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Seasonal Assessment of Physico-Chemical Water Quality Parameters of the Ganga River at Varanasi, India

Angad Yadav, Vishal Yadav

Department Of Civil Engineering, Institute Of Engineering And Technology, Lucknow, Uttar Pradesh, India.

Abstract : The present study investigates the seasonal variation in the water quality of the Ganga River at various ghats in Varanasi, Uttar Pradesh, India, during the year 2024–2025. The objective is to evaluate the spatial and temporal fluctuations in physicochemical parameters and assess the extent of pollution in the river water. Water samples were collected from seven strategically selected ghats—Sant Ravidas Ghat, Assi Ghat, Harish Chandra Ghat, Dashashwamedh Ghat, Lalita Ghat, Manmandir Ghat, and Namo Ghat—during the monsoon and winter seasons. The parameters analyzed include pH, temperature, dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), total alkalinity (TA), total hardness (TH), total dissolved solids (TDS), turbidity, and chloride content.The study revealed notable seasonal variations, particularly in DO, BOD, and COD values. Elevated levels of BOD and COD were observed during the monsoon season, indicating higher organic and chemical pollution loads likely due to increased surface runoff, sewage discharge, and anthropogenic activities along the riverbanks. Several parameters exceeded the permissible limits prescribed by the World Health Organization (WHO) and Central Pollution Control Board (CPCB), suggesting significant contamination. These findings indicate a deteriorating water quality status, posing potential risks to human health and aquatic biodiversity.This research underscores the urgent need for effective water quality monitoring, strict regulation of pollution sources, and implementation of sustainable management practices to protect the ecological integrity of the Ganga River in urban stretches like Varanasi.
Keywords: Ganga River, Varanasi, Water Quality, Physicochemical Parameters, Seasonal Variation, Pollution, WHO Standards

Introduction

The Ganga River, known globally as the Ganges, is revered as the holiest river in Hinduism and continues to play a central role in shaping the spiritual, ecological, cultural, and economic framework of India. (Mishra & Tripathi, 2007a)It is not only a river but a lifeline that supports one of the world's largest river basins. The Ganga originates from the Gangotri Glacier located in the western Himalayas of Uttarakhand, and flows southeast through the states of Uttar Pradesh, Bihar, Jharkhand, and West Bengal before entering Bangladesh and finally draining into the Bay of Bengal.(Kesari et al., 2022a) Covering a length of approximately 2,525 km, the river basin supports a population of over 400 million people, making it one of the most densely populated and economically important basins globally (Mishra & Tripathi, 2007b)

Apart from its religious significance, the Ganga provides water for drinking, irrigation, domestic use, industry, aquaculture, navigation, and cultural practices. The river's basin accounts for about 26% of India's landmass and supports nearly 43% of its population.(Tiwari et al., 2022) It is one of the primary sources of surface water in North India and plays a vital role in food security through its support for agricultural activities across the fertile Indo-Gangetic Plain.(Dutta et al., 2020)

Despite its vital significance, the Ganga River faces severe pollution from multiple sources, both point and non-point. With increasing urbanization, industrial development, and population pressure, the river is being subjected to an ever-growing volume of contaminants. Studies have shown that more than 80% of the river's pollution load is contributed by untreated municipal sewage, followed by industrial effluents, agricultural runoff, and ritualistic activities such as idol immersion and cremation .(Verma et al., 2022) The major cities located along the river—Kanpur, Varanasi, Patna, and Kolkata—are among the primary contributors to its deteriorating water quality.(*View of The Physiochemical, Biological Quality and Seasonal Variability of River Ganges in Varan*, n.d.)

In 2007, the Ganga was recognized by international environmental agencies as one of the five most polluted rivers in the world (Trombadore et al., 2020). Responding to the worsening situation, the Government of India launched several initiatives over the decades, including the Ganga Action Plan (1985), National River Conservation Plan (NRCP), National Ganga River Basin Authority (NGRBA), and the ongoing Namami Gange Mission. Although these programs have made some progress in terms of infrastructure and awareness, their overall impact remains limited due to challenges such as fragmented planning, poor execution, lack of public participation, and insufficient coordination among stakeholders (A. N. Singh et al., 2018).(Sharma et al., 2016a)

In addition to being a vital economic and cultural resource, the Ganga River is an ecological corridor that sustains rich biodiversity. (Kesari et al., 2022b)The river is home to more than 140 species of fish, over 90 species of amphibians, several mollusks,(Jazie, n.d.) reptiles, and critically endangered aquatic species such as the Ganges river dolphin (Platanista gangetica) and the gharial (Gavialis gangeticus .(Namrata, 2010) It also supports a wide range of migratory and resident bird species, especially along its floodplains and wetlands. Many of these ecosystems are under stress due to increasing contamination, flow alteration, and habitat fragmentation.(Ali1 et al., 2017)

Interestingly, scientific studies have also highlighted the Ganga River's unique self-purification capabilities. Research conducted by environmental scientists at the Indian Institute of Technology (IIT) Roorkee demonstrated that the Ganga can decompose organic matter 15 to 25 times faster than many other rivers in India, due to the presence of naturally occurring bacteriophages and high levels of dissolved oxygen in its upper stretches .(A. K. Rai et al., n.d.) The National Botanical Research Institute (NBRI) has also reported that Ganga water possesses natural antibacterial properties, which could explain the traditional belief in its healing and purifying nature .(Y. V. Singh et al., 2023)

One of the most iconic cities along the Ganga River is Varanasi, also known as Kashi or Banaras, which is considered one of the oldest continuously inhabited cities in the world. Located in the state of Uttar Pradesh, Varanasi holds immense religious and cultural importance and attracts millions of domestic and international tourists every year.(Dwivedi et al., 2018) The city is home to 88 ghats, which are long flights of stone steps leading down to the river, where religious rituals, cremations, spiritual baths, and daily worship ceremonies take place.(Y. V. Singh et al., 2023) Ghats like Dashashwamedh, Assi, Harish Chandra, Manikarnika, Sant Ravidas, Lalita, and Manmandir are among the most prominent and active.

These ghats serve as both spiritual centers and pollution hotspots. Ritual bathing, offering of flowers and food items, cremation ashes, and domestic discharges all contribute significantly to the degradation of water quality in this stretch.(Gautam et al., 2013) Despite the installation of sewage treatment plants (STPs) and interceptor drains, a substantial portion of untreated waste continues to enter the river directly. The intensity of human activity at these ghats increases significantly during festivals such as Dev Deepawali, Kartik Purnima, and Ganga Dussehra, further impacting the river's water quality (P. K. Rai et al., 2010).

The majority of the ghats in Varanasi were constructed after the 1700s during the Maratha rule and were supported by rulers such as the Peshwas, Holkars, Bhonsles, and Shindes (Scindias) .(Hamner et al., 2006) Many of these ghats are associated with mythological tales and historical figures, and although some are privately maintained, a large number are under the administration of the Varanasi Nagar Nigam and the Uttar Pradesh tourism department. Vaishali love u Given. the scale and complexity of pollution in the Ganga River, continuous monitoring and scientific assessment are imperative. Physicochemical parameters of river water, including pH, temperature, dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), turbidity, total dissolved solids (TDS), total hardness (TH), total alkalinity (TA), and chloride concentration, serve as important indicators of water quality(Mishra & Tripathi, 2007c). Monitoring these parameters seasonally allows for the identification of pollution sources, assessment of ecological health, and evaluation of treatment efficacy.(Poul & Myrthong, 2023)

The present study has been undertaken to evaluate the seasonal variations in key physicochemical parameters of the Ganga River at selected ghats in Varanasi during the wet and winter months of 2024–2025. The aim is to assess spatial and temporal trends in water quality and compare them with standard permissible limits prescribed by the World Health Organization (WHO) and the Central Pollution Control Board (CPCB). The findings of this study are expected to provide useful insights for environmental management, pollution mitigation, and sustainable river basin governance.(Sharma et al., 2016b)

1.2 Objectives of the Study

The present study aims to conduct a comprehensive assessment of the physico-chemical characteristics of the Ganga River water at various Ghats in Varanasi city. The key objectives are:

1. To evaluate the spatial variations in water quality across multiple Ghats, considering the influence of domestic discharge, ritualistic activities, and urban runoff.

2. To examine the temporal changes in selected physico-chemical parameters, particularly across different seasons, in order to understand seasonal trends and fluctuations.

3. To compare the observed data with standard permissible limits for water quality and assess the river's suitability for various uses.

4. To contribute updated and location-specific insights to the existing body of research, in alignment with previous studies such as Singh et al. (2023) and Poul & Myrthong (2023), and to support sustainable water resource management strategies for the Ganga River in Varanasi.

2. Materials and Methods

2.1 Sampling Strategy and Study Design

The assessment of river water quality demands a carefully structured sampling plan to ensure the accuracy and representativeness of the collected data. In the present study, water samples were collected from the Ganga River at nine major ghats in Varanasi, Uttar Pradesh, during two distinct seasons—monsoon (August–September 2024) and winter (January–February 2025). The selected ghats included Sant Ravidas Ghat, Assi Ghat, Harishchandra Ghat, Dashashwamedh Ghat, Lalita Ghat, Manmandir Ghat, Panchganga Ghat, Rajghat, and Namo Ghat. These sites were selected due to their varying levels of anthropogenic pressure, such as religious bathing, cremation, domestic discharge, and tourism.

Sampling was performed during morning hours (between 7:00 a.m. and 10:00 a.m.) to maintain consistency and to capture the water quality at a time of peak ritual activity. At each site, grab samples were collected from the surface (0.5 feet depth) using pre-cleaned 1-liter polyethylene bottles. The bottles were rinsed thrice with river water at the sampling location before the final collection to prevent contamination from external residues

The sampling strategy

1) Labeling of samples
2) Storage of samples
3) Sample Testing

2.2 Sample Preservation and Transportation

Immediately after collection, the samples were labelled with location code, date, and time, and stored in an insulated icebox maintained at approximately 4°C to minimize biological activity and degradation of sensitive parameters. All samples were transported to the Environmental Engineering Laboratory, Department of Civil Engineering, within 2–3 hours of collection. Parameters such as BOD, DO, and COD were analyzed on the same day to ensure data integrity, while other parameters were preserved appropriately following APHA (2017) and IS:3025 standard protocols [2,3].

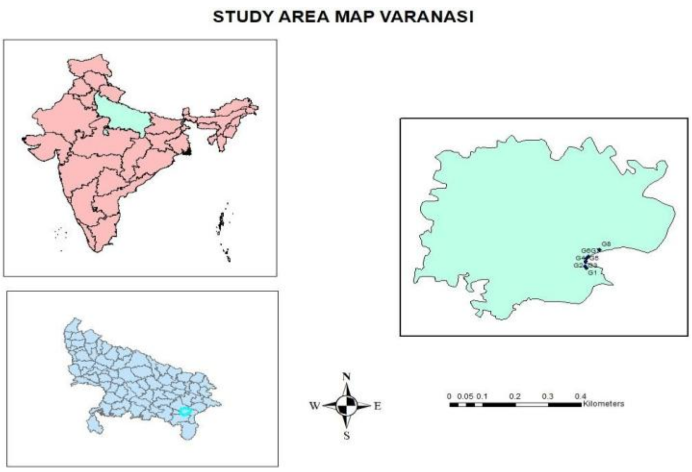

Fig.1. Location Map of Sampling Sites along the Ganga River in Varanasi

2.3 Physicochemical Parameter Analysis

The following eleven key physicochemical parameters were selected for water quality assessment due to their significance in indicating organic and inorganic pollution levels, as well as overall ecological health:

- pH
- Water temperature
- Turbidity
- Dissolved Oxygen (DO)
- Biological Oxygen Demand (BOD)
- Chemical Oxygen Demand (COD)
- Total Dissolved Solids (TDS)
- Total Hardness (TH)
- Total Alkalinity (TA)
- Chloride (Cl^-)
- **Total Suspended Solids (TSS)**

3. Area of Study

Varanasi, one of the oldest continuously inhabited cities in the world, is located on the northern banks of the Ganga River in eastern Uttar Pradesh, India. The city lies between latitudes 25.282°N to 25.450°N and longitudes 82.956°E to 83.034°E and stands at an average elevation of 80.71 meters above sea level. The city has immense historical, religious, and cultural significance and is globally recognized as a spiritual hub for Hindus, Jains, and Buddhists. Varanasi's population exceeds 1.2 million as per the 2011 census, with rapid urbanization putting increasing pressure on its natural resources, particularly the Ganga River .(Mishra & Tripathi, 2007a)

The riverfront of Varanasi is characterized by 88 ghats—stone embankments with steps descending into the river, each with its own religious, cultural, or historical context. Many of these ghats were constructed during the Maratha rule in the 18th century and are now managed by the municipal corporation or religious trusts

In the present study, a ~7-km stretch of the Ganga River was selected for detailed water quality monitoring, covering the following ghats(A. N. Singh et al., 2018):

1. **Sant Ravidas Ghat** – Southernmost ghat, close to Assi River confluence.
2. **Assi Ghat** – Popular for religious bathing and tourism.
3. **Harishchandra Ghat** – One of the major cremation sites.
4. **Dashashwamedh Ghat** – The most active and crowded ghat; daily Ganga Aarti performed here.
5. **Lalita Ghat** – Known for ritual immersion and spiritual gatherings.
6. **Manmandir Ghat** – Noted for astronomical observatory and pilgrim activities.
7. **Panchganga Ghat** – Historical site where five sacred rivers are believed to converge.
8. **Rajghat** – Located near the city boundary; moderate human activity.
9. **Namo Ghat** – Newly developed modern ghat with lesser but increasing usage.

These ghats were chosen due to their diverse anthropogenic influences, including cremation

(Harishchandra), mass bathing (Assi, Dashashwamedh), tourism (Manmandir, Lalita), and waste discharge points (Rajghat). This diversity ensures a holistic assessment of the Ganga's water quality across functional and spatial gradients within Varanasi.

By monitoring seasonal changes in physicochemical parameters at these key locations, the study aims to assess pollution trends and propose sustainable mitigation measures. This area-based analysis is crucial for the implementation of river rejuvenation programs under Namami Gange and for compliance with CPCB water quality classification standards .(Ali1 et al., 2017)

S. NO	SAMPLING SITE LOCATION	PH	TEMP (^{0}C)	TDS (mg/l)	TSS (mg/l)	DO mg/l	BOD (mg/l)	COD (mg/l)	HARDNEES (mg/l)	ALKALINITY (mg/l)	TURBIDITY (mg/l)	CHLORIDE (mg/l0
1	RAVI DASH GHAT	7.3	29.2	52	225	5.32	5.21	6.43	245	182	11.32	135
2	ASSI GHAT	7.4	29.2	45	268	4.53	4.56	6.98	253	174	11.94	129
3	HARISHCHANR A GHAT	7.2	30.4	67	283	4.54	5.86	7.84	268	194	13.45	141
4	LALITA GHAT	7.9	30.8	42	268	5.46	3.89	6.76	273	175	12.24	142
5	DASHASHWAM ED GHAT	7.4	31.2	56	240	5.96	4.65	7.11	251	178	12.84	136
6	MAAN MANDIR GHAT	7.5	31.6	46	245	6.54	3.76	6.56	261	169	11.54	134
7	MANIKARNIKA GHAT	7.1	31.9	58	264	7.43	3.43	5.43	254	155	11.10	130
8	NAMO GHAT	7.2	29.2	48	220	5.31	5.22	6.42	243	181	11.22	127

Table 1: The physico-chemical data table of the Ganga in Varanasi (during the rainy season)

S. NO	SAMPLING SITE LOCATION	PH	TEMP (0C)	TDS (mg/l)	TSS (mg/l)	DO (mg/l0	BOD (mg/l)	COD (mg/l)	HARDNESS (mg/l)	ALKALINITY (mg/l)	TURBIDITY (mg/l)	CHLORIDE (mg/l)
1	RAVI DASH GHAT	7.9	11.4	48	218	5.98	4.21	5.56	265	145	9.54	121
2	ASSI GHAT	8.6	11.5	41	245	5.76	4.12	5.38	260	138	9.24	118
	HARISHCHANR A GNAT	8.7	11.6	62	264	4.96	4.96	6.10	276	131	10.22	124
4	LALITA GHAT	8.6	14.1	38	248	5.65	3.23	5.19	279	128	9.54	130
5	DASHASHWAMEDH GHAT	8.5	12.4	53	229	6.06	3.54	5.98	266	146	9.29	120
6	MAANMANDIR GHAT	8.8	15.2	41	238	6.54	3.54	5.64	268	136	9.08	116
7	MANIKARNIKA GHAT	8.9	16.2	52	238	7.21	3.21	4.21	261	130	8.94	114
8	NAMO GHAT	7.6	10.8	49	217	5.91	4.25	5.57	270	140	9.58	123

Table 2: Varanasi's Ganga physico-chemical data table (during the winter season)

4. Results and Discussion

The seasonal analysis of water samples collected from selected ghats of the Ganga River in Varanasi revealed considerable variability in physicochemical parameters, reflecting both anthropogenic pressures and natural influences. Parameters were monitored during two major seasons—monsoon (August–September 2024) and winter (January–February 2025). The results are discussed parameter-wise below

4.1 Comparative Analysis with CPCB/State Government Water Quality Data (2023–2024):

A comparative evaluation with CPCB-monitored stations (2023–2024) reveals that BOD levels at Varanasi ghats such as Harishchandra (5.86 mg/L) are significantly higher than averages recorded at urban stretches like Kanpur and Prayagraj (2.0–4.5 mg/L). Similarly, DO values often fall below the Class B threshold of 6 mg/L, especially during the monsoon. These differences point to local anthropogenic pressures such as cremation ashes, sewage discharge, and ritualistic practices, underscoring the need for stricter control and real-time water quality monitoring at these locations.

Parameter	Varanasi Ghats (2024–25, This Study)	CPCB/UP Govt Data (2023–24)	Observation
pH	7.1 – 8.9	7.8 – 8.5	Varanasi slightly higher at some ghats
DO (mg/L)	4.53 – 7.43	6.0 – 11.5	Often below Class B limit in Varanasi
BOD (mg/L)	3.21 – 5.86	2.0 – 4.5	Higher at Harishchandra, Ravidas Ghats
TDS (mg/L)	220 – 283	2100–3800 (conductivity)	Lower in Varanasi, but methods differ
TSS (mg/L)	218 – 283	–	High near cremation/bathing ghats
Turbidity (NTU)	8.9 – 13.4	–	Reflects suspended organic matter
Water Class	C/D, some Below E	Mostly C/D	Varanasi more stressed at local points

Table.3 Comparative Analysis with CPCB/State Government Water Quality Data (2023–2024**)**

pH

The pH of river water, an indicator of acidity or alkalinity, ranged from 7.1 (Manikarnika Ghat) to 7.9 (Lalita Ghat) during the monsoon and 7.6 (Namo Ghat) to 8.9 (Manikarnika Ghat) during the winter. The slightly alkaline nature of water at most locations falls within WHO permissible limits; however, higher values at some ghats suggest the influence of detergents, organic decomposition, or industrial discharge

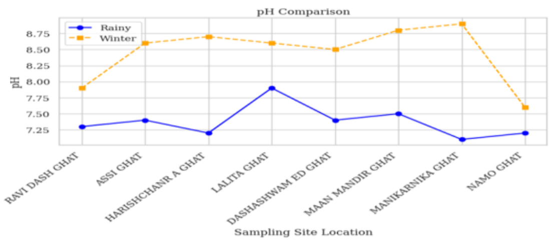

Fig. 2 Seasonal Variation of pH at Different Ghats

Temperature

Water temperature fluctuated between 29.2°C and 31.9°C in the monsoon and 10.8°C to 15.4°C in winter. Manikarnika Ghat consistently exhibited higher temperatures, likely due to cremation activities and shallow water levels. Seasonal variations influenced microbial activity and the solubility of gases such as oxygen.

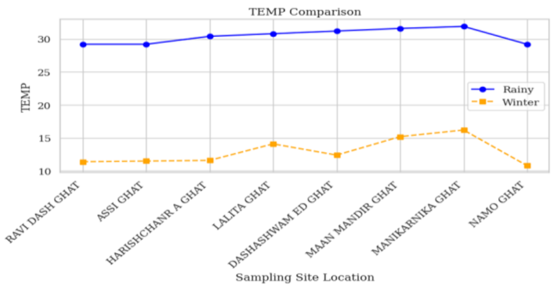

Fig. 3 Seasonal Water Temperature across Sampling Sites

Total Suspended Solids (TSS)

TSS, an indicator of turbidity and particulate matter, showed highest values at Harishchandra Ghat (67 mg/L) during the monsoon and 62 mg/L during the winter. The lowest values were found at Lalita Ghat in both seasons. High TSS suggests erosion, ritual activities, and incomplete waste degradation.

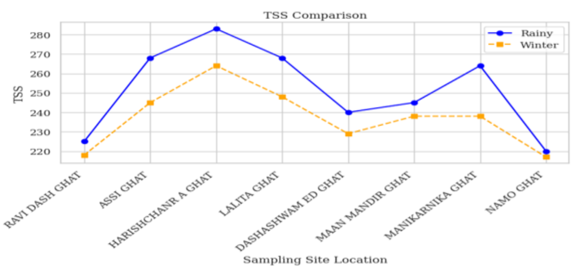

Fig. 4 Total Suspended Solids (TSS) Concentration in Monsoon and Winter

Total Dissolved Solids (TDS)

TDS values ranged from 220 mg/L (Namo Ghat) to 283 mg/L (Harishchandra Ghat) during the monsoon and 218 mg/L (Ravidas Ghat) to 264 mg/L (Manikarnika Ghat) in winter. Elevated TDS at cremation ghats and densely populated areas is attributed to ash, domestic waste, and effluent entry.

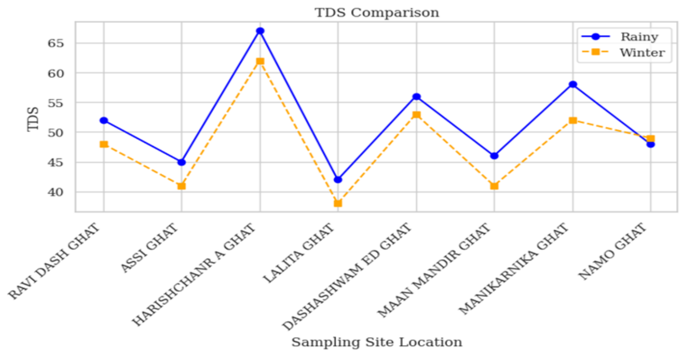

Fig. 5 Total Dissolved Solids (TDS) Across Ghats in Different Season

Dissolved Oxygen (DO)

DO is a critical indicator of aquatic health. The highest DO was recorded at Manikarnika Ghat (7.43 mg/L) during the monsoon, while Assi Ghat had the lowest (4.53 mg/L). Winter DO levels followed a similar trend. Lower DO near cremation and densely visited ghats indicates organic load and reduced reoxygenation capacity.

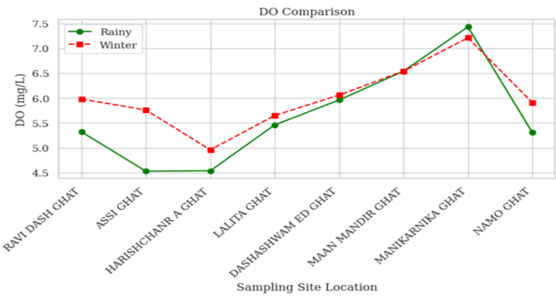

Fig. 6 Dis**Biochemical Oxygen Demand (BOD)**

Biochemical Oxygen Demand (BOD)

BOD values, indicating organic pollution, were significantly high at Harishchandra Ghat (5.86 mg/L) in the monsoon and 4.96 mg/L in winter. The lowest BOD was found at Manikarnika Ghat (3.21–3.43 mg/L). The elevated BOD levels indicate biodegradable pollutants, mainly from sewage and cremation waste.

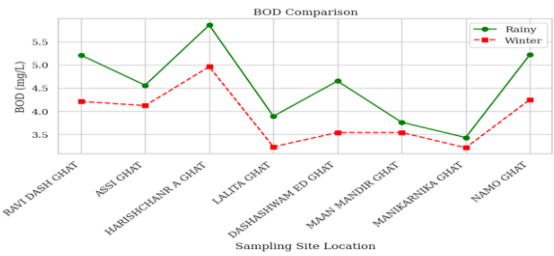

Fig.7 Biochemical Oxygen Demand (BOD) Levels at Varanasi Ghats

Chemical Oxygen Demand (COD)

COD was highest at Harishchandra Ghat (7.84 mg/L in monsoon; 6.10 mg/L in winter) and lowest at Manikarnika Ghat (5.43 mg/L and 4.21 mg/L, respectively). These values confirm the presence of chemically oxidizable pollutants, possibly from detergents, industrial effluents, and ceremonial waste.

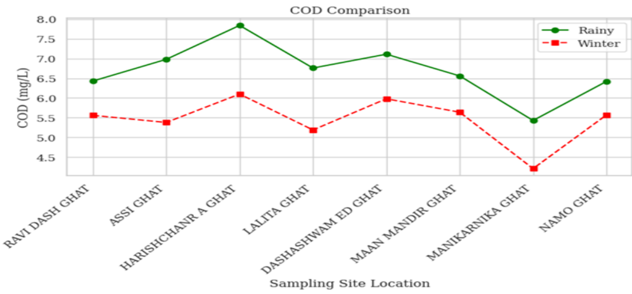

Fig. 8 Chemical Oxygen Demand (COD) during Monsoon and Winter

Total Hardness

Hardness ranged from 245 mg/L (Ravidas Ghat) to 273 mg/L (Lalita Ghat) during the monsoon and 260–279 mg/L in winter. These values suggest high mineral content, especially calcium and magnesium, which may originate from geological leaching or human-induced contamination.

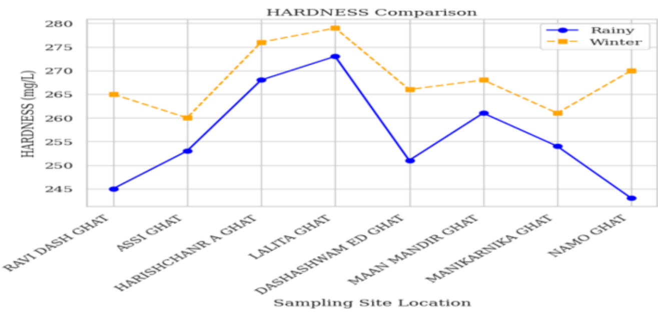

Fig.9 Total Hardness Values at Sampling Site

Alkalinity

The maximum alkalinity was 194 mg/L (Harishchandra Ghat) in the monsoon and 146 mg/L (Dasashwamedh Ghat) in winter. The lowest values were observed at Lalita Ghat (128 mg/L). High alkalinity is likely due to decomposition of organic matter and chemical cleaning agents.

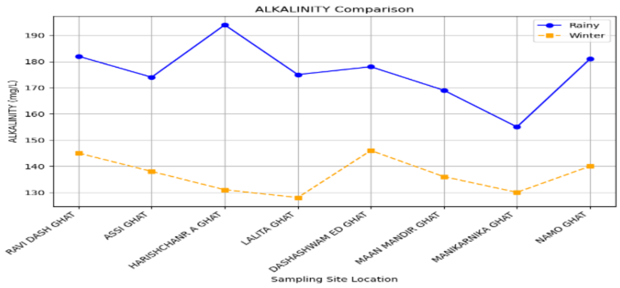

Fig. 10: Alkalinity Concentration in Ganga River Water

Turbidity

Turbidity values peaked at Harishchandra Ghat (13.45 NTU) and were lowest at Manikarnika Ghat (4.96 NTU) in winter. This aligns with high solid discharge and limited water flow near cremation ghats.

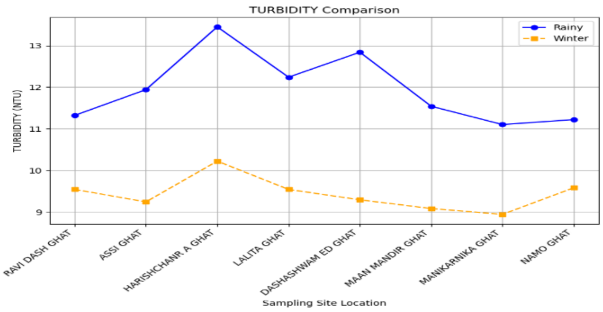

Fig. 11: Turbidity Levels across Different Ghat

Chloride

Chloride concentration ranged from 114 mg/L (Manikarnika Ghat) to 142 mg/L (Lalita Ghat). High chloride levels may indicate saline intrusion, sewage input, or use of salt-rich materials during rituals.

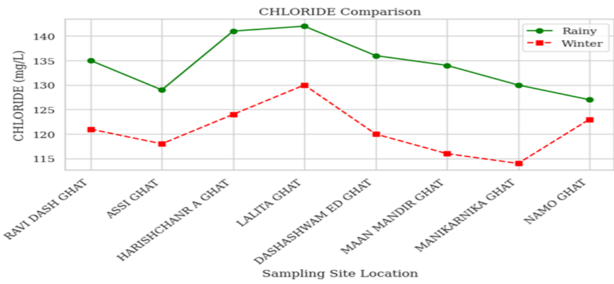

Fig. 12 Chloride Concentration Variation Seasonally

4.2 Heatmap Visualization of Physico-Chemical Parameters:

The spatial-temporal variations of key physico-chemical parameters were further visualized using heatmap-style graphs, allowing for clearer comparison across different ghats and between seasons. These color-coded plots provide an intuitive understanding of pollution hotspots and seasonal dynamics. Notably, Harishchandra Ghat consistently exhibited higher intensities of BOD, COD, turbidity, and TSS, especially during the monsoon season—reflecting its function as a major cremation site. In contrast, Namo Ghat and Lalita Ghat showed relatively cooler (lower intensity) color gradients across most parameters, indicating lesser anthropogenic pressure and better water quality.

The heatmap patterns confirmed that parameters like DO tend to decrease in areas with high organic and chemical pollution (evident in darker zones), while BOD and COD increase (seen as warmer red/yellow zones). The use of this visualization technique enhances the spatial resolution of the water quality data and helps identify priority areas for targeted intervention under river cleaning programs.

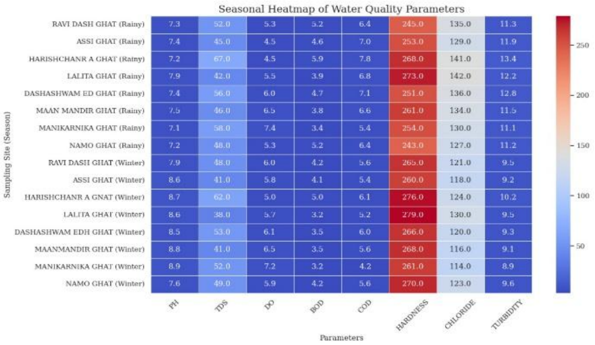

Fig. 13 Heatmap of Physico-Chemical Parameters (Monsoon Seasonand Winter Season

5. Conclusion

The present study offers an in-depth evaluation of the seasonal variation in physicochemical water quality parameters of the Ganga River at prominent ghats in Varanasi. The results clearly indicate that anthropogenic pressures—particularly religious, domestic, and industrial activities—have significantly affected the water quality of the river, making it unsuitable for direct domestic or drinking purposes without adequate treatment.

The parameters studied—including pH, DO, BOD, COD, TDS, TSS, alkalinity, hardness, turbidity, and chloride—exhibited considerable spatial and temporal variations across both monsoon and winter seasons. Among all monitored locations, Harishchandra Ghat, a major cremation site, emerged as the most polluted, with consistently high values of BOD, COD, turbidity, and suspended solids. In contrast, Namo Ghat and Lalita Ghat generally showed relatively lower pollutant concentrations, likely due to reduced human activity and recent infrastructure improvements.

The elevated BOD and COD values suggest substantial organic and chemical pollution loads, primarily from untreated sewage, ritual waste, and decaying organic matter associated with cremation. Low dissolved oxygen levels in some stretches further confirm the reduced capacity of the river to self-purify, especially during the monsoon season when runoff introduces additional contaminants from non-point sources such as pesticide-laden agricultural fields.

Additionally, high levels of TDS, alkalinity, and hardness point toward mineral contamination and the mixing of chemical residues. The elevated chloride and turbidity levels serve as indicators of saline intrusion and suspended impurities, respectively, both of which compromise the river's ecological integrity and threaten aquatic life.

These findings highlight the urgent need for a comprehensive and integrated river basin management approach. The current pollution load not only jeopardizes the health of the river ecosystem but also poses a direct threat to the millions of people who rely on the Ganga for spiritual, domestic, and economic purposes. Despite multiple interventions under government schemes such as the Ganga Action Plan and Namami Gange Mission, the persistent pollution reflects gaps in enforcement, infrastructure, and community participation.

Therefore, restoring the ecological health of the Ganga at Varanasi requires a multidimensional strategy involving scientific research, regulatory enforcement, infrastructure development, community education, and policy reforms. This study serves as a vital baseline for continuous water quality monitoring and should inform policy-makers, environmental engineers, and public health experts in designing effective remediation and conservation strategies.

The sacredness of the Ganga must be preserved not just in spiritual terms but also through scientific stewardship and sustainable practices that honor its ecological, cultural, and social significance.

6. Recommendations

To mitigate pollution and restore ecological health in the Varanasi stretch of the Ganga River, the following measures are strongly recommended:

1. **Strengthening of Monitoring and Enforcement**
    - Regular monitoring of water quality at all major ghats using real-time sensors.
    - Enforcement of existing environmental regulations with strict penalties for non-compliance.
2. **Expansion of Wastewater Treatment Infrastructure**
    - Immediate construction and upgrade of **Sewage Treatment**

Plants (STPs) near highly polluted ghats.
   - Treatment of all point and non-point sewage sources before discharge into the river.
3. **Ban on Ritual Waste and Cremation Residue Dumping**
   - Promotion of eco-friendly cremation practices.
   - Designated sites for ritual immersion away from river flow channels.
4. **Public Engagement and Behavioral Change**
   - Awareness campaigns among residents, pilgrims, and tourists on the impacts of river pollution.
   - Involvement of local communities and spiritual leaders in promoting sustainable practices.
5. **Research and Integration with Policy**
   - Use of baseline data from this study for policy decisions under national missions.
   - Encouragement of collaborative research on pollution load modeling and ecological restoration.

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