Journal of
Water Pollution & Purification Research
ISSN: 2394-7306
Volume 11, Issue 3, 2024
September–December
DOI (Journal): 10.37591/JoWPPR
https://journals.stmjournals.com/jowppr/
Research JoWPPR

Heavy Metal Contamination of Groundwater in Malwa Region of Punjab and Potential Technological Solutions

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Abstract

Bathinda is part of the Malwa region of Punjab and is part of a belt which was earlier called the cotton belt of India but is now hailed as the cancer belt of India. The Malwa region faces high cancer incidence rates. For every 1 million people living in this region, 1089 are diagnosed with cancer. The rate of cancer in the Malwa region is 36.13% higher than the national average of 800 in a million. Such a high cancer rate can be attributed to contamination of ground water by heavy metals such as As (Arsenic), U (Uranium), Pb (Lead), Se (Selenium) Hg (Mercury), and other metals. It is well established that Uranium poisoning is rampant in the Malwa region of Punjab. As per the Bureau of Indian Standards (BIS), the permissible limit of uranium in ground water is 30ppb. However, in Bathinda, the uranium content ranges from 30ppb to 325.1ppb, which is a staggering 980% higher than the permissible limit, making heavy metal contamination a serious issue. In this paper, we will be analyzing data on heavy metal contamination and identifying the main sources of such contamination of groundwater. Moreover, we will be exploring the effects of such heavy metals on the human body and how they affect cancer rates while also discussing potential affordable technologies that could be used to battle this issue.

Keywords: Cancer risk, groundwater, health hazards, heavy metals contamination, Malwa region, mitigation

INTRODUCTION

Heavy metals are defined as metallic elements with relatively high atomic weight or densities, which are toxic in low amounts [1]. The density of most heavy metals is known to be at least 5 times greater than water [2]. Due to their toxic nature, a lot of heavy metals such as As (Arsenic), Cr (Chromium), Cd (Cadmium), U (Uranium), etc. are known to be carcinogens. The most common heavy metals are Arsenic, Chromium, Cadmium, Copper, Lead, Mercury, Nickel, Uranium, and Selenium [3]. The contamination of freshwater or groundwater due to heavy metals can be due to both anthropogenic and natural (geogenic) reasons. Even though there is a natural presence of some number of heavy metals in the Earth's crust, in the recent days, the main source of contamination of groundwater is due to industrial activities such as mining and digging as well as urbanization [4]. The state of Punjab is facing a grave problem of heavy metal contamination from metals such as Uranium, Arsenic, Selenium and many more. Ample amount of testing has been done by the Central Government Water Board (CGWB) of India. According to one such report, a total of 2420 villages are affected by heavy metal contamination in India, out of which 88% of the villages fall in Punjab (2139), and the rest falling in

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Received Date: September 20, 2024
Accepted Date: September 26, 2024
Published Date: October 17, 2024

Citation: Shivank Mahajana, Hardev Singh Virk. Heavy Metal Contamination of Groundwater in Malwa Region of Punjab and Potential Technological Solutions. Journal of Water Pollution & Purification Research. 2024; 11(3): 1–14p.

the states of West Bengal and Assam [5]. The state of groundwater resources in Punjab is deplorable. According to a groundwater resource assessment conducted by the CGWB in 2022, the state of groundwater has been termed as "over-exploited" or "critical" in most regions of Punjab [6]. Our study mainly aims to investigate the correlation between the high cancer rates in the Malwa Region of Punjab and heavy metal contamination of groundwater in this region by focusing on heavy metals which are known to be carcinogens. Moreover, we also aim to investigate the causes of heavy metal contamination in this region as well as the adverse health effects due to prolonged exposure to heavy metal ingestion through water. We will also explore currently available technologies for detection of heavy metals in water and discuss the feasibility of implementing such solutions for removal of heavy metals in Bathinda district.

BACKGROUND INFORMATION

Guidelines and Standards for Water

WHO (World Health Organization), as an international body, is responsible for setting the acceptable limits of certain elements in groundwater. Such limits are set to ensure the safety of people in the name of public health. These limits are also set by WHO to encourage the development of national standards that encourage the safety of drinking water. These national guidelines may be set on the basis of the national, local, regional or geographical context of the region. As per the 4th Edition of the WHO GDWQ (World Health Organization Guidelines for Drinking Water Quality), published in 2017, the following are the acceptable limits of metal concentrations in groundwater [7] (Table 1).

Table 1. Acceptable limits set by WHO.

Elements	Acceptable Limit in ppm
Arsenic	0.01
Cadmium	0.003
Chloride	200-300
Chlorine	5.0
Chromium	0.05
Mercury	0.006
Nitrate	50
Uranium	0.3

Causes of Heavy Metal Contamination of Water

As discussed earlier, the causes of heavy metal contamination in this region are due to both natural and man-made causes. Over the years, several assumptions and hypotheses have been made to explain the high level of contamination, ranging from geogenic causes like river flow to man-made causes like over-usage of pesticides. It is relevant to assume that there might be some geogenic causes associated with such high metal concentration. First, climate plays a major effect on such contamination. The Malwa region is a water-logged region, due to which there is low mobility of groundwater. Moreover, due to its aridity, high rates of evaporation can be seen. These factors, coupled with a high concentration of TDS (Total Dissolved Salts) and a high salinity of the soil leads to enrichment of heavy metals such as Uranium. Another potential reason for such contamination is geogenic mobilization of metals due to water bodies. For example, geochemical and geological data indicates that the high presence of Uranium in the groundwater is primarily due to the mobilization of uranium from water bodies originating from the Himalayan Siwaliks [8].

While geological causes are not something that can be helped, anthropogenic causes certainly are. Human activities due to rapid industrialization and urbanization also lead to heavy metal contamination of water. One of the main causes of contamination of water in the Malwa Region is due to fly ash of coal, which is burnt in various industries, but predominantly in the thermal power plants located in the

Bathinda district. The use of coal in thermal power plants is extremely toxic as this fly-ash contains high levels of toxins with at least 17 toxic heavy metals and contaminants being present there like lead, cadmium, etc. [9]. The fly ash from thermal power plants contains high levels of uranium content as well. Moreover, it is known that in S-W Punjab, agriculture serves as the main source of income. Punjab has a history of over-usage of pesticides. In the green revolution in 1960s and 1970s, high-yielding cotton grains were introduced in Punjab. However, cotton is also susceptible to attacks from species such as *Helicoverpa armigera* (American Bollworm) and pink bollworms. As farmers started spraying pesticides, these species grew resistant to it, leading to the farmers spreading more and more of it [10]. Pesticides are usually sprayed in the months of July and August, during which temperatures are at a high. Such temperatures cause the pesticides to be suspended in air for a long time, causing other health risks.

Due to the silty soil of the Malwa region, there is less water holding capacity, leading to leaching of the soil as heavy metals, pesticides and other impurities present in the soil percolate downwards and eventually reach the groundwater, thus contaminating it [11]. It is also known that phosphate fertilisers and pesticides contain indiscriminate amounts of arsenic, cadmium and mercury which pollute our soil and subsequently pollute our water due to percolation [12]. Moreover, such heavy metal contaminated water is used for the irrigation of crops, and they absorb the heavy metals. Once these metals come into the food chain, they spread from one trophic level to the other. It is reasonable to conclude that there is a cycle for the contamination due to heavy metals as it goes from industry, atmosphere, soil, water, food and finally humans.

MATERIALS AND METHODS

Sources of Data

Since the contamination of water in Punjab is a huge problem, several efforts have been taken up by the Government of India and the ministries under it for the surveillance of water quality in this region. Some central agencies include the CGWB, which comes under the *Ministry of Jal Shakti* in India. They are responsible for conducting extensive analysis of various groundwater samples in all states of India, including Punjab. Moreover, they make most of their data public through various reports such as the *Groundwater Resource Assessment* (GWRA) and a *Ground water Yearbook* for all states of India as well as Union Territories. While there have been some studies conducted by the Punjab government specifically for this purpose, none of them are recent, with the last study being conducted in 2014 titled, "*Water Quality Issues and Challenges in Punjab",* which primarily discusses the negative effects of water pollution and contaminated water on the livestock, the environment as well as industries. One of the main factors attributed to pollution is pesticide usages, crediting the dramatic rise of pesticides in Punjab's cotton belt during the Green Revolution. Most of the data evaluated in this study is present on government websites such as PWSSD (Punjab Water Supply and Sanitation Department) as well as CGWB (Central Government Water Board). All the samples of water collected in the state of Punjab are analyzed in the sophisticated laboratory of PWSSD in Mohali using state-of-the-art machinery such as ICPMS (Inductively Coupled Plasma Mass Spectrometry) and Iron Chromatography.

Calibration of ICP-MS

Calibration experiment is necessary for the estimation of concentration of heavy metals in groundwater using the Agilent 7700 Series ICP-MS, with a detection limit ranging from <100 ppb to <1 ppt. The quantification was performed against the Certified Reference Material (CRM) 2A by Agilent Technologies (Part Number 8500-6940). Six concentration standards were meticulously prepared and introduced into the ICP-MS through an S10 auto-sampler unit. To establish a reliable calibration, a linear curve was constructed, exhibiting a high correlation coefficient (R2 ≥ 0.999) for all selected metals. Following the calibration, one quality control (QC) check and analysis of two different standards (20 and 50 ppb) were conducted both before and after sample processing. The Relative Standard Deviation (RSD) was determined to be below 4%, aligning with the standards set by the Bureau of Indian Standards (BIS) for measuring drinking water samples [13].

DISCUSSION AND RESULTS

Uranium

The analysis of water samples for uranium has been done at the Regional Advanced Water Testing Laboratory (RAWTL) of Punjab government located in the environs of PWSSD in Phase II of SAS Nagar (Mohali). The data for uranium concentration in Bathinda district is listed in Table 2 (Retrieved from Virk, 2019 [14]).

Table 2. U concentration of groundwater in Bathinda district.

S.N.	Name of Village	Source of Groundwater	Uranium Concentration (ppb)
1	Bhunder	Tubewell	325.100
2	Dulewala	Tubewell	205.800
3	Patti Karam Chand	Tubewell	164.000
4	Mehraj Patti Kala	Tubewell	164.000
5	Basti Talwal Khiali Gurusar	Tubewell	164.000
6	Kothe Maha Singh	Tubewell	164.000
7	Basti Kothe Ratia	Tubewell	164.000
8	Kothe Piple	Tubewell	164.000
9	Basti Tapahan Wala	Tubewell	164.000
10	Basti Rampura Road	Tubewell	164.000
11	Gurusar Mehraj	Tubewell	164.000
12	Gidder	Tubewell	140.500
13	SC Basti	Tubewell	140.500
14	Dulewala	Tubewell	139.900
15	Dhinger	RO Raw Water	123.580
16	Kothe Hardev Singh	RO Raw Water	123.580
17	Sema	Tubewell	101.000
18	Basti Himatpura	Tubewell	98.126
19	Gurusar Mehraj	Tubewell	98.126
20	Kalyan Malki	Tubewell	94.100
21	Kalyan Sadda	Tubewell	94.100
22	Kalyan Sukha	Tubewell	94.100
23	Bhai Rupa	Tubewell	88.600
24	Dhapali	Tubewell	87.000
25	Rayia	Tubewell	83.700
26	Adampura	Tubewell	77.375
27	Kotra Kaureana	Tubewell	72.300
28	Bhaini	Tubewell	66.500
29	Ghurelli	Tubewell	66.100
30	Pitho	Tubewell	65.000
31	Sandhu Khurd	Tubewell	62.900
32	Salabatpura	Tubewell	61.600

33	Gurdit Singh Wala	Tubewell	52.000
34	Jamine Basti	Tubewell	52.000
35	Diyalpura Bhaika	Tubewell	52.000
36	Basti Surjitpura	Tubewell	52.000
37	Basti Pitho Road	Tubewell	39.500
38	Badiala	Tubewell	39.500
39	Basti Market	Handpump	32.100
40	Jethuke	Handpump	32.100

As per the AERB (Atomic Energy Research Board), the permissible limit of uranium in water is 60*μ*g/L (ppb), whereas the guidelines released by BIS (Bureau of Indian Standards) state that the permissible limit is 30μg/L [15]. An essential information to note while referring to permissible limits for different metals in Table 1 is that $1\mu g/L = 1ppb$. In accordance with the AERB limits, 32 out of the 40 localities assessed are above the permissible limit set by AERB and uranium levels in all 40 localities are above the limit set by the BIS.

Figure 1 depicts the villages where the U values exceed the WHO limit of 30*μg/L* and the AERB limit of 60*μg/l*. The highest U concentration in groundwater is found in Bhunder village of Bathinda district followed by Dulewala.

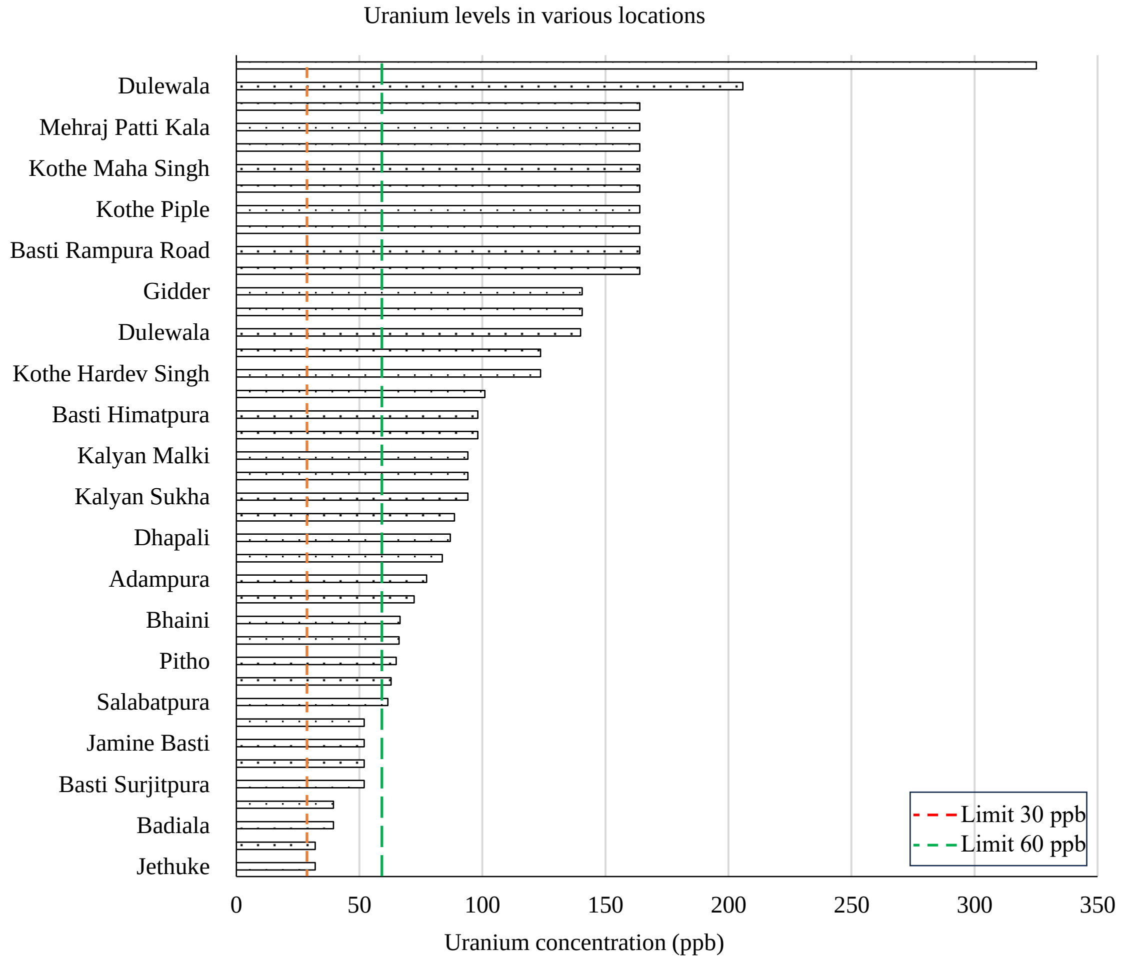

Figure 1. Uranium concentration in groundwater of Bathinda district.

With the ingestion of uranium, comes several health hazards. Theoretically speaking, ingestion of uranium leads to two types of risks: radiological and chemical [16]. Radiological risk is due to the radioactivity and radiation by uranium whereas chemical risk is due to Uranium being a heavy metal.

RADIOLOGICAL RISK ASSOCIATED WITH URANIUM INGESTION

To calculate the additional risk, set formulas were published by the United States Environmental Protection Agency (USEPA) in the year 2000 [17]:

Excess Cancer Risk = Uranium Level in Water (Bq/L) × Risk Factor (in Bq/L)
Risk factor is calculated as the product of the risk coefficient of uranium and the ingestion rate:
Risk Factor = Risk coefficient of Uranium × Total ingestion
The radioactivity concentration of uranium in Bq/L is 25 Bq in 1mg of water [18]. Thus:
Uranium Level (Bq/L) = Uranium Level ($\mu g/L$) × conversion factor (0.025$Bq/\mu g$)

Risk coefficients signify the additional risks or the change in lifetime cancer risk due to inhalation or ingestion of uranium [19]. Two other factors that will be used in calculating excess cancer risk are the morbidity and the mortality coefficients. Morbidity is the total number of cancer (fatal + non-fatal) whereas mortality is the total number of cancers that result in death. As per the USEPA, the cancer mortality coefficient for U-238 is 1.13×10^{-9} and the cancer morbidity coefficient 1.73×10^{-9} [20].

For the calculation of ingestion rate, we take the average amount of water consumed per day, which is 4.05 l/day and the average life expectancy is taken as 63.7 years (average of males and females) which is 23250 days [21]. Thus, total ingestion is:
Ingestion = 23250 days × 4.05l/day

Drawing upon our results, the cancer mortality risk of people who consume the contaminated water samples range from 1.64×10^{-4} to 8.647×10^{-4}, with the lowest value being in sample 32 (Salabatpura) and the highest value in sample 1 (Bhunder) from Table 2. This value is 8.6 times higher than the generally accepted level of radiological risk (10^{-4}), according to the limit set by AERB. In a similar fashion, the cancer morbidity ranges from 2.5×10^{-4} to 13.24×10^{-4}, which is an astonishing 13 times higher than the acceptable value.

ARSENIC

Arsenic contamination due to anthropogenic and geogenic causes in India is known in the states of Jharkhand, West Bengal, Punjab, Bihar and some other parts of Northern India. The first cases of Arsenic contamination (Arsenicosis) were observed in July 1983 in West Bengal [22]. Since then, numerous studies have been conducted to detect arsenic content in certain areas. A survey of 140,150 hand-tubewells in West Bengal found that 48.2% of samples had arsenic levels greater than 10 μg/L and 28.3% of the samples' levels were greater than 50 μg/L, contrary to the acceptable limit of 10μg/L. The study also showed that 90% of the children living in Arsenic affected villages had elevated arsenic content in their hair and nails [23]. Such a dominant risk of children being affected from arsenic toxicity is primarily due to higher water consumption on a body-weight basis. Arsenic is associated with several serious diseases and health issues and is categorized as one of WHO's 10 chemicals of public concern. Short term exposure of high levels of arsenic can result in acute arsenic poisoning which includes vomiting and diarrhea. Long term exposure to Arsenic through drinking water or food takes a long time with the first 5 years showing early pigmentation changes, lesions, hyperkeratosis etc. which serve as a precursor for skin cancer [24]. Potential Skin, lung or bladder cancer have led the International Agency for Research on Cancer to classify Arsenic as a carcinogenic [25]. Another adverse effect of Arsenic is on pregnancy outcomes. Exposure of arsenic to the mother can cause indirect exposure to the children in their uterus. Such exposure in the foetal stage or in early childhood years has increased mortality rates in young adults in their 20s due to cancer [26]. Early exposure of arsenic has also been attributed to negative impacts on cognitive thinking, memory and intelligence [27].

It has been established that arsenic concentration levels in groundwater are highest in the Majha belt districts, especially Amritsar [28, 29]. However, if we are to focus on the Malwa region, high levels of Arsenic have indeed been detected in parts of Malwa region such as Ferozepur district. Table 3 represents the arsenic concentration values for the Ferozepur district (Retrieved from Virk 2019 [30]), filtered to show high values of above 0.02 mg/L (Acceptable Value is 0.01 mg/L).

Table 3. Arsenic concentration in groundwater of Ferozepur district.

S.N.	Villages Surveyed	Groundwater Source	Arsenic (mg/l)
1	Bhadru	Tubewell	0.021
2	Ugo Ke	Tubewell	0.021
3	Ittian Wali	Tubewell	0.021
4	Mohkam Wala	Tubewell	0.021
5	Yare Shah Wala	Tubewell	0.021
6	Suwah Wala	Tubewell	0.022
7	Lehra Rohi	Tubewell	0.022
8	Boor Wala	Tubewell	0.024
9	Ch. Swah Wala	Tubewell	0.024
10	Basti Ram Lal	Tubewell	0.024
11	Basti Khan Ke	Tubewell	0.024
12	Basti Bagicha Singh	Tubewell	0.024
13	Basti Walia Wali	Tubewell	0.024
14	Basti Bhane Wali	Tubewell	0.024
15	Basti Ladhu Wali	Tubewell	0.024
16	Basti Chamre Wali	Tubewell	0.024
17	Basti Jhuge Kahan Singh	Tubewell	0.024
18	Rukna Wala	Tubewell	0.026
19	Kamal Middu	Tubewell	0.027
20	Sultan Wala	Tubewell	0.027
21	Changian	Handpump	0.029
22	Hamad Wala	Tubewell	0.030
23	Baggu Wala	Tubewell	0.031
24	Swah Wala	Tubewell	0.031
25	Gillan Wali	Tubewell	0.031
26	Nizam Wala	Tubewell	0.031
27	Dhindsa	Tubewell	0.031
28	Basti Gainder	Tubewell	0.031
29	Qutab Wala	Handpump	0.034
30	Bhamba Singh Wala	Tubewell	0.036
31	Palla Megha	Tubewell	0.036
32	Harijan Gura Singh	Handpump	0.055

Table 3 shows the values of Arsenic content in groundwater in various villages in Ferozepur district. The range of values varies from 0.021 - 0.055 mg/L, which is a staggering 5 times higher than the acceptable value. Chronic exposure to arsenic can cause compromised cognitive outcomes in youth as well as dermatological side-effects like lesions and hyper-keratosis, which could mark the beginning of skin cancer. Figure 2 shows the distribution of Arsenic in different villages of Ferozepur district to have a proper perspective, with the red line in the graph depicting the acceptable limit of 0.01 mg/L.

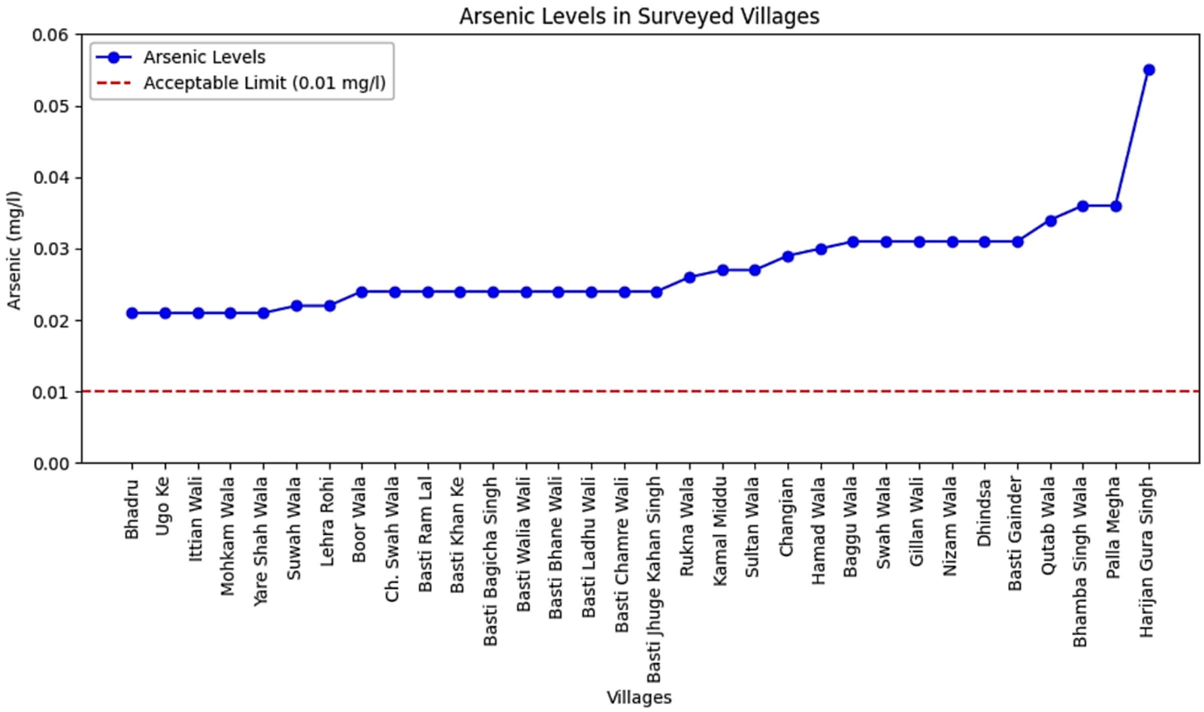

Figure 2. Arsenic distribution in groundwater of Ferozepur district

Lead

Lead contamination is a very serious concern in today's world. It has a drastic effect on children, with lead poisoning due to consumption of food being rampant since WW2 times. Some causes of lead contamination could be disposal of industrial affluents in water, lead-acid battery and its production, and production of various paints [31]. In Punjab, lead contamination is due to both geogenic and anthropogenic causes. For example, the Sutlej River, which serves as the main source of water for Punjab is known to contain high metal deposits along its boundary and in the pre-monsoon season [32]. Lead contamination causes both neurological and physical disabilities with specific damage to the kidneys and endocrine systems [33]. Moreover, lead contamination has also been linked with learning disabilities and behavior abnormalities in children. Children of ages 1-7 are particularly vulnerable to lead contamination [34]. Unlike other metals where a significant amount is needed to cause chronic health effects, even low lead blood levels can cause the above symptoms [33]. Considering such high levels of risk associated with lead exposure, ingestion and consumption, it is of utmost importance that exposure to lead must be prevented. Fortunately, limitation of lead exposure through water is relatively easy, with most RO (Reverse Osmosis) systems accounting for filtering of lead. However, lead contamination of groundwater does not only have direct effects on humans, but also have indirect effects on humans through plants. Contaminated groundwater, when used for irrigation, can lead to heavy metal contaminants moving across trophic levels. Even in plants, lead contamination leads to limited yields, reduced soil fertility and microbial activity as well as food chain contamination [34]. Table 4 shows the lead (Pb) levels in groundwater of Bathinda (Retrieved from Duggal et al. 2018 [35])

Approximately 46.67% of the samples exceed the recommended value of 0.01 *mg/L* for lead in groundwater. Lead concentration values range from 0.0023− 0.0779 *mg/L*, with the highest value being an astonishing 8 times higher than the permissible limit. The mean value of lead in Bathinda district from the above data is 0.0179 *mg/L*, which is 79% higher than the permissible limit. The standard deviation of the above values is 0.0199 *mg/L*. The lead distribution in Bathinda district is represented by a bar diagram (Figure 3), with the red line denoting the acceptable limit of 0.01*mg/L*, set by the Indian Bureau of Standards (Table 1). It puts things into a proper perspective about the dire situation of lead contamination in Bathinda district.

Table 4. Lead conc. in groundwater of Bathinda district.

S.N.	Sample Location	Pb (mg/L)
1	Malkana	0.0145
2	Rama Mandi	0.0779
3	Jajjal	0.0046
4	Talwandi Sabo	0.0319
5	Laleana	0.0286
6	Maur	0.0105
7	Sangat	0.0023
8	Kot Shamir	0.0131
9	Bathinda city	0.0075
10	Balluana	0.0457
11	Rampura Phul	0.0074
12	Nathana	0.0097
13	Goniana	0.0050
14	Bhai Rupa	0.0056
15	Bhagta	0.0048

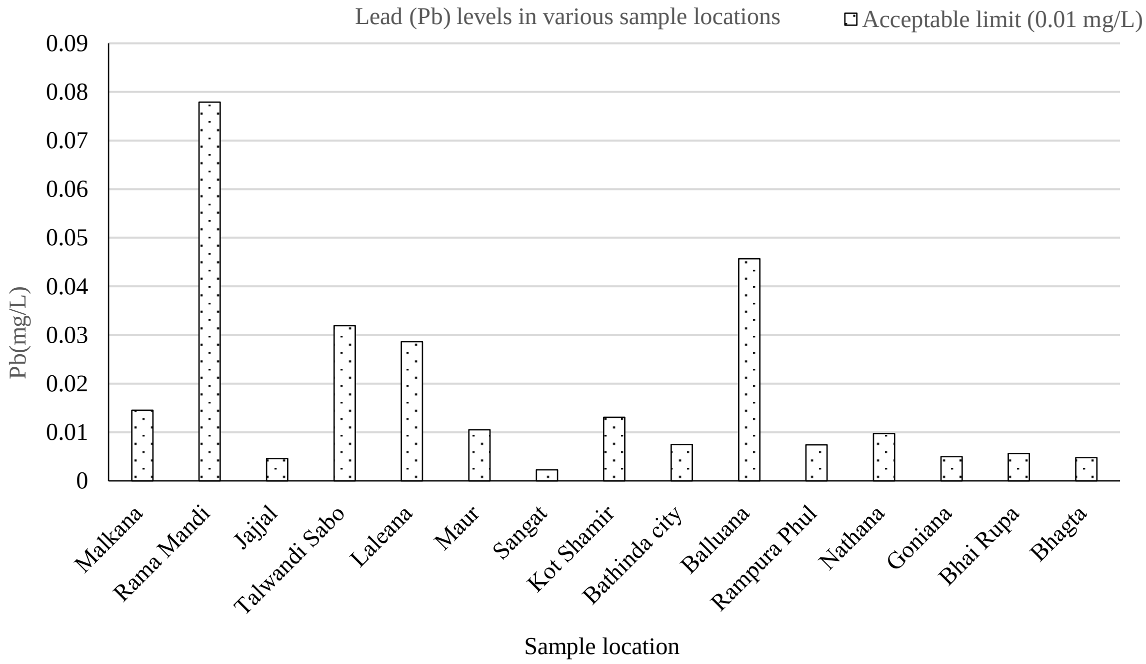

Figure 3. Lead distribution in groundwater of Bathinda district

POTENTIAL TECHNOLOGICAL SOLUTIONS

Heavy metal contamination of water bodies presents a significant environmental and health challenge. These persistent pollutants, including arsenic, uranium, and lead, require sophisticated treatment processes to ensure safe water consumption. A myriad of technological approaches have been developed to address this issue, each with its own strengths and limitations. These technological advances are paramount to our society and can be readily implemented in the state of Punjab. While some of these technologies might be a bit too advanced to be implemented on a mass scale, it is essential that the Government of India at least look into them and determine the feasibility of these technologies on the basis of various socio-economic factors. Employing the use of these technologies, various new kinds of filters can be made readily available to people on a mass scale. While some of these technologies such as RO (Reverse Osmosis) are already implemented in a lot of homes in Punjab, it is essential to look for other alternatives as well.

Membrane Based Technologies: Membrane based technologies are extremely popular right now, primarily due to its versatility. Membrane based technologies include nanofiltration, ultrafiltration, reverse osmosis and electrodialysis. Membrane based technologies are known for their ability to treat various affluents, be suspended solids and organic compounds, or inorganic contaminants and heavy metal removal [36]. Basically, how membrane filtration works is that it applies pressure to the liquid to be filtered, forcing the liquid through a membrane which has specific pore sizes [37]. These pore sizes are determined by the kind of filtration taking place. For example, a nano-filter's pore size ranges from $0.001 - 0.01\mu m$ whereas ultrafilter's pore size ranges from 0.02 to 0.01 μm [38]. This membrane allows smaller particles like water molecules to pass through whereas particles (which would be the affluents) stay above the membrane. Membrane filtration's effectiveness depends on several factors such as membrane type, operating conditions (parameters such as temperature, pressure, etc.) and fouling/cleaning (cleaning of accumulated particles stuck in the membrane) [39, 40]. Membrane filtration is preferred and more effective because it provides an advantage over more archaic methods of filtration. It avoids secondary pollutant generation and enables material recovery. For example, while cleaning/fouling the membrane, affluents that are stuck can be collected. The energy input required for different kinds of filtration is different. While reverse osmosis and electrodialysis require large inputs of energy, ultrafiltration offers a low energy alternative [41].

Nanofiltration (NF): It presents a less aggressive alternative to RO. Membranes used in nanofiltration have larger pore sizes and retain larger ions, while allowing the smaller ones to pass. This enables us to remove certain heavy metals, particularly those with large ionic radii. NF systems generally consume less energy compared to RO, making them a more suitable option for low-cost filters.

Adsorption Processes: Adsorption is a widely used technique for the filtration of heavy metals from water. Basically, it involves the accumulation of heavy metal ions on a solid adsorbent material such as agricultural waste, clay minerals, activated carbons or even elements such as granular ferric hydroxide [42]. Adsorption is a highly preferred method of removing heavy metals from water, primarily because of its cost-effectiveness, since low-cost adsorbents such as agricultural waste and industrial by-products can be used. They are also highly efficient, with heavy metal contamination in water being reduced to a great extent. Lastly, they are extremely versatile, as they can be used for a wide range of water sources [43]. But they also have a similar problem to membrane-based technologies, which is the requirement of fouling/cleaning of the adsorbent surface.

A popular adsorbent used for the removal of heavy metals from water is activated alumina, which is a porous, granular form of aluminium oxide (Al_2O_3). Activated alumina facilitates exchange of heavy metal ions with its own hydroxide ions, thus resulting in the effluents being removed [44]. It is particularly effective in removing heavy metals like lead, cadmium and copper. Activated alumina is widely used because of its cost-effectiveness. It possesses a large surface area, which increases adsorption of heavy metals [45]. Moreover, it has high regeneration potential, which means it can be regenerated and reused [46].

Another popular adsorbent that is specifically designed for arsenic removal is Granular Ferric Hydroxide (GFH). Studies show that GFH can attain significant removal rates for heavy metals from water, thus the reason it is used for both industrial as well as municipal water treatment. One advantage that GFH has over-activated alumina is that it is environment friendly as it does not produce any harmful by- products [45].

Advanced Oxidation Processes (AOPs): AOPs are being widely recognised as an effective method to remove heavy metals from water. AOPs are defined by their ability to generate hydroxyls ($\cdot OH$), which allows them to oxidise a wide range of pollutants including heavy metals [47]. Common AOP methods include UV light combined with hydrogen perioxide, ozone oxidation, Fenton's reagent, etc. AOPs have the ability to oxidise heavy metals, converting them into lesser toxic forms. AOPs can also convert heavy metals into insoluble forms, which can then easily be removed. Adsorption is also a type of AOP [48]. UV radiation combined hydrogen peroxide (UV/H_20_2) can also produce hydroxyl radicals. This type of AOP is highly effective in removing arsenic [49]. Fenton's reagent is another AOP, comprising of hydrogen peroxide and Iron, and also produces hydroxyl radicals [50]. However, both of these AOPs generate a lot of sludge, requiring appropriate treatment.

CONCLUSIONS

The issue of heavy metal contamination of water in the state of Punjab is a serious issue which plagues the community. It is an urgent environmental crisis which requires effective solutions.

Our study aims to highlight the prevalence of heavy metals (U, As, and Pb) in the ground waters of Bathinda and Ferozepur districts of the Malwa region of Punjab. The potential health effects of these heavy metals have been discussed and even calculated excess cancer risk of uranium contamination in water, which is a staggering 8 times higher than the prescribed limit of 10^{-4} as per AERB guidelines. These contaminants, often originating from both natural and anthropogenic sources, pose significant risks due to their toxicity and persistence in the environment. Potential technological solutions to remove heavy metal contamination of water in the Malwa region of Punjab have been proposed.

However, the implementation of these technologies must be tailored to specific local conditions and contaminants. It is crucial to consider factors such as the scale of contamination, the economic feasibility of the technology, and the potential for long-term maintenance and monitoring. Furthermore, a comprehensive approach that includes policy measures, community awareness, and ongoing research is essential to address the complex challenges of heavy metal contamination effectively.

This study underscores the need for continued innovation and collaboration among scientists, policymakers, and communities to develop and implement strategies that ensure safe and clean water for all. By advancing our understanding of contamination mechanisms and enhancing technological solutions, we can mitigate the impacts of heavy metals on health and the environment, paving the way for a healthier and more sustainable future.

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