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River Water Quality Assessment and Public Health Risks in Jammu and Kashmir: A Review

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ABSTRACT

Water contamination is an escalating global public health concern, driven by rapid population growth, industrial activities, and weak environmental governance. This review critically examines the quality of river water in Jammu and Kashmir (J&K), India, with a focus on five major river basins: Chenab, Jhelum, Neeru, Munawar Tawi, and Tawi. The study synthesizes data from 2010 to 2024, obtained from peer-reviewed journals, government reports, and non-governmental organizations, to identify key pollutants, their sources, and associated health risks. The study reveals that high levels of microbial contamination, including total coliforms, faecal coliforms, faecal strepto cocci, and clostridium perfringens, were found, particularly in the Tawi river. Water quality index (WQI) assessments indicate that the tawi river exhibits the poorest water quality, while the neeru river shows the quality of water. Additionally, heavy metals such as iron, nickel, and manganese were found at concentrations exceeding both national and WHO standards for drinking water in several rivers. Risk evaluations using hazard quotient (HQ) and hazard index (HI) suggest potential health hazards due to chronic exposure to these contaminants. The findings underscore the urgent need for comprehensive water quality monitoring, effective pollution control measures, and sustainable water management strategies to ensure safe drinking water and protect public health in the region.

1 | INTRODUCTION

The environment, once a pristine and balanced system, now faces significant degradation due to increasing human demand for comfort and development. This has led to polluted air, degraded land, and most critically, contaminated water resources. Recognizing the urgency of preserving water quality, legislative measures began emerging in the 1960s, emphasizing the need to monitor and manage freshwater systems (Singh, 2024; Tiyasha *et al.,* 2020). Water quality is a key aspect of water resource management and is typically assessed through physical, chemical, and biological parameters (Barroso *et al.,* 2024; Sutadian *et al.,* 2016). Rivers, as major sources of surface freshwater, are particularly vulnerable to pollution from urban, industrial, and agricultural sources (Asadollah *et al.,* 2021). In developing countries, the problem is exacerbated by rapid population growth, weak governance, and inadequate infrastructure (Shil *et al.,* 2019).

India faces a pressing freshwater crisis. While the country receives about 4000 billion cubic metres (BCM) of annual precipitation, only 1123 BCM is estimated to be utilizable (Bhat, 2014). The per capita availability, currently 1720.9 m^3, is projected to fall by 36% and 60% by 2025 and 2050 respectively (Ministry of Water Resources). According to UNESCO (2021), 25% of urban centers already experience water stress, and nearly 4 billion people worldwide face water scarcity for at least one month annually. These trends are driven by factors such as climate change, rising demand, poor management, and extreme weather events (Salehi, 2022). Although much research has focused on water quantity, quality concerns are equally critical, especially in regions suffering from scarcity. The overlap between poor water availability and degraded water quality poses severe public health risks. Sustainable development goal 6 (SDG-6) of the UN emphasizes clean water and sanitation, making it essential to ensure both availability and safety of drinking water (Singh and Su, 2022).

Numerous studies have highlighted high levels of microbial and chemical contamination in J&K's rivers, often exceeding WHO and national drinking water standards. This review compiles data from 2010 to 2024, sourced from peer-reviewed journals such as *Environmental Monitoring* *and Assessment*, *Journal of Applied and Natural Science*, *Nature and Pollution Technology*, *Sustainable Water Resources Management*, *Energy, Ecology and Environment*, and *Applied Water Science*. The objectives of this review are to: a) identify concentrations of microbial, physicochemical, and heavy metal contaminants in the Chenab, Jhelum, Neeru, Munawar Tawi, and Tawi rivers; b) assess human health risks using hazard quotient (HQ) and hazard index (HI) of heavy metals; c) investigate the primary pollution sources, including urbanization, industrial discharge, and agricultural runoff; and d) review existing water management strategies to address contamination in J&K.

2 | MATERIALS AND METHODS

2.1 | Study Area

2.1.1 | Physiography and Geology

Jammu and Kashmir (J&K), in the northwestern himalayas at about 34°50'1.16" N and 74°47'50.53" E (Singh *et al.,* 2023), is a Union Territory with 20 districts in the Jammu (26,293 km²) and Kashmir (15,948 km²) divisions. Formed 50 million years ago by Indian and Eurasian plate collision, J&K's terrain includes three geological zones: High Himalayas (crystalline rocks), Lesser Himalayas (Precambrian to Tertiary metasedimentary formations), and Sub-Himalayas (Murree Formation under the Siwalik Group). The Jammu division has five major physiographic units: a) High Hills/Mountains (Pirpanjal), b) Dun belt, c) Siwaliks, d) Murrees, and e) Outer plains (Sirowal and Kandi belt), further divided into i) Tawi Valley, ii) Pir Panjal, and iii) Chenab Valley (Shukla 2022). The Kashmir division features three physiographic units: a) Mountains (Zanskar, Pir Panjal), b) Karewas, and c) Alluvial Plains, plus a geographical area called Kashmir/Jhelum Valley. The Siwalik Group's Lower, Middle, and Upper subgroups are stratigraphically distinct. The Lower Siwalik Subgroup includes Middle Miocene red mudstone, fine- to medium-grained sandstone, and green sandstone. The Middle Siwalik Subgroup comprises medium to coarse-grained sandstone and Upper Miocene gray-brown mudstone. Major rivers include the Indus, Chenab, Jhelum, and Tawi (Kumar *et al.,* 2019). This study focuses on five river system watersheds: Jhelum, Chenab, Tawi, Munawar Tawi, and Neeru, as shown in *Fig. 1*.

2.1.2 | Climate and Hydrology

The J&K Himalayan climate is divided into four agroclimatic zones: subtropical, intermediate, temperate, and cold arid, based on Hasan's (1999) proposal. This classification focuses on rainfall, neglecting temperature and vegetation. The Köppen-Geiger classification lists three main climatic zones in J&K: temperate, cold, and desert, though it misclassifies Jammu as temperate, Kashmir as cold, and Ladakh as desert due to inaccurate data. Currently, Ladakh is cold and arid, Kashmir is temperate, and Jammu is subtropical (Romshoo *et al.,* 2020). Climate change has notably affected the region, evident in (1) declining glaciers, (2) catastrophic floods, (3) shorter winters and rainfall, and (4) longer summers and higher temperatures. Western disturbances, bringing moisture from the Atlantic, Mediterranean, Caspian, and Black seas, are vital for winter precipitation in Jammu and Kashmir. Key water sources include groundwater and rivers like Jammu Tawi, Chenab, Basantar, and Munawar Tawi, which drain into the region's outer plains. Munawar Tawi originates in Rajouri, flows through western areas, and into Pakistan. Chenab enters from Udhampur, draining the central region and branching into several distributaries. The Jammu Tawi river begins in Doda district and drains Jammu district.

HIGHLIGHTS

- Water quality deterioration in key river systems of J&K, is serious environmental and public health concerns.
- Identifies microbiological and heavy metal contamination levels exceeding WHO and national standards, supporting the urgency of intervention.
- The use of water quality index (WQI), hazard quotient (HQ), and hazard index (HI) frameworks adds depth and modern analytical relevance.

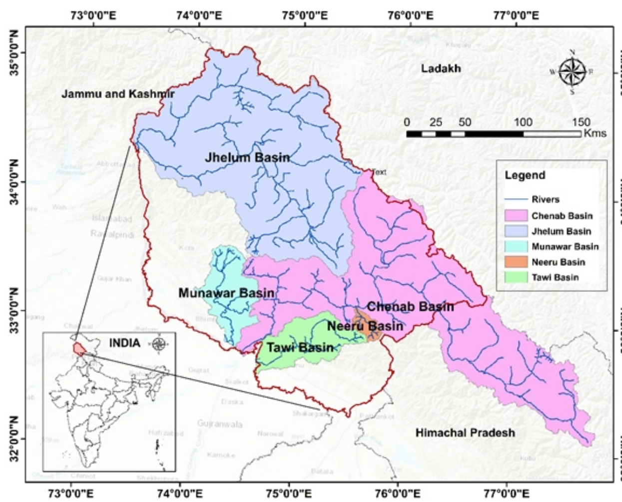

FIGURE 1 Map of the study area depicting river basins selected for study

2.2 | Data Collection

Data for this review paper was gathered from a variety of governmental and non-governmental sources about Jammu and Kashmir's drinking water quality and contamination, as well as from numerous individual studies that were published in national and international journals like Environmental monitoring and assessment, Journal of applied and natural science, Nature and pollution technology, water supply, Sustainable water resources management, Energy, ecology and environment, Applied water science, etc ranged between 2010 and 2024. These journals are Scopus-indexed and UGC-referred and searched with river water, water quality, and river water of Jammu and Kashmir as keywords. Table 1 shows that papers selected for different rivers having different seasons, whose range of different water quality parameters has been discussed in the paper.

2.3 | Analytical Methods

2.3.1 | Water Quality Indices

WQI have been calculated river-wise using standard weighted arithmetic water quality index (WQI) using formula (Ahsan *et al.,* 2021; Das *et al.,* 2023) is:

$$WQI = \frac{\sum Qn \times Wn}{\sum Wn}$$

Where: Q_n = Quality rating for each parameter; W_n = Unit weight for each parameter.

The Quality Rating (Qn) for each parameter is calculated using the formula:

Qn is calculated as: $Qn = 100 \times (Vn\text{-}Vi)/(Sn\text{-}Vi)$

In this equation Vn = Recorded value of nth parameter; Sn = Prescribed value of nth parameter; Vi = The ideal value of the nth parameter is zero for all parameters, except for pH, which is considered to be 7 (Kumar *et al.,* 2023).

Wn unit weight of nth parameter, unit weight is assigned (Table 2) according to the formula:

$Wn = K/Sn$

$K = 1/\Sigma 1/Sn$

Where K = constant of proportionality; Sn = Prescribed value of nth parameter.

$K = 1/\Sigma 1/Sn$

The WQI for each river is presented in Fig. 2.

2.3.2 | Estimation of Hazard Quotient (HQ) and Hazard Index (HI)

Using the concentrations provided in the papers, the hazard quotient (HQ) and hazard index (HI) due to the presence of heavy metals have been calculated (Goumenou & Tsatsakis, 2019) of various rivers using the formula:

HQ = (Average Daily Dose (ADD)) / (Reference Dose (RFD)).

ADD in mg/kg/day is calculated using:

TABLE 2 Unit weight assigned to different water quality parameters

Parameter	Unit Weight (W_n)
pH	0.20
TDS	0.15
EC	0.10
TA	0.10
Na^+	0.08
K^+	0.08
Ca^{2+}	0.10
TH	0.10
Mg^{2+}	0.08
Cl^-	0.08
NO_3^-	0.05
So_4^{2-}	0.05

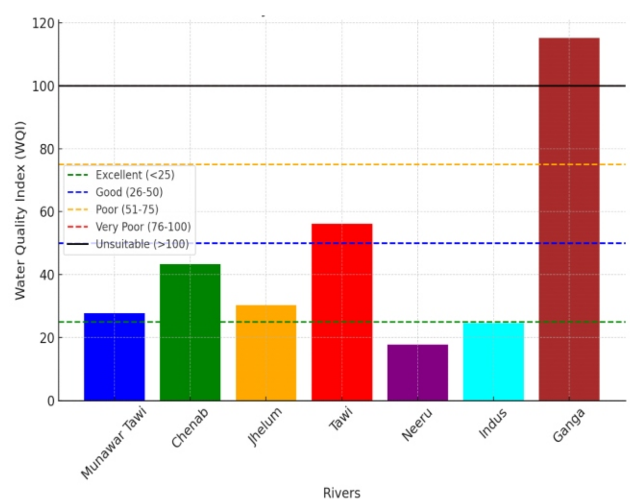

FIGURE 2 Water Quality Index of different rivers of Jammu and Kashmir

TABLE 1 Number of sampling sites studied in different papers and their frequency on sample collection

River	Sampling Sites	Frequency	References
Chenab	4	Biannual (Pre-monsoon and post-monsoon)	(Fotedar *et al.,* 2010)
	14	One time	(Khadse *et al.,* 2016)
	9	Biannual, from 2021-2024 (pre-monsoon and post-monsoon)	(Kausar *et al.,* 2020)
Jhelum	3	Monthly	(Mehmood *et al.,* 2017)
	25	Seasonal (June 2008 and January 2009)	(Mir & Jeelani, 2015)
Neeru	2	Bi-Annual (Pre-monsoon and post-monsoon)	(Dutt & Sharma, 2022)
	24	Seasonal (Winter, Spring, Summer & Autumn)	(Kumar *et al.,* 2019)
Tawi	26	Bi-Annual (Pre-monsoon and post-monsoon)	(Panjgotra *et al.,* 2022)
	3	January - June	(Kour *et al.,* 2022)
Munawar	27	Bi-Annual (January and June)	(Zeeshan & Azeez, 2016)

$$ADD = \frac{C \times IR \times EF \times ED}{BW \times AT}$$

Where, C: Metal concentration in water (mg L^{-1} or µg L^{-1}); IR: Ingestion rate (L/day; typically, 2 L/day for adults, 1 L/day for children); EF: Exposure frequency (days/year; often 365 days); ED: Exposure duration (years; commonly 70 years for lifetime exposure); BW: Body weight (kg; average 70 kg for adults, 15 kg for children); AT: Averaging time (days; lifetime = 70 × 36570\times 36570 × 365).

Formula for HI:

$$HI = \sum HQ$$

3 | RESULTS AND DISCUSSION

3.1 | Water Usability

In the union territory, groundwater is utilized for drinking, industrial activities, and irrigation. River water in the study area meets various needs, including drinking, domestic use, electricity generation, industrial processes, and irrigation. Research indicates that almost half of the schools and 30% of villages in Jammu and Kashmir have access to contaminated drinking water, despite the presence of abundant glaciers, freshwater lakes, and streams. The 2011 Census revealed that 48.2% of households had water on their premises, 28.7% had it nearby, and 23.1% had it further away. In rural regions, only 35.5% of households had water on-site, in contrast to 84.7% in urban settings. Furthermore, nearly two-thirds of villagers do not have enough potable water at home, illustrating significant disparities in water access.

3.2 | Physico-Chemical Parameters

The physicochemical parameters of the Munawar Tawi, Chenab, Jhelum, Tawi, and Neeru rivers were analyzed to assess water quality. The pH, total dissolved solids (TDS), electrical conductivity (EC), Total Alkalinity as $CaCO_3$, and ion concentrations were examined. Table 3 compares the physicochemical parameters of J&K's rivers with those of river indus and river ganga. Often, lower water quality parameters were found upstream and higher downstream rivers. The pH values of the rivers mostly fall within the BIS range of 6.5-8.5, with Chenab (8-8.5), Tawi (7.96-8.01), and Jhelum (6.9-8.9) showing near-neutral to slightly alkaline conditions. However, river ganga (5-7.75) is below this range, indicating slightly acidic conditions that could affect aquatic life and water corrosivity. Total dissolved solids (TDS), indicating overall ionic load, are within WHO limits (acceptable: 600 mg L^{-1}) for most rivers. Tawi (208-368 mg L^{-1}) and Ganga (250-254 mg L^{-1}) have higher TDS, while Chenab (40-227 mg L^{-1}) and Neeru (37-105 mg L^{-1}) show lower concentrations. Electrical conductivity (EC), indicating ionic concentration, is highest in Ganga (487-500

TABLE 3 Comparative Physicochemical parameters of some of the rivers of J&K, Indus River, River Ganga, BIS limits and WHO limits

Parameters / Rivers	pH	TDS (mg L^{-1})	EC (µS cm^{-1})	TA as $CaCO_3$ (mg L^{-1})	Na^+ (mg L^{-1})	K^+ (mg L^{-1})	Ca^{2+} (mg L^{-1})	TH (mg L^{-1})	Mg^{2+} (mg L^{-1})	Cl^- (mg L^{-1})	NO_3^- (mg L^{-1})	SO_4^{2-} (mg L^{-1})	References
Munawar Tawi	6.5-8.5	51-102	154-262	91-126	8-15	2-3	45-63	122-165	7-18	14-35	1-6	5-13	Zeeshan & Azeez, 2016
Chenab	8-8.5	40-227	67-400	10-31	1.2-4.8	1-2.2	28-180	40-272	8-92	6-30	5-8	3-36	Kausar *et al.,* 2020; Mir & Jeelani, 2015b; Zeeshan & Azeez, 2016
Jhelum	6.9-8.9	129.7	103-232	7.5-103	2.79-27.8	0.48-0.97	19-44	97-222	7.5-28.5	6-38	0.6-1.86	12-228	Mehmood *et al.,* 2017; Mir & Jeelani, 2015b; Zeeshan & Azeez, 2016
Tawi	7.96-8.01	208-368	316-462	130-169	7.88-13.44	1.3-3.27	28.67-41.45	266-320	46.41-67.69	45-97	2.37-4	13.47-15.58	Kour *et al.,* 2022; Panjgotra *et al.,* 2022
Neeru	7.5	37-105	56-184	54-203	1-1.57	0.7-6.4	3.5-13.8	42-206	1.2-3.6	0.6-2.9	0.37-4.47	1.3-4.87	Dutt & Sharma, 2022; Shukla, 2022
River Indus	7.6-8.3	122-199	5-244	16- 92	0.21-15.8	0.08-13	0.5-33	--	0.41-7.6	0.1-7	0.11-2.8	0.4-28	Charan *et al.,* 2023; Kaushik *et al.,* 2023; Rahman & Chughtal, 2013
River Ganga	5-7.75	250-254	487-500	172-1708	10-539	0.004-0.018	0.004-22	100-482	0.98-20.31	35-38	0.5-0.66	13-116	Ali *et al.,* 2021; Gani *et al.,* 2023; Satya & Narayan, 2018; Singh *et al.,* 2024a
BIS Limits													
a) Acceptable	6.5-8.5	500	NS	200	NS	NS	75	200	30	250	45	200	BIS, 2012
b) Permissible	–	2000		600			200	600	100	1000	NR	400	
WHO Limits													
a) Acceptable	6.5-8.5	600	NS	NS	200	NS	NS	NS	NS	250	50	250	WHO, 2022
b) Permissible	–	1000			–	12	200	500	150	600	NR	500	

NR: No Relaxation; NS: Not Specified

μS cm^{-1}) and Tawi (316-462 μS cm^{-1}), suggesting increased mineral or pollutant influx, likely from domestic or industrial discharge. Total Alkalinity (TA as $CaCO_3$) varies widely, with Ganga showing high levels (172-1708 mg L^{-1}), exceeding WHO's limit of 500 mg L^{-1}, indicating elevated bicarbonate or carbonate concentrations. Tawi (130-169 mg L^{-1}) and Munawar Tawi (91-126 mg L^{-1}) also show moderately high alkalinity, while Chenab (10-31 mg L^{-1}) and Indus (16-92 mg L^{-1}) remain low. These values reflect the buffering capacity of the rivers and potential influence from surrounding geology or anthropogenic waste.

Sodium (Na^+) concentrations, a key salinity marker, peak in Ganga (10-539 mg L^{-1}), far exceeding the WHO limit of 200 mg L^{-1}. Other rivers like Jhelum (2.79-27.8 mg L^{-1}), Tawi (7.88-13.44 mg L^{-1}), and Munawar Tawi (8-15 mg L^{-1}) remain safe. Neeru (1-1.57 mg L^{-1}) and Indus (0.21-15.8 mg L^{-1}) have low sodium levels, indicating less pollution. Potassium (K^+) levels are low overall, with Ganga having the least (0.004-0.018 mg L^{-1}). Tawi (1.3-3.27 mg L^{-1}) has the highest potassium, possibly due to agricultural runoff. Calcium (Ca^{2+}), essential for water hardness, is highest in Tawi (28.67-41.45 mg L^{-1}) and Chenab (28-180 mg L^{-1}), yet below the WHO limit of 75 mg L^{-1}. Ganga records a minimum of 0.004 mg L^{-1}, suggesting measurement anomalies.

Total hardness (TH), impacted by calcium and magnesium, is crucial too. Tawi (266-320 mg L^{-1}) and Ganga (100-482 mg L^{-1}) exceed the BIS limit of 200 mg L^{-1}, showing very hard water. Neeru (42-206 mg L^{-1}) and Jhelum (97-222 mg L^{-1}) are marginally acceptable. Munawar Tawi (122-165 mg L^{-1}) and Chenab (40-272 mg L^{-1}) show moderate hardness, while Indus data is missing. Magnesium (Mg^{2+}) is highest in Tawi (46.41-67.69 mg L^{-1}) and Ganga (0.98-20.31 mg L^{-1}), both over the WHO limit of 50 mg L^{-1}, indicating health concerns, particularly for renal patients. Chenab (8-92 mg L^{-1}) also has high magnesium levels. Meanwhile, Neeru (1.2-3.6 mg L^{-1}) and Indus (0.41-7.6 mg L^{-1}) are low.

Chloride (Cl^-) reaches its peak in Tawi (45-97 mg L^{-1}) and Munawar Tawi (14-35 mg L^{-1}), both within the WHO limit of 250 mg L^{-1}. Ganga (35-38 mg L^{-1}) and Indus (0.0.1-7 mg L^{-1}) are lower. Nitrate (NO_3^-), a sign of fertilizer runoff, stays within WHO levels in all rivers. Tawi (2.37-4 mg L^{-1}) and Chenab (5-8 mg L^{-1}) have slightly higher levels compared to Indus (0.11-2.8 mg L^{-1}) and Ganga (0.5-0.66 mg L^{-1}). Sulphate (SO_4^{2-}) peaks in Jhelum (12-228 mg L^{-1}) and Ganga (13-116 mg L^{-1}), nearing the WHO limit of 500 mg L^{-1}, possibly from industrial discharges. Indus (0.4-28 mg L^{-1}) and Neeru (1.3-4. 87 mg L^{-1}) show low sulphate levels.

River water in UT of J&K is slightly alkaline versus Ganga's pH of 5 to 7.75. Areas like Haridwar with higher population density have acidic, unfit water, although parameters like TDS, EC, Na, K, Ca^2, TH, Mg^2, Cl, NO_3, and SO_4^2 conform (Ali *et al.,* 2021; Charan *et al.,* 2023; Gani *et al.,* 2023; Kaushik *et al.,* 2023; Rahman & Chughtal, 2013; Satya & Narayan, 2018; Singh *et al.,* 2024a), except for TA in Ganga varying between 172-1708 mg L^{-1}, exceeding limits in some areas.

River water in UT of J&K is clearer than in densely populated areas. Dissolved oxygen (DO), biological oxygen demand (BOD), and chemical oxygen demand (COD) are key indicators of river ecosystem health. DO indicates oxygen levels for aquatic life, while BOD and COD assess organic and inorganic pollution, impacting water treatment and ecosystem balance. Monitoring these parameters aids pollution assessment and informs effective water management strategies for sustainability (Magadum *et al.,* 2017). Chenab's DO and BOD range from 5.4-7.9 mg L^{-1} and 2-10.4 mg L^{-1} (Khadse *et al.,* 2016). Tawi's BOD and COD are 2-3 mg L^{-1} and 9-14 mg L^{-1}, within acceptable drinking water limits (Kour *et al.,* 2022). Jhelum's BOD is 23-35 mg L^{-1} and COD is 38-67 mg L^{-1} (Ahangar & Kaur, 2021). Information on other Jammu and Kashmir rivers is lacking, while Ganga shows DO, BOD, and COD at 6.9-10.8 mg L^{-1}, 2.9-4.7 mg L^{-1}, and 15-19 mg L^{-1} (Balkrishna *et al.,* 2024). Phosphates in Chenab measure 0.16-29 mg L^{-1} (Khadse *et al.,* 2016), Neeru at 0.01-0.17 mg L^{-1} (Kumar et al., 2019), and Ganga at 0.05-1.3 mg L^{-1} (Varma & Jha, 2024).

Active pollutants include pathogens, inorganic contaminants, and various ions that can taint water and spread disease. When concentrations exceed standards, these compounds pose health risks. Pathogens encompass protozoans, bacteria, and viruses, while inorganic contaminants consist of heavy metals, toxic elements, acids, and salts. Surpassing permissible levels can harm water quality and ecosystem health. Therefore, monitoring and managing these pollutants is vital for human health and environmental balance Bacteriologic.

3.3 | Bacteriological Contamination

Bacteriological analysis of the rivers Munawar Tawi, Chenab, Jhelum, Tawi, and Neeru indicates significant contamination, posing potential health risks. Various bacterial species have been reported in these rivers, with Tables 4(a) and 4(b) summarizing the findings from different studies. Total coliform counts were notably high in the Tawi (*Har ki Poudi, Sidhra*), Jhelum (*downstream*), and Chenab (*near Ramban*), suggesting contamination from diverse sources. Exposure to Total Coliform is associated with diarrhoea, fever, and abdominal cramps (Khadse *et al.,* 2016; Mahajan *et al.,* 2018; Qayoom *et al.,* 2023). Faecal coliform, also detected at these sites, indicates faecal contamination and can lead to more severe health outcomes, including diarrhoea, fatal hemolytic uremic syndrome, and even death in vulnerable individuals

TABLE 4(a) Bacterial contamination of river waters in J&K

Bacterial species	Location where it is found	Health impacts	References
Total Coliform	Tawi (Har ki poudi, Sidhra), Jhelum Downstream, Chenab near Ramban	Diarrhea, fever, abdominal cramp	Khadse *et al.,* 2016; Mahajan *et al.,* 2018; Qayoom *et al.,* 2023
Faecal Coliform	Tawi (Har ki poudi, Sidhra), Jhelum Downstream, Chenab near Ramban	Diarrhea, fatal hemolytic uremic syndrome and even death	Aravinthasamy *et al.,* 2021; Khadse *et al.,* 2016; Mahajan *et al.,* 2018; Qayoom *et al.,* 2023
Faecal Streptococcus	Tawi (Har ki poudi, Sidhra), Jhelum Downstream	Urinary infection, diarrhea & typhoid fever	Bisimwa *et al.,* 2022; Mahajan *et al.,* 2018; Qayoom *et al.,* 2023
Clostridium Perfringens	Tawi (Har ki poudi, Sidhra)	Food poisoning, antibiotic-associated diarrhea, and sporadic diarrhea	Mahajan *et al.,* 2018; Qayoom *et al.,* 2023; Venhorst *et al.,* 2022

TABLE 4(b) Bacterial contamination level of river waters in J&K

Bacterial species	River Tawi	River Jhelum	River Chenab	References
Total Coliform (CFU/100 ml)	1360-2390	301-439	160	Khadse *et al.,* 2016; Mahajan *et al.,* 2018; Qayoom *et al.,* 2023
Faecal Coliform (CFU/100 ml)	165-227	61-70	20	Aravinthasamy *et al.,* 2021; Khadse *et al.,* 2016; Mahajan *et al.,* 2018; Qayoom *et al.,* 2023
Faecal Streptococcus (CFU/100 ml)	665-859	46-52	Investigation pending	Bisimwa *et al.,* 2022; Mahajan *et al.,* 2018; Qayoom *et al.,* 2023
Clostridium Perfringens (CFU/100 ml)	605-716	Investigation pending	Investigation pending	Mahajan *et al.,* 2018; Qayoom *et al.,* 2023; Venhorst *et al.,* 2022

(Aravinthasamy *et al.,* 2021; Khadse *et al.,* 2016; Mahajan *et al.,* 2018; Qayoom *et al.,* 2023). Faecal Streptococcus was found in the Tawi and Jhelum and is linked to urinary tract infections, diarrhoea, and typhoid fever (Bisimwa *et al.,* 2022; Mahajan *et al.,* 2018; Qayoom *et al.,* 2023). Additionally, Clostridium perfringens, detected in the Tawi, is known to cause food poisoning, antibiotic-associated diarrhoea, and sporadic gastrointestinal illness (Mahajan *et al.,* 2018; Qayoom *et al.,* 2023; Venhorst *et al.,* 2022). Across all rivers, Total Coliform concentrations were significantly higher than Faecal Coliform. For instance, in the Tawi river, Total Coliform levels ranged from 1360 to 2390 CFU/100 ml, while Faecal Coliform levels were between 165 and 227 CFU/100ml. This indicates the presence of both faecal and non-faecal coliform bacteria. These findings highlight the presence of pathogenic bacteria in the river waters of Jammu & Kashmir, underscoring the need for continuous monitoring and remedial action to safeguard public health.

3.4 | Heavy Metals

Heavy metals from natural and anthropogenic sources are persistent contaminants that accumulate in aquatic ecosystems, posing serious threats at trace concentrations. Their behavior varies with sediment interaction and water chemistry, with environmental impacts influenced by speciation changes during transport (Mohiuddin *et al.,* 2011). Heavy metals pose significant health risks: cadmium (Cd) harms kidneys and bones and contributes to cardiovascular disease; hexavalent chromium (Cr VI) is carcinogenic; excessive copper (Cu) and iron (Fe) can cause gastrointestinal distress, liver damage, and oxidative stress; lead (Pb) is a neurotoxin affecting cognitive development in children; cobalt (Co) can impact the heart and nervous system at high levels; and manganese (Mn) exposure is linked to neurological disorders like Parkinson's disease. Mercury (Hg) is toxic to the nervous system, causing tremors and memory loss; nickel (Ni) can lead to dermatitis and lung cancer; zinc (Zn), while essential, may cause nausea and immune dysfunction in excess; and arsenic (As) is linked to skin lesions and various cancers (Kannan *et al.,* 2021). These contaminants usually enter water bodies via industrial discharge, mining, and improper waste disposal, ultimately affecting human health through bioaccumulation and contaminated food and water (Singh *et al.,* 2024b). In the rivers of Jammu and Kashmir, high levels of various heavy metals have been reported. The Chenab River shows iron and nickel concentrations exceeding permissible limits, likely from geological or industrial sources (Fotedar *et al.,* 2010). The *Jhelum* River has measurable zinc, copper, and arsenic levels, though within safe limits; these may stem from urban runoff, agriculture, or industrial sources (Mehmood *et al.,* 2017). The tawi river displays elevated iron levels, possibly due to soil erosion or industrial discharge, necessitating pollution control measures (Sharma & Gandotra, 2019). In the neeru river, significant nickel and manganese concentrations suggest contamination from natural or industrial sources requiring immediate remediation (Gandhi *et al.,* 2017). Compared to the Indus and ganga rivers (Table 5(a)), the rivers in Jammu and Kashmir have relatively higher heavy metal loads, attributed to the unique geological composition and weathering of local rock formations (Charan *et al.,* 2023; Matta *et al.,* 2020).

3.5 | Water Quality Assessment

The WQI values presented in *Fig. 2* show that the River Tawi has the poorest quality among J&K rivers, while the Neeru demonstrates the best water quality. The ganga river has a WQI above 100, making it unsuitable for drinking. The reference dose has been sourced from WHO and USEPA, revealing that chenab river water does not indicate any significant health risk for adults, but is unfit for children due to excessive lead exposure, as shown in Table 5(b). Water from the river jhelum is safe for adults to drink; however, it also presents significant health risks for children due to arsenic and copper exposure. Water from the river Tawi is deemed suitable for drinking according to HQ and HI, but bacteriological parameters must be considered before usage for such purposes. For the river neeru, the HI value for adults is below 1, thus suitable for drinking purposes; however, for children, the HI exceeds 1, suggesting potential health risks from prolonged exposure to the water. Manganese (Mn) is the largest contributor to the overall risk. Special attention should be given to mitigate its concentration, as children are more vulnerable to its toxic effects.

3.6 | Potential Sources of Pollution

The river tawi in Jammu city suffers from sewage discharge from about 17 channels originally designed for floodwater but now serve as drains. Additional small drains carry domestic waste and agricultural runoff to the river's middle and lower sections. Untreated wastewater from old Jammu city and surrounding areas seeps into these channels before reaching the tawi river. Many homes lack sewer connections, there are no sewage treatment plants (STPS) midstream, and downstream STPS are nonfunctional. Jammu adds about 100 million litres per day to the Tawi's pollution (Slathia & Jamwal, 2022). In the River Chenab, sewage introduces various pollutants, including organic waste and pathogens, raising BOD levels, which lowers the oxygen needed for aquatic life. Coliform bacteria presence indicates faecal contamination, posing health risks (Ahmad & Iqbal, 2016; Dutta, 2020; Fotedar *et al.,* 2010; Khadse *et al.,* 2016). Jhelum River water quality declines due to rising population, agriculture, and waste from homes and floating markets, making it unsafe for human use. Contaminants include pathogens, heavy metals, and industrial waste. Downstream residents depend on this water for irrigation and daily use. Markets significantly contribute to water pollution with

TABLE 5(a) Heavy metals found in some of rivers of J&K and its comparison with other major rivers of the country

Heavy metals	Chenab	Tawi	Neeru	Indus	Ganga	References	BIS, 2012
Iron (mg L^{-1})	0.5	0.32	-	-	7.0	Fotedar *et al.,* 2010; Matta *et al.,* 2020; Sharma & Gandotra, 2019	0.3
Nickel (mg L^{-1})	0.06	-	0.26	-	-	Fotedar *et al.,* 2010; Sharma & Gandotra, 2019	0.02
Manganese (mg L^{-1})	-	-	2	-	-	Gandhi *et al.,* 2017	0.1-0.3
Total Arsenic (mg L^{-1})	-	-	-	0.016-0.09	-	Charan *et al.,* 2023	0.01
Cadmium (mg L^{-1})	-	-	-	0.02-0.027	-	Charan *et al.,* 2023	0.003
Lead (mg L^{-1})	-	-	-	0.05-0.108	-	Charan *et al.,* 2023	0.003

TABLE 5(b) Hazard Quotient (HQ) and Hazard Index (HI) values for different rivers of J&K

River Chenab		River Jhelum		River Tawi		River Neeru	
HQ for Adults	HQ for Children	HQ for Adults	HQ for Children	HQ for Adults	HQ for Children	HQ for Adults	HQ for Children
Cu: 0.036, Zn: 0.005, Pb: 0.653, Ni: 0.086, Mn: 0.053 Fe: 0.002	Cu: 0.972, Zn: 0.130, Pb: 17.78, Ni: 2.33, Mn: 1.44, Fe: 0.056	As: 0.05, Zn: 0.010, Cu: 0.044	As: 1.35, Zn: 0.28, Cu: 1.19	Zn: 0.017, Cu: 0.021, Fe: 0.012, Pb: 0.016	Zn: 0.04, Cu: 0.05, Fe: 0.029, Pb: 0.038	Cu: 0.050, Ni: 0.071, Zn: 0.006, Co: 0.081 Mn: 0.408	Cu: 0.117, Ni: 0.167, Zn: 0.015, Co: 0.189, Mn: 0.952
HI for Adults	HI for Children	HI for Adults	HI for Children	HI for Adults	HI for Children	HI for Adults	HI for Children
0.83 (<1)	22.71 (>1)	0.10 (<1)	2.81 (>1)	0.067 (<1)	0.157 (<1)	0.617 (<1)	1.439 (>1)

plastic and other debris dumped into waterways (Gull *et al.,* 2023; Mehmood *et al.,* 2017; Mir & Jeelani, 2015; Qayoom *et al.,* 2023; Sheikh *et al.,* 2022). Bhaderwah discharges sewage directly into river Neeru, worsening its contamination and contributing to environmental degradation (Dutt & Sharma, 2022; Gandhi *et al.,* 2017; Kumar *et al.,* 2019). As munawar tawi flows into Rajouri town, it collects significant sewage and domestic waste, increasing pollution (Zeeshan *et al.,* 2017; Zeeshan & Azeez, 2016).

4 | Research and Policy Gaps

The review of existing literature and data sources during the preparation of this manuscript reveals significant research and policy gaps in the assessment and management of water quality in the rivers of the union territory of Jammu & Kashmir. Firstly, there is a notable absence of comprehensive studies on biological contaminants in many rivers, such as munawar tawi and river Ujh. Critical parameters, including ammonical nitrogen, nitrites, and pesticide residues, have been largely overlooked in water quality assessments. Additionally, the presence of microplastics- emerging pollutants with significant ecological and health implications- remains uninvestigated across most water bodies in the region. While some studies have addressed heavy metal contamination, only a limited subset of metals has been analyzed, and only in select rivers.

Basic water quality indicators such as dissolved oxygen (DO), biochemical oxygen demand (BOD), and chemical oxygen demand (COD) are missing for several important rivers, including Neeru and Munawar. Furthermore, data on phosphate levels-an essential parameter in understanding nutrient loading and eutrophication-are largely unavailable for major rivers like the Tawi, Jhelum, Indus, and Munawar. This lack of systematic and region-wide data impedes accurate water quality modeling, pollution source identification, and risk assessment.

From a policy perspective, although India has established several national-level initiatives such as the Ganga action plan (1985), National river conservation plan (1987), Mission clean ganga (2014), and Yamuna action plan (1993), these are not sufficiently tailored to address the unique hydro-geological and ecological conditions of the rivers in Jammu & Kashmir. Most of these programs have focused on large national rivers, leaving regional and transboundary tributaries in the union territory underrepresented. Moreover, while constitutional provisions such as Entry 17 of the state list and Entry 56 of the Union List provide a framework for water governance, jurisdictional complexities and inter-state water sharing conflicts often hamper effective management of shared water resources.

Schemes such as the accelerated irrigation benefits programme (AIBP), NABARD-funded Soil and Water Conservation projects, and Jal Jeevan Mission have laid foundational groundwork for water resource development. However, these initiatives need stronger integration with real-time monitoring, pollution control, and scientific research tailored to the fragile ecosystems of Jammu & Kashmir. Addressing these research and policy gaps is imperative for building a sustainable, evidence-based water quality management strategy for the region.

5 | CONCLUSIONS AND SUGGESTIONS

The rivers of the union territory of Jammu & Kashmir face alarming levels of contamination from multiple sources, including untreated sewage, industrial discharges, agricultural runoff, and geological leaching of heavy metals. The presence of biological pollutants, heavy metals, and emerging contaminants like microplastics threatens not only ecosystem health but also the well-being of the communities that depend on these water bodies. Unfortunately, many critical water quality parameters remain unstudied in several rivers, and existing data are fragmented and inconsistent, highlighting urgent research gaps. Despite ongoing national initiatives such as the Jal Jeevan Mission, Ganga Action Plan, and various river conservation schemes, their reach and impact remain limited in the context of the region's specific challenges. Furthermore, many policies focus primarily on large national rivers, leaving vital tributaries in Jammu & Kashmir under-monitored and under-managed.

Addressing these challenges calls for an integrated and region-specific water quality management strategy that combines rigorous scientific research, real-time monitoring, public health risk assessments, and strict enforcement of pollution control regulations. Policymakers, environmental authorities, academic institutions, and local communities must work collaboratively to fill the research void, close policy gaps, and adopt innovative solutions. Protecting the freshwater ecosystems of Jammu & Kashmir is not only a regional necessity but a national priority. Sustainable management of these rivers will ensure clean and safe water for current and future generations and preserve the ecological balance in one of India's most sensitive and strategic landscapes. Let this research serve as a call to action towards safeguarding our precious water resources and fostering a more resilient and sustainable future.

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