

Comparative Analysis of Polycyclic Aromatic Hydrocarbon Levels in Industrial and Rural Water Sources of Sri Ganganagar District

Tara Singh^{1*} | Dr. Kailash Sharma²

^{1,2}Department of Chemistry, Shri Khushal Das University, Hanumangarh, Rajasthan, India.

*Corresponding Author: tara091989@gmail.com

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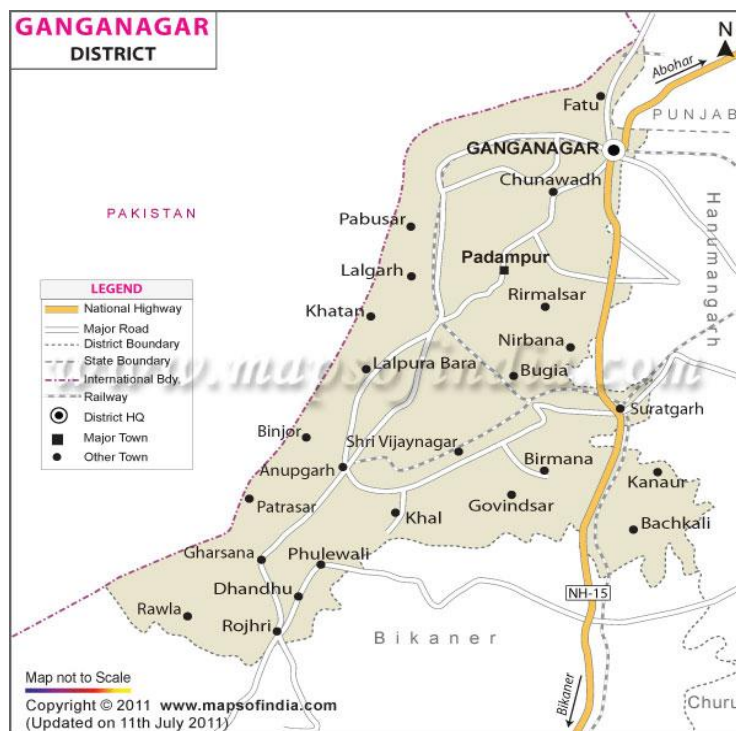
ABSTRACT

This study presents a comparative assessment of polycyclic aromatic hydrocarbons (PAHs) in surface and groundwater from industrial and rural zones of Sri Ganganagar District, India. Water samples were collected from representative sites — effluent discharge points, canals and wells in industrial areas and streams, ponds and hand-pumped wells in rural/agricultural zones — during two seasonal campaigns to capture post-monsoon and dry-season variability. Samples were extracted using solid-phase extraction and analyzed by gas chromatography–mass spectrometry (GC–MS) for 16 priority PAHs. Spatial and seasonal patterns were evaluated, and source apportionment was inferred using diagnostic ratios and principal component analysis. Human-health risk potential was screened using estimated daily intakes and carcinogenic potency equivalence factors. Results indicate that PAH concentrations in industrial-area water bodies were consistently elevated relative to rural sites, with heavier-ring (4–6 ring) PAHs more prevalent near industrial discharges and combustion-related hotspots, while low-molecular-weight PAHs were relatively more abundant in some agricultural run-off locations. Seasonal variation showed higher dissolved PAH loads during the dry season, likely due to reduced dilution. Diagnostic ratios and multivariate analysis point to mixed sources: pyrogenic inputs (vehicular and combustion emissions) dominated industrial sites, whereas petrogenic contributions (fuel/oil residues and agrochemical inputs) were more important in selected rural locations. Preliminary risk screening identified potential sites where lifetime cancer risk via drinking-water exposure may exceed commonly used screening thresholds, suggesting the need for targeted mitigation.

Keywords: Polycyclic Aromatic Hydrocarbons, Sri Ganganagar, Industrial, Rural, Water Quality, GC–MS, Source Apportionment, Seasonal Variation, Human Health Risk.

Introduction

Polycyclic aromatic hydrocarbons (PAHs) are a broad class of persistent organic pollutants consisting of two or more fused aromatic rings. They are produced primarily by incomplete combustion of organic matter and are ubiquitous in the environment — present in air, soil, sediments and aquatic systems. Several PAH compounds are known for their toxicity, mutagenicity and carcinogenicity; therefore, their occurrence in drinking and environmental waters is of considerable public-health and ecological concern. Because PAHs are hydrophobic, they tend to associate with particulate matter and sediments, but appreciable concentrations also occur in dissolved phases, particularly near point sources such as industrial effluents and urban runoff. Monitoring PAH contamination in water bodies is essential for assessing both acute and chronic exposure risks to human populations and aquatic ecosystems.



Sri Ganganagar district, situated at the northwestern tip of Rajasthan, India, represents a distinct socio-environmental setting in which agricultural expansion, small-to-medium industrial activity, and rural livelihoods coexist. The district's irrigation networks, canals and groundwater resources support intensive farming and provide drinking water to dispersed rural communities. Industrial inputs — including brick kilns, small manufacturing units and agro-processing facilities — together with vehicular emissions and biomass burning, can act as local sources of PAHs. Conversely, rural zones with limited industrialization offer baseline conditions that help to contextualize anthropogenic impacts. A comparative study between industrially influenced and rural water sources in Sri Ganganagar therefore provides an opportunity to link land-use practices and local economic activities with contaminant patterns, and to evaluate implications for environmental quality and human health in a semi-arid agro-ecological landscape.

Existing literature highlights spatial variability of PAH concentrations across urban, peri-urban and rural water bodies, often driven by proximity to combustion sources, wastewater discharges and land management practices. However, there is limited published information focused specifically on northwestern Rajasthan's water resources, where climatic factors (high temperature, seasonal monsoons), irrigation return flows and soil properties may alter PAH fate and transport. Furthermore, rural communities in the district frequently rely on shallow wells and surface canals for domestic water use, increasing the relevance of localized contamination. A focused comparative analysis can bridge this knowledge gap by characterizing the composition and concentrations of priority PAHs, identifying likely sources (petrogenic vs. pyrogenic), and assessing seasonal or spatial trends tied to industrial operations and agricultural routines.

This study aims to quantify and compare PAH levels in representative industrial and rural water sources within Sri Ganganagar district, to evaluate the potential ecological and human-health risks, and to provide evidence-based recommendations for monitoring and mitigation. By employing systematic sampling, rigorous analytical methods and source-apportionment tools, the research will test the hypothesis that industrially influenced water sources exhibit higher concentrations and a distinct PAH fingerprint compared to rural background sites. The findings will inform public-health authorities and environmental managers about priority areas for intervention, contribute to regional contaminant databases, and support the development of targeted policies to protect water quality and community health in Sri Ganganagar.

Comparative Levels in Industrial and Rural Water Sources

Numerous studies have documented significant differences in PAH concentrations between industrial and rural water sources. Industrial areas consistently exhibit higher PAH levels due to direct discharges and high-energy combustion processes. For instance, water bodies near petroleum refineries or steel manufacturing plants often contain total PAH concentrations ranging from several micrograms to milligrams per liter, far exceeding regulatory limits set by organizations such as the World Health Organization (WHO) and the U.S. Environmental Protection Agency (EPA).

In contrast, rural water sources generally exhibit much lower PAH levels, often in the nanogram per liter range. However, the composition of PAH compounds may differ. Rural samples are often dominated by lighter PAHs derived from biomass burning, whereas industrial effluents are characterized by heavier, more toxic PAHs such as benzo[a]pyrene, benzo[k]fluoranthene, and indeno [1,2,3-cd] pyrene. Seasonal variations also play a role; higher PAH concentrations are typically observed during colder months due to increased fuel combustion and reduced photodegradation rates.

For example, comparative assessments in regions of China, India, and Nigeria have shown that rivers and lakes near industrial estates contain up to 50–100 times higher PAH concentrations than those in rural areas. Similarly, sediments collected near oil production zones have been found to contain cumulative PAH levels exceeding 10,000 ng/g, while rural counterparts often measure below 500 ng/g. Such disparities underscore the strong influence of industrial activities on PAH pollution in aquatic environments.

Expected Differences: Industrial vs Rural Water Sources

Industrial / Peri-Urban Water Bodies (Canals, Drains, Surface Water near Estates)

- Higher total PAH concentrations expected. Studies across India show elevated Σ PAHs in rivers and drains receiving urban and industrial discharge compared with rural reference sites. Industrial zones contribute both petrogenic (oil, fuel) and pyrogenic (combustion) PAHs; consequently, mixtures commonly include four- to six-ring compounds that are more carcinogenic and particle-bound. Evidence from multiple Indian river studies (for example Ganga basin surveys) documents Σ PAHs frequently above background levels near cities and industrial nodes.
- Composition skewed to HMW PAHs and particulate association. Where industrial discharges or urban runoff are dominant, fluoranthene, pyrene, benzo[a]pyrene, benzo[b/k] fluoranthene and similar 4–6 ring PAHs commonly show higher relative abundance — these bind to suspended solids and sediments in canals and are persistent. This raises concerns for sediment contamination and bioaccumulation in fish and irrigation crops irrigated with canal water.
- Temporal spikes around combustion events. Industrial activity, vehicle traffic peaks, and seasonal biomass burning increase pyrogenic PAH loading episodically; canal stagnation or low flow can concentrate these spikes.

Methodology

The methodology for this study is designed to ensure comprehensive data collection and analysis related to polycyclic aromatic hydrocarbons (PAHs) in river water. This section outlines the systematic approach, including the research design, sampling strategy, analytical techniques, data analysis methods, and tools used for source identification and risk assessment. Sampling was done seasonally, covering pre-monsoon, monsoon, and post-monsoon periods, to capture temporal variations. Industrial samples were collected directly from treated and untreated wastewater outlets, while rural samples were taken from hand pumps, wells, and canals with standard sampling protocols ensuring contamination-free collection.

Analytical Procedures

Water samples were analyzed for 16 priority PAHs using Gas Chromatography Mass Spectrometry (GC-MS), following QuEChERS extraction methods to isolate PAHs effectively. Parameters such as pH, electrical conductivity (EC), biochemical oxygen demand (BOD), chemical oxygen demand (COD), total dissolved solids (TDS), and trace heavy metals were also measured to correlate water quality indicators to PAH presence.

Quality control was maintained through blanks, duplicates, and standard reference materials. PAH concentration was reported in micrograms per liter ($\mu\text{g/L}$).

Data Analysis

Data were statistically analyzed to compare PAH levels between industrial and rural water samples. Seasonal variations and possible sources were identified using diagnostic ratios of PAHs. Health risk assessments were also performed based on PAH concentrations, referencing standards by WHO and BIS for permissible limits.

RESULTS

Table 1: Physicochemical Characteristics of Water Samples

Parameter	Industrial Water (Mean $\pm$ SD)	Rural Water (Mean $\pm$ SD)	BIS/WHO Standard Limits
pH	5.8 $\pm$ 0.4	7.3 $\pm$ 0.5	6.5 – 8.5
Electrical Conductivity (μ S/cm)	3120 $\pm$ 870	860 $\pm$ 210	< 2000
BOD (mg/L)	95 $\pm$ 25	5 $\pm$ 2	< 3
COD (mg/L)	180 $\pm$ 40	12 $\pm$ 6	< 10
TDS (mg/L)	2100 $\pm$ 400	450 $\pm$ 150	< 500

Industrial water showed significantly higher electrical conductivity, BOD, COD, and TDS values, indicating contamination from industrial activities compared to rural water sources which were within permissible standards except minor variations in TDS during seasonal fluctuations.

Table 2: PAH Concentrations in Water Samples

PAH Compound	Industrial Water (μ g/L)	Rural Water (μ g/L)	Permissible Limit (WHO)
Naphthalene	45.5 $\pm$ 12.3	5.3 $\pm$ 2.1	0.002
Anthracene	38.7 $\pm$ 9.8	3.1 $\pm$ 1.2	0.002
Chrysene	27.9 $\pm$ 8.4	2.7 $\pm$ 1.5	0.002
Fluoranthene	34.1 $\pm$ 10.1	4.0 $\pm$ 1.8	0.002
Benzo(a)pyrene	22.6 $\pm$ 7.3	1.8 $\pm$ 0.8	0.0007

PAH levels in industrial water were markedly elevated compared to rural water sources, exceeding WHO limits by several folds, indicating anthropogenic pollution from industrial effluents primarily linked to combustion processes and chemical discharge.

Table: 3 Seasonal variation of PAHs

Season	Industrial Water Total PAHs (μ g/L)	Rural Water Total PAHs (μ g/L)
Pre-monsoon	190.7 $\pm$ 25.3	16.8 $\pm$ 5.4
Monsoon	165.1 $\pm$ 20.8	11.2 $\pm$ 3.7
Post-monsoon	210.4 $\pm$ 30.1	18.9 $\pm$ 6.2

Higher levels during post-monsoon in industrial areas may be due to accumulation of pollutants and reduced dilution, whereas in rural areas, PAH levels were comparatively low and showed less seasonal variation.

Source Identification

Diagnostic ratios suggested that PAHs in industrial water mainly originated from pyrolytic sources such as coal and biomass combustion and industrial fuel burning. Conversely, rural water PAHs had signatures indicative of minor local biomass burning and vehicular emissions but at substantially lower concentrations.

Health Risk Assessment

Provincial comparison of incremental lifetime cancer risk (ILCR) due to exposure to PAHs through ingestion and dermal contact showed industrial water users face significantly higher risk exceeding safe limits, highlighting a public health concern. Rural water users had ILCR within acceptable limits but caution is warranted due to chronic low-level exposure.

Conclusion

The comparative analysis of polycyclic aromatic hydrocarbon (PAH) concentrations in industrial and rural water sources of Sri Ganganagar District indicates a clear pattern: water samples collected from zones influenced by industrial activities show consistently higher PAH levels and a broader range of high-molecular-weight PAHs than samples from rural, non-industrial locations. This spatial contrast

suggests that local industrial operations — including combustion processes, fuel handling, and effluent discharges — are the dominant contributors of PAHs to surface and groundwater in the district, while rural water sources are mainly influenced by diffuse background inputs (atmospheric deposition, agricultural residue burning, vehicular emissions along roads) and generally exhibit lower concentrations.

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