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APPRAISAL OF HOOGHLY RIVER WATER QUALITY USING POLLUTION INDICES

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ABSTRACT

Water quality of Bhagirathi-Hooghly River is measured by the West Bengal Pollution Control Board (WBPCB) and the river is one of the significant drinking water sources for Kolkata Metropolitan Area (KMA). This paper made an attempt to investigate water qua lity of the river. Water quality data Collected from WBPCB for 2015-16 and 2018-19 across eight monitoring stations and analyzed in this study. Study reveals that pollutant loads from urban local bodies have shown stronger impact on the water environment. Water Quality Index (WQI) indicates that pollution of the Hooghly River increases during monsoon and post monsoon period while at summer it remains relatively low. BOD and total coliform count shows a strong correlation apart from pH and dissolved oxygen. The average pH of the river water ranges from 8 to 9 throughout the year. Total Dissolves Solids (TDS) and electrical conductivity also shows significant correlation. Principal Component Analysis (PCA) reveals that BOD, total coliform and turbidity varies together which is result of unregulated discharge of sewage water from urban local bodies (ULB) in the river.

Keywords: *Water Quality Index, Monsoon, Hooghly River, BOD*

INTRODUCTION

The nature of surface water is extremely sensitive issue and it is incredible ecological concern around the world. With the fast improvement of our economy and the speeding up of urbanization, pollution of river happened ceaselessly. Natural process as well as anthropogenic factors impacts on the degradation of surface waters and impede their utilization for drinking, industrial and agricultural purpose (Singh et. al, 2005).Huge amounts of domestic and industrial wastewater discharge directly into the river, which prompts the water system, become highly contaminated. In India to inspect, regulate and observe the water quality of different river Central Pollution Control Board (CPCB) was established in 1974 under the Water Act, 1974. In West Bengal water quality monitoring of water bodies are carried out by West Bengal Pollution Control Board (WBPCB).

Water quality of Bhagirathi-Hooghly River was widely surveyed by WBPCB in 2004 and 2007 on some points like Berhampur, Garden Reach and Diamond Harbor (WBPCB, 2009 and Bandyopadhyay et. al., 2014). Chakraborty and Gupta (2003) further examined the water quality of Hooghly River among Palta and Dhankheti *Khal* based on 6 limnological parameters[1]. Central Pollution Control Board (CPCB, 2013) likewise examined the diverse water quality parameters of river Bhagirathi-Hooghly and revealed satisfactory amount of average DO value (5 mg/l) at all inspecting stations for the time of 2006-2011. They further noted that high normal BOD levels (3 mg/l) at a few points' like–Howrah-Shivpur, Dakhineswar, Palta, Serampur, Uluberia, and Garden reach and Diamond harbor. BOD values of those previously mentioned locations show an increasing trend. A fluctuating pattern is watched for the fecal coliform value at all inspecting stations. They concluded that, the river water of Bhagirathi-Hooghly is contaminated in regard to various limnological parameters, contamination (both natural and inorganic) and coliform level through whole stretch of West Bengal. West Bengal Pollution Control Board (WBPCB), 2016 altogether checked the various limnological parameters of the river Bhagirathi-Hooghly at a few sampling stations. As per their review report, the DO values at all examining stations are consistently over the standard norms in both pre and post-monsoon months. This demonstrates the river water is appropriate to sustain the aquatic life. The BOD is found over level of consideration (i.e., 3.0 mg/l) at Berhampur, Palta and Garden reach during both pre and post-monsoon months; Dakshineswar during pre-monsoon months; Tribeni, Howrah-Shivpur and Diamond harbor during post-monsoon months. Total and fecal coliform level is discovered very high in both pre and post-monsoon seasons and it is viewed as that the river water can't use for drinking and recreational purpose. The investigation further uncovered that the micro-pollutant (trace metal, pesticides, heavy metals etc.) were very high in the river water of Bhagirathi-Hooghly.

The bathing standard for running water has been fixed by CPCB, India. As indicated by CPCB, the DO level of standard bathing water ought to be equivalent or over 5 mg/l, BOD value should not surpass 3 mg/l and the fecal coliform numbers ought to be under 500/100 ml of water. However, it is reported that not a solitary monitoring station of the river satisfies the washing guideline as the Total Coliform Counts (TCC) and Fecal Coliform Counts (FCC) esteems are exceptionally high in practically all the stations. A Broad investigation was also made by CSIR-NEERI (2014) in the three stretches of stream Ganga based on various physico-chemical parameters, Microbiological Parameters and heavy metals. Nath et.al., (2017)

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[1] The investigation of limnology incorporates aspects of the organic, chemical, physical, and topographical qualities and elements of inland waters (running and standing waters, fresh and saline, natural and man-made).

additionally examined nine limnological parameters of Hooghly waterway at four distinctive inspecting stations from September-2015 to March-2016 and recorded low DO levels, high alkalinity and turbidity from all the stations.

With this background, the present study aims to explore water quality of Hooghly River at 8 different monitoring stations and find out the relationships among the various parameters and their contribution in water pollution. Details of parameters and methodology are discussed in the following section. After introduction, second section explains the challenges come from urban local bodies located at the left and right bank of Hooghly River. Third section discusses the various programs formulated to improve the quality of water and fourth section elaborates about the methodology which includes study area data and methods. The following section analyzes the results and thereafter conclusion is drawn based on results.

The Key Issues Emerged Out from Cities on the Hooghly River

The study area is located within and beyond Kolkata Metropolitan Area (KMA).Within this metropolitan area four municipal corporation and 42 municipalities located[2]. The key issue originates from these urban areas include lack of sewage network, and Sewage Treatment Plant (STP). In fact it is reported that the 36 Class I cities located in Uttar Pradesh, Bihar and West Bengal alone contribute 96 percent of the wastewater in the Ganga River (Narain, 2014). More specifically it is reported that West Bengal treats just 49 percent of the waste water before dumping it in the Ganga, says an evaluation report on the contamination in the stream, conducted by the Central Pollution Control Board (CPCB) (Basu, 2015). The report expressed concern about inefficiency of STPs in West Bengal. It noted that West Bengal generates 1,311 million liters a day (MLD) of waste water but 34 STPs treats only 214 million liters a day[3]. The reason behind such low treatment of wastewater is due to dysfunctional STPs (Basu, 2015). Following table 1 shows the sewage generation and treatment capacity of some class I urban local bodies under KMA.

An overview of the table 1 reveals that in most of the cases class I ULBs do not have a sewage treatment plant and in some city it exists but it has lower capacity to treat waste water. Therefore it suggests that untreated waste water directly discharge into the Hooghly River. It also reported that some of the STPs are underutilized and inefficient even though its capacity to treat waste water surpasses the generated wastewater. Furthermore the highest number of point sources was identified in West Bengal as 54 in number.

Though very little has been emphasized on establishing sewage treatment plant in various plans and priority is given to the cleaning of Ganga. Most cities along the Ganga do not have sewage network system. Due to this reason drains are not connected to sewage treatment plant. Hence the existing open drains directly discharge to the river. In any case, the appropriate responses are not simply forming new sewage treatment plants but prepare a comprehensive plan to tackle urban wastes.

Apart from drainage and sewage problem of these cities, the other important source of pollution in the River Hooghly is the industrial wastes. Many small scale industries discharge noxious chemical pollutants into the river. Following table 2 shows the hazardous waste generation within KMA.

There are two selected sites for common disposal of developed and generated hazardous waste of entire KMA are Dankuni in Hooghly district and Haldia in Purba Mednipur District[4]. These two sites are operated since 2005. Though, the Hazardous Waste rule came into force in 1989 with 18 categories. After the amendment of 2003, government introduced three schedules of hazardous wastes. However, it is reported that at the landfill sites of ULBs there is no practice of waste segregation, so metals like zinc, nickel, lead and arsenic often get dumped in those sites and leach into the soil which contaminate the ground water as well as nearest canals (TOI, 2013).

Table: 1 Status of Sewage Generation and Treatment Capacity

City	Sewage Generation MLD	Treatment MLD	City	Sewage Generation MLD	Treatment MLD
Kolkata	618	172	Halisahar	16.8	NT
South Dumdum	53	NT	North Barrackpore	19.2	16.7
RajpurSonarpur	33	45.4	Rishra	13.5	15.3
Kamarhati	48.8	40	Howrah	136.2	63.9
North Dumdum	29.7	NT	Bhatpara	59.57	28.5
Naihati	20.5	NT	Mahestala	52.5	3.9
Uluberia	27.3	NT	Serampore	26.7	18.9
Kanchrapara	17	NT	Chandannagar	16.1	22.7

Source: Pollution Assessment: River Ganga-Central Pollution Control Board, 2013, NT: No Treatment

[2] Most of the municipalities are class I cities whose population is more than one lakh

[3] Of 1,311 MLD of waste water, 47 per cent is generated by Kolkata alone

[4] Both Dankuni and Haldia are located close to the Hooghly River and these places have direct as well as indirect impact on the quality of the river water in various ways. Moreover these places are located within sample site ambit.

Table: 2 Hazardous Waste Generations in KMA 2010-11

Districts	Hazardous Waste Generating Units	Disposable	Recyclable	Incinerable	Total (MTA)
Nadia	15	696.877	254.854	387.221	1338.952
Hooghly	63	3373.767	4971.749	347.797	8693.313
Howrah	175	3765.548	7513.346	456.91	11735.804
North 24 Parganas	109	954.984	12931.743	104.884	13991.611
South 24 Parganas	91	24941.433	1332.949	52.819	26327.302
Kolkata	173	1707.683	1395.968	481.477	3585.128

Source: West Bengal Pollution Control Board, 2010-11, MTA- Metric ton per annum

Programs to Clean and Enhance the Quality of Water

The Central Pollution Control Board (CPCB), which is India's national body for checking natural contamination, embraced an exhaustive scientific survey in 1981-82 so as to characterize waterway waters as indicated by their assigned best uses. This report was the first efficient record that shaped the premise of the Ganga Action Plan (GAP). It detailed land-use examples, residential and industrial pollution loads, manure and pesticide use, hydrological viewpoints and river classifications. This stock of contamination was utilized by the Department of Environment in 1984 while planning a strategy report. Understanding the requirement for earnest intercession the Central Ganga Authority (CGA) was set up in 1985 under the chairmanship of the Prime Minister (Sharma, 1997).

The Ganga Project Directorate (GPD) was built up in June 1985 as a national body working inside the National Ministry of Environment and Forest. The GPD was expected to fill in as the secretariat to the CGA and furthermore as the Apex Nodal Agency for execution. It was set up to co-ordinate the various services included and to regulate assets for this 100 percent centrally-sponsored plan. The program was seen as a once-off speculation giving self-evident impacts on river water quality. The GPD was to remain set up until the GAP was completed. The arrangement was officially propelled on 14 June 1986. The central purpose was to catch and divert the wastes from urban settlements away from the river. Treatment and affordable utilization of waste, as a method for helping resource recovery, were made a basic piece of the arrangement (Sharma, 1997). It was understood that exhaustive co-ordinated exploration would need to be led on the following aspects of the Ganga:

- The sources and nature of the contamination.
- A more rational arrangement for the utilization of the assets of the Ganga for farming, animal husbandry, fisheries, woods, and so on.
- The demographic, social and human settlements on the banks of the stream.
- The conceivable restoration of the inland water transport facilities of the Ganga, along with the feeders and distributaries

Formulation of GAP was only the first step in river water quality management. Its mandate was limited to quick and effective, but sustainable, interventions to contain the damage. The studies conducted by the CPCB in 1981-82 showed that pollution of the Ganga was increasing but had not assumed serious proportions, except at certain main towns on the river such as industrial Kanpur and Calcutta on the Hooghly, together with a few other towns.

The GAP was just the initial phase in river water quality management. Its directive was constrained to fast and powerful, yet sustainable, intercessions to contain the harm. The investigations did by the CPCB in 1981-82 uncovered that contamination of the Ganga was expanding however had not expected genuine extents, aside from at certain primary towns on the waterway, for example, mechanical Kanpur and Calcutta on the Hooghly, along with a couple of different towns.

The central purpose of the arrangement was focused to control all civil and modern wastes. All conceivable point and non-point source of contamination were recognized. The control of point source of urban city wastes for the 25 Class I towns on the main river was started from the 100 percent centrally contributed venture funds. The control of urban non-point sources was likewise handled by direct mediations from central funds. The control of non-point source farming run-off was attempted in a staged way by the Ministry of Agriculture, chiefly by lessening utilization of manure and pesticides. The control of point sources of modern wastes was finished by applying the polluter-pays-rule (Chaudhury and Walker, 2019).

In 1987, targets were adjusted to re-establishing stream water quality to the less severe class B "Washing Class" principles (NRCD, 2009)[5]. Studies directed by CPCB

[5] Both Dankuni and Haldia are located close to the Hooghly River and these places have direct as well as indirect impact on the quality of the

demonstrated that most contamination in the stream is gotten from city squander and mechanical emanating. Accordingly, priority was moved to capture attempt and redirection of wastewater and its treatment in STP (IIT-Consortium, 2011).

In 2009, GOI building on lessons from the past disappointment in GAP took a more far reaching, basin-wide and multi-sectoral approach and established the National Ganga River Basin Authority (NGRBA) under Section (3) of the Environment (Protection Act, 1986). The NGRBA is an arranging, financing, observing and organizing body of the union and state government. In 2010, the Ministry of Environment and Forests gave the duty of setting up a Ganga River Basin Management Plan (GRBMP) to a consortium of seven Indian Institute of Technology (IITs) to make monitoring plan for a long-term commitment for a drawn out responsibility (IIT-Consortium, 2015). The primary objective of NGRBA was to make sure effective pollution abatement and conservation of river by adopting a well-planned methodology of river basin management plan. NGRBA has been disintegrated in 2016 and is presently called the National Council for Rejuvenation, Protection, and Management of River Ganga.

In 2014, Government of India declared one of its most aspiring plans called *Namami Ganges Mission* (NGM), otherwise called the "*Namami Gange*", for tidying up Ganga with a financial plan of more than $3 billion USD. The goal is to improve the quality of Ganga with consistent and unpolluted flow while keeping up its ecological and geological integrity by 2020. To accomplish long haul objectives, programs in NGM depend on suggestions of GRBMP. Moreover, usage of NGM is partitioned into Entry-Level Activities (for sure fire noticeable effect), Medium-Term Activities (to be executed inside five years of time span) and Long-Term Activities (to be actualized inside 10years) (Ministry of Water Resources, 2016).

The fundamental exercises proposed under NGM are: 1) development of sewage treatment plants with expanded limit; 2) riverfront improvement programs for development, modernization, and redesign of crematories; 3) biodiversity preservation and afforestation along waterway banks; 4) public awareness program; and 5) industrial effluent checking through establishment of ongoing water quality observing stations. Additionally, public private program model for development of common effluent treatment plants (CETPs) and zero liquid discharge policy from contaminating enterprises has likewise been adopted to control industrial pollution (Ministry of Water Resources, 2016).

river water in various ways. Moreover these places are located within sample site ambit.

METHODOLOGY

Details of the methodology are discussed in the following different sub-section.

Site of the Study

Water quality of river Hooghly is being observed at different areas and surveyed contingent on the Physico-chemical and bacterial parameters (includes BOD, COD, DO, temperature, pH, complete coliforms, and faecal coliforms and so on.). Central Pollution Control Board (CPCB) is commanded with the duty of undertaking nonstop Real Time Water Quality Monitoring (RTWQM) of River Ganga at 36 locations[5]. Bhagirathi-Hooghly River is one of the main distributaries of the Ganga River and traverses a distance 507 km in West Bengal before debouching Bay of Bengal. The lower reach of the Bhagirathi below Swarupganj is known as Hooghly. It flows for about 282 km and within this stretch maximum number of urban population is concentrated in West Bengal.

West Bengal State Pollution Control Board (WBSPCB) is monitoring the water quality of the Ganga and its tributaries at 14 locations under National River Water Monitoring Programme (NWMP). For the purpose of the study we choose eight water quality monitoring stations of Hooghly River and it stretched from Tribeni to Diamond Harbour. These are the final eight water quality measuring stations located near the Bay of Bengal. These sites remain relevant for the study because it encompass Kolkata Metropolitan Area and its immediate surroundings. Moreover it has 43 urban local bodies consist the Kolkata urban agglomeration. All these urban local bodies have direct influence on the water quality of the Hooghly River.

Table: 3 Water Quality Monitoring Stations

Stations	Districts
Tribeni	Hooghly
Palta	North 24 Parganas
Serampur	Hooghly
Dakshineswar	Kolkata
Garden reach	Kolkata
Howrah-Shibpur	Howrah
Uluberia	Howrah
Diamond Harbour	South 24 Parganas

Source: WBPCB, 2019

The board monitors the water quality monthly basis. Water quality monitoring was done at 14 locations of the river Ganga from Murshidabad to Diamond Harbour during the year 2018-2019. The activity has been performed since 1980s with additions some new water quality monitoring stations in between.

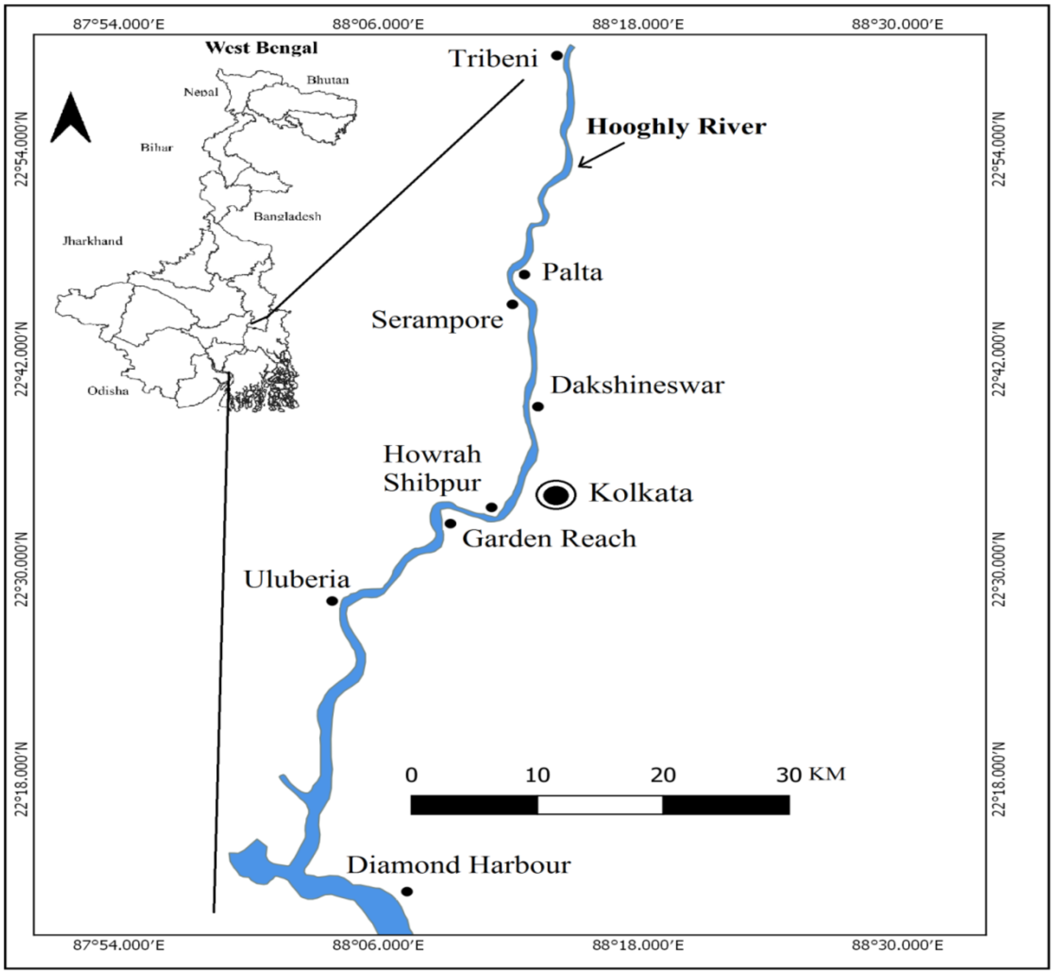


Fig. 1: Water Quality Monitoring Stations in Hooghly River

The distance between the northern and southern water quality monitoring station is more than 100 km apart. Except Diamond Harbour all other water quality monitoring stations is located within the Kolkata Metropolitan Area (KMA). It is worthwhile to note here that Palta is one of the eight water quality monitoring stations situated along the right bank of Hooghly River from where the drinking water is supplied to the city of Kolkata.

Data and Methods

To assess the water quality of the Hooghly River temporal data of 2015-16 and 2018-19 has been used for the study. Seven parameters of water quality have been taken into consideration for analysis. Following table 4 shows the details of parameters and their standard and ideal values.

It is important to note that West Bengal Pollution Control Board measures 25 to 50 parameters of water quality at each station. All the idea values are taken as zero for the drinking water except for pH and DO.

To measure the water quality weighted arithmetic Water Quality Index (WQI)[6] method used and it is characterized the water quality as indicated by the level of purity by

Table: 4 Water quality parameters

Parameters	Units	Standard Value	Ideal Value
pH	pH units	6.5-8.5	7
Biochemical Oxygen Demand (BOD)	mg/l	3	0
Dissolved Oxygen (DO)	mg/l	5	14.6
Total Dissolved Solids (TDS)	mg/l	500	0
Turbidity	NTU	5	0
Total Coliform (TC)	MNP/100 mL	500	0
Electrical Conductivity (EC)	µS/cm	300	0

Source: West Bengal Pollution Control Board utilizing the most generally measured water quality factors. Moreover WQI is constructed for three different seasons i.e. summer, monsoon and post monsoon. The strategy has been broadly utilized by the different researchers (Rao et al. 2010; Chauhan and Singh, 2010).The calculation of WQI was prepared by using the following equation

WOI=∑QiWi/∑Wi……………… (I)

The quality rating scale (Qi) for each parameter is calculated by using this expression

Qi= 100[(Vi-Vo/ Si-Vo)]…………………… (II)

Where, Vi is the estimated concentration of ith parameter in the analyzed water

Vo is the ideal value of this parameter in pure water Vo = 0 (except pH =7.0 and DO = 14.6 mg/l) Si is recommended standard value of ith parameter

The unit weight (Wi) for each water quality parameter is calculated by using the following formula.

Wi = I/ Si…………………… (III)

Where, Wi = Relative (unit) weight for nth parameter, Si= Standard permissible value for nth parameter, I = Proportionality constant.

That means, the Relative (unit) weight (WI) to various water Quality parameters are inversely proportional to the recommended standards for the corresponding parameters[7].

The rating of water quality according to this WQI is given in the following table 3

Table: 5 Water Quality Index (WQI)

WQI	Rating of Water Quality	Grading
Below 50	Excellent	A
50-100	Good water	B
100-200	Poor water	C
200-300	Very poor (bad) water	D
Above 300	Unsuitable (unfit) for drinking	E

After calculating WOI, water quality parameters have been correlated with each other. Parameter of the multivariate correlations is given to table 8 and 9. Long term surveys and monitoring programs of water quality are a sufficient way to deal with information on river hydrochemistry and contamination, yet they produce enormous sets of data which are frequently hard to decipher (Dixon and Chiswel, 1996).The issue of data decrease and understanding of multi-constituents chemical and physical estimations can be drawn closer through the use of multivariate statistical analysis (Massart et al., 1983; Wenning and Erickson, 1994).Number of papers demonstrates the significance of multivariate analysis in the treatment of explanatory and environmental information (Brown et al., 1994, 1996). Principal Component Analysis (PCA) can be utilized for dimensionality decrease in data set by holding those characteristics of the data set that contribute most to its difference, by keeping lower order principal components and disregarding higher order ones. It is extremely helpful in the investigation of data corresponding to large number of variables. It has been broadly utilized as they are fair techniques which can demonstrate relationship among samples and variables (Wenning and Erickson, 1994). It is utilized to diminish the dimensionality of the data set by clarifying the correlation among a large set of variables in terms of a principal components without losing much information. As of late, numerous investigations have been finished utilizing principal component analysis in the analysis of water quality parameters (Lohani, 1984).

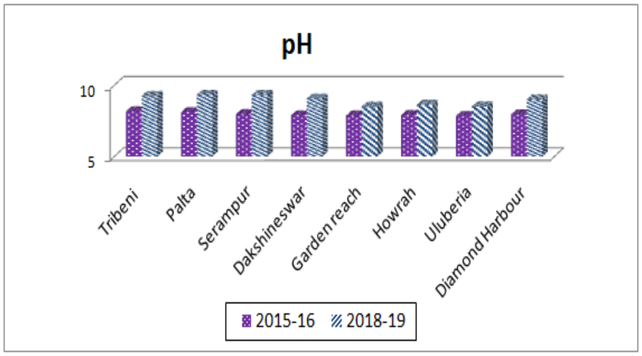
Reisenhofer et al. (1998) noticed that the PCA supports the results of multivariate cluster analysis, which confirms the separating ability of the considered parameters of the Timavo River. Ceballos et al. (1998) sums up that PCA shows water typology defied by 9 factors, gathered in two principal components for three lakes, situated in upper east Brazil. Morales et al. (1999) investigates the nature of beach front water in the Gulf of Valencia (Spain) by factor analysis. Mishra (2008) also performs PCA to analyze the water quality in the upper course of Ganga River. Therefore, the PCA is one of the most impressive and normal methods utilized for decreasing the dimensionality of enormous datasets without loss of data (Vega et al., 1998; Gómez, 1999; Helena et al., 2000; Pesce and Wunderlin, 2000).

Results and Discussion of the Water Quality of Hooghly River

To assess the water quality of the Hooghly River seven parameters have been taken into consideration from eight different stations located from Tribeni to Diamond Harbour. From the analysis it shows that pH is highest (9.26) at Diamond Harbour while it is lowest at Garden Reach (7.82). In fact average pH of the each station remains above 8 throughout the 2018-19. Though the pH for almost all station was ranges from 7.85 to 8.18 in 2015-16. It is also important to note that pH increases in all stations over the last few years. Fluctuation of pH is less in Serampore and maximum at Diamond Harbour and Palta. Likewise BOD is found maximum (10.1) as well as minimum (0.7) at Serampore in 2018-19. The highest (4.84) average BOD is found at Dakshineswar. BOD fluctuates less (CV 22.73) at Garden Reach while fluctuates maximum (CV 65.42) at Serampore in 2018-19. This is because of untreated wastewater of Serampore and its neighbouring ULBs directly throw into the river unlike KMC[8].

[7] Since relative weight to various water quality parameters are inversely proportional to the recommended standards for corresponding parameters, it is expressed as for example in case of pH relative weight is 1/8.5= 0.1176, BOD (0.33), DO and Turbidity (0.2), TC and TDS (0.002), EC (0.0033)

[8] KMC or Kolkata Municipal Corporation does not throw its wastewater into the Hooghly river rather the waste water is treated through East Kolkata Wetland and ultimately throws into the river Bidyadhari located in West.



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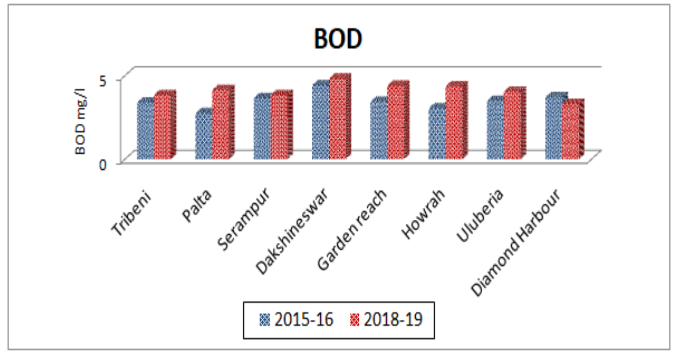

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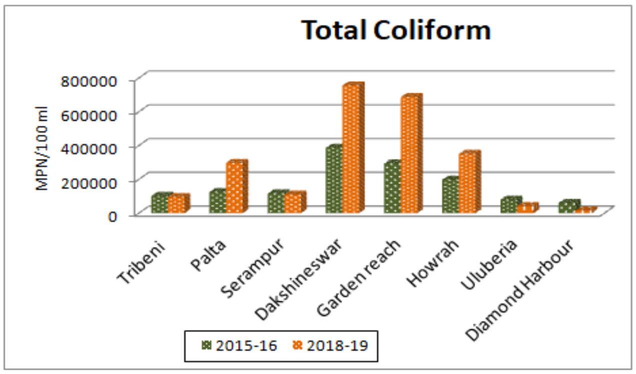

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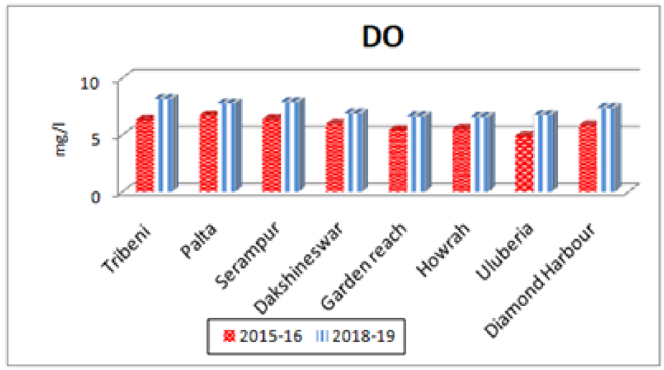

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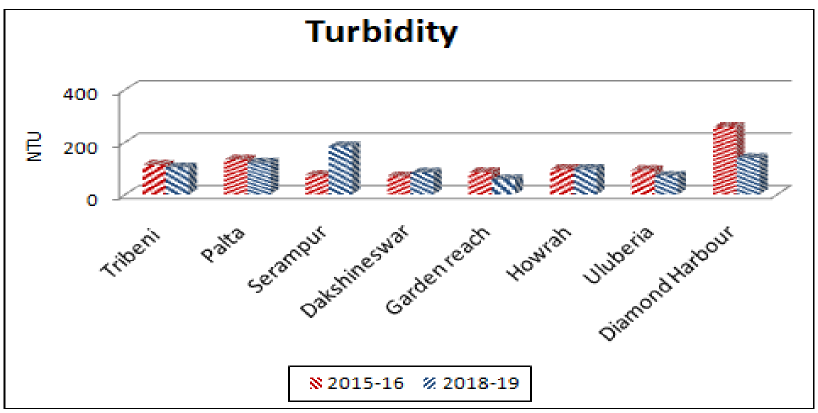

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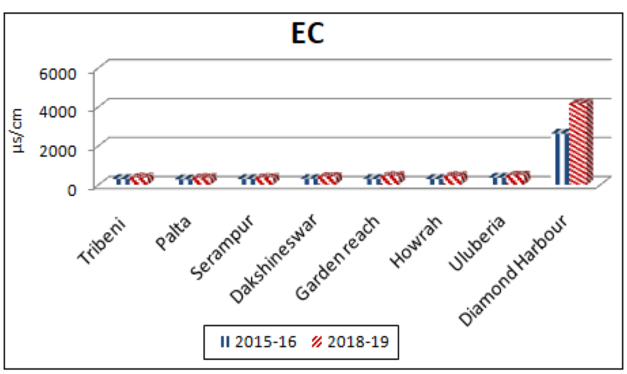

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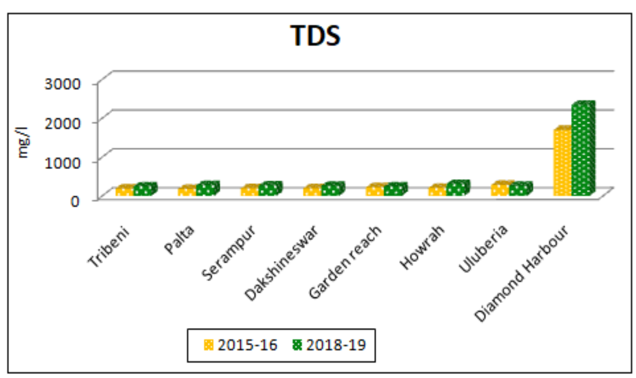

Fig. 7

Dissolved Oxygen is found highest (9.7) at Tribeni in 2018-19. DO value increases at all the station from 2015-16 to 2018-19. Moreover DO values are less in those stations situated close to the Kolkata, while it increases away from Kolkata. Similarly total coliform is also found highest (1600000) in Dakshineswar and Garden Reach both stations are close to Kolkata. This is due to discharge of untreated sewage water from ULBs and industries located near Kolkata. On the other hand Total Dissolve Solids (TDS) (5910) and Electric Conductivity (EC) (9515) and turbidity (201) are found maximum at Diamond Harbour located at extreme south of Hooghly River. Moreover, it is noticeable that each of the parameters highly fluctuates at Diamond Harbour compare to others stations. One of the significant reasons for this is the discharge of sediment loaded water from Rupnarayan River to the Hooghly River. Rupnarayan is a tributary of Hooghly River and the river meets Hooghly few Kilometers away from Diamond Harbour.

To understand the overall water quality weighted arithmetic water quality index is formulated for three different seasons and for two different time periods i.e. 2015-16 and 2018-19.

Water quality index confirms that none of the stations water quality is good for bathing. However the water quality index is not uniform across all the spatial and temporal scale. WQI reveals that water quality remains relatively good in summer and became poor in the monsoon season. In summer 2018-19, water quality of Tribeni (WQI range from 232 to 837) remains relatively good compare to other stations. During monsoon water quality also remains good at Tribeni while WQI at Serampore remains poor at the same time. WQI is remaining good at Uluberia (170) during post monsoon while it is found poor in Serampore (911). Water quality at Tribeni remains good due to absence of industry and presence of vast stretch of agricultural land. In case of Serampore, huge volume of untreated water discharge into the river from several industries and ULBs.

If we exclude the turbidity parameter then the WQI value drops sharply and reflects different water quality scenario of the river altogether. It suggests that at this stretch river water carries huge amount sand, silt and clay particle and that reflects through its turbidity value. Moreover it reveals that throughout the year water quality remains good at Diamond Harbour (WQI range 93 to 98) followed Uluberia (WQI ranges 92 to 121) and Tribeni (WQI ranges 122 to 163) and these stations are far from Kolkata. On the other hand, water quality remains highly poor in Dakshineswar (495) and Garden Reach (547) located within and near to Kolkata. Therefore, turbidity plays crucial role in the quality of water in the river.

Likewise, WQI of 2015-16 reveals that water quality of all the stations remain poor throughout the year. Water quality at Diamond Harbour (WQI 1980) is the poorest among all the stations throughout the year. While water quality in Uluberia (595) remains relatively less poor in monsoon and post monsoon. It is because of Uluberia located at the southern most part of KMA and thereafter vast rural area begins. At summer water quality is remain less poor in Howrah compare to rest of the stations. Nonetheless water quality remains more or less poor in all monitoring stations.

Following WQI a multiple correlation is drawn to understand the relationship among the parameters. The result of correlation matrix for the data set is shown in

Table 6 : Water Quality Index (WQI) 2018-19

Stations	Summer	Monsoon	Post Monsoon
Tribeni	282.89 (125.79)	411.91 (163.37)	837.44 (122.72)
Palta	407.10 (230.02)	700.59 (261.02)	835.31 (197.42)
Serampur	667.34 (161.46)	911.79 (134.60)	871.08 (122.53)
Dakshineswar	626.12 (495.70)	834.39 (449.14)	529.28 (486.02)
Garden reach	515.02 (547.89)	746.92 (471.81)	370.15 (280.43)
Howrah	464.18 (248.40)	732.84 (174.41)	507.02 (342.22)
Uluberia	271.97 (119.30)	587.68 (121.39)	170.43 (92.04)
Diamond Harbour	621.30 (95.34)	674.18 (98.22)	613.33 (93.02)

Source: Calculated by author, 2020, Note: parentheses figures excludes turbidity parameter in WQI

Table 7: Water Quality Index (WQI) 2015-16

Stations	Summer	Monsoon	Post Monsoon
Tribeni	469.26 (184.98)	1005.90 (133.04)	457.08 (162.57)
Palta	506.96 (180.81)	1220.19 (153.28)	495.60 (152.49)
Serampur	354.34 (183.40)	668.46 (187.37)	406.55 (143.33)
Dakshineswar	528.51 (335.44)	816.04 (454.83)	424.30 (255.48)
Garden reach	458.39 (225.49)	885.37 (401.38)	480.06 (204.54)
Howrah	424.19 (139.89)	866.88 (241.62)	550.66 (254.66)
Uluberia	715.22 (150.37)	595.16 (181.28)	337.22 (117.04)
Diamond Harbour	1980.35 (133.32)	1294.56 (185.54)	652.06 (114.80)

Source: Calculated by author, 2020

Note: parentheses figures excludes turbidity parameter in WQI

Table 8, where some clear hydro-chemical relationships can be readily inferred. Following table 8 shows that pH has a highly positive relationship with dissolved oxygen (r=0.88) and turbidity (r=0.71). It means increase pH of river water increases the DO and turbidity of the water. Likewise BOD has positive relationship with total coliform (r=0.87); it means greater BOD can generates more coliform bacteria in water and it may accelerate the stress of aquatic life since it reduce the DO in water.

Similar correlation is drawn with 2015-16 data and it shows pH has highly positive correlation with dissolved oxygen (r=0.82). Electric conductivity has strong positive correlation with TDS (r= 0.99) and Turbidity (r=0.99). Moreover, TDS has perfect positive correlation with turbidity (r= 1.00) of the water. It is responsible for contamination of insoluble inorganic matter. It is probable that the toxicity of heavy metals in Hooghly River has not endangered to aquatics yet, because of weak correlation with the microbial related variables.

Three PCs are extracted, together explaining more than 93% of the variance of information contained in the original data. Table 9 and 10 summaries the PCA results including the loadings exceeded 0.1 and the eigenvalue of each PC. PC 1 explains 55% of the variance and is mainly contributed by TC, BOD, and DO. Principal Component 2 explains 28% of the variance and is mainly contributed by pH, DO, TDS and EC.

The first principal component is strongly correlated with three of the original variables. The first principal component positively correlates with increasing turbidity but show negative contribution to BOD and TC scores. This suggests that these three criteria vary together. If turbidity increases, then the remaining two variables BOD and TC tend to decrease as well. This component can be viewed as water quality of river deteriorated with high turbidity but low BOD and TC. This is explained by the higher BOD value, the greater the amount of organic matter or "food" available for oxygen consuming bacteria. If the rate of DO consumption by bacteria exceeds the supply of DO from

Table 8 : Multiple Correlation of Water Quality Parameters in 2018-19

parameters	**pH**	**BOD**	**DO**	**TC**	**TDS**	**Turbidity**	**EC**
pH	1						
BOD	-0.272	1					
DO	**0.8859***	-0.5343	1				
TC	-0.241	**0.8702***	-0.5135	1			
TDS	0.0643	-0.6969	0.0695	-0.3926	1		
Turbidity	**0.7170***	-0.587	0.6726	-0.5371	0.3206	1	
EC	0.0342	-0.6895	0.0462	-0.3827	**0.9991***	0.2911	1

Source: Calculated by author, 2020 * significant at 0.05 percent level

On the other hand, TDS has positive relationship with EC (r=0.99) of the water; it suggests that greater the TDS higher will be electric conductivity in the river.

Table 9 : Multiple Correlation of Water Quality Parameters in 2015-16

parameters	**BOD**	**DO**	**FC**	**TC**	**pH**	**TDS**	**Turbidity**	**EC**
BOD	1							
DO	-0.1525	1						
FC	0.658	0.1096	1					
TC	0.4693	-0.1039	**0.9009***	1				
pH	-0.401	**0.8258***	-0.2145	-0.385	1			
TDS	0.192	-0.0801	-0.3194	-0.3957	-0.0997	1		
Turbidity	0.192	-0.0801	-0.3195	-0.3957	-0.0997	**1.0000***	1	
EC	0.1946	-0.0548	-0.3105	-0.3927	-0.0804	**0.9996***	**0.9996***	1

Source: Calculated by author, 2020, * significant at 0.05 percent level

Table: 10 Variance Explained by Principal Components

Component	**Eigen Values**	**Variance**	**Cumulative Variance**
Component 1	3.86	0.55	0.55
Component 2	1.99	0.28	0.83
Component 3	0.75	0.10	0.93

Source: Calculated by author, 2020

Table: 11 Correlations between Principal Component and Original Variables

Variable	Component 1	Component 2
pH	0.303	0.490
BOD	-0.466	0.164
DO	0.361	0.452
TC	-0.400	0.027
TDS	0.347	-0.471
Turbidity	0.404	0.255
EC	0.337	-0.487

Source: Calculated by author, 2020

aquatic plants, algae photosynthesis or diffusing from air, unfavourable conditions occur. Depletion of DO causes stress on aquatic organisms, making the environment unsuitable for life. BOD is also used extensively for wastewater treatment, as decomposition of organic waste by microorganisms is commonly used for treatment. The second principal component increases with four of the values, with increase pH and DO but with decrease TDS and EC. This component can be viewed as a measure of how quality of water varies with sewage and hazardous waste discharge.

CONCLUSIONS

The paper made an attempt to revisit the water quality of Hooghly River and tried to find out the various factors that plays crucial role in maintaining the water quality. Study reveals that water quality fluctuates across the spatial and temporal scale in the river. During summer water quality remains relatively better than monsoon and post monsoon period. Water Quality Index (WQI) shows that Uluberia and Tribeni have relatively better water quality compare to other monitoring stations. Presence of Turbidity in the river water is a significant component that increases the pollution level much higher. PCA reveals that apart from turbidity nutrient factors (BOD and DO) and sewage and industrial waste water increase the level of pollution in the water.

Paper also throws light on trajectories of various programs introduced to clean water of Hooghly since 1990s. It is evident from the discussion that even after several programs and steps authority fails to control and regulate the pollution in the river. One of the significant reasons behind the uncontrollable pollution in the river is the lack of sewage and drainage facilities in the ULBs located along the bank of Hooghly. So to clean and maintain good quality of river water, it is imperative to build sewage and drainage network as well as make alternative network for small industries waste discharge.

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