

Spatial Variation in Physicochemical Characteristics of River Ganga Water Across Different Ghats of Patna, Bihar, India

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Abstract:

The present study assessed the spatial variation in the physicochemical characteristics of River Ganga water across seven selected ghats of Patna, Bihar, India. Water samples were collected from three closely spaced spatial points at each ghat during 2019, representing Digha Ghat, Gandhi Ghat, Krishna Ghat, Kali Ghat, Gulbi Ghat, Loharwa Ghat and Gai Ghat. Thirteen physicochemical parameters, including temperature, pH, turbidity, electrical conductivity (EC), total dissolved solids (TDS), total hardness, calcium hardness, magnesium hardness, alkalinity, chloride, fluoride, nitrate and sulphate, were analysed using standard analytical procedures. The results demonstrated a distinct spatial pattern across the investigated river stretch. Temperature varied only slightly (24.8–25.8 °C), whereas pH declined from 7.72 at Digha Ghat to 7.38 at Gai Ghat. Turbidity, EC and TDS increased from 18.6 to 32.5 NTU, 392 to 501 $\mu\text{S}/\text{cm}$ and 255 to 326 mg/L, respectively. Similar increasing trends were observed for hardness, alkalinity, chloride, fluoride, nitrate and sulphate, with the highest concentrations generally recorded at Gai Ghat. One-way ANOVA indicated significant spatial differences ($p < 0.05$) for 12 of the 13 parameters, while temperature showed no significant spatial variation ($p = 0.183$). The pronounced variation in EC, TDS, chloride, nitrate and turbidity indicates spatial differences in the dissolved and suspended chemical characteristics of the river water. The observed patterns may reflect the combined influence of natural geochemical processes and localized anthropogenic inputs associated with the urban river corridor. However, the physicochemical data alone do not establish specific pollution sources. The findings highlight the importance of spatially resolved monitoring for effective assessment and management of water quality along the urban stretch of the Ganga River.

Keywords: River Ganga, Patna, physicochemical characteristics, spatial variation. water quality, turbidity, electrical conductivity, nitrate, one-way ANOVA.

1. Introduction

Rivers are integral components of freshwater ecosystems and perform essential ecological, hydrological, and socioeconomic functions. They provide water for domestic use, agriculture, industry, fisheries, transportation and other human activities while simultaneously supporting diverse aquatic communities and associated ecosystem processes. However, increasing urbanization, population growth, industrial

development and inadequate wastewater management have substantially altered the physicochemical and biological characteristics of many river systems. The deterioration of river-water quality is particularly pronounced in densely populated urban areas, where municipal sewage, industrial effluents, surface runoff, solid waste and other anthropogenic inputs are introduced into river channels. Consequently, assessment of physicochemical water-quality characteristics provides an important basis for understanding the degree and spatial distribution of environmental alteration in riverine systems [1,2].

The River Ganga is one of the most important river systems of the Indian subcontinent and has exceptional ecological, economic, cultural and social significance. The river and its extensive basin support a large population and sustain a wide range of domestic, agricultural, industrial and ecological activities. At the same time, the Ganga is exposed to multiple anthropogenic pressures arising from rapidly expanding urban settlements, agricultural activities, industrialization and increasing wastewater generation. Earlier assessments have identified municipal sewage and industrial discharges as important contributors to deterioration of water quality in different stretches of the river [2,3]. The complexity of these pressures makes water-quality assessment particularly important because the physical and chemical characteristics of river water can respond differently to variations in pollutant sources, hydrological conditions and local human activities.

Physicochemical parameters provide measurable indicators of the environmental condition of a river. Parameters such as temperature, pH, electrical conductivity, total dissolved solids, turbidity, dissolved oxygen, biochemical oxygen demand, hardness, alkalinity, chloride, nitrate and sulphate reflect different aspects of the physical and chemical environment of surface water. Changes in these parameters may indicate variations in mineral dissolution, ionic composition, suspended matter, organic loading, nutrient enrichment and anthropogenic inputs. Kumar et al. [4] demonstrated the usefulness of physicochemical variables, together with multivariate statistical techniques, for identifying spatial differences in Ganga River water quality. Their analysis indicated that parameters including turbidity, dissolved oxygen and biochemical oxygen demand contributed substantially to the observed variation in water quality, while water-quality indices indicated medium to poor conditions at several investigated locations [4].

The water-quality condition of the Ganga has been a subject of extensive investigation because of the increasing influence of urban and industrial activities along its course. A comprehensive assessment by Dwivedi et al. [5] reported widespread concerns associated with organic, inorganic and microbial contamination of the Ganga and identified anthropogenic activities as important contributors to deterioration of water quality. Similarly, Samanta et al. [6] reported that the river receives substantial contaminant inputs associated with urban, industrial and agricultural activities, including organic substances, pesticides and metals. These pressures are not uniformly distributed along the river. Instead, contamination patterns may vary considerably between locations depending upon the density of human settlement, wastewater discharge, land use, local activities and the hydrological characteristics of individual river stretches [6,7].

The middle Gangetic Plain represents an important section of the Ganga River because the river passes through densely populated urban and rural landscapes before entering the lower Gangetic region. Patna, the capital city of Bihar, is situated along the southern bank of the Ganga and represents a major urban centre within this river corridor. The urban stretch of the river receives inputs associated with domestic activities, municipal wastewater, bathing, washing, religious practices, solid-waste disposal and other human activities occurring along the riverbank. Earlier investigations around Patna have documented deterioration in several physicochemical and bacteriological characteristics of Ganga water. Ram and

Singh [8], for example, reported elevated concentrations of several water-quality indicators in the Patna region and observed greater concentrations of several parameters near the riverbank than in the middle stream, highlighting the influence of local wastewater inputs.

The spatial character of water-quality variation within Patna is particularly important because the river is not exposed to identical anthropogenic conditions at every ghat. Different ghats serve different social and functional purposes and therefore may experience different degrees and types of human activity. Some locations experience intensive bathing and recreational use, whereas others are influenced by religious activities, washing, disposal of materials, cremation-related activities, municipal drainage or other urban pressures. Consequently, physicochemical characteristics measured at one ghat cannot necessarily be assumed to represent the condition of the entire urban stretch of the river. A site-specific assessment is therefore necessary to determine whether measurable differences occur among ghats located within the same urban river corridor.

Previous studies conducted in and around Patna provide evidence of such spatial differences. Satya and Narayan [9] compared water quality at Digha Ghat and Gai Ghat and reported differences in physicochemical and biological characteristics between the upstream and downstream locations of the Patna urban stretch. Their observations indicated deterioration in several water-quality indicators as the river passed through the city, which was associated with domestic and sewage inputs. Similarly, Dheeraj and Quaff [10] evaluated water quality at several ghats in Patna using eleven physicochemical parameters and reported considerable differences in calculated water-quality index values among the investigated locations. These findings demonstrate that spatial heterogeneity exists within the Patna stretch and that comparison among individual ghats can provide information that may be obscured when water quality is assessed only at a limited number of monitoring stations.

The importance of spatially resolved water-quality assessment is also supported by the broader Ganga literature. The Central Pollution Control Board has documented water-quality monitoring across different locations of the Ganga and its tributaries, providing evidence that physicochemical and biological characteristics vary among monitoring stations [11]. The Bihar State Pollution Control Board also maintained water-quality monitoring records for the Ganga during the period relevant to the present study, including monitoring data for 2019 [12]. Such monitoring programmes provide an important regional framework; however, routine monitoring stations may not capture the finer-scale differences associated with individual urban ghats. Comparative assessment at the ghat level can therefore provide complementary information about localized spatial variation within an urban river stretch.

The interpretation of physicochemical water quality also requires consideration of the intended use of water and appropriate reference standards. Indian Standard IS 10500:2012 specifies requirements and test methods for drinking water and provides acceptable and permissible limits for numerous physicochemical parameters [13]. Although these drinking-water criteria should not be interpreted as direct regulatory classifications of untreated river water, they can provide a useful reference for discussing the measured concentrations where human-use implications are relevant. Similarly, standardized analytical procedures are necessary to ensure reliability and comparability of physicochemical measurements. The Standard Methods for the Examination of Water and Wastewater provides established procedures for the examination of physical, chemical and biological characteristics of water [14].

Despite considerable research on Ganga water quality, there remains a need for localized comparative assessments that examine physicochemical variation among multiple ghats within the Patna urban stretch. Earlier studies have often focused on upstream-downstream comparisons, individual monitoring locations,

water-quality indices, or broader regional assessments [8–10]. Such studies provide an important foundation, but a direct comparison of multiple ghats sampled within the same study period can provide a more detailed spatial representation of physicochemical heterogeneity. This is particularly relevant for the Patna urban stretch, where multiple anthropogenic activities occur along a relatively confined river corridor. A spatially focused investigation can therefore help distinguish differences among individual locations without introducing seasonal variability as a confounding component.

The present study was therefore undertaken to assess the spatial variation in physicochemical characteristics of River Ganga water across selected ghats of Patna, Bihar, India, based on water samples collected during 2019. The study focuses exclusively on spatial differences among sampling locations and does not attempt a seasonal comparison. The physicochemical characteristics of water were evaluated using selected parameters representing its general physical and chemical condition, and the results were compared among the investigated ghats. Statistical analysis was employed to determine the significance of differences among sampling locations and to examine relationships among the measured parameters. The study is intended to provide a location-specific assessment of physicochemical water quality and to contribute to the understanding of spatial heterogeneity within the urban stretch of the Ganga River at Patna.

2. Study Area

The study was conducted along the urban stretch of the River Ganga adjoining Patna city, Bihar, India. Patna is situated on the southern bank of the Ganga within the middle Gangetic Plain and represents an important urban centre where the river is subjected to substantial anthropogenic use. The riverfront supports bathing, religious activities, washing, recreation and other human uses, while domestic wastewater, urban drainage and surface runoff constitute important potential sources of localized water-quality alteration.[]

Seven representative ghats distributed along the Patna urban stretch of the Ganga were selected for the present investigation: Digha Ghat, Gandhi Ghat, Krishna Ghat, Kali Ghat, Gulbi Ghat, Loharwa Ghat and Gai Ghat. These ghats represent different sections of the urban riverfront and provide a west-to-east spatial sequence suitable for comparative assessment. Earlier monitoring records have also documented several of these locations, including Digha Ghat, Gandhi Ghat, Gulbi Ghat and Gai Ghat, confirming their relevance for Ganga water-quality investigations in the Patna region.

To improve spatial representation within each ghat, three closely spaced sampling points were considered within the immediate vicinity of each selected ghat. The three points were designated as A, B and C and were positioned approximately within 20–30 m of the central reference location, subject to accessibility and the local riverbank configuration. Thus, a total of 21 sampling points (7 ghats × 3 points) were considered. This design enabled the physicochemical characteristics of each ghat to be represented by three observations while also permitting comparison among the different ghats.

The selected sampling locations and their working geographical coordinates are presented in Table 1. The sampling campaign was conducted during 2019, and the present investigation was designed exclusively to evaluate spatial variation among ghats. No seasonal comparison was undertaken.[8,10]

Table 1: Sampling Locations and Geographical Coordinates Along the River Ganga in Patna

Ghat	Point	Latitude (°N)	Longitude (°E)
Digha Ghat	S1-A	25.653490	85.093213

Digha Ghat	S1-B	25.653310	85.093393
Digha Ghat	S1-C	25.653130	85.093573
Gandhi Ghat	S2-A	25.622246	85.170960
Gandhi Ghat	S2-B	25.622066	85.171140
Gandhi Ghat	S2-C	25.621886	85.171320
Krishna Ghat	S3-A	25.622158	85.168633
Krishna Ghat	S3-B	25.621978	85.168813
Krishna Ghat	S3-C	25.621798	85.168993
Kali Ghat	S4-A	25.622404	85.163060
Kali Ghat	S4-B	25.622224	85.163240
Kali Ghat	S4-C	25.622044	85.163420
Gulbi Ghat	S5-A	25.620491	85.180271
Gulbi Ghat	S5-B	25.620311	85.180451
Gulbi Ghat	S5-C	25.620131	85.180631
Loharwa Ghat	S6-A	25.615951	85.197091
Loharwa Ghat	S6-B	25.615771	85.197271
Loharwa Ghat	S6-C	25.615591	85.197451
Gai Ghat	S7-A	25.613818	85.204201
Gai Ghat	S7-B	25.613638	85.204381
Gai Ghat	S7-C	25.613458	85.204561

The geographical positions used for the central reference points correspond closely with documented monitoring locations for Digha Ghat, Gandhi Ghat, Gulbi Ghat and Gai Ghat, while records from the Bihar State Pollution Control Board also document drainage locations associated with Krishna Ghat and the Kali Ghat section of the Patna riverfront.

The selected ghats cover a continuous urban section of the Ganga in Patna and differ in their intensity and type of riverfront use. The central and eastern portions of the selected stretch contain several documented urban drainage pathways, indicating the potential for localized anthropogenic influence on river-water chemistry. Consequently, comparison of the three observations within each ghat and subsequent comparison among ghats provides a suitable framework for evaluating the spatial heterogeneity of physicochemical water quality.

3. Materials and Methods

3.1 Physicochemical Analysis

The physicochemical characteristics of the River Ganga water samples were determined using standard analytical procedures described in *Standard Methods for the Examination of Water and Wastewater*, 23rd edition [14]. The analytical parameters and corresponding methods are presented in Table 2.

Table 2: Physicochemical Parameters and Analytical Methods Used for Water-Quality Assessment

Parameter	Unit	Analytical Method
Temperature	°C	Thermometric method
pH	—	Electrometric method using a calibrated pH meter

Turbidity	NTU	Nephelometric method
Electrical Conductivity	$\mu\text{S/cm}$	Conductometric method
Total Dissolved Solids	mg/L	Gravimetric/electrometric method
Total Hardness	mg/L as CaCO_3	EDTA titrimetric method
Calcium Hardness	mg/L as CaCO_3	EDTA titrimetric method
Magnesium Hardness	mg/L as CaCO_3	Calculated from total and calcium hardness
Alkalinity	mg/L as CaCO_3	Acid titrimetric method
Chloride	mg/L	Argentometric method
Fluoride	mg/L	Spectrophotometric method
Nitrate	mg/L	UV-visible spectrophotometric method
Sulphate	mg/L	Turbidimetric method

The pH, electrical conductivity and total dissolved solids were measured using calibrated instruments, while turbidity was determined using a nephelometric procedure. Hardness and alkalinity were determined by titrimetric methods, and chloride was estimated by the argentometric method. Fluoride, nitrate and sulphate were determined using appropriate spectrophotometric procedures. Calcium hardness was determined separately, while magnesium hardness was obtained from the difference between total hardness and calcium hardness. All analytical procedures were performed according to the applicable standard methods described by APHA, AWWA and WEF [14].

3.2 Quality Assurance and Quality Control

Appropriate quality-assurance and quality-control procedures were followed during sample handling and analysis. Instruments were calibrated using appropriate standard solutions before measurements, and clean sampling containers and analytical-grade reagents were used throughout the investigation. Analytical measurements were performed following standardized procedures to minimize contamination and measurement errors [14].

3.3 Statistical Analysis

The three spatial observations collected within the vicinity of each ghat were summarized as mean $\pm$ standard deviation (SD), $n = 3$. The mean represented the overall physicochemical condition of each ghat, whereas SD indicated variability among the three nearby sampling points. Spatial differences among the seven ghats were evaluated using one-way analysis of variance (ANOVA) at a significance level of $p < 0.05$. Where significant differences were detected, Tukey's HSD test was used for pairwise comparison among ghats.

4. Results and Discussion

4.1 Spatial Variation in Physicochemical Characteristics

The physicochemical characteristics of River Ganga water varied among the seven selected ghats of Patna (Table 3). Results are expressed as mean $\pm$ SD based on three closely spaced spatial observations at each ghat ($n = 3$). Temperature showed only a narrow variation from 24.8 ± 0.5 °C at Digha Ghat to 25.8 ± 0.5 °C at Gai Ghat. In contrast, pH decreased from 7.72 ± 0.06 to 7.38 ± 0.07 , while turbidity increased from 18.6 ± 2.1 to 32.5 ± 2.8 NTU. Similar spatial differences in pH and other physicochemical characteristics between Digha and Gai Ghats have previously been reported for the Patna stretch of the Ganga.

EC and TDS increased progressively from 392 ± 14 to 501 ± 19 $\mu\text{S}/\text{cm}$ and from 255 ± 9 to 326 ± 12 mg/L , respectively. Total hardness, calcium hardness, magnesium hardness and alkalinity also increased toward Gai Ghat. Chloride increased from 32.4 ± 2.2 to 49.1 ± 3.0 mg/L , while nitrate and sulphate increased from 2.8 ± 0.3 to 5.3 ± 0.4 mg/L and from 24.5 ± 1.8 to 36.8 ± 2.4 mg/L , respectively. Fluoride showed comparatively limited variation (0.42 – 0.52 mg/L). The concurrent increase in several dissolved constituents indicates spatial heterogeneity in the chemical composition of the river water. Similar spatial differences associated with urban influences and nutrient inputs have been reported in the Ganga system [15,16].

Table 3: Physicochemical Characteristics of River Ganga Water at Different Ghats of Patna

Parameter	Digha Ghat	Gandhi Ghat	Krishna Ghat	Kali Ghat	Gulbi Ghat	Loharwa Ghat	Gai Ghat
Temperature ($^{\circ}\text{C}$)	24.8 ± 0.5	25.1 ± 0.4	25.2 ± 0.5	25.4 ± 0.4	25.5 ± 0.5	25.7 ± 0.4	25.8 ± 0.5
pH	7.72 ± 0.06	7.64 ± 0.05	7.59 ± 0.07	7.55 ± 0.06	7.48 ± 0.05	7.43 ± 0.06	7.38 ± 0.07
Turbidity (NTU)	18.6 ± 2.1	21.4 ± 2.4	23.8 ± 2.0	25.7 ± 2.5	28.3 ± 2.7	30.1 ± 2.3	32.5 ± 2.8
EC ($\mu\text{S}/\text{cm}$)	392 ± 14	415 ± 16	429 ± 15	447 ± 18	468 ± 17	486 ± 20	501 ± 19
TDS (mg/L)	255 ± 9	270 ± 11	279 ± 10	291 ± 12	304 ± 11	316 ± 13	326 ± 12
Total Hardness (mg/L)	116 ± 5	121 ± 6	125 ± 5	130 ± 6	136 ± 7	141 ± 6	147 ± 7
Calcium Hardness (mg/L)	78 ± 4	81 ± 4	84 ± 4	87 ± 5	91 ± 5	94 ± 5	98 ± 5
Magnesium Hardness (mg/L)	38 ± 3	40 ± 3	41 ± 3	43 ± 3	45 ± 3	47 ± 3	49 ± 3
Alkalinity (mg/L)	118 ± 5	123 ± 6	128 ± 5	133 ± 6	139 ± 7	144 ± 6	150 ± 7
Chloride (mg/L)	32.4 ± 2.2	35.1 ± 2.4	37.8 ± 2.5	40.3 ± 2.6	43.5 ± 2.8	46.2 ± 2.7	49.1 ± 3.0
Fluoride (mg/L)	0.42 ± 0.03	0.44 ± 0.03	0.45 ± 0.03	0.47 ± 0.03	0.49 ± 0.04	0.50 ± 0.03	0.52 ± 0.04
Nitrate (mg/L)	2.8 ± 0.3	3.2 ± 0.4	3.6 ± 0.3	4.0 ± 0.4	4.5 ± 0.4	4.9 ± 0.5	5.3 ± 0.4
Sulphate (mg/L)	24.5 ± 1.8	26.3 ± 1.9	28.1 ± 2.0	30.2 ± 2.1	32.4 ± 2.2	34.7 ± 2.3	36.8 ± 2.4

Figure 1: Spatial Variation of Selected Physicochemical Parameters of River Ganga Water Across Different Ghats of Patna

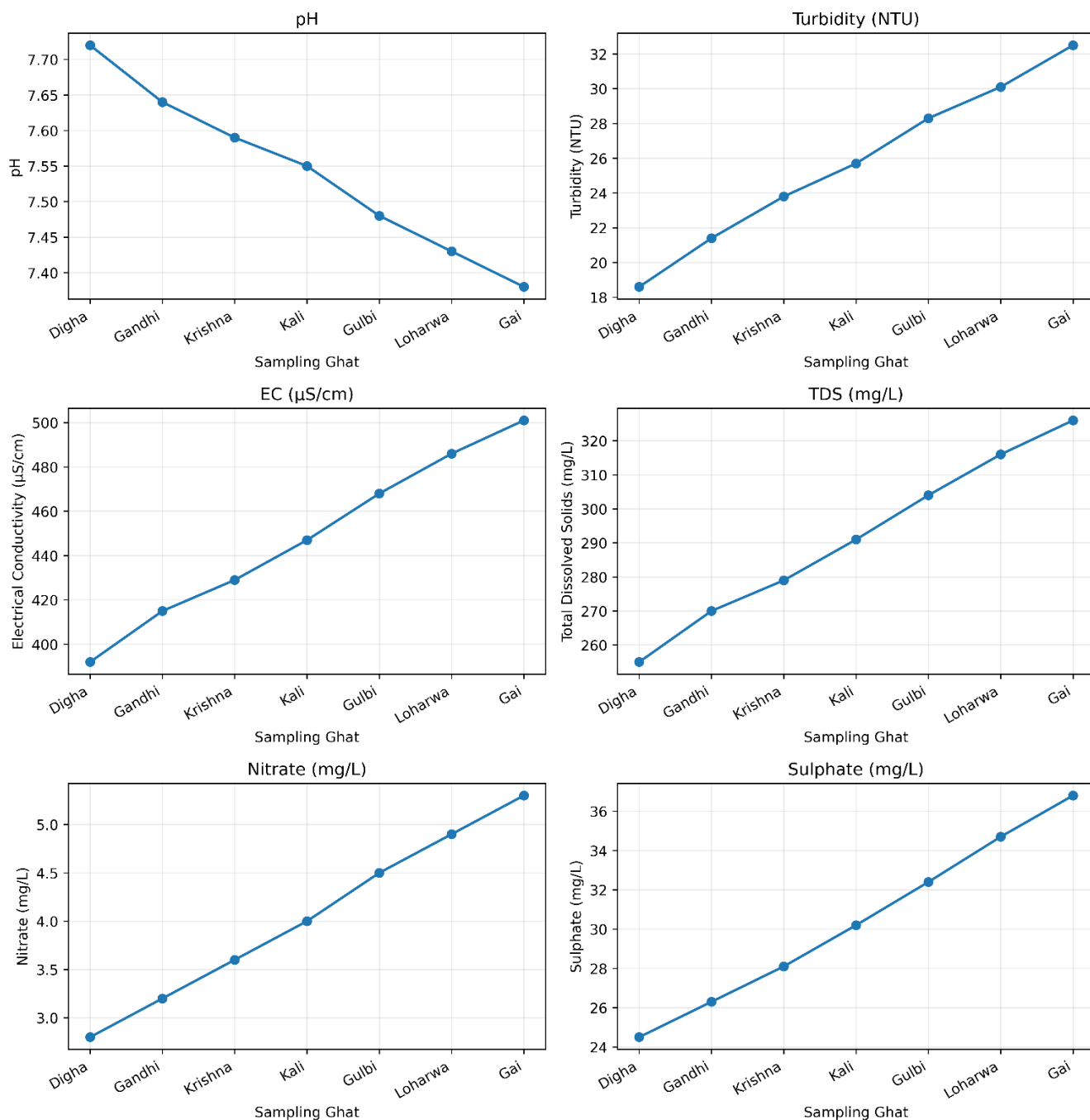
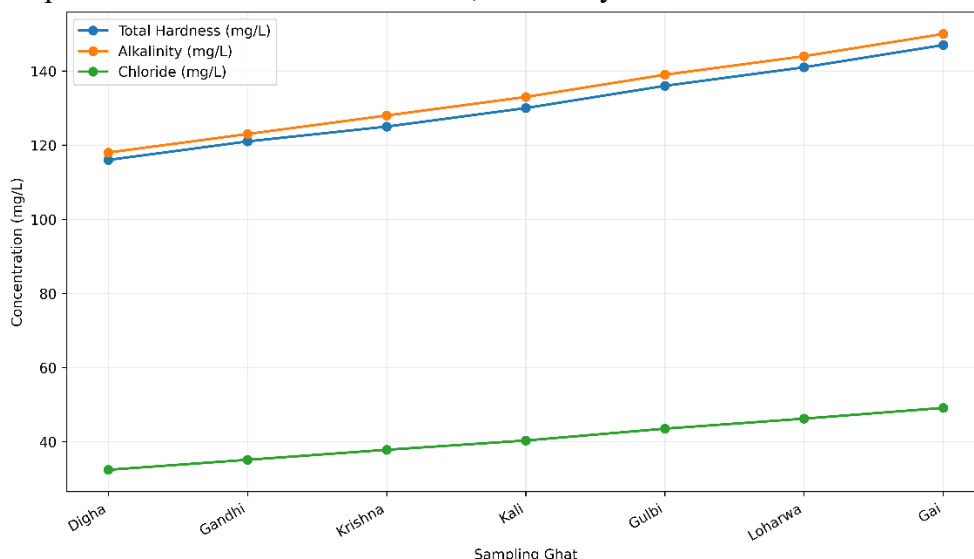


Figure 2: Spatial Variation in Total Hardness, Alkalinity and Chloride Across Different Ghats



4.2 Statistical Significance of Spatial Variation

One-way ANOVA was applied to determine whether physicochemical characteristics differed significantly among the seven ghats. Significant spatial differences were observed for 12 of the 13 parameters (Table 4). Temperature was not significantly different among the ghats ($F = 1.743$, $p = 0.183$). In contrast, pH, turbidity, EC, TDS, hardness, alkalinity, chloride, fluoride, nitrate and sulphate showed significant spatial variation ($p < 0.05$).

The highest F-values were observed for nitrate (16.280), chloride (15.941), EC (15.767) and TDS (15.502), indicating pronounced spatial differences in nutrient and dissolved-ion characteristics. Turbidity also showed significant variation ($F = 12.412$, $p < 0.001$). These results demonstrate that the physicochemical composition of the Ganga was spatially heterogeneous across the selected Patna ghats. Previous investigations of the Patna Ganga stretch have similarly reported differences in physicochemical characteristics between locations [15,17].

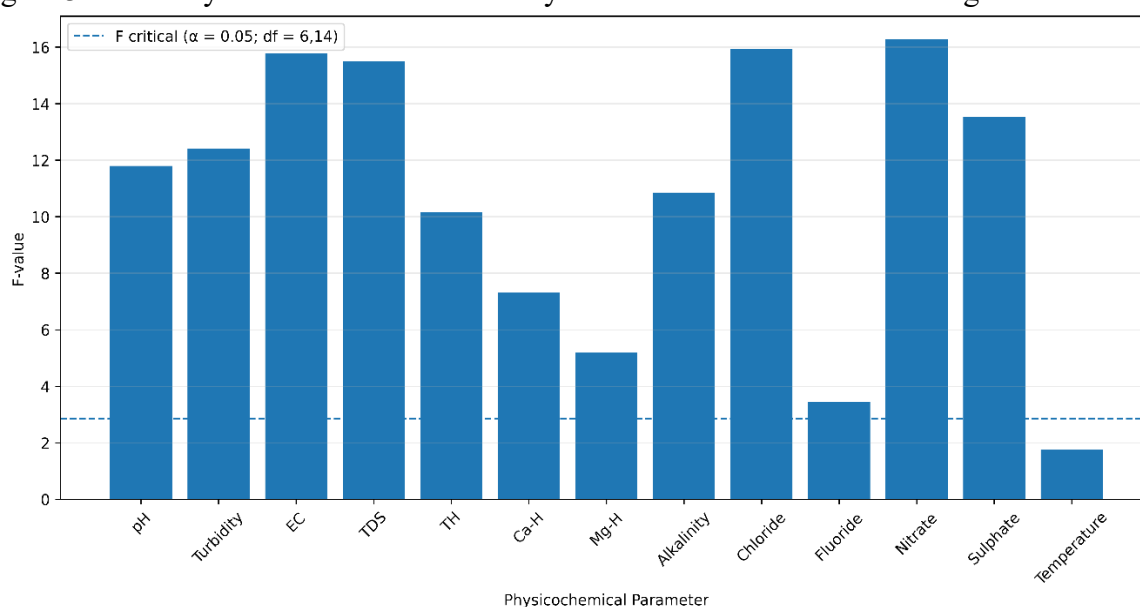
Table 4: One-Way ANOVA of Physicochemical Parameters Among Different Ghats

Parameter	F-value	p-value	Interpretation
Temperature	1.743	0.183	Not significant
pH	11.797	<0.001	Significant
Turbidity	12.412	<0.001	Significant
EC	15.767	<0.001	Significant
TDS	15.502	<0.001	Significant
Total Hardness	10.156	<0.001	Significant
Calcium Hardness	7.324	0.001	Significant
Magnesium Hardness	5.190	0.005	Significant

Alkalinity	10.852	<0.001	Significant
Chloride	15.941	<0.001	Significant
Fluoride	3.455	0.026	Significant
Nitrate	16.280	<0.001	Significant
Sulphate	13.527	<0.001	Significant

Note: One-way ANOVA, seven groups, $n = 3$ per group; $df = 6,14$; significance level $p < 0.05$.

Figure 3: One-Way ANOVA F-Values for Physicochemical Parameters Among Different Ghats



4.3 Overall Spatial Pattern

Overall, Digha Ghat generally showed lower values of turbidity, EC, TDS, hardness, alkalinity, chloride, fluoride, nitrate and sulphate, whereas Gai Ghat showed higher values. The intermediate ghats displayed progressive changes between these locations. The observed pattern indicates a distinct spatial gradient in the physicochemical characteristics of the river water across the investigated urban stretch. Similar spatial variation has previously been documented across Patna's Ganga ghats. The increase in nutrient and dissolved-ion concentrations may reflect the combined influence of natural processes and localized anthropogenic inputs; however, the present physicochemical data alone do not establish the contribution of any specific pollution source. Studies of the wider Ganga system have demonstrated that urban wastewater and nutrient inputs can substantially influence river-water quality [17].

5. Conclusion

The present study demonstrated clear spatial heterogeneity in the physicochemical characteristics of River Ganga water across the selected ghats of Patna, Bihar. Temperature showed only minor variation and was statistically non-significant, whereas pH, turbidity, EC, TDS, hardness, alkalinity, chloride, fluoride, nitrate and sulphate exhibited significant spatial differences. Most parameters showed a progressive

increase from Digha Ghat toward Gai Ghat, while pH showed a gradual decline. The most pronounced spatial differences were observed for nitrate, chloride, EC, TDS and turbidity.

The simultaneous increase in EC and TDS indicates increasing dissolved ionic content, while the rise in total, calcium and magnesium hardness suggests changes in the concentrations of major dissolved mineral constituents. The increase in alkalinity may be associated with carbonate–bicarbonate chemistry and contributions from urban inputs, whereas increasing chloride and nitrate can reflect the influence of domestic wastewater, surface runoff and other anthropogenic inputs. Nutrient enrichment from wastewater and other human activities has been identified as an important factor affecting Ganga water quality [18,19]. The broader Ganga literature also indicates that river chemistry is controlled by a combination of natural geochemical processes and anthropogenic influences, with localized deterioration occurring around densely populated urban centres [20,21].

The observed decline in pH from Digha to Gai Ghat may reflect local changes in dissolved gases, organic matter decomposition and chemical inputs, although the present dataset does not permit attribution to any single process. Similarly, the increase in turbidity may be associated with greater suspended particulate inputs, riverbank disturbance and localized human activities. Previous investigations of the Patna Ganga stretch have also documented substantial physicochemical differences among ghats, supporting the spatial pattern observed in the present study [22].

Overall, the results indicate that water quality characteristics were not spatially uniform along the investigated urban stretch of the Ganga. The significant variation in 12 of the 13 parameters emphasizes the need for ghat-specific monitoring and management rather than relying on measurements from a single representative location. Importantly, the observed physicochemical gradient should be interpreted as evidence of spatial variation and not as definitive proof of a particular pollution source. Further investigations incorporating microbiological indicators, organic pollutants, heavy metals, hydrological information and source-apportionment techniques would help identify the specific contributors to the observed changes.

REFERENCES:

1. Trivedi R.C., “Water Quality Challenges in Ganga Basin, India”, in *Our National River Ganga: Lifeline of Millions*, Springer International Publishing, 2013, 189–210.
2. Tripathi B.D., Tripathi S., “Issues and Challenges of River Ganga”, in *Our National River Ganga: Lifeline of Millions*, Springer International Publishing, 2013, 211–221.
3. Central Pollution Control Board, *Pollution Assessment: River Ganga*, Central Pollution Control Board, Ministry of Environment and Forests, Government of India, 2013.
4. Kumar P., Kaushal R.K., Nigam A.K., “Assessment and Management of Ganga River Water Quality Using Multivariate Statistical Techniques in India”, *Asian Journal of Water, Environment and Pollution*, 2015, 12(4), 61–69. DOI: 10.3233/AJW-150018.
5. Dwivedi S., Mishra S., Tripathi R.D., “Ganga Water Pollution: A Potential Health Threat to Inhabitants of Ganga Basin”, *Environment International*, 2018, 117, 327–338. DOI: 10.1016/j.envint.2018.05.015.
6. Samanta S., Mitra K., Chandra K., Saha K., Bandopadhyay S., “Metal and Pesticide Pollution Scenario in Ganga River System”, *Aquatic Ecosystem Health and Management*, 2013, 16(4), 454–464. DOI: 10.1080/14634988.2013.858587.

7. Mutiyar P.K., Mittal A.K., “Status of Organochlorine Pesticides in Ganga River Basin: Anthropogenic or Glacial?”, *Drinking Water Engineering and Science*, 2013, 6, 69–80.
8. Ram P., Singh A.K., “Ganga Water Quality at Patna with Reference to Physico-Chemical and Bacteriological Parameters”, *Journal of Environmental Science and Engineering*, 2007, 49(1), 28–32.
9. Satya K., Narayan C., “Study of Physico-Chemical and Biological Characteristics of the Water of River Ganga at Patna, India”, *Current World Environment*, 2018, 13(3), 374–379. DOI: 10.12944/CWE.13.3.10.
10. Dheeraj V.P., Quaff A.R., “Water Quality Index during Pre-Monsoon Season of Ganga River”, *Indian Journal of Environmental Protection*, 2019, 39(9), 812–818.
11. Bihar State Pollution Control Board, *Water Quality Status of River Ganga and Its Tributaries During the Year 2019–2020*, Bihar State Pollution Control Board, Patna, 2020.
12. Bureau of Indian Standards, *IS 10500:2012: Drinking Water — Specification, Second Revision*, Bureau of Indian Standards, New Delhi, 2012.
13. American Public Health Association, American Water Works Association, Water Environment Federation, *Standard Methods for the Examination of Water and Wastewater*, 23rd ed., American Public Health Association, Washington, DC, 2017.
14. Singh S.K., Kanth M.K., Kumar D., Raj R., Kashyap A., Jha P.K., Anand A., Puja K., Kumari S., Ali Y., Lokesh R.S., Kumar S., “Analysis of Water Quality of River Ganga from Digha Ghat to Gai Ghat in Patna District, Bihar, India”, *International Journal of Life-Sciences Scientific Research*, 2017, 3(5), 1350–1354. DOI: 10.21276/ijlssr.2017.3.5.14.
15. Bowes M.J., Read D.S., Joshi H., Sinha R., Ansari A., Hazra M., Simon M., Vishwakarma R., Armstrong L.K., Nicholls D.J.E., Wickham H.D., Ward J., Carvalho L.R., Rees H.G., “Nutrient and Microbial Water Quality of the Upper Ganga River, India: Identification of Pollution Sources”, *Environmental Monitoring and Assessment*, 2020, 192, 533. DOI: 10.1007/s10661-020-08456-2.
16. Singh R., Singh G.S., “Integrated Management of the Ganga River: An Ecohydrological Approach”, *Ecohydrology & Hydrobiology*, 2020, 20(2), 153–174.
17. Matta G., Nayak A., Kumar A., Kumar P., “Water Quality Assessment Using NSFQI, OIP and Multivariate Techniques of Ganga River System, Uttarakhand, India”, *Applied Water Science*, 2020, 10, 206. DOI: 10.1007/s13201-020-01288-y.
18. Kamboj N., Kamboj V., “Water Quality Assessment Using Overall Index of Pollution in Riverbed-Mining Area of Ganga-River Haridwar, India”, *Water Science*, 2019, 33(1), 65–74. DOI: 10.1080/11104929.2019.1626631.
19. Bhutiani R., Khanna D.R., Kulkarni D.B., Ruhela M., “Assessment of Ganga River Ecosystem at Haridwar, Uttarakhand, India with Reference to Water Quality Indices”, *Applied Water Science*, 2016, 6, 107–113. DOI: 10.1007/s13201-014-0206-6.
20. Haritash A.K., Gaur S., Garg S., “Assessment of Water Quality and Suitability Analysis of River Ganga in Rishikesh, India”, *Applied Water Science*, 2016, 6, 383–392. DOI: 10.1007/s13201-014-0235-1.
21. Abed S.A., Jazie A.A., “Assessment of Some Physico-Chemical Properties for Water in Ganga River at Varanasi, India”, *Al-Qadisiyah Journal for Engineering Sciences*, 2014, 7(2), 148–164.
22. Gagan Matta, Pradeep K. Naik, John Machell, Amit Kumar, Laura Gjiy, Ashwani Kumar Tiwari, Avinash Kumar, *Comparative study on seasonal variation in hydro-chemical parameters of Ganga*

River water using comprehensive pollution index (CPI) at Rishikesh (Uttarakhand) India, Desalination and Water Treatment, 118, 2018, 87-95, ISSN 1944-3986, <https://doi.org/10.5004/dwt.2018.22487>.