Observations on Diurnal Variations in Some Selected Stretch of the Hooghly Estuary (India)

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The Hooghly estuary is a rich regimen of water source for commercial fisheries exploitation. It is more so for exploitation of the type of fish known as Hilsha (*Hilsha ilisha, Hilsha toli*), which is possibly as old as the Hooghly itself. Of late, due to various reasons, there has been a downward trend in the Hilsha and other fish exploitation of this stretch of the estuary. One amongst many reasons is attributed to indiscriminate discharge of waste water either with inadequate treatment or with no treatment at all. Yet another conceivable reason is the decrease in fresh water flow on the one hand and the upward intrusion of the marine zone on the other. The joint action of such two or other reasons have in recent days necessitated the researchers to take up zone classification (zonation) work of this estuary on the basis of chlorinity conflict recommended at the Indo-Pacific council meeting in at Australia. It will not be exaggeration of fact if it is said that older classifications of marine zone, tidal, gradient and fresh-water zone of the Hooghly do not hold good any more. The flora and fauna which serve as basal link in the entire environment is largely dependent on the particular zone of specific physico-chemical and biological characteristics. It is the extent of diurnal fluctuations of salinity and temperature along with other physico-chemical factors on which the acclimatising capacity of the aquatic fauna and flora depend and not on the actual amount of salinity. It is believed that the value at which the gills pump water from which food particles are filtered, depends upon the salinity of the medium, or more accurately stated upon the frequency, amplitude and duration of changes in salinity. An exact knowledge of distribution of salt water in the estuary and the extent of its variability are of importance in any estuarine studies as a whole, since it can be used in estimating the movement of substances (pollutant) discharged into the estuary. As such this is one of the main factors that influence the distribution of plant and animal [1]. Almost very insignificant work has been done in this respect in India. The literature search reveals that there were isolated attempts by previous workers to study the environmental conditions of the Hooghly estuary during maximum and minimum water level in a particular day, which obviously enough does not reflect the true condition of diurnal variations [5, 17]. Thus it was considered necessary to have basic data on the frequency, amplitude and duration of changes in respect of temperature, turbidity, pH, dissolved oxygen, total solids and salinity at some selected points of the estuary as compared to the standard reference point (Digha) at purely marine zone, for which purpose this experiment was specifically designed. The data presented herein will not only serve to know the present status but also will be of indirect help to make future studies more simplified and specific.

Hydrological Features of the Estuary

Before explaining the experimental set-up and its results thereof, it would not be out of place to mention a few salient points on the hydrological features of the estuary in general and the Hooghly in particular. This will help in better understanding the problem.

The Hooghly is a tidal estuary. The mechanism of water flow in tidal estuaries is complex and incompletely understood as yet. KETCHUM [12], PRITCHARD [13, 14, 15, 16], TODD and LAU [21], STOMMEL [18], KENT and PRITCHARD [11] have reported some interesting work on estuaries. Despite this, the concept remains unacceptable in its totality. An apparent theory frequently presented could be summed up having regard to the correct application of continuity concepts. A certain amount of fresh water passes through the estuary from the upland river or stream and to maintain the continuity an equal amount of sweet water must be carried through each section. As one proceeds down the estuary, the salinity increases, thereby indirectly showing that only a certain portion of the total volume must be sweet water. And so the seaward-directed flow must increase in proportion to the decreasing fraction of fresh water. PRITCHARD attempted to explain the mechanism as follows: Any segment of an estuary has (1) two sides, (2) bottom, (3) surface, and (4) two cross-sections – one in fresh-water river side and the other down in the side of the estuary proper. At any given time the sum of the river water discharged through the upper section and of the flow through the lower section, will equal the rate of change of volume within the section. At the same time there will be flux of salt through the lower segment. Under conditions of mean steady state, the integrated inflow of mass of water into the segment through the section over a tidal period, must equal the integrated outflow of water mass (during the same time) through the lower section; the net flux of salt through the lower section during the tidal action must be zero. If S is meant to describe the rate of change of salt concentration, then

$$\frac{\partial s}{\partial t} = - \frac{\partial (v_1 s)}{\partial x_i}.$$

For a sectionally homogenous estuary, the mean time of salt balance equation of one or more tidal cycle is

$$\frac{\partial \bar{s}}{\partial t} = - \bar{v}_1 \frac{\partial \bar{s}}{\partial x_1} - \frac{I}{A} \frac{\partial}{\partial x_1} \left\{ A \langle v_1' s' \rangle \right\},$$

where $\bar{v}_1$ is the mean sectional velocity averaged over one or more tidal periods, $\bar{s}$ the mean salinity at the section, and $\langle v_1' s' \rangle$ is the mean product of velocity and salinity deviations resulting from the turbulent motion. At mean steady state $d\bar{s}/dt = 0$, and one is apt to get

$$O = - \bar{v}_1 \frac{\partial \bar{s}}{\partial x_1} + \frac{I}{A} \frac{\partial}{\partial x_1} \left\{ A K_1 \frac{\partial \bar{s}}{\partial x_1} \right\}.$$

It is obvious that the mean salt balance is expressed by a balance between the advection and turbulent diffusion. As such it is considered necessary to know the appropriate mixing parameters (that is eddy diffusivities) if one wants to know the river inflow into an estuary from the salinity observation. The present knowledge of turbulent diffusion is certainly insufficient to allow a determination of the river inflow into a tidal estuary by any means other than tedious procedure of measuring time series of current observations (PRITCHARD, op. cit.). Generally, on the basis of mixing and salinity profile, estuaries could be classified to belong to any one of the following categories:

(1) partially mixed estuary,
(2) vertically homogenous estuary,
(3) sectionally homogenous estuary, and
(4) salt wedge estuary.

In any partially mixed estuary, the "halocline" is existent, which separates the higher salinity at deeper water from that of the lower salinity at about surface layers. Here the tidal movement is large as compared to fresh-water inflow, but still the resulting pattern of mixing is such that there exists a transition layer of relatively rapid increase in salinity with depth. The other type of estuary, known as vertically homogenous estuary, exhibits a thorough pattern of mixing, thereby resulting in a uniform salinity from surface to bottom. In this type of estuary there does not exist any vertical or lateral stratification of salinity. The salinity decreases from the mouth to the head of the estuary. According to PRITCHARD (op. cit.), in relatively wide estuaries in the northern hemisphere the salinity on the right bank (looking towards the sea) will be lower than the salinity on the left side owing to the resultant effects of the earth's rotation; for the southern hemisphere the converse is true. The net seaward flow occurs along the right bank and the net motion directed towards the head of the estuary occurs on the left side. A laterally directed flow carries water from the left side of the estuary to the right, and large-scale horizontal mixing occurs between the counter flows on the two sides of the vertically homogeneous estuary. In the sectionally homogeneous estuary the circulation pattern is quite simple, being a seaward movement at all depths and the only variation in salinity is the increase from head to mouth.

In all these types of estuary, tidal movement is large as compared to the fresh-water inflow. In contrast with these types of estuary there exists yet another type of estuary, known as salt-wedge estuary, where the river-water inflow is large compared to the tidal-water flow. Along the bottom of such an estuary, the sea-water enters as a wedge, with fresh water flowing seaward on the top of the wedge. The river inflow will move seaward over the stationary wedge as a thin fresh-water layer, and if no frictional drag exists between the lighter river-water and the denser sea-water, the wedge would extend upstream to the point where the river bottom intersects the mean sea-level. In the real fluid some frictional drag always exists, and the extent of intrusion of the wedge up the estuary depends upon the magnitude of the frictional drag, *vis-à-vis* relative velocities between the two layers of uneven densities. Under conditions of high river flow the wedge exists only a short distance beyond the mouth of the estuary, whereas for the low river flows the wedge extends many miles upstream into the estuary. The Mississippi river in the U.S.A. is an example of a salt-wedge estuary.

Unlike the Mississippi river, the Hooghly estuary is currently not considered to be a salt-wedge estuary. The phenomenon of salt-water penetration which occurs in the Hooghly estuary appears to take place in the form of a mixture and not as a salt-water wedge [22]. Broadly, the estuary has been classified into three sections:

(1) the upper Hooghly from Nadia to the Jubilee Bridge,

(2) the lower Hooghly from Jubilee Bridge to the Hooghly point,

(3) the estuary Hooghly from Jubilee point to Sagar.

At the time of strong tides during the dry seaon, the tidal water pushes up to Swarupganj (80 miles above Calcutta). During the monsoon season with good monsoon flow, the tidal impact is not felt beyond Akra (8 miles below Calcutta). The present study on diurnal variation was confined in the middle reach of the Hooghly estuary. Despite its being common to many features of other estuaries in the world, the phenomenon of "bores" is very conspicuous and peculiar to this estuary. Bores occur almost throughout the year in this area, which pushes the marine water further up with greater impact. Knowledge is not sufficiently advanced to enable the occurrence of bores to be predicted correctly, but from general consideration certain days during the year on which bores may occur could be very approximately predicted. Owing to the occurrence of bores as also on the basis of the salinity measurement made by the Calcutta Port Commissioners at various locations along the river show that there is no vertical stratification of salinity as would have been if a salt-wedge did exist. Besides, this "halocine" is also non-existent and as such it could not possibly be classified as a partially mixed estuary. Obviously the matter boils down to the point that the Hooghly estuary is either a vertically homogeneous estuary or sectionally homogeneous estuary. Bose (op. cit.) reported that there does not exist any appreciable vertical stratification in the Hooghly estuary. Ghosh and Basu [8] tested the validity of Pritchard's observation on salinity variation in the right and left bank of relatively large vertically homogeneous estuary as also the extent of "appreciable" variation of salinity in the Hooghly. The details of observation are given in their paper, but it could be summed up that Hooghly seems neither a vertically homogeneous nor a sectionally homogeneous estuary in the light of Pritchard's classification of the estuary. The hydrological data available indicates that the Hooghly is a hybridisation of the vertically homogeneous and sectionally homogeneous type of estuary.

Materials and Methods

Three sampling stations were selected, one each at Calcutta, Fuleshwar and Diamond Harbour, and also a standard reference sampling point (Fig. 1) at Digha. Digha was selected because of its proximity as also for its easy approachability. Hourly samples of estuarine water, from 6 inches below the surface for a 24-hour period continuously on a number of days, were collected on board M.L. *Rohita* and M.V. *Sunderban*. All analyses (except total solids) were done on the spot to avoid variation owing to storage, change of temperature and transportation. The sea-water samples at Digha were collected by employing a diver for a 24-hour period at hourly intervals.

The dissolved oxygen was estimated by the acid-modification of Winkler's test in duplicate at each collection. Chloride was estimated by Mohr's titrimetric method

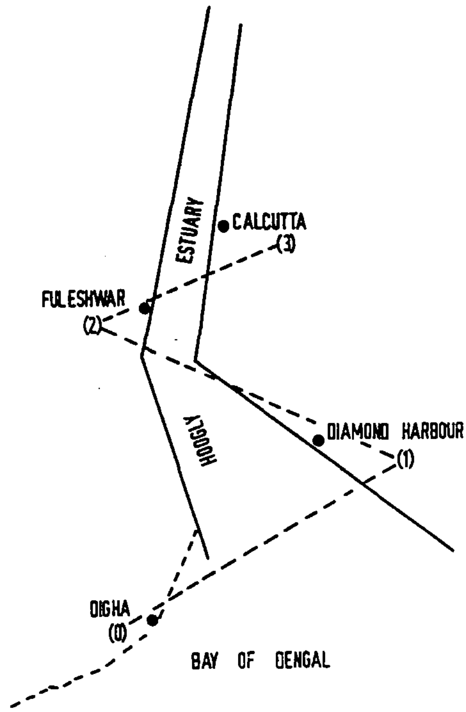

Fig. 1. Location of sampling centres in the estuary.

using potassium chromate and silver nitrate. The salinity figures as reported therein have been derived from the observed values of chloride by employing the following equation, as suggested by KNUDSEN:

$$S^0/_{00} = 0.030 + 1.8050\ Cl^0/_{00},$$

pH estimation was done by the use of Lovibond colour comparator and turbidity by the use of Jackson's candle turbidimeter. Other tests were done as per A.P.H.A. method [2].

Experimental Observations

The analytical data obtained at all stations have been shown as maximum, minimum and average values. The air temperature and water temperature have been combined in Fig. 2. Turbidity (in silica scale), pH, salinity, total solids and dissolved oxygen have been shown in Figs. 3 to 7. During a 24-hour period, generally two high tides and two low tides occur. The physico-chemical conditions during these two high (maximum) and low (maximum) tides have been averaged into one value and have been tabulated (Table 1) to show the possible extent of variation at maximum high and low water levels.

Temperature. The average air and water temperature of sea-water were higher than those of the temperature of all estuarine stations. In the estuary, maximum water temperature was observed to be 28.5 °C at Fuleshwar and minimum (18.0 °C)

Table 1. Condition During Maximum High Tide and Maximum Low Tide*)

Place/Centre	Tide	Air Temp. (°C)	Water Temp. (°C)	pH	Turbidity	Dissolved Oxygen (mg/l)	Total Solids (mg/l)	Chloride as Cl.°/₀₀	Salinity parts per thousand
Digha (0)	H.T.	29.5	30.0	8.4	165.0	6.0	52590.0	19.12	34.55
Digha (0)	L.T.	30.5	30.5	8.4	114.0	6.0	56910.0	18.87	34.09
Diamond Harbour (1)	H.T.	30.25	24.0	8.15	1140.0	8.66	12700.0	5.5	10.0
Diamond Harbour (1)	L.T.	26.75	24.25	8.15	1300.0	8.6	13050.0	4.9	8.85
Fuleshwar (2)	H.T.	26.5	26.35	8.1	217.5	7.62	4010.0	1.74	3.17
Fuleshwar (2)	L.T.	28.5	26.75	8.05	1080.0	7.19	3140.0	0.96	1.75
Calcutta (3)	H.T.	22.75	22.25	8.1	850.0	6.64	1300.0	0.15	0.27
Calcutta (3)	L.T.	23.75	20.25	8.1	662.5	6.28	940.0	traces	traces

*) Average of two high tides (H.T.) and low tides (L.T.) in a day.

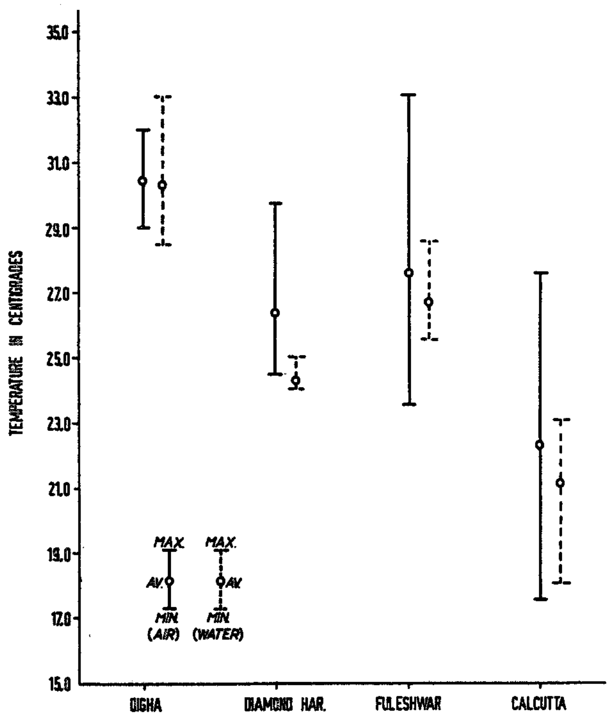

Fig. 2. Temperature variations of diurnal studies.

at Calcutta. Water temperature at Digha was 33.0 °C maximum and 28.5 °C minimum, with a 24-hour average of 30.4 °C. Air temperature was maximum of 33.0 °C at Fuleshwar and minimum (17.5 °C) at Calcutta. Air temperature at Digha was 32.0 °C maximum and 29.0 °C minimum, with an average of 30.5 °C. Insignificant variations

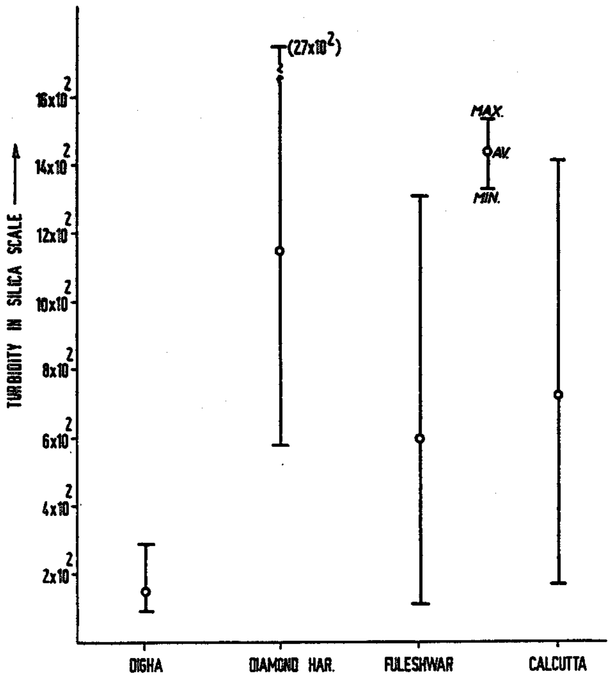

Fig. 3. Turbidity variations of diurnal studies.

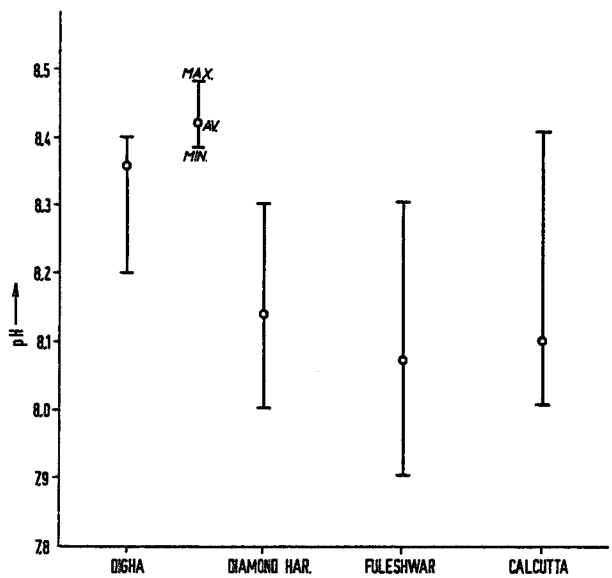

Fig. 4. pH variations of diurnal studies.

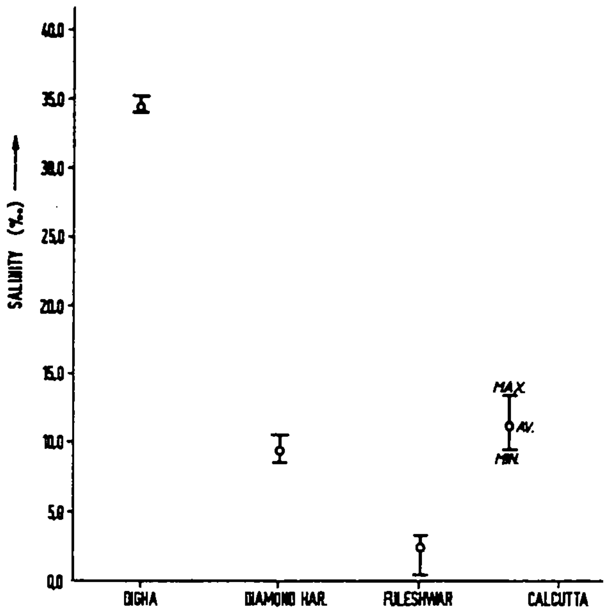

Fig. 5. Salinity ($^0/_{00}$) variations of diurnal studies.

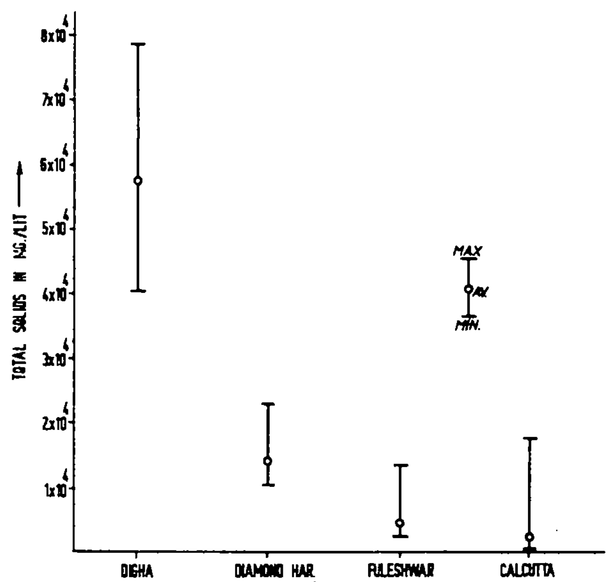

Fig. 6. Total solids variations of diurnal studies.

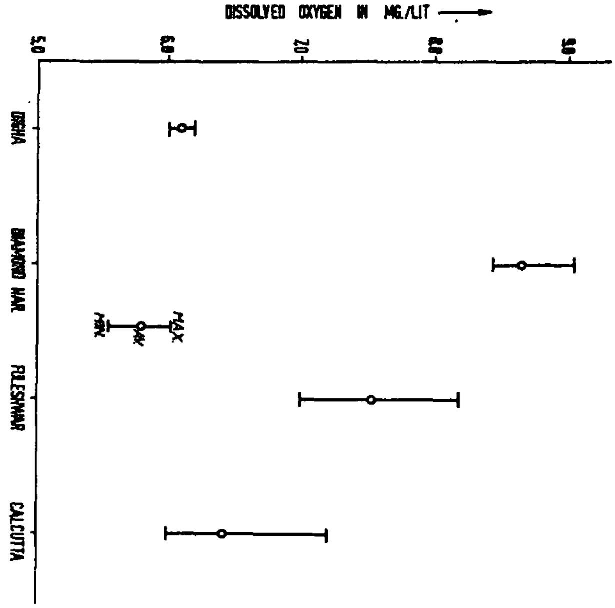

Fig. 7. Dissolved oxygen variations of diurnal studies.

of 0.5 °C, 0.25 °C, 0.4 °C, were observed in water temperature between high and low water levels at Digha, Diamond Harbour and Fuleshwar, respectively, whereas at Calcutta a difference of 2.0 °C was observed.

pH. The pH of sea-water showed little fluctuations, its maximum and minimum being 8.4 and 8.2 respectively, with an average of 8.36. As compared to the standard reference point, pH variation was high in the Hooghly samples. Maximum and minimum observed pH for Diamond Harbour being 8.3 and 8.0, for Fuleshwar 8.3 and 7.9, and for Calcutta 8.4 and 8.0. Generally at high and low tides pH variation was almost nil at all points.

Turbidity. From Fig. 3 it will be evident that the sea-water was comparatively less turbid than the estuarine water samples – as it should be theoretically. The maximum turbidities at Diamond Harbour, Fuleshwar and Calcutta being 2700.0, 1300.0 and 1400.0 respectively, as against that of Digha which was only 285.0. The minimum turbidity observed at Digha was 87.0 and the values increased by 561% (575.0), 20.6% (105.0) and 84.0% (160.0) at points from 1–3. Turbidity was always high at all points, except Fuleshwar, at maximum high tide than the maximum low tide.

Salinity. At Digha, it was in the range of 34.09 parts per thousand to 35.01 parts per thousand, and those of sampling points 1, 2 and 3 were 8.5–10.5$^0/_{00}$, 0.39–3.22$^0/_{00}$, and traces–0.39$^0/_{00}$ respectively. Salinity variation at Digha was 0.46$^0/_{00}$ whereas it varied to the extent of 1.15$^0/_{00}$ at Diamond Harbour, 1.42$^0/_{00}$ at Fuleshwar, and 0.3$^0/_{00}$ at Calcutta between two extremes of the cycle of tide. The salinity decreases from the mouth to the head of the estuary as is normally expected in this type of estuary.

Total solids. A total solids of 78,640.0 mg/l were observed at Digha with a gradual fall up to Fuleshwar. At sampling point 3 of the estuary there was an increase in total solids value, even though the salinity at this point was low as compared to Fuleshwar (point 2).

Dissolved oxygen. The dissolved oxygen content of the Digha water ranged between 6.2 mg/l and 6.0 mg/l. Amongst all estuarine points, the D.O. was highest at Diamond Harbour (9.03 mg/l) and lowest at Calcutta (5.98 mg/l). Even the minimum of D.O. (8.42 mg/l) at Diamond Harbour was higher than the maximum observed D.O. value (7.19 mg/l) at Calcutta. The dissolved oxygen fluctuations at Digha and Diamond Harbour were insignificant at the extreme of the tides. However, at Fuleshwar and Calcutta the average dissolved oxygen was higher at high tide as compared to low tide condition.

Discussion

Critical studies of data presented herein reveals some very informative and challenging particulars.

Leaving aside the air temperature, if the temperature of water mass is considered then the maximum temperature difference of 5 °C was observed at Calcutta as compared to 3.0 °C and 1.0 °C respectively at Fuleshwar and Diamond Harbour. According to Vant Hoff's formulation, for every 10 °C rise of temperature the metabolic rate of organisms is doubled. But this temperature factor should not be taken for granted as the only general criteria for deleterious effect at all stages of the life cycle of fish, because the temperature plays an important role for (1) immediate survival, (2) good growth, (3) migration, (4) escape from predation, (5) successful osmoregulation, (6) spawning, etc. These are all activities of one kind or other, some required throughout the life cycle others imposing requirement for a specific time limit. HUET [9] observed that the fish have the capability of adapting themselves quicker to a rise in temperature than to a drop in temperature. The maximum drop in temperature (2.5 °C) was noticed at Calcutta between 11 p.m. and midnight. In other centres both rise and drop in temperature was slow and gradual. At all centres the average air temperature was higher than the average water temperature. But the maximum air temperature was higher than the maximum water temperature at all estuarine stations even though it was the other way round in the case of sea-water. The explanation for this variation may be attributed to the higher salt concentration in the sea-water on the one hand and the thermal radiation factor on the other hand. The flora and fauna, as is well known, in an estuarine environment are not only affected by the temperature but also by the other factors such as pH, dissolved oxygen, suspended matter and dissolved toxic materials, etc.

The pH variation was lowest in sea-water as compared to the estuarine water samples. Tarzwell points out that certain fish have been able to live longer between pH of 4.0–4.5. If the best water for fish is a slightly alkaline water then the preferred pH range should be 7.0–8.0. Reports indicate that the extreme limits which the fish could withstand are close to pH 4.0 and 10.0. Sudden and appreciable variation in pH of water is undesirable. Earlier, the authors reported that the Hooghly estuarine water has sufficient reserve bicarbonate alkalinity and as such the variation in pH is likely to be less significant. pH value of the estuarine water being in the range of 7.9 and 8.4, may not be an inhibitory factor for major flora and fauna including fish in this stretch.

The maximum chlorinity conflict of $1.57^0/_{00}$ has been observed at Fuleshwar and next to it at Diamond Harbour, which confirms a finding of the previous workers that these two areas are absolutely in the gradient zone. In Calcutta, the chlorinity conflict was observed only during high tide period. The sampling point 1 being situated absolutely in marine zone gave low chlorinity conflict value of $0.51^0/_{00}$. The previous work indicated that the marine zone is being pushed up gradually for more than one reason. The resultant impact of this intrusion of saline water, if continued unabated, may adversely jeopardise the growth and propagation of fish particularly available in this reach of the estuary. With the commissioning of the Farakka Barrage, the fresh water inflow is likely to improve.

Dissolved oxygen in aquatic environment is an important parameter for any aerobic organisms. It has to be looked upon, broadly, from three aspects: (a) the dissolved oxygen required just to permit the aquatic organisms to exist – the incipient lethal level, (b) the level that permits to be active to a given specific degree, and (c) the level that will permit the fish to remain in a given locality. Each of these play a significant role under a particular condition. In absence of any detailed work with the oxygen requirement of the different types of fish in this area it is difficult to conclude as to what are the type of fish that will survive the incipient lethal level of dissolved oxygen requirements. Broadly, the data showed that the dissolved oxygen variation in Digha was maximum and those of Calcutta and Fuleshwar were minimum. The dissolved oxygen content at Diamond Harbour was highest, being 9.03 mg/l, and lowest at Calcutta, being 5.98 mg/l. Theoretically the solubility of oxygen should be more where the salt concentration (temperature being same) is less. Even though the chloride value was high at Diamond Harbour, yet the dissolved oxygen value was considerably higher at this place as compared to Fuleshwar and Calcutta where progressively a low salinity trend was observed. The only explanation of this anomaly may be attributed to the indiscriminate discharge of pollutant in this stretch of the estuary. Between Calcutta and Fuleshwar, and even a little above Calcutta, there are a good number of discharging outlets through which organic pollutants find their way into the estuary. As the waste goes into the estuary it exerts oxygen demand for stabilization from the oxagen budget of the estuary itself, thereby the dissolved oxygen in this area shows a downward trend. Earlier survey undertaken by the authors [3, 4] indicated that beyond Fuleshwar point, at downward flow, the major industrial installations throwing organic pollutant as well as sewage outfall were scanty. Despite the variation in dissolved oxygen at the various outfall areas the river maintains in most cases a dissolved oxygen level well beyond the lethal limits.

Total solids at the Calcutta point was high as compared to Fuleshwar, although the chloride concentration of the latter was higher than that of the former. The reason may be attributed to the fact that there is an increase in the total solid content owing to the solids contributed by various industrial effluents.

Conclusions

As discussed above, the present investigation reveals that:

(1) Almost a steady state of dissolved oxygen (6.0 to 6.2 mg/l) was found at Digha water. The highest dissolved oxygen was recorded at Diamond Harbour with the gradual lowering of values at all points from the mouth to the head of the estuary.

(2) Average pH at Digha was 8.4, whereas at other centres it was about 8.1. The bicarbonate alkalinity (reserved) of the estuarine water give a good buffering action.

(3) The chlorinity conflict at Fuleshwar was maximum and it was minimum at Calcutta. Diamond Harbour occupies an intermediate position in so far as chlorinity conflict is concerned. Digha typified a marine condition.

(4) Average air temperature was higher at all stations than the average water temperature. Sudden variations in temperatures were few, an exception in one case was observed when temperature dropped suddenly by 2.5 °C at midnight. The overall condition of the estuary during a 24-hour period did not exhibit any adverse condition owing to factors causative to diurnal variations. The public health hazards from the chemical and bacteriological point of view have not been accounted in this study, as such there is a great need to undertake a detailed study on this aspect.

RÉSUMÉ

Dans le présent travail, les variations diurnes dans quelques tronçons choisis de l'estuaire du fleuve Hooghly aux Indes sont décrites.

Si l'effectif en poissons a, depuis quelques années, sérieusement diminué dans l'estuaire du fleuve Hooghly, c'est certainement en partie à cause de la pollution due aux décharges d'eaux usées brutes ou insuffisamment traitées. Mais il y a aussi d'autres raisons dont les principales sont d'une part la réduction des apports d'eau fraîche et d'autre part l'intrusion progressive de la zone marine. L'étude des eaux de l'estuaire a révélé ce qui suit:

1) Teneur presque constante en oxygène dissous à Digha Water (6,0 à 6,2 mg/l). Teneur maximum à Diamond Harbour, puis diminution graduelle des valeurs à tous les points de mesure de la bouche à la tête de l'estuaire.

2) A Digha, la valeur pH moyenne était de 8,4, alors qu'elle atteignait environ 8,1 aux autres points de mesure. L'alcalinité bicarbonatée (réservée) de l'eau de l'estuaire procure un bon effet-tampon.

3) Les divergences entre les teneurs en chlore étaient à leur maximum à Fuleshwar et à leur minimum à Calcutta. A ce point de vue, Diamond Harbour occupe une position intermédiaire. A Digha, les conditions marines sont en prépondérance.

4) A toutes les stations, la température moyenne de l'air était plus élevée que celle de l'eau. Il y eut peu de variations subites, sauf en un cas où la température diminua très rapidement de 2,5 °C à minuit. L'ensemble des conditions régnant dans l'estuaire au cours d'une période de 24 heures n'a subi aucune influence défavorable de la part de facteurs responsables des variations diurnes. Il n'a pas été tenu compte dans cette étude d'éventuels risques pour la santé publique pouvant être causés par des facteurs chimiques et bactériologiques. Il y aurait lieu d'entreprendre une étude spéciale de cet aspect du problème.

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