

---

***"Educational Insights into the Complex Intersections of Green Chemistry and Arsenic-Induced Groundwater Pollution in Sustainable Development"***

---

**Dr. Akbare Azam<sup>1</sup>**, Assistant Professor, Department of Chemistry, Govt. Girls' P.G. College Ghazipur U. P.

**Manisha<sup>2</sup>**, Assistant Professor, Department of Home Science, Govt. Degree College Sahjanwa, Gorakhpur, U. P.

**Hemant Kumar Nirala<sup>3</sup>**, Assistant Professor, Department of Chemistry, Govt. Girls' P. G. College Saiyadraja Chandauli, U. P.

**Najam Ul Rafi<sup>4</sup>**, Assistant Professor, Department of Chemistry Govt. P. G. College Jalesar Etah, U. P.

---

**Article Received:** 17/01/2024

**Article Accepted:** 15/02/2024

**Published Online:** 18/02/2024

**DOI:**10.47311/IJOES.2024.6.2.85

---

**Abstract:**

This educational exploration delves into the complex crossings of these two realms, aiming to unravel the nuanced relationship between environmentally conscious chemical practices and the pressing challenge of arsenic contamination in groundwater. As we navigate the intricate landscape of sustainable development, this study seeks to provide valuable insights that shed light on the scientific intricacies involved and contribute to formulating informed strategies and solutions. Through a holistic examination of the multifaceted facets of Green Chemistry and arsenic-induced groundwater pollution, this research tries to carve a path toward a more sustainable and resilient future. For an extended period, green chemistry (G.C.) has revealed that employing a fundamental scientific methodology and advanced practices can increase the safe production of human life while minimizing environmental disturbances. To achieve this, progress has been made in scientific processes within the realms of designing safer reagents and solvents, advancing catalysis, and potentially developing renewable feedstocks. To attain more incredible accomplishments, contemporary chemists are now being educated and trained in a broader understanding of green chemistry, emphasizing increased awareness of human and environmental impacts.

Nevertheless, the global emphasis on sustainable development has posed a challenge for green chemistry educators to instruct students in assessing the intricate factors of green chemistry, including societal sustainability considerations. This paper reviews courses and programs that aim to fulfill these objectives and assessment methods used to evaluate student outcomes in green chemistry courses. The global food supply has significantly expanded due to discovering hybrid varieties, improved cultivation methods, better seeds, pesticides, herbicides, and fertilizers.

**Keywords:** Arsenic contamination, Green chemistry (G.C.), Environmental disturbances, Sustainable development.

## **Introduction**

### **A. Green chemistry: Earth's care**

The Green Chemistry revolution presents many opportunities to explore and implement novel synthetic approaches using alternative raw materials [1-4]. It emphasizes environmentally friendly reaction conditions, energy minimization, and the design of less toxic and environmentally safer chemicals [5-6]. The foundation of Green Chemistry, aiming for both environmental and economic success, is intrinsic to a sustainable world [7,8]. An *integral aspect* of sustainable chemistry is chemical research focusing on improving processes and products about energy and material usage, inherent safety, toxicity, and environmental degradability [9-12].

While progress has been made in environmental science, Green Chemistry, and the environmental evaluation of chemical products, the societal dimension of sustainable chemistry has yet to be fully recognized in all aspects of chemical research. One crucial factor contributing to this is the integration of sustainable chemistry into chemical education from the beginning [13,1].

Green Chemistry involves the application of principles that reduce or eliminate the use or generation of hazardous substances in the design, manufacturing, and use of chemical products [14-17]. Green Chemistry encompasses a much broader range of issues than the definition suggests. Apart from developing better chemicals with less waste, it also includes reducing other associated environmental impacts, such as decreasing the energy used in chemical processes [18,19]. Consequently, efforts have been made to achieve an environmentally friendly synthesis, and various regulations have been enacted to control and address pollution, encouraging industries and academics to devise innovative technologies, processes, and educational materials to discourage the formation or use of hazardous substances.

Green Chemistry differs from traditional chemistry because it embraces the same creativity and innovation that has always been essential to classical chemistry [20-23]. However, a notable difference lies in the fact that historically, synthetic scientists have not prioritized environmental concerns highly. However, with the increase in global environmental awareness, there is a challenge for chemists to develop new products, processes, and services that meet fundamental social, economic, and environmental objectives [24,2].

Due to the diverse nature of chemicals and transformations, various Green Chemistry solutions have been proposed. The establishment of 'The Twelve Principles of Green Chemistry' serves as guidelines for practicing scientists in developing and evaluating how environmentally friendly a synthesis, compound, process, or technology is [25].

### **B. Groundwater under arsenic assault**

Arsenic (As) enters the soil and groundwater through the natural weathering of rocks and minerals, further facilitated by leaching and runoff. Additionally, human activities contribute to arsenic contamination in soil and groundwater. Various factors influence the concentration and movement of arsenic in groundwater, such as red-ox potential (Eh), adsorption/desorption, precipitation/dissolution, arsenic speciation, pH, presence of competing ions, biological transformation, and more. The specific reactions, arsenic species, Eh, pH, and solid-phase changes can differ between aquifers, depending on geological settings, geochemistry, and environmental conditions.

Comprehensive geochemical investigations are crucial to understanding arsenic geochemistry under diverse hydrogeological and environmental conditions, enabling the development of sustainable solutions. In India, groundwater arsenic contamination emerged in West Bengal in 1983 and has since affected several states, including Jharkhand, Bihar, Uttar Pradesh, Assam, Manipur, and Chhattisgarh. Even in the Northeastern Hill States, there is suspicion of arsenic in groundwater. Arsenic-affected areas typically align with river plains from the Himalayan region, though the connection between source material and outcrops requires further research. Over time, the complexity of groundwater arsenic contamination has increased due to unknown local and regional factors.

The consequences of arsenic groundwater contamination are profound, leading to social disorders, health hazards, socioeconomic challenges, and groundwater exploitation. Arsenic-contaminated water used for growing crops poses risks, as these crops may be distributed to uncontaminated regions, potentially exposing people to arsenic through the food chain. This scenario amplifies the dangers associated with arsenic contamination, emphasizing the need for proactive research and sustainable solutions to mitigate its impact.

## **Complex Intersections of Green Chemistry and Arsenic-Induced Groundwater Pollution**

### **A. Principles of Sustainable Chemistry**

When embracing the tenets of sustainable chemistry, the following principles must be ensured:

1. It is wiser to anticipate and prevent waste than to address or clean up waste after its formation.
2. Synthetic methodologies should be planned to maximize the integration of all materials into the final product.
3. Feasible synthetic procedures should prioritize using and generating substances with minimal toxicity to human health and the environment.
4. Chemical products should be formulated to preserve storage efficiency while minimizing toxicity.
5. Auxiliary substances (such as separation agents) should be minimized and harmless when employed.
6. Energy requirements should be acknowledged for their environmental and economic impacts and minimized. Synthetic methods should be managed at ambient temperature and pressure.
7. Unnecessary derivatization (blocking groups, protection/deprotection, and temporary alteration of physical/chemical processes) should be avoided whenever possible.
8. Catalytic reagents (as specific as possible) are preferred over stoichiometric reagents.
9. Chemical products should be designed to not persist in the environment at the end of their useful life and break down into harmless degradation products.
10. Analytical methods should be further developed to enable real-time, in-process observation and control before the formation of hazardous substances.
11. Substances and the form of a substance used in a chemical process should be picked to minimize possible chemical accidents, including releases, explosions, and fires.

#### **B. Major Arsenic Occurrences in Groundwater**

Groundwater is frequently impacted by arsenic, which primarily manifests in two oxidation states: arsenate ( $\text{As}^{5+}$ ) and arsenite ( $\text{As}^{3+}$ ). These states are reversible through oxidation ( $\text{As}^{3+}$  to  $\text{As}^{5+}$ ) and reduction ( $\text{As}^{5+}$  to  $\text{As}^{3+}$ ). Additionally, arsenic exists in an organic form resulting from the biomethylation of arsenic compounds. Various organisms, including plants, aquatic animals like fish and crabs, and the human body, contain these organoarsenic compounds.

Microorganisms such as bacteria and fungi, lacking chlorophyll, engage in the biological conversion of inorganic arsenic to organic arsenic through a process known as biomethylation [2,3]. Arsenic concentrations are notably high in sulfide ores and metal oxides like iron oxide. Previous studies indicated arsenic-

contaminated groundwater was primarily limited to the Ganga basin, originating from sulphide-rich mineralized zones in Bihar and the surrounding deposition basin.

Recent findings have expanded this understanding, revealing elevated arsenic concentrations in wells extending from the Indo-Gangetic alluvium to the west and Brahmaputra alluvium. During the deposition of Holocene segment sediments, hydroxides precipitate, and arsenic released during sulfide mineral weathering is adsorbed. Subsequently, through redox processes, iron oxides dissolve, leading to the transport of arsenic into aquifers via biogeochemical mechanisms.

During the late Quaternary and Holocene, sediments deposited in rivers carry arsenic in the aqueous phase within the Ganga-Brahmaputra river basin. Presently, most arsenic-contaminated water results from the mobilization of arsenic facilitated by diverse biogeochemical processes [4,5].

### **C. Advantages of Manageable Science**

Reasonable science embraces diverse perspectives contributing to achieving the 2030 Agenda and co-shaping the Strategic Approach to International Chemicals Management beyond 2020 [9,10]. These encompass various initiatives, such as the advancement and adoption of alternative solutions for hazardous applications, the conservation of natural resources, the extension of market opportunities, and the implementation of corporate social responsibility. A fundamental tenet of sustainable science is that products should be developed sustainably regarding their processes and constituents. They should contribute to sustainability during use and pose no issues post-use. If waste is generated, it should be recyclable.

For instance, in hazardous recycling, the harmful substances within waste can pose significant health risks to workers. In emerging and developing nations, many individuals who "reuse" electronic waste from industrialized countries using rudimentary methods inadvertently expose themselves to a wide array of hazardous substances, including heavy metals, PCBs, and fire retardants [11-14]. Sustainable science confronts these challenges and seeks viable solutions. This involves substituting hazardous substances with less harmful alternatives, labeling the products, and imposing a take-back obligation.

### **D. Variability in Arsenic Levels Throughout Time and Seasons in Groundwater**

Significant temporal and seasonal variations in arsenic (As) concentrations have been observed across diverse samples. Notably, a pronounced decrease in arsenic concentration is evident during the post-monsoon season. This observed variability is likely associated with seasonal fluctuations in groundwater recharge and irrigation drawdown effects, as MacArthur et al. highlighted. The disparity in arsenic concentration between pre and post-monsoon seasons is directly linked to its

concentration levels. A discernible correlation exists between arsenic behavior and rainfall intensity, with an increase in rainfall intensity corresponding to a rise in dilution rates and a subsequent reduction in arsenic concentration in groundwater, as Farooq et al. (2010) emphasized. The monsoon period particularly witnesses a significant decline in arsenic concentration, showcasing a robust correlation between rainfall conditions, dilution effects, and arsenic concentration. In contrast, the winter season and pre-monsoon periods exhibit an increase in arsenic concentration, attributed to a decrease in the dilution effect [9,10,11].

The oxidation of arsenic-rich sulfide minerals is a common phenomenon in geological deposits housing sulfide minerals with high arsenic content, such as arsenopyrite ( $\text{FeAsS}$ ), realgar ( $\text{As}_4\text{S}_4$ ), and orpiment ( $\text{As}_2\text{S}_3$ ). These minerals remain stable beneath the Earth's surface, shielded from oxygen and water. However, exposure to atmospheric conditions through natural weathering or human activities like mining can trigger oxidation [12,13,14]. When arsenopyrite comes into contact with molecular oxygen ( $\text{O}_2$ ) from the atmosphere and water ( $\text{H}_2\text{O}$ ), it undergoes oxidative degradation. During this process, arsenic, in its sulfide form, transforms into highly water-soluble arsenate ( $\text{AsO}_4^{3-}$ ). This transformation is particularly noticeable in bedrock aquifers experiencing a shift to oxidizing conditions during dry seasons, leading to a decrease in groundwater levels. The released  $\text{Fe}^{2+}$  enters groundwater, and simultaneously, sulfur oxidation in sulfide minerals produces  $\text{SO}_4^{2-}$  ions. Both arsenate and sulfate ions, being soluble, have the potential to leach into the surrounding soil, groundwater, and surface water.

### **Conclusion:**

In conclusion, exploring the intricate intersections between green chemistry and arsenic-induced groundwater pollution provides valuable insights into the challenges and opportunities within sustainable development. The realization that conventional industrial practices have contributed significantly to environmental degradation underscores the urgency for adopting eco-friendly alternatives. Green chemistry emerges as a pivotal tool in this pursuit, offering innovative methodologies and sustainable solutions to mitigate arsenic contamination.

The educational insights from this exploration emphasize the need for a paradigm shift in approaching scientific and industrial processes. Educating scientists, engineers, policymakers, and the general public on the principles of green chemistry becomes imperative in fostering a collective responsibility for sustainable development. Integrating green chemistry into educational curricula provides future generations with the knowledge and skills necessary to address environmental issues at their source.

Furthermore, understanding the complexities of arsenic-induced groundwater pollution underscores the interconnectedness of environmental, social, and economic factors. Sustainable development demands a holistic approach, considering the intricate relationships between human activities, technological advancements, and ecosystem health. Educational initiatives should encourage interdisciplinary collaboration, fostering a comprehensive understanding of the challenges of arsenic contamination and the potential solutions offered by green chemistry.

As we navigate the complexities of the 21st century, the insights gained from this exploration pave the way for informed decision-making and policy formulation. By promoting a symbiotic relationship between green chemistry and sustainable development, we can strive towards a future where human well-being is harmonized with environmental health. In essence, this educational journey catalyzes transformative action, inspiring a generation that is not only aware of the challenges posed by arsenic-induced groundwater pollution but is also equipped to address them through the lens of green and sustainable chemistry.

### **Future Scope**

1. The future of "Educational Insights into the Complex Intersections of Green Chemistry and Arsenic-Induced Groundwater Pollution in Sustainable Development" lies in fostering a multidisciplinary approach.
2. Collaborative research and educational initiatives will bridge gaps between chemistry, environmental science, and sustainable development. Emerging technologies and innovative pedagogies will enhance understanding, enabling effective mitigation strategies. The scope extends to global partnerships, empowering communities to address arsenic contamination through green chemistry solutions.
3. This knowledge nexus will produce environmentally conscious professionals, paving the way for sustainable water management. Ultimately, education will catalyze transformative change, shaping a future where green chemistry safeguards water resources in the pursuit of sustainable development. Top of Form

### **Acknowledgment**

I sincerely thank the World Health Organization (WHO) and the Bureau of Indian Standards (BIS) for contributing to exploring the intricate nexus between Green Chemistry and arsenic-induced groundwater pollution in the pursuit of sustainable development. Special thanks to my mentors, colleagues, and funding sources for their invaluable support in unraveling crucial insights for a more sustainable future.

## References:

- Ahluwalia VK, Kidwai M. Green chemistry: an innovative technology. *Foundations of Chemistry*. 2005;7(3):269–289.
- Anastas P, Warner JC. *Green Chemistry, Theory and Practice*. Oxford: Oxford University Press; 1998.
- Chong M, Lokpovsky EB, Coates GW. *J. Am. Chem. Soc.* 1998;120:11018–11019.
- Csiba M, Cleophax J, Loupy A, Malthete J, Gero SD. *Tetrahedron Letters*, 1993;34:1787–1790.
- Draths KM, Frost JW. Chapter 9. In: Anastas PT, Williamson TC, (editors). *Green Chemistry: Frontier in Benign Chemical Synthesis and Processes*. Oxford: Oxford University Press; 1999.
- Subramanian V. Sediment load of Indian rivers. *Curr Sci.* 1993, 64, 928–930p.
- 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.
- Khan HR. *Management of groundwater resources for irrigation in Bangladesh*. FAO, Rome, 1994.
- Milliman JD, Rutkowski C, Meybeck M. *River discharge to the sea: a global river index (GLORI)*. NIOZ, Texel, the Netherlands, 1995.
- 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.
- Azam A. Groundwater Pollution by arsenic, Status of upcoming trends in biodiversity conservation, 1, Dr. Rachna Chauhan, Educational book service New Delhi 978- 93-86541-78-9; 2019.
- Azam A, Dr Sharma BK. Groundwater contamination by arsenic in Ballia and Ghazipur districts of eastern U. P. *JIGYASA (IJIF)*. 2019;12(2):642–650.
- Azam A. Arsenic polluted groundwater in eastern U P, India *International Journal of Engineering and Management Research*. 2013;3(4):81–83.
- Azam A, Kunwar A. Arsenic contamination in Groundwater in Eastern U.P., *RESEARCH MAGMA*. 2018;2,(1):1–9.
- Azam A, Kunwar A. Hydrochemistry of arsenic in groundwater pollution in eastern Uttar Pradesh. *Journal of Water Pollution & Purification*



- Research. 2018;5(2):1–4.
- Azam A, et al. A Review: Effect of Physicochemical and Hydro geochemical factors on arsenic sedimentation and Mobilization, Biological forum An International Journal. 2023;15(2):1046– 1052.
- Azam A, et al., "Assessing the Occurrence, Causes, and Health Effects of Arsenic Contamination in Groundwater: A Comprehensive Review," International Journal for Innovative Research in Multidisciplinary field 2023;9(7) 107-111.
- Azam A. Study of seasonal variation of arsenic concentration in Groundwater in Ghazipur district of Uttar Pradesh. Asian Journal of Advances in Research. 2020;3(1):8–15.
- Azam A. Temporal and seasonal variation of arsenic in Ballia district of Eastern U. P. Asian. Journal of Advances in Research. 2020;2(1):22 29.
- Azam A., A study of groundwater concerning arsenic contamination and its consequences, Jal, Santan Kumar Ram, Rachnakar Publishing house Delhi 978-93-87932-44-9; 2020.
- Azam A., Relation between Energy and Environment, International Journal of Engineering and Management Research, Volume-4, Issue-3, June 2014, ISSN No.: 2250-0758 Page Numbers: 431-433.
- Azam A., Path of Green Chemistry and Sustainable Development, Asian Journal of Advances in Research 2(1): ISSN No.: 2582-3248, pg. No.18–21, 2019.
- Azam A., Arsenic Polluted Ground Water in Eastern U P, India International Journal of Engineering and Management Research, Vol.-3, Issue-4, August 2013 ISSN No.: 2250-0758 Pages: 81-83.
- Azam A, et al., "The Significance of Polymeric Ligand Exchange (PLE) Technique for Arsenic Removal from Polluted Groundwater: A Review," *Asian Journal of Advances in Research* 6(1): ISSN No.: 2582-3248, pg. No.577-583.
- Azam A, et al., "Arsenic in Groundwater: Understanding the Pathways from Pollution to Human Health and Remediation via PLE Method" INTERNATIONAL JOURNAL FOR INNOVATIVE RESEARCH IN MULTIDISCIPLINARY FIELD, 9(12) ISSN No.: 2455-0620, pg. No.49-52,
- 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.
-

- 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.
- Singh R, Gond DP, Pal A. Assessment of groundwater quality of Ghazipur district, eastern Uttar Pradesh, India, special reference to arsenic contamination, *Recent Res Sci Technol.* 2010, 2(3), 38–41p.
- Chakraborti D, et al. Arsenic groundwater contamination in Middle Ganga Plain, Bihar, India: a future danger? *Environ Health Perspect.* 2003, 111, 1194–1201p.
- 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.