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Groundwater Contamination of Amritsar District of Punjab due to Heavy Metals Iron and Arsenic and its Mitigation

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Abstract
Punjab is facing a crisis situation due to high levels of heavy metals in underground water table of Punjab. ICAR has reported arsenic beyond safe limit in 13 districts of Punjab. According to PWSSD report, the highest number of qualities affected (QA) habitations due to arsenic and iron fall under the geographical area of Amritsar district in Punjab. In this survey, groundwater quality data pertaining to arsenic and iron is reported. Heavy metal contamination due to arsenic and iron can be got rid of by using a nanotechnology-based technique called AMRIT (Arsenic and Metal Removal by Indian Technology). It is proposed to install 1508 AMRIT plants in the Punjab State under the World Bank Project. Pilot plants of AdEdge and ion exchange companies have been also installed for mitigation of arsenic.

Keywords: *Heavy metal contamination, arsenic, iron, acceptable limit, AMRIT*

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INTRODUCTION
Punjab is facing a crisis situation due to heavy metals contamination in the underground water table. Recent reports published in 'The Tribune' (www.tribuneindia.com) concerning high toxicity of heavy metals in the groundwaters of Punjab are alarming [1–3]. The report published on January 28, 2018 is exhaustive and is based on a study of health hazards of heavy metals diagnosed in Baba Farid Centre of Special children at Faridkot in Punjab. The report concludes that toxic metals have poisoned the sub-soil 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% of total habitations (villages or cluster of houses) in India that are adversely affected with the presence of heavy metals in groundwater. According to the data compiled by the Central Ground Water Board (CGWB), the total number of villages affected by heavy metal contamination is 2420 in India, out of which 2139 fall in Punjab, 273 in Bengal, 7 in Assam and only one in Karnataka.

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). PWSSD report presented an analysis of groundwater collected from 15384 homes with heavy metal contamination found in 2080 habitations. The analysis presented in this study is also based on PWSSD data collected in three phases during 2009 to 2016 and compiled in April 2016. Most of this data is available on the website of Ministry of Water Resources, Government of India [4].

Survey reports on groundwater contamination of Majha, Malwa and Doaba belts of Punjab due to heavy metal arsenic have been published by the present author in recent years [5-7]. Some other investigators have also reported higher levels of arsenic than the permissible limit of 10 ppb in groundwater of Punjab [8-10]. Till today, there is no conclusive evidence for source of arsenic contamination in waters of Punjab.

WHO GUIDELINES AND INDIAN STANDARDS FOR WATER

The primary aim of the WHO (World Health Organisation) guidelines for drinking-water quality (GDWQ) is the protection of public health. The origin of WHO guidelines for Drinking-Water Quality (GDWQ) goes back to the 1950s. 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 [11]. 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.

WHO had adopted a public standard on arsenic in drinking water since 1958. The last edition of WHO GDWQ (1993) established 0.01 mg/l (10 ppb) as a provisional guideline value for arsenic in drinking water with a view to reducing the concentration of arsenic in drinking-water. In a number of countries, including India, the WHO provisional guidelines of 0.01 mg/l have been adopted as the standard. The cancer risk assessment for arsenic in drinking water is calculated by using a multistage model based on an epidemiological study by Tseng [12].

The Bureau of Indian Standards (BIS) has adopted WHO guidelines and standards for most of the heavy metals in Table 2 under the heading "General Parameters Concerning Substances Undesirable in Excessive Amounts" [13]. It includes all metals listed in PWSSD analysis except arsenic. I wonder why such a toxic metal has been ignored in BIS report.

THE STUDY AREA

Location

Amritsar district 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) [14]. Total area of the district is 2647 km2. 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 area is occupied by Indo-Gangetic alluvium [14]. 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, whereas in the central part of the district soils are fine loamy, calcareous and are well drained.

ARSENIC CONTENT IN GROUNDWATER AND ITS HEALTH HAZARDS

Arsenic contamination in groundwater is a matter of immediate concern in Punjab due to its health hazards. Punjab Agriculture University (PAU) scientists were the first to undertake arsenic investigation in groundwater and canal waters in Majha belt of Punjab [8]. A research report recently prepared by the Indian Council of Agriculture Research (ICAR) has reported arsenic beyond safe limit in 13 districts of Punjab [16]. According to PWSSD report, with acceptance level (AL) set at 0.01 mg/l (10 ppb) [11], there are 2748 habitations out of 6884 surveyed in Punjab, which fall under quality affected (QA) category (40% nearly). Out of all QA habitations in Punjab, 60% fall in Majha belt of Punjab, namely, Amritsar, Gurdaspur and Tarn districts.

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

Amritsar district has maximum number of 505 QA habitations in Punjab. A list of 50 villages is given in Table 1 with arsenic values in the range of 0.072 to 0.168 mg/l. The highest value of arsenic (0.168 mg/l) was recorded in the water supply of Budha Theh, followed by arsenic value of 0.111 mg/l in three villages, namely Bath, Khatrai Khurd and Khatrai Kalan. No correlation of arsenic content and the depth of water source is established in PWSSD analysis.

Iron contamination above the acceptable limit (1.0 mg/l) is recorded in 70 villages. A list of 50 villages is provided in Table 2 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 arsenic and 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*. for Jammu district of J & K state of India [17]. Ahmad *et al*. have reported spatial variation and health risks of heavy metal contaminated drinking water from Sumra basin in Bangladesh [18].

Wongsasuluk *et al.* 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[19]. Rapant and Krcmova´ reported that the cancer risk caused by arsenic in groundwater reached as high as 10^{-4}, or more than 100 people in a million in Slovakia [20].

What is the source of arsenic in the groundwater of Amritsar district? It needs to be investigated in greater detail to eliminate health hazard effects of arsenic beyond the acceptable level set by WHO. Heavy metal contamination is potentially a significant problem in several community and agricultural areas because agrochemicals, including plant nutrients and fertilizers can lead to dramatic increases in the concentrations of heavy metals in the water and soil [21]. Arsenic anomalies in ground waters of Amritsar may be attributed to excessive use of fertilizers, herbicides and pesticides. Arsenic is a cancer-causing agent. The induction of cancer is caused by arsenic which results from its absorption in the gastro-intestinal system. Long term ingestion of low arsenic concentrations in drinking water can lead to bladder, lung and prostate cancer [22–24].

Table1: *Arsenic Contamination (>.07 mg/l) in Groundwater of Amritsar District. Acceptable Limit in Groundwater is 0.01 mg/l (10 ppb).*

Sr. No.	Villages Surveyed	Source of Groundwater	Depth (m)	Arsenic (mg/l)
1	BudhaTheh	Water Supply scheme	148	0.168
2	Bath	Tubewell	122	0.111
3	Khatrai Kalan	Tubewell	120	0.111
4	Khatrai Khurd	Tubewell	122	0.111
5	Jauns	Tubewell	150	0.104
6	Chak Kamal Khan	Tubewell	150	0.098
7	Josh	Tubewell	150	0.094
8	Badhar	Tubewell	150	0.091
9	Mahaddipur	Tubewell	150	0.090
10	Dial Bharang	Tubewell	92	0.087
11	Dial Pura	Tubewell	92	0.087
12	Urdhan	Tubewell	92	0.087
13	Vachhoya	Tubewell	150	0.087
14	Jassar	Tubewell	132	0.086
15	Makowal	Tubewell	132	0.086
16	Dalam	Tubewell	450 ft	0.086
17	Basti BaziGaran	Tubewell	152 m	0.086
18	Odhar	Tubewell	150	0.085
19	Barar	Tubewell	150	0.083
20	Kakar	Tubewell	150	0.083
21	Mehmadpura	Tubewell	150	0.083
22	Saurian	Tubewell	150	0.083
23	Tarin	Tubewell	150	0.083
24	Dharamkot	Tubewell	150	0.083
25	Boharwala	Tubewell	60	0.082
26	Gorey Nangal	Tubewell/ W/s Scheme	138	0.082
27	Majhi Meun	Handpump	61	0.081
28	Mohar	Tubewell	159	0.081
29	Raipur Khurd	Tubewell	138	0.079
30	Mattiya	Tubewell	150	0.078
31	Rokhey	Tubewell	150	0.078
32	Bhullar	Tubewell	110	0.077
33	Chogawan	Tubewell	110	0.077
34	Tapiala	Tubewell	110	0.077
35	Khanowal	Tubewell	140	0.076
36	Kotla Kazian	Tubewell	150	0.076
37	Mohan Bhandarian	Tubewell	145	0.076
38	Mehlan Wala	Tubewell	165	0.076
39	Kotla Gujran	Tubewell	125	0.075
40	Saido Ghazi	Handpump	61	0.074
41	Bhalla Pind	Tubewell	180	0.074
42	Jhanjoti	Tubewell	125	0.074
43	Kuralian	Tubewell	135	0.073
44	Malowal	Tubewell	145	0.073
45	KotKesar Singh	Tubewell	60	0.073
46	Johal	Tubewell	150	0.073
47	Kotli Amb	Tubewell	152	0.073
48	Kiampura	Tubewell	150	0.072
49	Abusaid	Tubewell	58	0.072
50	Mukam	Tubewell	136	0.072

Table2: *Iron Contamination (>2 mg/l) of Groundwater in Amritsar District. Acceptable limit 1.0 mg/l (ppm) it is OK*

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	Null	Null	9.390
5	Shahzada	Null	Null	9.390
6	Gaggar	Null	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	Null	NULL	5.570
15	Harar Near Bhure Gill	Handpump	240	5.337
16	Rakh Nag	Handpump	80	5.180
17	Wadha Chack	Handpump	121	5.024
18	Padiana	Handpump	80	5.000
19	Talwandi Nahar	Ro Raw Water	NULL	4.950
20	Phirvaria	RO Raw Water	60	4.640
21	Kot Kesar Singh	RO Raw Water	60	4.640
22	Kotla Sadar	RO Raw Water	60	4.640
23	Gorey Nangal	Null	Null	4.630
24	Abadi Rakhe Shah	Handpump	80	4.234
25	Sahliwal	Handpump	122	4.068
26	Bhure Gill	RO Raw Water	64	3.805
27	Urdhan	RO Raw Water	60	3.155
28	Dial Pura	RO Raw Water	60	3.155
29	Chung	Null	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	85	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 RO	64	2.270
43	Makam	Raw Water RO	60	2.265
44	Chak Sikander	Null	Null	2.260
45	Nizampura	Null	Null	2.260
46	Loharka	Null	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 Shahid Waryam Singh	Handpump	80	2.030
			Average	4.536

MITIGATION OF ARSENIC AND IRON FROM GROUNDWATER

AMRIT Methodology of Arsenic Removal from Water

The presence of arsenic in various ionic and molecular forms in the aquatic environment is a major concern of the world due to their severe toxicity towards human beings. A number of technologies have been tried in the field and each of them has associated challenges (cost, complexity, efficiency and sludge). Adsorption has earned attention as one of the most widely used methods for decontamination of arsenic. Old technologies using commercial ferric hydroxide are increasingly becoming outdated. For arsenic removal, nanomaterials perform 25 times better over activated alumina and 10 times better over commercial ferric hydroxide.

The acronym AMRIT stands for arsenic and metal removal by Indian technology. The main component of AMRIT is composed of nanoscale iron oxyhydroxide, prepared with a particle size less than 3 nm. The synthesis of nanoscale iron oxyhydroxide and its efficacy for removal of arsenic from water is described elsewhere [25, 26]. Choice of iron-based compounds is based on the fact that they are commonly found in water. Engineering such compounds based on nanotechnology enables them to pick large quantity of arsenic. Particle size below a critical limit increases the number of surface atoms substantially leading to higher surface energy. An important aspect is to ensure that such nanoparticles are strongly anchored onto solid surfaces so as to make sure that they do not leach into water, thereby preventing secondary contamination. Simultaneously, the adsorbed arsenic does not get released from the composition, thereby ensuring that spent material can be disposed locally.

What it means in terms of performance and affordability? AMRIT water purification unit is a cost-effective and simple solution for providing clean drinking water to people, especially in areas where the water table is contaminated by arsenic and iron. AMRIT composition can handle up to an input load of 5 ppm of arsenic (equally well for both forms of arsenic, As^{3+} and As^{5+}) and bring the output below the detection limit (<1 ppb). Composition is at least 5–6 times more efficient than any other adsorbent available currently. Since the contact time required for removal is fairly low (less than 1 min), the composition is used in the size of 0.2 mm, thereby offering negligible pressure drop. This helps from several aspects: treatment cost reduces, filtration unit becomes smaller, filtration unit can be operated with minimum pressure, easily maintainable by local community and reduced sludge quantity.

Schematic diagram of mitigation of iron and arsenic from groundwater using AMRIT technology is shown in Figure 2. PWSSD has installed pilot plants in Amritsar district using AMRIT methodology of arsenic removal from potable water. The project is being funded under the World Bank initiative to provide clean water in a mission mode. AMRIT technology-based plants are operational in Ajnala and Majitha blocks of Amritsar district. Figure 3 shows the plant which supplies the arsenic and iron free groundwater to Mehlanwala village of Amritsar district.

AdEdge India and Ion Exchange Technologies for Arsenic Mitigation

AdEdge (USA) has extensive experience in the removal of arsenic from water, as well as other contaminants, including iron, manganese, hydrogen sulfide, fluoride, nitrate and uranium. AdEdge Water Technologies (AdEdge) and InNow India Pvt. Ltd. (InNow) recently announced a joint venture to provide innovative water treatment solutions for municipalities in India for the removal of arsenic, nitrate, radionuclides, and fluoride among other contaminants. The joint venture has started its operations in India under the name AdEdge India. AdEdge Package Units and modular systems use a variety of treatment processes including adsorption using Bayoxide® E33, coagulation/filtration, and ion exchange [27]. Figure 4 shows a pilot plant set up by AdEdge India in Ucha Kila village of Amritsar district.

Ion exchange treatment of drinking water is based on a technique where one or more undesirable contaminants are removed from water by exchange with another non-objectionable or less objectionable substance. Both the contaminant and the exchanged substance must be dissolved and have the same type (+,-) of electrical charge [28]. Ion Exchange Company was a pioneer in water treatment in India and is engaged in water and environment management, with a strong international presence. The author visited the pilot plant of this company in Kuralian village of Amritsar district on April 3, which was non-functional due to some technical problems (Figure 5).

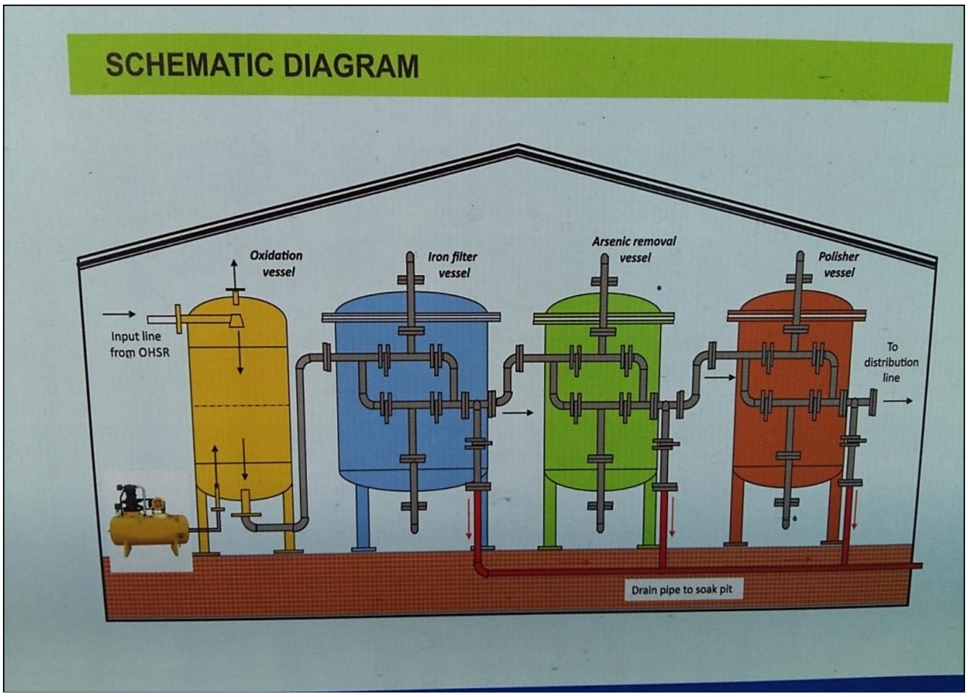

Fig. 2: *Schematic Diagram of Mitigation of Iron and Arsenic using AMRIT Technology.*

Fig. 3: *AMRIT Technology Based Plant in Mehlanwala Village of Amritsar District.*

Fig. 4: *AdEdge India Plant Using Bayoxide® E33 in UchaKila Village of Amritsar District.*

Fig. 5: *Ion Exchange Technology Based Plant in Kuralian Village of Amritsar District.*

CONCLUSIONS

1 High contents of arsenic and iron in groundwaters of Amritsar district are a serious health hazard to inhabitants of the area.

2 Mitigation measures must be taken on war footing for the safety of public living in rural areas of the district.

3 Niti Ayog of Govt. of India and World Bank has provided financial support for mitigation of arsenic and other heavy metals in groundwater.

4 Considering the overall cost of mitigation, it is suggested to augment the supply of canal water for drinking purposes in

Amritsar district, as is being done in Chandigarh and Mohali.

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REFERENCES

1 Sood A. Groundwater High in Arsenic, No Steps to Protect Food Chain: Situation Alarming in Majha Districts, Observes Dept. Report. Chandigarh: The Tribune; 2018. [Online] Available from www.tribuneindia.com [Accessed on Feb 2018].
2 Singh J. *Heavy Metals, Deep Impact*. Chandigarh: The Tribune; 2018. [Online]. Available from www.tribuneindia.com [Accessed on Feb 2018].
3 Vijay M. *State Groundwater Most Contaminated.* Chandigarh: The Tribune; 2018. [Online] Available from www.tribuneindia.com [Accessed on Feb 2018].
4 Ministry of Water Resources, Government of India. [Online] Available from www.indiawater.gov.in/IMIS reports.
5 Virk HS. A Preliminary Report on Groundwater Contamination of Majha Belt of Punjab due to Heavy Metal Arsenic. *Research & Reviews: A Journal of Toxicology*. 2017; 7(3): 27–33p.
6 Virk HS. A Survey Report on Groundwater Contamination of Malwa Belt of Punjab due to Heavy Metal Arsenic. *Int J Sci Res (IJSR)*. 2019; 8(3):1721-1726p.
7 Virk HS. A Survey Report on Groundwater Contamination of Doaba Belt of Punjab due to Heavy Metal Arsenic. *Int J Sci Res (IJSR).* 2019; 8(4):151-56p.
8 Hundal HS, Singh K, Singh D. Arsenic Content in Ground and Canal Waters of Punjab, North-West India. *Environ Monit Assess.* Jul 2009; 154(1-4):393-400p.
9 Hundal HS, Kumar R, Singh K, *et al*. Occurrence and Geochemistry of Arsenic in Groundwater of Punjab, Northwest India. *Commun Soil Sci Plant Anal.*2007; 38(17–18): 2257–2277p.
10 Bajwa BS, Kumar S, Singh S, *et al*. Uranium and Other Heavy Toxic Elements Distribution in the Drinking Water Samples of SW-Punjab, India. *J Radiat Res Appl Sci.*2017; 10(1): 13-19p.
11 World Health Organization (WHO). *Drinking Water Guidelines and Standards*. Chapter 5. Geneva: Switzerland; 1993; Guidelines for Third Edition Volume 1 Recommendations, WHO, Geneva, 2004. https://www.who.int/water_sanitation_health/dwq/GDWQ2004web.pdf; Guidelines for Drinking-water Quality Fourth Edition, WHO, Geneva, 2011: https://apublica.org/wp-content/uploads/2014/03/Guidelines-OMS-2011.pdf.
12 Tseng WP. Effects of Dose-Response Relationship of Skin Cancer and Blackfoot Disease with Arsenic. *Environ Health Perspect.*1977; 19:109–119p.
13 The Bureau of Indian Standards (BIS). *Indian Standard Drinking Water Specification (Second Revision)*. New Delhi: Publication Unit, BIS; May 2012.
14 Ground Water Information Booklet. Amritsar District, Punjab. http://cgwb.gov.in/District_Profile/Punjab/Amritsar.pdf.
15 Central Ground Water Board, Ministry of Water Resources, Government of India, North Western Region, Chandigarh. 2013. http://cgwb.gov.in/District_Profile/Punjab/Gurdaspur.pdf,
16 ICAR Report. *Punjab, Haryana Groundwater has Arsenic beyond Limit, Says Report*. Chandigarh: The Tribune: Nov 27, 2015. [Online] Available from www.tribuneindia.com [Accessed on Feb. 2017].
17 Kaur M, Kumar A, Mehra R, *et al*. Human Health Risk Assessment from Exposure of Heavy Metals in Soil Samples of Jammu District of Jammu and Kashmir, India. *Arab J Geosci.*30 Jul2018; 11(15): 411p.

18 Ahmad N, *et al*. Appraising Spatial Variations of As, Fe, Mn and NO3 Contaminations Associated Health Risks of Drinking Water from Surma Basin, Bangladesh. *Chemosphere*. 2019; 218: 726-740p.

19 Wongsasuluk P, Chotpantarat S, Siriwong, *et al*. Heavy Metal Contamination and Human Health Risk Assessment in Drinking Water from Shallow Groundwater Wells in an Agricultural Area in Ubon Ratchathani Province, Thailand. *Environ Geochem Health.* Feb 2014; 36(1):169-82p.

20 Rapant S, Krcˇmova´ K. Health Risk Assessment Maps for Arsenic Groundwater Content: Application of National Geochemical Databases. *Environ Geochem Health.*2007; 29: 131–141p.

21 Rattan RK, Datta SP. Chhonkar PK, *et al*. Long-Term Impact of Irrigation with Sewage Effluents on Heavy Metal Content in Soils, Crops and Groundwater: A Case Study. *Agr Ecosyst Environ*.2005; 109(3-4): 310–322p.

22 Carlson-Lynch H, Beck BD, Boardman PD. Arsenic Risk Assessment. *Environ Health Perspect.*1994; 102(4): 354–356p.

23 Mushak P, Crocetti AF. Risk and Revisionism in Arsenic Cancer Risk Assessment. *Environ Health Perspect*. 1995; 103(7–8): 6834–6839p.

24 Nakadaira H, Nakamura K, Mutoh K, *et al*. Arsenic Residues in Well Water 36 y after Endemic Arsenic Poisoning. *Arch Environ Health*. 2000; 55(5): 364p.

25 AMRIT: Arsenic and Metal Removal by Indian Technology Brochure. www.dstuns.iitm.ac.in/filesdec2015/1.%20Amrit%20Brochure.pdf

26 Anil Kumar A, Som A, Longo P, *et al*. Confined Metastable 2-Line Ferrihydrite for Affordable Point-of-Use Arsenic-Free Drinking Water. *Adv Mater*.2017; 29(7): 1–7p.

27 AdEdge Water Technologies LLC.https://www.wateronline.com/.../adedge-india-formed-joint-venture-between-adedge-...

28 Ion Exchange Treatment of Drinking Water. https://www.des.nh.gov/organization/commissioner/pip/factsheets/.../dwgb-2-12.pdf

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