RESEARCH ARTICLE

DOI: 10.34256/ijceae2225

International Journal of Civil, Environmental and Agricultural Engineering

Development of Canadian Water Quality Index (WQI) of Vidhyadhari, an Estuarine River in Eastern India

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Received : 23-06-2022, Revised: 04-09-2022, Accepted : 07-09-2022, Published: 27-12-2022

Abstract: Surface water represents one of the most utilized sources for water distribution systems globally, despite the fact that rapid urbanization and industrialization has reduced its cleanliness. As a result, the end-user's health is seriously impacted by the dirty water. Nevertheless, it is clear that many developing nations, including India, pay little regard to or care about this crucial issue. The Vidhyadhari River has become a receiver of high organic and bacteriological load of entire Kolkata City through Basanti canal. As a result, the purpose of this investigation is to evaluate how rapid urbanization and industrialization has changed the water quality of Vidhyadhari River using Canadian Water Quality Index (WQI). We have used seasonal water quality data collected at two monitoring stations (Haroa bridge and Malancha) from 2011 to 2020 to study the water quality of Vidhyadhari River. Results of the study indicated that the annual WQI value of Haroa brigde ranged between 21.62 (very bad) and 62.89 (medium) with an average of 27.29 (bad), whereas annual WQI value of Malancha station ranged between 15.44 (very bad) and 43.09 (bad) with an average of 18.77 (very bad). In comparison to downward location, the water quality of Vidhyadhari River was somehow good at upstream i.e., Haroa brigde. According to WQI, the water quality of Vidhyadhari River fall into bad to very bad category, which indicated deterioration of river water quality. Factor analysis revealed that both stations are predominated by hardness cluster (hardness, calcium, magnesium and chloride) followed by cluster of total dissolved solids (TDS), sulphate and ammonia. Sewer, excessive human activity, industrial discharges, poor sanitation, and urban runoff outflow can be extrapolated as the main causes for the deterioration of Vidhyadhari River water quality. This study emphasized the significance of implementing measurement

actions, introduction of watershed characteristics and implications for developing water management strategies.

Keywords: Water Quality Index; Vidhyadhari River; Water quality parameters; Haroa brigde; Factor analysis

1. Introduction

Geomorphology of a region shapes river course. With time natural hazards like earthquake and flood change the source of water volume. A river at its final stretch before joining the sea follows a meander path and forms a constantly reducing slope of river bed resulting in deposition of silt and mud. The effect is quite pronounced since the tidal current associated with flood and ebb tides also differ in magnitude. Worldwide the urban agglomerations that form near the mouth of the rivers have to adapt according to the change in fluvial dynamics. Situated at the interface between fresh- and marine waters, estuaries are among the most biologically productive ecosystems in the world and are of great ecological and economic importance [1-3]. Yet, these water bodies are becoming some of the world's most threatened habitats [4] and face degradation due to human induced alterations to their dynamic variability [5-7]. Kolkata, the clustering of more than 10million people although famously known as being situated at the east bank of River Ganges, a well-developed network of drains and rivulets help in releasing its sewage and domestic discharges through the eastern side of the city. The natural slope of the city is towards the east, opposite to river Ganges, and offers the opportunity to discharge liquid waste, after being naturally treated with partial reduction in organic load at East Kolkata Wetland, a unique RAMSAR site, to river Vidyadhari, a creek draining into Bay of Bengal. Vidhyadhari, once a major river with the history of Chandraketugarh civilization booming at its bank [8], over the years lost its connection with fresh water sources and has become a sewage canal with high organic and bacteriological load.

Being a part of Sundarban Estuarine System (SES), the largest monsoonal, macro-tidal, delta-front, estuarine system in India, Vidhyadhari has been studied with other estuaries for interpreting variations for tidal, current and mixing feature prevailing in the estuary [9, 10] and salinity variations through tides, seasons and spaces [11]. However, comprehensive water quality characterization for different pollutants has never been scrutinized till date. Water Quality index (WQI) is a comparative tool to evaluate the efforts made to ameliorate the water quality and not really a tool to evaluate water quality absolutely. Over the years, rivers of different countries with different flow patterns and basin usage characteristics have been assessed by WQI that categorizes the water quality with end use-based classification [12-16].

The apex body of pollution control in India recently has come up with a detailed framework for assessing different polluted stretches of rivers in the country based on priority class. The 23 km stretch of river Vidhyadhari (from Haroa [22.602740°N & 88.676025°E] to Malancha burning Ghat, [22.504260°N & 88.781424°E]; (Figure. 1) has been categorized as

Priority class I (Central Pollution Control Board, 2018) with immediate implementation of rejuvenation plan [17].

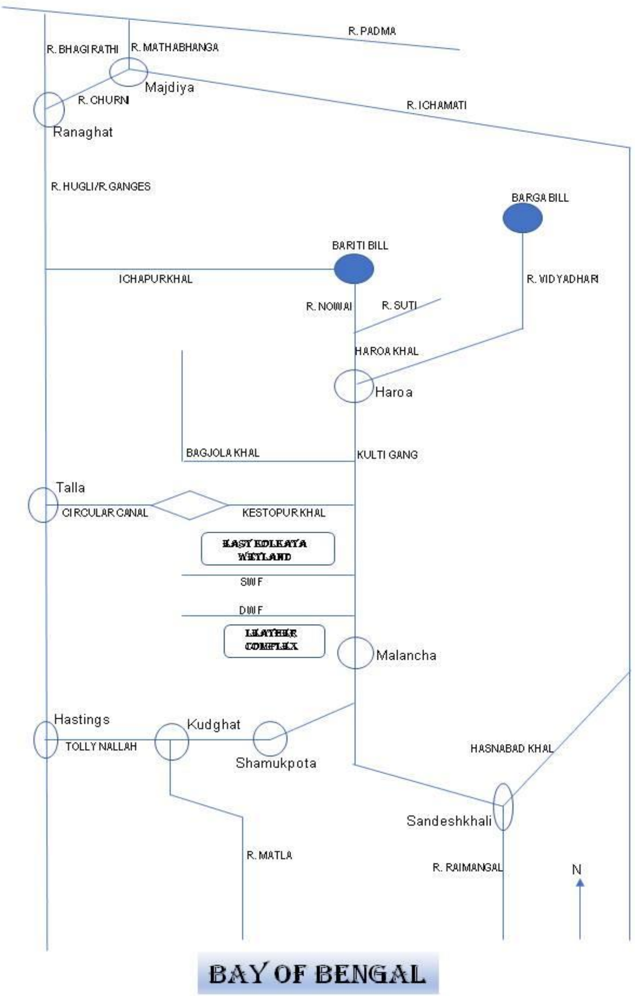

Figure 1. Course of River Vidhyadhari

In between Haroa and Malancha, Bagjola Khal (draining five densely populated municipalities), Kestopur Khal, Storm water flow (SWF) and Dry weather flow (DWF) channel (Figure. 2) discharge liquid waste from different pumping stations across Kolkata Municipal area (KMC). With this background the current study aims to calculate water quality index of these two locations on River Vidhyadhari in order to analyze the impact of Kolkata, in particularly urbanization and industrialization and its outskirt on the pollution of river Vidhyadhari.

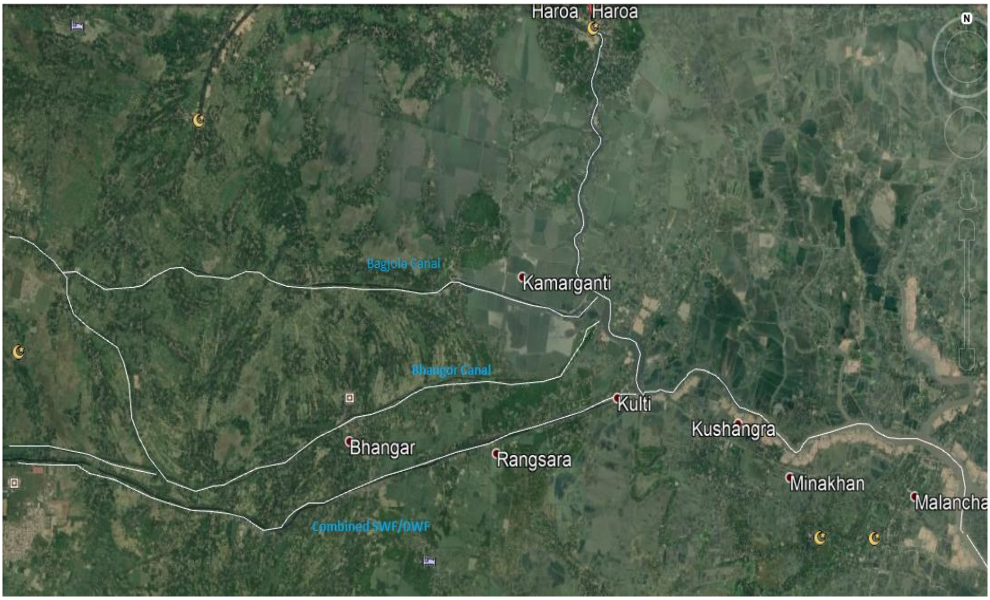

Figure 2. Satellite Image: Vidhyadhari from Haroa to Malancha

2. Materials and Methods

2.1 Study Area

Vidhyadhari is originated from "Barga Bill" a meander cut off of river Bhagirathi near Haringhata district Nadia in the state of West Bengal [18]. The river is bifurcated in two branches at Tehatta; the eastern branch is live till date and locally known as Kulti Gang and opened its outlet through the Hariabhanga estuary. Ichhamati, the eastern branch of Mathabhanga, a distributary of river Padma, is bifurcated near Hasnabad and the western creek named Hasnabad khal joins Kulti gang to form river Raimangal. Nowai, a tributary of Vidhyadhari, starts from Bariti Bill, which is connected to river Hugli through ichapore canal merges with Suti to form Haroa khal and drains major part of the north 24 parganas, the urban sprawl of Kolkata metropolitan area. Haroa Khal meets river Vidhyadhari upstream of Haroa town. The State Pollution Control Agency is monitoring the river water quality of Vidhyadhari in terms of physico-chemical parameters monthly basis for last ten years (2011 to 2020) at upstream of Haroa bridge, the baseline before discharge of KMC wastes and at Malancha, the corresponding downstream location.

3. Methodology

The secondary database was screened in two stages. First, to eliminate the saline water effect only the dataset associated with ebb tide was considered. Second, the data quality of the secondary data was checked according to the six steps of Checking Analyses' Correctness as per method number 1030E. The final dataset was grouped in four seasons *e.g.,* Summer (March-April-May), Monsoon (June-July-August), Post Monsoon (September-October-

November) and Winter (December-January-February) and the average value and range were calculated for each parameter. Validation of the dataset was carried out with Pearson's Correlation technique that ensured usual relational matrix among the analyzed physico-chemical parameters for both the locations.

In order to develop Canadian Water Quality Index (CWQI) with most relevant parameters *i.e.,* the parameters with highest variability, the twenty-one parameters [a total of 14 water quality items, which were water temperature, pH, dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), total dissolved solids (TDS), electrical conductivity (EC), chloride, fluoride, calcium hardness, magnesium hardness, total hardness, total alkalinity, nitrate, phosphate, sodium, potassium, sulphate, ammonia and total fixed solids (TFS)] under discussion for forty datasets (2011 to 2020, 10 years comprising of four seasons each) have been studied for exploratory factor analysis and five factors could be extracted for each location. However, based on reliability statistics the factors with Cronbach's α value more than 5 have only been considered. Since the variables might have temporal variability, ANOVA was applied for each parameter in both the locations to verify whether this particular variability is being superimposed in selection of variables for indexing. Monitored values of the extracted parameters were compared with drinking water standard of IS 10500-2012 and the designated best use (DBU) criteria for Drinking water source after conventional treatment and disinfection of Central Pollution Control Board, India.

CCME Water Quality Index 1.0 is a very much flexible type of index calculation method that doesn't specify variables, objectives and time period used for the study [19, 20]. It allows users to select these baseline parameters to represent particular location in terms of Scope, Frequency and Amplitude. These are the three pillars for WQI determination.

Scope is the number of variables whose objectives are not met

$$F1 = \frac{The\ number\ of\ of\ Failed\ Variables}{Total\ number\ of\ Variables} * 100$$

Frequency is the frequency with which the objectives are not met

$$F2 = \frac{The\ number\ of\ of\ Failed\ Tests}{Total\ number\ of\ tests} * 100$$

Amplitude represents the amount by which failed test values do not meet their objectives

$$F3 = \frac{nse}{0.01nse + 0.1}$$

$$\text{Where, nse} = \frac{\sum_{i=1}^{n} Excursion(i)}{Number\ of\ Tests}$$

And Excursion(i) = $\left(\frac{Objective(j)}{Failed\ Test\ Value\ (i)}\right) - 1$ or $\left(\frac{Failed\ Test\ Value(i)}{Objective(j)}\right) - 1$; depending upon The number of times by which an individual concentration is greater than (or less than, when the objective is a minimum).

$$\text{Finally, the CCMEWQI} = 100 - \left(\frac{\sqrt{F1^2 + F2^2 + F3^2}}{1.732}\right)$$

The divisor 1.732 normalizes the resultant values to a range between 0 and 100, where 0 represents the "worst" water quality and 100 represents the "best" water quality.

3. 1. Data Analysis

Statistical computations like ANOVA, factor analysis and correlation were made using SPSS 18.0 software.

4. Results

It has been noticed from comparing the values of the physico-chemical parameters for both the locations that except BOD, COD, nitrate, ammonia and alkalinity the average values of each of the other parameters were recorded to be high in Malancha, the downstream location (Table 1 and Tables S1 & S2). It is therefore quite evident that the chemical compositions resulting mostly from anthropogenic activity i.e., the organic load show a higher trend in the upstream location compared to the downstream location. Phosphate also shows a marginal increase in Haroa (not in average value but in maximum value recorded) which also can be attributed to the release from suspended particles or reduced sediments, as part of the phosphate buffer mechanism [21].

Mainly sodium with potassium makes highest contribution towards cationic charge balance; however, alkaline earth metals were more dominant in governing water chemistry rather than the alkali metals; this is in sync with earlier study of this region [22].

Pearson's Correlation shows COD, BOD and TSS are positively correlated at 0.01 significant level (Table 2). TDS shows direct proportionality with hardness, alkalinity and all ions detected. Negative correlation is evident for DO with organic parameters like BOD (@0.01 significant level), COD & TSS (@0.05 significant level) and TDS. However, negative correlation is noticed between ammonia and chloride whereas nitrate doesn't show any significant correlation with chloride.

Calcium and magnesium concentrations in surface waters show constant rise from the head of the estuary towards its mouth along with chlorinity. Strong positive correlation can be observed indicating their conservative behavior since calcium and magnesium appear to take some part in the biogeochemical cycles of the rivers [23, 24]. The same trend is also evident from the current study. Malancha being nearer to the mouth of the river compared to Haroa, the sea water impact is validated by the innate significance.

Based on reliability study the maximum variability (19.69%) of the upstream location (Table 3) is defined by the hardness cluster (Hardness, Calcium, Magnesium and Chloride). About 17% variability is explained by the cluster of TDS, Sulphate and Ammonia followed by the Organic load cluster (COD, BOD, DO, TSS). The Malancha location records this hardness cluster to be the highest significant factor followed by TDS and sulphate. In this case also the third factor remains the organic load cluster. The trend of factor analyses is further supported by one-way ANOVA that show season wise variability @5% level for BOD, COD and Sulphate in Haroa point (Table 4). The parameters in the Malancha point show no season-wise significance.

Table 1. Range of values for the parameters monitored in both the locations

Range of values	Haroa			Malancha		
	Maximum	Minimum	Average + SD	Maximum	Minimum	Average + SD
Ammonia (mg/L)	20.4	0.1	4.95±4.55	9.0	0.0	2.47±2.91
BOD (mg/L)	28.6	2.5	12.2±7.05	18.1	0.2	9.01±5.03
Calcium hardness (mg/L)	360.0	38.0	1614±705.61	480.0	22.0	2251.53±757.91
Chloride (mg/L)	1272.0	90.0	1.13±0.99	3424.0	300.0	1.4±0.76
COD (mg/L)	90.0	15.6	1.26±1.44	80.0	13.0	0.75±0.69
Conductivity (µS/cm)	2949.0	345.0	7.71±0.26	3738.0	679.0	7.59±0.29
DO (mg/L)	3.7	0.4	26.94±4.79	3.7	0.6	27.72±3.32
Fluoride (mg/L)	2.7	0.2	113±71.29	0.6	0.2	153.43±101.79
Magnesium hardness (mg/L)	170.1	10.6	449±254	327.0	24.3	865.25±719.49
Nitrate (mg/L)	7.4	0.0	41.56±16.11	2.4	0.0	29.44±14.52
pH	8.4	7.3	0.44±.39	8.4	7.3	0.36±0.09
Phosphate (mg/L)	0.5	0.0	59.82±45.57	0.2	0.0	98.04±70.82
Potassium (mg/L)	36.1	4.0	.14±.13	40.0	3.0	0.09±0.07
Sodium (mg/L)	849.0	34.3	15.27±6.96	1350.0	100.0	18.28±6.89
Sulphate (mg/L)	143.1	13.8	407±192.95	632.0	24.0	479.63±345.32
TDS (mg/L)	1778.0	134.0	62.87±30.71	2406.0	420.0	119.5±128.75
Temp (°C)	35.0	17.0	215.17±52.3	35.0	17.0	179.22±38.9
TFS (mg/L)	1852.0	176.0	888.33±445.14	2318.0	288.0	1533.22±1438.7
Total alkalinity (mg/L)	330.0	98.0	848.83±378.85	260.0	102.0	1243±493.13
Total hardness (mg/L)	1600.0	138.0	526.5±334.34	1800.0	84.0	1243.83±493.13
TSS (mg/L)	496.0	16.0	140±103.45	1140.0	22.0	166.39±253.15

Table 2. Pearson's Correlation on water quality parameters

Param eter ↓→	BOD		TDS		TSS		Cl		NH3-N		COD		DO		NO3-N		PO4-P		SO4		Alk		Hard		Na		Mg		K		F		pH		Temp		TFS		Ca	
BOD	1	1	+	-	+	+	-	+	++	+	++	++ +	--	--	+	+	-	+	+	+	+	+	-	+	+	-	-	+	+	+	-	-	-	-	-	-	+	+	-	+
TDS	+	-	1	1	+	+	++ +	++	++	-	++	++	+	+ +	+	-	-	-	++ +	++ +	++	-	+	+	++ +	+	+	+	++ +	++ +	+	+	+	-	-	+	++ +	+	+	+
TSS	+	+	+	+	1	1	+	-	+	-	++ +	++ +	--	-	+	-	-	+	+	-	+	+	-	-	-	-	-	-	+	+	+	-	-	+	-	+	+	++ +	-	-
Cl	-	+	++ +	++	+	-	1	1	-	--	+	-	+	+	+	+	-	-	+	+	+	++	++ +	++ +	+	+	++ +	++ +	+	+	+	+	+	+	-	-	++ +	+	++ +	++
NH_3-N	++	+	++	-	+	-	-	--	1	1	+	+	--	--	+	-	+	++ +	++ +	-	+	-	-	-	+	+	-	-	+	-	-	+	+	-	-	-	++	-	+	+
COD	++ +	++ +	+	+	+ +	++	+	-	+	+	1	1	-- -	-	+	-	-	+	+	+	++	-	+	-	+	-	-	+	++	+	-	-	-	-	-	+	++	++	+	-
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NO_3-N	+	+	+	-	+	-	+	+	+	-	+	-	-	+	1	1	-	+	+	+	+	++ +	+	++	+	+	+	++	+	-	+	+	+	- -	-	-	+	-	+	+
PO_4-P	-	+	-	-	-	+	-	-	+	++ +	-	+	-	-	-	+	1	1	-	-	-	++	-	-	+	-	-	-	-	-	-	-	+	- -	+	-	-	-	-	+
SO_4	+	+	++ +	++ +	+	-	++ +	+	++ +	-	+	+	-	+	+	+	-	-	1	1	++ +	+	+	++	++	+	+	++ +	++	++ +	+	+ +	+	-	-	-	++ +	+	+	+
Alk	+	+	++	-	+	+	+	++	+	-	++	-	-	-	+	++ +	-	++	++ +	+	1	1	+	++	+	-	+	+	++	+	+	+	+	-	-	-	++	+	+	++
Hard	-	+	+	+	-	-	++ +	++ +	-	-	+	-	+	-	+	++	-	-	+	++	+	++	1	1	+	+	++ +	++ +	+	-	-	+ +	-	+	-	-	++	+	++ +	++ +
Na	+	-	++ +	+	-	-	+	+	+	+	+	-	+	+	+	+	+	-	++	+	+	-	+	+	1	1	+	+	++ +	-	+	+	-	-	+	-	++ +	-	++	+
Mg	-	+	+	+	-	-	++ +	++ +	-	-	-	+	+	+	+	++	-	-	+	++ +	+	+	+	++ +	++ +	+	1	1	+	-	-	+ +	-	+	+	+	+	+	++ +	++ +
K	+	+	++ +	++ +	+	+	+	+	+	-	++	+	-	+	+	-	-	-	++	++ +	++	+	+	-	++ +	-	+	-	1	1	+	+	-	-	-	+	++ +	++	++	+
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TFS	+	+	++ +	+	+	++ +	++ +	+	++	-	++	++	-	-	+	-	-	-	++ +	+	++	+	++	+	++ +	-	+	+	++ +	++	+	-	+	+	-	-	1	1	++	+
Ca	-	+	+	+	-	-	++ +	++	+	+	+	-	+	-	+	+	-	+	+	+	+	++	++ +	++ +	++	+	++ +	++ +	++	+	-	+	-	+	-	-	++	+	1	1

Table 3: Exploratory Factor Analysis for Haroa & Malancha

Criteria for Test		**Haroa**		**Malancha**			
KMO Measure of Sampling Adequacy		0.575		0.516			
Bartlett's Test of Sphericity		Significant		Significant			
Factors identified based on Eigen Value>1		5		5			
Total variance explained		73.24%		75.27%			
Significant factors for reliability statistics Cronbach's α > 0.5							
Factor	**% Variance explained**	**Components**	**Cronbach's α**	**Factor**	**%Variance explained**	**Components**	**Cronbach's α**
F1	19.69	Hardness, Calcium, Magnesium, Chloride	0.778	F1	17.525	Hardness, Mg, Ca	0.592
F2	17.936	TDS, Ammonia, SO_4^{2-}	0.665	F2	13.581	TDS, SO_4^{2-}	0.537
F3	16.261	COD, BOD, DO, TSS	0.511	F3	12.334	COD, BOD, TSS, DO	0.504
Low communality (<0.5) noted for		Nitrate (0.388), alkalinity (0.434), fluoride (0.460)		Sodium (0.249)			

Table 4. Trend of physico-chemical parameters that show season-wise significance in Haroa point (W=winter, S=summer, M=monsoon, PM=post-monsoon)

Variability of different parameters based on critical difference (@5% significance level)			
BOD (crit diff = 5.52)	COD (crit diff = 10.87)	Sulphate (crit diff = 21.43)	Average values for different season (in mg/l)
17.52_{W}	50.66_{W}	94.28_{S} ↓	
13.52_{S}	48.14_{S}	69.88_{W}	
10.44_{M}	39.75_{M} ↓	55.46_{M}↓	
7.33_{PM}	27.70_{PM}	31.85_{PM}	

The Canadian WQIs calculated seasonal basis to identify the changes in water quality during a specific period (2011 to 2020) are shown in Figure 3. The yearly WQI for Haroa brigde ranged between 21.62 (very bad) and 62.89 (medium) with an average of 27.29 (bad), whereas annual WQI value of Malancha station ranged between 15.44 (very bad) and 43.09 (bad) with an average of 18.77 (very bad). For Haroa brigde, the average water quality concentrations for the water quality items used to calculate the monthly CWQI were 1.1 mg/L DO (9.2–14.8), 4.9 ammonia, 12.2 mg/L BOD, 113.9 mg/L calcium hardness, 449.4 mg/L chloride, 59.8 mg/L magnesium hardness, 62.9 mg/L sulphate, 888.3 mg/L TDS and 526.5 mg/L total hardness, and for Malancha station, they were 1.4 mg/L DO (9.2–14.8), 2.5 ammonia, 9 mg/L BOD, 153.4 mg/L calcium hardness, 865.3 mg/L chloride, 98 mg/L magnesium hardness, 119.5 mg/L sulphate, 1533.2 mg/L TDS and 781.1 mg/L total hardness. The seasonal changes are very prominent throughout the study period (Figure 4). Lower WQI value is recorded in post-monsoon followed by summer, monsoon and winter.

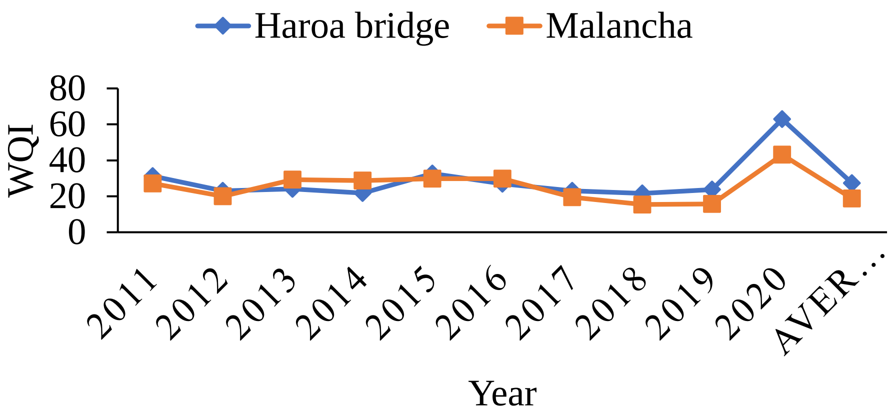

Figure 3. Changes in Canadian WQI during the study period

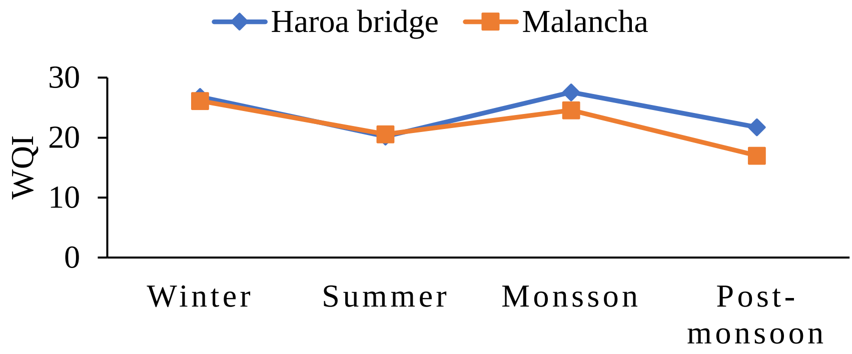

Figure 4. Seasonal changes in Canadian WQI during the study period

5. Discussion

In the estuarine region the seasonal variability is impacted by the upstream discharges. Although Bidhyadhari is supposed to receive a significant discharge through Storm Weather Flow (SWF) canal, Dry Weather Flow (DWF) canal and Bagjola khal draining several congested municipality areas and the industrial sector of leather complex; however, the upstream location of Habra is showing much higher organic loadings compared to Malancha, where tidal dilution eliminates the possibility of building up the concentration of different physico-chemical parameters. The organic discharges like BOD, COD and ammonia which is mostly associated with sewer discharge are showing high value in Haroa compared to the other location. Dry seasons like winter and summer showing higher average values for all three temporally significant parameters compared to monsoon and post monsoon when overall dilution occur. Therefore, variability contributed by the temporal variation possibly not affecting the natural variability of the parameters.

In estuary and coastal marine environments, seawater sulfate is the starting sulfur compound for all sulfur transformations, and microbial sulfate reduction is the dominant pathway of the sediment metabolism [25, 26]. Mangrove estuaries constitute a dominant ecosystem within tropical coastlines. Their sediments are typically composed of fine clays rich in organic matter. Semi-permanent flooding reduces oxygen diffusion through the sediments resulting in an anoxic sedimentary environment [27]. A common characteristic of these sediments is a sharp transition from oxic to anoxic conditions within centimeters of the sediment-water interface. This transition is dominantly driven by bacterial mediated oxidation of organic matter within the sediments [28, 30]. In the current scenario, the upstream Haroa is completely urbanized and the downstream Malancha, an agriculture base, can be considered as the far upstream point of Sundarban mangrove show high concentration of sulphate, a soluble nutrient that oscillate due to tidal influence. Sulphate was the second most dominant cation owing to the nature of sea water as well as due to the oxidation of mangrove sulphide by oxygen percolation through the dense root network of mangrove vegetation as well as the exposure of surface sediment layer to the ambient air during low tide regime.

During low tide mud flats are exposed to the ambient environment. As a result, overlying nitrogenous matter is oxidised to nitrate. Also, microbial activity is enhanced during ebb due to lower salinity which is again a dominant factor for upstream location and Haroa records high value of nitrate.

An Index number may be defined as a measure of the average change in a group of related variables over two different situations. However, the main idea in developing a Water Quality Index (WQI) consists in encompassing a wide range of variables into a single numeric value [31]. The objective of the WQI is to classify the waters relative to biological, chemical and physical characteristics defining their possible uses and managing their allocations [32-34].

Factor analysis, a method to describe the inherent variability in data set and imparting the relative share of variability to the true set of parameters was applied to both the locations. For both the locations the majority of the significance is shared by hardness factors which are not been calculated as significant in temporal variation as evident from ANOVA (Table 4).

Sewer, excessive human activity, industrial discharges, poor sanitation, and urban runoff outflow can be extrapolated as the main causes for the deterioration of Vidhyadhari River water quality. In the factor analysis, factor 1, correlation between the qualities offered by hardness factors (Ca-hardness, Mg-hardness and total hardness for both stations. Factor 2 was considered to be a possible factor that might be correlated with dissolved solids like TDS and SO4. Factor 2 was determined to be a potential factor involving organic matter in the water system because it had a substantial association with BOD, COD, and DO.

WQIs can be considered as models of water quality, i.e., a simplified representation of a complex reality, where variables are selected and methods for weighing and aggregating the variables are defined. In all approaches of WQI calculation, four common steps are used [34, 35]: (i) selection of variables, (ii) transformation, following a common scale, of these variables that have initially different dimensions, (iii) creation of subindices by assignment of a weighing factor to each transformed variable, and (iv) computation of a final index score using the aggregation of subindices [36-38]. The introduction of statistics and multivariate analysis over the last decade now permits selection of variables based on spatio-temporal dimensions of its course during its cycle and according to its allocations and uses, thus increasing the robustness of the final result. The water quality guideline-based weighing method where the weights are defined as functions of the standards proposed in these guidelines are generally followed to avoid subjectivity [39, 35].

Based on the WQI value for ten years, the water quality of Vidhyadhari River was somehow good at downstream i.e., Malancha in comparison to upstream location. According to WQI, the water quality of Vidhyadhari River fall into bad to very bad category, which indicated deterioration of river water quality. It is thought that the grades were affected by sewage treatment facility wastewater that entered the rivers. Since different contaminants have different impacts on river water quality, it is essential to regulate effluents water quality from long-term perspective. This will affect how wastewater from local sewage treatment facilities enters the system. However, a closer look to the year-wise calculation of WQI shows interchangeably comparable values for both the locations for the first six years i.e, upto 2016. Since 2017 the downstream WQI score steadily deteriorated. Surprisingly, the WQI value for both the stations substantially improved for the year 2020 (for Haroa station it is medium grade and for Malancha it is bad). This is probably due to imposition of COVID-19 lock-down, which also shut down the industrial activities and as a result the pollution load into the river bed reduced. Even then the WQI of Malancha (downstream) remained quite low than Haroa

(Upstream). It might indicate the possibility of saltwater ingression along the river as already mentioned in earlier studies of the region [40-42].

The estuarine character of the river Vidhyadhari, after complete severance of the Gangetic freshwater flow at their upstream heads [43-44], is maintained by the semi-diurnal tides at mouth and the freshwater received as local runoff such as monsoon rainfall and floods resulting from the freshwater accumulation in the upstream parts of the Ganga during the monsoons. With illegal encroachment on river bed restricting tidal effect at longer stretches and mixing of toxic industrial waste from leather processing in sewage canal drastically reducing the self-cleaning efficiency, the river has become one of the major polluting rivers in India. However, the discharges at upstream locations are diluted at downstream due to tidal influence. The major pollutants identified are COD, BOD and Ammonia which are associated with sewerage input. The overall water quality remains better during monsoon and post-monsoon seasons.

Experimental evidence also indicates that at too high salinity mangroves spent more energy to maintain water balance and ion concentration rather than primary production and growth. This results in reduction in biomass, leaf area, increase osmotic pressure in leaf sap and decreases total nitrogen, potassium and phosphorus minerals. Minimum values were generally encountered in the period of monsoon due to influx of river borne freshwater and maximum values were during summer for less degree of freshwater contribution from the upstream areas [45]. Salinity distribution in the estuary depends on the strength and amplitude of tide, influx of fresh water runoff throughout the seasons and location of sites. The tide in area is predominantly semidiurnal and the vertical tide range at the coastal areas varies from 5.2m [11, 46] during spring to 1.8m at the neap tide. It is already evident from the earlier study that the area is devoid of any statistically significant tidal variation of the salinity due to less river flow of fresh water into the estuarine area. Whole area of Sundarban becomes almost equally diluted by the fresh water influx during monsoon. After the cessation of precipitation, the river runoff gradually decreased and due to invasion of seawater through tides, salinity values gradually increased initially especially in all the coastal areas that resulted in sharp salinity differences between coastal areas and riverside areas. At the onset of pre-summer, the river water discharge was reduced considerably especially in Matla-Bidyadhari estuary due to lack of fresh water discharge source and consequently salinity values increased a lot even in riverside areas.

6. Conclusion

It is estimated that some 80 per cent of coastal and marine water quality impairment worldwide is caused by broad-scale land-use activities [47]. Land-based activities such as urban and industrial and agricultural development can have significant detrimental effects on marine and estuarine environments by contributing suspended sediment, nutrients, pathogens, heavy metals and other pollutants. Due to the influence of freshwater discharge and the re-suspension of bottom sediments induced by physical processes, the concentrations of the components in the water do not generally have any simple relationships between them [48]. At both the locations pollution indices are steadily deteriorating. Although except BOD, COD and sulphate no parameter show significant variation in ANOVA, the seasonal trend is evident in combined indices with dry seasons (summer and winter) showing higher concentration values corresponding to baseflow consisting of only untreated or partially treated effluent. The rarity of fresh water at the origin to be a major cause in deterioration of water quality during dry seasons and to increase the fresh water input in the river by clearing the choked waterway would be considered with equal importance as with treatment of sewage before discharge to river Vidhyadhari.

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Funding: No funding was received for conducting this study.

Conflict of interest: The Authors have no conflicts of interest to declare that they are relevant to the content of this article.

Data, Materials and/or Code availability:

All data generated or analysed during this study are obtained from the WBCPCB (http://emis.wbpcb.gov.in/waterquality/showwqprevdatachoosedist.do)

Consent:

All authors approved for submission