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Heavy Metals Contamination of Groundwater in Patiala District of Punjab State, India

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Abstract
Punjab is facing a crisis situation due to high levels of uranium (U), especially in Malwa belt, along with heavy metals in underground water table of Punjab in selected districts both in Malwa and Majha belts. 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. Nearly 50% habitations are found to be quality affected due to high contamination of arsenic, iron, aluminium, magnesium, selenium, fluorides, nitrates and other basic parameters. Uranium and Fluoride contamination dominates the scenario in Patiala district with heavy metals (aluminium, lead and nickel) following suit as major pollutants of the groundwater. 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 Patiala district of Punjab (India). Our analysis shows that Patiala is the most contaminated district of Punjab State, and perhaps of India?

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

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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 [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. In the Tribune report published on February 7, 2018, it was reported that 88 percent of habitations affected by heavy metals in groundwater of India belong to Punjab State [6–8].

Punjab Water Supply and Sanitation Department (PWSSD) is involved in testing groundwater samples from more than 50% habitations of Punjab. The analysis of heavy metal contamination of groundwater has been done 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 (World Health Organization) Guidelines for Drinking-Water Quality (GDWQ) is the protection of public health. International Standards for Drinking-Water were first published in 1958 after WHO organised a series of expert meetings in Geneva during 1956. These Standards 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.

QUALITY OF GROUNDWATER IN PATIALA DISTRICT

The Central Ground Water Board (CGWB) Report throws some light on the nature of soil and geomorphology of the Patiala district [13]. Patiala district of Punjab State lies between 29º49′ to 30º40′N latitudes and 75º58′ to 76º48′E longitudes (Figure 1). Total geographical area of the district is 3218 sq. km. The district area is occupied by Indo-Gangatic alluvial plain and consists of three types of region, through the Upland plain, the Cho-infested Foothill Plain and the floodplain of the *Ghaggar* River. The elevation of land ranges from 240 to 278 m amsl. Due to arid climate, the soils are light coloured. Tropical arid brown soils exist in the major parts of the district. Here soils are deficient in nitrogen, phosphorus and potassium. In Patran and Samana blocks, soils are arid brown. These are calcareous in nature and in most cases *Kankar* layers occur.

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.

Table 1: *Lead (Pb) Contamination in Groundwater of Patiala District (Acceptable limit 0.01 mg/l).*

Sr. No.	**Villages surveyed**	**Source of ground water**	**Depth (m)**	**Lead (mg/l)**
1	Punia Khana	Tubewell	235	0.190
2	Dera Musalmana	Handpump	90	0.049
3	Kalwa	Handpump	90	0.049
4	Alampur	Handpump	70	0.048
5	Kalburshan	Tubewell	250	0.039
6	Sehajpur Khurd	Tubewell	200	0.033
7	Sehajpur Kalan	Tubewell	200	0.033
8	Dulatpur Fakiran	Tubewell	150	0.032
9	Mirjapur	Tubewell	150	0.032
10	Kakrala	Tubewell	500	0.031
11	Hassanpur Kamboan	Tubewell	180	0.029
12	Paror	Tubewell	165	0.028
13	Uppli	Tubewell	165	0.028
14	Nandpur Kesho	Tubewell	154	0.028
15	Sadh Majra	Tubewell	138	0.028
16	Gurdialpura	Tubewell	138	0.028
17	Bahmna	Tubewell	200	0.027
18	Behmna/Bajigar Basti	Tubewell	200	0.027
19	Harijan Basti	Tubewell	200	0.027
20	Kheri Bheema	Tubewell	116	0.027
21	Niamatpur	Tubewell	242	0.026
22	Shadipur	Tubewell	242	0.026
23	Alampur	Tubewell	200	0.026
24	Balamgarh	Tubewell	200	0.026
25	Fatan Majri	Tubewell	277	0.026
26	Basti Harchandpura	Tubewell	250	0.026
27	Nanhera	Tubewell	250	0.026
28	Talwandi Malik	Tubewell	200	0.026
29	Sullar	Tubewell	198	0.026
30	Thakurgarh	Tubewell	250	0.025
31	Hussainpur	Tubewell	250	0.025
32	Dera Alipur	Tubewell	250	0.025
33	Massingan	Tubewell	273	0.025
34	BirKauli	Tubewell	250	0.025
35	Rongla	Tubewell	107	0.025
36	Lang	Tubewell	107	0.025
37	Dera Banta Singh	Tubewell	74	0.025
38	Lalgarh	Tubewell	74	0.025
39	Dera Balbir Singh	Tubewell	74	0.025
40	Bahadurgarh	Tubewell	74	0.025
41	Danipur	Tubewell	74	0.025
42	Dodra	Tubewell	150	0.025
43	Gajewas	Tubewell	250	0.025
44	Basti Channa	Tubewell	126	0.025
45	Sapperheri	Tubewell	126	0.025
46	Assmanpur	Tubewell	126	0.025
47	Patti Sodhian	Tubewell	200	0.025
48	Shahpur Afgana	Handpump	70	0.024
49	Rajgarh	Tubewell	240	0.024
50	Rattanheri	Tubewell	240	0.024
			AVERAGE	0.031

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

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.

Table 2 represents aluminium content values ranging from 0.213 to 1.242 mg/l, with average value 0.396 mg/l. All the villages of Patiala district listed in Table 2 have Al values more than the permissible limit of 0.2 mg/l [12]. In its 2010 assessment of Al in drinking water, the World Health Organization (WHO) has calculated a nonregulatory 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 Al in drinking water. An operational guidance (OG) value of 0.050 mg/l is proposed for total Al to optimize water treatment and distribution systems [18].

Table 2: *Aluminium (Al) Contamination in Groundwater of Patiala District (Acceptable limit 0.03 mg/l).*

Sr. No.	Villages surveyed	Source of groundwater	Depth (m)	Aluminium (mg/l)
1	Choura	Tubewell	NULL	1.242
2	Bolri	Tubewell	NULL	1.190
3	Wazirabad	Tubewell	300	1.140
4	Mirjapur	Tubewell	300	1.140
5	Bhur Majra	Hand pump	70	0.984
6	Kheri Gurna	Tubewell	262	0.704
7	Nepran	Tubewell	250	0.653
8	Barkatpur	Tubewell	122	0.633
9	Bhoglan	Tubewell	275	0.480
10	Ghungran	Tubewell	200	0.457
11	Shahpur Raian	Tubewell	200	0.457
12	Gharam Kalan	Tubewell	300	0.420
13	Gharam Khurd	Tubewell	300	0.420
14	Shergarh	Hand pump	90	0.408
15	Mangewal	Hand pump	NULL	0.375
16	Mugal Sarai	Tubewell	289	0.363
17	Dittupur	Tubewell	99	0.352
18	Dera Nira-nkarian Da	Tubewell	232	0.337
19	Hassanpur Jattan	Tubewell	315	0.321
20	Kaboolpur	Tubewell	315	0.321
21	Punia Khana	Tubewell	235	0.318
22	Kassiana	Tubewell	NULL	0.317
23	Kharajpur	Tubewell	NULL	0.311
24	Nandgarh	Tubewell	NULL	0.302
25	Kulwanoo	Tubewell	NULL	0.286
26	Allowal	Tubewell	238 ft	0.271
27	Ganeshpur	Tubewell	NULL	0.267
28	Ram Nagar	Tubewell	122	0.252
29	Mehergarh Batta	Raw Water of RO	137	0.247
30	Mehergarh Batti	Raw Water of RO	137	0.247
31	Seel	Tubewell	250	0.243
32	Bhunerheri	Tubewell	250	0.240
33	Mohabbet Pur	Tubewell	250	0.239
34	Shankarpur	Tubewell	250	0.239
35	Dera Kartarpur	Tubewell	250	0.237
36	Nandgarh urf Manak Dehar	Tubewell	NULL	0.236
37	Bakshi-wala	Tubewell	183	0.236
38	Naina	Tubewell	183	0.236
39	Chuharpur Jattan	Tubewell	NULL	0.234
40	Jansua	Tubewell	NULL	0.230
41	Nagawan	Tubewell	240	0.227
42	Mund Khera	Tubewell	152	0.227
43	Patran	Tubewell	NULL	0.226
44	Therri	Tubewell	NULL	0.223
45	Deogarh	Tubewell	178	0.222
46	Drauli	Tubewell	NULL	0.220
47	Samana Rural	Tubewell	NULL	0.215
48	Kutbanpur	Tubewell	NULL	0.215
49	Behar Jach	Tubewell	NULL	0.213
50	Fatehgarh Chhanna	Tubewell	NULL	0.213
			Average	0.396

Lead Contamination

Lead is usually found in drinking water as a result of leaching from distribution and plumbing system components. Lead is commonly found in the environment, both naturally and as a result of human activities. Lead can enter drinking water when plumbing materials that contain lead corrode, especially where the water has high acidity or low mineral content that corrodes pipes and fixtures.

Health Canada has proposed a maximum acceptable concentration (MAC) of 0.005 mg/l (5 µg/l) for total lead in drinking water, based on a sample of water taken at the tap and using the appropriate protocol for the type of building being sampled. Every effort should be made to maintain lead levels in drinking water as low as reasonably achievable (or ALARA) [19].

US EPA (Environmental Protection Agency) has set the maximum contaminant level goal for lead in drinking water at zero because lead is a toxic metal that can be harmful to human health even at low exposure levels. Lead is persistent, and it canbio-accumulate in the body over time. Young children, infants, and fetuses are particularly vulnerable to lead because the physical and behavioural effects of lead occur at lower exposure levels in children than in adults. In children, low levels of exposure have been linked to damage to the central and peripheral nervous system, learning disabilities, shorter stature, impaired hearing, and impaired formation and function of blood cells [20].

Table 1 registers Lead contamination values in the range of 0.024 to 0.190 mg/l, with average value of 0.031 mg/l. The highest value of Lead (0.190 mg/l) in groundwater is recorded in Punia Khana village. Lead is considered to be one of the most toxic heavy metals; hence its mitigation is a major problem in Patiala district.

Nickel Contamination

The primary source of nickel in drinking water is leaching from metals in contact with drinking water, such as pipes and fittings. However, nickel may also be present in some groundwater as a consequence of dissolution from nickel ore-bearing rocks. Nickel concentrations in groundwater depend on the soil use, pH, and depth of sampling. Acid rain increases the mobility of nickel in the soil and thus might increase nickel concentrations in groundwater [21].

Nickel compounds are generally inactive in bacterial mutation assays but active in mammalian cell systems [22]. It was concluded that nickel-induced responses involved cell toxicity in all gene mutation studies using mammalian cells. A number of studies on the carcinogenicity of nickel compounds in experimental animals are available [23]. Generally, tumours are induced at the site of administration of the nickel compound. WHO report includes case studies of Nickel ingestion in industrial workers (nickel doses from 7 to 35 mg/kg of body weight) who developed symptoms, including nausea, vomiting, diarrhoea, giddiness, lassitude, headache, and shortness of breath.

Inhalation is an important route of exposure to nickel and its salts in relation to health risks. IARC [24] concluded that nickel compounds are carcinogenic to humans (Group 1), whereas metallic nickel is possibly carcinogenic to humans (Group 2B). However, there is a lack of evidence of a carcinogenic risk from oral exposure to nickel. In a review of nickel removal, it was concluded that conventional coagulation, clarification, and granular activated carbon filtration can give nickel removals of 35–80%, depending on the speciation of the nickel [21].

Table 3 registers nickel contamination in groundwater levels from 0.020 to 0.190 mg/l, with an average level of 0.030 mg/l. There is a need to undertake epidemiological studies of nickel exposed population in Patiala district. The source of heavy metals in the state of Punjab is an enigma for the scientists. A comprehensive but preliminary report was published by the author [25] in 2017 about Uranium and heavy metal contamination of groundwater in Punjab.

Table 3: *Nickel (Ni) Contamination in Groundwater of Patiala District (Acceptable limit 0.02 mg/l).*

Sr. No.	Villages surveyed	Source of groundwater	Depth (m)	Nickel (mg/l)
1	Dera Rajla	Tubewell	148	0.106
2	Rajla	Tube well	148	0.106
3	Phedpura	Tubewell	200	0.051
4	Majri Akalian	Tubewell	75	0.041
5	Kalwa	Tubewell	122	0.039
6	Rajgarh	Tubewell	340	0.038
7	Chuharpur Marasian	Tubewell	340	0.038
8	Chuharpur Kalan	Tubewell	340	0.038
9	Balheri	Hand pump	70	0.035
10	Mohinder Complex Kheri Gujjran	Tubewell	205	0.035
11	Dera Dhakraba	Tubewell	165	0.034
12	Mehmadpur	Tubewell	165	0.034
13	Dhakraba	Tubewell	165	0.034
14	Dilawarpur	Tubewell	165	0.034
15	Senserwal	Tubewell	360	0.031
16	Daun Khurd	Tubewell	120	0.027
17	Prem Singh Wala	Tubewell	200	0.026
18	Bujrak	Tubewell	200	0.026
19	Khanpur Gorian	Tubewell	250	0.026
20	KotlaNasru	Tubewell	163	0.025
21	Kamaspur	Tubewell	163	0.025
22	Badanpur	Tubewell	163	0.025
23	Bishanpur Chhana	Tubewell	150	0.024
24	Ishabpur	Tubewell	150	0.024
25	Kheri Musal Manan	Tubewell	150	0.024
26	Jamalpur	Tubewell	200	0.024
27	Rasulpur	Hand pump	70	0.023
28	Haripur Jhugian	Hand pump	70	0.023
29	Katlahar	Hand pump	70	0.023
30	Amanpur	Tubewell	167	0.023
31	Sultanpur	Tubewell	200	0.023
32	Khuhti Channa	Tubewell	200	0.023
33	Bahman Majra	Tubewell	200	0.023
34	Patti Sodhian	Tubewell	200	0.023
35	Aman Vihar Jasowal	Tubewell	180	0.022
36	Ranjit Nagar	Tubewell	182	0.022
37	Narangwal	Tubewell	142	0.022
38	Sirkapra	Tubewell	142	0.021
39	Dedhera	Tubewell	182	0.021
40	Bibipur	Tubewell	182	0.021
41	Kakrala	Tubewell	182	0.021
42	Kularan	Tubewell	250	0.021
43	Dwarkapur	Tubewell	98	0.021
44	Rampur Partan	Tubewell	98	0.021
45	Uja Patti	Tubewell	98	0.021
46	Ghanaur	Tubewell	300	0.021
47	Sheikhupur Rajputan	Hand pump	70	0.020
48	Badshahpur	Tubewell	250	0.020
49	Fatan Majri	Tubewell	277	0.020
50	Kadrabad	Tubewell	250	0.020
			Average	0.030

CONCLUSION

1. Patiala district is most contaminated district of the Punjab State due to heavy metals and Uranium as reported in my investigations of its groundwater.
2. Lead contamination of groundwater is alarming and needs immediate measures for its mitigation.

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