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Water Quality Degradation in the Daman Ganga River under Industrial Influence

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Abstract
The Daman Ganga River is one of the vital freshwater resources in western India. Rapid industrialization and urbanization in the Vapi Daman region are threatening this valuable water source. This study assesses the water quality of the river at two representative locations downstream of the GIDC Weir near NH, 48, Vapi (17 July 2025) and Zery Causeway, Daman(UT) (18 July 2025) to evaluate spatial variations in the pollution status. A wide range of physicochemical, nutrient, ionic, and bacteriological parameters were measured following APHA, BIS, WHO, and CPCB standard protocols. The results show a definite quality degradation downstream, with the Daman site exhibiting significantly higher levels of conductivity, suspended and dissolved solids, nutrients (NH3-N, TKN, phosphate), organic pollution indicators (COD, BOD), major ions, fluoride, and coliform bacteria. A dimensionless min-max normalization method was employed to combine multi, parameter datasets, thus facilitating inter, parameter comparison and visualization of cumulative pollution trends. The normalized results pinpoint the heavy metal effluents and dissolved solids from industrial effluents and municipal sewage as the major contributors to water quality deterioration downstream, along with a decrease in dissolved oxygen content. In general, the study reveals the impact of human activities on the Daman Ganga River, especially in the downstream stretch, which calls for the implementation of pollution control measures, strengthening of regulations, and continuous monitoring to ensure ecological integrity and public health.

Keywords: *Daman Ganga River; Water quality assessment; Industrial pollution; Nutrient enrichment; Dimensionless normalization; River monitoring.*

1. Introduction

The increasing anthropogenic stresses due to rapid industrialization and urbanization have raised apprehensions over the ecological health of riverine systems worldwide, especially those playing a crucial role in serving as a source of drinking water and irrigation for various agricultural purposes (Shrivastava et al., 2015). The presented study addresses a vital need for a proper assessment of the water quality of the Daman Ganga River, similarly plagued by these environmental stressors in the Vapi and Daman(UT) regions of India (Priyadarshee et al., 2024). Since rivers play an essential function in day-to-day activities such as drinking, bathing, and washing, besides acting as a receptacle of industrial and domestic wastes, knowledge about the physicochemical and biological characteristics of the Daman Ganga River is of utmost importance in pollution control and management (Majumdar&Avishek, 2024; Patel &Sahoo, 2022). In this aspect, the research focuses on analyzing several physicochemical parameters, heavy metal concentrations, and bacteriological characteristics for a holistic understanding of the ecological status of the river, often missed when comparing various studies based on individual parameters (Mishra & Kumar, 2020). Such integrated analyses are of immense significance in devising better programs on the monitoring of water quality and ensuring the suitability of water for varied purposes, besides safeguarding this priceless natural resource for human civilization in the future. This type of integrated assessment holds paramount significance because the river is susceptible to various forms of pollution from both point and nonpoint sources, with

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the extensive state of urbanization, agricultural practices, industrialization, and increase in human population deteriorating the quality of water (Lkr et al., 2020). Human activities commonly deteriorate freshwater bodies around the world, thereby reducing their potential utilization for domestic, agriculture, and industries (Rather et al., 2022). Even poor sanitation affects about 780 million people globally and leads to waterborne diseases, accounting for 6-8 million annual deaths worldwide (Pati et al., 2025). Thus, contamination of freshwater due to industrial and agricultural activities in general poses a serious threat to public health and socioeconomic development, and there is a dire necessity of integrated water quality assessment (Sharma et al., 2024). In India, due to rapid population growth, industrial expansion, and poor management of waste generated, a river like the Daman Ganga is highly prone to such degradation, and for this, it requires regular monitoring to find out sources of contamination and their impacts (Kumar et al., 2024; Sharma et al., 2023). [1-3]

2. Literature Review

Management of water resources effectively requires knowledge of the existing water quality and past river pollution and management-related studies. Many researchers have emphasized the importance of assessing physicochemical characteristics and monitoring temporal changes in water quality to locate the sources of pollution and mitigate its impact. With increasing population and growth of industries, the pressure on the water bodies is mounting, with domestic and industrial effluents being major contributors to pollution in rivers like Mithi and Indrani. Such studies will help planners manage water quality and restore the river by underlining the need for continuous monitoring and coordination among stakeholders. Monitoring is still a challenge in India due to a lack of access to remote sites and inadequate skilled personnel, which hinders environmental monitoring programs. [4-6]

3. Methodology

This section of the paper essentially presents detailed protocols and analytical techniques to ensure reproducibility, reliability, and validity of results from this study. The approach supports an in-depth assessment of physicochemical parameters, heavy metals, and bacteriological indicators in the Daman Ganga River. Water samples were systematically taken from a set of preselected sites along the river and spanned both the Vapi and Daman(UT) regions. Further laboratory analysis was conducted based on accepted international standards provided by recognized global organizations such as the World Health Organization (WHO), the Bureau of Indian Standards (BIS), the American Public Health Association (APHA), and the Central Pollution Control Board (CPCB). These standards and procedures, cited in Kumar et al. (2024), Majumdar&Avishek (2024), and Shrivastava et al. (2015), guarantee methodological stringency. The rigorous, standardized methodologies adopted for their identification and quantification are critically important. Further, they allow for an appropriate assessment of spatial and temporal variations in pollutant concentrations, drawing a clear picture of the overall health of the aquatic ecosystem. In turn, this supports the formulation of targeted, evidence-based remediation strategies, as well as control plans for pollution. References to Muhammed et al. (2025), Priyadarshee et al. (2024), and Sen et al. (2023) highlight further the value of such an approach in providing a basis upon which policy and practical intervention can be based. [7-10]

4. Results

Date and type of sample collection: 17.07 & 18.07.2025

Table 1 Name of the location: River Damanganga at Vapi& Daman(UT)

Location	pH	Temp.	Cond.	Turb.	TSS	TDS	FDS	D.O.	COD	BOD	NH_3-N
River Daman Ganga at downstream of GIDC Weir, Near NH-48,	7.4	29	180	71	29.	123	91	7.8	9.0	1.0	0.41

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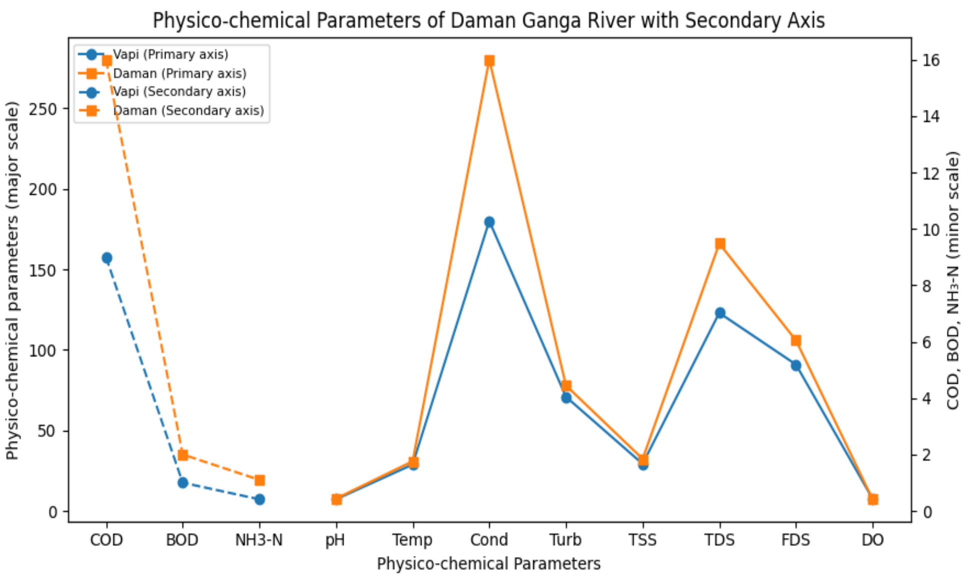
Vapi(17.07.2025)	4				4						
River Daman Ganga at Zery Causeway, Daman-UT(18.07.2025)	7.84	31	280	78	32.5	166	106	7.5	16.0	2.0	1.1

Location	TKN	O-PO_4-P	T.Phosp.	T.Hard.	Ca^{+2}	Mg^{+2}	P-Alk.	T.Alk.	F-
River Daman Ganga at downstream of GIDC Weir, Near NH-48, Vapi(17.07.2025)	1.6	0.042	0.98	65.7	18.0	5.1	2.0	72	0.80
River Daman Ganga at Zery Causeway, Daman-UT(18.07.2025)	2.2	0.049	1.2	79.6	21.1	6.5	4.0	86	3.9

Location	Cl^-	SO_4^{-2}	NO_2-N	NO_3-N	B	Na^+	K^+	% Na	SAR	T.Coli	F.Coli
River Daman Ganga at downstream of GIDC Weir, Near NH-48, Vapi(17.07.2025)	7.8	13.8	0.010	0.33	0.08	6.56	0.5	17.72	0.35	54x10^5	24x10^5
River Daman Ganga at Zery Causeway, Daman-UT (18.07.2025)	21.0	22.3	0.012	0.50	0.11	17.54	0.66	32.18	0.86	92x10^5	35x10^5



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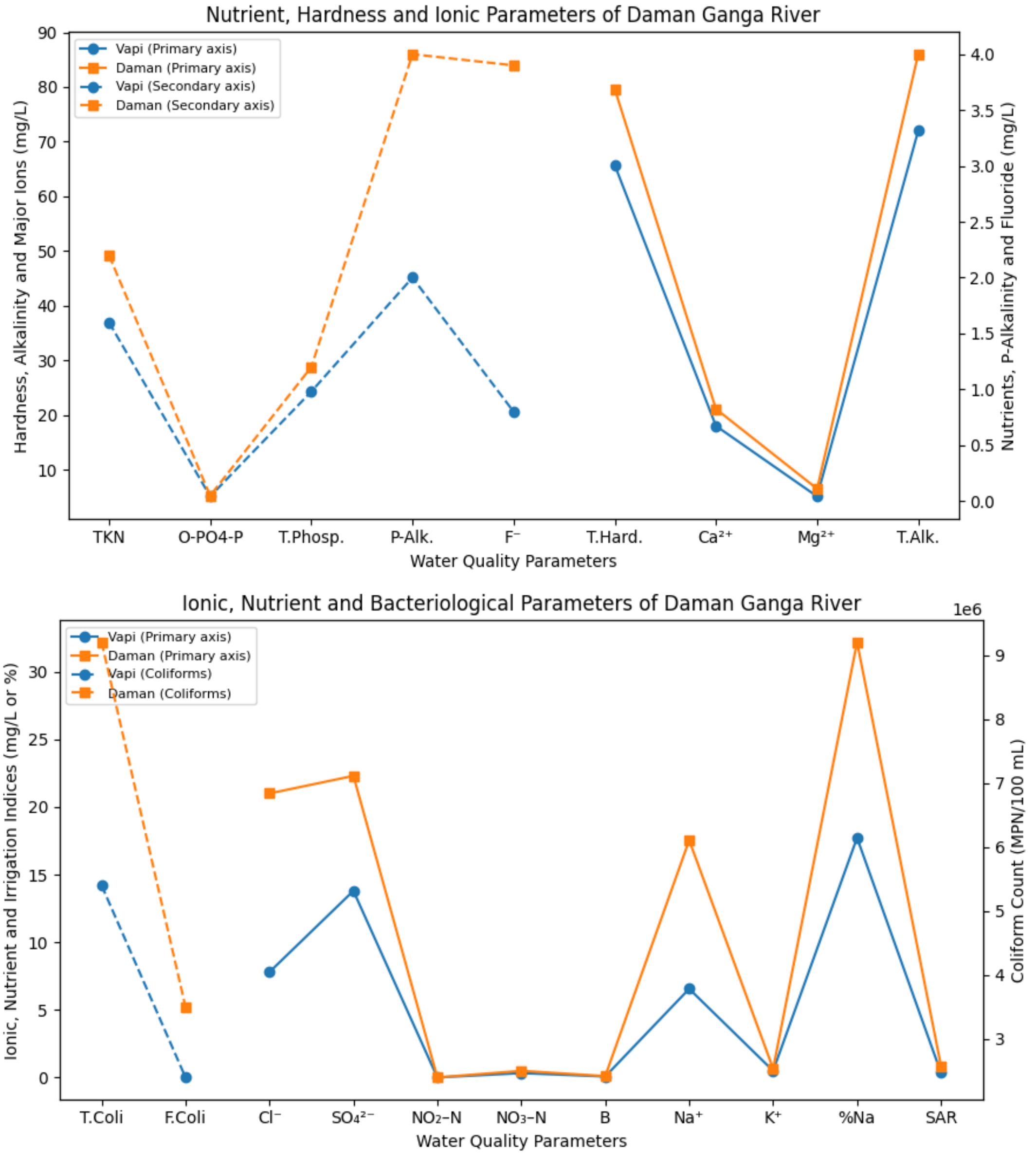

Figure 1 Physio, Nutrient and Ionic Graphs

5. Discussion

Analysis of the physicochemical parameters reveals distinct differences between the two sampling locations, with "River Daman Ganga at Zery Causeway, Daman"(UT) consistently exhibiting higher values for multiple parameters indicative of environmental degradation compared to "River Daman Ganga at downstream of GIDC Weir, Near NH-48, Vapi"(Gautam et al., 2024; Ongh et al., 2024). [11-15]

- Conductivity, Total Dissolved Solids, and Total Suspended Solids: The Daman site shows markedly higher conductivity (280 vs. 180 µS/cm), TDS (166 vs. 123 mg/L), and TSS (32.5 vs. 29.4 mg/L). These elevated levels directly reflect pollution inputs and adversely affect aquatic life by disrupting osmoregulation and increasing turbidity (Gautam et al., 2024; Mahmood et al., 2019; Ongh et al., 2024). High conductivity confirms the presence of ionic pollutants from anthropogenic sources (Gautam et al., 2024). Increased TDS demonstrably reduces light penetration, hindering photosynthesis and

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lowering dissolved oxygen levels (Mahmood et al., 2019). High TSS promotes sludge accumulation, oxygen depletion upon settling, and transport of toxic heavy metals and pollutants (Gautam et al., 2024; Hasnan et al., 2021). [16-20]

- Chemical Oxygen Demand and Biochemical Oxygen Demand: COD (16.0 vs. 9.0 mg/L) and BOD (2.0 vs. 1.0 mg/L) are elevated at Daman. High COD unequivocally signals organic contamination and substantial oxygen demand (Anyanwu& Blessing, 2019; Gautam et al., 2024). Elevated BOD confirms greater organic pollutant loads (Anyanwu& Blessing, 2019). Unpolluted waters maintain BOD below 2 mg/L; the Daman site reaches this limit, while Vapi remains compliant (Anyanwu& Blessing, 2019).
- Ammonia Nitrogen: Ammonia nitrogen (1.1 vs. 0.41 mg/L) is substantially higher at Daman, a definitive marker of organic pollution (al., 2023; Tahiru et al., 2020). Unpolluted waters hold ammonia below 0.2 mg/L, exceeded at both sites (Tahiru et al., 2020). [21-25]
- Turbidity: Turbidity (78 vs. 71 NTU) is higher at Daman, reducing light penetration and disrupting photosynthesis, thereby stressing aquatic organisms by limiting oxygen availability (Hasnan et al., 2021; Mahmood et al., 2019).
- Dissolved Oxygen: D.O. is marginally lower at Daman (7.5 vs. 7.8 mg/L). D.O. is essential for aquatic metabolism and ecosystem health (Kumar et al., 2021; Ongh et al., 2024); both sites exceed the 5 mg/L threshold, but the Daman decline aligns with heightened biological oxygen consumption (Anyanwu& Blessing, 2019). [26-30]
- Temperature: Temperature is higher at Daman (31 vs. 29°C), directly influencing aquatic physiology, metabolism, oxygen solubility, and chemical reaction rates (Escatron et al., 2022; Mahmood et al., 2019; Ongh et al., 2024).
- pH: pH is higher at Daman (7.84 vs. 7.44), a key determinant of water quality affecting organism metabolism and toxicity (Escatron et al., 2022; Ongh et al., 2024). Both sites align with the 6.5–8.5 range optimal for fish (Ongh et al., 2024).
- Comparing additional physicochemical parameters confirms a clear trend of elevated concentrations at Daman, evidencing stronger anthropogenic pressures (Lkr et al., 2020; Rather et al., 2022).
- Total Kjeldahl Nitrogen: TKN rises from 1.6 to 2.2 mg/L, reflecting organic nitrogen from sewage, runoff, and effluents with incomplete degradation (Das, 2025). Acceptable levels span 2–6 mg/L (Bremner, 1965).
- Orthophosphate and Total Phosphate: Orthophosphate increases slightly (0.042 to 0.049 mg/L), total phosphate from 0.98 to 1.2 mg/L, driven by sewage and runoff; these promote eutrophication, algal blooms, oxygen depletion, and biodiversity loss (Mahadevan et al., 2020; Seymenov, 2022). Orthophosphate is the primary bioavailable form (Gumelar et al., 2017).
- Total Hardness, $Ca^{+}2$, and $Mg^{+}2$.All rise at Daman (79.6 vs. 65.7 mg/L hardness; 21.1 vs. 18.0 mg/L $Ca^{+}2$ 6.5 vs. 5.1 mg/L $Mg^{+}2$), mainly from rock weathering but amplified by mining, quarrying, and runoff (Titilawo et al., 2019).
- Phenolphthalein Alkalinity and Total Alkalinity: Both elevate (P-Alk. 4.0 vs. 2.0 mg/L; T-Alk. 86 vs. 72 mg/L), buffering pH via carbonates/bicarbonates; increases link to flow changes, geology, or alkaline effluents (Ahmed et al., 2024; Chithra et al., 2021).
- Fluoride: Fluoride surges from 0.80 to 3.9 mg/L, exceeding WHO's 1.5 mg/L limit (Kaur et al., 2017); anthropogenic sources like industry elevate it beyond natural <0.05–1.6 mg/L, harming biota and health (Camargo, 2003; Du et al., 2022).
- Chloride: Chloride climbs from 7.8 to 21.0 mg/L from sewage, effluents, and runoff, increasing corrosivety, acidification, and biota stress (DragomirBalanica et al., 2020;

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Kelly et al., 2010).

- Sulfate: Sulfate increases from 13.8 to 22.3 mg/L from wastes and runoff, inducing osmotic/ionic toxicity and altering nutrient cycles (Berens et al., 2024; Karjalainen et al., 2023; Žák et al., 2020). [31- 35]
- Nitrite Nitrogen and Nitrate Nitrogen: Both higher at Daman (NO_2-N: 0.012 vs. 0.010 mg/L; NO_3-N: 0.50 vs. 0.33 mg/L), signaling pollution; nitrite >1 mg/L toxifies biota (Ariffin et al., 2019; Titilawo et al., 2019).
- Boron: Boron rises slightly (0.08 to 0.11 mg/L) from weathering and inputs; excesses toxify plants and sensitive species (Patel &Sahoo, 2022). [36-40]
- Sodium, Potassium, %Na, and Sodium Adsorption Ratio: Elevated at Daman (Na^+: 17.54 vs. 6.56 mg/L; K^+: 0.66 vs. 0.5 mg/L; %Na: 32.18 vs. 17.72; SAR: 0.86 vs. 0.35), from effluents and agriculture, impairing irrigation via salinization (Fadila& BOUDEFFA, 2023; Zhang et al., 2019).
- Total Coliform and Fecal Coliform: Drastically higher at Daman (T.Coli: 92×10^5 vs. 54×10^5,F.Coli, 35×10^5 vs. 24×10^5 MPN/100mL), confirming fecal pollution and disease risks (Hadi, 2023; Ujianti&Androva, 2019). [41-44]

Conclusion

The comprehensive assessment of the Daman Ganga River's water quality reveals a clear and concerning degradation at the Zery Causeway in Daman(UT) compared to the GIDC Weir downstream of NH-48 in Vapi. The data consistently indicates that the Daman site experiences significantly higher levels across a broad spectrum of physicochemical, nutrient, and bacteriological parameters, suggesting substantial anthropogenic pressures.

Specifically, the Daman location shows elevated concentrations of parameters indicative of pollution such as:

- Conductivity, Total Dissolved Solids, and Total Suspended Solids, which reflect increased pollutant inputs and adversely affect aquatic life by disrupting osmoregulation and reducing light penetration (Gautam et al., 2024; Hasnan et al., 2021; Mahmood et al., 2019).
- Chemical Oxygen Demand and Biochemical Oxygen Demand, signaling higher organic contamination and greater oxygen demand, which can lead to depleted dissolved oxygen crucial for aquatic ecosystems (Anyanwu& Blessing, 2019).
- Ammonia Nitrogen (NH3-N), a definitive marker of organic pollution, and Total Kjeldahl Nitrogen, indicating organic nitrogen from various discharges (Das, 2025; Tahiru et al., 2020).
- Orthophosphate and Total Phosphate, driven by sewage and runoff, contributing to eutrophication, algal blooms, and subsequent oxygen depletion (Gumelar et al., 2017; Mahadevan et al., 2020).
- Total Hardness, Calcium (Ca+2), and Magnesium (Mg^+2), primarily from natural sources but amplified by human activities (Titilawo et al., 2019).
- Phenolphthalein Alkalinity and Total Alkalinity, influenced by geological factors and potentially alkaline effluents (Chithra et al., 2021).
- Fluoride, with concentrations at Daman exceeding WHO's recommended limits and posing risks to biota and human health (Camargo, 2003; Kaur et al., 2017).
- Chloride and Sulfate, originating from sewage, industrial effluents, and runoff, impacting water corrosivity and exerting toxic effects on aquatic organisms (Karjalainen et al., 2023; Kelly et al., 2010).
- Nitrite Nitrogen (NO2-N) and Nitrate Nitrogen (NO3-N), signaling organic pollution, with nitrite being particularly toxic to aquatic life (Titilawo et al., 2019).
- Sodium (Na^+), Potassium (K^+), % Sodium, and Sodium Adsorption Ratio, which are elevated due to effluents and agricultural practices, potentially impairing irrigation suitability (Zhang et al., 2019).
- Crucially, Total Coliform and Fecal Coliform counts are drastically higher at Daman,

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confirming significant fecal contamination and indicating increased risks of waterborne diseases (Ujianti&Androva, 2019).

In summary, while both sites exhibit some level of anthropogenic influence, the Zery Causeway at Daman(UT) consistently shows a more pronounced deterioration in water quality across almost all assessed parameters. This comprehensive analysis underscores the urgent need for targeted remediation and pollution management strategies in the Daman region to safeguard the ecological health of the Daman Ganga River and ensure its suitability for diverse purposes for future generations. This is particularly critical given the potential for persistent toxic elements to bioaccumulate, causing long-term ecological damage and posing significant health risks to humans and wildlife (Corbett et al., 2025). The pervasive degradation underscores the critical necessity for a robust water quality management plan, similar to those proposed for other highly impacted river systems, to mitigate the cascading effects of pollution and restore ecosystem functionality (Shrivastava et al., 2015). Such a plan should integrate regular monitoring, source reduction strategies, and advanced wastewater treatment technologies to address the diverse range of pollutants identified (Majumdar&Avishek, 2024). Furthermore, the elevated levels of iron, phosphate, nitrate, and ammonium ions downstream of wastewater discharge points, coupled with high electrical conductivity and total dissolved solids, highlight significant contamination requiring immediate intervention to prevent further ecological damage and safeguard public health (Patel &Sahoo, 2022; Wadghane et al., 2024). This comprehensive approach is essential for balancing anthropogenic activities that contribute to water quality degradation and nutrient imbalances with the imperative of environmental preservation ("Anthropogenic Influence and Climate Change on Water and Nutrient Dynamics in the Kebir-Rhumel Basin, (Northeastern Algeria)," 2024). These findings align with global trends where extensive urbanization, industrialization, and agricultural practices lead to significant deterioration of freshwater sources (Lkr et al., 2020). Moreover, the observed water quality degradation, particularly in the hyporheic zone, indicates a critical reservoir of contamination influenced by industrial discharges and hydrological shifts, necessitating targeted remediation efforts and stricter regulatory frameworks for pollution control (Hasanuzzaman et al., 2025). Therefore, a multi-faceted approach involving policy interventions, technological advancements, and community engagement is crucial for effective water quality management and the restoration of the Daman Ganga River's ecological integrity (Ghosh et al., 2024). This underscores the broader challenge of river pollution in India, where industrial waste, domestic sewage, and agricultural runoff significantly degrade essential freshwater resources (Kumar et al., 2024). These pollutants introduce a myriad of emerging contaminants, including pharmaceuticals and microplastics, which pose severe, long-term ecological risks to aquatic ecosystems and human health (Kumkar et al., 2023). To combat this, comprehensive strategies are required, encompassing real-time monitoring systems, upgraded wastewater treatment facilities, and stringent regulatory enforcement to mitigate anthropogenic impacts and restore water quality (Kumar et al., 2024). Effective river basin management requires governmental commitment to defining stakeholder roles, funding policy initiatives, and fostering diverse communication channels with agricultural communities (Banda et al., 2024). This holistic approach would not only address the immediate pollution challenges but also foster sustainable practices to preserve the long-term ecological health and biodiversity of the Daman Ganga River (Majumdar&Avishek, 2024).

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