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TEMPERATURE AND SALINITY STRUCTURE OF GOSTHANI ESTUARY, EAST COAST OF INDIA

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ABSTRACT

Changes in temperature and salinity distribution in relation to depth and distance in the shallow Gosthani Estuary were studied during the four different seasons (December 1987 to November 1988). The influence of gravity-impelled flow of freshwater from the head of the estuary and the vertical stratification in temperature and salinity that ensued were described. The effects of annually forming sand bar that occludes the mouth and the breaching of it later, and on the changing pattern of the temperature and salinity in estuary were considered in some detail. The effect of increased tidal inputs from the marine end marking the commencement of the recovery phase of the system from freshwater flooding and the establishment of horizontal and vertical gradients in temperature and salinity, was followed. The period of marine domination, when vertically isothermal and isohaline conditions prevailed, was a prolonged one.

INTRODUCTION

THE STRETCH of the river over which neritic influence is felt, depends upon several factors such as the gradient of the river bed, the width and shape of the river, the duration and magnitude of freshwater runoff and the tidal pressure imposed by the sea.

The Gosthani River, one of the minor rivers opening into the Bay of Bengal arises in the eastern ghats at an altitude of 1275 m. After flowing through a hilly terrain over a distance of 60 km the river enters the plains at Thatipudi and thereafter takes a southeast direction for about 40 km and finally opens into the Bay of Bengal near Bhimunipatnam, 30 km north of Visakhapatnam. At Thatipudi a dam was constructed to form a reservoir, the capacity of which is 3,325 mcft and the live storage is 3,175 mcft.

The area investigated includes a stretch of about 3.5 km of the Gosthani Estuary extending between the confluence and Chirpada (Fig. 1).

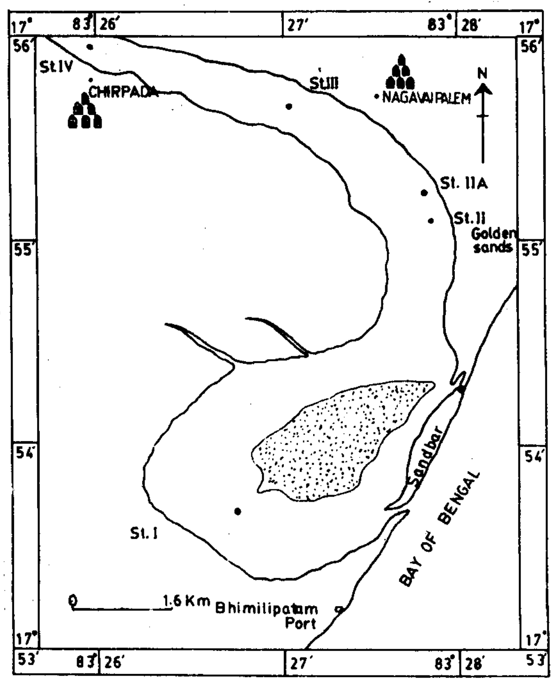

FIG. 1. Study area (Gosthani Estuary).

A prominent feature in the morphology is the presence of an island in the vicinity of the river mouth.

The recent studies (Dhanalakshmi *et al.*, 1978) reveal that the river mouth has been experiencing extensive changes in the geomorphology including shifting of the mouth and establishment of sand bar resulting from a massive coastal drift across the river mouth prior to onset of southwest monsoon resulting in the total occlusion of the mouth.

Sea water penetrates upto 5 km towards the head of the Gosthani Estuary as manifested by the visual rise and fall of the water level. The width of the mouth is 20 m at times of low water and about 80 m at times of high water. The total occlusion of the river mouth is a notable major topographical feature that proved of great consequence in the exchange of sea and river waters. Morphological changes of the river mouth are important in not only controlling water movements across the mouth, but also in physico-chemical features in the estuary. The establishment of a sand bar is a common feature of tropical shallow estuaries of India (Panikkar and Aiyar, 1937; Chacko *et al.*, 1954; Evangeline, 1975; Nair and Ganapathy, 1983).

Considerable work was done on the various aspects of hydrobiology of Godavari (Rama Sarma, 1965, 1970; Ganapati and Rama Sarma, 1965; Rama Sarma and Ganapati, 1968), Coringa (Rama Sarma, 1971), Vellar (Rangarajan, 1958; Jacob and Rangarajan, 1959), Adayar (Chacko *et al.*, 1954; Evangeline, 1975), Edaiyar-Sadras (Nair and Ganapati, 1983; Satpathy *et al.*, 1987; Rajagopal *et al.*, 1989), Cochin Backwater (Kurian, 1959; George and Krishna Kartha, 1963; Ramamirtham and Jayaraman, 1963; Devassy and Gopinadhan, 1970; Josanto, 1975) and Mandovi and Zuari (Anthony *et al.*, 1974; Cherian *et al.*, 1975) estuaries systems.

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MATERIAL AND METHODS

Four stations were fixed opposite permanent landmarks where hydrographical data were collected. The sampling schedule was so arranged that all the four stations were covered mostly during the falling phase of the tide. A country boat was used to reach the sampling sites.

Samples were collected at fortnightly intervals both at the surface and subsurface levels. The surface water was collected with a clean bucket. The sub-surface samples were collected with a shallow sea water sampler devised for the purpose. Water temperature was measured with a mercury thermometer of 0.1° C sensitivity. Salinity was estimated by the standard titration method of Knudsen.

RESULTS

Northeast monsoon season (Dec.-Feb.)

Temperature : Owing to the prevailing cold weather, a general fall in water temperature was noticed. The surface water temperature ranged from 21° to 31°C and that of bottom water from 23.5° to 32.0° C. In general the surface waters were cooler than the bottom waters during December and January, while the reverse was the case during Febrauary. The waters were nearly vertically isothermal where the depth of the water column was low. Further, the waters at Stn. I and II were less warm. A perceptible rise in surface temperature was noticed in February, foreshadowing the approach of hot weather season. The surface-bottom differences ranged from 0° to 3°C.

Salinity : Commencing from December the water turned brackish from neritic end. The trend of distribution of salinity by the end of December (Fig. 2) indicates that the penetration of sea water from the neritic end was fairly quick. The salinity ranged from 0.40 to 30.11‰

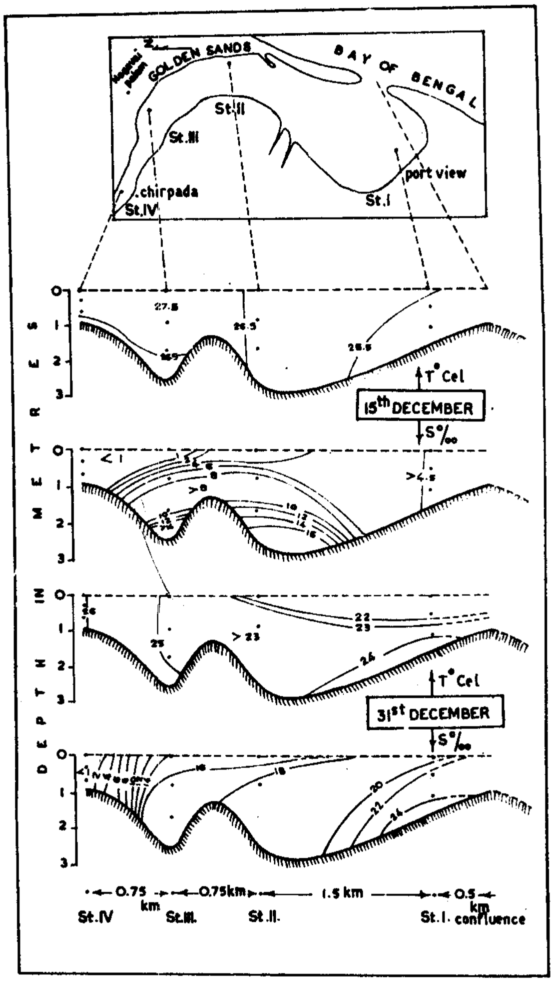

FIG. 2. Temperature and salinity structure in December 1987.

both at surface and bottom levels. The observed surface-bottom differences ranged from 0 to 16 ‰. The surface-bottom differences occurred mainly in January and February. The differences were high during early December at Stn. II and III *i.e.* 12.23‰ and 16.55‰ respectively.

Hot weather season (Mar.-May)

Temperature : The rise in water temperature due to the direct influence of the warm bed

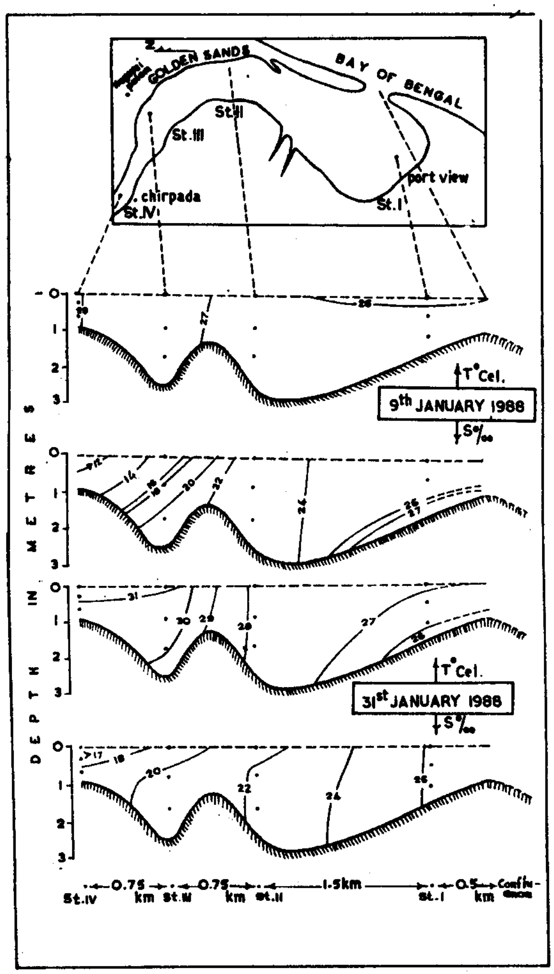

FIG. 3. Temperature and salinity structure in January 1988.

and banks of the estuary is evidenced by a general rise in water temperature and the narrow horizontal and vertical temperature gradients. The water temperature ranged from 27.5° to 33.0° C both at the surface and bottom. The surface-bottom differences ranged from 0°-1° C.

The waters at the various stations were vertically isothermal.

Salinity : The general level of salinity at the four stations had progressively risen considerably from March onwards. The surface (Fig. 6 & 7) when surface-bottom differences varying between 7 and 8 ‰ prevailed. The study revealed an interesting pattern in that the surface and intermediate salinities at Stn. IV were higher than at identical levels at Stn. III despite

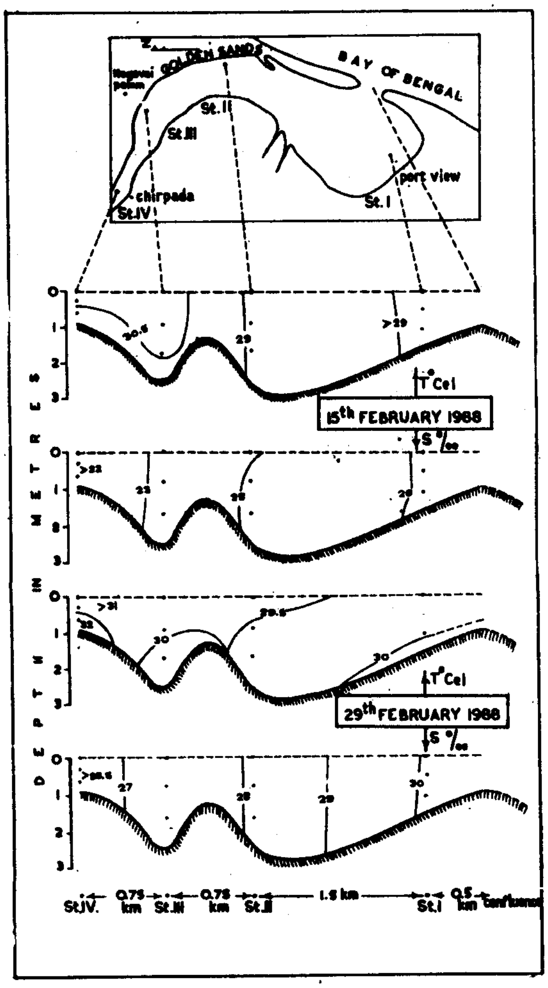

FIG. 4. Temperature and salinity structure in February 1988.

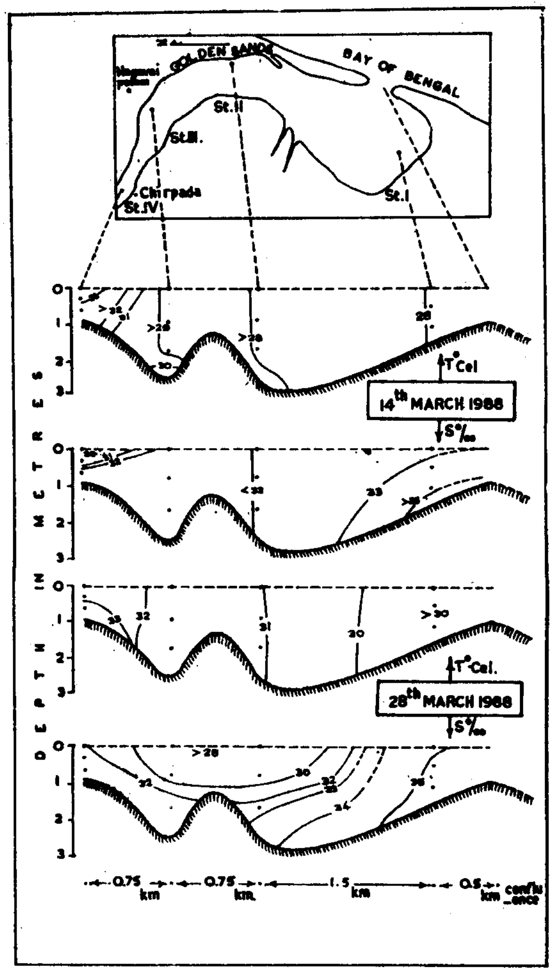

FIG. 5. Temperature and salinity structure in March 1988.

salinity varied between 24.30 to 39.12 ‰ and the bottom salinity between 2.07 to 39.12 ‰. The waters were vertically isohaline except at Stn. II, III and IV (Fig. 5) and at Stn. III the fact that the waters at Stn. III are relatively closer to the mouth than those at Stn. IV. The surface-bottom differences ranged from 0 to 8.67 ‰.

Southwest monsoon season (Jun.-Aug.)

Temperature : The water temperature ranged from 27° to 32° C at the surface and from 28.5° to 32.0° C at the bottom levels. The magnitude of horizontal temperature gradients ranged from 0.5° to 2.0° C both at the surface and bottom levels and the surface-bottom differences ranged from 0° to 2.5° C.

Salinity : The salinity ranged from 0.4 to 35.23 ‰ both at the surface and bottom levels and the surface bottom differences ranged from 0 to 24.97 ‰ considering the entire southwest monsoon season. The salinity was fairly high during June and the values ranged from 32.23 to 35.25 ‰ both at the surface and bottom levels with a low horizontal gradient. The surveys conducted on 15th and 27th July portray interesting pattern of salinity distribution (Fig. 9). Reverse horizontal gradients in salinity of the magnitude of 7.87 ‰ at the surface and 7.47 ‰ at the bottom were established due to the heavy fresh water drainage from the upper catchment area towards Stn. IV.

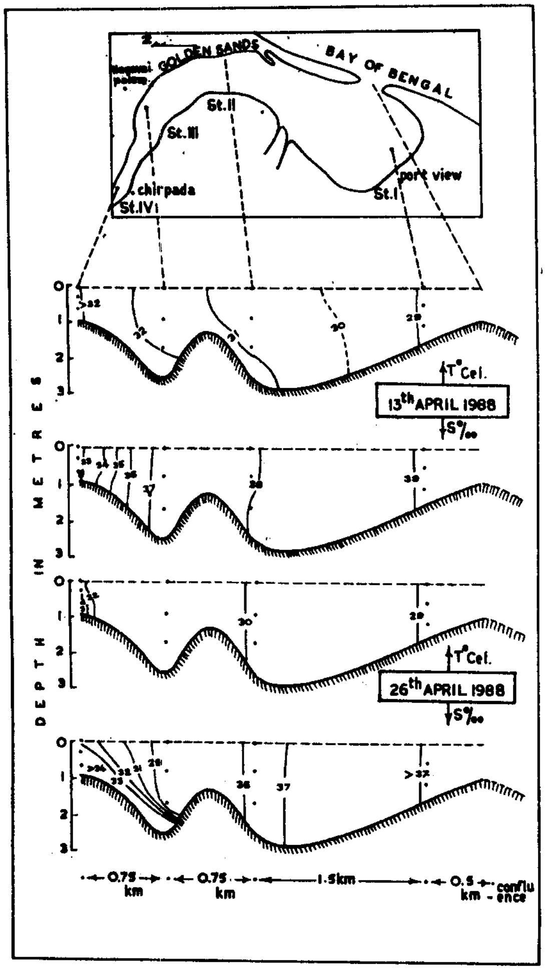

FIG. 6. Temperature and salinity structure in April 1988.

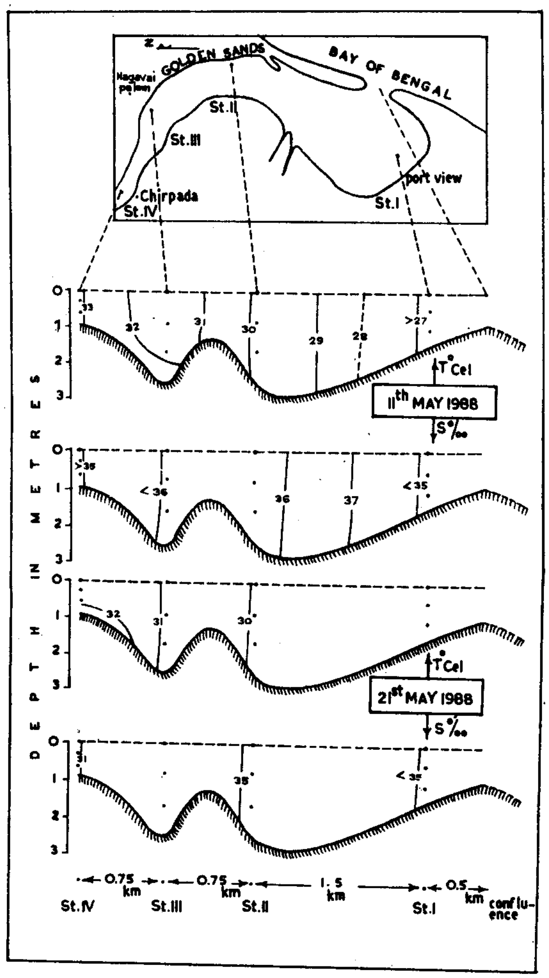

FIG. 7. Temperature and salinity structure in May 1988.

The salinity distribution pattern had changed considerably by the end of July, consequent on the breaching of the sand bar. Monsoon became active and the surface waters registered a perceptible decline in salinity (Fig. 9). Owing to incursion of freshwater the August the magnitude of freshwater flow, aided by local rains, increased heavily, so that the entire water in the estuary was flushed out as indicated by the establishment of freshwater conditions at all levels, horizontal and vertical (Fig. 10).

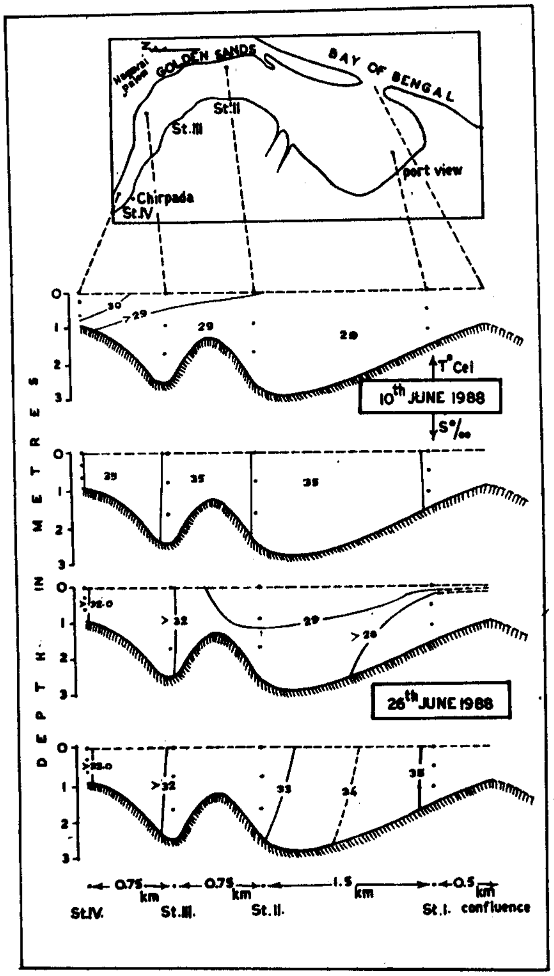

FIG. 8. Temperature and salinity structure in June 1988.

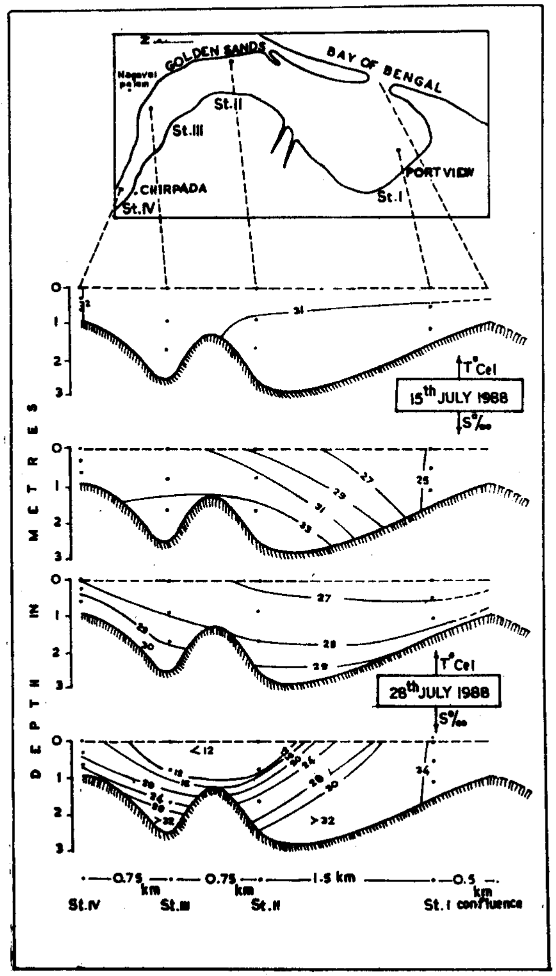

FIG. 9. Temperature and salinity structure in July 1988.

hitherto prevailing horizontal and vertical structure in salinity got disrupted and horizontal gradients of 17 ‰ at the surface and 4 ‰ at the bottom were observed. By the end of

Post-southwest monsoon season (Sep.-Nov.)

Temperature : The surface water temperatures ranged from 25.0° to 31.0°C and the bottom temperatures from 26.0° to 31.0°C. The horizontal gradients in temperature during the season were of a low magnitude ranging from 1.0° to 1.5°C and the surface-bottom differences ranged from 0° to 1.5°C.

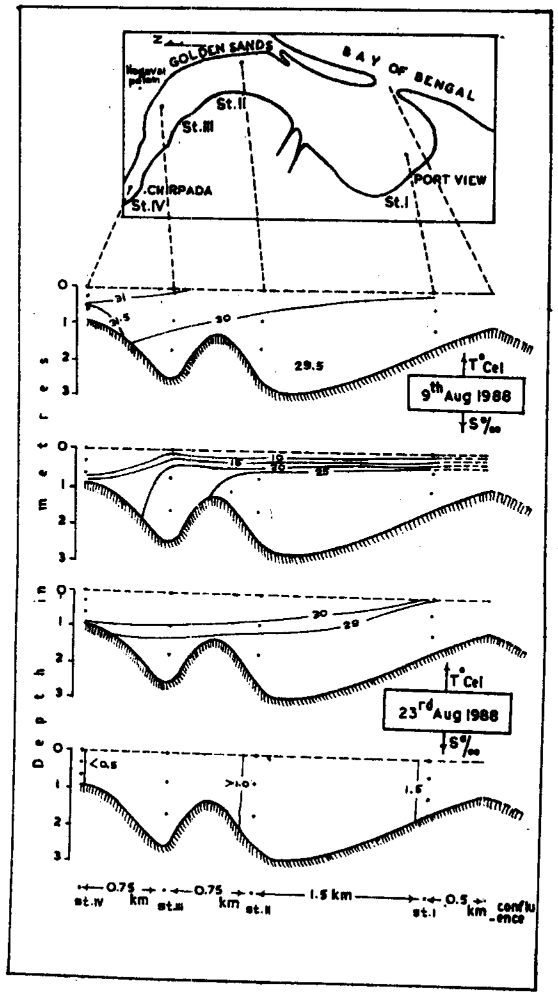

FIG. 10. Temperature and salinity structure in August 1988.

Salinity : This season was marked by the establishment of brackishwater conditions following a disruption of the observed pattern of horizontal and vertical salinity distribution (Fig. 11). This happened as a result of the freshwater let off from the Thatipudi Reservoir into the river towards the end of August. The establishment of brackishwater conditions, consequent on the penetration of sea water along the bottom by the end of September (Fig. 11), was as quick as the disruption of the established salinity gradient, a few days earlier.

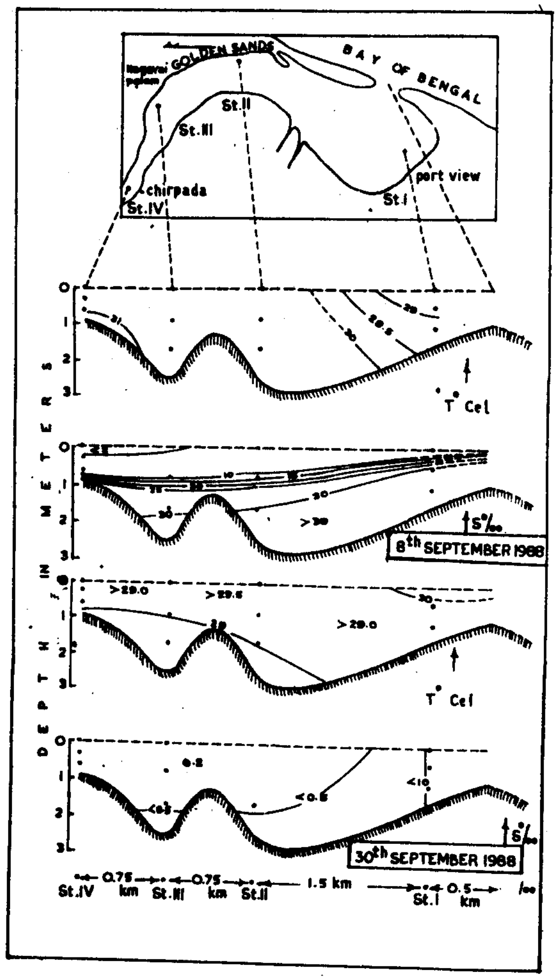

FIG. 11. Temperature and salinity structure in September 1988.

The estuary underwent a similar exercise again *i.e.* disruption of the salinity gradient by the end of September owing to local heavy rains that occurred during the second and third week of September resulting in the filling of the entire estuary with freshwater from surface to bottom (Fig. 11). With the cessation of rains, the sea water penetration increasing through tidal pressure, there was a quick recovery of the system and salinity increased progressively from October onwards slowly and progressively from the confluence (Fig. 12) resulting in intense stratification. Salinity ranged from near zero value to 21.83 ‰ at the surface and from near zero values to 32.07 ‰ at the bottom levels and the surface-bottom differences ranged from 0 to 28 ‰.

Discussion

Temperature

The temperature in a normal estuary is known to be initially controlled by the sea and the river and their proportions in the mixture at different states of tides (Day, 1951) and is therefore, a function of temperature of the entering stream and the sea together with tidal states. This being a shallow estuary with wide intertidal flats bordering the broad expanse behind the sand bar, the influence of solar radiation and evaporative cooling causing marked temperature changes, should be taken into account.

The estuarine stretch investigated is limited, not by choice, but because of the extreme shallowness beyond Stn. IV, where the water was about ankle to knee deep. The horizontal and vertical gradients in temperature, were reported to be wider in positive, deep and open major river estuaries such as Gautami (Rama Sarma, 1965), Vasista (Sai Sastry, 1987), tributaries of Godavari and Krishana (Ramanadham and Varadarajulu, 1975). In the Vellar Estuary (Jacob and Rangarajan, 1959) reported a similar wider range.

Vertical differences in temperature at different stations in Gosthani Estuary ranged from 0^{0} to 8^{0} C during the study period. Maximum differences prevailed during northeast monsoon and southwest monsoon seasons. These vertical thermal differences may be attributed to the differential warming of the surface and bottom waters and also the density differences between the less dense waters flowing over dense salt waters intruding from marine end. Considering the entire stretch studied the surface waters were less warm than those at the bottom (Fig. 2). Maximum differences prevailed in December and July of the northeast and southwest monsoon periods respectively. During the hot weather season the heat acquired by water is partly utilised in evaporation, partly reflected and a good amount is distributed to the underlying layers, under the stress of the wind (Birge and Juday, 1931). During the hot weather season the waters were vertically isothermal and the observed homogeneity resulted from active mixing under the influence of tides and prevailing high winds.

Salinity

During a major part of the study the salinity distribution pattern in relation to depth, distance and time revealed a decrease with increasing distance from the mouth as is the case of all 'normal' or 'positive' estuaries. The data on freshwater runoff indicate that inflows of freshwater into the estuary occur essentially during the southwest monsoon and the period extends from July upto and including October.

The ranges in the surface and bottom salinities were extensive, characteristic of both periodically closed and permanently open estuaries which experience annual freshwater flooding. The observed annual ranges were zero values to about 39.0 ‰ at the surface and bottom level near the confluence and from near zero values to 35.23 ‰ at the surface and from 0.40 to 35.0 ‰ at the bottom level at Stn. IV higher up.

The pattern of salinity distribution during the northeast monsoon season revealed an interesting phase in exhibiting a horizontal dome-shaped orientation of isohalines during

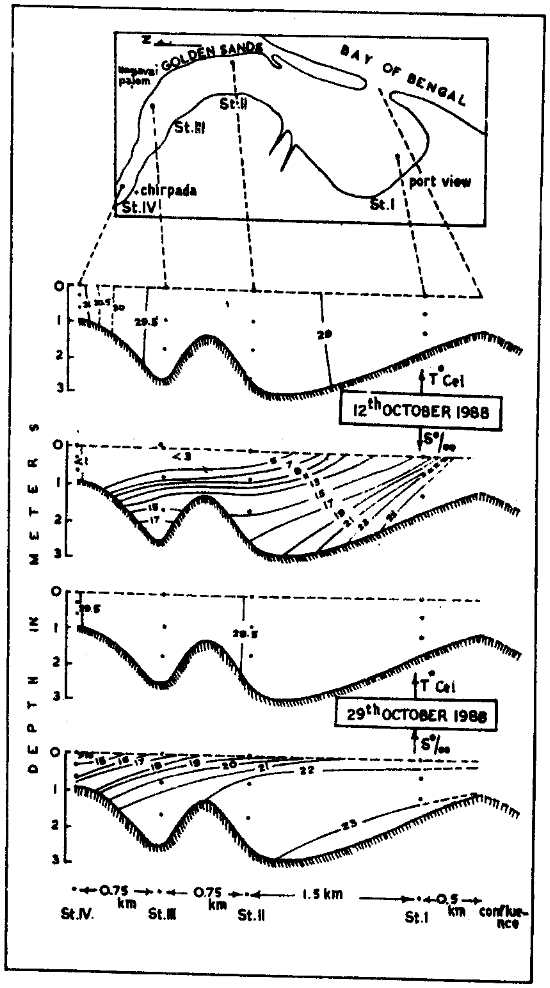

FIG. 12. Temperature and salinity structure in October 1988.

early December (Fig. 2). Salinities at the intermediate stations (II and III) were higher at the bottom than at either end. While the occurrence of low salinity at Stn. IV is understandable, the occurrence of low salinity as Stn. II and III relative to that at Stn. I, has obviously resulted from (i) incomplete flushing of sea water received from the neritic end during successive flood tides during early December and (ii) the two small depressions

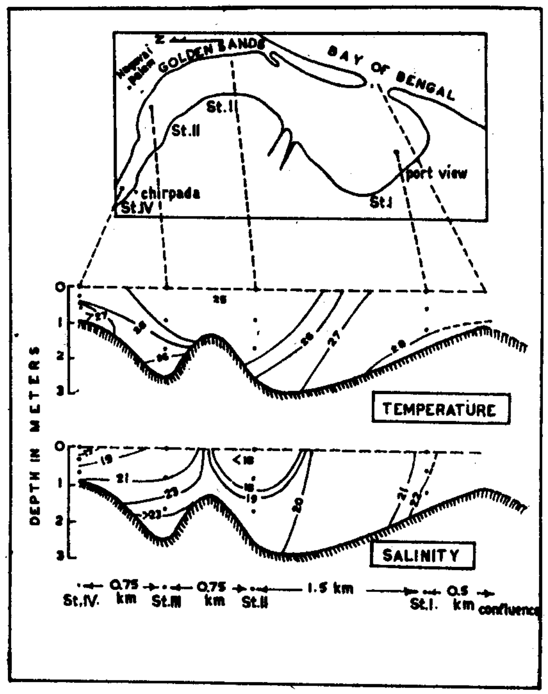

FIG. 13. Temperature and salinity structure on 14 November 1988.

at the bottom may have acted as receptacles of more saline water intruded earlier has been trapped, temporarily. The dome-shaped orientation of isohalines was only a transient phase which disappeared by the end of December and a pattern characteristic of a positive estuary reappeared (Fig. 2). The influence of freshwater inflow was still evident by the close packing of isohalines noticed more vividly at the freshwater end than at the neritic. The vertical orientation of isohalines at Stn. III and IV and the slanting orientation at Stn. I and II indicates the isohaline condition at the former and the slightly stratified condition at the latter respectively. With a progressive increase in salinity at all stations in the estuary, the zone of vertical stratification had shifted from the confluence to Stn. III and IV (Fig. 2) owing to tidal mixing and reduced freshwater inflows.

During the hot weather season there was a rapid increase in salinity, because of (i) the neritic inflow gaining momentum, (ii) cessation of freshwater inflows and (iii) high evaporation. The pattern of salinity distribution during middle of March was normal (Fig. 5). But at the end of March (Fig. 5) and again at the end of April (Fig. 6), the salinity distribution showed a departure from the normal pattern, *i.e.* relatively higher salinities at Stn. I and IV compared to those at the intermediate stations (II and III). This being a hot weather season the effect of evaporation on the ankle-deep waters at Stn. IV obviously was far higher because of shallowness compared to the waters farther down stream resulting in a rise in salinity. De Souza and Sen Gupta (1988) found an identical situation in Mandovi and Zuari Estuaries where concentrated brine was discharged from salt pans. It is, of interest to note that the maximum salinity recorded in the water on the coast was of the order of 35.5 ‰, the salinity of estuarine water varied between 38.0 ‰ and 39.0 ‰ in this season. There was a complete vertical homogeneity in the distribution of temperature and salinity in May owing to active mixing aided by wind and tidal currents.

During the southwest monsoon season, marked by a massive northerly littoral drift and formation of a sand bar which occluded the mouth, the estuary remained cut off from sea till it was breached manually. During this period the water level gradually rose by about 2 to 3 m above the average level obviously due to the seaward push of saline water located beyond Stn. IV as indicated by high salinity for about 3 weeks till a freshwater spate passed down from the upper catchment area in addition to the local rainfall and land drainage. Consequently a reversed gradient in salinity got established (Fig. 8). After the sand bar was breached, the estuarine water obviously was not flushed effectively into the neritic zone as evidenced by the disposition of isotherms and isohalines (Fig. 9). While there was a considerable lowering in salinity at Stn. II and III, salinities at the two extreme stations were relatively higher. The concave orientation of ishohalines indicates that the intensive stratification noticed at Stn. II and III had resulted from the pressure exercised by the inflowing freshwater from the upper reaches. Later, consequent on the activity of southwest monsoon, the seaward flow of freshwater at the surface level increased (Fig. 10) and the resident estuarine water was totally flushed into the neritic zone freshening the water at all levels and at all stations (Fig. 10).

During the post-southwest monsoon season the intrusion of sea water into the estuary gaining momentum, the system's recovery from major freshwater spate was fairly quick as evidenced by intense salinity stratification (Fig. 11). But no sooner than the system commenced recovering, another flash spate of freshwater aided by unusual local heavy rains occurred during September. This resulted in a disruption of the system's recovery again as evidenced by salinity structure (Fig. 11). The estuarine water was replaced by freshwater at all levels.

The disruption of the system was quicker than before. There was a progressive increase in salinity from the confluence and consequently a progressive shift, in the establishment of vertical stratification (Fig. 12). In November again there was a departure in the salinity distribution pattern, *i.e.* higher salinities at the two ends (Stn. I and IV). Obviously, high saline water got trapped in a trough at Stn. III during the preceding flood phase of the tide when sampling was made. This phase was ephemeral.

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