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Linking Industrial Water Pollution, Hydrochemical Change, and Plant Diversity: Implications for Urban Water System Resilience in Gujarat, India-Integrating Evidence up to 2025

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Abstract

The swift pace of industrial growth and urban development has profoundly impacted water quality and ecological balance across various regions in India. This article compiles findings on the environmental resilience of urban water systems facing industrial stress, focusing specifically on Surendranagar, Wadhvan, Gujarat. Findings from hydrochemical studies, ecological evaluations, and resilience frameworks indicate that the discharge of industrial effluents, urban runoff, and excessive groundwater extraction have compromised the quality of both surface and groundwater. The alterations have subsequently impacted the diversity of aquatic and semi-aquatic plants, promoting species that tolerate pollution and are invasive, while diminishing the presence of native biodiversity. This review consolidates insights from both regional and global studies conducted until 2025, emphasizing the importance of cohesive water management, ecological restoration, and enhanced monitoring, particularly of emerging contaminants, to bolster the resilience of urban water systems. Water quality is a critical aspect of environmental resilience, particularly in the context of industrial pollution. The health of groundwater resources is closely linked to plant diversity, which can be adversely affected by eutrophication. Additionally, urban water systems play a significant role in managing these challenges.

Keywords: Water quality; Environmental resilience; Industrial pollution; Groundwater; Plant diversity; Eutrophication; Urban water systems

1. Introduction

The quality of water plays a crucial role in the health of ecosystems, the safety of the public, and the advancement of sustainable development. Environmental resilience denotes the ability of ecosystems to withstand disturbances, adjust to changes, and preserve their functional integrity when faced with stress [20]. Nonetheless, swift industrial development and urban expansion have progressively undermined this resilience, especially in semi-arid areas of India where water shortages intensify the effects of pollution.

Groundwater serves as the main source of drinking and domestic water for a significant portion of India; however, it is particularly susceptible to contamination from industrial discharges, sewage, and agricultural runoff [3][13][21]. Surface waters, including rivers and ponds, are similarly exposed to untreated or partially treated waste, which diminishes their ability to self-purify [15]. The pressures are particularly noticeable in industrial clusters throughout Gujarat, such as Surendranagar and Wadhvan, where the textile, chemical, and engineering sectors are prevalent [11][12][14].

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The degradation of water quality has a significant impact on aquatic and riparian plant communities from an ecological perspective. The process of nutrient enrichment and organic loading leads to eutrophication, which promotes the growth of fast-growing invasive macrophytes while inhibiting native species, ultimately diminishing biodiversity and the resilience of ecosystems [7][8][18]. Aquatic vegetation plays a crucial role in regulating water quality by absorbing nutrients and stabilizing sediments, establishing a reciprocal relationship between biological organisms and hydrochemistry [1][5][6].

This review examines the connections between industrial pollution, the decline in water quality, and alterations in plant diversity within urban-industrial environments, using Surendranagar–Wadhvan as a primary example.

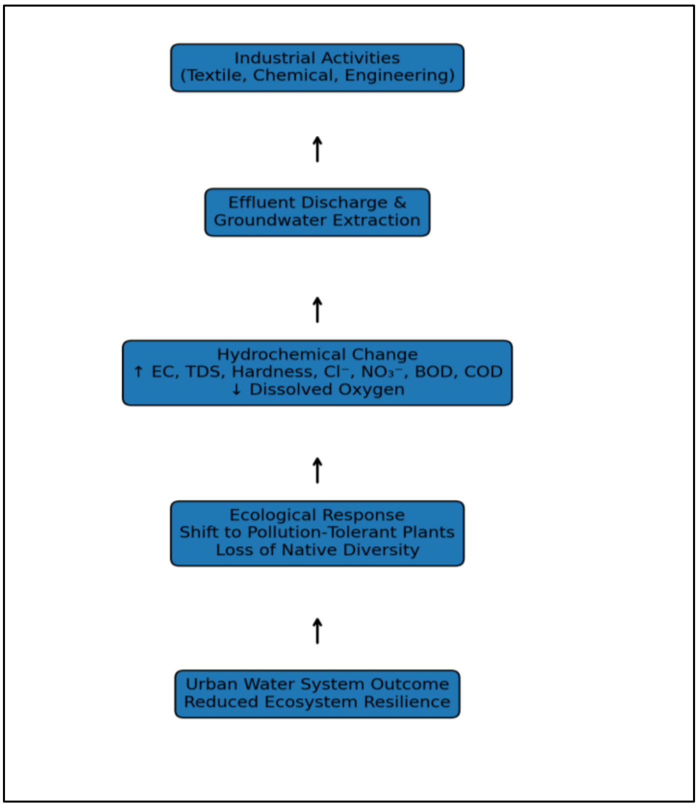

Figure 1 Conceptual framework linking industrial pollution, hydrochemical change, plant diversity, and urban water system resilience

2. Industrial Impacts on Water Quality: Evidence from Global to Local Scales

2.1. Global and National Perspectives

Many investigations show that the release of industrial wastewater modifies hydrochemical factors including electrical conductivity (EC), total dissolved solids (TDS), hardness, chloride, nitrate, and organic load (BOD/COD) [2][15]. The prolonged infiltration of wastewater has been demonstrated to introduce enduring organic pollutants into aquifers, heightening risks to both human and ecosystem health [2].

Throughout India, industrial clusters display variations in groundwater quality influenced by geological conditions and human activities [3]. Elevated levels of TDS, nitrate, and hardness are frequently observed in areas with significant industrial activity, especially in regions experiencing intense groundwater extraction [14]. Seasonal studies show that water quality generally worsens during the pre-monsoon summer as a result of decreased dilution and heightened evaporation [11][15].

2.2. Regional Evidence from Gujarat and Surendranagar–Wadhvan

Assessments conducted in Gujarat indicate that industrial activities have a considerable effect on the quality of both surface and groundwater [3][14][21]. Research conducted in Wadhvan Taluka indicates increased electrical conductivity, hardness, and nitrate levels in groundwater adjacent to industrial zones, frequently surpassing the BIS drinking water standards [11][23].

Investigations into surface water in the Wadhwana Reservoir and the Bhogavo River system reveal increased levels of BOD, COD, and nutrients downstream from industrial areas, especially during the summer months [12][15]. The results are consistent with hydrogeological studies indicating that the fractured Deccan Trap basalts and alluvial aquifers in Surendranagar district are particularly vulnerable to contamination [13].

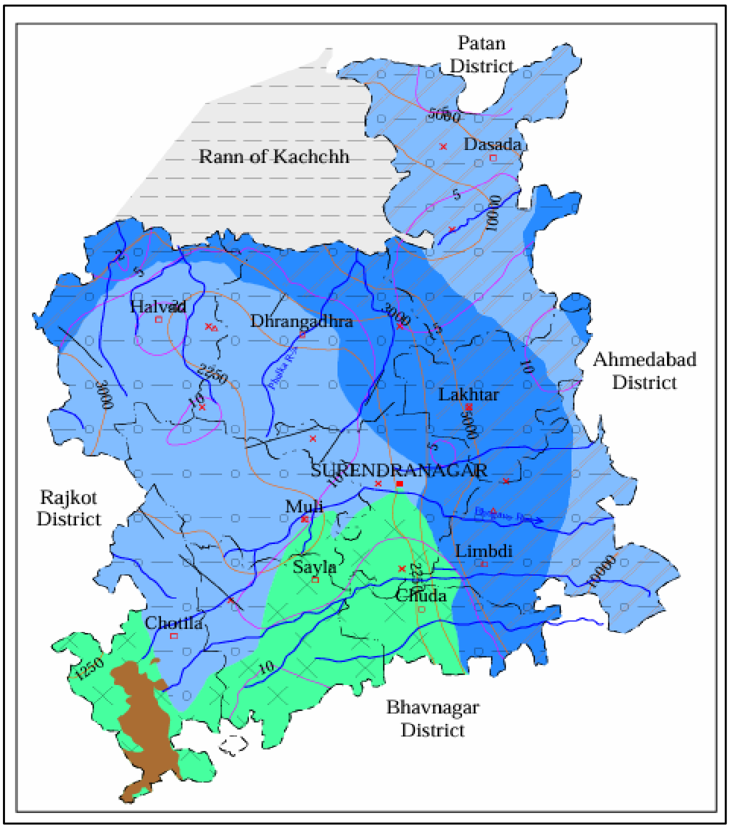

Figure 2 Hydrogeological map of Surendranagar District showing aquifer distribution and groundwater potential [13]

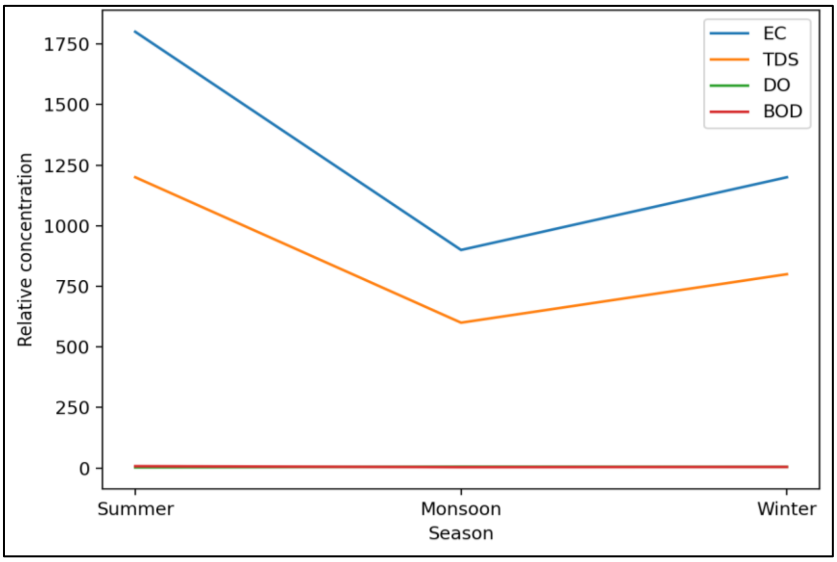

Figure 3 Seasonal variation in key water quality parameters in industrially influenced sites of Surendranagar–Wadhvan.

3. Interactions Between Water Quality and Plant Diversity

3.1. Eutrophication and Vegetation Shifts

The alteration of aquatic vegetation is primarily influenced by nutrient enrichment, specifically nitrogen and phosphorus. Eutrophication encourages the growth of invasive species like Eichhornia crassipes and Cabomba caroliniana, which can outcompete native plants and lead to a decrease in biodiversity [7][18]. Comparable trends have been observed in freshwater systems worldwide [8][9].

In Surendranagar–Wadhvan, species that can tolerate pollution are prevalent in degraded water bodies, whereas sensitive taxa are found only in areas with lower pollution levels—aligning with observations from other industrial environments [4][10].

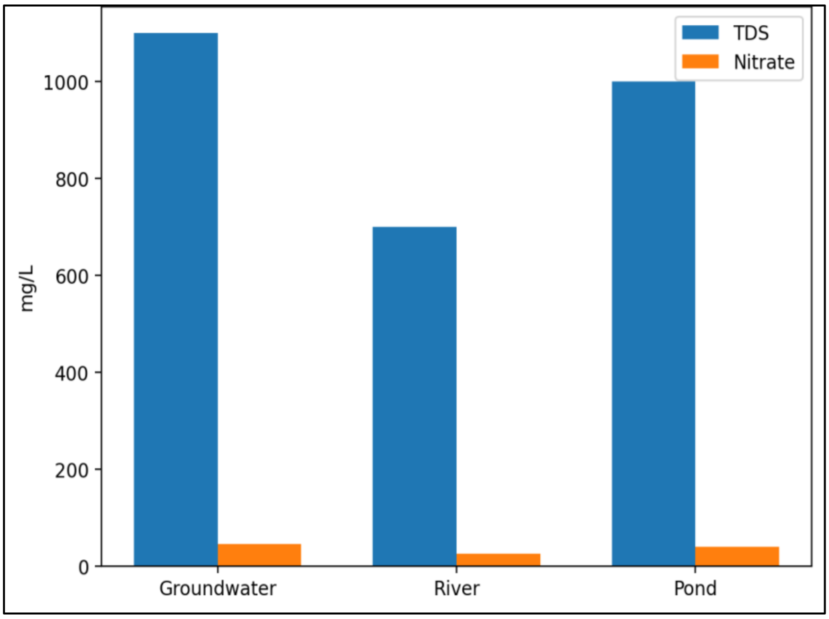

Figure 4 Comparative water quality of groundwater, river water, and pond water in Surendranagar–Wadhvan

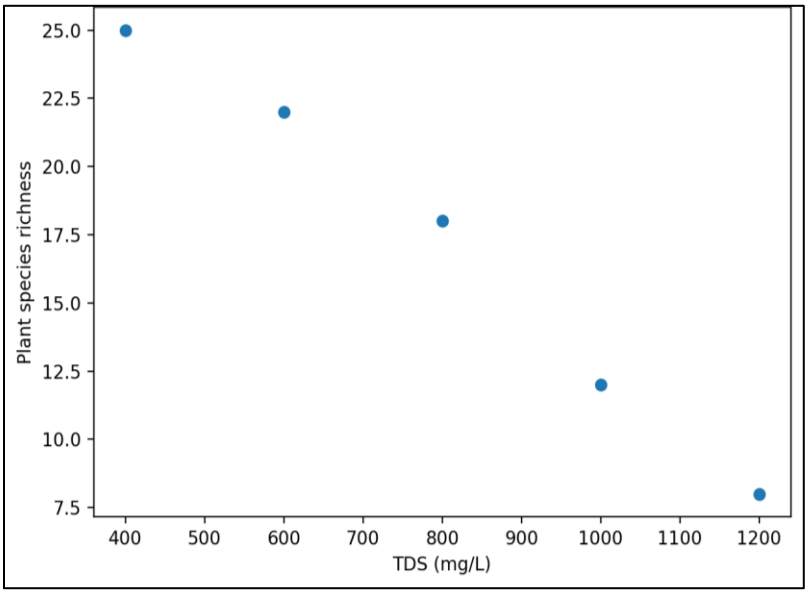

Figure 5 Relationship between pollution level and plant species richness.

3.2. Feedback Effects of Plants on Water Quality

Aquatic plants enhance water quality through the absorption of nutrients, sediment trapping, and the reduction of suspended solids [1][6]. Mosaic systems that integrate submerged and emergent plants have demonstrated effectiveness in addressing eutrophication when faced with moderate pollution levels [6]. Under conditions of significant organic stress, plant communities tend to transition towards species that are more tolerant, which consequently provide diminished purification advantages [5].

3.3. Implications for Ecosystem Resilience

The reduction of native plant diversity indicates a decrease in ecological resilience. Frameworks focused on social-ecological resilience highlight the importance of a comprehensive evaluation of hydrochemical, biological, and governance elements to comprehend and rehabilitate impaired water systems [20]. In Surendranagar–Wadhvan, ongoing industrial pressure poses a risk to long-term adaptive capacity unless timely intervention is implemented.

4. Innovative Approaches in Water–Ecology Evaluation

Recent studies support the use of multi-parameter monitoring that incorporates traditional water quality indicators (pH, TDS, BOD, COD, nutrients) in addition to biological indicators like macrophyte diversity [1][7]. Studies on emerging contaminants emphasize the importance of incorporating pharmaceuticals, PFAS, and markers of antibiotic resistance into standard evaluations [2][15].

Geospatial modeling, long-term monitoring, and composite resilience indices, such as DPSIR frameworks, are being utilized more frequently to assess the sustainability of urban water systems [9][20].

5. Implications for Management and Policy

According to the accumulated evidence, the primary recommendations are as follows:

- Implementing stricter regulations and real-time monitoring of industrial effluents [14][23].
- Enhancing wastewater treatment facilities within industrial estates [15].
- Adopting watershed-scale management that incorporates groundwater recharge, pollution control, and land-use planning [13].[21].
- Ecological restoration through the implementation of constructed wetlands and the reintroduction of native plant species [6][7].
- Community involvement and collaborative governance for sustainable water management [20].

6. Conclusion

This review compiles evidence up to 2025 showing that industrial pollution greatly compromises water quality and ecological resilience in urban areas such as Surendranagar–Wadhvan. The decline in hydrochemical quality and changes in plant diversity indicate underlying stress within freshwater ecosystems. Enhancing resilience necessitates a cohesive approach to water governance, sophisticated monitoring systems, and ecological restoration methods that harmonize industrial growth with environmental sustainability.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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