

Pharmaceutical Effluent Based Biochemical Contamination In The Sirsa Tributary of River Sutlej, India

Anil Jindal, Preetam Kumar, Bhagat Singh

Abstract: *The pharmaceutical and chemical effluents from the Baddi Barotiwala Nalagarh industrial cluster have severely degraded the Sirsa tributary of the River Sutlej. This study demonstrates an environmental emergency threatening aquatic biodiversity and reflected downstream human water security demand. The contamination is a multi-parameter pollution syndrome rather than pharma residuals alone due to persistence wastewater inflow and ineffective pollution management. The complete failures across all recorded water quality indicators under study, as extreme acidic pH (3.2), anoxic dissolved oxygen (1.22 mg/L) due to the addition of chemical residues resulted in mass mortality of fishes and carnivorous birds, very high chemical oxygen demand (365 mg/L), TDS, BOD, high nutrient concentrations, elemental contaminations and warm foothill water temperature (57.5°C). It may be due to the toxicity of ammonia (6.65 ± 2.96 mg/L at S₂), exceeding the WHO limit of 0.5 mg/L for drinking water supply. Further, such changes in hydrobiological parameters, supported by principal component analysis that also resulted in 89% of total variance related to water quality dynamics with PC1 showed high positive loadings for TDS, COD and turbidity as well as strong negative loadings for DO and pH. The water pollution is chronic and enduring rather than episodic is confirmed by seasonal studies. Even during peak discharge season has constantly resulted in the exceeded concentrations (Mean $\pm$ SD in ppb) at S2 for Boron (2156 ± 72), Magnesium (31315 ± 192) and Thallium (03.34 ± 0.64) with overall MI values at S1 (1.55), S2 (5.82) and S3 (2.57) demonstrating that monsoon flows are insufficient to provide effective dilution. The predominance of pharmaceutical chemicals (antibiotics) that are not biodegradable and resistant to traditional biological treatment methods is confirmed by very high COD:BOD ratio. This site S2 was strongly affected and found to be uninhabitable due to the presence of*

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*elemental dust and untreated wastewater discharged by chemical industrial units of the Baddi region. The water quality index value (106.94) at S₃ also indicated very poor and strongly impaired river health. Palmer's algal index score at S₃ exceeded 20, confirming heavy organic pollutant load with declined trends read as $H' = 0.87$ at S₁ to $H' = 0.36$ at S₃ and increased in $S = 2.8$ at S₁ to $S = 6.2$ at S₃ with predominance of *Tubifex tubifex*, *Chironomus* larvae and *Oscillatoria* sp. as classical bioindicators responded to present polysaprobic conditions with a severe dip in dissolved oxygen. There is also serious hazard to public due to the biochemical collapsed of niche, extreme dangers are faced by downstream communities that depend upon the Sutlej river water for their survival. The results placed the Sirsa tributary among the most seriously polluted freshwater system in India that have been touched by pharmaceuticals, requiring immediate rehabilitation and restoration practices.*

Keywords: Pharmacy residuals, flow of pollutants, CETP, river health, drinking water, complications

Introduction

The riverine water system is complex in ecology in the northern part of India under the Himalayan mountain ranges. The river pathways have no origin as well as no ending, without any geographical boundary, only resulting in hydrogeochemical cycles in the aquatic environment. The life of aquatic riverine ecosystems is directly or indirectly dependent upon the quality of water body, as alterations in the bio-chemical parameters affect the diversity more in the case of the aquatic ecosystems than the terrestrial ones because the aquatic riverine resources have a narrow range of limits to assimilate the uncontrolled rate of dumping of pollutants into them. In river health assessment, aquatic life is governed by a stable state of physicochemical properties and their reproduced traits, thereby enabling biota to create adaptive radiations that enhance long term production and control the restoration of rivers (Wetzel, 2001; Allan & Castillo, 2007).

The manufacturing hub in the Baddi geographic cluster, focused on the pharmaceutical business, is one of the fastest-growing industrial sectors in the world, with more than 700 pharma units that account for more than 35% of Asia's drug production. It acts as a water pollution hot spot source in the area because numerous pollutant gutters pour into the Sirsa River basin from pharmaceutical industries, as observed while studying the impact of

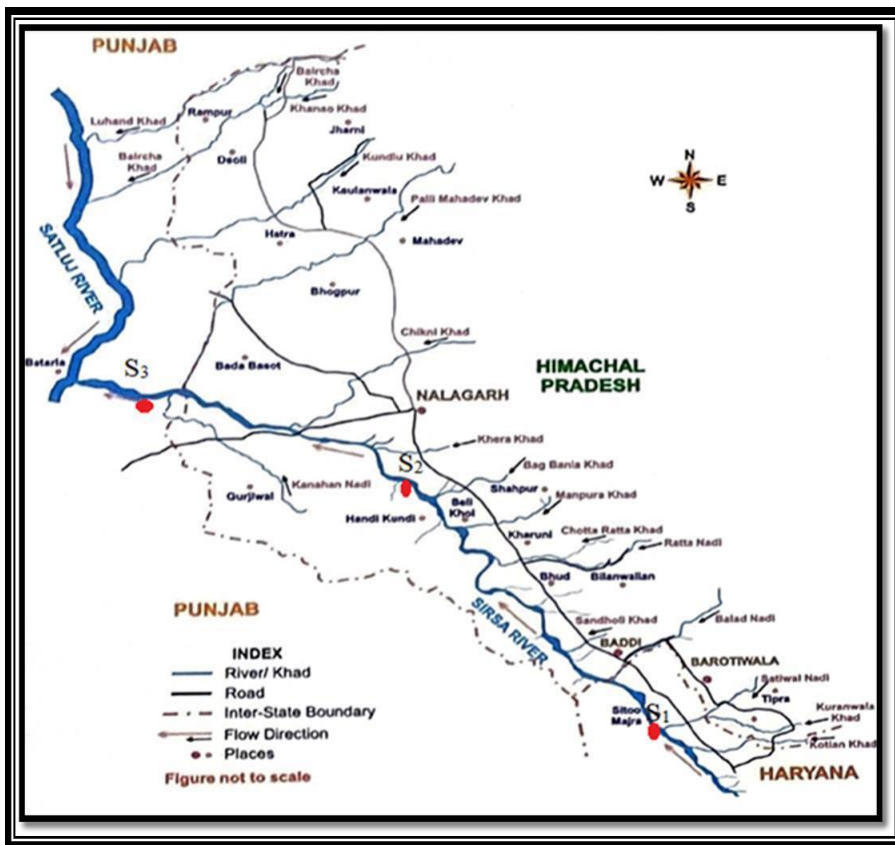
antibiotics (ciprofloxacin, norfloxacin, ofloxacin, azithromycin, levofloxacin and levofloxacin) on fish, algae and daphnia and reported negative ecological repercussions (Zhang & Wen, 2008; Aus der Beek et al., 2016; Dixit et al., 2024b). The investigations conducted by the National Green Tribunal found that 37 out of 111 monitored antibiotic production units did not comply with the Common Effluent Treatment Plant's recommended discharge limits (National Green Tribunal [NGT], 2021).

Thus, the direct impact of pollutants on the water quality of Indian rivers has become crucial as water bodies are severely contaminated because of fast industrial belt start-ups without a corresponding development of pollution control infrastructure (Bhardwaj et al., 2018; Himachal Pradesh State Pollution Control Board [HPSPCB], 2021). The previous studies that examined isolated parameters in this region; above subject is a unique one that integrates multi-parameters related to water chemistry, heavy metal profiling and multi-taxon biological assessment with defined pollution gradient indices across four seasons. The present investigation aimed at comprehensively evaluating the extent of pollutant dumping and its consequent impacts on the water quality of the Sirsa River and its associated effluent nallah, with particular emphasis on implications for human health, ecological integrity and material assets.

Material & Methods

It originated from the lower foothill of Kasauli upstream Kalka in Haryana, traversing through the Baddi industrial belt, Asia's largest pharmaceutical manufacturing hub, before it entered into the Ramsar wetland Ropar of Punjab; during its downward course, it receives ruthless pollutants from industries in the Baddi area, thereby also acting as a hotspot representative model of localised biochemical water pollution in India, with the 4th position in air quality index of 366 recorded by CPCB, 2025. The water samples, collected from three strategically selected sites: S₁ Lotic Zone (upstream reference site beyond the Baddi main bridge or Maranwala bridge), S₂ (Pollutant Discharge Point nearer to the Common Effluent Treatment Plant at Jagatkhana Bridge) and S₃ (Lentic downstream zone at Ghanauli Bridge) as shown in (**Fig. 1**) for 12 consecutive months (March 2024 to Feb. 2025). Fifteen (15) biochemical parameters as were analyzed using (APHA, 2022; Trivedy & Goel, 1986) and statistically analyses using IBM SPSS Statistics

v.26 and R v.4.3. Parameters like pH, turbidity, initial free carbon dioxide, TDS and fixation of dissolved oxygen were determined on the spot. For the rest of the parameters, 0.5L (triplicate) of river water brought to the laboratory. It filtered and analyzed for total alkalinity, total hardness, chlorides, nitrates, ammonia, phosphates and Sulphates. Unfiltered samples used for the determination of BOD and COD. The observed parameter values compared against permissible limits established by the World Health Organization (WHO, 2022) and Bureau of Indian Standards (BIS IS: 10500, 2012). The calculation of water quality index was done with reference to the addition of biochemical residues to estimate the number of biota in the river water, characteristics of disturbed riverine ecosystems where sensitive



(Source:IPH Department Himachal Pradesh)

Fig. 1: Map showing study area depicting S₁, S₂ and S₃ the effluents impaired locations.

Results & Discussion

The present study on the Sirsa River in the Baddi industrial region indicates that the river ecosystem is experiencing considerable stress due to the continuous influx of industrial effluents. Analysis of water quality parameters clearly shows increased turbidity, reduced dissolved oxygen, elevated levels of biochemical and chemical oxygen demand, all of which point toward deteriorating ecological health. The ultimate goal is not merely achieving numerical compliance with water quality standards but restoring a living river ecosystem capable of supporting fish populations, maintaining biodiversity, providing water resources for human needs, and serving as a source of natural beauty and cultural meaning for communities whose lives are intertwined with the river. This goal is achievable through sustained commitment to science based management, regulatory enforcement, industrial accountability and recognition that clean water is not a luxury but a fundamental requirement for environmental health, public wellbeing and sustainable development (Dixit et al., 2024a).

Based on the evidence collected, the dominant biochemical stressor reported at S₂ (near pollutant nallah) combined with near anoxic dissolved oxygen conditions due to extreme acidity that produce immediate lethal effects on all aquatic life (**Fig. 2**). At S₃ (downstream), the dominant stressors shift to chronic turbidity (11.5–25 NTU), persistent organic loading (BOD, 13.2±0.9 mg/L), and load of heavy metals, which collectively may cause sub-lethal physiological stress, habitat degradation, and impaired reproduction in resident fish populations due to decrease in fecundity. The biological indicators tested, fish assemblage composition specifically the ratio of sensitive rheophilic cyprinids (*Barilius*, *Schizothorax*) to tolerant generalists (*Channa*, *Cyprinus*) proved the most reliable integrative indicator of ecological degradation, responding predictably to the pollution gradient. Plankton taxa (particularly rotifer assemblages) provided rapid response early warning signals of water quality shifts. Fish communities in the downstream region displayed reduced species richness and increased dominance of pollution-tolerant taxa. Such shifts are

species are eliminated due to hypoxic conditions, toxic contaminants and habitat simplification. Similar patterns have been reported in other industrially impacted rivers, where tolerant cyprinid species persist while ecologically sensitive taxa disappear (Setia et al., 2020; Sharma et al., 2018)).

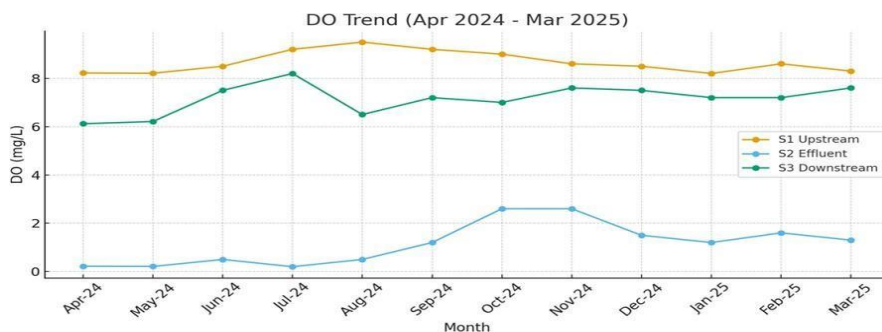


Fig. 2: Monthly fluctuations in Dissolved Oxygen at S₁, S₂ and S₃ of Sirsa riverine study area.

Mean pH of 3, with extreme low values reaching 2.2 in April 2024 and January 2025, combined with mean DO of only 1.4 ± 0.5 mg/L (minimum 0.2 mg/L), creates a condition of absolute biological inhabitability. The decline in dissolved oxygen observed at downstream locations is likely attributable to increased organic loading from industrial and municipal effluents, which elevates microbial respiration and biochemical oxygen demand (Jindal & Sharma, 2011). Reduced flow velocity in effluent mixing zones may further limit reaeration, thereby intensifying oxygen depletion. Such causal pathways established well in the study conducted, acidic conditions in the pH 2.2–4.5 range mobilize heavy metals from sediments and industrial substrates, dramatically increasing their bioavailability; simultaneously, the extraordinarily high organic and chemical oxygen demand. COD averaging 138.00 ± 11.5 mg/L with peaks of 365.5 mg/L in March 2025, derived microbial and chemical oxidation that consumes dissolved oxygen faster than atmospheric reaeration can replenish it. The extremely high CV values at S₂, COD at 76.14%, turbidity at 71.76%, DO at 72.11%, and pH at 29.78%, provide quantitative evidence of poorly controlled, highly variable industrial discharge rather than any natural process. The

COD range from 37.5 mg/L to 365.5 mg/L represents nearly a ten-fold variation within a twelve-month period (**Fig. 3**). This pattern is diagnostic of batch processing operations discharging without equalization, inconsistent CETP performance, and variable effluent composition from the diverse mix of pharmaceutical, chemical, textile, and electroplating industries in the Baddi corridor. Domestic wastewater, by contrast, characteristically shows COD CV values below 30% due to the continuous and relatively uniform nature of human waste generation. The industrial fingerprint at S₂ is therefore unambiguous both in its magnitude and in its statistical character (Singh et al., 2024).

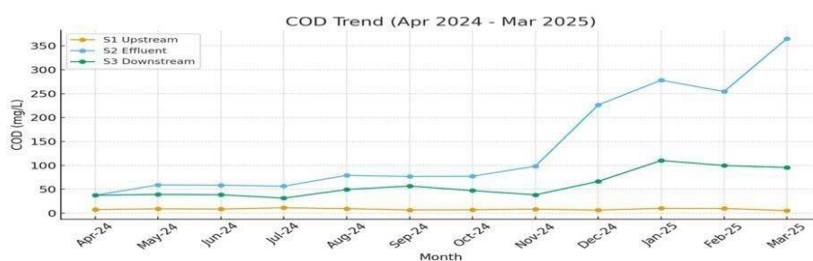


Fig. 3: Monthly fluctuations in COD at S₁, S₂ and S₃ of Sirsa riverine study area.

The winter escalation in COD deserves explicit emphasis. From December 2024 through March 2025, COD values at S₂ exceeded 226.5 mg/L, peaking at 365.15 mg/L, 3 to 5 fold increase relative to the same site during summer monsoon months (37.5–79.2 mg/L). This seasonal pattern reflects the convergence of three reinforcing mechanisms: reduced river discharge lowers dilution capacity even if absolute pollutant mass remains constant; lower temperatures reduce biological treatment efficiency in the CETP; possible seasonal increases in pharmaceutical and chemical production generate higher waste loads during the period when assimilative capacity is most constrained (Sharma et al., 2021; Singh et al., 2023). The winter COD peak propagates directly to S₃, where COD increases from 31.5–57 mg/L during summer-monsoon to 66.5–110.2 mg/L during winter, confirming direct hydraulic transmission of the industrial signal, the December-March period represents the critical vulnerability window demanding priority regulatory

attention and treatment optimization. At S₃ (downstream), the dominant stressors shift character from acute lethal toxicity to chronic sublethal stress. Mean BOD of 13.2 ± 0.9 mg/L (4% increase from S₁), mean turbidity of 13.6 ± 1.3 NTU, and mean COD of 59.24 ± 2.5 mg/L collectively define an ecosystem under chronic organic and particulate loading that, while not immediately lethal to tolerant species, progressively impairs physiological function, reproduction, and habitat quality. The causal mechanisms reported that eutrophic niche at S₃ near Ghanauli bridge persistence with dramatic increase in nitrate (153.8 ± 3.8 µg/L, 3% increase from S₁ baseline of 56.7 ± 1.5 µg/L) combined with elevated phosphate (77.01 ± 2.72 µg/L), invited threats to primary productivity and oxygen dynamics. The spatial distribution of physicochemical parameters and heavy metal concentrations reveals a distinct pollution gradient within the Sirsa River system. Upstream locations exhibited relatively stable water quality conditions, reflecting minimal anthropogenic disturbance. In contrast, the effluent channel recorded the highest contaminant loads, while downstream sections displayed partial dilution but persistent biochemical stress (Dwivedi & Vankar 2014) while working on industrial hub Unnao, India.

Industrial processes in the Baddi area, including pharmaceuticals, textiles, chemicals, cosmetics and food processing, known to generate waste streams containing a mixture of salts, solvents, dyes, catalysts and heavy metals (Herojeet et al., 2017; Rajkumar et al., 2020). The extremely high levels of sodium and magnesium observed at S₂ for example reflect the use of these ions in detergent manufacturing, chemical formulation and pharmaceutical processing. The application of Metal index reported to estimate water quality and co-related it with health hazards. Variations in concentration of Metals were recorded near common effluent treatment plant on pollutant Nallah (S₂) in decreasing order read as Mg>Na>Ca>B>Zn>Cu>Mn>Fe>Mo>Al>Tl>Se in ppb. The concentration of Metals reported at S₁, S₂, S₃ were within permissible limit of WHO and Bureau of Indian Standards, except the value of Boron, Magnesium and Thallium were exceeded these guidelines constantly at site S₂ of study area. The present Metal index value at S₁, S₂ and S₃ were 1.55, 5.82 and 2.57 respectively

on Sirsa river in the Baddi area concurrences with findings (Chaturvedi & Dave, 2012; Majumdar & Avishek, 2024) related to Dandro river metal pollutants and heavy metal indices of Ismailia Canal, Nile River. The site S₂ affected strongly due to presence of elemental dust and untreated wastewater discharged by chemical industrial units of Baddi region. This site (S₂) was nearer to common effluent treatment plant on the bank of Sirsa river and found to be unsuitable at all with more value (5.82) of metal index. The biological collapse and dominance of pollution tolerant taxa observed downstream as the cumulative outcome of multi-contaminant stress rather than organic enrichment. Elevated concentrations of heavy metals detected in the effluent channel and downstream sites indicate strong anthropogenic inputs. These metals are known to bind with suspended particles and sediments, acting as long-term reservoirs that gradually release contaminants into the water column under fluctuating physicochemical conditions. Chronic exposure to such metals can impair gill function, disrupt enzymatic activity, and reduce reproductive success in fish, thereby contributing to the observed decline in species diversity. The interplay between abiotic and biotic trends reinforces that industrial effluent in Baddi has fundamentally altered the river's planktonic community structure (Sharma et al., 2022), where once a diverse assemblage of protozoans, rotifers, benthos and phytoplankton likely existed, the modern community increasingly dominated by a narrow group of tolerant bio-indicator of ecological stress (**Fig. 4**).

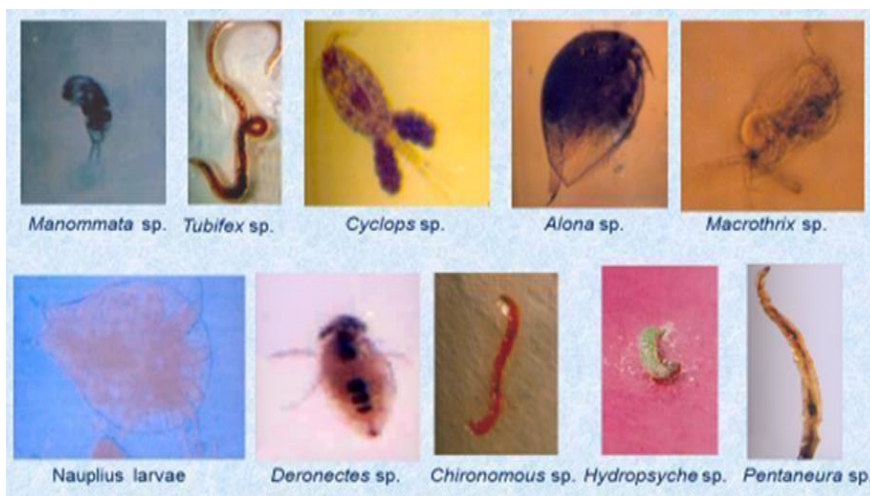


Fig. 4: Population dynamics of bio-chemical tolerant taxa at Ghanauli bridge (S₃) except net spinning caddisfly at S₁

The biological impacts attributed due to biochemical stressors compounded by pharmaceutical toxicity operating through mechanisms, microfauna resistance gene selection and endocrine disruption, neurotoxicity could not be quantified within the scope of this investigation. The present study documents the physicochemical and biological consequences of receiving pharmaceutical laden effluent. The consistent presence of these pollutants across seasons suggests chronic input rather than isolated pollution incidents. This continuous discharge highlights major gaps in effluent treatment practices and points to the inadequacy of existing industrial waste management systems in the region. The downstream site (S₃) provides critical insight into the fate and transport of pollutants released from industrial effluents. Although concentrations at S₃ are noticeably lower at S₂, they remain significantly elevated compared to upstream levels, illustrating the persistent movement of dissolved and particulate contaminants downstream. This pattern indicates that pollutants released in the effluent channel do not simply dilute or settle immediately; instead, they transported into larger surface water systems where they may accumulate, interact with sediments, and pose long-term ecological risks. The downstream persistence of boron, sodium, and magnesium further demonstrates the overall alteration of water chemistry attributable to industrial discharge. These elements are highly soluble and non-reactive, enabling them to travel long distances within aquatic systems. As a result, downstream aquatic organisms and plants may experience heightened exposure to these ions, potentially affecting physiological functions and altering species composition in the ecosystem.

Water Quality Index (WQI) reflects overall water quality class, despite other indices MI and HPI (Sarhat & Basim, 2023) for metal pollutants river Sirwan, calculated in present study as per guidelines (Brown et al., 1972; Horton, 1965). It is meant for A & C classes designated (CPCB, 2012) for drinking water in India, depicted in **Table 1** as comparative advanced International tool across 3 study sites, provided with baseline approach to assessed water chemistry as done earlier on river Chenab (Khadse et al., 2016) and on

Brahmaputra and Ganga river basin (Sarkar et al., 2026) to determined water quality index.

Table 1: The weighted arithmetic Water Quality Index calculation and its annual variations at S₁, S₂ and S₃ of the Sirsa riverine study area (2024-2025)

Parameter	sn	1/sn	∑1/sn	k = 1/(∑1/sn)	vid	Wn = k/sn (Weightage)	Vn	Vn/Sn	Vn/Sn*100=Qn	WnQn S ₁	WnQn S ₂	WnQn S ₃
TDS (mg/L)	500	0.002	2.98	0.34	0	0.00068	154.5	0.309	30.9	0.03	0.032	0.05
pH	7	0.143	2.98	0.34	7	0.049	7.8	1.114	111.42	5.39	3.80	2.07
Dissolved Oxygen (mg/L)	6	0.167	2.98	0.34	14.6	0.056	8.6	1.44	143.34	8.094	4.89	1.31
BOD _s (mg/L)	2	0.5	2.98	0.34	0	0.169	3.5	1.75	175	29.65	76.52	47.45
COD (mg/L)	10	0.1	2.98	0.34	0	0.0338	8.5	0.85	85	2.89	15.7	46.76
Nitrate (mg/L)	45	0.02	2.98	0.34	0	0.0075	56.7	1.26	126	0.94	2.57	0.985
Total Alkalinity (mg/L)	200	0.005	2.98	0.34	0	0.0016	171.7	0.86	85.85	0.145	0.103	0.234
Boron (mg/L)	0.5	2	2.98	0.34	0	0.6778	0.01	0.02	2	1.356	3.26	1.356
Sodium (meq/L)	26	0.038	2.98	0.34	0	0.0130	0.061	0.002	0.235	0.003	0.004	0.039
Total Hardness (mg/L)	300	0.003	2.98	0.34	0	0.0011	155.4	0.518	51.8	0.058	0.017	0.085
Chlorides (mg/L)	250	0.004	2.98	0.34	0	0.0013	5.8	0.0232	2.32	0.003	0.028	0.075
Water Quality Index										48.56	106.94	100.42

The WQI plot integrates the cumulative impact of multiple water quality parameters on S₁ maintains the lowest WQI (48.56), representing good water quality with seasonal fluctuations at Baddi Bridge upstream due to inflow of lotic rivulets originated from Kausauli hills. S₂ that lies adjacent to CETP but downstream at Jagatkhana bridge consistently showed highest WQI (106.94) annual mean values, falling into the poor to extremely polluted category throughout the year due to acidic pH, high turbidity, very low DO and excessive COD/TDS with traces of Boron and Sodium related to irrigation, industrial cooling, controlled waste disposal. S₃ shows intermediate WQI (100.42) values but remains far above S₁,

confirming that effluent discharged from S₂ severely degrades downstream water quality. It reflected very close copy printing on WQI, defined (Sarkar et al., 2026) while indexing Brahmaputra River basin and Ganga river basin in India. The widening gap between S₁ and S₃ during winter months highlights maximum ecological stress when dilution capacity is minimal (**Fig. 5**). Findings on WQI supported by hydrobiological studies done during investigations that highlighted pristine lotic water conditions like rivulets as compared to Sirsa riverine basin and Sutlej polluted in the end due to ionic elemental load and organic pollutants.

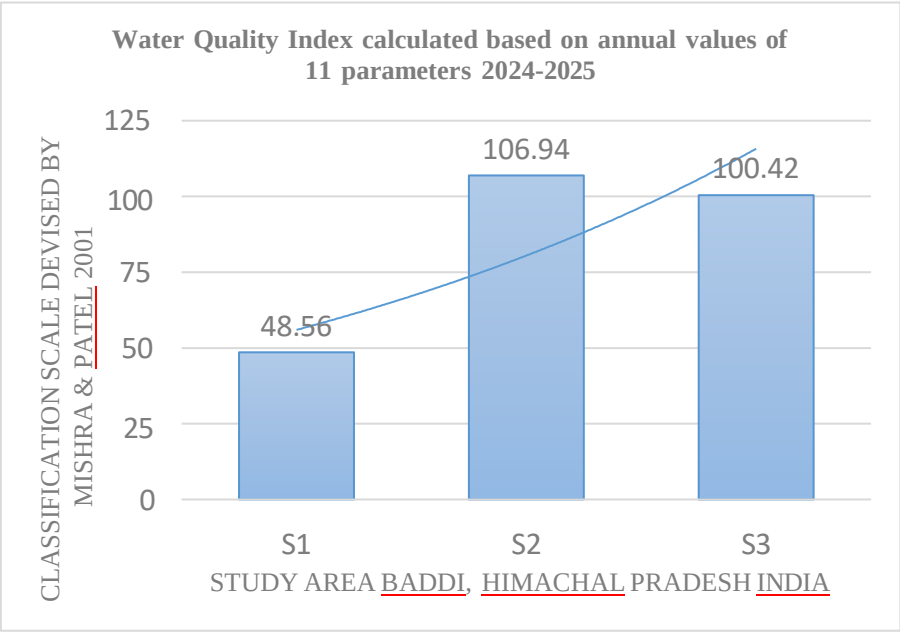


Fig. 5: The Water Quality Index Variations at S₁, S₂ and S₃ of Sirsa riverine study area (2024-2025)

Seasonal hydrological variations play a significant role in modulating pollutant levels. The dataset reveals clear trends associated with winter, pre-monsoon, summer and monsoon conditions. Winter months, characterized by low surface water flow and minimal rainfall, show concentrated pollutant levels due to reduced dilution. Pre-monsoon months exhibit notable spikes in several metals, likely influenced by industrial production cycles and

high evaporation rates. Summer months present high levels for some metals, such as iron and zinc, reflecting concentration effects amplified by elevated temperatures and low water volume. Monsoon and post-monsoon periods typically reduce pollutant concentrations due to increased rainfall and runoff. However, the dataset demonstrates that monsoon-driven dilution is insufficient to restore downstream concentration load. This was particularly evident due to the presence of pollutants entering the water system was highly ruthless in that time; and the processes such as sediment resuspension and remobilization continue to influence water chemistry during monsoon flows (Kummerer, 2009). The degree of persistence across all seasons underscored the chronic nature of industrial pollution in the region with some seasonal observations were strongly influenced by hydrological and environmental factors, particularly monsoonal runoff, temperature variations and nutrient influx. The dominance of phytoplankton and pollution tolerant species during monsoon and post monsoon seasons reflects the impact of external inputs such as agricultural runoff and wastewater discharge, leading to eutrophication. Conversely, the presence of sensitive diatom species in winter indicates reduced pollution levels and improved water quality. Zooplankton species such as *Cyclops* and *Daphnia* demonstrate adaptive resilience and play a crucial role in maintaining ecological balance. This section summaries these findings to interpret their broader ecological, public health and regulatory implications. It situates the dataset within established scientific knowledge regarding industrial water pollution, highlights key concerns arising from the persistent elevation of major ions and trace metals and examines the potential long-term consequences of unchecked effluent discharge. Together, these interpretations contribute to a deeper understanding of how industrial activities are reshaping water chemistry in Baddi and similar industrial corridors across developing regions. It is similar with the findings on river Ghaggar in Punjab (Kaur et al., 2024) and river Yamuna in Delhi NCR region (Gani et al., 2025).

This study reinforces the urgent need for comprehensive reforms including strengthened legal frameworks with meaningful penalties, mandatory pre-treatment standards for industries, real-time

monitoring with public data disclosure, independent technical audits of treatment facilities, community participation in monitoring and decision-making, and political will to prioritize environmental sustainability alongside economic development. Long term sustainability requires watershed-scale restoration including flow augmentation to enhance dilution capacity and maintain minimum environmental flows, riparian buffer zone establishment to protect water quality and habitat, community-based monitoring programs creating public stewardship, and industrial process transformation toward green chemistry principles that prevent pollution at the source rather than treating waste after generation

Conclusion

The comprehensive approach integrating pollution prevention, treatment optimization, natural attenuation enhancement, and institutional capacity building offers the best prospect for restoring River Sirsa to functional ecological and social condition capable of supporting biodiversity, providing water resources for human use and sustaining cultural connections between communities and their riverine environment. The foul smelling, dark wastewater has been discharged from the Kotla choe and other drainage lines flowing into the Balad Nadi that merged with Sirsa rivulet, carrying heavy metals, including arsenic, lead, cadmium, nickel and barium reported by The Tribune, 28 August, 2026 based on the findings of Grewal, SS and he suggested that phytoremediation using vetiver grass, construction of check dams, reuse of Sirsa nadi water for vegetative barriers, green park, belts along the stream bank for protection of shoreline area and renovation of ponds near the Sirsa basin to improve groundwater recharge. It co-occurrences with the present ecological degradation draft of the Sirsa river which does not represent statistical association between pharmaceutical industrial activities, thereby declining water quality and diversity, but rather reflects identifiable causal chains through which specific biochemical stressors produced specific biological outcomes at each site. The spatial distribution of physicochemical parameters and heavy metal concentrations reveals a distinct pollution gradient within the Sirsa River system. Upstream locations exhibited

relatively stable water quality conditions, reflecting minimal anthropogenic disturbance. The effluent channel recorded the highest contaminant loads, while downstream sections displayed partial dilution but persistent ecological stress in the low-lying adjoining belt, where villagers are continuously facing drinking water related complications issue, remained pending at the end of stakeholders.

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Ethics The authors of this study reported above data in accordance with the guidelines of Indian Government Principles for the Utilization and Care of Vertebrate Animals for Research Laboratory purpose.

Competing interests The authors declare no competing interests.

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