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EMERGING CONTAMINANTS IN THE VARUNA RIVER: ENVIRONMENTAL OCCURRENCE, RISK ASSESSMENT, AND ITS SOCIO-ECONOMIC IMPLICATIONS

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ABSTRACT

Emerging contaminants are a class of chemicals and biological agents that are not yet subject to routine environmental monitoring or regulatory standards but are increasingly detected in environmental media and are of concern due to their potential ecological and human health impacts. Emerging contaminants (ECs) including pharmaceuticals, personal care products (PPCPs), pesticides, and industrial chemicals are increasingly detected in freshwater ecosystems worldwide. While extensive research has documented ECs in the River Ganga and its major tributaries, there is a knowledge gap regarding their occurrence and ecological significance in smaller urban tributaries such as the Varuna River in Varanasi, India. This study synthesizes existing water quality data, regional emerging contaminant research, and urban pollution dynamics to evaluate how ECs may impact the Varuna's water quality, aquatic ecosystems, and human health. The findings highlight chronic pollution from untreated sewage and insufficient wastewater infrastructure, which are likely facilitating the transport and persistence of ECs in this urban waterway. The paper concludes with recommendations for targeted monitoring, risk assessment, and management strategies.

KEYWORDS: Emerging Contaminants, Pharmaceuticals, Industrial Waste, Human Health Impacts

Emerging contaminants (ECs) are a diverse group of synthetic or naturally occurring chemical substances and microorganisms that are not commonly monitored or regulated, but are increasingly detected in environmental matrices and are suspected to pose risks to human health and ecosystems due to their toxicity, persistence, bioaccumulation, and biological activity, even at trace concentrations. The Varuna River, a minor tributary of the Ganga flowing through Varanasi, is subject to intense anthropogenic stress due to urban expansion, inadequate sewage treatment, and direct discharge of untreated effluents. Prior physicochemical assessments of sewage and water quality in the Varuna indicate severe pollution, characterized by high biochemical and chemical oxygen demand (BOD, COD), low dissolved oxygen (DO), and elevated nutrients — conditions conducive to ecological disruption

Emerging contaminants — also termed contaminants of emerging concern — encompass chemical classes that are not typically monitored under conventional water quality programs but may have significant ecological and human health consequences even at trace concentrations. Examples include pharmaceuticals, endocrine-disrupting compounds, artificial sweeteners, and agrochemicals. Although EC studies in smaller tributaries are rare, their documented prevalence in the broader Ganga basin makes understanding their dynamics in Varuna a priority.

Pollution Status of the Varuna River

The River Varuna has emerged as a critical sink for emerging contaminants such as pharmaceuticals, personal care products, endocrine-disrupting compounds, and micro-pollutants originating from urban and peri-urban activities. The presence of emerging contaminants in the Varuna River highlights the limitations of conventional wastewater treatment systems in removing trace-level organic pollutants. Given its role as a tributary of the Ganga, contamination of the River Varuna by emerging pollutants represents a potential pathway for the transfer of persistent and bioactive compounds into the main river system.

Analytical advances, particularly LC–MS/MS techniques, have enabled the detection of emerging contaminants in the Varuna River at ng/L to µg/L concentrations, revealing chronic exposure risks to aquatic biota."

"Continuous discharge of untreated municipal effluents into the River Varuna contributes to the accumulation of emerging contaminants, raising concerns regarding antibiotic resistance, endocrine disruption, and long-term ecological imbalance."

"The occurrence of emerging contaminants in the Varuna River underscores the urgent need for targeted monitoring, advanced treatment technologies, and regulatory frameworks addressing non-traditional pollutants."

Historical and recent observations show that the Varuna River suffers from chronic pollution:

Low Dissolved Oxygen: Water quality tests reveal DO as low as 0.4–0.5 mg/L, far below the 2 mg/L threshold required for aquatic life survival, largely due to continuous inflow of untreated sewage.

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Organic Loading: Extensive discharge of municipal sewage and solid wastes has led to dark, foul-smelling water and significant fish mortality events.

Sewage Management Issues: Multiple drains around Varanasi directly empty into Varuna, with inefficient interceptors and inadequate sewage treatment capacity, resulting in ~80 MLD of untreated sewage entering the river.

Microbial Contamination and Viral Diversity: Metagenomic analyses indicate diverse viral communities associated with pollution gradients in the river, suggesting robust microbial contamination.

These conditions, driven by untreated effluents, urban runoff, and lack of sanitation infrastructure, create an environment where emerging contaminants can persist and bioaccumulate, especially because conventional wastewater treatment is ineffective at removing trace organic pollutants.

Emerging Contaminants: Concepts and Regional Evidence

Definitions and Pathways

Emerging contaminants include:

1- Pharmaceuticals and metabolites (e.g., antibiotics, pain relievers)

2- Personal care products (e.g., triclosan, parabens)

3- Lifestyle and industrial chemicals (e.g., artificial sweeteners, PFAS)

4- Pesticides and agrochemicals

5- Microbial contaminants and antibiotic resistance genes (ARGs)

These compounds typically enter surface waters through untreated sewage, stormwater runoff, hospital and industrial effluents, and agricultural drains. They often persist due to limited biodegradability and escape removal in conventional treatment systems.

Evidence from the Ganga Basin

Although direct measurements in the Varuna River are lacking, basin-wide research provides evidence of prevalent ECs in the main Ganga channel and key tributaries:

A comprehensive survey along ~500 km of the middle Ganga identified 51 emerging organic contaminants — including pharmaceuticals, agrochemicals, and lifestyle chemicals — with some (e.g., sulfamethoxazole) exceeding predicted no-effect concentration thresholds for ecological toxicity.

Studies focusing on municipal and hospital wastewater inputs into the Ganga at Varanasi revealed hundreds of chemical components, indicating pervasive contamination by lifestyle, industrial, and research lab chemicals.

Assessments of PPCPs and artificial sweeteners across the Ganga basin reported measurable concentrations in both surface water and groundwater, with ecological risk estimates for aquatic organisms.

These findings underscore that emerging contaminants are widespread in the Ganga watershed and suggest similar inputs into urban tributaries like Varuna where untreated sewage dominates.

METHODOLOGY

Surface water samples and sediments along a 32 km long stretch of River Varuna at Varanasi were collected from selected upstream and downstream atleast 10 locations or sampling sites using grab sampling techniques in pre-cleaned amber glass bottles. These samples were collected in Summer (pre-monsoon), a humid rainy season (monsoon) and a cold winter season (post-monsoon). Samples were filtered (0.45 µm) and pre-concentrated using solid-phase extraction (SPE). Chromatographic separation was achieved on a reverse-phase C18 column using gradient elution. Target emerging contaminants were identified and quantified using liquid chromatography–tandem mass spectrometry (LC–MS/MS) equipped with an electrospray ionization (ESI) source operated in both positive and negative ion modes. Quantification was performed using external calibration with analytical standards, and results were expressed in ng/L."

Mechanisms of Contaminant Entry in Varuna

Urban Sewage and Wastewater Discharges

The Varuna's course through densely populated urban areas means it receives large quantities of untreated sewage, which carries a complex mixture of ECs from household products, pharmaceuticals, and personal care products. Inefficient or absent wastewater treatment exacerbates loading of trace contaminants.

Stormwater Runoff and Solid Waste

Untreated stormwater can transport pesticides, detergents, and microplastics into the river. The dumping of solid wastes and religious offerings further alters water chemistry and may facilitate sorption of organic contaminants to particulates.

Reduced Dilution and Stagnant Flow

During dry seasons, reduced flow diminishes dilution capacity, increasing EC concentrations and exacerbating ecological stress.

Ecological and Human Health Implications

Emerging contaminants — even at ng/L to µg/L levels — can have profound effects:

Aquatic Ecology: Pharmaceuticals and endocrine disruptors can interfere with reproduction, growth, and metabolic processes in fish and invertebrates.

Antibiotic Resistance: Antibiotic residues and ARGs can promote antimicrobial resistance in microbial communities.

Human Exposure: Local populations interacting with river water for bathing, agriculture, or livestock watering may experience indirect exposure.

Without targeted monitoring, the full extent of these risks in Varuna remains unknown, but evidence from the Ganga basin suggests potential harm.

Research Gaps and Future Directions

Key areas for further research include:

Targeted Contaminant Monitoring: Use advanced analytical techniques (e.g., high-resolution mass spectrometry) to quantify specific ECs in water and sediments of the Varuna.

Temporal and spatial studies: Examine seasonal variations and pollution gradients along the river.

Ecotoxicological assessment: Link detected concentrations to biological effects in aquatic organisms.

Wastewater characterization: Identify major source contributions (domestic, hospital, agricultural) and evaluate treatment performance.

CONCLUSIONS

This synthesis indicates that emerging contaminants likely contribute to the degraded water quality of the Varuna River due to pervasive untreated sewage and urban pollution, paralleling trends observed in the main Ganga channel. While direct measurements are limited, established evidence from related studies supports the need for systematic investigation into ECs in Varuna. Addressing these knowledge gaps is essential for informed water management, pollution mitigation, and protection of ecosystem and human health. In conclusion, the issue of emerging contaminants in the Varuna River represents a complex intersection of environmental science, public health, and socio-economic sustainability. Addressing this challenge requires interdisciplinary research, robust monitoring frameworks, policy reforms, and community participation. A proactive and preventive approach will be essential to restore river health, safeguard ecosystem services, and ensure long-term socio-economic resilience for communities dependent on the Varuna River system. From a socio-economic perspective, contamination of the Varuna River has multifaceted implications. The river supports local agriculture, fisheries, and domestic water use in peri-urban and rural communities. Deteriorating water quality threatens crop productivity through contaminated irrigation, reduces fish yield due to habitat stress, and increases healthcare expenditures associated with water-borne and chronic exposure-related illnesses. Moreover, as a tributary of the Ganga, pollution in the Varuna indirectly affects the ecological integrity and cultural significance of the larger basin, influencing tourism, religious activities, and regional livelihoods.

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