ESTUARINE OCEANOGRAPHY OF THE VEMBANAD LAKE

PART I: THE REGION BETWEEN PALLIPURAM (VAIKOM) AND THEVARA (COCHIN)

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ABSTRACT

The paper gives the results pertaining to the region between Pallipuram (Vaikom) and Thevara (Cochin) of a detailed estuarine-oceanographic study attempted on the Vembanad lake from Pallipuram in the south to Azhikode in the north. The study was aimed primarily at classifying to what type of estuary the lake belongs. As the two factors almost equally influencing the lake, namely the incursion of salt water from the Arabian sea and fresh water from the rivers, both being by far governed by the monsoon, the major classification was attempted on a seasonal basis.

This southern stretch of the lake, from Pallipuram to Thevara, is found to be distinctly different in character from the northern stretch, from Cochin to Azhikode, almost throughout the year, evidently due to its distinct circulation pattern, induced in turn by the greater and varied river runoff received into this region. During the monsoon, as a result, this region of the lake is a highly stratified Salt-wedge type of estuary; but during both the pre- and postmonsoon periods it changes partly over to the Partially mixed type and partly to the Vertically homogeneous type, the latter occurring at the shallowest stations Perumbalam and Pallipuram.

The incursion of upwelled waters into this region and the mixing process like entrainment during monsoon are discussed. A future line of work for continuous salinity and velocity measurements, which will be highly helpful in understanding the mixing process, is indicated.

INTRODUCTION

Early studies of estuaries were mostly studies of distribution of properties of estuaries, confined accordingly to the interests and specialities of the observers. Because of such limitations, these studies were not able to account for the variation of properties commonly occurring not only among different estuaries but also within each estuary among different seasons. The 'Estuarine Oceanography' was first suggested by Cameron and Pritchard (1963) to the study of the quasi-dynamic balance between the freshwater continuously being drained from the land into the estuary and the sea water pressing inward, which in turn might explain the property variations. These two influences, characteristically differing from estuary to estuary, make the circulation and mixing in each estuary distinct; and unless these two contributing factors were comprehended in detail, both in space and in time, it might not be possible to define the estuary correctly.

The Vembanad lake is by far the largest of the lakes along the south-west coast of India, and, with its sizeable fishery resources and its aiding extensively in transport, it plays an important role in the economy of the region. The lake, freely opening into the Arabian sea at two places, Cochin and Azhikode, forms an extensive estuary topographically divisible into two arms: a southern one extending south from Cochin to Vaikom and a northern one extending north from Cochin to Azhikode, (Fig. 1). The southern arm, the larger of the two, receiving the bulk of the land drainage through many rivers and canals and the sea connected with it only through the opening at Cochin, is more or less a typical tropical estuary; whereas the northern one, receiving river discharge only from a major river, the Periyar, and being connected with the sea at two ends, Cochin and Azhikode, is hydrographically unlike the southern arm.

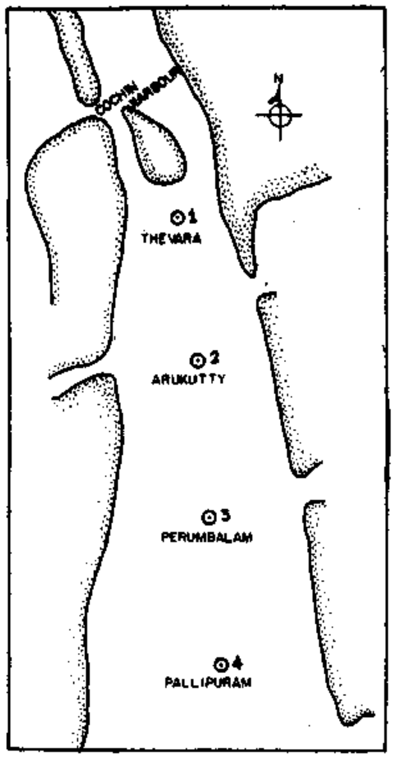

FIG. 1. Location of hydrographic stations in the Vembanad Lake from Vaikom to Cochin. (distance between stations is 5-6 miles; sketch not according to scale)

Over the past two decades a few attempts were made at correlating tidal oscillations with the observed salinity changes of the estuary, which had varied in intensity from station to station depending on their distance from the Cochin inlet. Balakrishnan (1957), one of the earliest to study the surface salinity of the Ernakulam channel, attributed the rapid salinity fluctuations to the influence of tide. But George and Kartha (1963), examining five years' data on tides and salinity, did not find tidal influence on the surface salinity of the channel. From the higher surface salinities during January-May that were independent of the tide they had inferred that there was possibly present a bottom layer of a more saline and cooler water in the channel. Ramamirtham and Jayaraman (1963), more or less confirming this view, reported the occurrence of a well-oxygenated state of water around the Willingdon island from November to May. According to these authors between June and October the flood waters from the rivers predominated at the surface while a tongue of upwelled water distinguishable by the low temperature and oxygen content, forced in by tide and upwelling, extended along the bottom of the estuary and maintained a vertical temperature gradient of 4°-6°C in 5-6 m. This vertical gradient, however, was to disappear along with the resistance to mixing closely after the end of the postmonsoon period; this rapid transformation marking the completion of an annual cycle of changes. Later, Josanto (1975), having studied the entire region from Alleppey to Azhikode, gave a detailed picture of the spread of saline water along the bottom of the estuary.

The present account deals with the observations on temperature, salinity and dissolved-oxygen content in the southern arm of the estuary, between Pallipuram and Thevara, both in space and in time, and with a process of entrainment by which part of the intruding sea water below is eroded back to the sea. The account also attempts at classifying the estuary based on the distribution of salinity and the flow characteristics during the different seasons.

Methods of Study

Four stations were fixed in the estuary, at Thevara, Arukutty, Perumbalam and Pallipuram (Vaikom) (Fig. 1). In all the stations the parameters, salinity, temperature, and dissolved oxygen, were measured both at the surface and at the bottom once in a fortnight from October 1980 to May 1982. The distribution patterns of the properties are presented as contour diagrams instead of the usual graphs as such a presentation done earlier by Ramamritham and Jayaraman (1963) is deemed more useful for understanding and interpreting the patterns.

Distribution of properties

Temperature

The distribution of the surface temperature in the area is presented in Fig. 2. It may be seen from this figure that the maximum surface temperature occurred during peak summer (April) and that there was a gradual increase of temperature from station 1 to the head of the estuary, the maximum occurring at the stations Perumbalam and Pallipuram. This was obviously because these stations at the southern head of the estuary, being the shallowest stations, varying in depth from 2.5 m to 3.5 m, did not receive the colder sea water, which intrudes minimum during summer.

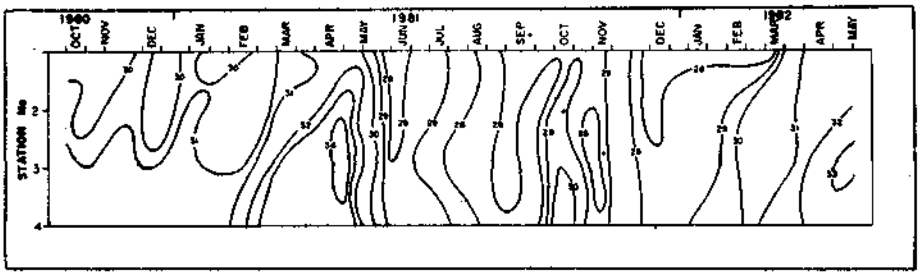

FIG. 2. Distribution of surface temperature in the investigational area.

The minimum surface temperature was observed during peak monsoon, during which season also there was a gradual increase of temperature southward, though the increase was not so conspicuous as in summer. The bottom temperature (Fig. 3), on the other hand, was more regularly distributed with a time gradient and an ascendant, obviously as a result of the influence of upwelled waters on the bottom layers. During the peak monsoon (August) the colder water was more marked at Thevara station, though the intrusion of which could be traced up to Perumbalam. After the monsoon there was a gradual increase of temperature at the bottom till the maximum (32°C) was reached by the end of April.

An examination of the thermal stratification in the estuary may be interesting. Thevara being the station nearest to the sea, the influence of sea water,

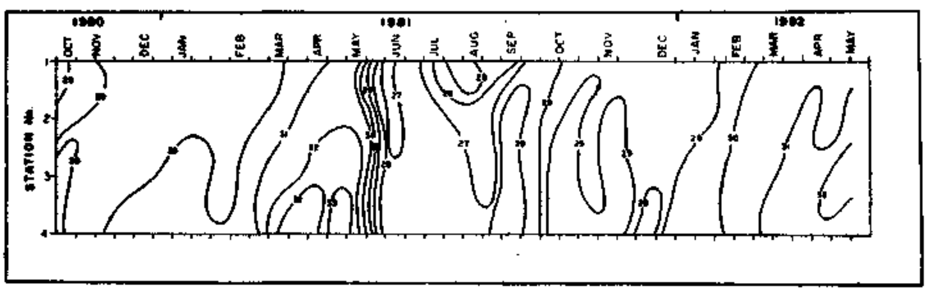

FIG. 3. Distribution of bottom temperature.

which is coldest during monsoon, was maximum at this station. But in a vertical column of 10-11 m there was a temperature difference of 3-4°C between the bottom, indicative of the existence of an estuarine thermocline — rather a metalimnion (Wetzel 1975) — at this Station. This feature extended up to Arukutty, 10 km south of Cochin. Except for this feature at the height of the monsoon, the vertical stratification of temperature was almost nil resulting in a more or less isothermal condition vertically. Longtitudinal variation in temperature was negligible along the surface, though it was present in the bottom layer during monsoon.

Salinity

Salinity variations were more conspicuous in the longitudinal direction down the estuary (Figs. 4 & 5). Considering the December-January period of 1980-81, the variations at the bottom were from 1 to 33‰, the latter value occurring at the Station at Thevara (Fig. 5). However, the variations were not so prominent at the surface layers during this period, though here too the average gradient from the region of confluence to the head of the estuary was strong (Fig. 4). The surface to bottom differences in salinity were not much during pre-monsoon period as can be seen from the figure.

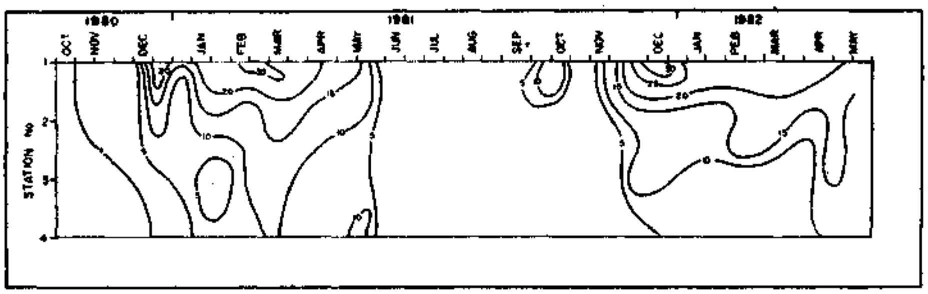

FIG. 4. Distribution of surface salinity.

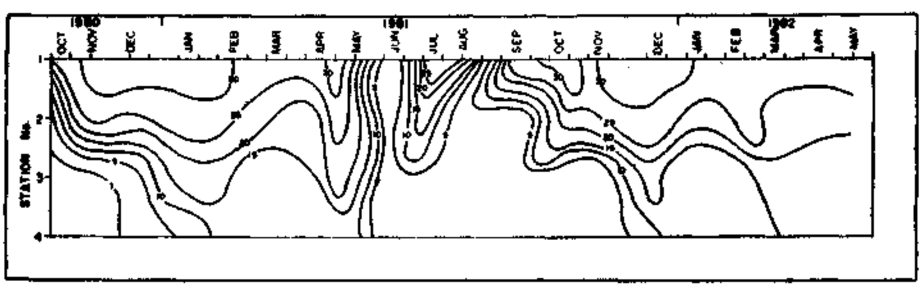

FIG. 5. Distribution of bottom salinity

The onset of monsoon brought a drastic change in the salinity distribution similar to temperature. From June to about early October the surface salinity values were almost zero. However, the bottom values were comparatively high, resulting in a well-defined salinity stratification in the vertical. Thus a strong halocline could be inferred during the monsoon. This halocline lost its vertical stratification while proceeding to the head of the estuary, and was much weaker beyond Arukutty. After the monsoon, there was an increase in salinity both at the surface and at the bottom with the maximum occurring during the period December-February.

Dissolved Oxygen

The distribution of dissolved oxygen was more or less uniform in the surface layers (Fig. 6). The observed variations were restricted to the bottom layers, and that too only during monsoon (Fig. 7). During the monsoon, when the bottom salinity varied between 34 and 35‰, the oxygen content was as low as 0.5 ml/l. The oxygen-deficient cold water at the bottom at Thevara and Arukutty stations at this time was identical to the cold inshore waters off Cochin.

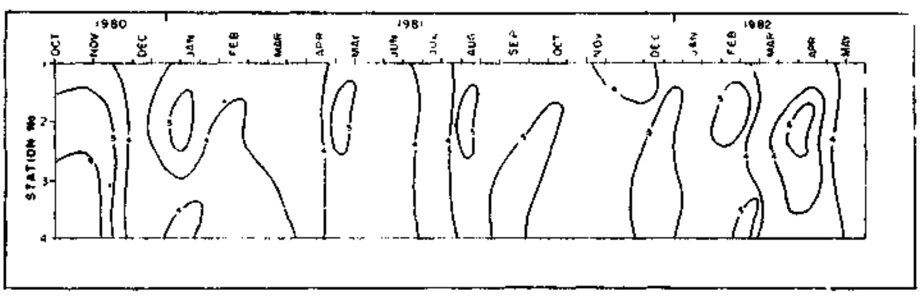

FIG. 6. Distribution of dissolved oxygen at the surface.

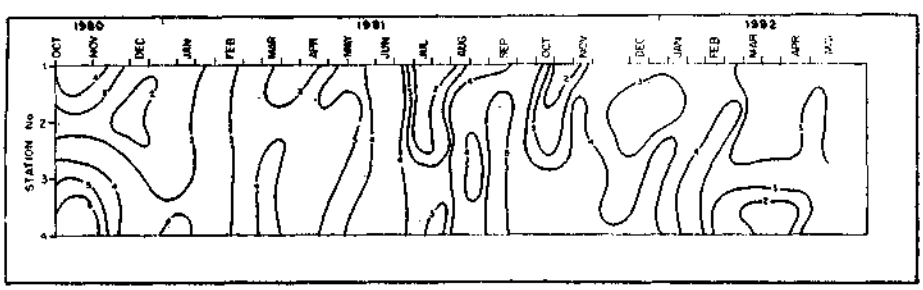

FIG. 7. Distribution of dissolved oxygen at the bottom.

DISCUSSION

From the above observations it can be seen that the distribution of salinity in the southern arm of the Vembanad lake undergoes drastic changes with seasons. Also, a conspicuous longtitudinal variation is evident. Hence, assigning a particular single classification to this part of the estuary becomes difficult. Pritchard (1952) has geomorpholigically classified the estuaries into (1) Coastal plain estuaries, (2) Fjords and (3) Bar-built estuaries; but the Vembanad lake distinct as it is from any of these, cannot be assigned to any one of the above classification. A better classification was suggested on the basis of salinity distribution and the tidal flow characteristics in an estuary by Pritchard (1963) and Cameron and Pritchard (1963). They have given four main types under this consideration, viz:

1. Highly stratified or salt wedge
2. Fjords
3. Partially mixed
4. Laterally inhomogeneous and Sectionally homogeneous

Considering the salinity distribution pattern in this arm of the Vembanad lake during monsoon, it can be observed that a strong halocline exists in the region from surface to bottom. The vertical mixing in the presence of such a halocline is highly restricted and, as has been observed during the period of study, there exists a seaward surface flow whose velocity decreases towards the mouth of the estuary. The velocity of this flow is much less in the region Arukutty to Thevara compared to the region Arukutty to Perumbalam. According to Pritchard (1955), in a Saltwedge estuary the water less dense than the seawater flows outwards over the surface of the saline layer. The velocity of the surface layer decreases towards the mouth as the estuary widens. There can be no mixing of salt water and fresh water and no motion at all in the Saltwedge. Considering all these it can be inferred that, during monsoon and early post monsoon, this part of the Vembanad lake belongs mostly to the Saltwedge type.

During monsoon, as mentioned earlier, the velocity of the surface flow towards the sea is considerable and the halocline is also well stratified. Hence it is possible for a thin layer at the top of the salt wedge to be swept seawards, because of the velocity shear. When this shear is sufficiently strong, waves form and break at the interface and the deeper salty water is mixed with the surface fresh water. Describing a similar situation, Tully (1958) has stated that fresh water flowing over sea water would enroute entrain the latter to form a halocline, in which salinity would increase with its approach to the sea as well as with its depth. Such a type of entrainment is a oneway process. The mixing in the southern stretch of the estuary from Cochin to Vaikom during the monsoon appears to belong to this category though the mixing itself is weak.

During pre-monsoon and late post-monsoon periods, the surface-bottom differences in salinity are much less than those encountered in the monsoon, indicating that the halocline has become weak and, by a process of mixing, there is a more or less isohaline water column in the estuary. It is significant that the velocity of the surface seaward flow during the pre- and late post-monsoon is much less when compared to that during monsoon. Hence, during the pre- and late post-monsoon mixing due to entrainment is more or less absent. But the reversing currents associated with the tides could still greatly enhance the exchange between the surface and the bottom waters. Dyer (1973) stated that it requires only a small tidal range to make the entire contents of the estuary oscillate. Such tidal motions (Ketchum 1951) cause the movement of the water masses across the bottom and generate extra turbulance, which sends salt water into the upper layers and fresh water into the lower layers and the salinity in both the layers increases towards the mouth of the estuary. Thus, during the pre- and late post-monsoon seasons the southern arm of the Vembanad is a Partially mixed type owing to the turbulant mixing which enhances exchange processes in the vertical.

The stations south of Arukutty are shallow as has been mentioned earlier, and the water column is mostly homogeneous in the vertical during the pre- and post-monsoon seasons. Dyer (1972) has mentioned that with increasing tidal range mixing can become sufficiently intense for the water column to be homogeneous in estuaries which are shallow. Pritchard (1954), however, has shown that the horizontal advective flux and the vertical non-advective flux of salt are the most important factors in maintaining the salt balance and that the vertical non-advective flux of salt is partly related to the magnitude of the oscillatory tidal currents. Thus, during the pre- and post-monsoon seasons, the shallow region south of Arukutty belongs to a well-mixed Sectionally homogeneous type because of the reversing tidal currents and greater turbulance resulting in increased fluxes of salt in the horizontal as well as the vertical, leading ultimately to homogeneous conditions.

Observations on the direction of drifting of reversing bottles used in sampling deeper layers showed a landward counter flow when the surface flow was seaward. According to Tully (1958) turbulance is a consequence of the velocity shear between the upper seaward-moving zone and the lower inward-moving zone, and the turbulance may be regarded as the random exchange of fluid elements. This probably is the mechanism of mixing in operation during the pre- and post-monsoon seasons in the southern arm of the Vembanad lake.

When fluid elements are exchanged vertically in a stratified fluid their displacement is opposed by stability which acts against turbulance, and this would restrict vertical mixing (Tully 1958). Thus the strong vertical stratification and the presence of the halocline during monsoon results in high vertical stability, which would hinder vertical mixing in the region from Cochin to Vaikom. Therefore, turbulence appears to be more efficient in restoring vertical homogeneity of the waters than the process of entrainment, which is weak as mentioned earlier in the investigational area.

An examination of the salinity distribution reveals that the variations in a longitudinal plane are from 5 to 30‰, down the estuary indicative of a laterally inhomogeneous type of estuary, since estuaries which are vertically homogeneous may show a variation in salinity in the longitudinal direction. Moreover, the absence of strong vertical gradients of salinity during the pre- and post-monsoon seasons suggests that the salt distribution in such an estuary is not governed by vertical processes, but rather by lateral and longtudinal transfers by advective or non-advective means. On the other hand, it is a fact that the vertical mixing of water elements is responsible for the homogeneity of a water column. The apparent inconsistency arises from an as yet unsatisfactory description of the non-advective flux processes (Cameron and Pritchard 1963). Therefore, sophisticated monitoring and interpretation of the short-term variability of salinity and currents in the vertical are desirable to achieve a satisfactory understanding of the role of vertical mixing processes in the investigational area.

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