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Evaluation of Water Quality along the Bank of River Hoogly (Kolkata Metropolitan Area) Using the Physico-Chemical Parameter and Water Quality Index

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Abstract: The Hoogly River in the Gangetic delta plays a fundamental role in local society, as a source of irrigation and drinking water and as a sink for urban waste water. In order to analyze spatial and temporal variability of the overall water quality of the watershed Water Quality Index (WQI) by aggregative and multiplicative methods were calculated from eight physico-chemical parameter taking water samples from six different locations in and around Kolkata throughout a year during both high tide and low tide conditions. Seasonally, it was found that water quality decreases from winter to summer but it improves during monsoon. Depending on the location, different parameters like BOD, COD, DO, Conductivity etc. were responsible for the episodic fluctuation of water quality. The study reveals that the tributaries like Damodar, Roopnaryan and urban waste water discharge jointly contribute to the appreciable content of toxic metal in the bottom sediment of Hoogly River.

Key words: Gangetic delta, Water Quality Index (WQI), physico-chemical parameter, heavy metal, urban waste water, high tide, low tide.

Introduction

Water is one of the most important commodities which mankind has exploited more than any other resources for the sustenance of life. Only 1% of the earth's water is fresh water. The availability of water both in terms of quality and quantity is essential for the very existence of mankind. Due to the worldwide concern that good quality freshwater may become a scarce resource in the near future, developing countries and countries with transition economies have increased their interest in water quality monitoring programmes during the past decades (Bordalo et al., 2001; Jonnalagadda and Mhere, 2001). Earlier people used to recognize the importance of water from the standpoint of quantity. Recognition of the importance of water quality developed more slowly, only in the recent years. It is the result of alarming degradation in water quality caused due to toxic pollutants of various kinds like organic, inorganic, organometallics etc. which are continuously discharged into the water bodies from domestic, agricultural and industrial sectors.

To assess the degree of pollution, several water quality parameters have been measured. Some of these are: Dissolved Oxygen (DO), Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), Total Dissolved Solids (TDS), Total Suspended Solids (TSS), pH, Oil and Grease, Turbidity, Conductivity, Total Hardness, Alkalinity, Chloride and Nitrate.

This water quality is highly variable over time and position due to both natural and human factors (Park and Kim, 2003). Due to these spatial and temporal variations in water chemistry, a monitoring programme that will provide a representative and reliable estimation of the quality of river water is necessary. Traditional approaches to assessing river water quality are based on the

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comparison of experimentally determined parameter values with the existing local normative. In many cases, the use of this methodology allows for a proper identification of contaminated sources, and may be essential for checking legal compliance; however, it does not readily give a global vision on the spatial and temporal trends in the overall water quality in a watershed. Consequently, the sample of water may be termed as 'pollution free' based on certain parameters, but may have to be termed as 'polluted' based on other parameters. Hence it becomes difficult, if not impossible, to label the water as fit or unfit for use for a particular service.

In order to assess the suitability of water for diverse uses, there is a need to devolve an index similar to the air quality model that will categorize the quality of water. This index should integrate the significant physico-chemical and biological constituents of water and present them in a simple, yet scientifically defensible manner. Attempts to categorize water according to its degree of purity date back to the mid-twentieth century (Horton, 1965). House and Newsome (1989) state that the use of Water Quality Index (WQI) allows 'good' and 'bad' water quality to be quantified by reducing a large quantity of data on a range of physico-chemical and biological variables to be a single number in a simple, objective and reproducible manner. Since 1965, when Horton proposed the first WQI, a great deal of consideration has been given to the development of index methods. However, Ott (1978) and Steinhart et al. (1981) reviewed more than 20 water quality indices being used till late seventies. Steinhart et al. (1982) applied a new environmental quality index to summarize technical information on the status of, and trends, in Great Lakes Ecosystem.

Several authors have proposed the use of a WQI as a means to derive a numerical expression for the general quality of surface water (Brown et al., 1970; Ott, 1978; Miller et al., 1986; Bordalo et al., 2001). A single WQI value makes information more easily and rapidly understood than a long list of numerical values for a large variety of parameters. Additionally, WQI's also facilitate comparison between different sampling sites and/or events. Consequently, they are considered better for transmitting information to general audiences. When their specific characteristics and limitations are taken into consideration (Ott, 1978; Flores, 2002), WQI's can be very useful for the purpose of management and decision-making.

The use of a WQI was initially proposed by Horton, 1965 and Brown et al., 1970. Since then, many different methods for the calculation of WQI's have been developed. In general, they all consider similar physical and chemical parameters but differ in the way the parameter values are statistically integrated and interpreted (Zagatto et al., 1998). Ocampo-Duque et al. (2006) studied water quality in rivers using fuzzy interference systems. Said et al. (2004) and Park and Kim (2003) studied changes in fresh water quality. Karagul et al. (2005) studied seasonal and positional changes in water quality of the Buyuk Melen River Basin (Duzce, Turkey). Alberto et al. (2001) evaluated spatial and temporal variations in Suquia River water quality.

The results presented in this paper are based on physicochemical water quality parameters determined in the Hoogly River system during a period of approximately one year (May 2004-April 2005). On the basis of these data, the water quality condition in the lowest stretch of Ganges Delta which is spread along the bank of river Hoogly has been analyzed. With a view to estimate the extent of pollution load being received by the River Hoogly water samples were collected from different strategic locations during high tide and low tide situations in three different seasons (summer, monsoon and winter) of a year.

Materials and Methods

Study Area and Sampling Sites

The Ganges is a major river in Indian subcontinent flowing east through the eponymous plains of northern India into Bangladesh. The 2510 km long river begins at the Gangotri Glacier in the state of Uttarkhand in the central Himalayas and drains into the Bay of Bengal through its vast delta in the Sunderbans (Figure 1). After traveling 200 km through Himyalaya, river Ganges meets with its main tributary, Yamuna and starts flowing in a south-eastern direction through the plains of northern India. At Pakaur, the river begins its first attrition with the branching away of its first distributaries, the River Bhagirathi, which goes on to form the River Hoogly as shown in Figure 1. The Ganges and its tributaries develop a large and fertile basin with an area of about one million square kilometres that supports one of the world's highest density human populations.

In this study, the area of concern was the city Kolkata and its Metropolitan area that is located at the lowest stretch of the Ganges delta and spread along the river Hoogly (Figure 2). Water samples from the river Hoogly were collected from six different locations within the area under consideration as given in Table 1. The distance of the sampling point has been provided considering the first sampling location i.e. Khardah to be reference point. The sampling locations are shown in Figure 2.

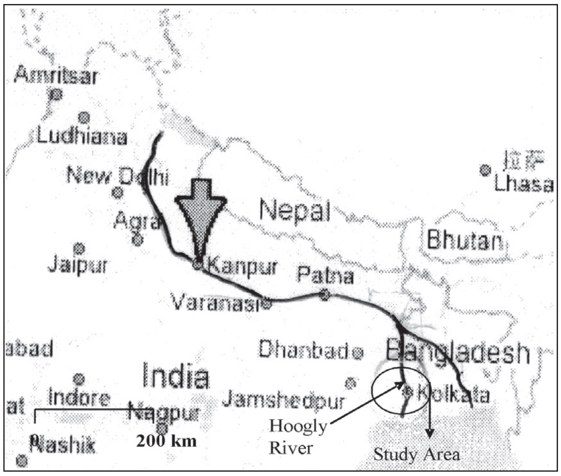

Figure 1: Flow path of Hoogly river which is a distributary of Ganges River and the study area.

Table 1: Sampling locations and the distance between them

Sampling Location (Figure 2)	*Distance* (in km)*	*Sampling period*		
		Summer	*Monsoon*	*Winter*
Khardah	0	April-May, 2004	July-August, 2004	December, 2004-January, 2005
Agarpara	5			
Dakshineswar	11			
Bagbazar	18			
Babughat	23			
Diamondharbour	75			

* Distance has been measured with reference to most upstream sampling location.

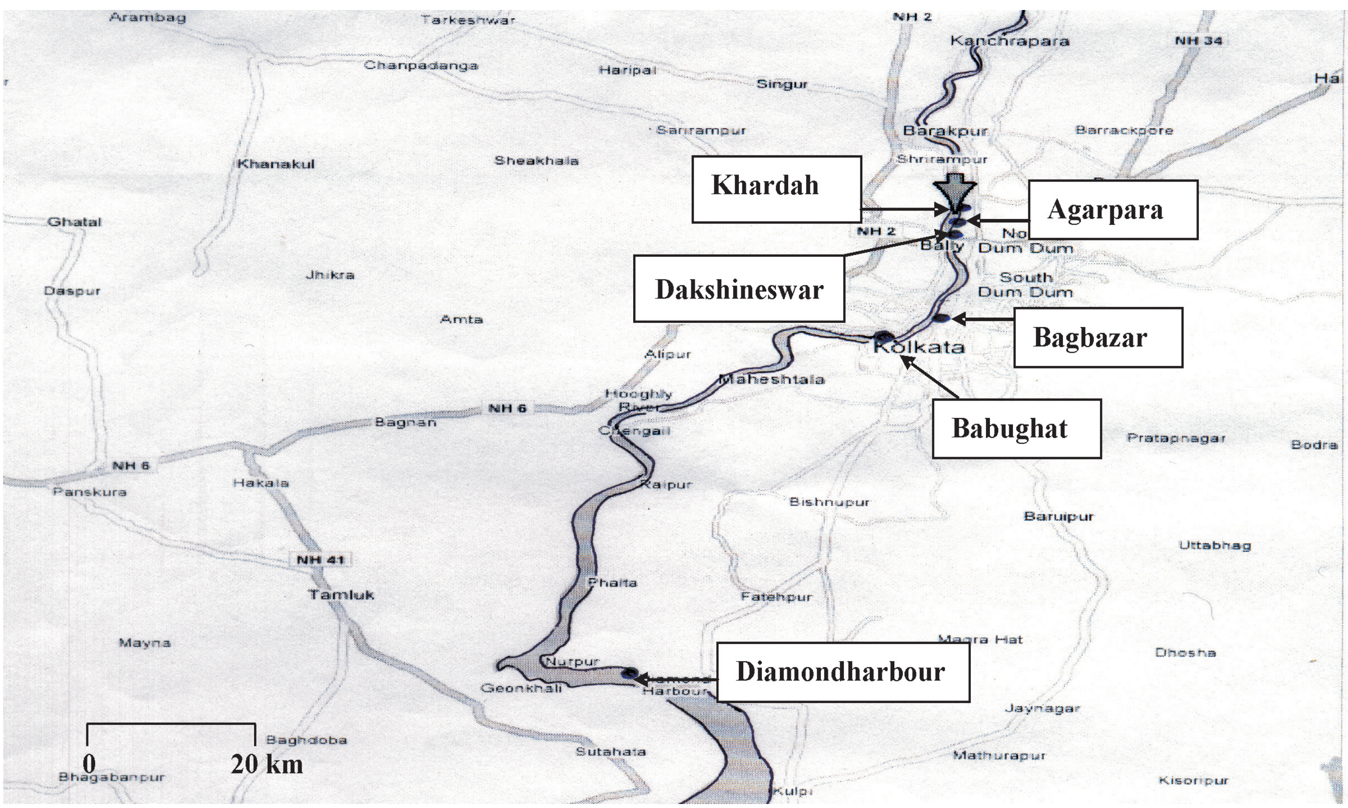

Figure 2: Enlarged view of study area and sampling locations.

Sample Collection, Preservation and Analysis

Water samples and bottom sediments were collected at frequent intervals in each season. After analyzing each sample, the average value of each parameter was taken as the representative value for that season. Sampling programmes were individually tailored to fit each situation so as to ensure that representative sample is obtained i.e. the composition of sample is identical to that of the water stream from which it is collected and the sample share the same physico-chemical characteristics with the water source at the time and the site of sampling. Two universal types of sampling procedures (Spot or grab samples and Composite samples) have been employed as per requirement. Another important point that has to be remembered is that the sampling is done from near the bank and the quality of the water collected must be appreciably influenced by local discharges as well as by the soluble and insoluble salts present in the soil of the banks. Had sampling been done from the middle of the river, the local effects of either bank would have been averaged.

To achieve accuracy, the time interval between sampling and analysis was shortened as far as possible. It may be mentioned that the measurements of temperature, pH and dissolved oxygen were done at field i.e. at the spot of the sampling area.

Water samples were tested for eight parameters like pH, turbidity, total suspended solid (TSS), total dissolved solid (TDS), dissolved oxygen (DO), chemical oxygen demand (COD), biochemical oxygen demand (BOD), oil and grease etc.

Sample preservation before analysis is as important as collection of truly representative sample. It is essential to protect the sample from changes in composition and deterioration with ageing due to various interactions like redox reactions, microbial activity, algal growth etc. Colour, odour and turbidity change with the ageing of sample. The sample holding time ranges from zero for parameters such as pH, temperature and DO, to six months for hardness. The preservation techniques of water sample for determination of different parameters have been shown in Table 2.

Analysis of all the parameters of the sample has been done following the procedure prescribed in the standard literature (APHA, 1995).

Conceptual Framework of Water Quality Index (WQI)

The development and formulation of WQI involves four stages:

(i) Parameter selection
(ii) Transformation of parameter estimates to a common scale.
(iii) Assignment of weightages to all the parameters.
(iv) Aggregation of individual parameter scores to produce a final index score.

Water quality parameters had been asked to rank according to their significance as contributor to overall quality by different experts. The rating was done on a scale of 1 (highest) to 5 (lowest), based on the polluting effect of the parameter relative to other parameters. Each of the parameters represents only a part of the overall quality, thus parameters of lesser importance even cannot be discarded, since they are still part of the overall quality.

In the next step, arithmetic mean was calculated on the rating scores of the experts to arrive at the "mean of all significance rating" for each individual parameter.

Then to convert the rating into weights, a temporary weight of 1.0 was assigned to the parameter which received the highest significance rating. All other temporary weights were obtained by dividing the highest rating by the corresponding individual mean rating of the parameters. Each temporary weight was then divided by the sum of all temporary weights to deduce the final weights, which must sum up to one. A total weight of 1.0 is thus distributed among the parameters to reflect their relative importance of the parameters. The weightage (Table 3) thus assigned to a parameter is an indication of the degree to which water quality may be affected by that particular parameter.

Table 2: Sample collection and preservation

	Parameter	*Container*	*Preservative and Temperature*	*Maximum holding time*
Water Quality Parameter	pH	Polyethylene	Not needed	0-2 hours
	Dissolved Oxygen	Polyethylene, Glass	Not needed	Analyzed as early as possible
	Turbidity	Polyethylene	Not needed	0-6 hours
	TSS and TDS	Polyethylene, Glass	No preservative, Cool to 4°C	7 days
	Chemical Oxygen Demand	Polyethylene, Glass	H_2SO_4 to pH<2, Cool to 4°C	28 days
	Biochemical Oxygen Demand	Polyethylene, Glass	No preservative, Cool to 4°C	48 hours
	Oil and Grease	Polyethylene, Glass	H_2SO_4 to pH<2, Cool to 4°C	28 days

Table 3: Parameter significance for water quality assessment

	pH	*DO*	*Turbidity*	*BOD*	*COD*	*Oil and Grease*	*TSS*	*TDS*
Weight assigned (w_i)	0. 10	0.25	0.05	0.20	0.20	0.10	0.05	0.05

It may be noted that, $\sum w_i = 1.0$

The next step is the transformation of parameters to a common quality scale referred commonly as the quality rating score. The quality rating score is assigned to a particular parameter depending on an individual judgement or a consensus opinion of experts based on the water quality standards. It reflects the magnitude of violation of set of standards. The quality rating is done on a scale of 0 to 100 (i.e. highest to lowest polluting).

Finally, an overall quality rating is derived by multiplying the final weights (w_1) of each individual parameter with the corresponding quality rating (q_1), the sum of which gives the required single number WQI.

The systematic opinion research technique, as attempted by Robert M. Brown, incorporates the judgement of a large and diverse panel of experts in water quality management. The procedure used in formulating the Water Quality Index in this study is DELPHI process.

Calculation of Water Quality Index

Method 1: Aggregative method:

$$\mathrm{WQI}_a = \sum_n q_i w_i$$

where WQI_a = the aggregative water quality index, a number within 0 to 100, q_i = the quality of the i^{th} parameter between 0 and 100, w_i = the weight of the i^{th} parameter, a number between 0 and 1, and n = the total number of parameters.

In this type of index, the weighted mean indices do not permit sufficient lowering of the index if any one significantly relevant parameter exceeds the permissible limit. Based on the calculated WQI, the classifications are shown in Table 4.

Method 2: Multiplicative method

$$\mathrm{WQI}_m = \Pi\, (q_i)^{w_i}$$

In this method weight to individual parameter is assigned based on a subjective opinion. The classifications are shown in Table 5.

The weight (Table 3) reflects parameter's significance for use and has considerable impact on the index.

Table 4: Classification of water quality based on aggregative WQI method

WQI_a value	*Class*	*Description*
63-100	A	Excellent
50-63	B	Good to Moderate
38-50	C	Bad
Below 38	D	Bad to Very bad

Table 5: Classification of water quality based on multiplicative WQI method

WQI_m value	*Class*	*Description*
81-100	A	Very good
51-80	B	Good
21-50	C	Medium
0-20	D	Bad

Results and Discussion

During its course of journey from the Himalayas to the Bay of Bengal, the river Hoogly has passed through the area where population density is excessively high. In either bank of the river there is also huge number of large, medium, and small scale industries. The contamination of the river water is mainly due to anthropogenic activity and indiscriminate industrial discharge to the river. In the present study all the sites selected for sampling are near the mouth of the sea. Under low tide conditions, the water flows down towards the sea. So normally expected the quality of this water must be poor. Due to the increase in the contamination level resulting from the accumulation of pollutants during its entire course of journey. During high tide, water rushes in towards the river from the sea. As already stated, the sampling points are quite close towards the mouth of the sea, so during high tide, the bulk volume of the river water is constituted by the water from the sea. The sea is an enormously vast water body when compared with the river. The concentration of the water pollutants gets largely diluted there. When this water enters into the river, near the mouth, its quality must be appreciably better than its corresponding low tide situation.

In this section between Khardah and Babughat the river is not fed by any tributaries but in between Babughat and Diamondharbour two important rivers namely Damodar and Roopnarayan falls into the river Hoogly. Thus the water quality at Diamondharbour is likely to be affected by these two rivers. All the water samples were collected from the east bank of the river. During pre-monsoon, the quality of the river water is primarily influenced by the discharges into the water body from the adjoining areas. During monsoon, rainwater drains down not only the accumulated contaminants but also the soluble and insoluble salts from both the banks. On the other hand the addition of large volume of rainwater into the river body brings in a dilution effect.

By critically observing the variation characteristics of WQI charts at different seasons it can be stated that the water quality improves in all seasons excepting summer during high tide condition as the river comes nearer to the mouth of the sea. During pre-monsoon period (Figures 3 and 4) at low tide, inappreciable amount of water is

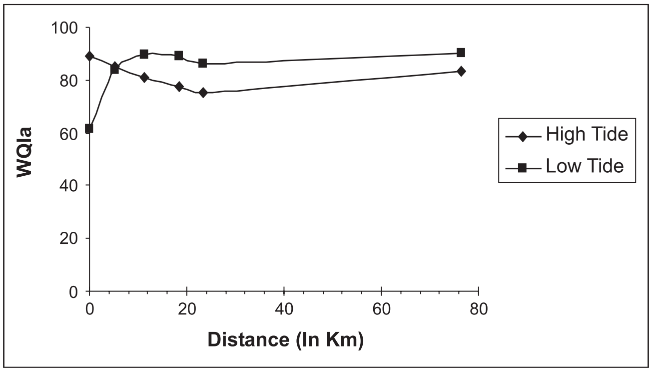

Figure 3: Variation of aggregative WQI during pre-monsoon (Distance has been measured with reference to most upstream sampling location).

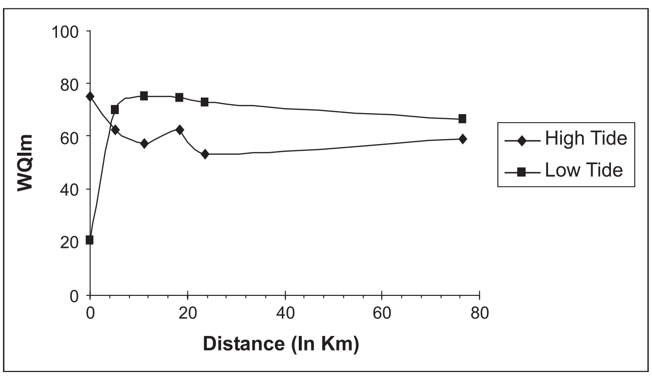

Figure 4: Variation of multiplicative WQI during pre-monsoon.

draining into the river from the adjoining area. As the river is a large water body the adverse effect caused by the small quantities of the pollutants added to the vast quantity of water is not pronounced. Hence it was observed that BOD, COD and DO levels were within the permissible range in almost all sampling points. At high tide, during pre-monsoon period water enters into the river from the sea. This results in a large increase in volume of water and due to this, the concentration of pollutants gets largely decreased and as there are not many industrial establishments beyond Diamondharbour, there is less chance of pollutants getting added beyond Diamondharbour and increased water volume results in high value of DO. During this period, turbidity is higher almost at all locations whereas at monsoon the value is medium and at post-monsoon period the value is almost below the detection limit. Due to the decreased volume of water flowing through during pre-monsoon, River Hoogly visually carries a good quantity of mud and hence the water can rarely be found to be transparent. So, lowering of pollutant concentration during high tide is overridden due to the increase of DO, turbidity and TSS which result in the fall of overall water quality as compared to the low tide situation.

During monsoon (Figures 5 and 6), water quality is always better during high tide compared to low tide. In this season two opposing factors simultaneously influence the overall quality of water. On one hand, pollutant concentration increases due to rain water run-off from the adjoining areas, on the other hand rain water directly falling into the river causes dilution effect. It was observed that DO value largely decreases and BOD increases appreciably from Babughat region due to large amount of contaminants discharged by Howrah industrial belt present at the opposite bank of the river Hoogly. Hence, in spite of dilution effect the overall water quality drops during this season.

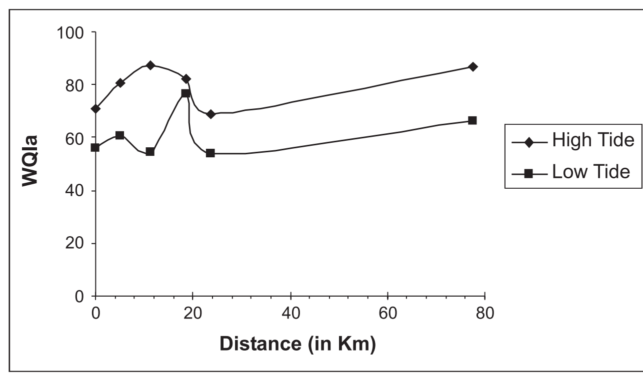

Figure 5: Variation of aggregative WQI during monsoon.

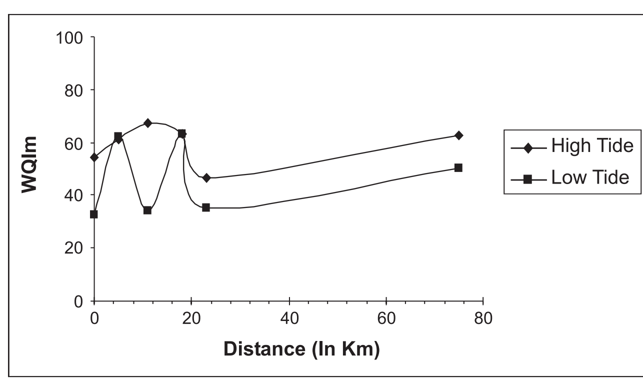

Figure 6: Variation of multiplicative WQI during monsoon.

During post-monsoon (Figures 7 and 8) water quality does not change appreciably during high and low tide situations. During post-monsoon due to the absence of rainwater drainage the potential BOD load decreases. Hence the DO value rises from its corresponding monsoon values. Since the average temperature during this season is within 18 to 25°C, evaporation rate is also low. Low temperatures also attribute to lower activity of microorganism which results in good control of DO. Hence, post-monsoon was found to be the best season with respect to the water quality of river Hoogly.

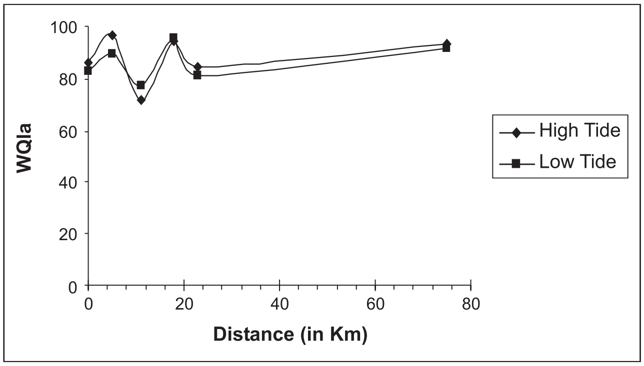

Figure 7: Variation of aggregative WQI during post-monsoon.

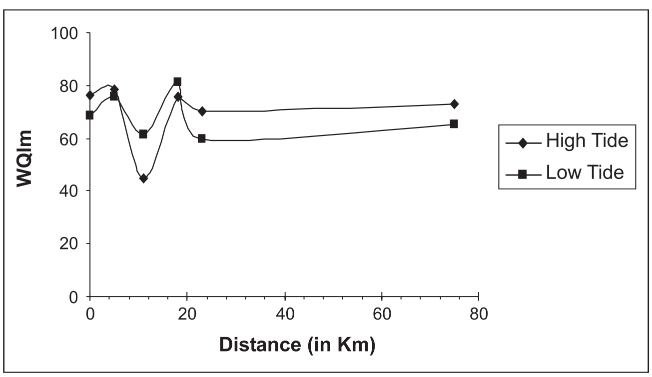

Figure 8: Variation of aggregative WQI during pre-monsoon.

Conclusion

Human population and industrial activities have an enormous influence on the pollution of river water. Pollution level enrichment occurs during the low-flowing periods, as well as during summer and monsoon. This seasonal variation is attributed to agricultural activities, industrial wastewater and domestic wastewaters, which are released, untreated or partly treated to the river. So it has been observed that the results of population growth and industrial development are reflected in a deteriorating water quality in previously unaffected areas of the Hoogly River. In retrospect, it seems obvious that progress towards improving man's health and welfare could result only from better control over our environment. Proper identification of the polluting bodies, adoption of pollution abatement measures and periodic dredging of the canal may be considered to be the need of the hour to save the river from becoming a pollutant carrier but instead, turn it into a potentially navigable stream.

This study suggests that the water quality of the Hoogly river basin is impacted by high turbidity, colour and total (mostly particulate) trace metals due to high suspended sediment load. This can be attributed to natural and anthropogenic sources of upstream or local origin. Local origin for anthropogenic sources in most of the cases is very unlikely (except on the most local scale), given that total annual discharge from all communities and industries within this sub-basin represents only a fraction of a percent of the total annual discharge of the Hoogly River at the head of the Ganges Delta.

Based on WQIs model, the raw water quality in the basin is categorized as moderate to bad along the Hoogly River for overall, drinking and aquatic water uses. The water quality fluctuates from Khardah to Babughat but then improves as it approaches the sea. This study demonstrates that using different WQI protocols and sensitivity analyses to evaluate water quality does identify the specific problematic variables/parameters that may be contributing towards lowering the WQI values and categories. This information can be of great value for water users (public), water suppliers (municipalities and city councils), planners, policy makers, and scientists reporting on the state of the environment.

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