Studies on tide depended salt-silt wedge and identification of turbidity maxima in Cochin estuary

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Present study consists the development of salt-silt wedge in the estuarine environment and the identification of the occurrence of turbidity maxima zone(s) during the pre-monsoon season in the southern arm of Cochin estuary. An occurrence of secondary turbidity maxima zone has also been identified. It also consist Concurrent features among various hydrographic parameters, such as temperature, salinity, turbidity and current pattern The oscillatory behavior of the turbidity maxima zone(s) are analyzed with respect to the tidal rhythm.

[Keywords: salt-silt wedge, turbidity maxima, Cochin estuary]

Introduction

Estuary shows a composite dynamic behavior. Cohesive sediment transport in estuaries can lead to the development of turbidity maxima, which induces problems in both ecological and economical form. Movement of cohesive sediments can cause siltation in waterways and harbour docks, or erosion of estuarine banks. To deal with these problems, costly dredging operations are generally needed. Moreover, pollutant may then be adsorbed onto fine sediments and be available for re-suspension by strong tidal currents, short wave action and dredging operations. This desorption of contaminants from their particulate phase can significantly impact the ecological balance of shallow, near-shore areas. Therefore, accurate predictions of cohesive sediment transport processes in estuarine and coastal waters are of vital importance to environmental management. In order to understand the movement of suspended sediments in the estuarine environment, various surveys were conducted seasonally in Cochin estuary and results are present in this paper.

Materials and Method

Field surveys were conducted during pre-monsoon period of 2007. During this period the river discharge is minimum and therefore seawater intrusion is maximum for this estuary; During this season, estuary mainly shows a partially mixed condition favoring the development of turbidity maxima. In order to identify the salt-silt development and turbidity maxima zone(s) in this estuary, two detailed surveys were held on (1) 21-02-2007 and (2) 17-04-2007; the observations were made at single station, with respect to tide, IFP jetty and all along the southern arm of Cochin estuary, from IFP jetty to Vaikom, 20 GPS positioned stations, 2-way, from 8.00 A.M. to 6.45 P.M., respectively (Fig.1). Data on parameters namely temperature, salinity, turbidity, current speed and direction at an interval of 15 minutes each were collected at surface, mid depth and bottom, using EMCON instruments. The temperature and salinity were measured with Ship Borne Data Logger [temperature 0.0-50.0°C, accuracy ±0.1; salinity 0.0-38.0 psu, accuracy ± 0.1], turbidity in 0.0-1000 JTU, ±2%, and current speed and direction with current meter (accuracy ±2 cm/s).

Results and Discussion

Study No. 1: Salt – Silt Wedge

Temperature

Fig.2a depicts mid-depth and bottom values of the temperature as high compared to the surface values during the initial period of observation (high tide).
After some time, these values at surface gradually increases and reaches a maximum value of 29.9°C. This hike in temperature is due to the increase in insulation as the day progresses. Surface values of temperature are more susceptible to variation in this estuary compared to mid-depth and bottom layers. Minimum and maximum values of temperature at the surface are 17.0°C and 29.9°C respectively. At mid-depth, the temperature starts with a high value 29.2°C and it remains constant throughout the high tide period. Comparable change is noticed in the mid-depth values thereafter, with the reversal of the tide as evident from the Fig. 2a. At bottom, during the flood, the temperature is high (29.3°C), which later shows a decreasing trend. Compared to surface temperature which shows more or less similar values (~26.30°C), the bottom and mid-depth values are fluctuating (13.6 – 28.9°C).

Salinity

Salinity values indicated a steady and gradual fall from the commencement of study coinciding with the ebb phase of the tide (Fig. 2b). Surface, mid-depth and bottom values are almost comparable, thereafter, salinity values show an increasing trend (from 1300 hours) as the tide phase changes from low to high, with a phase difference at IFP jetty. The bottom salinity values are high compared to the surface and mid-depth values. At the end of high slack, the surface and mid-depth salinity showed low values (~29.0psu) but the bottom layer salinity showed higher values (~31.0psu). Jomon and Kurup10 (1987) observed that during the pre-monsoon period, the diurnal variations of salinity were found to be in phase with the tide, salinity increasing during flood tide and decreasing during ebb tide. Salinity values were often found to be higher at the estuarine inlet. It is reported that salinity values at mid-depth were closer to bottom salinity than the surface salinity during both ebb and flood tides. Influence of tides decreasing with distance from the estuarine mouth was also evidenced in this study.

Udaya Varma et al.11, (1981) observed that during pre-monsoon, at high tide, the salinity slightly increased in the estuary and then decreased during the low tide. They had observed that salinity of Cochin estuary was always lower than that of the nearby coastal waters, which indicated that Cochin estuary is a positive type of estuary. They had also noticed that all stations accounted for salinity in the range of 32.0 to 36.5psu. During different phases of tide, the vertical salinity gradient was negligible indicating the presence of a comparatively well-mixed layer in Cochin estuary. Rasheed et. al.12, (1995) examined the surface salinity values which gradually increased throughout the flood phase and further on, ending at a constant value, during pre-monsoon period and later, decreasing during the ebb phase. The middle and bottom salinity values were slightly higher during the initial flood phase than those at surface, but nevertheless, attained a constant value (32.0 psu) as that of the surface during slack period. From the foregoing, the present results are in conformity with reports on salinity distribution in Cochin estuary to the extent that during pre-monsoon, well mixed conditions prevail during low tide phase but partially mixed conditions may result during flood period. There are indications that a salt-wedge development is apparent from the results of this study functioned by tides.
**Turbidity**

The initial observation at IFP jetty revealed that the bottom layer was occupied by a high turbidity, (95.0 JTU) and the surface has a low turbidity value of 27.0 JTU as evidenced from the Fig. 2c. By the end of low tide, the bottom turbidity values had decreased gradually and thereafter a fluctuation was noticeable. The surface and mid-depth turbidity values also showed this kind of fluctuations, as the tide progressed. On the high tide phase, the surface values increased to peak values (about 97.0 JTU), as revealed in Fig. 2c. Towards the end of the survey, as the tide phase changes to ebb (Fig. 2d), a moderate decrease in turbidity values was also observed. In Cochin estuary maximum transparency in water column had been reported during the pre-monsoon period (Qasim et al. 13, 1968). Again during this period, Gopinathan and Qasim 14 (1971) reported that the suspended sediment concentrations in Cochin estuary were relatively low. They had observed these values were about 10 mg/l at the surface and with little change in concentrations up to mid-May. The values at near bottom for this estuary were higher than those observed at surface. This study reveals that the turbidity profile follows the tide rhythm with mild lag and that as reported earlier; the bottom values often are higher than those at surface.

**Currents**

The stick plots on current vectors clearly demonstrate the cyclic behavior of the tide in this estuary. At the commencement of observation, comparatively higher current speeds were observed at all depths (surface, mid-depth, and bottom). Maximum surface current observed was 98.0 cm/s and minimum 12.0 cm/s followed by mid-depth values of 100.0 cm/s maximum and minimum of 7.0 cm/s (Fig. 3a-c). At bottom, higher current was observed (87.0 cm/s) whereas the minimum was 8.0 cm/s.

It is observed from Fig. 3a-c that the current flow is towards the downstream of the estuary upto 1.00 P.M. and thereafter upstream to coincide with the flood. Generally the current speeds justify the gradual and progressive tide incursion, in and out of this estuary.

Worthwhile to note is the pattern in current vectors when at all three depths, the direction is similar, but the magnitude is largest at the surface. Mild variation in direction is also noted as tide alters from ebb to flood, mainly at mid-depth and bottom.
According to Udaya Varma et al. (1981), during the pre-monsoon period, the flow pattern is mainly depended on tidal conditions. During high tide, the flow was into the estuary from bottom to the surface with a velocity not exceeding 70 cm/s. Velocities were more or less of the same order of magnitude near the harbor mouth and again, in both the channels (Ernakulam and Mattancherry). During low tide, the highest velocity was often observed in both the channels around 70 cm/s, each. Highest velocity was recorded at harbor mouth as 110 cm/s. Duration of flooding and ebbing on spring tide days is longer by more than 1 hour compared to neap tide days. Flood currents were faster than the ebb currents and the highest current velocity occurred during April, recorded as 125 cm/s at surface during flood at station located on the southern side of the estuarine mouth in the approach channel (Jomon and Kurup, 1987). Primary data collected in 1998-99 as part of Carrying Capacity Studies reported the seasonal variations of current speed in the Cochin estuary during pre-monsoon, as surface currents in the range of 5-195 cm/s, and that at bottom 4-77 cm/s.

Study No. 2: Turbidity Maxima Zone in Southern Arm

Study of salt-silt wedge leads essentially to the identification of estuarine turbidity maxima zone(s) [ETM], which for an estuary at Cochin could play an important role in the sedimentation processes, especially at the harbor sites. The port often experiences heavy traffic, and sedimentation brought about by the presence of ETM will bring about a major conundrum in the estuarine morphology. To study the suspensate development and formation of the ETM zone with respect to tide, another detailed field investigation from IFP Jetty to Vaikom and return was held on 17-04-2007 from 8:00 am to 6:30 pm.

Tide Phase (Low to High)

Temperature

Surface temperature showed low values (25.5°C-27.5°C) compared to the mid-depth values. Generally, the surface, mid-depth and bottom values are showing an increasing trend from IFP Jetty to Vaikom. As the day progresses, this increasing trend may be due to the enhanced solar radiation (Fig.4a). It is noticed that the difference in range of temperature between the mid-depth and bottom are low compared to the difference in temperature between surface and mid-depth layers. This may be due to the differential vertical mixing between layers.

Salinity

Observations had begun coinciding with the phase of tide, altering from low to high tide. Higher values of salinity were observed at bottom, but as expected, a decrease was observed towards the surface (Fig.4b). This pattern of scenario continues, but the values of the salinity goes on decreasing towards upstream. Generally, at surface and subsurface layers, decrease in salinity is noticed throughout the period. A minimum value of salinity (8.5 psu) was observed near Vaikom at the surface, mid-depth and bottom layers; here, at upper most locations, a well-mixed condition was noticed.

Turbidity

During pre-monsoon period, Gopinathan and Qasim (1971) had observed that the estuarine waters are marked by uniformly high salinity (32.0 psu) and high temperature of about 29.0-32.0°C. The fresh water discharge into this system during this period is minimal and hence no stratification in occurs in the...
water column. Initially, turbidity in the surface waters showed a low value of 25.0 JTU and bottom waters a high of 48.0 JTU. An increasing trend was observed at all depths, cruising towards upstream. Near to Thevara New Bridge, the surface waters showed high turbidity values compared to mid-depth but at bottom, low values prevailed. Near Kumbalam Bridge, high values of turbidity (66 – 77 JTU) were recorded at surface, mid-depth as well as at bottom (Fig.4c); this infers turbidity maxima development in the estuarine zone linked to tidal propagation (Fig 4d). Thereafter, at Perumbalam North, another peak in turbidity was observed which is identified as a secondary ETM zone. On moving further upstream, turbidity values remained more or less the same (30.0 to 40.0 JTU). Conceptually, the ETM occurs at low to mid salinity values, often in the mid-estuarine reaches for partially mixed estuaries; certain high latitude estuaries have reported ETM in the very low salinity regimes too\textsuperscript{1,15,16}. It is interesting to note that in this study, two peak zones could be identified for Cochin estuary.

Currents

Fig.5a-c indicates that the surface current was flowing downstream (northerly) in this estuary and at mid-depth and bottom, the flow was towards upstream (locally modified to channel orientation) in the initial period of observation. Later, even after the lapse of two hours, along the surface layers, the currents were directed downstream indicating the prevailing circulation pattern for this estuary. However, along the bottom and partially, at mid-depths, the flow was towards upstream, signifying the two layer structure during pre-monsoon months.

Tide Phase (High to Low)

Temperature

Observations from Vaikom to IFP Jetty are helpful to identify the estuarine conditions during the reverse phase. The phenomena relates to bottom and mid-depth temperature of high values (~27.5°C) compared to surface (Fig.6a); the surface waters showed low values around 21.0°C. This observation of warm sea water presence (along bottom and mid-depth layers) indicates the intrusion and partial mixing of dissimilar water masses, evidenced on the downstream segment of this estuary.

Salinity

As the low tide commences, it is noted that the salinity at the surface, mid-depth and bottom have almost similar values (10.0 to 12.0 psu) but an increasing trend is visible towards downstream (Fig.6b). The observations also support the contention

![Fig. 5a-c—Stick plots of currents from Ernakulam (stn. 1) to Vaikom (stn. 20) during high tide period on 17/04/2007](image)

![Fig. 6a-d—Distribution of temperature, salinity, turbidity and tide (predicted) from Vaikom (stn. 20) to Ernakulam (stn. 1)](image)
that the upper estuary section is well mixed whereas, the mid and lower estuary regions are stratified in terms of salinity, as the bottom values are greater than those noted at mid-depths and surface. This feature is prominent at the fag end of the low tide, as the receding ebb is prominently driven at surface, followed by waters of mid-depth and later along bottom; the last set of readings indicate the start of next high tide in this estuary.

**Turbidity**

Unison variations in turbidity values were observed from Vaikom to IFP Jetty in Ernakulam channel. Initially low turbidity values were observed in the entire water column. Towards downstream, an increasing trend was observed. It is noticed that during this period, higher value of turbidity occurred at surface and mid-depth layers. This is inferred as the transport of the entire column of turbidity maxima from the previous phase of the tide to mid and lower estuarine sections. Only mild fluctuations in turbidity were noticed, thereafter, (Fig.6c). The location identified for development of turbidity maxima during the period of observations, is the Perumbalam region as low turbidity values were observed towards upstream and later maintained downstream, to coincide with the ebb tide.

**Currents**

Profiling the estuary, stick plot results plotted in Figs.7a-c, deduced the flow pattern at all depths - the maximum current speeds observed at surface, mid-depth and bottom were 98.0, 80.0, 86.0 cm/s respectively and minimum were 15.0, 16.0, 9.0 cm/s respectively. The surface flow was southerly, meaning the prevalence of flood in upper estuary though the predicted tide at Cochin inlet would indicate the commencement of ebb. The lag in tide phase is much evident from the results, in that, the current vectors reveal a time factor extending up to 3 – 4 hours against predicted tide at Cochin inlet. As time lapses, and observations shifted to down estuary, the pattern of flow too has altered at mid-depth and bottom as to evidence ebb flow conditions; the end current readings justify the strengthening of ebb flow (northerly at IFP Jetty).

**Oscillatory behavior of the Turbidity Maxima Zone**

From the results assimilated, during the first period of observation, (low to high tide phase) traversing towards upstream, the turbidity maxima zone was identified one near Kumbalam bridge and other at Perumbalam north (secondary maxima). Studies at the singular location (IFP Jetty) had identified earlier the development of salt-silt wedge, and entry of saline waters into the estuary during the high tide period, especially in pre-monsoon season. This process leads to the physical development of turbidity maxima which is the accumulation of suspended particulates in a particular region of the estuary conditioned by the salinity factors (leading to flocculation) and on extent of riverine inputs of suspended solids.

On reversal to the next tidal phase, the observations held on transit downstream (high to low tide period), the turbidity maxima zone was identified in the vicinity of Perumbalam. This indicates that on cyclic propagation of the tide, the turbidity maxima zone is translocated towards upstream; clearly this depicts that the turbidity maxima zone is oscillating to and fro with respect to the tide and eventually, controlled by mixing that takes place in between surface and subsurface layers.

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