.32
2	Sialka	Tubewell	150	208.07
3	Udhoke Kalan	Tubewell	122	79.69
4	Jalalpur Sheron	Handpump	230	77.57
5	Maure	Tubewell	150	72.29
6	Pheruman	Tubewell	138	69.25
7	Kazi Kot	Tubewell	150	68.70
8	Akbarpura	Handpump	150	67.00
9	Hoshiar Nagar	Tubewell	152	64.89
10	Neshta	Tubewell	152	59.58
11	Mohawa	Tubewell	152	59.58
12	Kamalpura	Raw Water of RO	61	56.65
13	Sanguna	Tubewell	65	56.65
14	Khurmanian	Tubewell	125	52.46
15	Variah	Tubewell	135	49.81
16	Khatrai Khurd	Tubewell	122	47.93
17	Bath	Tubewell	122	47.93
18	Khatrai Kalan	Tubewell	122	47.93
19	Mehta	Tubewell	150	45.48
			Average	81.36

CONCLUSION

1. Amritsar district is one of the most contaminated districts of the Punjab state due to heavy metals and Arsenic in its groundwater as reported in our investigations.
2. The use of canal water is recommended for purposes of drinking due to high cost of mitigation of heavy metals.

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Cite this Article

Hardev Singh Virk. Groundwater Contamination due to Heavy Metals and other Pollutants in Amritsar District of Punjab. *Research & Reviews: A Journal of Toxicology*. 2019; 9(3): 19–28p.

