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# Water Quality Assessment of River Ganga in West Bengal based on Physico-Chemical and Bacteriological Parameters

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***Abstract*:** The present study reveals the seasonal and spatial changes in physico-chemical as well as bacteriological parameters in the lower stretch of river Ganga at West Bengal. Water samples were collected from five different sampling stations viz., Serampore, Palta, Tribeni, Nabadwip and Berhampore on monthly basis for two consecutive years 2019-2020 and 2020-2021. Sixteen physico-chemical parameters- water temperature, total suspended solids, turbidity, total dissolved solids, electrical conductivity, pH, dissolved oxygen, biochemical oxygen demand, chemical oxygen demand, nitrate, nitrite, phosphate-phosphorous, total hardness, total alkalinity, sodium and potassium, and two bacteriological parameters - total coliform and fecal coliform were measured to assess the water quality of river Ganga at selected stations on a seasonal basis. Correlation analysis on these parameters displayed significant positive and negative correlations among themselves. Physico-chemical parameters didn't vary significantly at different sites, however seasonal variations were significant. The two bacteriological parameters were significantly different at different sampling sites but only total coliform significantly differed seasonally. DO, BOD, TH, TC and FC are critical parameters in this study. Among the five sampling stations, Berhampore and Serampore were more polluted in respect of bacteriological parameters. Human religious activities and mass bathing near Berhampore sampling station were responsible for high bacteriological pollution.

***Keywords*:** ANOVA, Bacteriological parameters, Physico-chemical parameters, River Ganga, Water quality

River Ganga occupies a unique position in the cultural ethos of India. Millions of Hindus accept its water as sacred and count as river of faith, devotion and worship. River Ganga is considered to begin at confluence of Bhagirathi and Alaknanda at Devprayag in Garhwal Himalayas. It has total length of 2,525 km, raises in the western Himalayas in the Indian state of Uttarakhand, and flows south and east through the Gangetic Plain of North India and goes to Bay of Bengal through Bangladesh (Rai 2013). The entire pathway of the Ganga can be divided into three major stretches-upper, middle and lower. After flowing through the Sivalik hills, the Ganga enters plains at Haridwar. Then it flows southwards, passes through the plains of Uttar Pradesh and enters Bihar in the Rohtas district. After Bihar, the Ganga enters West Bengal and flows towards south and nearly 40 km below at Farakka, it divides into two streams. The left stream flows eastwards into Bangladesh and the right stream (Bhagirathi) continues to flow south through West Bengal (Paul 2017). The Bhagirathi flowing west and south-west of Kolkata is known as Hooghly. After reaching Diamond Harbour, it attains a southward direction and is split into two arms before reaching the Bay of Bengal (Rahaman 2009). The pathway of Ganga from Varanasi to Ganga Sagar is referred as its lower segment or stretch (GRB EMP 2010).

The Ganga was ranked among the five most polluted rivers of the world in 2007 (Rai 2013). The quality of river water is being degraded due to rapid population growth, agricultural and industrial developments, making it unsuitable for various uses (Singh et al., 2016). The river is also a site for religious bathing (Kanvar mela, Kumbh mela etc.), idol immersion, washing and watering of animals and the disposal corpses. Tourism is another important factor that contributes higher pollution load. The river supports 400 million people and is worshipped by more than one billion of countries population (Das and Taminga 2012). Therefore, comprehensive monitoring of river water quality is necessary to safeguard public health and protect the vulnerable and valuable fresh water resource (Singh 2014).

Physico-chemical characteristics of river water affect the biological characteristics and indicate the status of river water quality. Water temperature influences the pH, alkalinity and DO of the water (Matta 2014). Turbidity influences the light penetration inside water affecting the aquatic life (Tambekar et al., 2013). pH affects aquatic organisms as most of the metabolic activities are pH dependent (Kumar et al., 2011). Dissolved oxygen, biochemical oxygen demand and chemical oxygen demand are three of the most important chemical parameters for water quality analysis. Alkalinity in water sample implies the presence of hydroxides, bicarbonates, carbonates ions (Kamboj and Kamboj 2019). The assessment of bacteriological parameters like total coliform and fecal coliform is very important as presence of pathogenic bacteria in water body can cause several water-borne diseases in both human and animals (Panda et al., 2018). Open defecation in the river bed, excreta of animals, burning and throwing of dead bodies, domestic waste water and biomedical wastes are the major sources of bacterial contamination (Panda et al., 2017).

Many authors assessed water quality of river Ganga and pointed out BOD, COD, TH, TSS and FC as critical parameters due to industrial pollution, sewage and human activities (Khare et al., 2011, Singh et al., 2016, Khan et al., 2017). Most of the earlier works on water quality of river Ganga were done in the middle stretch of Ganga (Tripathi et al., 2014, Matta 2014, Singh et al., 2016, Chauhan and Bhardwaj 2018). Very little research work has been done on the water quality in the lower stretch of the Ganga, particularly in West Bengal. Hence, the present study was undertaken to assess the impact of seasonal variation on physico-chemical and bacteriological parameters of the Ganga river water at its lower stretch. The study will provide a clear picture about the Ganga river which is very close to meet the Bay of Bengal.

## MATERIAL AND METHODS

**Study area:** The present study was carried out in the lower stretch of the Ganga, known as Bhagirathi-Hooghly in West Bengal to examine water quality status. Water samples were collected from five sampling sites i.e. Serampore (22.76˚N, 88.34˚E), Palta (22.77˚N, 88.34˚E), Tribeni (22.98˚N, 88.40˚E), Nabadwip (23.39˚N, 88.37˚E) and Berhampore (24.11˚N, 88.25˚E). The sampling sites (Fig. 1) were populated areas with high domestic and industrial effluents and come under used based class B and C of surface water in India according to Water Quality Standards of CPCB updated on 23rd October, 2019 (https://cpcb.nic.in/water-quality-criteria/). Serampore station is located on the right bank of the river Ganga in Hooghly district. It is very busy navigation route connecting major cities of either side of the river banks. The major polluting source comes from the domestic waste water through big drains. Palta is located on left bank of the river Ganga in the North 24 Parganas district. Some temples are situated near station and a big city Barrackpore is located in its close proximity. Major pollutants come from bathing, washing and effluents from drains. Tribeni station is located on the right bank of the river in Hooghly district near the burning Ghat of Tribeni. The name 'Tribeni' is believed to be originated from divergence of three historical rivers- Kunti, Ganga and Saraswati (mythical). Domestic sewage, religious bathing, washing and burning corpse are the major sources of pollutants. Nabadwip is located on the left bank of Ganga River in the district of Nadia. It is an important place for religious purpose with many big temples situated all over the city. Sampling station was located near Monipur Ghat. Bathing and religious rituals are the major pollution sources. Berhampore is one of the biggest cities in West Bengal located in Murshidabad district. Berhampore sampling station was on the left bank of the river near College Ghat of Berhampore. Although an electric crematorium is situated in this Ghat, many open-air cremations are done regularly and the corpse are thrown into the river. Many drains discharge their waste water without any treatment near the sampling station.

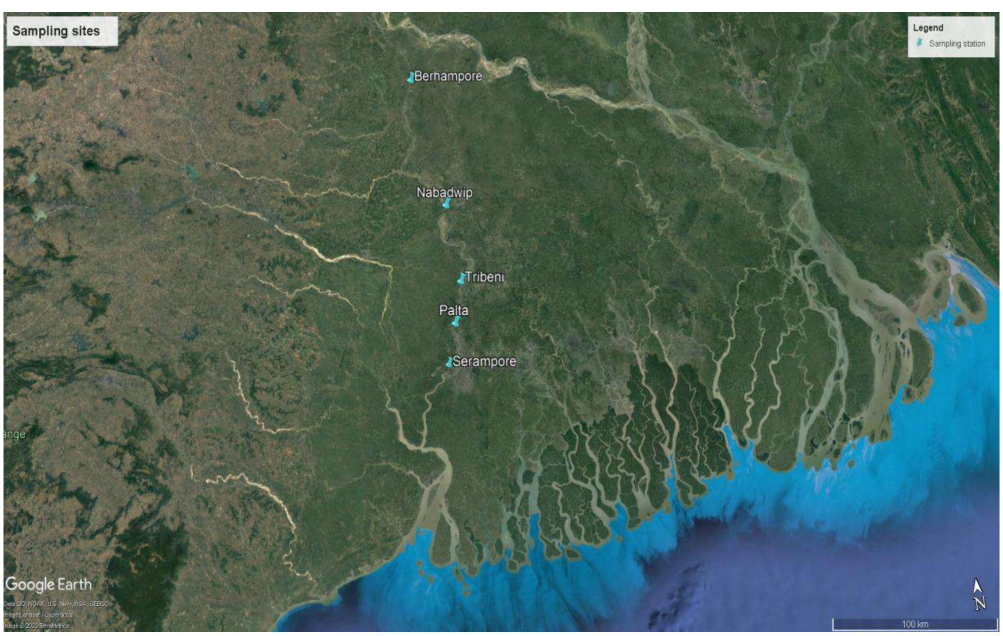


**Fig. 1.** Location of sampling sites in the lower stretch of river Ganga (Source: ©Google Earth)

**Sample collection and storage:** The water samples were collected at monthly interval throughout the year for duration of two years i.e. October 2019- September 2021 from the mentioned sampling sites. Water samples were collected at a depth of 1.0-1.5 m using a clean plastic bucket, transferred to clean plastic bottles and transported to the laboratory on ice and stored in refrigerator (4-6˚C) till analysis.

**Physico-chemical and bacteriological analysis:** All the parameters were analyzed according to the Standard Methods of American Public Health Association (23rd Edition 2017) (Table 1). Some physico-chemical parameters were recorded on the spot like water temperature (WT), pH, and dissolved oxygen (DO). Other parameters were analyzed in the laboratory.

**Statistical analyses:** Distribution of data was analyzed by Normality tests. Correlations among water parameters were estimated by non-parametric Spearman's rank correlation. Significant variations in water parameters due to sites and seasons were assessed by univariate ANOVA of log transformed values, followed by Tukey's post hoc test ($\alpha<0.05$). The statistical tests were performed in the SPSS software.

## RESULTS AND DISCUSSION

**Physical parameters:** The average water temperature varied from a minimum 21˚C at Berhampore during winter to a maximum 31˚C at Palta during rainy season (Table 2). Seasonally, the values of WT were highest in rainy season

**Table 1.** Methods used for physico-chemical and bacteriological parameters

| Parameter | Unit | Method of analysis/ Instrument |
|---|---|---|
| Water Temperature (WT) | ˚C | Glass thermometer |
| pH | Unit less | pH meter and pH electrode |
| Dissolved Oxygen (DO) | mg/L | Winkler's Method |
| Electrical Conductivity (EC) | µS/cm | Conductivity meter and conductivity electrode |
| Turbidity | NTU | Turbidity meter |
| Total Suspended Solids (TSS) | mg/L | Gooch crucible method (Gravimetric) |
| Total Dissolved Solids (TDS) | mg/L | Drying method (Gravimetric) |
| Chemical Oxygen Demand (COD) | mg/L | Open reflux method |
| Biochemical Oxygen Demand (BOD) | mg/L | 3 days' BOD measurement method |
| Nitrate ($NO_3$-N) | mg/L | Cadmium Reduction Method (Spectrophotometric) |
| Nitrite ($NO_2$-N) | mg/L | Spectrophotometric method |
| Phosphate-Phosphorus ($PO_4$-P) | mg/L | Stannous chloride method (Spectrophotometric) |
| Sodium (Na) | mg/L | Flame photometer |
| Potassium (K) | mg/L | Flame photometer |
| Total Alkalinity (TA) | mg/L | Titrimetric method |
| Total Hardness as $CaCO_3$ (TH) | mg/L | Titrimetric method |
| Total Coliform (TC) | MPN/100 ml | Most probable number method |
| Fecal Coliform (FC) | MPN/100 ml | Most probable number method |

**Table 2.** Physical parameters (mean ± standard deviation) at different sites in different seasons

| Station | Season | WT (ºC) | TSS (mg/L) | TDS (mg/L) | EC (µs/cm) | Turbidity (NTU) |
|---|---|---|---|---|---|---|
| Serampore | Summer | 29±3 | 45±29 | 159±55 | 338.4±75.1 | 51.5±28.3 |
| | Rainy season | 30±2 | 128±59 | 150±31 | 254.5±18.1 | 123.1±51.5 |
| | Winter | 23±3 | 50±32 | 201±44 | 339.9±40.5 | 53.3±32.7 |
| Palta | Summer | 29±2 | 89±50 | 156±61 | 329.7±56.9 | 82.1±46.8 |
| | Rainy season | 31±2 | 134±93 | 146±26 | 251.3±20.2 | 157.5±60.5 |
| | Winter | 23±4 | 63±37 | 196±29 | 336.8±50.2 | 60.1±46.4 |
| Tribeni | Summer | 29±2 | 53±21 | 186±37 | 354.5±65.6 | 51.3±18.8 |
| | Rainy season | 31±1 | 131±56 | 151±22 | 258.6±20.1 | 120.7±75.7 |
| | Winter | 22±3 | 85±45 | 200±33 | 344.3±49 | 74.5±48.7 |
| Nabadwip | Summer | 29±2 | 55±25 | 165±60 | 347.3±67.3 | 47.6±18.5 |
| | Rainy season | 30±1 | 183±81 | 146±17 | 235.8±16 | 168.1±86.9 |
| | Winter | 22±3 | 63±33 | 190±34 | 322.4±57.7 | 57.1±33.2 |
| Berhampore | Summer | 28±3 | 29±20 | 162±56 | 337.5±68.5 | 39.5±20.7 |
| | Rainy season | 30±1 | 217±157 | 148±22 | 251.4±23.3 | 162.2±81.2 |
| | Winter | 21±3 | 58±30 | 193±24 | 347.7±29.6 | 52.1±36.6 |

followed by summer and winter. The average turbidity varied from a minimum 39.5 NTU during summer at Berhampore to a maximum of 168.1 NTU during rainy season at Nabadwip. Previously, lower and higher range of turbidity have been reported from river Ganga – 28.66 to 63.66 NTU (Tripathi et al., 2014, Allahabad) and 126.29 to 165.56 NTU (Matta 2014, Uttarakhand) – the higher value was during monsoon. The higher number of suspended particles present in water results in higher turbidity. Both TSS and turbidity were higher in rainy season. The average TSS was maximum (217 mg/L) during rainy season at Berhampore and minimum (29 mg/L) during summer at Berhampore. Due to the surface run off and dissolving clay matter of the river banks, TSS always tends to be higher in rainy season.

Total dissolved solids indicate the presence of ions in water. The average TDS varied from 146 mg/L at Palta during rainy season to 201 mg/L at Serampore during winter. This is below the permissible limit as per BIS standard (500 mg/L). The average value of electrical conductivity was maximum (354.5 µS/cm) during summer at Tribeni and minimum (235.8 µS/cm) during rainy season at Nabadwip. The values are within the acceptable range of 20-500 µS/cm (Vijayakumar and Amanchi 2024). TDS and EC are closely associated with each other as the dissolved ions are responsible for greater conductivity in water sample. TDS and EC were lowest in rainy season due to dilution in water and highest in winter, similar to Yadav and Srivastava (2011) at Gazipur, Uttar Pradesh.

**Chemical parameters:** pH varied from minimum 7.84 at Tribeni during rainy season to maximum 8.30 at Berhampore during winter (Table 3). Joshi et al. (2009) and Kumar et al. (2018) also reported slightly alkaline nature of the Ganga River water at Haridwar. pH value becomes lower in rainy season due to heavy deposition of slightly acidic rain water. Average dissolved oxygen, biological oxygen demand and chemical oxygen demand varied from minimum 4.7 mg/L during rainy season at Palta, 2.20 mg/L during rainy season at Berhampore and 9.09 mg/L during winter at Nabadwip, respectively, to maximum 8.9 mg/L during winter at Berhampore, 3.52 mg/L at Tribeni during winter and 12.13 mg/L at Tribeni during rainy season, respectively. DO was highest in winter followed by summer and rainy season, similar to Ramganga River at Kumaun Himalaya (Verma 2013), and fell below the BIS standard of minimum 5 mg/L during rainy season. Solubility of oxygen in water decreases with increase in temperature. BOD exceeded the BIS standard (3 mg/L) in winter and indicates polluted status.

Nitrate, nitrite and phosphate varied from minimum 0.45 mg/L during summer at Nabadwip, 0.02 mg/L during summer at Tribeni and 0.06 mg/L during winter at Serampore,

**Table 3.** Chemical parameters at different sites in different seasons (mean ± standard deviation)

| Station | Season | pH | DO (mg/L) | BOD (mg/L) | COD (mg/L) | $NO_3$-N (mg/L) | $NO_2$-N (mg/L) | $PO_4$-P (mg/L) | TH (mg/L) | TA (mg/L) | Na (mg/L) | K (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Serampore | Summer | 8.05±0.2 | 6.4±0.6 | 2.76±0.7 | 9.96±1.7 | 0.47±0.1 | 0.03±0 | 0.09±0 | 137.52±27.8 | 132.91±26.9 | 16.3±4.3 | 4.3±0.6 |
| | Rainy season | 7.88±0.2 | 5.1±0.5 | 2.45±0.8 | 11.01±1.5 | 0.55±0.2 | 0.06±0.1 | 0.13±0.1 | 111.72±10.4 | 105.87±15.9 | 14±5.4 | 4.6±0.8 |
| | Winter | 8.26±0.2 | 8.6±1.9 | 3.38±1.2 | 10.59±2.9 | 0.48±0.1 | 0.1±0.1 | 0.06±0 | 157.60±12.6 | 151.46±12.3 | 17.9±2.8 | 4.2±0.6 |
| Palta | Summer | 8.14±0.2 | 6.2±1 | 2.97±0.39 | 10.53±3 | 0.49±0.13 | 0.06±0.1 | 0.08±0.03 | 138.53±25.52 | 135.48±26 | 17.4±3.6 | 4.3±0.6 |
| | Rainy season | 7.92±0.17 | 4.7±0.4 | 2.48±0.4 | 11.08±1.52 | 0.55±0.19 | 0.04±0.02 | 0.13±0.05 | 117.25±17.09 | 108.72±10.18 | 13.9±5.7 | 4.8±0.8 |
| | Winter | 8.19±0.12 | 8.3±1.5 | 3.37±1.36 | 11.79±3.89 | 0.5±0.08 | 0.05±0.05 | 0.06±0.02 | 152.10±15.73 | 153.74±15.8 | 17.3±3 | 4.0±0.3 |
| Tribeni | Summer | 8.18±0.32 | 6.9±0.9 | 3.03±0.52 | 11.04±2.08 | 0.51±0.18 | 0.03±0.01 | 0.08±0.03 | 144.42±21.51 | 137.11±30.73 | 17.2±4.6 | 4.5±0.6 |
| | Rainy season | 7.84±0.12 | 5.2±0.4 | 2.82±0.62 | 12.13±2.1 | 0.59±0.18 | 0.05±0.06 | 0.10±0.05 | 117.13±11.5 | 106.68±9.22 | 15.4±6.3 | 4.7±0.9 |
| | Winter | 8.17±0.13 | 8.3±1.4 | 3.52±1.37 | 10.76±2.1 | 0.49±0.11 | 0.06±0.04 | 0.07±0.03 | 151.22±17.84 | 154.21±15.12 | 18.7±2.5 | 4.4±0.7 |
| Nabadwip | Summer | 8.20±0.2 | 6.8±0.6 | 2.55±0.67 | 9.41±1.2 | 0.45±0.08 | 0.02±0.02 | 0.07±0.03 | 134.12±25.72 | 133.72±28.19 | 16.9±3.6 | 3.9±0.4 |
| | Rainy season | 7.90±0.14 | 5.7±0.3 | 3.10±0.81 | 11.71±2.68 | 0.52±0.15 | 0.04±0.03 | 0.12±0.05 | 121.30±33.83 | 101.51±7.43 | 12.2±3.5 | 4.0±0.7 |
| | Winter | 8.29±0.23 | 8.5±1.5 | 3.06±0.95 | 9.09±1.54 | 0.46±0.08 | 0.03±0.05 | 0.08±0.02 | 143.36±17.05 | 146.30±14.61 | 17.2±2.4 | 4.0±0.7 |
| Berhampore | Summer | 8.16±0.3 | 6.8±1.0 | 2.67±0.96 | 10.14±1.69 | 0.48±0.1 | 0.03±0.02 | 0.16±0.22 | 142.40±27.62 | 127.98±24.84 | 16.6±4.0 | 4.1±0.5 |
| | Rainy season | 7.93±0.11 | 5.9±0.5 | 2.20±0.64 | 11.02±2.0 | 0.51±0.16 | 0.02±0.01 | 0.11±0.04 | 110.20±5.31 | 107.38±8.66 | 11.6±5.5 | 4.8±0.9 |
| | Winter | 8.30±0.21 | 8.9±1.0 | 3.05±0.62 | 9.89±2.03 | 0.47±0.08 | 0.03±0.01 | 0.07±0.04 | 150.03±8.32 | 153.46±17.03 | 17.1±3.1 | 3.8±0.3 |

respectively, to maximum 0.58 mg/L during rainy season at Tribeni, 0.10 mg/L at Serampore during winter and 0.13 mg/L at Serampore during rainy season, respectively. Slightly higher values ($NO_3$-N: 0.35 – 0.81 mg/L, $PO_4$-P: 0.27 – 0.75 mg/L) have been reported from river Ganga at Allahabad (Tripathi et al., 2014). High quantity of these nutrients is harmful for any water body as it causes algal bloom and hampers the indigenous aquatic life.

Total hardness was maximum (157.60 mg/L) during winter at Serampore and minimum (110.20 mg/L) during rainy season at Berhampore. Water with TH>75 mg/L is considered hard water (Kumar et al., 2010). Total alkalinity varied from minimum 101.51 mg/L at Nabadwip during rainy season to maximum 154.21 mg/L at Tribeni during winter. TH and TA were higher in winter followed by summer and became lowest in rainy season due to deposition of rain water.

Sodium varied from minimum 11.6 mg/L during rainy season at Berhampore to maximum 18.7 mg/L during winter at Tribeni. Potassium was maximum (4.8 mg/L) during rainy season at Berhampore and minimum (3.8 mg/L) during winter at Berhampore. These values are much higher than the range of Na (0.40-0.90 mg/L) and K (1.10-1.40 mg/L) reported by Singh et al. (2016) for Ganga River at Varanasi.

**Bacteriological parameters:** Total coliform ranged from 3350 to 258500 MPN/100 ml in summer, 15500 to 490000 MPN/100 ml in rainy season and 4650 to 175000 MPN/100 ml in winter (Table 4). Fecal coliform ranged from 1550 ml to 156500 MPN/100 ml in summer, 6500 to 125000 MPN/100 ml in rainy season and 2650 to 109500 MPN/100 ml in winter. These values are much lower than those from Ganga River at Haridwar (Chauhan and Bhardwaj 2018, Kumar et al., 2018), where heavy influx of pilgrims is common. However, they exceeded the tolerance limit for inland surface water subject to pollution (IS: 2296-1982) which is set at 5000 MPN/100 ml for TC and 2500 MPN/100 ml for FC (Environmental Standards 2014). TC and FC were higher in rainy season followed by summer and winter. Coliform bacteria tend to be lower in winter as water temperature remains lower than the optimum temperature for bacterial growth.

**Correlation coefficients (ρ) among various water quality parameters:** Water quality parameters displayed significant positive and negative correlations among themselves (Table 5). pH had strong positive correlation with EC, DO, TH, TDS, TA and Na, while negative correlation with TSS, $PO_4$-P, $NO_3$-N, K, TC, FC, COD and turbidity. Water temperature was strongly positively correlated with TSS, $PO_4$-P, K, TC, FC and turbidity, and negatively with pH, EC, DO, BOD, TH, TDS, TA and Na. These correlations indicate response of other parameters towards seasonal changes in water temperature and rain. For instance, both DO and BOD decreased during rainy season and increased during winter displaying strong positive correlation. TC and FC showed strong positive correlation with WT, TSS and $PO_4$-P, indicating that increased TSS and $PO_4$-P at high temperature boosts the bacterial multiplication. Dilution of water during rainy season lowered

**Table 4.** Bacteriological parameters (range) at different sites in different seasons

| Station | Season | Total coliform (MPN/100 mL) | Faecal coliform (MPN/100 mL) |
|---|---|---|---|
| Serampore | Summer | 17000-240000 | 14000-130000 |
| | Rainy season | 39500-260000 | 19500-100000 |
| | Winter | 4900-164500 | 3300-101500 |
| Palta | Summer | 50000-240000 | 13000-105000 |
| | Rainy season | 40000-240000 | 11500-109500 |
| | Winter | 18000-175000 | 10000-95000 |
| Tribeni | Summer | 13000-170000 | 7900-92000 |
| | Rainy season | 15500-130000 | 6500-79000 |
| | Winter | 5600-55000 | 1300-36000 |
| Nabadwip | Summer | 8500-258500 | 5650-156500 |
| | Rainy season | 25000-490000 | 12000-118500 |
| | Winter | 4650-175000 | 2650-109500 |
| Berhampore | Summer | 3350-205000 | 1550-94500 |
| | Rainy season | 50000-270000 | 26500-125000 |
| | Winter | 21000-150000 | 6900-104500 |

**Table 5.** Spearman's rank correlation coefficients (ρ) among various water quality parameters

| Parameters | pH (ºC) | EC (µs/cm) | DO (mg/L) | BOD (mg/L) | TSS (mg/L) | $NO_3$-N (mg/L) | $NO_2$-N (mg/L) | PO4-P (mg/L) | TH (mg/L) | TDS (mg/L) | Na (mg/L) | TA (mg/L) | K (mg/L) | TC MPN/100ml) | FC (MPN/100ml) | COD (mg/L) | Turbidity (NTU) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WT (ºC) | -.634** | -.527** | -.816** | -.334** | .395** | .128 | -.123 | .450** | -.527** | -.424** | -.408** | -.691** | .317** | .318** | .263** | .095 | .450** |
| pH | 1.000 | .587** | .732** | .199* | -.577** | -.341** | .038 | -.469** | .355** | .434** | .456** | .675** | -.238** | -.411** | -.405** | -.218* | -.562** |
| EC (µs/cm) | | 1.000 | .703** | .148 | -.514** | -.135 | .001 | -.166 | .697** | .707** | .579** | .748** | .000 | -.376** | -.337** | .012 | -.603** |
| DO (mg/L) | | | 1.000 | .277** | -.538** | -.200* | -.059 | -.395** | .637** | .545** | .460** | .779** | -.232* | -.374** | -.330** | -.141 | -.632** |
| BOD (mg/L) | | | | 1.000 | -.059 | .037 | .301** | -.227* | .261** | -.008 | .216* | .219* | -.102 | -.056 | -.049 | .265** | -.094 |
| TSS (mg/L) | | | | | 1.000 | .235** | .039 | .289** | -.336** | -.241** | -.413** | -.465** | .024 | .265** | .218* | .252** | .845** |
| $NO_3$-N (mg/L) | | | | | | 1.000 | -.095 | .311** | -.010 | -.153 | -.184* | -.306** | -.041 | -.023 | .039 | .230* | .114 |
| $NO_2$-N (mg/L) | | | | | | | 1.000 | -.116 | -.004 | .050 | .112 | .066 | .096 | .018 | -.080 | .198* | .128 |
| $PO_4$-P (mg/L) | | | | | | | | 1.000 | -.125 | -.112 | -.205* | -.378** | .257** | .280** | .243** | .198* | .257** |
| TH (mg/L) | | | | | | | | | 1.000 | .553** | .429** | .661** | -.012 | -.265** | -.230* | -.067 | -.440** |
| TDS (mg/L) | | | | | | | | | | 1.000 | .413** | .672** | .072 | -.218* | -.214* | -.080 | -.309** |
| Na (mg/L) | | | | | | | | | | | 1.000 | .661** | .438** | -.227* | -.210* | .152 | -.456** |
| TA (mg/L) | | | | | | | | | | | | 1.000 | .030 | -.341** | -.330** | -.144 | -.502** |
| K (mg/L) | | | | | | | | | | | | | 1.000 | .106 | .049 | .214* | .011 |
| TC (MPN/100 mL) | | | | | | | | | | | | | | 1.000 | .908** | -.012 | .328** |
| FC (MPN/100 mL) | | | | | | | | | | | | | | | 1.000 | .036 | .258** |
| COD (mg/L) | | | | | | | | | | | | | | | | 1.000 | .152 |

**= p≤0.01; *= p≤0.05; Bold numbers indicate significant correlation

**Table 6.** F-value (significance) showing effect of sites and seasons on water parameters

| Dependent parameter | Site | Season | Site * Season |
|---|---|---|---|
| WT (ºC) | .932 (.448) | 121.978 (.000) | .277 (.972) |
| pH | .703 (.591) | 33.320 (.000) | .462 (.880) |
| EC (µs/cm) | .441 (.779) | 45.694 (.000) | .227(.985) |
| Turbidity (NTU) | .780 (.541) | 41.798 (.000) | .950(.480) |
| DO (mg/L) | 2.110 (.085) | 101.647 (.000) | .417 (.908) |
| BOD (mg/L) | .997 (.412) | 6.513 (.002) | .644 (.739) |
| COD (mg/L) | 1.337 (.261) | 3.139 (.047) | .654 (.730) |
| TSS (mg/L) | .753 (.559) | 34.538 (.000) | 1.955 (.059) |
| TDS (mg/L) | .440 (.780) | 15.163 (.000) | .208 (.989) |
| $NO_3N$ (mg/L) | .597 (.666) | 3.039 (.052) | .072 (1.000) |
| $NO_2N$ (mg/L) | 1.937 (.110) | 1.645 (.198) | .727 (.668) |
| P (mg/L) | .582 (.676) | 5.934 (.004) | .900 (.520) |
| TH (mg/L) | .186 (.945) | 31.984 (.000) | .527 (.834) |
| TA (mg/L) | .351 (.843) | 58.336 (.000) | .155 (.996) |
| Na (mg/L) | .823 (.513) | 11.609 (.000) | .270 (.974) |
| K (mg/L) | 2.794 (.030) | 6.515 (.002) | .742 (.654) |
| TC (MPN/100 mL) | 3.158 (.017) | 6.476 (.002) | 1.363 (.221) |
| FC (MPN/100 mL) | 2.485 (.048) | 2.707 (.071) | .838 (.571) |

Na leading to low EC and TDS indicating strong positive correlation.

Physico-chemical parameters didn't vary significantly at different sampling sites, except for K, but bacteriological parameters were significantly different site-wise (Table 6). Post-hoc test (Table 7) resulting into homogenous subsets showed significantly higher mean K in Tribeni than in Nabadwip. Mean TC at Serampore was significantly higher than at Tribeni, while both TC and FC were significantly higher at Berhampore than at Tribeni. All the physico-chemical parameters except nitrate and nitrite differed significantly season-wise. Post-hoc test placed WT, DO, TH and TA into three subsets with significantly different values in all the three seasons (Table 8). WT, turbidity, TSS, $PO_4$-P and K were significantly higher while EC, pH, DO, BOD, TDS, TH, TA and Na were significantly lower in rainy season than in other seasons. Winter season differed significantly from other seasons in terms of maximum pH, DO, BOD, TDS, TH, TA and Na, and minimum WT, $PO_4$-P and K. Among bacteriological parameters, only total coliform varied significantly in different seasons with significantly higher value in rainy season.

**Table 7.** Mean values of significantly different water parameters across five sites

| Parameter | Sites | | | | |
|---|---|---|---|---|---|
| | Tribeni | Nabadwip | Palta | Serampore | Berhampore |
| K (mg/L) | 4.55±0.15$^{b}$ | 3.95±0.11$^{a}$ | 4.33±0.13$^{ab}$ | 4.35±0.14$^{ab}$ | 4.23±0.15$^{ab}$ |
| TC (MPN/100 mL) | 46858.33±8437.96$^{a}$ | 84229.17±22124.53$^{ab}$ | 96331.25±12599.05$^{ab}$ | 109183.33±15444.98$^{b}$ | 110943.75±16037.19$^{b}$ |
| FC (MPN/100 mL) | 25354.1±4980.73$^{a}$ | 38533.33±8629.10$^{ab}$ | 42947.92±6520.04$^{ab}$ | 47575±7232.36$^{ab}$ | 55031.25±7572.30$^{b}$ |

Small superscript alphabets represent homogenous subsets after Tukey's post-hoc test (α=0.05).

**Table 8.** Mean values of significantly different water parameters across three seasons

| Parameter | Seasons | | |
|---|---|---|---|
| | Winter | Summer | Rainy |
| WT (ºC) | 22.28±0.49$^{a}$ | 28.73±0.35$^{b}$ | 30.28±0.23$^{c}$ |
| DO (mg/L) | 8.54±0.23$^{c}$ | 6.61±0.13$^{b}$ | 5.31±0.10$^{a}$ |
| TH (mg/L) | 150.86±2.32$^{c}$ | 139.40±3.90$^{b}$ | 115.52±2.84$^{a}$ |
| TA (mg/L) | 151.83±2.30$^{c}$ | 133.44±4.14$^{b}$ | 106.03±1.65$^{a}$ |
| EC (µs/cm) | 338.22±7.09$^{b}$ | 341.46±10.12$^{b}$ | 250.33±3.20$^{a}$ |
| Turbidity (NTU) | 59.44±6.14$^{a}$ | 54.38±4.88$^{a}$ | 146.33±11.32$^{b}$ |
| pH | 8.24±0.03$^{b}$ | 8.15±0.04$^{b}$ | 7.89±0.02$^{a}$ |
| BOD (mg/L) | 3.28±0.17$^{b}$ | 2.80±0.10$^{a}$ | 2.61±0.11$^{a}$ |
| COD (mg/L) | 10.43±0.42$^{a}$ | 10.22±0.31$^{b}$ | 11.39±0.31$^{b}$ |
| TSS (mg/L) | 63.65±5.66$^{a}$ | 54.3±5.62$^{a}$ | 158.35±15.51$^{b}$ |
| TDS (mg/L) | 196.05±5.04$^{b}$ | 165.75±8.31$^{a}$ | 148.1±3.64$^{a}$ |
| $PO_4$-P (mg/L) | 0.07±0.00$^{a}$ | 0.09±0.02$^{ab}$ | 0.12±0.01$^{b}$ |
| Na (mg/L) | 17.64±0.43$^{b}$ | 16.87±0.61$^{b}$ | 13.40±0.83$^{a}$ |
| K (mg/L) | 4.07±0.08$^{a}$ | 4.21±0.09$^{a}$ | 4.57±0.13$^{b}$ |
| TC (MPN/100 mL) | 63628.75±8534.88$^{a}$ | 83998.75±12323.29$^{a}$ | 120900±14590.22$^{b}$ |

Small superscript alphabets represent homogenous subsets after Tukey's post-hoc test (α=0.05)

## CONCLUSIONS

The present study analyzed total 18 physico-chemical and bacteriological parameters in the lower stretch of the Ganga. These parameters varied significantly season-wise. DO, BOD, TH, TC and FC were identified as critical parameters in this stretch of the Ganga. Rainy season was more polluted with heavy increase in both TC and FC leading to drastic fall in DO. BOD was alarmingly high in winter. Among the five sampling stations, Berhampore and Serampore were more polluted in respect of bacteriological parameters owing to discharge of waste water without prior treatment and throwing of corpses. The water quality of river Ganga, considered as most sacred, is unfit for use without proper treatment. Therefore, the role of Sewage Treatment Plants (STPs) plays very important part to revive the water quality. Both Central and State Governments have taken some major steps to purify the water and recover the holy status of the Ganges. Regular monitoring is essential to keep a check on water quality and also to maintain the aesthetical value.

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