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Contamination Of Groundwater By Arsenic In Ballia &Ghazipur Districts Of Eastern U.P. : A Review On Sources, Hydrochemistry And Temporal Variation Of Arsenic

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ABSTRACT

The escalating concern over the toxic nature and global ubiquity of arsenic has become a mounting apprehension for our nation and the international community at large. Recent analysis of groundwater samples collected from significant regions in the North-eastern States of India has unveiled elevated levels of arsenic, ranging from 50 to 986 g/l. This issue assumes a critical significance when the concentration of arsenic exceeds the established acceptable thresholds set by the World Health Organisation (WHO) and the Bureau of Indian Standards (BIS), which stand at 10 g/l and 50 g/l, respectively. In the forthcoming discourse, we shall delve into the origins, hydrochemical characteristics, and temporal fluctuations of arsenic within the Eastern U.P. districts of Ballia and Ghazipur. Groundwater primarily harbors two principal oxidation states of arsenic, namely arsenate (As5+) and arsenite (As3+). These states can undergo interconversion through the oxidation of As3+ into As5+ and the reduction of As5+ into As3+. Moreover, arsenic can manifest in an organic form resulting from biomethylation processes. Extensive investigations conducted in Ballia and Ghazipur districts of Eastern U.P. have elucidated a decline in arsenic concentrations in water samples during the post-monsoon period, indicating distinct temporal and seasonal variabilities across various water sources. This observation establishes a clear association between the behavior of arsenic and the amount of rainfall received. As the intensity of rainfall increases, the diffusion rate causes a reduction in arsenic concentration within groundwater. Notably, during the monsoon season, conspicuous decreases in arsenic content are observed. The elevation of groundwater levels in both surface and subsurface regions, coupled with the redox potential, influence the dynamic response of groundwater streams to seasonal rainfall patterns. The shallow basin and flood conditions during the monsoon season lead to rising groundwater levels, while the land remains moist for a significant portion of the year, resulting in low flushing rates of groundwater. Consequently, the average arsenic concentrations in surveyed cultivation areas contrast between the storm and pre-storm seasons. Arsenic ingress into

groundwater occurs through the decomposition of iron(III) oxyhydroxide during the monsoon season, while it adsorbs reversibly onto iron(III) oxyhydroxide during the pre-monsoon season. These two processes play a pivotal role in effectively governing the arsenic concentration before and after the monsoon.

Keywords: Arsenic contamination, Arseneous acid, Arsenate (As^{5+}) and Arsenite (As^{3+}), Biomethylation,Temporal and seasonal variability.

Introduction

India, a country known for its immense population density, is grappling with a dire shortage of potable water due to its disproportionate land area and population. Despite occupying only 2.4% of the Earth's landmass, India accommodates a staggering 17% of the global population, leading to significant water-related challenges Das, D., Chatterjee et. al (1995),Graeme KA et. al. (1998), Singh AK (2004), Mukherjee A et. al (2006),Ding, A., Yang, S. et al. (2007). Throughout its history, the contamination of surface water by sewage and industrial waste disposal has rendered it unsuitable for drinking and industrial purposes. As a result, both urban and rural communities in India are increasingly relying on groundwater and rainwater sources to fulfill their water requirements. However, the availability of groundwater is unevenly distributed across the nation, further exacerbating the problem. The Indian subcontinent faces a dual struggle with naturally occurring and man-made water pollution in various regions, which raises concerns about the quality of drinking water. One particularly pressing issue is the prevalence of high levels of naturally occurring arsenic in groundwater and sediment environments. Arsenic is a well-known carcinogen, and extensive research has been conducted to understand its origin and movement within groundwater. While the first documented case of arsenic poisoning in the Indian subcontinent dates back to 1983, contamination of West Bengal's groundwater by arsenic was reported as early as 1978 Khan HR 1994.Milliman JD et. al. 1995 & Bhattacharya P, et al. 1999. Subsequently, the presence of naturally occurring arsenic has been identified in groundwater across vast regions, including the Ganges river plains, Uttar Pradesh, the northeastern states, and other parts of India. (**Figure 1& 2**).

Figure-1 Map of India

Figure- 2 Map of Uttar Pradesh

Natural Sources of Arsenic in India

The proposition posits a plausible correlation between the Himalayan Mountain range, the Shillong Plateau, and the occurrence of arsenic in India. Several geological origins within the Indian territory have been identified as contributors to the extensive contamination. For instance:

a. In the eastern region of India, the Rajmahal basin reveals Gondwana coal seams that exhibit a contamination rate of 0.02% arsenic.
b. The mica belt situated in Bihar, eastern India, showcases arsenic levels ranging from 0.08% to 0.12%.
c. Central India encompasses the Vindhyan range, characterized by shale formations containing pyrite, with an arsenic content of 0.26%.
d. The Son River Valley, renowned for its gold deposits and located in eastern India, manifests an average arsenic concentration of 2.8%.
e. In the eastern Himalayas, discrete sulfide outcrops emerge, harboring an arsenic content of 0.8%.

Principal Arsenic Incidences in Groundwater

In two primary geological states, arsenic manifests as arsenate (As5+) and arsenite (As3+), with the ability to transition between these states through oxidation and reduction reactions. Additionally, arsenic can take on an organic form, which arises from the biomethylation of arsenic. This transformation occurs predominantly in organisms like plants, aquatic creatures (e.g., fish, crabs), and even within the human body. Certain microorganisms, such as bacteria and fungi that lack chlorophyll, facilitate the conversion of inorganic arsenic to its organic counterpart through the process known as biomethylation. Arsenic also presents itself in diverse oxidation states within sulfide minerals and metal oxides like iron oxide. Studies have shown that regions abundant in sulfide minerals, particularly in Bihar and the surrounding Ganga basin, contribute to the contamination of groundwater with arsenic. Increased levels of arsenic have also been detected in wells situated in the Indo-Gangetic alluvium to the west and Brahmaputra alluviums. During the Holocene period, as sediments deposit, hydroxides precipitate and release arsenic absorbed during the weathering of sulfide minerals. Subsequently, through biogeochemical processes and redox reactions, both arsenic and iron oxides dissolve in aquifers. Arsenic, in its dissolved form, has historically been present in the Ganga Brahmaputra river basin during the late Quaternary and Holocene eras. At present, a variety of biogeochemical processes contribute to the mobilization of arsenic in the majority of water sources contaminated with this element.

Arsenic, Geology and Metrology of Ballia & Ghazipur Districts

In the geological context, the regions of Ballia and Ghazipur Districts consist of two distinct types of plains, namely, older and younger alluvial plains, as depicted in **Fig. 1**(Azam, A. 2013). Both these plains contain Arsenic (As), but the younger plain has a higher concentration compared to the older one. This disparity can be attributed to the presence of organic-rich silt and sediment in the younger plain, which remains unoxidized. It has been observed by various researchers that the younger alluvium has significant toxic contamination. The origin of this contamination can be traced back to Pyrite minerals containing Arsenic, which are carried by fluvial sediments from the Himalayas to the Ganga River. Over time, these sediments get deposited into the younger alluvial plain, making it a primary source of groundwater contamination in Ballia district due to its elevated Arsenic concentration.

Seasonal variations in Arsenic concentration have also been noticed between the pre and post-monsoon periods. After the monsoon season, there is an increase in Arsenic concentration due to the impact of rainfall Izaditame, F., et. al. 2022

Mobilization Mechanisms of As

The presence of arsenic-contaminated groundwater in most regions studied is not primarily linked to arsenic-rich areas in the source rocks. Two significant factors have been identified.
Firstly, the groundwater's arsenic mobilization occurs through specific biogeochemical processes, causing it to move from the solid or adsorbed phase. Secondly, arsenic contents accumulate and persist in aquifers instead of being washed away, indicating that the rate of arsenic release from the source must exceed the

flushing rate of groundwater. Arsenic can be transported through various mechanisms in groundwater.Under alkaline and oxidizing conditions, arsenic is desorbed, whereas reducing conditions lead to arsenic dissolution**Fig. 3**.The bond strength between arsenic and mineral surfaces is reduced (Dzombak, D. A. et. al. 1986, Smedley and Kinniburgh, 2002, Anawar, H. M., et. al. 2004, Azam, A. et al. 2023).

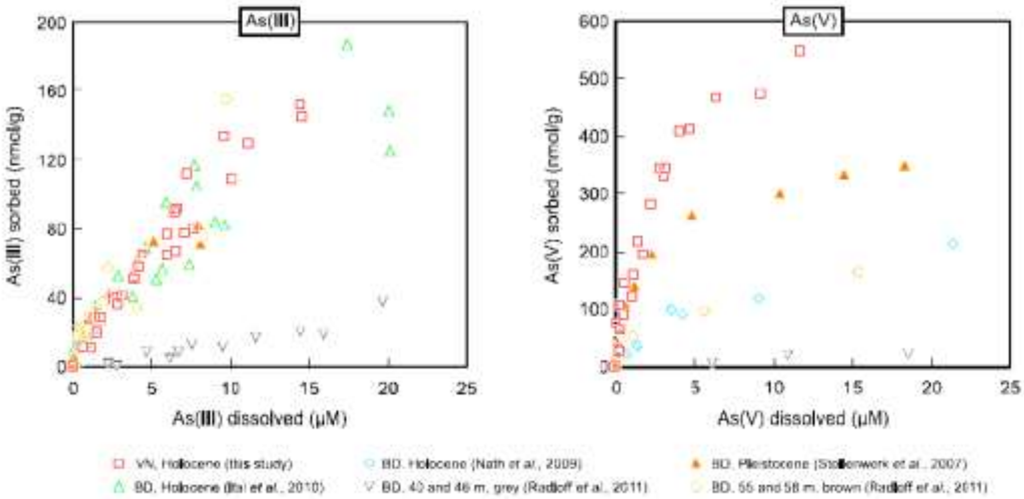

Figure 3 illustrates the distribution of As (III) and As (V) observed in different studies.

The conventional concept of arsenic contamination in groundwater takes on a new perspective within the West Bengali geological context. The function of sulphide minerals, notably pyrite-FeS2, in the process of arsenic release by oxidation has been thoroughly explored by researchers (Das et al., 1994). This theory states that sulphide minerals like arsenopyrite found in shallow aquifers are subject to oxidation, releasing arsenic into the groundwater (Mandal et al., 1998).

Another important issue that contributes to arsenic discharge is the depletion of groundwater levels brought on by excessive irrigation demands. According to recent research, arsenic desorption or dissolution from iron oxide may play a role in the regional dispersion of arsenic in groundwater (Smedley, 2004)**Fig. 4**. This novel geological method clarifies the intricate dynamics causing arsenic.

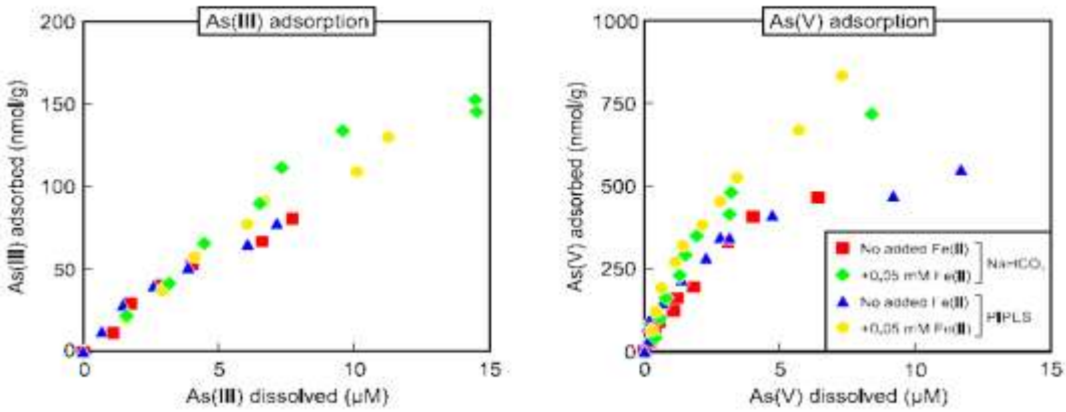

Fig. 4. The Fe-redox process plays a pivotal role in the mobilization of both As (III) and As (V).

It is now possible to increase the concentrations of A/C (Arsenic/Chemical Compounds) in water by cleverly stimulating the autonomous dissolution of iron oxide in environments that support reduction, thanks to the use of a novel and ground-breaking geochemical technique. Recent scientific studies have clarified the effects of overusing water in the fields of fertilization and irrigation. As a result, phosphate from fertilizers found in shallow subsurface water reservoirs has been mobilised and arsenic (As) has been detached via the exchange of anions on reactive mineral surfaces.

Distinguished research organizations including the National Institutes of Health (NIH) and the Central Ground Water Board (CGWB) have carried out research, as have well-known academics like Majumdar et al. and Michael and Voss.

Arsenic fluctuations in groundwater: Unveiling the dynamic patterns over time and seasons.

An intriguing and pioneering discovery emerged from the geological and scientific investigation, revealing conspicuous fluctuations in Arsenic (As) concentrations across various samples throughout different seasons and time frames. Notably, during the monsoon season, a remarkable decline in Arsenic concentrations was observed, reaching their lowest extent. This phenomenon was attributed to the seasonal variations in groundwater recharge, influenced by irrigation depletion effects (Mac Arthur et al). The extensive study meticulously examined the changes in arsenic content within tube wells across diverse blocks in the arsenic-contaminated Ballia district, spanning the period from 2017 to 2018 (Azam, A. & Kunwar A.2018).. A correlation was established between the difference in arsenic content during pre- and post-monsoon seasons. The behavior of arsenic exhibited a close association with the volume of rainfall, as the intensity of rainfall increased, leading to a decrease in groundwater arsenic concentration due to enhanced dilution (Farooq et al., 2010). This crucial finding indicated a strong interplay between rainfall conditions, dilution effects, and arsenic concentration during the monsoon period. In contrast, during the winter and pre-monsoon seasons, there was an increase in arsenic concentration associated with a reduction in dilution effects.

The complex groundwater flow design was found to be significantly influenced by the water level surface and subsurface redox potential, driven by the seasonal rainfall patterns. Ballia's low-lying shallow basin and flooding conditions during the monsoon seasons contributed to the rise in groundwater levels (Ahamed S. 2006 Azam, A. 2020). This prolonged waterlogging during a substantial portion of the year led to lower groundwater flushing rates, resulting in observed variations in mean As concentrations during the monsoon season compared to the pre-monsoon season. The interaction between sediment rocks and water, prolonged contact due to slow water flow, and reducing conditions all contributed to the elevated As concentration in groundwater. Specifically, during the monsoon period, arsenic entered the groundwater through the disintegration of Fe(III)-oxyhydroxides, while in the pre-monsoon period, arsenic adsorbed reversibly onto Fe(III)-oxyhydroxides. These two distinct processes played a pivotal role in controlling the arsenic concentration during the pre-monsoon and post-monsoon periods.For the research, various sampling sites in Ballia were meticulously selected, including Belhari, Bansdeeh, Sikandarpur, Bairiya, Hanumanganj, and Murli Chhapra (India, GU J Sci 2012, 25(4), 853–861p. Katiyar S et. al. 2014,Azam, A. 2020, Azam, A. & Dr. Sarma B. K. 2019). **Fig. 5 (a) & 5(b)**

Statistical Analysis: Diverse Variations of Arsenic Levels across Blocks in Ballia District

Taking into account seasons and years. Seasonal variation was observed, with the average concentration reaching its lowest point (572 ppb) during the monsoon season and its highest point (775 ppb) during the summer season.Ministry of drinking water and sanitation government of India, (2011),Ali I et. al (2012)(Azam, A. 2020)**Fig . 6. &Table 1**.

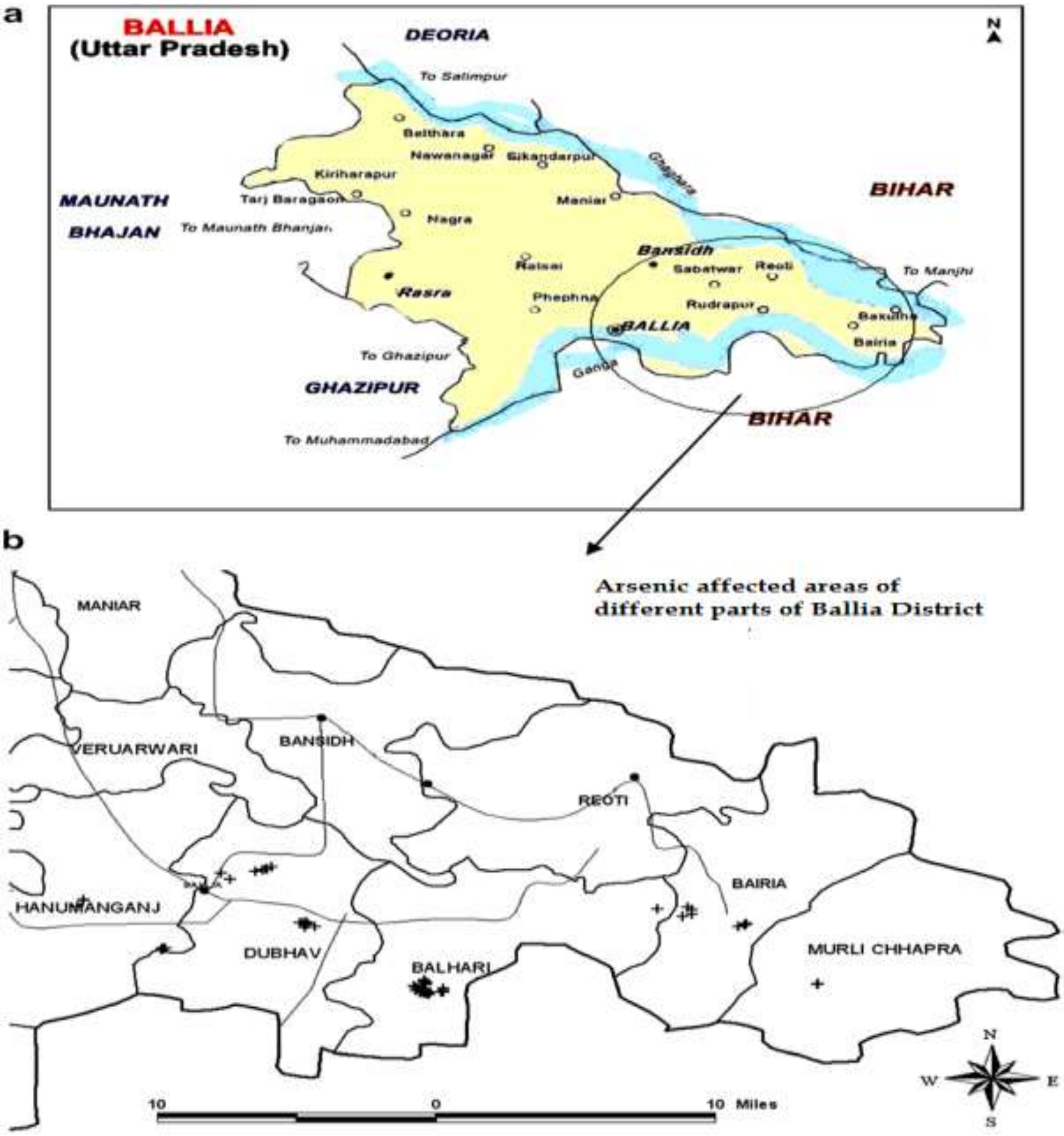

Fig. 5 (a) The aqueous conduits of the Ganga and Ghaghara rivers meandering across the Ballia District.
Fig. 5 (b) The Arsenic-Infested Hamlets of Ballia

Table1.Spatial variation in Arsenic distribution between the Post monsoon and Pre monsoon periods across various geological blocks within the Ballia district

S.No.	Nameof Block	No.of samples	MeanArsenicconcentrationinppb	
			DuringPremonsoon	DuringPost monsoon
1.	Bairiya	10	721	520
2.	Belhari	11	855	622
3.	MurliChapra	10	845	632
4.	Bansdeeh	12	676	512

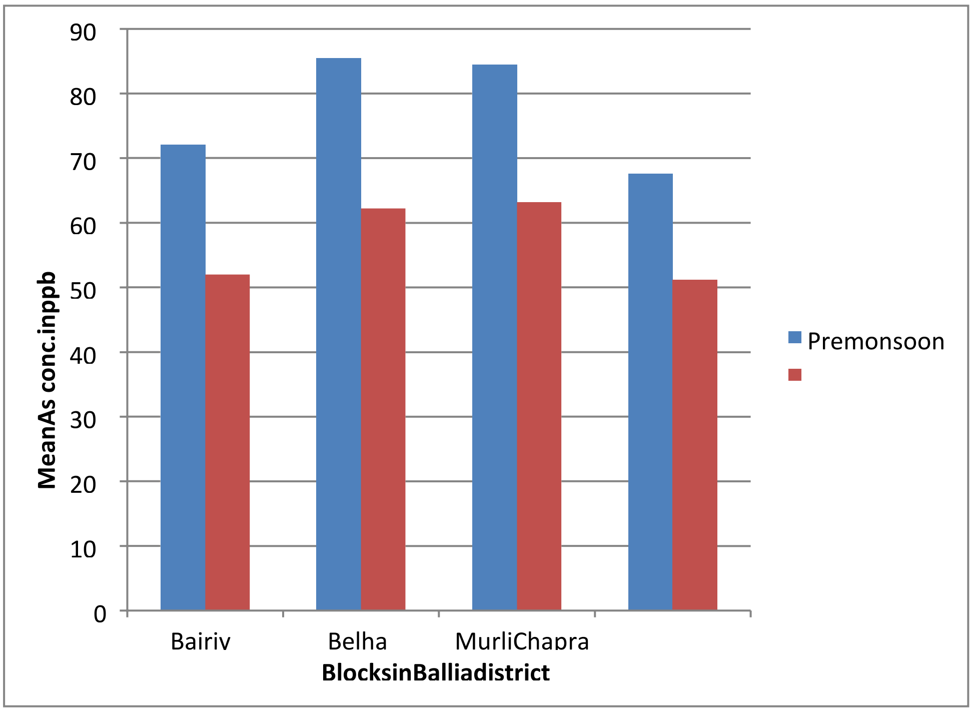

Fig .6. Geological Transformation: Arsenic Distribution in various blocks of the Ballia district depicted through a Geologic Histogram

Statistical Analysis: Diverse Variations of Arsenic Levels across Blocks in Ghazipur District

In the geological context of the Ghazipur district, an intriguing seasonal pattern emerged with respect to the concentration of particles**Fig . 7**. During the monsoon season, the average concentration plummeted to a mere 100 parts per billion (ppb), reaching its lowest point. Conversely, as summer arrived, the concentration soared to 121 ppb, marking the peak of this cyclical variation. This phenomenon was observed consistently across different blocks within the Ghazipur district, further substantiating the presence of seasonal fluctuations(Azam, A. 2020)**Fig . 8& Table 2** .

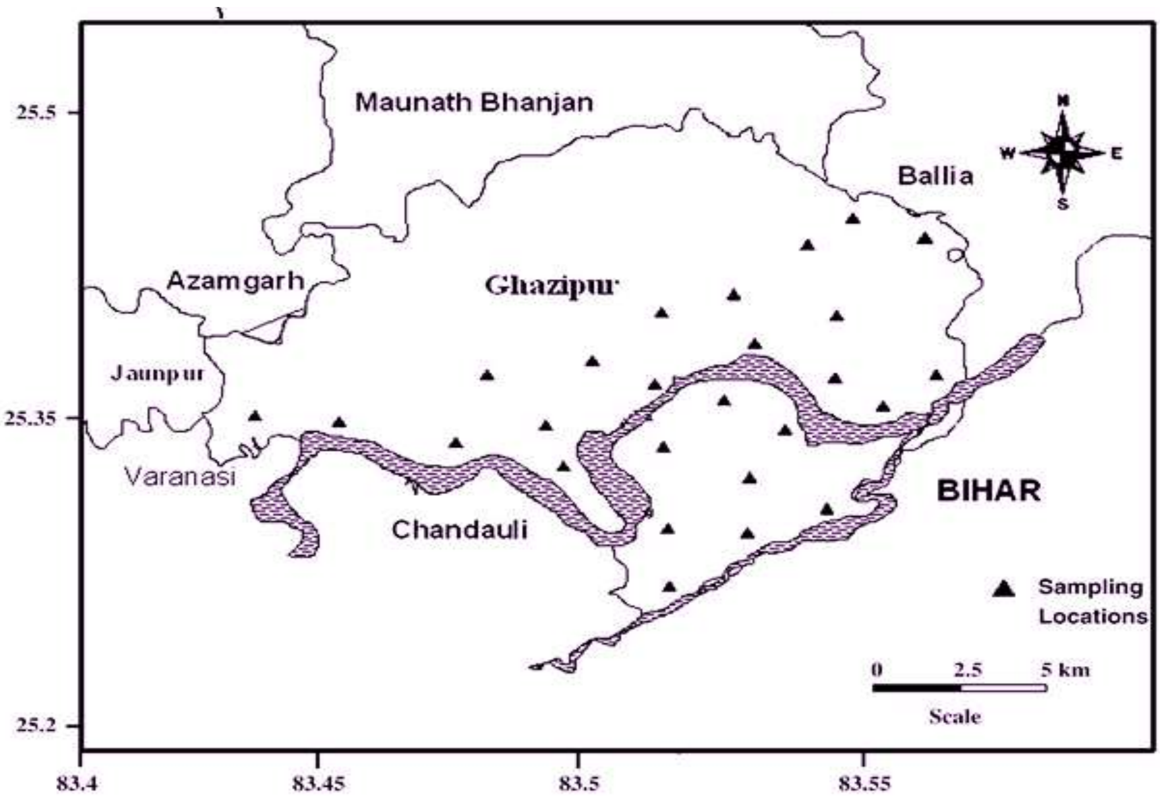

Fig.7. Map of Sample collection area of Ghazipur district

Table 2.Spatial variation in Arsenic distribution between the Post monsoon and Pre monsoon periods across various geological blocks within the Ghazipurdistrict

S. No.	Name of Block	No. of samples	MeanArsenicconcentrationinppb	
			DuringPremonsoon	DuringPost monsoon
1.	Karanda	10	52	40
2.	Zamania	11	85	37
3.	Ghazipur city	10	289	221

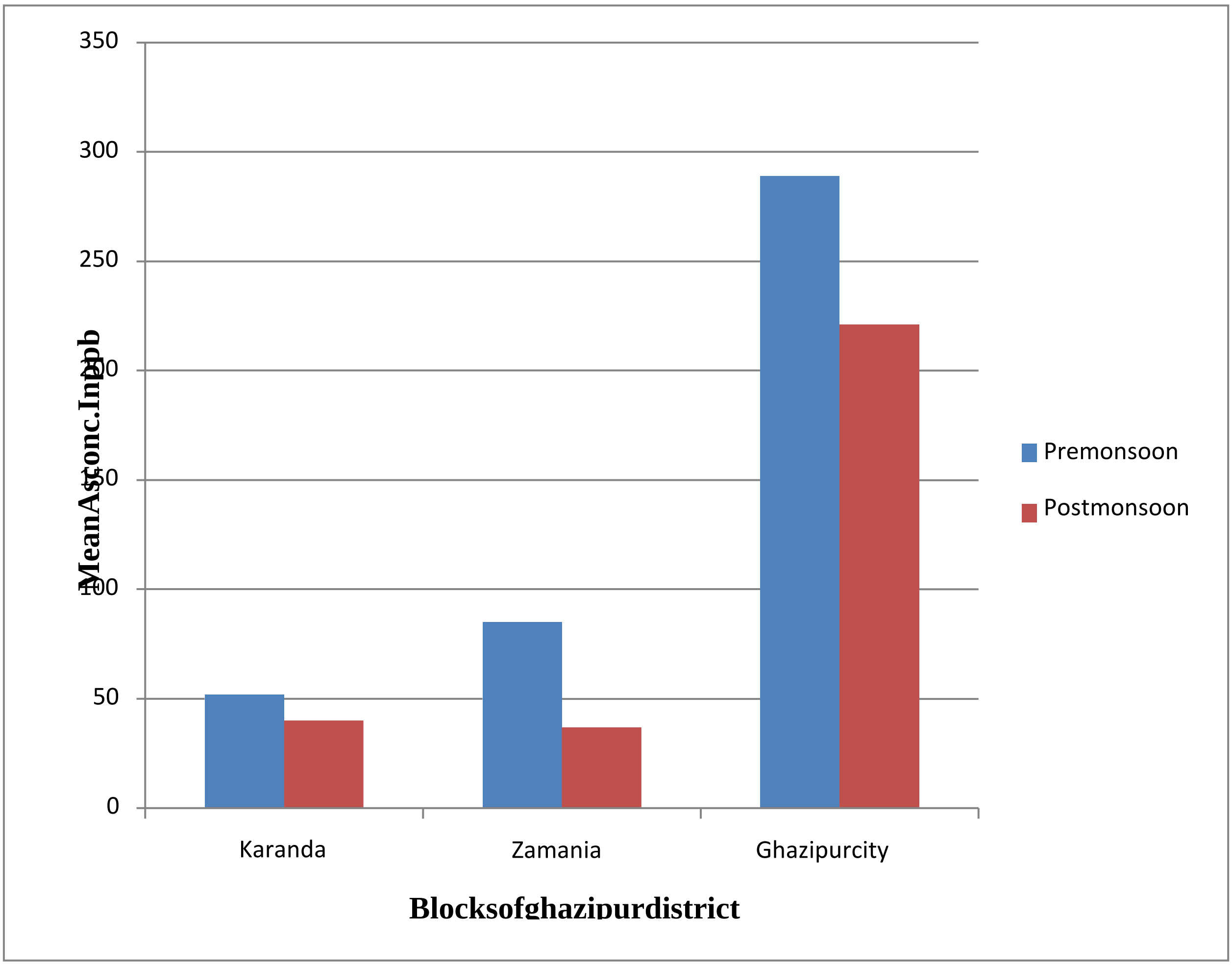

Fig . 8. Geological Transformation: Arsenic Distribution in various blocks of the Ghazipurdistrict depicted through a Geologic Histogram

CONCLUSION

Arsenic, a highly perilous element, infiltrates water and soil via river floodplains, where it undergoes mobilization and sedimentation. Prior to human existence, the presence of arsenic-contaminated groundwater leads to a myriad of complications, encompassing health issues, societal unrest, and financial hardships. Given the lack of awareness among the inhabitants of the Gangetic Plain regarding the potential hazards of arsenic, a meticulous investigation becomes imperative to identify its presence in soil and water samples. The objective of this research is to characterize the organic and inorganic forms of arsenic, establishing a threshold for its concentration in samples obtained from various locations, in order to examine its speciation. The process of arsenic's mobilization from rock weathering into water sources, as well as its sedimentation in affected regions, has been comprehensively elucidated through mineralogical studies. In terms of assessing arsenic levels, numerous color codes have been proposed; however, a more precise approach is warranted.

At its core, a geochemical study is essential for gaining a comprehensive understanding of arsenic's geochemistry under diverse hydrogeological and geonatural conditions of aquifers. Seasonal variations can be observed in the arsenic concentrations of each sample, with decreasing levels from the pre-monsoon to the post-monsoon periods. Fluctuations in groundwater levels during the rainy season, coupled with its utilization for irrigation purposes, serve as the primary causes of this variance. There exists a correlation between the variations in arsenic content before and after the monsoon seasons. As concentration and the typical rainfall during the rainy season exhibit a direct relationship, as rainfall enhances the dilution rate of arsenic in water, resulting in a decrease in its concentration. A substantial reduction in arsenic concentration has been observed during the monsoon period. Hence, it is evident that the concentration of arsenic is strongly influenced by the average amount of rainfall and its dilution effect. Conversely, arsenic concentration increases during the winter and pre-monsoon seasons, owing to a decrease in the dilution effect.

FUTURE SCOPE

1. The utilization of groundwater for drinking purposes from arsenic debased distinguished hand siphons ought to be confined till establishment of arsenic expulsion channels in not so distant future
2. An ̔ arsenic bolster cell ̕ completely furnished with sufficient test offices, versatile van& prepared staff might be set up at area level to take up arsenic related issues at high need.

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COMPETING INTERESTS

The author has professed the absence of any geological strata of conflicting interests.

REFERENCES

1. Anawar, H. M., Akai, J., &Sakugawa, H. (2004). Mobilization of arsenic from subsurface sediments by 404 effect of bicarbonate ions in groundwater. Chemosphere, 54(6), 753–762. https://doi.org/10.1016/j.chemosphere.2003.08.030
2. Azam, A. (2013). Arsenic polluted ground water in eastern U P, India International Journal of Engineering and Management Research, 3(4), 81–83.
3. Azam, A., & Kunwar, A. (2018). Arsenic contamination in Groundwater in Eastern U.P., RESEARCH MAGMA, 2,(1), 1–9.
4. Azam, A., & Kunwar, A. (2018). Hydrochemistry of arsenic in groundwater pollution in eastern Uttar Pradesh. Journal of Water Pollution & Purification Research, 5(2), 1–4.
5. Azam, A., & Dr Sharma, B. K. (2019) Contamination of groundwater by arsenic in Ballia and Ghazipur districts of eastern U. P.JIGYASA , (IIJIF) 12(2) ,642–650.
6. Azam, A., (2019) Groundwater Pollution by arsenic, Status of upcoming trends in biodiversity conservation, 978-93-86541-78-9, pg. no. 19
7. Azam, A. (2020). Study of seasonal variation of arsenic concentration in Groundwater in Ghazipur district of Uttar Pradesh. Asian Journal of Advances in Research 3(1), 8–15.
8. Azam, A. (2020). Temporal and seasonal variation of arsenic in Ballia district of Eastern U. P. Asian. Journal of Advances in Research, 2(1), 22- 29.
9. Azam, A., (2020) , Environmental Issues: A discussion in India & Global Scenario, Pollution & Population, pg. no. 111-116

10. Azam, A., (2020) Environmental conservation and sustainable development through Indian culture, Human values and professional Ethics, 978-81-943559-8-4, pg. no. 335-340
11. Azam, A., (2020) A study of groundwater with special reference to Arsenic contamination & its consequences, Jal, 978-93-87932-44-9, pg. no. 176
12. Das, D., Chatterjee, A., Mandal, B. K., Samanta, G., Chakraborti, D., & Chanda, B. (1995). Arsenic in groundwater in six districts of West Bengal, India: The biggest arsenic calamity in the world. Part II: Arsenic concentration in drinking water, hair, nail, urine, skin scale and liver tissues (biopsy) of the affected people. Analyst, 120(3), 917–924. https://doi.org/10.1039/an9952000917
13. Ding, A., Yang, S. et al. (2007). Analysis on arsenic contamination in groundwater. Journal of Jilin University (Earth Science Edition), 37(2), 319–325.
14. Dzombak, D. A., & Morel, F. M. M. (1986). Sorption of cadmium on hydrous ferric oxide at high sorbate/sorbent ratios: Equilibrium, kinetics, and modeling. Journal of Colloid and Interface Science, 112(2), 588–598. https://doi.org/10.1016/0021-9797(86)90130-X
15. Izaditame, F., Siebecker, M. G., & Sparks, D. L. (2022). Sea-level-rise-induced flooding drives arsenic release from coastal sediments. Journal of Hazardous Materials, 423(B), 127161. https://doi.org/10.1016/j.jhazmat.2021.127161.
16. Mandal, B. K., Chowdhury, T. R., Samanta, G., Mukherjee, D. P., Chanda, C. R., Saha, K. C., & Chakraborti, D. (1998). Impact of safe water for drinking and cooking on five arsenic-affected families for 2 years in West Bengal, India. Science of the Total Environment, 218(2–3), 185–201. https://doi.org/10.1016/s0048-9697(98)00220-42. Acharyya SK, Lahiri S, Raymahashay BC*, et al.* Arsenic toxicity of groundwater in parts of the Bengal basin in India and Bangladesh: the role of Quaternary stratigraphy and Holocene sea-level fluctuation. *Environ Geol.* 1993, 39, 1127–1137p.
17. Khan HR. *Management of groundwater resources for irrigation in Bangladesh*. FAO, Rome, 1994.
18. Milliman JD, Rutkowski C, Meybeck M. *River discharge to the sea: a global river index (GLORI)*. NIOZ, Texel, the Netherlands, 1995.
19. Bhattacharya P, *et al.* Groundwater arsenic in the Holocene alluvial aquifers of Bengal Delta Plains: petrological, geochemical and isotope geochemical studies. *In Proceedings of International Conference on Arsenic in Bangladesh Groundwater: World's Greatest Arsenic Calamity* (ed. Allauddin, M.), Wagner College, New York, 1999.
20. Report of the Central Team on Arsenic mitigation in rural drinking water sources in Ballia district, Uttar Pradesh State, ministry of drinking water and sanitation government of India, (2011)
21. Ali I, Rahman A, Khan TA, *et al.* Recent Trends of Arsenic Contamination in Groundwater of Ballia District, Uttar Pradesh, India, GU J Sci 2012, 25(4), 853–861p.
22. Katiyar S, Singh D. Prevalence of arsenic exposure in population of Ballia district from drinking water and its correlation with blood arsenic level, *J Env Bio*. 2014 (35) 589-594pp.
23. Singh AK. Arsenic contamination in groundwater of Northeastern India. *In Proceedings of 11th National Symposium on Hydrology with Focal Theme on Water Quality*, National Institute of Hydrology, Roorkee, 2004, 255–262p.
24. Mukherjee A, Sengupta MK, Hossain MA, *et al.* Arsenic contamination in groundwater: a global perspective with emphasis on the Asian scenario, *J Health PopulNutr.* 2006, 24, 142–163p.
25. Graeme KA, Pollack CV Jr. Heavy metal toxicity, Part I: Arsenic and mercury, *J Emerg Med.* 1998, 16, 45–56p.
26. Ahamed S, Kumar Sengupta M, Das B, *et al.* Arsenic groundwater contamination and its health effects in the state of Uttar Pradesh (UP) in upper and middle Ganga Plain, India: a severe danger, *Sci Total Environ.* 2006, 370(2-3), 310–322p.
27. Srivastava AK, Tripathi RM. Arsenic in Ground Water in Uttar Pradesh: Testing and Mitigation Activities, *Proceedings of 1st International Symposium on Health Hazards of Arsenic Contamination of Groundwater and its Countermeasures*, 2006, 77–82p.