Arsenic Contamination in Groundwater of Haryana's National Capital Region and Their Comparative Assessment (Mahendragarh, Rewari, and Jhajjar Districts)

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Abstract:

The present study is a comparative research paper on arsenic contamination in groundwater between three districts in Haryana, India: In terms of Mahendragarh, Rewari and Jhajjar, based on the data obtained. This research highlights the extent of arsenic in multiple water sources, its prevalence and variability, as well as factors that may contribute to its levels, health impacts, and implications for agriculture. The results indicate a clear regional pattern, with arsenic contamination being most pronounced in Mahendragarh and having the highest variability of values in Jhajjar. Statistical analysis has proved that these differences are very significant. The variability in the patterns of contamination is due to a complex interaction of the geological and hydrogeological factors, climatic and soil conditions as well as human influences. On top of that, the research also addresses associations between arsenic exposure and health symptoms among different arsenic populations and hypothesizes that exposure variability is an important factor in determining health. Concerns regarding effects on agriculture and bioaccumulation in crops are also discussed. This research sheds light on the pressing need for remedial action, public health measures and ongoing monitoring in order to combat the massive arsenic contamination crisis and its impacts on human health and agricultural viability in impacted areas.

Keywords: Arsenic, Heavy metal, contamination, Groundwater, Haryana.

Introduction

Although naturally occurring, arsenic is one of the greatest public health threats in the world because it's very high toxicity can occur even after long-term exposure, as well as its prevalence globally in groundwater. Of the three forms of arsenic, the inorganic variety is the most toxic and a well-known carcinogen that the World Health Organization has identified as one of the top ten compounds harmful to public health. Arsenic poisoning, via drinking water and food, accounts for millions of cases globally. As maximum limit of arsenic on drinking water, World Health Organization. (2019), US-EPA and EU suggest acceptable levels of 10 parts per billion (ppb) or 10 micrograms per liter (μg/L) [1]. In the case of India, the permissible concentration set by IS: 10500 is 0.05 mg/L (50 mμg/L), while levels above 10 mμg/L are viewed with concern. Groundwater Arsenic has been a major concern in the geography of some regions of India, including West Bengal (2017, 2013, 2010, 1996) [2, 3, 4, 5], Assam(2004) [8], Bihar (2016) [7], Chhattisgarh (2017) [10], Haryana (2021) [12], Jharkhand (2022) [9], Karnataka(2017) [11], and Uttar Pradesh(2019) [6]. This has often been attributed to geogenic sources, in which arsenic is released from rocks and sediments into groundwater by natural chemical processes. This issue can be intensified by anthropogenic influences, such as over-extraction of groundwater for irrigation or industrial processes, which can change flow patterns and potentially concentrate arsenic itself. Groundwater arsenic pollution has also been reported in the Indian northern state of Haryana. The present study narrows down to Mahendragarh, Rewari and Jhajjar districts of Haryana comparing the nature and prevalence of arsenic contamination within the groundwater in the districts. The goal is to provide an analysis of the collected data to gain insights into what might be driving the spatial distribution of arsenic concentrations and arsenic concentration variability, the reason for the impact on health and agriculture in these districts.

Materials and Methods

This study is based on the analysis of obtained data concerning arsenic contamination in groundwater in Mahendragarh, Rewari, and Jhajjar districts of Haryana. The data includes descriptive statistics of arsenic concentration in water (ppb) and relative standard deviation (RSD), as well as results from statistical tests (t-tests and ANOVA) comparing these parameters within and between the districts. The study also incorporates information on the prevalence of various health symptoms attributed to arsenic exposure and observations on the impact of contamination on different water sources and agricultural practices.

The dataset for each district includes the mean, standard deviation (SD), minimum (Min), and maximum (Max) values for arsenic concentration (ppb) and RSD. Statistical significance within each district was assessed using t-tests, with reported t-values and corresponding p-values. A comparative analysis of the means of arsenic concentration and RSD between the three districts was conducted using ANOVA, with reported F-values and p-values. The significance level for all statistical tests was set at p \< 0.01.

The study also draws upon data related to arsenic levels and RSD in different water sources, including hand pumps, tube wells, and canals, across the three districts. Furthermore, the prevalence of various health symptoms (darkening skin, constant sore throat, skin lesions, tingling in fingers/toes, red swollen skin, abnormal heart rhythm, muscle cramps) in each district is provided, along with the results of ANOVA to assess the statistical significance of the differences in symptom prevalence between the districts.

The results considers the potential influence of geological and hydrogeological features, climatic conditions, soil composition, and anthropogenic activities. The impact on agricultural crops and the relationship between cropping patterns and arsenic variability are also discussed.

Results

The analysis of the obtained data reveals significant variations in arsenic contamination levels and variability across the three districts of Haryana.

Arsenic Concentration in Groundwater:

Table1: DESCRIPTIVE STATISTICS OF THE STUDY VARIABLES OF MAHENDRAGARH LOCATION

Location	Parameters	Mean	SD	Min	Max	T value	P value
	As in Water (conc. ppb)	3.80	0.00	3.79	3.81	5945.016	0.0000**
Mahendragarh	As in Water (conc. RSD)	14.67	0.08	14.50	14.80	1297.739	0.0000**

$**p<0.01$

Mahendragarh, the mean arsenic concentration in water was found to be 3.80 ppb, with a very low standard deviation of 0.00 and a narrow range between the minimum (3.79 ppb) and maximum (3.81 ppb) values. This indicates remarkable consistency in arsenic levels across samples in this district. The t-test for arsenic concentration in Mahendragarh yielded a t-value of 5945.016 and a p-value of 0.0000 (p\<0.01), confirming the statistical significance of the observed concentration.

Mahendragarh, the mean RSD for arsenic in water was 14.67, with a standard deviation of 0.08 and a range from 14.50 to 14.80. The t-test for RSD in Mahendragarh showed a t-value of 1297.739 and a p-value of 0.0000 (p\<0.01), indicating statistical significance.

Table2: DESCRIPTIVE STATISTICS OF THE STUDY VARIABLES OF REWARI LOCATION

Location	Parameters	Mean	SD	Min	Max	T value	P value
	As in Water (conc. ppb)	0.77	0.00	0.77	0.78	2250.969	0.0000**

Rewari	**As in Water (conc. RSD)**	**29.75**	**0.29**	**29.30**	**30.30**	**888.090**	**0.0000****

****p<0.01**

Rewari district showed a mean arsenic concentration of 0.77 ppb, also with a very low standard deviation of 0.00 and a narrow range of 0.77 to 0.78 ppb. The consistency in arsenic levels in

Rewari samples is high. The t-test for arsenic concentration in Rewari resulted in a t-value of 2250.969 and a p-value of 0.0000 (p\<0.01), indicating statistical significance.

Rewari had a mean RSD of 29.75, with a standard deviation of 0.29 and a range from 29.30 to 30.30. The t-test for RSD in Rewari yielded a t-value of 888.090 and a p-value of 0.0000 (p\<0.01), confirming statistical significance.

Table3: DESCRIPTIVE STATISTICS OF THE STUDY VARIABLES OF JHAJJAR LOCATION

Location	**Parameters**	**Mean**	**SD**	**Min**	**Max**	**T value**	**P value**
Jhajjar	**As in Water (conc. ppb)**	**0.88**	**0.00**	**0.88**	**0.89**	**2753.935**	**0.0000****
	As in Water (conc. RSD)	**48.35**	**0.11**	**48.10**	**48.50**	**3183.870**	**0.0000****

****p<0.01**

Jhajjar district had a mean arsenic concentration of 0.88 ppb, with a standard deviation of 0.00 and a range of 0.88 to 0.89 ppb. Similar to the other two districts, there is a certain amount of variability, but the standard deviation is negligible. The t-test for arsenic concentration in Jhajjar yielded a t-value of 2753.935 and a p-value of 0.0000 (p\<0.01), confirming the statistical validity of the observed levels.

Jhajjar displayed the highest mean RSD of 48.35, with a standard deviation of 0.11 and a range from 48.10 to 48.50. The t-test for RSD in Jhajjar showed a t-value of 3183.870 and a p-value of 0.0000 (p\<0.01), supporting the statistical validity of these findings against high RSDs.

Table4: DIFFERENCE IN MEANS OF THE STUDY VARIABLES BETWEEN MAHENDRAGARH, REWARI, AND JHAJJAR LOCATION.

As conc.	Location	**Mean**	**SD**	**Min**	**Max**	**F value**	**P value**
As in Water (conc. ppb)	Mahendragarh	3.80	0.00	3.79	3.81	14317799.160	**0.0000****
	Rewari	0.77	0.00	0.77	0.78		
	Jhajjar	0.88	0.00	0.88	0.89		
As in Water (conc. RSD)	Mahendragarh	14.67	0.08	14.50	14.80	349377.291	**0.0000****
	Rewari	29.75	0.29	29.30	30.30		
	Jhajjar	48.35	0.11	48.10	48.50		

**p<0.01

A comparative analysis using ANOVA revealed a highly significant difference in the mean arsenic concentration between the three districts, with an F-value of 14317799.160 and a p-value of 0.0000 (p\<0.01). Mahendragarh exhibited the highest average arsenic content (3.80 ppb), significantly exceeding that of Jhajjar (0.88 ppb) and Rewari (0.77 ppb).

The ANOVA analysis for RSD also revealed a highly significant difference in the mean RSD values between the three districts, with an F-value of 349377.291 and a p-value of 0.0000 (p\<0.01). Jhajjar showed the maximum variability in measurements (mean RSD = 48.35), followed by Rewari (29.75), while Mahendragarh exhibited the minimum variation (14.67).

Arsenic Levels in Different Water Sources:

Analysis of arsenic content in different water sources (hand pumps, tube wells, and canals) across the districts also showed significant regional variations. In hand pumps, Mahendragarh had the highest mean arsenic concentration (3.604 ppb), followed by Jhajjar (0.885 ppb) and Rewari (0.774 ppb). Jhajjar showed the highest RSD for hand pumps (48.4%), compared to Rewari (29.7%) and Mahendragarh (30.7%).

For tube wells, Mahendragarh again had the highest arsenic content (3.801 ppb) with the lowest variability (14.7% RSD), indicating uniform pollution of deep groundwater. Jhajjar (0.71 ppb, 41.8% RSD) and Rewari (0.589 ppb, 21.7% RSD) exhibited lower concentrations but higher variability.

In canal water, Mahendragarh showed the highest arsenic levels (3.496 ppb, 25.4% RSD). Jhajjar had higher values than its other water sources (0.927 ppb, 46.6% RSD), implying possible surface water system pollution. Rewari canal waters were among the least polluted (0.633 ppb, 26.9% RSD).

Table 5: ANOVA ANALYSIS OF ARSENIC CONTENT IN DIFFERENT WATER SOURCES COLLECTED FROM DIFFERENT REGIONS LIKE JHAJJAR, REWARI, AND MAHENDRAGARH IN HARYANA (n=100 samples).

Irrigation Source	**Region**	**Mean Arsenic (ppb)**	**Mean RSD (%)**	**p-value (Arsenic)**
Hand pumps	Jhajjar	0.885	48.4	0.041 (Significant)
	Rewari	0.774	29.7	
	Mahendragarh	3.604	30.7	
Tube wells	Jhajjar	0.71	41.8	0.0003 (Highly Significant)
	Rewari	0.589	21.7	

	Mahendragarh	3.801	14.7	
Canals	Jhajjar	0.927	46.6	0.007 (Significant)
	Rewari	0.633	26.9	
	Mahendragarh	3.496	25.4	

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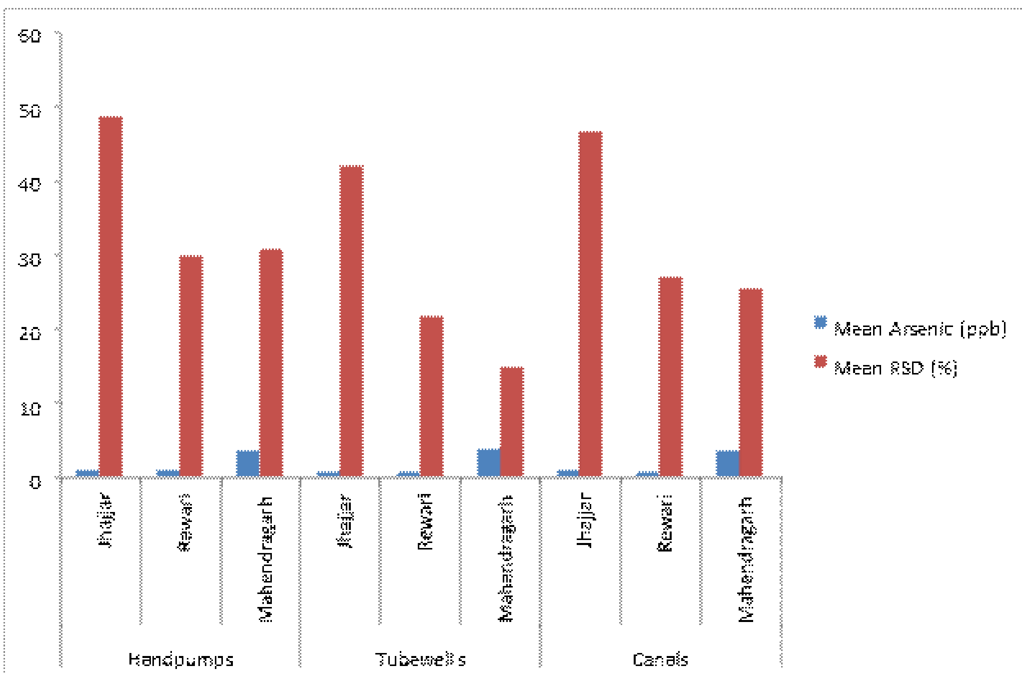

Figure1: (Water source/Site location) shows the mean and RSD values of arsenic found in different sources of water in handpumps, tube-wells and canals in Jhajjar, Rewari and Mahendragarh region of Haryana.

Health Impacts:

The ANOVA results on the prevalence of health symptoms attributed to arsenic exposure showed a statistically significant difference between the three districts. Interestingly, all symptoms were most prominently reported in Jhajjar, which had intermediate arsenic exposure levels (mean 0.88 ppb). The most significant symptoms in Jhajjar included hyperpigmentation (22.50%), persistent pharyngitis (27%), erythematous skin (18.50%), and paresthesia in the extremities (13.50%). Skin lesions (p=0.002) and muscular cramps (p=0.003) showed the most significant differences between locations.

Table6: ANOVA ANALYSIS OF HEALTH PROBLEMS DUE TO ARSENC CONTENT IN

DIFFERENT REGIONS LIKE JHAJJAR, REWARI, AND MAHENDRAGARH IN HARYANA.

Symptom	Jhajjar (Mean %)	Rewari (Mean %)	Mahendragarh (Mean %)	p-value (ANOVA)
Darkening Skin	**22.50%**	**18%**	**14%**	**0.012 (Significant)**
Constant Sore Throat	**27%**	**16.50%**	**12.50%**	**0.005 (Significant)**
Skin Lesions	**5.50%**	**3.50%**	**1.50%**	**0.002 (Highly Significant)**
Tingling in Fingers/Toes	**13.50%**	**11%**	**7%**	**0.018 (Significant)**
Red Swollen Skin	**18.50%**	**14.50%**	**10%**	**0.008 (Significant)**

Abnormal Heart Rhythm	**8%**	**6%**	**4%**	**0.021 (Significant)**
Muscle Cramps	**4.50%**	**2.50%**	**0.50%**	**0.003 (Highly Significant)**

The prevalence of symptoms generally corresponded with the sequence of arsenic RSD values (Jhajjar > Rewari > Mahendragarh) rather than the mean concentration levels (Mahendragarh > Jhajjar > Rewari). This suggests that the variability in arsenic exposure may have a greater impact on health outcomes than the absolute concentration values. The high RSD in Jhajjar could imply more fluctuation in arsenic levels, leading to intermittent exposure to high peak concentrations that may cause more severe health effects despite a lower mean concentration.

Agricultural Impacts:

The study indicates a multifaceted relationship between agricultural practices and patterns of arsenic contamination. Regions with diverse crops and water-intensive cultivation like rice and sugarcane showed higher variability in arsenic content (RSD values between 41.8 and 48.4). This is particularly alarming given that rice is known for efficient arsenic uptake. Areas primarily cultivating crops like wheat, mustard, and bajra showed moderate fluctuations (RSD 21.7-29.7). Regions with crops like gram requiring less irrigation exhibited lower variability (RSD 14.730.7). The co-occurrence of other heavy metals alongside arsenic raises concerns about potential synergistic harmful effects on agricultural productivity and health through bioaccumulation in food crops.

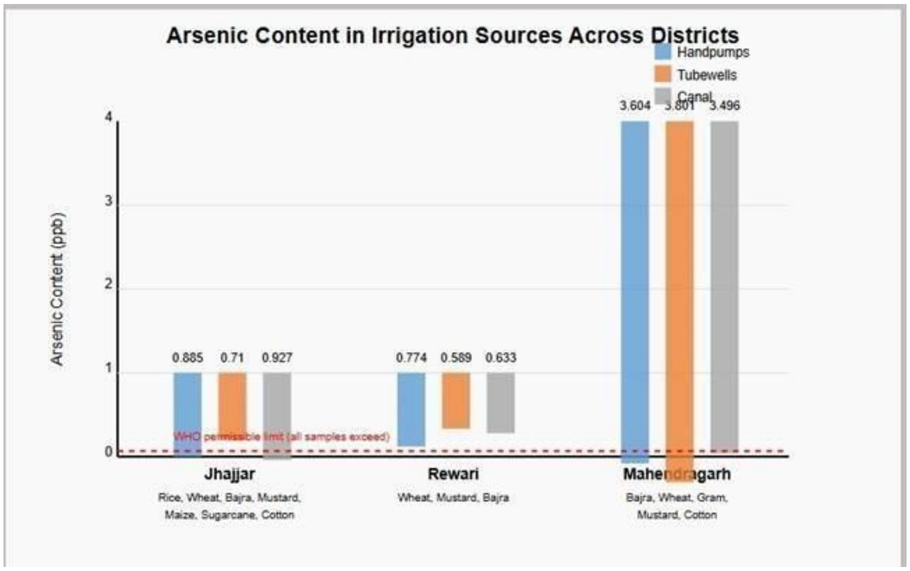

Figure2: Shows the arsenic concentration (in ppb) with crops growing in different regions of Haryana like Jhajjar, Rewari and Mahendragarh.

Discussion

The findings of this comparative analysis underscore the significant challenge of arsenic contamination in groundwater in Mahendragarh, Rewari, and Jhajjar districts of Haryana. The observed disparities in arsenic concentration and variability between the districts highlight the influence of localized geological, hydrogeological, and anthropogenic factors (Smedley & Kinniburgh, 2002) [13].
Mahendragarh consistently high arsenic concentrations across different water sources, coupled with low RSD, suggest a widespread and uniform source of contamination, likely geogenic in origin. The distinct geology of Mahendragarh, characterized by schist rocks rich in arsenic, combined with low precipitation, stagnant deep aquifers, and potentially mining activities, could contribute to this severe and uniform pollution. The low rainfall in this semi-arid region limits the dilution and removal of pollutants.

In contrast, Jhajjar and Rewari exhibit lower mean arsenic concentrations but higher variability, particularly in Jhajjar. This suggests that while geogenic sources are likely involved, other dynamic factors play a more significant role in influencing arsenic levels in these areas (Smedley & Kinniburgh, 2002) [13]. The alluvial soils with clay and sand layers in Jhajjar, moderate rainfall, shallow aquifers with seasonal fluctuations, and extensive groundwater depletion for irrigation can lead to more heterogeneous arsenic distribution patterns and increased variability in concentrations. Similarly, Rewari semi-arid climate, low precipitation, high evaporation, and varied geology with quartzite rocks and alluvial deposits can contribute to concentrated arsenic in residual groundwater and greater variability in analytical precision.

The unexpected inverse correlation between arsenic concentration and the prevalence of health symptoms, where Jhajjar with intermediate concentration shows the highest symptom prevalence, is a critical finding. This challenges the assumption that health impacts are solely dictated by mean arsenic levels and suggests that the pattern and variability of exposure may be more crucial. High variability in arsenic levels, as seen in Jhajjar, could lead to intermittent exposure to high peak concentrations, causing more significant health damage even if the average concentration is lower. Additionally, exposure through other pathways, such as the consumption of arsenic-accumulating crops like rice, which is cultivated in Jhajjar, could contribute to the observed health effects.

The impact on agriculture is also evident, with water-intensive cropping patterns potentially influencing the variability of arsenic in irrigation water. The bioaccumulation of arsenic and other heavy metals in food crops poses an additional health risk to the population.

The findings align with previous research highlighting the geogenic nature of arsenic contamination in groundwater in the Ganges-Brahmaputra-Meghna delta and other alluvial plains, including parts of India. Studies have also shown that geological formations, hydrogeological conditions, and anthropogenic activities significantly influence arsenic mobilization and distribution in groundwater (Smedley & Kinniburgh, 2002) [13]. The complex speciation of arsenic in water, with varying toxicity of inorganic forms like As (III) and As (V), further complicates the assessment of health risks (Smedley & Kinniburgh, 2002) [13].

The statistically significant differences in both arsenic levels and health symptom prevalence between the districts underscore the need for region-specific interventions. While Mahendragarh requires urgent measures to address high and widespread contamination, Jhajjar needs attention due to the high variability in exposure and the observed health impacts, potentially linked to peak exposures and other exposure pathways.

Conclusion

This comparative analysis of arsenic contamination in groundwater in Mahendragarh, Rewari, and Jhajjar districts of Haryana reveals a complex scenario with significant spatial variations in contamination levels and variability. Mahendragarh exhibits the highest and most uniform arsenic concentrations, likely due to specific geological features and hydrogeological conditions. Jhajjar, while having lower mean concentrations, shows the highest variability, which appears to be correlated with a higher prevalence of arsenic-related health symptoms, suggesting that variability in exposure may be a critical determinant of health outcomes. The contamination also poses risks to agricultural sustainability through its impact on irrigation water quality and potential for bioaccumulation in food crops.

The study highlights the urgent need for comprehensive strategies to address arsenic contamination in these regions. These strategies should include:

- **Targeted Remediation**: Implementing site-specific remediation technologies based on the characteristics of contamination in each district and water source.
- **Alternative Water Sources:** Exploring and providing access to safe alternative drinking water sources for the affected population.
- **Regular Monitoring:** Establishing sturdy monitoring programs to track arsenic levels in groundwater and irrigation water.
- **Public Health Interventions:** Conducting health awareness campaigns, providing medical support for affected individuals, and investigating the link between exposure patterns and health outcomes in more detail.

- **Agricultural Management:** Promoting agricultural practices that minimize arsenic uptake by crops and exploring water treatment options for irrigation.
- **Further Research:** Conducting in-depth studies to better understand the complex interplay of factors influencing arsenic mobilization and speciation, and to assess the cumulative health risks from various exposure pathways.

Addressing arsenic contamination requires a multi-pronged approach involving government agencies, local communities, researchers, and non-governmental organizations to safeguard public health and ensure sustainable water resource management in the affected areas of Haryana.

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