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*Review Paper*

# Reviewing the degradation of water quality of Hooghly river with relation to environmental issues using multivariate statistical techniques

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## Abstract

*This study reviewing the degradation of water quality of Hooghly River with relation to environmental issues using multivariate statistical techniques. The river plays a vital role in supporting the ecological balance and meeting the water needs of a large population, especially in Kolkata. However, increasing anthropogenic activities and urbanization have significantly degraded its water quality. To understand the variation in water quality, samples were collected from three major ghats like Bag bazar, Babughat, and Howrah Ferry Ghat. Various physicochemical parameters such as temperature, pH, conductivity, total dissolved solids (TDS), dissolved oxygen (DO), and oxidation-reduction potential (ORP) were analysed during pre-monsoon and post-monsoon seasons. Multivariate statistical techniques, including Pearson correlation and Principal Component Analysis (PCA), were used to identify relationships among variables and major pollution sources. The Water Quality Index (WQI) was also applied to evaluate the overall suitability of water for use. The results indicate significant seasonal and spatial variations in water quality. High conductivity and TDS values, along with low DO levels, suggest the presence of organic and inorganic pollution mainly from sewage discharge, industrial waste, and urban runoff. PCA results revealed that anthropogenic activities and seasonal factors are the major controlling elements influencing water quality. The study highlights the urgent need for proper monitoring and management strategies to improve the water quality of the Hooghly River and ensure sustainable utilisation of water resources.*

**Keywords:** Water Quality, Climate issues, Physicochemical Parameters, Pollution, Anthropogenic Activities.

## Introduction

Water is one of the most essential natural resources that sustains life and maintains ecological balance. The quality of water plays a crucial role in supporting aquatic ecosystems as well as fulfilling human needs such as drinking, agriculture, and industrial activities. In recent decades, rapid population growth, urbanization, and industrialization have led to a significant deterioration of river water quality across the world. In addition to anthropogenic factors, climate change has emerged as a critical driver influencing the spatiotemporal variability of river water quality. Variations in temperature, precipitation patterns, and seasonal flow regimes significantly affect the physicochemical characteristics of water, including dissolved oxygen, conductivity, and nutrient concentration[1-3]. These changes not only impact aquatic life but also reduce the suitability of water for human use. The Ganga basin accounts for 45 percent of India's total irrigated land In West Bengal, the Ganga River is known as the Hooghly River, which serves as a lifeline for millions of people, particularly in the Kolkata metropolitan region. The river supports domestic water supply, transportation, fisheries, and various economic activities. However, increasing discharge of untreated sewage, industrial effluents, and solid waste has severely affected its water quality[4-6].

The present study focusses to evaluate the pollution status of Hooghly River and various types of contaminations responsible for the poor condition of the river. Identifying its sources and to provide management approaches. Also studied the major factors controlling water quality using multivariate methods and assessed the overall water quality status through the Water[7,8]. It will help to understand the impact of climate change and anthropogenic activities on river systems and will contribute to the development of sustainable water management strategies. Therefore, it is essential to evaluate the degradation of water quality in Hooghly River and to assess the environmental implications associated with it. Traditional methods often fail to capture the complex relationships among multiple water quality parameters. In this context, multivariate statistical techniques such as Pearson correlation and Principal Component Analysis (PCA) provide an effective framework to identify dominant factors and pollution sources.

**Literature Review:** Water quality assessment has received considerable attention in recent decades due to increasing environmental degradation and its adverse impacts on human health and aquatic ecosystems. Several studies have identified rapid urbanization, industrialization, and population growth as the major contributors to river water pollution, particularly in developing countries[7-10].

Rivers flowing through densely populated regions are highly vulnerable to contamination from untreated domestic sewage, industrial discharge, and agricultural runoff[11,12]. In addition to anthropogenic influences, climate change has emerged as a significant factor affecting water quality dynamics. Changes in temperature, precipitation patterns, and hydrological regimes can alter the physicochemical characteristics of water bodies[13-15]. Rising temperatures tend to reduce dissolved oxygen (DO) levels, while irregular rainfall and increased surface runoff can elevate concentrations of total dissolved solids (TDS), nutrients, and other pollutants[20]. These variations contribute to the spatiotemporal heterogeneity of water quality, necessitating integrated analytical approaches.

Multivariate statistical techniques have been widely applied to evaluate complex relationships among water quality parameters. Pearson correlation analysis is commonly used to determine the degree of association between different variables, while Principal Component Analysis (PCA) helps in reducing data dimensionality and identifying dominant factors controlling water quality[6,7]. Previous studies have demonstrated that PCA is effective in distinguishing between natural processes and anthropogenic pollution sources[5,6]. The Water Quality Index (WQI) is another widely used method for assessing overall water quality. It integrates multiple physicochemical parameters into a single composite value, facilitating easy interpretation and comparison across different locations and time periods. Many researchers have combined WQI with multivariate statistical techniques to obtain a comprehensive understanding of water quality status and pollution sources[21].

In the Indian context, particularly in the Ganga River Basin, several studies have reported significant deterioration of water quality due to increasing anthropogenic pressures[8,9]. The Hooghly River, a major distributary of the Ganga, has been subjected to severe pollution loads from urban sewage, industrial effluents, and port-related activities, especially in the Kolkata metropolitan region[22]. However, limited studies have comprehensively addressed the combined impact of climate change and anthropogenic activities on the spatiotemporal variation of water quality in the Hooghly River using multivariate approaches.

Therefore, the present study aims to fill this research gap by applying multivariate statistical techniques to evaluate the influence of climatic variability and human activities on the water quality of the Hooghly River. This integrated approach provides a deeper understanding of the controlling factors and supports the formulation of effective water management and pollution mitigation strategies.

**Data Source:** The present study is based on primary data collected from the Hooghly River in West Bengal, India. Water samples were collected from three selected sampling locations like Bagbazar Ghat, Babughat, and Howrah Ferry Ghat—based on their varying pollution potential and urban influence. These sites represent important stretches of the river within the Kolkata metropolitan region. Sampling was carried out during two distinct seasons, namely pre-monsoon and post-monsoon, to capture the seasonal variability in water quality. The selection of these seasons is crucial as climatic factors such as temperature, rainfall, and river discharge significantly influence the physicochemical characteristics of river water. The study considered key physicochemical parameters including temperature, pH, electrical conductivity, total dissolved solids (TDS), dissolved oxygen (DO), and oxidation-reduction potential (ORP). These parameters were selected due to their importance in determining overall water quality and ecological health.

## Methodology

To assess the spatiotemporal variation of water quality and identify the controlling factors, a combination of statistical and analytical methods was employed. Basic statistical measures were used to analyse the variation of physicochemical parameters across different locations and seasons. Box and whisker plots were applied to visualize the distribution and variability of parameters, highlighting seasonal differences and spatial patterns. The Pearson correlation coefficient (r) values were used to examine the correlation between pairs of physicochemical parameters. It can range from +1 to -1. Closer r values to 1 imply strong significant and negative/positive correlations between variables, whereas r values close to D suggest no significant and negative/positive correlations. The principal component analyses (PCA) is one of the most popular and widely used multivariate data analysis techniques. PCA apply the concept of dimensionality reduction to reduce a large number of indicators into a small number of comprehensive indicators, where each principal component can reflect the majority of the information. PCA > 0.5 revealed the most associated variables, assisting in the identification of anthropogenic or geogenic origins.

The PCA equation: $y_{ij}=a_{ij}x_{ij}+a_{i2}x_{2j}+a_{i3}x_{3j}+\ldots\ldots + a_{im}x_{mj}$ Where y is component score, a represents component loading (eigenvectors), x is the measured value of the variable, I is the component number, j is the sample number and m represents total number of variables. For the various physicochemical characteristics, box and whisker plots were used to show the spatiotemporal variations. The WQI model is a water rating scale that shows the overall impact of characteristics on water quality for any desired usage. Brown devised the WQI in 1970, and Backman updated it in 1998.

According to the World Health Organization (WHO), the WQI model aids in determining the influence of individual water quality characteristics. The following model's mathematical statement is as follows: $WQI=\sum q_n w_n/\sum w_n$ Where n number of

water quality parameters. $q_n$= quality rating of nth water quality parameter and $w_n$= unit weight of $n^{th}$ water quality parameter.
The quality rating ($q_n$) indicates employments of the given equation: $q_n=[(v_6-v_{id})]$ x 100 Where Vo observed value of the $n^{th}$ water quality parameter, $V_{id}$= ideal value for the $n^{th}$ parameter in pure water and $S_n$ = standard permissible value of nth water quality parameter. The ideal values ($V_{id}$) for all parameters are 0 except pH (7) and DO (14.6). The unit weight (w) is determined by utilising the accompanying equation: $W_n=k/S_n$ Where, $S_n$ =standard permissible value of the nth parameter and k proportionality steady and it is computed utilising the accompanying condition: K= $[1/\sum 1/s_n=12\ldots n)]$. The WQI has been categorized into five classes as mentioned in Table-1. The WQI values determine water quality from excellent to unsuitable for us.

**Table-1:** Water Quality Standards:

| WQI Range | Quality of water |
|---|---|
| 0-25 | Excellent |
| 26-50 | Good |
| 51-75 | Poor |
| 76-100 | Very poor |
| >100 | Unsuitable for use |

**Study Area:** The present study was conducted along the Hooghly River, a major distributary of the Ganga River, flowing through the state of West Bengal, India. The selected stretch of the river lies within the Kolkata metropolitan region, covering parts of Kolkata and Howrah, which are among the most densely populated and industrially active urban centers in eastern India. Geographically, the study area extends approximately between 22°30′N to 22°35′N latitude and 88°20′E to 88°25′E longitude. The Hooghly River in this region is characterized by its tidal nature, influenced by the Bay of Bengal, which plays a significant role in controlling the hydrodynamics and water quality of the river. The study focuses on three important sampling locations—Bagbazar Ghat, Babughat, and Howrah Ferry Ghat—selected based on their varying degrees of anthropogenic pressure, including domestic sewage discharge, industrial effluents, religious activities, and urban runoff.

Climatically, the region experiences a tropical monsoon climate with distinct seasonal variations, including pre-monsoon, monsoon, and post-monsoon periods. Temperature and rainfall patterns significantly influence the physicochemical characteristics of river water, leading to noticeable spatiotemporal variations in water quality. Due to rapid urbanization, population growth, and increasing anthropogenic activities, this stretch of the Hooghly River has become highly vulnerable to water pollution. Therefore, the study area provides an ideal setting to assess the impact of climatic factors and human activities on the spatial and temporal dynamics of river water quality using multivariate statistical techniques.

**Objective:** Hooghly River is the most polluted river in West Bengal, India so the water needs to be checked before use. Needs to identify the level of water quality degradation at different locations, particularly focusing on pollution hotspots such as Babughat and evaluate the environmental implications of water quality degradation on aquatic ecosystems and human use and analyse the influence of environmental factors and anthropogenic activities on river water quality. Hooghly river water quality needs to be checked, monitored and needs proper management. Hence, an effort is being made to evaluate the quality of the Hooghly River in Kolkata, West Bengal (India) and to provide its management practices.

## Results and Discussions

The analysis of physicochemical parameters of the Hooghly River reveals notable patterns of water quality degradation influenced by environmental and anthropogenic factors, with distinct seasonal variability. The average water temperature of the study area was recorded at 25.9°C, showing minimal spatial variation among the selected sites. However, a clear seasonal trend was observed, with higher temperatures during the pre-monsoon season compared to the post-monsoon period. This variation is primarily attributed to increased solar radiation and reduced water volume during pre-monsoon months. Elevated temperature levels play a crucial role in influencing metabolic activities of aquatic organisms and significantly affect overall water quality characteristics, including dissolved oxygen availability and biological processes[18,19].

The pH values of the river water indicated mildly acidic conditions, with an average value of 6.83. A higher pH was observed during the pre-monsoon season, whereas post-monsoon values showed a slight decline, likely due to dilution effects from rainfall and increased inflow of organic matter. Variations in pH can directly influence chemical reactions and biological functions within the aquatic ecosystem. Electrical conductivity values exceeded the permissible limits recommended by WHO standards, indicating a high concentration of dissolved ions in the river water. A noticeable increase in conductivity during the post-monsoon season suggests the influence of surface runoff carrying dissolved salts, urban waste, and other pollutants into the river system. Among the study locations, areas with intense human activity exhibited relatively higher conductivity levels, reflecting significant anthropogenic impact[13,14].

Similarly, Total Dissolved Solids showed higher concentrations during the post-monsoon season compared to the pre-monsoon period. This increase can be attributed to the influx of dissolved materials through runoff and waste discharge. Elevated TDS levels are known to adversely affect aquatic organisms by disrupting physiological processes and reducing water clarity.

Moreover, the presence of dissolved contaminants can lead to unpleasant taste, odour, and colour, making the water unsuitable for domestic use without proper treatment.

Dissolved Oxygen (DO), a critical indicator of water quality, was found to be lower than the recommended standards, highlighting poor ecological health of the river. The mean DO concentration was higher during the pre-monsoon season and declined significantly in the post-monsoon period. This reduction is indicative of increased organic pollution load, which enhances microbial activity and oxygen consumption. Low DO levels pose serious threats to aquatic life, potentially leading to habitat degradation and loss of biodiversity. The observed deterioration in water quality is strongly linked to environmental issues such as unregulated sewage discharge, urban runoff, and industrial effluents. The river receives substantial loads of organic and inorganic pollutants from densely populated urban areas, particularly at major ghats. These anthropogenic pressures, combined with seasonal climatic variations, contribute significantly to the degradation of water quality[19].

Furthermore, the application of multivariate statistical techniques, particularly Principal Component Analysis (PCA), indicates that parameters such as conductivity, TDS, and temperature are strongly associated with anthropogenic influences, whereas dissolved oxygen and pH reflect natural ecological processes. This confirms that human-induced activities play a dominant role in controlling water quality degradation in the Hooghly River. Overall, the results clearly demonstrate that the Hooghly River is experiencing progressive environmental stress, with post-monsoon conditions showing comparatively higher pollution levels due to increased runoff and contaminant influx. Immediate attention and effective management strategies are essential to mitigate further degradation and to ensure the sustainability of the river ecosystem[9-11].

The Pearson correlation matrix provides a detailed understanding of the interrelationships among the physicochemical parameters of the Hooghly River and helps identify the underlying factors responsible for water quality degradation in relation to environmental issues. The correlation analysis revealed several significant relationships at the 0.05 level of significance, indicating both natural processes and anthropogenic influences on water chemistry. A strong positive correlation was observed between electrical conductivity and total dissolved solids (TDS), as well as between conductivity and salinity, and TDS and salinity. This relationship suggests that the presence of dissolved ionic substances is a major contributor to the ionic strength of the river water. Since TDS primarily represents inorganic constituents such as salts and minerals, its close association with conductivity reflects increased pollutant load, likely originating from urban runoff, domestic sewage, and other anthropogenic inputs. In contrast, a significant negative correlation was observed between temperature and dissolved oxygen (DO)[1-3]. This inverse relationship indicates that higher water temperatures reduce the solubility of oxygen, thereby limiting its availability for aquatic organisms. Such conditions are particularly critical during the pre-monsoon season when elevated temperatures may intensify biological stress and reduce ecosystem resilience[14,15].

Additionally, pH exhibited a negative correlation with oxidation-reduction potential (ORP), highlighting the complex chemical interactions within the aquatic environment. Variations in pH influence the redox conditions of the water, which in turn control the transformation and mobility of nutrients and contaminants. Lower ORP values indicate reducing conditions, which may enhance the release of toxic metals and inhibit the breakdown of organic pollutants. The combined effect of low dissolved oxygen and reduced ORP conditions suggests an increased risk of pollutant accumulation and reduced self-purification capacity of the river. These findings clearly indicate that both environmental factors (such as temperature and seasonal variation) and anthropogenic pressures (such as waste discharge and runoff) play a crucial role in controlling the water quality dynamics of the Hooghly River. Overall, the correlation matrix highlights that the degradation of water quality is not governed by a single parameter but is the result of complex interactions among multiple physicochemical variables influenced by environmental and human-induced factors[20].

**Table-2:** Pearson correlation matrix among physicochemical parameters.

| Parameters | Temp. (·c) | pH | Conductivity (µS) | TDS (ppm) | Salt |
|---|---|---|---|---|---|
| Temperature (·c) | 1.00 | | | | |
| pH | -0.15 | 1.00 | | | |
| Conductivity | -0.20 | -0.39 | 1.00 | | |
| TDS (ppm) | -0.20 | -0.38 | 1.00* | 1.00 | |
| Salt(ppm) | 0.19 | -0.34 | 0.97* | 0.97* | 1.00 |

*Correlation is significant at the 0.05 level[20].

Figure-1 illustrates the spatiotemporal variation of physicochemical parameters, namely temperature, pH, conductivity, total dissolved solids (TDS), dissolved oxygen (DO), and oxidation–reduction potential (ORP), across three sampling sites (BG, BBG, and HFG) during pre-monsoon (pre-monsoon) and post-monsoon (post-monsoon) periods.

Temperature showed moderate variation among the sites, with comparatively higher values during the pre-monsoon season. A slight decrease in temperature was observed during the post-monsoon period, which may be attributed to rainfall and seasonal cooling effects[10].

The pH values remained within a slightly alkaline to near-neutral range in the pre-monsoon season, whereas a decline towards neutral or slightly acidic conditions was observed during the post-monsoon period. This shift may be due to dilution effects and increased organic matter input during monsoon runoff[25-27].

Conductivity and TDS exhibited a similar trend across all sites, with higher values recorded during the post-monsoon period. This indicates an increased load of dissolved ions, possibly due to surface runoff carrying domestic, industrial, and agricultural wastes into the river system[25-27].

Dissolved oxygen (DO) levels were relatively higher during the pre-monsoon season but showed a decreasing trend in the post-monsoon period, particularly at BBG. The reduction in DO may be associated with increased organic pollution and microbial activity, leading to higher oxygen consumption[25-27].

ORP values were predominantly negative during the pre-monsoon period, indicating reducing conditions in the water body. However, a noticeable increase towards less negative or slightly positive values was observed during the post-monsoon season, suggesting improved oxidizing conditions due to enhanced aeration and mixing[25-27].

Overall, the observed variations indicate that seasonal changes significantly influence the water quality of the study area. The post-monsoon period is characterized by increased ionic concentration and altered chemical conditions, likely driven by runoff and anthropogenic inputs.

**Principal component analysis of the river water quality parameter:** Contribution of eigenvalues among the factors is shown in Figure-2. The water quality parameters were successfully grouped using PCA based on the similarity of their inter-relationships. The top three PCs (F1, F2, and F3) had eigenvalues greater than one and accounted for 90.83 percent of the total cumulative variability among the parameters. The first eigenvalue (3.28) accounted for 46.80% of total variability, followed by F2 and F3, which contributed 25.74 percent and 18.29 percent, respectively. The two eigenvalue components accounted for 72.54 percent of the data set's initial variability. It confirmed the existing data set's strong applicability (Figure-2).

The factor loading of water quality measures is shown in Table-4. Factor loadings were classified as "strong", "moderate,' and 'weak,' respectively, for absolute loading values of > 0.75, 0.75-0.50 and 0.50-0.30.

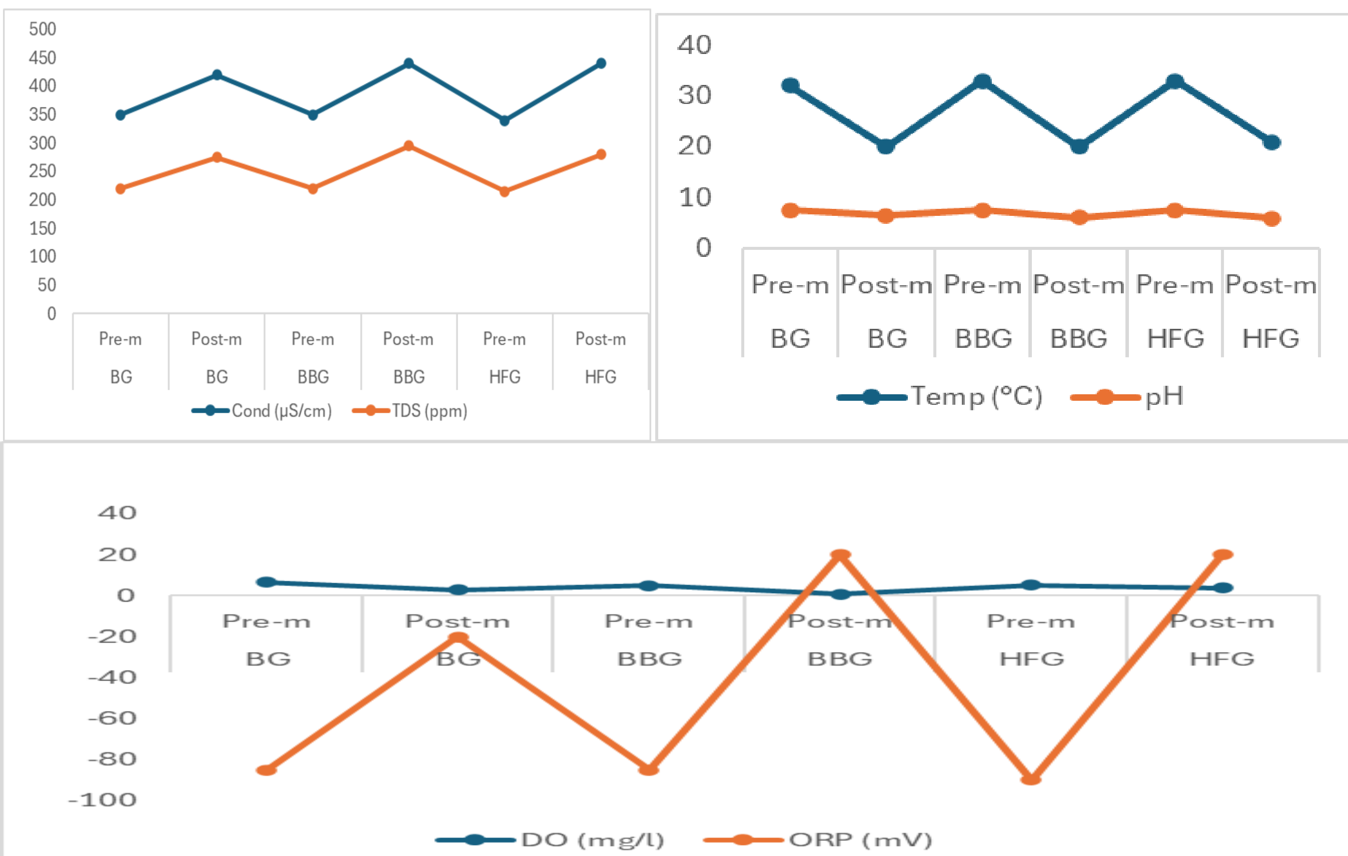


**Figure-1:** Spatiotemporal Variations of a) Temperature, b) pH c) Conductivity d) TDS e) DO f) ORP BG-Bag bazar ghat BBG-Babu ghat HFG-Howrah Ferry ghat.

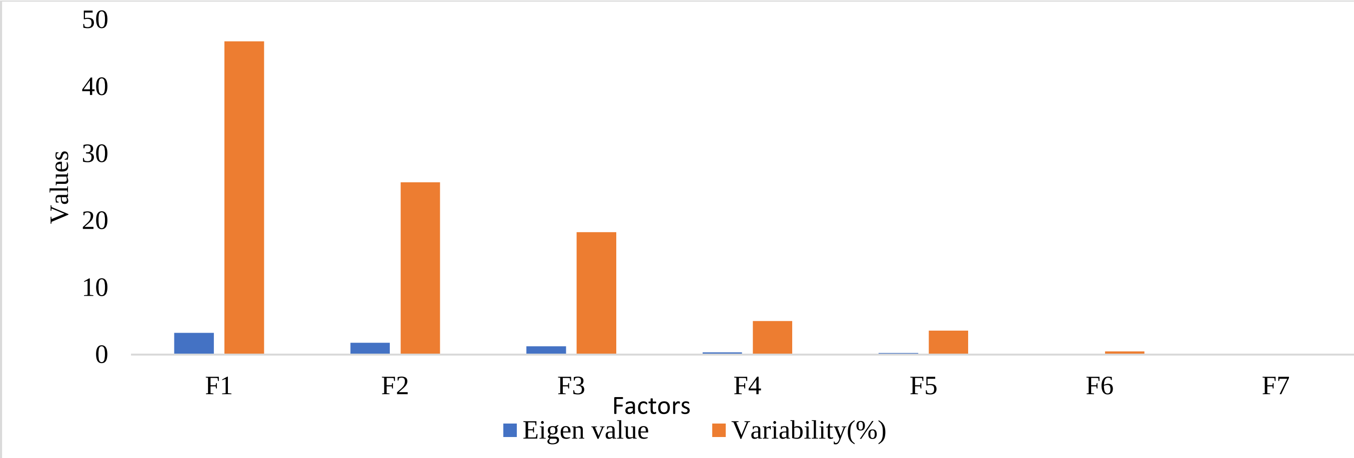


**Figure-2:** Contribution of eigenvalues among the factors.

**Table-4:** Factor loadings of water quality parameters.

| Variable | F1 | F2 | F3 |
|---|---|---|---|
| Temperature (·c) | -0.14 | -0.88 | -0.27 |
| pH | -0.56 | 0.44 | -0.56 |
| Conductivity | 0.97 | 0.14 | -0.15 |
| TDS (ppm) | 0.97 | 0.14 | -0.16 |
| Salt(ppm) | 0.95 | 0.16 | -0.17 |

Conductivity, TDS, and salt had a substantial positive factor loading in the F1 of PCs, while pH had a modest negative factor loading. This PC represented the indicators of organic pollution linked to human pollution sources. Organic acids are formed when high concentrations of organic effluents consume a lot of oxygen. Hydrolysis of these acidic compounds could also result in a decrease in water pH. Pollutants from adjacent sources, such as sewage, industrial waste, and brick kiln waste as solid waste, could increase conductivity and TDS.

The substantial contribution to F2 was temperature, while the moderate contributors were DO and ORP. Temperature had substantial negative factor loadings, whereas ORP (negative) and DO (positive) have moderate factor loadings, which might be attributed to the physical and chemical features of the water. This reveals that this PC is a proxy for seasonal fluctuations such as rain, agricultural activities, run-off with solid loads, and bank erosion.

The pH (negative), DO, and ORP (positive) factor loadings in the F3 of PCs were modest and were impacted by both seasonal variables and anthropogenic activities. The negative factor loading has shown that hydrolysis of acidic substances can lower water pH[20].

**Water Quality Index (WQI):** The water quality index is a tool for detecting overall water quality, and it can be characterised as a reflection of the combined impact of numerous water quality criteria. The general WQI scores varied from 45.04 to 83.79, with a mean of 69.74 indicating very poor (Table-1), respectively and were unfit for drinking. Pre-monsoon samples had a WQI of 48. 18 to 95.43, while post monsoon samples had a WQI of 33.36 to 80.32. The WQI reading 69.74 indicates that the water was unfit for drinking and household use[9]. It could be due to a combination of human-caused and natural events near the river. The physio-chemical features of water in the ecosystem may be modified by runoff from rice fields, home. urban, and industrial sewage, and other contaminants that collect in the river. So, to avoid water-borne infections, the water from this river must be treated before being use. The results reveals that the Hooghly River water quality is getting polluted due to pollution from various anthropogenic loads. The proper and urgent management measures are needed to combat the upcoming serious problems of the river pollution.

**Anthropogenic and Environmental Factors Influencing Water Quality Degradation in the Hooghly River:** The degradation of water quality in the Hooghly River is the result of a complex interaction between anthropogenic pressures and natural environmental processes, as evidenced by the physicochemical analysis and multivariate statistical techniques applied in the study. Rapid urbanization and industrial development along the riverbanks have significantly contributed to the deterioration of water quality[26]. The discharge of untreated domestic sewage increases the organic load in the river, leading to a decline in dissolved oxygen (DO) levels, which is critical for aquatic life. Industrial effluents further aggravate the situation by elevating parameters such as conductivity, total dissolved solids (TDS), and salinity, indicating a high concentration of dissolved ions. The strong positive relationship observed among conductivity, TDS, and salinity suggests that these parameters originate from common anthropogenic sources, including industrial discharge, municipal wastewater and urban runoff. Additionally, agricultural activities in the surrounding regions contribute to non-point source pollution through the runoff of fertilizers and pesticides, thereby altering the chemical composition of the river water[28].

Environmental factors also play a significant role in regulating water quality variations in the river. Seasonal changes, particularly between pre-monsoon and post-monsoon periods, influence parameters such as temperature, pH, and dissolved oxygen. Higher temperatures during the pre-monsoon season tend to reduce oxygen solubility, while post-monsoon conditions may dilute certain pollutants but simultaneously introduce additional dissolved and suspended materials through runoff. Hydrological dynamics, including river flow, tidal influence, and sediment transport, further affect the dispersion and concentration of pollutants. Natural processes such as erosion and sediment resuspension contribute to fluctuations in TDS and conductivity levels. Climatic factors, especially rainfall patterns, also influence the dilution and mobilization of contaminants within the river system.

**Management Strategies and Recommendations for Water Quality Improvement:** Effective management of water quality degradation in the Hooghly River requires a comprehensive and integrated approach that combines technological, regulatory, and community-based interventions. First, it is essential to ensure the proper treatment of domestic wastewater through the establishment and upgradation of sewage treatment plants, thereby preventing the direct discharge of untreated sewage into the river. Strict enforcement of environmental regulations for industries is equally important, including the mandatory installation and regular monitoring of effluent treatment plants to control the release of toxic substances[13]. Sustainable urban planning should be prioritized to minimize unregulated expansion along riverbanks, along with the development of efficient solid waste management systems to prevent dumping into the river.

In addition, agricultural practices need to be improved by promoting the use of eco-friendly fertilizers and pesticides and by creating vegetative buffer zones along the riverbanks to reduce runoff pollution. Continuous monitoring of water quality using advanced techniques such as multivariate statistical analysis can help in identifying pollution sources and tracking temporal variations effectively[9]. Furthermore, public awareness programs and community participation should be encouraged to foster a sense of responsibility towards river conservation. The adoption of these strategies will not only help in reducing pollution levels but also contribute to the long-term sustainability and ecological health of the Hooghly River system[17].

## Conclusion

The present study highlights the significant spatiotemporal variation in the water quality of the Hooghly River within the Kolkata metropolitan region, driven by the combined influence of climatic factors and anthropogenic activities. The analysis of physicochemical parameters reveals that water quality deteriorates notably in areas subjected to intense urban pressure, particularly near Babughat and Howrah Ferry Ghat, where domestic sewage discharge and human activities are more prominent. Seasonal assessment indicates that the pre-monsoon period is characterized by higher concentrations of dissolved substances due to reduced flow and increased evaporation, whereas the post-monsoon season shows partial improvement in water quality as a result of dilution effects from rainfall. However, the persistence of certain pollutants even after the monsoon suggests continuous input from anthropogenic sources[16]. The multivariate statistical techniques, including correlation analysis and Principal Component Analysis (PCA), effectively identified the key factors influencing water quality. The results demonstrate that parameters such as electrical conductivity, total dissolved solids, and temperature are primarily associated with anthropogenic inputs, while dissolved oxygen and pH reflect both natural processes and ecological responses[18].

Furthermore, the Water Quality Index (WQI) indicates that the overall water quality of the studied stretch ranges from moderate to poor, making it unsuitable for direct consumption without adequate treatment. The findings emphasize the urgent need for effective river management strategies, including proper waste disposal, regulation of industrial discharge, and continuous monitoring of water quality. In conclusion, this study provides a comprehensive understanding of the dynamic nature of river water quality and underscores the importance of integrating climatic and anthropogenic factors in river management and policy planning for sustainable water resource utilization.

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