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Assessment of Water Quality Parameters of the Bhagirathi River Using the Arithmetic Weighted Index Method (WQI)

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Abstract: The river is a vital source of fresh water and plays a crucial role in supporting ecosystems and human societies. However, rapid population growth and increasing anthropogenic activities have led to the degradation of this valuable natural resource. The Water Quality Index (WQI) is an essential tool used to assess overall water quality by integrating various physical, chemical, and biological parameters into a single representative value. In this study, parameters such as temperature, pH, total dissolved solids (TDS), total hardness (TH), chloride, dissolved oxygen (DO), calcium, and biochemical oxygen demand (BOD) were analyzed in laboratory settings. Results showed that maximum temperatures occurred during the monsoon and summer seasons, while lower temperatures were recorded in winter. The WQI values indicated that the Bhagirathi River in Uttarkashi maintained acceptable water quality during winter, but the quality declined in summer and was unsuitable for human consumption during the rainy season. This analysis aids public planning, pollution control, and water management.

Key words: Water Quality Parameters • Water Quality Index • Multiple test results • Computing a single value • Fish population.

Introduction:

In Uttarkashi district, the Bhagirathi River originates from the Gangotri Glacier at Gaumukh (30°55'N / 70°07'E) at an elevation of 4,012 meters above sea level (Naithani et al., 2008). The river's total catchment area spans approximately 8,846.64 km² and is further subdivided into the watersheds of the Bhagirathi, Bhilangana, and Asi Ganga rivers. Throughout its course, particularly up to the run-of-river Maneri project, the river reflects the dynamic nature of the Ganga.The Water Quality Index (WQI) provides a valuable tool for expressing overall water quality as a single mathematical value that reflects cumulative conditions (Miller et al., 1986). Across the globe, freshwater ecosystems are under significant threat from anthropogenic activities, including habitat degradation, fragmentation, and pollution. The Ganga River, including its tributaries such as the Bhagirathi, is no exception. Human activities have severely impacted water quality, harming aquatic life and surrounding communities (Laishram et al., 2007).

During repeated monsoon seasons, the river collects substantial sediment loads—comprising stones, gravel, and sand—which are deposited to form mounds. These sedimentary deposits continually reshape the river's morphology, contributing to erosion and flooding along its banks (Kamboj, Pandey, Shoaib, 2012).The Bhagirathi River is also a site for hydropower development, with several operational dams. While essential for energy production, these dams pose serious environmental challenges, including water diversion, obstruction of fish migration, hydropeaking, reservoir sediment flushing, landscape submergence, and disruption of biogeochemical cycles (Truffer et al., 2003).As a primary source of freshwater for the people of Uttarkashi, it is crucial to maintain an adequate ecological flow in the Bhagirathi River—particularly downstream of dam structures—to preserve aquatic biodiversity (Tiwari & Tiwari 2022). Alterations to the natural flow regime due to hydroelectric projects in the Bhagirathi basin are expected to have direct and long-term effects on aquatic ecosystems. Government initiatives have invested significantly in monitoring and assessing water quality. Indices such as the WQI serve as effective communication tools, summarizing complex water quality data into accessible information for both policymakers and the general public. As human populations and their demands continue to grow, the strain on natural resources, including water, increases. This underscores the urgent need for robust water management practices and pollution assessment mechanisms. Designing and applying indices to track spatial and temporal changes in river pollution is essential.The primary objectives of this study are to evaluate the current status of water pollution from Gangotri to Uttarkashi, and to support the protection of vital water resources and public health. By using WQI, decision-makers can develop comprehensive river basin management strategies that integrate water quality data and anticipate future water usage patterns (Bordalo et al 2001).

Materials and Methods:

Study area :Five sampling sites—Gangotri, Harsil, Maneri I, Uttarkashi, and Maneri II—were selected for the analysis of the Water Quality Index (WQI), as illustrated in Figure 1. Water samples were collected from these designated stations at 30-day intervals throughout the year 2019–2020. Parameters such as temperature, pH, dissolved oxygen (DO), and alkalinity were measured immediately at the sampling sites using standard equipment. Additional parameters, including total dissolved solids (TDS), total suspended solids (TSS), biological oxygen demand (BOD), total hardness, and chloride concentration, were analyzed in the laboratory following the standard procedures outlined by the American Public Health Association (APHA 1995).

Geology of the Study Area:

The study area encompasses a diverse range of rock formations, including white and cream-colored quartzite, which transitions into talc-chlorite schists along tectonic thrust zones. Other notable lithological units present include migmatites, augen gneisses, garnetiferous mica-schists, and amphibolites. Quartzite is the dominant rock type in the region, often interbedded with silts and metal-rich volcanic deposits, along with gases that interact through geochemical processes (Reports of the Multipurpose and Hydro-Electric Project Organization, Irrigation Department, Dehradun, Uttaranchal, 1985).Geologically, the area lies within a seismically active zone and is classified as Zone IV according to the Bureau of Indian Standards (BIS) seismic zoning map of India. This categorization indicates a high level of seismic hazard, necessitating careful consideration in hydrological and infrastructural planning.

Water Quality Index (WQI:

It is a single numerical value derived from various water quality parameters that collectively indicate the overall condition of river water. In this study, nine parameters were selected for the calculation of the WQI. Data were collected from five different sampling sites to assess spatial variations in water quality. The calculated WQI values from these sites were compared with the standard values recommended by international and national agencies such as the World Health Organization (WHO), Bureau of Indian Standards (BIS), and Indian Council of

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Medical Research (ICMR). For the WQI computation, the method proposed by Brown et al. (1972) was adopted, and the process involved the following steps:

$$WQI = \sum WnQn / Wn$$

$$Q_n = (V_n - V_i) / (V_s - V_i) \times 100$$

The ideal value of all parameters was zero except (pH= 7 and DO= 14.6).

Where K (constant) = $1/[1/(V_{s1} + 1/V_{s2} + 1/V_{s3} + 1/V_{s4} \ldots\ldots. + V_{sn})]$ or $K = \frac{1}{\sum (1/Si)}$

In addition, Table No. 01 classifies water based on its suitability for different types of usage, including drinking, domestic, irrigation, and industrial purposes. This classification aids in evaluating the usability of water samples collected from different sites and during various seasons.For the assessment and interpretation of water quality data, Table No. 02 presents the standard permissible limits for various physicochemical parameters of water, as recommended by international and national agencies such as the World Health Organization (WHO), Bureau of Indian Standards (BIS), and Indian Council of Medical Research (ICMR). These standards serve as a reference for determining the suitability of water for human consumption and other uses.

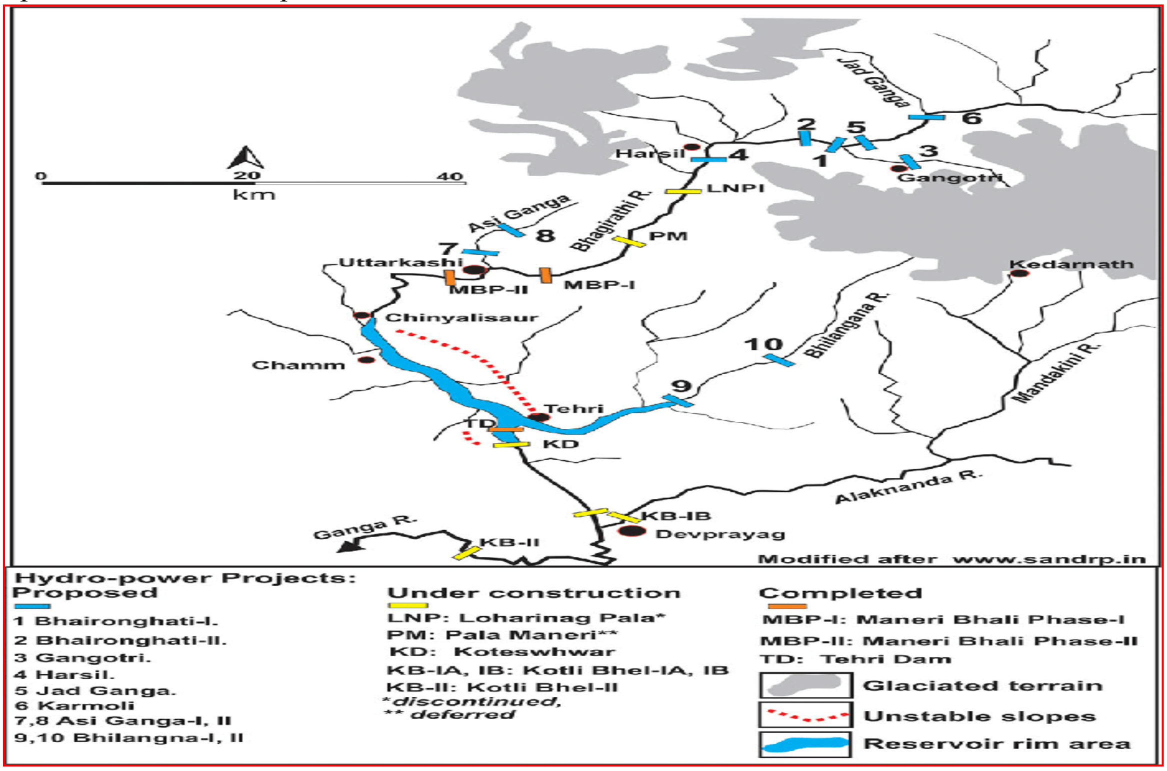

Fig 1: Location map of Study area

Table 1: Water Quality Index Level (Brown et al 1972) and Status of Water quality

S.No	Water Quality Index	Status of Water quality	**Grading**	Usages
1	0-25	Excellent	A	Drinking, irrigation
2	26-50	Good	B	Domestic , irrigation
3	51-75	Poor	C	Irrigation
4	76-100	Very Poor	D	Irrigation
5	Above 100	Unsuitable For drinking purpose	E	Proper treatment required before use

Table 2. Drinking Water Quality Recommended Agency (Standard values)

S.No	Parameters	Standard values	Standard values
1	pH	ICMR/BIS	8.5
2	Conductivity MS Cm^{-1}	ICMR/BIS	300
3	DO Mg/L	ICMR	05
4	TDS (mg /L)	ICMR/BIS	500
5	Calcium (mg /L)	BIS	75
6	Hardness (mg /L)	ICMR/BIS	300
7	Alkalinity(mg /L)	ICMR	120
8	Chloride(mg /L)	BIS	250
9	BOD(mg /L)	ICMR	05

Result and Discussion

Tables 3 to 7 present the detailed findings of the physicochemical analysis of Bhagirathi River water samples, collected from multiple sites along its course. The samples were analyzed across three different seasons—winter, summer, and monsoon—to evaluate seasonal variation in water quality.For the computation of the Water Quality Index (WQI), nine key physicochemical parameters were selected and monitored. These parameters serve as indicators of overall water quality and help assess the river's suitability for various uses. One of the observed parameters, pH, showed values ranging from 7.1 to 7.6 across all sampling locations throughout the three seasons. This indicates that the water remained mildly alkaline at all sites, suggesting a generally stable and acceptable pH level for both ecological health and human use.

Table 3: Seasonal water quality index at Site 1

		Monsoon		Winter		Summer	
S.No	Parameters	Observed Value	Quality Rating (qn) Wnqn	Observed Value	Quality Rating (qn) Wnqn	Observed Value	Quality Rating (qn) Wnqn
1	pH	7.12	1.704	7.10	1.42	7.21	2.982
2	Conductivity umhos/ cm2)	138.0	0.276	155.0	0.31	104	0.208
3	DO(mg/L)	7.71	25.98104	10.5	15.46042	7.91	25.22688
4	TDS(mg/L)	50.3	0.04024	88.2	0.07056	74.31	0.059448
5	Calcium (mg/L)	23.12	0.73984	25.23	0.80736	24.12	0.77184
6	Hardness (mg CaCO3/ L)	49.25	0.0985	72.23	0.14446	52.23	0.10446
7	Alkalinity (mg CaCO3/ L)	10.23	0.127875	8.23	0.102875	10.12	0.1265
8	Chloride(mg/ L)	8.63	0.024164	4.21	0.011788	4.7	0.01316
9	BOD (mg/L)	1.41	10.2084	0.92	6.6608	1.1	7.964
			ΣWnqn=39.20		ΣWnqn= 24.99		ΣWnqn= 37.46

According to the results of the present study, pH values were observed to be highest during the summer season, while comparatively lower values were recorded during the monsoon and winter seasons. The elevated pH levels in summer can be attributed to increased photosynthetic activity by algal blooms, which consume carbon dioxide and lead to the precipitation of calcium and magnesium carbonates from bicarbonate ions, thereby raising the pH. In contrast, electrical conductivity (EC) levels were found to be higher during the winter season and lower in the summer across all sampling sites. This seasonal variation in conductivity may be due to reduced water volume during the dry winter months, resulting in a concentration effect where dissolved ions become more concentrated due to less dilution. This phenomenon has also been noted in previous studies (Ovie, S. I. 1994).

Table 04 Seasonal water quality index at Site 2

		Monsoon		**Winter**		**Summer**	
SN	Parameters	Observed Value	Quality Rating (qn) Wnqn	Observed Value	Quality Rating (qn) Wnqn	Observed Value	Quality Rating (qn) Wnqn
1	pH	7.26	3.692	7.1	1.42	7.22	3.124
2	Conductivity umhos/ cm2)	155	0.31	160.0	0.32	111	0.222
3	DO(mg/L)	8.01	24.84979	11.12	13.1225	7.13	28.16813
4	TDS(mg/L)	51.5	0.0412	150	0.12	51.2	0.04096
5	Calcium (mg/L)	18.12	0.57984	30.12	0.96384	20.13	0.64416
6	Hardness (mg CaCO3/ L)	78.23	0.15646	49.91	0.09982	52.23	0.10446
7	Alkalinity (mg CaCO3/ L)	32.12	0.4015	30.12	0.3765	42	0.525
8	Chloride(mg/ L)	18.16	0.050848	15.23	0.042644	8.23	0.023044
9	BOD (mg/L)	2.33	16.8692	1.22	8.8328	2	14.48
			ΣWnqn=46.95		ΣWnqn= 25.29		ΣWnqn=47.34

The dissolved oxygen (DO) content in the Bhagirathi River was observed to be highest during the cooler months, with a gradual decline reaching its lowest levels between June and September. The elevated DO levels in winter can be attributed to lower water temperatures, reduced turbidity, and photosynthetic activity of green algae that colonize submerged stones and rocks (Badola, S.P., 2009). DO is a vital indicator of water quality as it reflects the balance of physical and biological processes in the aquatic ecosystem.In this study, DO concentrations ranged from 7.71 to 12.9 mg/L. The lowest DO levels occurred during the summer months of April and July, primarily due to the reduced solubility of oxygen at higher temperatures (Hynes, H.B., 1978). Additionally, during summer, water levels decline and become more concentrated with organic and inorganic pollutants, increasing the oxygen demand for the oxidation of organic matter (Sharma, K.D. et al., 1981). Conversely, increased DO levels in January can be linked to greater oxygen solubility at colder temperatures (Verma, S.R. et al., 1984).Total Dissolved Solids (TDS) values were also higher during the winter season at all sampling sites. This observation is consistent with the findings reported in the NEERI Report (2011) on the Bhagirathi River. The increased TDS in winter may be due to reduced dilution and higher ionic concentration caused by lower water volume.Calcium concentrations followed a similar trend, with peak levels in winter and the lowest during the monsoon season across all study sites. The total hardness of the water, which results from the presence of bicarbonates, sulfates, chlorides, and nitrates of calcium and magnesium, ranged from 49.25 to 84.4 mg/L (Kumar, A. et al., 2010). The maximum hardness was recorded in the winter season, while the lowest values were observed during the monsoon (Ayoade, A.A. et al., 2009).

Alkalinity is an important physicochemical parameter that reflects the buffering capacity of water, or its ability to neutralize strong acids without significant changes in pH. It is primarily influenced by the concentration of bicarbonates (HCO_3^-), carbonates (CO_3^{2-}), and hydroxide ions (OH^-). These constituents play a vital role in maintaining the chemical stability of aquatic ecosystems by resisting drastic pH fluctuations.

Table 5: Seasonal water quality index Site 3

		Monsoon		**Winter**		**Summer**	
S.No	Parameters	Observed Value	Quality Rating (qn) Wnqn	Observed Value	Quality Rating (qn) Wnqn	Observed Value	Quality Rating (qn) Wnqn
1	pH	7.31	4.40	7.5	7.1	7.4	5.68
2	Conductivity(mS cm-1)	97.64	0.195	125.43	0.25086	112.2	0.2244
3	DO(mg/L)	8.5	23.00	12	9.804167	8.5	23.00208
4	TDS(mg/L)	80.4	0.064	91	0.0728	71	0.0728
5	Calcium (mg/L)	34.7	1.11	51.2	1.6384	43.6	1.3952
6	Hardness (mg CaCO3/ L)	54.16	0.108	76	0.152	58.16	0.11632
7	Alkalinity (mg CaCO3/ L)	17.25	0.215	15.23	0.190375	20.5	0.25625
8	Chloride(mg/L)	18.3	0.051	12.5	0.035	17.08	0.047824
9	BOD (mg/L)	4.1	29.68	1.22	8.8328	2.45	17.738
			ΣWnqn= 58.83		ΣWnqn= 28.07		ΣWnqn= 48.53

Alkalinity in natural water bodies is primarily contributed by carbonate and silicate salts, often in conjunction with hydroxyl ions in free state (Trivedi, S. and Goyal, P.K., 1986). In the present study, alkalinity values ranged from 8.23 to 42 mg/L across all sampling sites. The highest levels were recorded during the summer season, while lower values were observed during winter. These findings are consistent with the NEERI Report (2011), which also reported elevated alkalinity during the monsoon and summer seasons, and reduced values during winter. Seasonal variation in alkalinity is often influenced by temperature-dependent biological activity and evaporation rates, which can increase ion concentration in the warmer months. Chloride, another critical parameter, serves as an important indicator of sewage pollution due to its prevalence in urine and domestic wastewater. It enters aquatic systems through sewage effluents, surface runoff, and drainage discharges, contributing to the brackish taste of water when present in higher concentrations. In the current study, as well as in various rivers across India, chloride levels peaked during the summer season, likely due to increased evaporation and reduced dilution of pollutants during periods of lower water volume (Sabat, C. and Nayer, P., 1995).

Table 6: Seasonal water quality index at Site 4

		Monsoon		Winter		Summer	
S.No	Parameters	Observed Value	Wnqn	Observed Value	Wnqn	Observed Value	Quality Rating (qn) Wnqn
1	pH	7.49	6.958	7.2	2.84	7.6	8.52
2	Conductivity(mS cm-1)	108.21	0.21642	127.5	0.255	115.05	0.2301
3	DO(mg/L)	8.95	21.30521	12.9	6.410417	9.5	19.23125
4	TDS(mg/L)	78.13	0.062504	87.16	0.069728	80.25	0.0642
5	Calcium(mg/L)	42.6	1.3632	58.4	1.8688	44.5	1.424
6	Hardness (mg CaCO3/ L)	65.1	0.1302	84.4	0.1688	64	0.128
7	Alkalinity (mg CaCO3/ L)	19.2	0.24	17.23	0.215375	21.8	0.2725
8	Chloride(mg/L)	19	0.0532	16.5	0.0462	18.16	0.050848
9	BOD (mg/L)	4.25	30.77	2.23	16.1452	2.4	17.376
			ΣWnqn= 61.09		ΣWnqn= 28.01		ΣWnqn= 47.29

Chloride concentrations in the present study ranged from 4.21 to 19 mg/L across all sampling sites. The highest chloride levels were recorded during the monsoon season, while the lowest were observed during winter. This trend may be attributed to increased runoff and surface water inflow during monsoon, which carries chloride-rich domestic and industrial discharges into the river. These findings are consistent with earlier observations by Nautiyal et al. (1988), who also reported elevated chloride levels during the monsoon and lower concentrations during the winter season.Another important parameter for assessing water pollution is the Biochemical Oxygen Demand (BOD), which indicates the amount of oxygen required by microorganisms to decompose organic matter in water.

Table 7: **Seasonal water quality index at Site 5**

		Monsoon Season		Winter season		Summer Season	
S.N	Parameters	Observed Value	Wnqn	Observed Value	Wnqn	Observed Value	Wnqn
1	pH	7.41	5.822	7.3	4.26	7.44	6.248
2	Conductivity(mS cm-1)	96.64	0.19328	122.8	0.2456	115	0.23
3	DO(mg/L)	8.1	24.51042	12.5	7.91875	9.23	20.24938
4	TDS(mg/L)	79.4	0.06352	87.95	0.07036	77.20	0.06176
5	Calcium(mg/L)	33.7	1.0784	55	1.76	44	1.408
6	Hardness (mg CaCO3/ L)	55.16	0.11032	82.16	0.16432	59.23	0.11846
7	Alkalinity (mg CaCO3/ L)	18.25	0.228125	16.23	0.202875	21.6	0.27
8	Chloride(mg/L)	17.3	0.04844	15.16	0.042448	17.08	0.047824
9	BOD (mg/L)	4.2	30.408	1.56	11.2944	2.96	21.4304
		ΣWnqn= 62.46		ΣWnqn= 25.95		ΣWnqn= 50.06	

In this study, BOD values ranged from 0.92 mg/L to 4.25 mg/L, with the highest concentrations observed during the rainy season and the lowest during the winter months. The increased BOD during the monsoon can be attributed to higher organic matter input from surface runoff and sewage contamination. These results align with the findings of Chauhans and Singh (2010).Seasonal Water Quality Index (WQI) values, calculated based on nine key physicochemical parameters, are presented in Tables 3, 4, 5, 6, and 7, highlighting temporal variations in water quality across the study sites during winter, summer, and monsoon seasons.

Water Quality Index Results (WQI):

A study was conducted to assess the Water Quality Index (WQI) at five key locations along the Bhagirathi River—Gangotri, Harsil, Maneri, Uttarkashi, and a downstream site near Uttarkashi—across three seasons: rainy, winter, and summer.

Site	Rainy Season	Winter Season	Summer Season
Gangotri	39.20	24.99	37.46
Harsil	46.95	25.30	47.33
Maneri	58.83	28.08	48.53
Uttarkashi	61.10	28.02	47.30
Downstream Uttarkashi	62.46	25.96	50.07

Interpretation

- WQI increases downstream, indicating deteriorating water quality due to increased anthropogenic activity such as urbanization, tourism, and agricultural runoff.
- According to Brown et al. (1972):
    - WQI < 25 indicates excellent water quality (Grade A).
    - 25–50 = Good to Moderate (Grade B).
    - >50 = Poor (Grade C).
- Thus, winter season water is of acceptable quality (Grade B), while rainy and summer seasons show poor quality (Grade C), making the water unsuitable for direct consumption without treatment.
- Similar seasonal trends were observed by Zhong et al. (1996) and Jha et al. (2007).

Ecological Impact: Fish Population Dynamics

- Monthly fish catch data showed:
    - Peaks in February and March (winter).
    - Lows in July and August (monsoon).
- Reduced fish populations during the rainy and summer seasons may be linked to worsened water quality, increased turbidity, and pollutant load.

Recommendations

- Water quality monitoring should be intensified, especially during high-risk seasons.
- Use of indigenous or sustainable water treatment technologies is recommended to make river water suitable for household and drinking purposes.
- Untreated river water should not be used for consumption, particularly during summer and monsoon seasons when pollution levels are elevated.

Conclusions

The Water Quality Index (WQI) is an effective tool for simplifying complex water quality data into a single, comprehensible value. It allows for consistent evaluation of water across different seasons and geographic locations, aiding both scientific research and public awareness. In this study, WQI analysis revealed that water in the study area is safe for drinking during the winter season. However, a decline in water quality was observed during the monsoon and summer, likely due to surface runoff and increased pollutant loads. Despite seasonal variations, all water samples remained suitable for irrigation. Currently, advanced water treatment technologies such as reverse osmosis, UV radiation, and activated charcoal filtration are not widely used during the rainy season, which limits efforts to improve potable water quality during high-contamination periods. The study highlights the urgent need for environmental conservation, especially in ecologically fragile areas like Uttarkashi. Preventing deforestation is essential to curb soil erosion and sedimentation, which severely affect water quality. Additionally, the research provides important baseline data for future ecological assessments. A clear decline in water quality was documented from Gangotri to Uttarkashi, largely due to anthropogenic pressures such as domestic and industrial wastewater discharge, underscoring the need for better waste management and pollution control.

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