Estimation of Arsenic Contamination in the Groundwaters of the Ballia District: A Comprehensive Survey

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Abstract: ***Arsenic toxicity in drinking water is a major health concern worldwide as well as in India, as it is reported to cause several diseases like hyperkeratosis, skin cancers, changes in pigmentation, and cancers of the liver and kidney. The level of arsenic in the groundwaters of several regions of India is quite higher than the maximum permissible limit of 10 ppb (WHO, 1993). The objective of the present study is to survey the level of arsenic in the Ballia district. Arsenic levels in groundwater from 115 different locations were estimated by atomic absorption spectrophotometer as well as field test kit. Our data showed the arsenic concentrations in groundwater samples to vary from 0 - 150 ppb with an average value of 22.54 ppb. Mean arsenic levels in the groundwater sample from depths of ≤80 feet and >80 feet were ~33 ppb and ~4 ppb, respectively. Arsenic contamination in 40% of the groundwater samples was > 10 ppb, while 60% had arsenic levels below 10 ppb. The Bairiya, Bansdih, and Ballia Sadar tahsils were highly contaminated (> 40 ppb), while Belthera Road, Rasra, and Sikandarpur were less contaminated (< 10 ppb).***

Keywords: Arsenic, groundwater, arsenicosis, aquifer, Ganga river basin

1. Introduction

Arsenic is a very toxic heavy metalloid found in both inorganic and organic forms throughout the earth's crust. It is distributed unevenly, with a zero to very high concentration in different countries across the globe. The maximum recommended permissible limit and safe concentration of arsenic in the drinking water is 10 ppb, which was 50 ppb prior to 1993 (WHO, 1993). It was considered the most hazardous substance by the WHO and a class 1 human carcinogen by the International Agency for Research on Cancer. In the natural water arsenic usually exists in the arsenite (As^{3+}) and arsenate (As^{5+}) forms, the former being more toxic [1]. Earlier studies have shown that high levels of arsenic contamination in drinking water is a global problem affecting several countries, including India, Bangladesh, China, Pakistan, Nepal, Vietnam, Burma, Thailand, Cambodia, as well as countries in Africa and South America [2-4]. In India, studies on arsenic contamination in groundwater started in the 80s decade [5,6] (Datta and Kaul, 1976; Saha, 1984). Later, the study came from West Bengal, where six districts were reported to have arsenic concentrations more than 50 ppb [7]. Since then, several studies have been done so far to determine the groundwater contamination of arsenic across the country [3,8-15]. The major source of arsenic contamination in the groundwater is geogenic and accounts for more than 90% of arsenic release. The young Holocene-age alluvial and deltaic sediments are rich reservoirs of arsenic. Besides, erosion and dissolution of arsenic-rich rocks and minerals (arsenopyrite and pyrite), usually in anoxic (reducing) conditions, are the major natural ways to release arsenic into aquifers [4,16]. Although most of the sources of arsenic contamination are natural, anthropogenic activities like agricultural discharge in the form of pesticides and herbicides, industrial activities like mining, smelting, and coal combustion, wood preservatives, and excessive pumping of groundwater also contribute significantly [17]. Arsenic releases from these sources into air, soil, and water, affecting the food chain and human health.

Arsenic exposure imposes several harmful effects on the aquatic organisms living in the water body, including fish, prawns, molluscs, etc. [18]. The extent of arsenic's ability to produce toxicity can vary depending on physio-chemical properties in the aquatic environment, such as temperature, salinity, pH, and water hardness. Acute exposure to high arsenic, either via ingestion or inhalation, causes severe abdominal pain, nausea, vomiting, hypotension, cardiac arrhythmia, haemolysis and neurological issues. The long-term exposure to arsenic, usually through groundwater, causes changes in pigmentation, hyperkeratosis, cancer of skin, kidney and liver, hypertension and coronary heart diseases, peripheral neuropathy and cognitive impairment. Besides, arsenic toxicity also causes disruption of endocrine glands, leading to type 2 diabetes and impaired lung function [19-23]. Studies have also reported increased polymorphism and chromosomal aberrations in the people consuming arsenic-contaminated groundwater [24,25]. The presence of arsenic can be detected in nail, hair, urine and skin of the people consuming arsenic-contaminated groundwater

[26,27]. Among aquatic organisms, fishes are one of the most important biotic components of aquatic environments as well as a source of easily digestible protein for human beings. Arsenic exposure causes significant changes in the health and physiology of fish, including reduced growth and development and inhibition of sperm production [28]. It affects almost every vital organ of fish, including gills, liver, kidneys, and intestines. Studies have reported decreased red blood cell and haemoglobin content and altered white blood cell count in fishes exposed to arsenic. Alterations in several biochemical and stress markers, including generation of reactive oxygen species and altered levels of enzymes such as superoxide dismutase, catalase, and LDH, have also been reported [18,29-31]. Consumption of such fishes constitutes a potential threat to humans, including cancer and respiratory and dermatological ailments [32].

Ballia is the easternmost district of Uttar Pradesh and is located between two large rivers, the Ganga and the Ghaghara. Acharyya and colleagues (2005) reported that arsenic contamination in groundwater of the Middle Ganga plains is restricted to narrow entrenched channels [33]. Earlier studies have reported a high concentration of arsenic in different regions of the Ballia district [34-38]. However, a complete map of arsenic contamination in groundwaters of Ballia district is lacking, leaving most of the regions unexplored. Therefore, the present study is aimed to determine the arsenic contamination in the groundwaters and its horizontal (variation across a landscape) and vertical (variation at different depths within the same location) distribution in the Ballia District.

2. Materials and Methods

In the present study, collection of groundwater samples was done tahsil-wise and block-wise to get uniform sampling. Depth of water source and distance to both the rivers (the Ganga and Ghaghara) were recorded. Arsenic concentration in the groundwater samples was determined by atomic absorption spectroscopy (AAS) at the district laboratory, UP Jal Nigam, Ballia, and by the arsenic field test kit. In the AAS method, collected water samples were digested with 1% nitric acid to fix the arsenic, and estimation was done according to RoyáChowdhury (1995) [8]. Determination of the arsenic concentration in the field was done by an arsenic field test kit as per the manufacturer's protocol (Orlab, India). The estimation was repeated thrice with a fresh sample each time per site. Statistical analysis was performed by student t-test and one-way ANOVA using GraphPad tool, and p-value < 0.05 was considered significant.

3. Results

To get the uniformity, groundwater samples from total 115 different sites (localities) of the Ballia district were taken, covering all six tahsils (Ballia Sadar, Bairiya, Bansdih, Rasra, Sikandarpur and Belthara Road) and all 17 blocks so that almost all areas of the district got covered (fig. 1). The details of the groundwater sampling sites, including village name, depth and type of water source and arsenic concentration, are given in tables 1-6. The concentration of arsenic showed a high variation ranging from 0 to 150 ppb. The mean concentration of arsenic in the Ballia district was found to be 22.54 ppb, nearly 2-fold higher than the WHO-recommended maximum permissible limit of arsenic in drinking water. The mean concentrations of arsenic in the groundwater samples at ≤ 80 feet and > 80 feet depth were ~33 ppb and ~4 ppb, respectively (fig. 2).

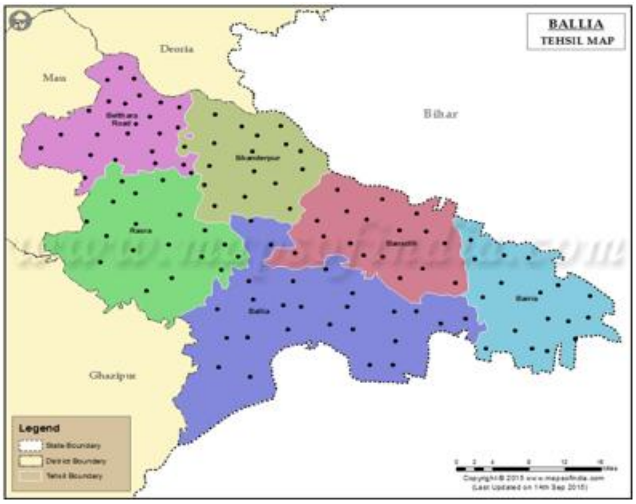

Figure 1: Map of Ballia district showing groundwater sampling sites in all six tahsils (N= 115)

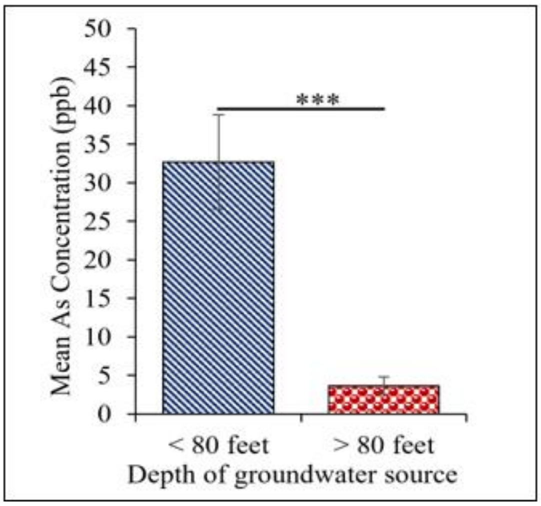

Figure 2: Depth-wise variation in the mean arsenic concentration in groundwater samples. *Denotes statistical significance (p-value < 0.05) by unpaired t-test.

The data of the present study also exhibited variation in arsenic contamination across different locations at the same depth (Figs. 3a and 3b). For better representation of risk caused by arsenic contamination, the result was grouped into three categories, viz., < 10 ppb (low risk), 11-50 ppb (moderate risk), and > 50 ppb (high risk). In 29% (n = 33) and 11% (n = 11) of groundwater samples, the contamination of arsenic was found between 11-50 ppb and 51-150 ppb, respectively (figs. 4a and 4b). Arsenic contamination in the remaining 60% (n = 69) of groundwater water samples was found to be less than 10 ppb. The locations with very high arsenic contamination (> 50 ppb) are Jamuaan (65 ppb), Haldi (70 ppb), Kirtupur (75 ppb), Chain Chhapra (80 ppb), Tengarhi (90 ppb), Hanumanganj (90 ppb), Chandpur (100 ppb), Sawrunbandh (100 ppb), Tutwari (100 ppb), Halpur Chatti (110 ppb), Malahua (130 ppb), Handiya Kala (140 ppb), and Naya Gaon (150 ppb).

The tahsil-wise mean arsenic concentrations were found to be significantly high in the Bairiya (~50 ppb) and Bansdih (~50 ppb) tahsils, followed by the Ballia Sadar (~40 ppb). The mean arsenic contamination in the groundwater of the Belthera road (~5 ppb), Rasra (~2 ppb) and Sikandarpur (~8 ppb) was found to be < 10 ppb (fig. 5).

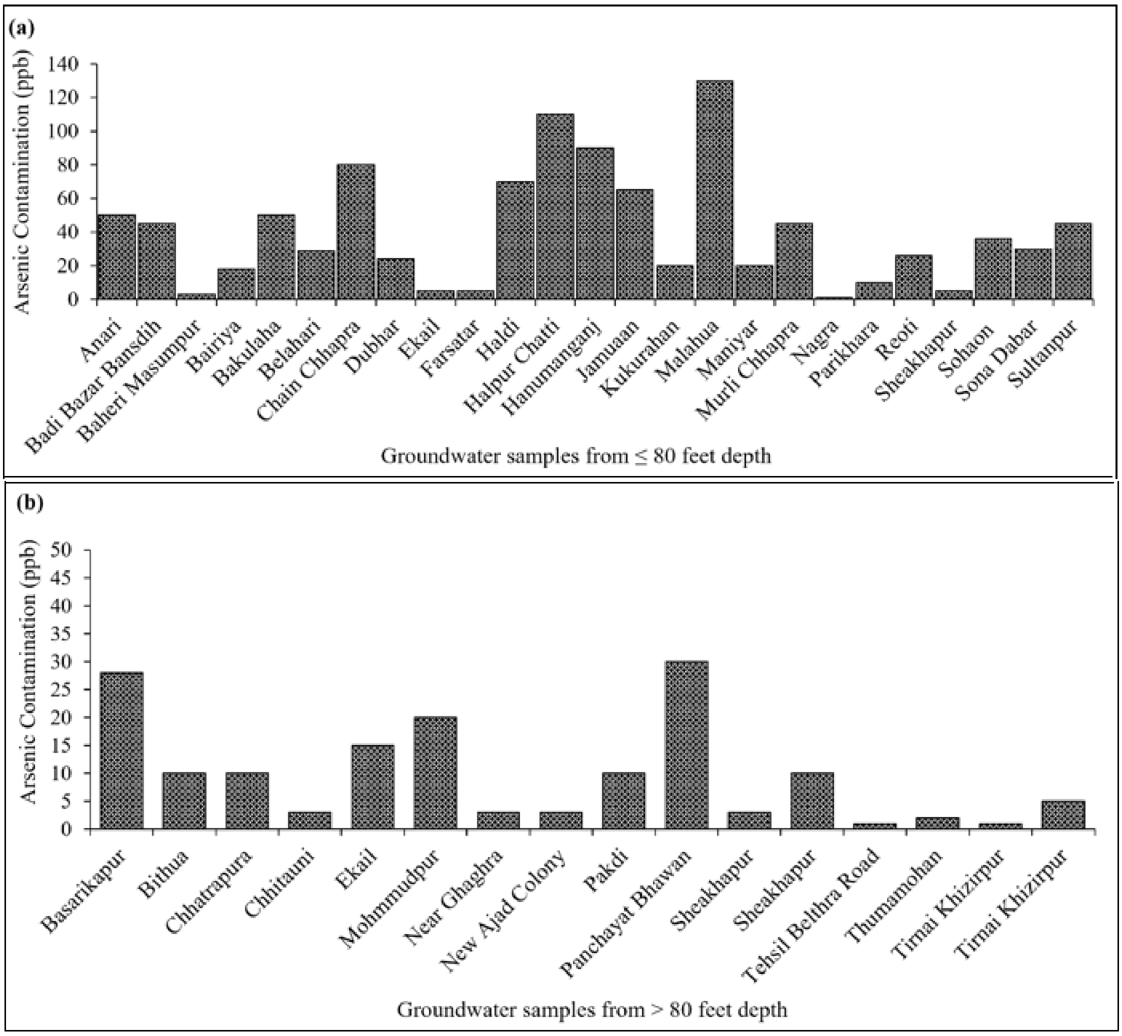

Figure 3: Horizontal variation of arsenic contamination in groundwater samples at < 80 feet depth (a) and > 80 feet depth (b)

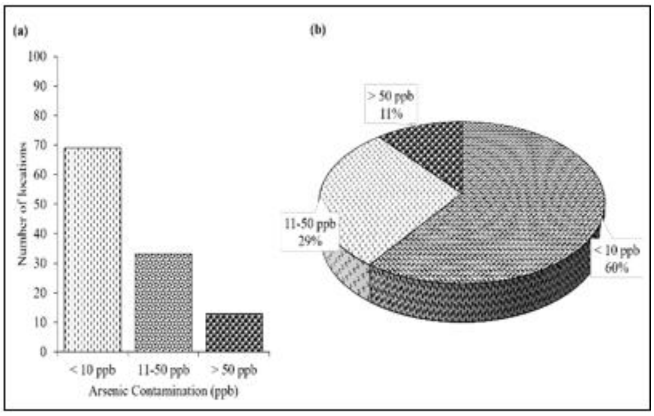

Figure 4: Diagrams showing number (a) and percentage (b) of groundwater sample locations and their arsenic contamination

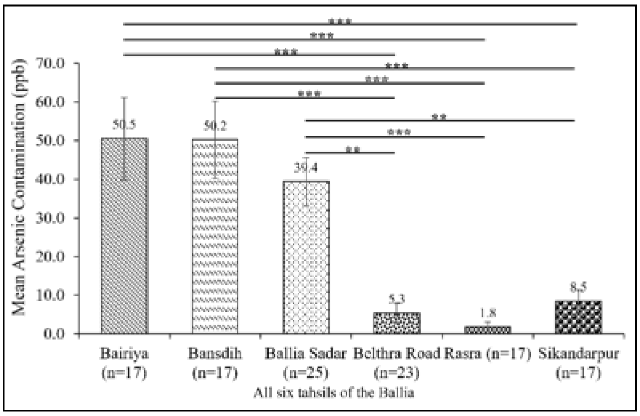

Figure 5: Tahsil-wise mean arsenic contamination in groundwaters of Ballia district. One-way ANOVA was applied and p-value < 0.05 was considered significant.

Table 1: Arsenic distribution in groundwaters of the Ballia Sadar tahsil

Tahsil	Location	Groundwater source	Depth (in feet)	Arsenic level (in ppb)
Ballia Sadar (n= 25)	Agarsanda	India Mark-II	120	0
	Akhar	India Mark-II	120	50
	Basantpur	India Mark-II	120	25
	Basarikapur	India Mark-II	120	45
	Bigahi	India Mark-II	120	10
	Daulatpur	India Mark-II	120	60
	Dubahar	Handpump	60	24
	Gangahara	India Mark-II	120	0
	Haldi	Handpump	60	70
	Hanumanganj	Handpump	60	90
	Hasnagar	India Mark-II	120	25
	Jamuwa	Handpump	60	65
	Janari	Handpump	60	50
	Mudadih	India Mark-II	120	25
	Ojhwalia	India Mark-II	120	80
	Parikhara	Handpump	60	10
	Patkhauli	India Mark-II	120	0
	Purash	India Mark-II	120	50
	Rohunwa	India Mark-II	120	15
	Sawarnbandh	India Mark-II	120	100
	Sohaon	India Mark-II	120	25
	Sohaon	Handpump	60	36
	Sona dabar	Handpump	60	30
	Takarsan	Handpump	60	0
	Tutvari	India Mark-II	120	100

Table 2: Arsenic distribution in groundwaters of the Bairiya tahsil

Tahsil	Location	Groundwater source	Depth (in feet)	Arsenic level (in ppb)
Bairiya (n= 17)	Bairiya	Handpump	60	18
	Bakulaha	India Mark-II	120	70
	Bakulha	Handpump	60	50
	Chainchapra	Handpump	60	80
	Dhaturi Tola	India Mark-II	120	35
	Handia Kala	India Mark-II	120	140
	Husainabad	India Mark-II	120	10
	Karmanpur	India Mark-II	120	10
	Kasauri Kala	India Mark-II	120	10
	Kotwa	India Mark-II	120	0
	Madhubani	India Mark-II	120	25
	Murlichhapra	Handpump	60	45
	Naya gaon	India Mark-II	120	150
	Reoti	Handpump	60	26
	Sigahi	India Mark-II	120	50
	Talibpur	India Mark-II	120	50
	Tengarhi	India Mark-II	120	90

Table 3: Arsenic distribution in groundwaters of the Bansdih tahsil

Tahsil	Location	Groundwater source	Depth (in feet)	Arsenic level (in ppb)
Bansdih (n= 17)	Asega	India Mark-II	120	0
	Badi Bazar Bansdih	Handpump	60	45
	Belhari	Handpump	60	29
	Bijlipur	India Mark-II	120	0
	Chandpur	India Mark-II	120	100
	Dhanauti	India Mark-II	120	0
	Halpur	India Mark-II	120	80
	Halpur Chati	Handpump	60	110
	Kharid	India Mark-II	120	25
	Kirtupur	India Mark-II	120	75
	Maharajpur	India Mark-II	120	45
	Mairitar	India Mark-II	120	65
	Malhunwa	Handpump	60	130
	Maniyar	India Mark-II	120	30
	Maniyar	Handpump	60	20
	Nipania	India Mark-II	120	10
	Rajagaon	India Mark-II	120	90

Table 4: Arsenic distribution in groundwaters of the Rasra tahsil

Tahsil	Location	Groundwater source	Depth (in feet)	Arsenic level (in ppb)
Rasra (n=17)	Rasra	INDIA MARK-II	140	0
	New Ajad Colony	Submersible	140	0
	Basti	INDIA MARK-II	120	0
	Saray Bharati	INDIA MARK-II	120	0
	Sahi Mohammadpur	INDIA MARK-II	120	0
	Chhitauni	Submersible	90	3
	Amhara	Tubewell	60	3
	New Ajad Colony	INDIA MARK-II	120	3
	Rampur Asli	INDIA MARK-II	120	0
	Rampur Asli	Hand pump	40	0
	Balua	Submersible	150	0
	Balua	Tubewell	80	0
	Hajouli	INDIA MARK-II	120	0
	Sawra	Hand pump	60	0
	Aundi	INDIA MARK-II	120	0
	Thumamohan	INDIA MARK-II	120	2
	Kukurahan	Hand pump	60	20

Table 5: Arsenic distribution in groundwaters of the Belthera Road tahsil

Tahsil	Location	Groundwater source	Depth (in feet)	Arsenic level (ppb)
Belthara Road (n= 22)	Lahsani	INDIA MARK-II	120	0
	Malipur	Hand pump	60	0.1
	Kothiya	INDIA MARK-II	120	0.1
	Jamuaan	INDIA MARK-II	120	0.2
	Nagra	Hand pump	60	1
	Chhatrapura	INDIA MARK-II	120	10
	Udharan	INDIA MARK-II	120	0
	Rajkiya Chikitsalaya	INDIA MARK-II	120	0
	Baharpur	INDIA MARK-II	120	0
	Haldirampur	Hand pump	60	0
	Haldirampur	INDIA MARK-II	120	0
	Siar Campus	INDIA MARK-II	120	0
	Madhuvan othada	INDIA MARK-II	120	0.2
	Belthra Road Crossing	Hand pump	60	0.5
	Tirnai Khizirpur	Submersible	180	1
	Tehsil Belthra Road	INDIA MARK-II	120	1
	Near Ghaghra	INDIA MARK-II	120	3
	Tirnai Khizirpur	INDIA MARK-II	120	5
	Farsatar	Hand pump	65	5
	Bithua	INDIA MARK-II	120	10
	Panchayat Bhawan	INDIA MARK-II	120	30
	Haldirampur	Tanki	60	50

Table 6: Arsenic distribution in groundwaters of the Sikandarpur tahsil

Tahsil	Location	Groundwater source	Depth (in feet)	Arsenic level (ppb)
Sikandarpur (n= 17)	Basarikapur	INDIA MARK-II	120	0
	Sheakhapur	INDIA MARK-II	120	3
	Sheakhapur	Hand pump	50	5
	Ekail	Hand pump	60	5
	Sheakhapur	INDIA MARK-II	120	10
	Ekail	INDIA MARK-II	120	15
	Mohmmudpur	INDIA MARK-II	120	20
	Basarikapur	INDIA MARK-II	120	28
	Sultanpur	Hand pump	60	45
	Gouri	INDIA MARK-II	120	0
	Akhani	INDIA MARK-II	120	0
	Eakel	INDIA MARK-II	120	0
	Jethwar	INDIA MARK-II	120	0
	Bachapar	INDIA MARK-II	120	0
	Shivmandi	INDIA MARK-II	120	0
	Baheri Masumpur	Hand pump	60	3
	Pakdi	INDIA MARK-II	120	10

4. Discussion

Contamination of groundwater with heavy metal toxicants like arsenic, mercury, lead, cadmium, etc., has been a subject of stress for human beings for a long time. Arsenic is notoriously called “king of poisons” or “poison of kings” due to its odourless and tasteless nature, making it undetectable. Consumption of arsenic-contaminated water is harmful not only for the human being but also for the aquatic animals once it is discharged into the water bodies like ponds, lakes, and rivers. Therefore, in the present study we have investigated the arsenic contamination in the groundwater of the Ballia district, which is a densely populated and highly fertile region of Uttar Pradesh. Our data showed that the groundwater samples display variations across Ballia, ranging from 0.0 ppb to 150 ppb, suggesting an irregular pattern of arsenic contamination. In 29% of groundwater samples, the arsenic contamination was found to be between 11 ppb - 50 ppb and could be of moderate risk with possibilities of adverse health effects such as skin lesions, diabetes and cardiovascular diseases if consumed for long-term. However, several countries still use the older standard (50 ppb, WHO, 1942) as their interim national standard of 50 ppb due to practical difficulties in removing arsenic from the water. In 11% of the groundwater samples, arsenic contamination was quite high (> 50 ppb) and could be of high risk, causing adverse health effects like changes in pigmentation, hyperkeratosis, and skin, bladder and lung cancer if consumed for several years. This necessitates the purification and other required treatments of groundwater samples before consumption by the people living in those areas. Remaining sixty percent of total samples have arsenic contamination < 10 ppb, which is under the maximum permissible limit of WHO and thus could be of low risk if consumed without any prior treatment.

Our data revealed significantly higher arsenic contamination (~ 33 ppb) at groundwater sources of 80 feet or below 80 feet compared to groundwater sources above ~ 80 feet (~ 4 ppb). The observed vertical differences in the arsenic contamination, particularly the higher arsenic level at low depth, could be due to aquifer stratigraphy and age of sediments. The shallow aquifers that are formed in Holocene alluvial plains and river deltas tend to have higher arsenic contamination because they contain abundant organic matter and fine-grained, arsenic-rich iron oxyhydroxides [4,16,39]. The fine-grained layers of shallow aquifers slow the vertical movement of groundwater, allowing the release of arsenic. In contrast, deeper aquifers are composed of older, coarser-grained sediments with rapid flush, which dilute the released arsenic and thus contain lower arsenic in the water. Besides, the shallow aquifers are usually anoxic (oxygen-poor), causing reductive dissolution of arsenic-bearing iron oxyhydroxides, the primary mechanism of arsenic release into the water. In deeper aquifers, the stable redox conditions slow down the mobilization of arsenic or promote its sequestration in the form of stable arsenic sulfide minerals. Moreover, our data also showed horizontal variation (patchy distribution) in arsenic contaminations at different localities (figs. 3a and 3b), which could be possible due to differences in the local geological heterogeneity, topographical and geomorphic differences and flow pattern of groundwater [4,11,39]. Besides geogenic causes, the variability in the arsenic contamination observed in the present study could be possible due to anthropogenic activities such as excessive consumption of groundwater for farming and other agricultural usage, which causes arsenic from deeper contaminated layers to migrate upwards or create localized reductive conditions by altering groundwater flow patterns. The high levels of arsenic observed in the groundwaters of the Bairiya, Bansdih and Ballia Sadar tahsils in contrast to the Belthera, Rasra and Sikandarpur tahsils may be due to their proximity to the Ganga river basin [35,40].

5. Conclusion

The findings of the present study indicate horizontal and vertical variations in arsenic concentration in groundwater samples from different localities. The groundwater samples from Ballia Sadar, Bansdih, and Bairiya Tahsil are severely contaminated with arsenic and need to be purified and mitigated before consumption, while those from Rasra, Belthera Road, and Sikandarpur Tahsil are less contaminated. Although we have estimated arsenic from many areas of the Ballia district, the results of this study need to be assisted by inductively coupled plasma mass spectrometry (ICP-MS) and other cutting-edge technologies to provide a more precise and comprehensive picture of arsenic levels in the groundwater.

Acknowledgement:
We would like to thank In charge, District Laboratory, Jal Nigam, Ballia for providing Atomic Absorption Spectrophotometer facility.

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