J. mar. biol. Ass. India, 1971, **14** (2): 487-495

ON THE HYDROGRAPHY OF THE COCHIN BACKWATER, A SOUTH INDIAN ESTUARY*

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ABSTRACT

The Cochin Backwater is a system of lakes and estuaries along the west coast of South India. The hydrographical conditions depend on the influence of the sea and the rivers. The Cochin Backwater is connected with the sea by the inlet of the Cochin harbour and some minor entrances. The land and islands are of alluvial origin.

Meteorologically three seasons can be observed :
(1) Pre-monsoon season from January to May, dry and hot.
(2) Monsoon season from June to August, moist and cool, with much rain and wind.
(3) Post-monsoon season from September to December, moist, constantly becoming hotter and dry.

The seasons can also be traced in the hydrographical situations in the Cochin Backwater. The north-east monsoon can seldom be traced in Kerala, and it is usually not considered as a separate season.

During the pre-monsoon season the Cochin harbour area, which has been investigated by the author, shows no salinity stratification. During the SW monsoon the conditions change very quickly in accordance with the freshwater influx from the rivers. The stratification built up during the monsoon season persists throughout the post-monsoon season until at the beginning of the new year the influence of the sea grows and the river output decreases to small amounts.

INTRODUCTION

THE Kerala backwaters extend as far as 20 km into the country of South India and extend mainly between 9° and 11° north latitude. In Fig. 1, a general picture of the area is given. The right dotted line indicates the western boundary of the Western Ghats and the left dotted line the eastern boundary of the coastal alluvial land. Between both extends a low hilly area which consists mainly of laterite and its derivates. The hatched area indicates the backwaters from the old Periyar mouth in the north to the Vembanad Lake in the south (V.1.). The contours of Fig. 2 are indicated as ' special map '.

This work was sponsored by a research fellowship given by the Ministry of Education, Government of India, by the ' Deutsche Forschungsgemeinschaft ', and by the ' Deutscher Akademischer Austauschdienst '. The author wishes to thank Dr. N. K. Panikkar, Director, and Dr. S. Z. Qasim, Director-in-charge, both of National Institute of Oceanography, India, for valuable aid and encouragements. Mr. A. S. H. Abidi, New Delhi, was so kind as to help to collect the samples. My special thanks goes to Mr. C. K. Gopinathan, Cochin, for his valuable criticisms, for

* Presented at the ' Symposium on Indian Ocean and Adjacent Seas — Their Origin, Science and Resources ' held by the Marine Biological Association of India at Cochin from January 12 to 18, 1971.

conducting salinity determinations and for making a number of calculations. Mr. J. V. Juario, Bremerhaven, kindly read the English version of the manuscript.

The Kerala backwaters are separated from the sea by an alluvial bar or sand spit. Dense population, industries and the harbour contribute to the pollution.

The central part of these backwaters is called the Cochin Backwater, a part of which is shown in Fig. 2. The hydrographical data in this paper have been collected from August 1965 to July 1966 on stations 1 to 4 in 1 and 7 m depth. The distance

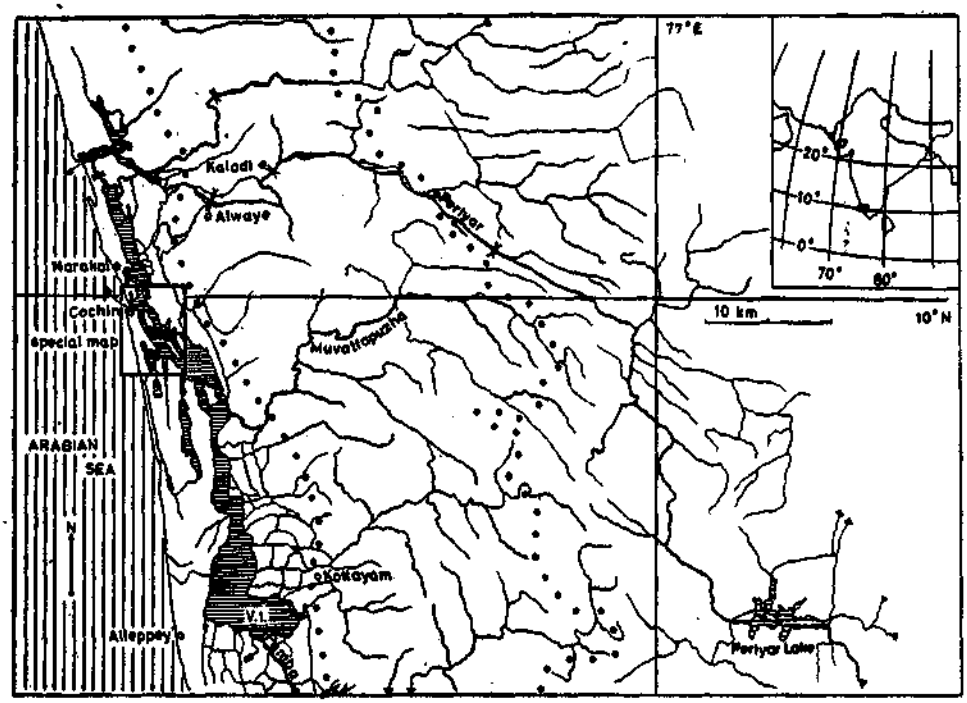

Fig. 1. River and channel system in the main catchment area of the Cochin Backwater. V.1.—Vembanad Lake. Special map indicates position of Fig. 2.

between stations 1 and 4 measures ca. 13 km. The arrows indicate the ebb current direction, and for some places a rough idea of the depth profile is given : the straight line shows the position of the profile ; at station 1 the maximum depth was ca. 13 m. Apart from the main entrance from the sea to the backwaters at Cochin (near station 1 in Fig. 2), several minor inlets can be found along the Kerala coast, some of them being open only during the monsoon season. The main inlet or barmouth at Cochin supplies the backwaters with sea water and serves as the main mouth for the rivers. The Periyar River is the biggest of them. About three-fifth of its discharge flow through the Cochin inlet, whereas about two-fifth enter the sea through another inlet farther north (*Courtesy:* Chief Engineer, Irrigation, Trivandrum).

The tides enter the backwaters mainly through the Cochin inlet. At Cochin the mean tidal difference measures about 45 cm, varying between 110 and 5 cm

(Deutsches Hydrographisches Institut 1964). Thus, the Cochin Backwater can be characterised as a ' tropical bar built estuary '.

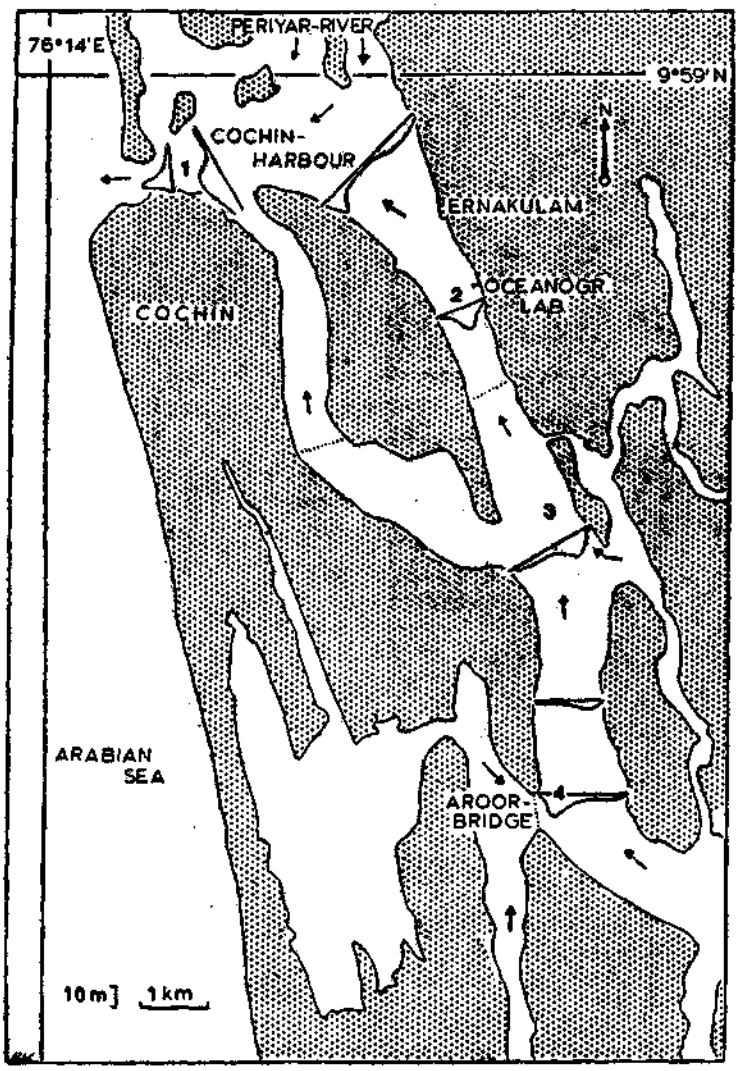

Fig. 2. Cochin Harbour with stations. Scales : left : depths in the profiles, right : distances.

The Seasons

Although five seasons can be observed in India, only three are important in Kerala, namely : pre-monsoon, south-west monsoon and post-monsoon seasons. The conditions as observed in 1965/66 are shown in Fig. 3,I. The rainfall data at Cochin may give an idea of the rainfall in the whole catchment area of the backwaters

(data from Witt. Uebersee 1965+66). The Periyar River discharge curve runs parallel to the rain curve (Fig. 3,II).

Generally seen, the south-west monsoon season starts in May, June or July, lasts some weeks or months, and varies considerably in strength. After the monsoon season, the rainfall decreases slowly during the post-monsoon season, which lasts until the end of the year. This season is characterised by decreasing precipitation and increasing drought. In 1965 there was rainfall during December, but it had little influence. From January onwards, practically no rain was observed during the pre-monsoon season ; but in April and May, a slow increase indicated the next monsoon season. The Periyar River discharge data (Fig. 3,II ; *Courtesy:* Chief Engineer, Irrigation, Trivandrum) show a phase displacement which is figured by thick dashed lines.

Observations

The hydrographical situation in the Cochin Backwater during the seasons is clearly shown in Fig. 4 where length profiles of the salinity between stations 1 and 4 are given.

Pre-monsoon season : Figure 4,I shows the typical homogeneous situation of the pre-monsoon season during April.

Only a very weak, if there was any, vertical gradient of the salinity was observed. The salinity was almost marine, slowly decreasing towards the inner parts of the Backwater. This situation lasted from December or January until the beginning of the monsoon rains.

South-west monsoon season : (Fig. 4,II) A short while after the monsoon rains had started the water in the rivers rose very much (Fig. 3,II), and great masses of fresh water flowed into the Backwater. The great amount of river water pushed out the sea and brackish water. Then only a small component, from 10 to 30‰, was sea water, mixed with the river water. The strong river current together with the tides caused an entire mixture, and a stratification could not be built up. From the surface to the bottom the Backwater was filled up with more or less homogeneously mixed water with very low salinity. By then, the condition of a marine bight no longer existed. Even the lowest reaches of the Backwater had the character of a river mouth. This situation lasted a few weeks.

During the south-west monsoon, the freshwater component had been traced in the sea west of the shore. George (1961) measured the salinity of the water 14 kms north of the Cochin inlet, and obtained a salinity of 35‰ before and 12‰ during the monsoon. This amounts to about 35‰ sea water during the monsoon.

During the monsoon season, no brackish or marine zooplankton, which at times was very abundant during the other seasons, was found in the area under investigation. No freshwater zooplankton community could develop and fill the gap ; thus, the water was almost depleted of zooplankton.

End of monsoon : At the end of the rainfall as the river water subsided, the freshwater influx decreased and lost its influence on the hydrography. The freshwater could no longer fill up the whole basin of the Backwater from the surface to the bottom,

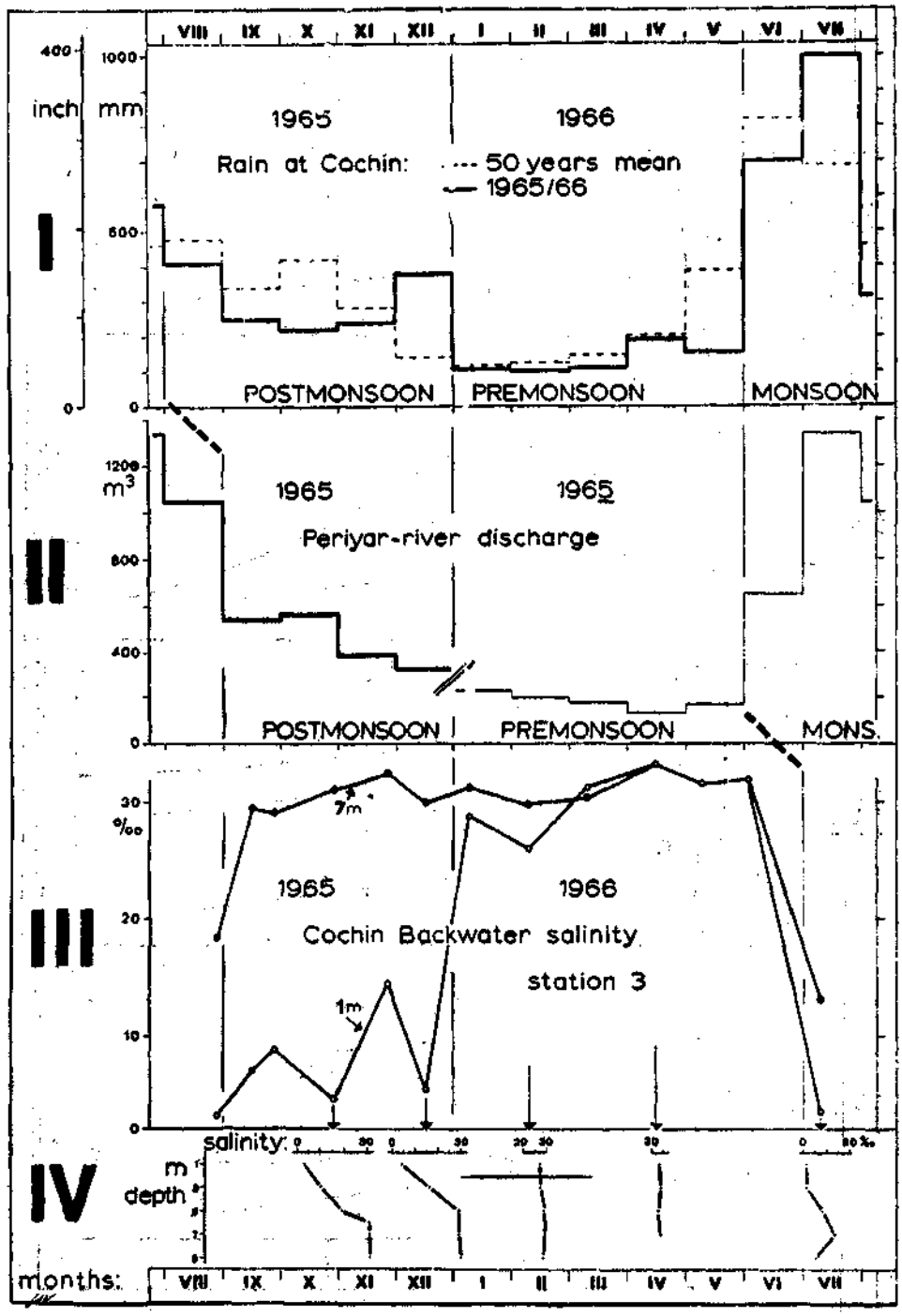

Fig. 3. Monthly variations at Cochin. I : Rainfall 1965/66 and 50 years mean. II : Periyar River, total discharge in $m^3 \cdot 10^6$. III : Station 3, salinity in 1 m and 7 m depth. IV : Station 3, salinity relative to depth, arrows indicate moment of collection.

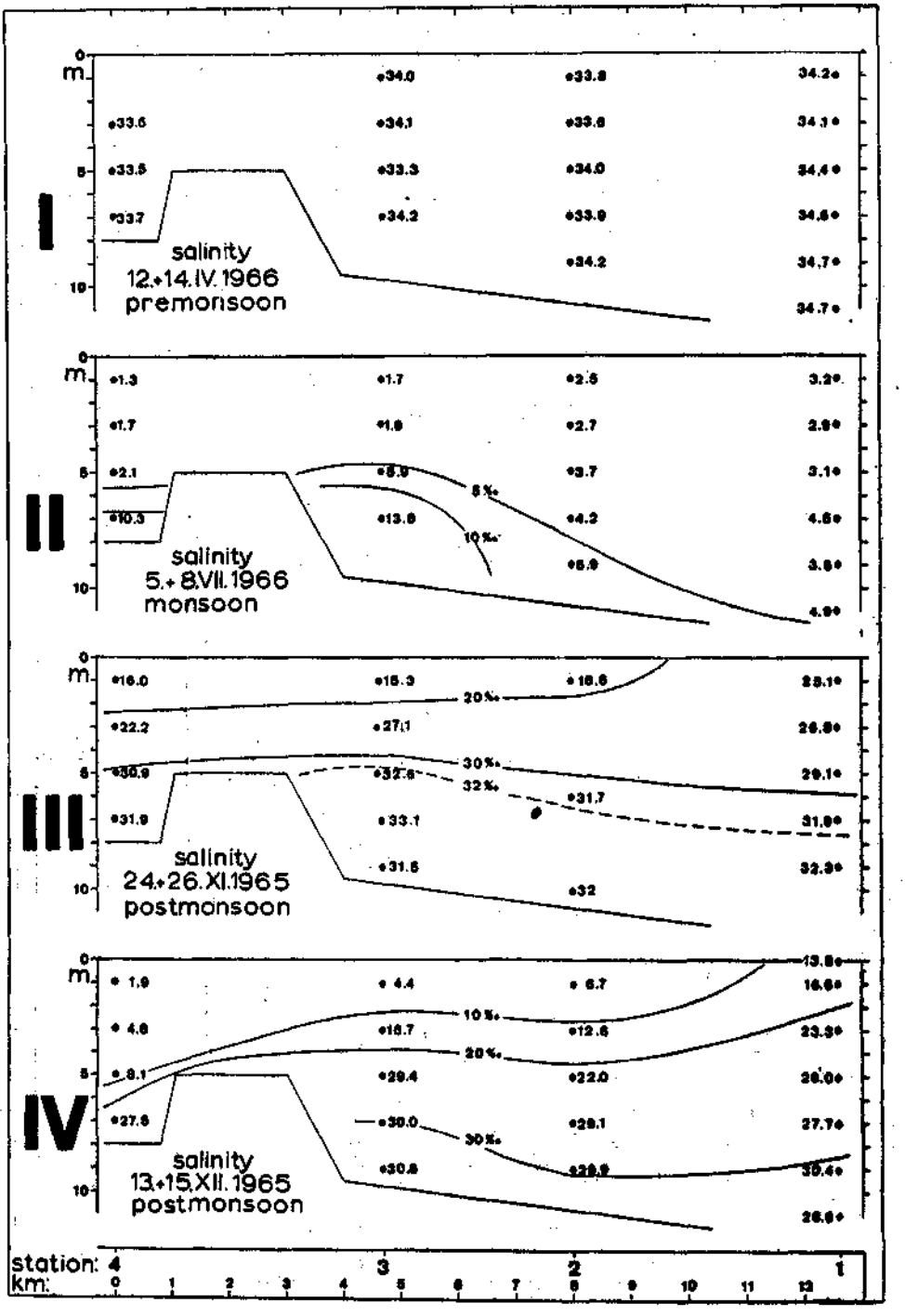

Fig. 4. Seasonal salinity profiles in the Cochin Backwater. I: Pre-monsoon season. II: South-west monsoon season. III: Post-monsoon season. IV: Post-monsoon season with intermediate rainfall.

and it was only limited to the surface layer. The outflow at the surface caused a near bottom counter current by which the sea water intruded along the deeper channels. For a short time a sharp interface may have appeared near the inlet, but we could not measure it exactly. Usually, the tidal forces cause a mixture zone between the upper and lower layer so that no sharp interface could persist. Yet, there was a stratification between the upper layer with a low salinity and the lower layer with a high salinity, but the salinity increased continuously with depth.

Post-monsoon season: Fig. 4,III shows the conditions typical for the post-monsoon season. The river outflow steadily decreased until the end of the year. The stratified situation as described above persisted to a certain extent, but the surface salinity continuously increased. Still the Backwater was stratified due to some river water flowing at the surface layer above the brackish water.

Intermediate casual rains may cause a sudden influx of freshwater at the surface, as in December 1965 (Fig. 4,IV). But the general feature of this season, namely, the two layer situation, was not seriously disturbed. Fig. 4,IV is similar to the conditions found at the end of the monsoon season.

Pre-monsoon season: Towards the end of the year, when the river flow decreased to very low values, the conditions of the premonsoon season described above took place, and again the Backwater was homogeneously mixed. However, a weak horizontal salinity gradient always remained, with increasing salinity towards the mouth.

The monthly salinity changes for station 3 in 1 and 7 m depth are given in Fig. 3,III. Soon after the rainfall started in June 1966, in both depths, the salinity dropped almost abruptly to low values. In the other stations the 7 m value for salinity was even lower and close to the 1 m value. In August 1965, when the monsoon rains had come to their end, the Periyar discharge was still high and the salinity was still very low in 1 and 7 m depth, although the layers were already separated by differences in salinity. In the following months, from September to December, the typical post-monsoon situation was observed : the 7 m and the 1 m layers were clearly separated due to pronounced salinity difference between both. Only from January onwards were both depths indistinguishable by their salinities. This was an effect of the very low river discharges during these months and the predominance of the tidal currents.

Some vertical salinity figures at station 3 are given in Fig. 3,IV. During the pre-monsoon season, there were practically no vertical salinity differences. This was not always the case at the beginning of the monsoon when some water with higher salinity might have still remained in some niches or corners in the Backwater or might have intruded at the bottom. But at the end of the monsoon and during the post-monsoon season, there existed a bottom layer with high salinity, and above this, the salinity continuously decreased towards the surface, indicating a thorough mixture zone in the uppermost 5 or 7 metres. However, even during this season and during the pre-monsoon season, the bottom layer very rarely had pure sea water.

The Stability

The force with which the stratification withstands the mixing by turbulence, can be demonstrated by the stability E. In Fig. 5, the stability E. 10^6 is shown between the 1 m and 7 m samples plotted against the months and the meteorological seasons.

As in the foregoing figure, 1 m and 7 m are taken as representatives for the upper and the lower or bottom layer.

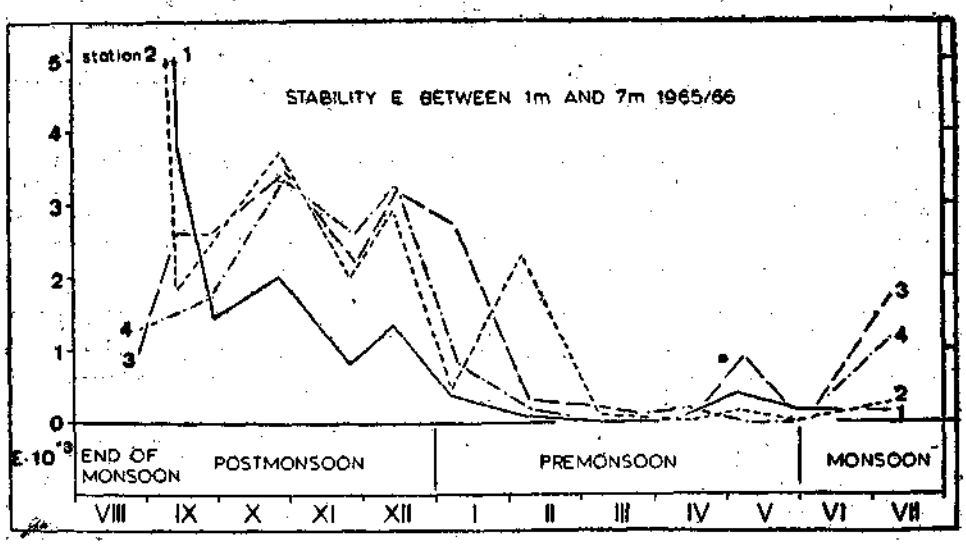

Fig. 5. Monthly variations in stability E.10³

The extent to which mixture takes place depends on the strength of the currents —from tides and river outflow—that support the mixing process, and on the stability with which the two layers withstand the mixing processes. The stability E may be expressed as

$$E \frac{1}{ro_1} \frac{d\,ro}{d\,z},$$

where ro_1 is the specific gravity of the water at 1 m depth, d ro the difference of the specific gravities of the water layers at 1 m and 7 m depth, and d z the vertical distance in metres between the two layers, here 6 m (Dietrich 1963). As the temperature changes were very slight in this case, ro mainly depended on the salinity ; thus, the stability depended on the salinity-differences between the two layers.

An impression of the seasonal changes in the four stations visited monthly is given in Fig. 5. These changes can be better demonstrated by this method than in the foregoing figures. At the end of the monsoon season, the stability was very high indicating that the surface and the deep layers were indeed separated. But as was mentioned above, there is no abrupt change of the salinity between 1 m and 7 m. In the course of the following seasons, as the freshwater inflow abated, the stability decreased. And from February onwards, the stability was very low indicating a situation of a vertically homogeneously mixed estuary. Some higher values of E in December and May were the results of some irregular rainfall. For the high values in October, no reasons could be found.

Above all, during the monsoon and at the beginning of the post-monsoon season when great salinity differences characterised the situation, the stability was very high. And it was low when no freshwater influx influenced the salinity conditions.

Temperature : The temperature of the water altered but not much ; seasonal changes were observed but no accurate measurements were made. The daily changes may have superimposed the seasonal changes so that no conclusions on the hydrographical conditions could be expected.

CONCLUSIONS

The Cochin Backwater is a part of an estuary, the hydrographical structure of which is subject to great changes depending on the seasons. It is a catchment basin for several rivers, and it opens to the sea through one major and several minor inlets. The tidal currents cause thorough mixture of the waters as long as the flow from the rivers does not supply the upper layer with new freshwater. When this occurs, the Backwater is stratified into a surface layer with low salinity and a bottom layer with high salinity. The strength of the river outflow depends on the rainfalls which, in turn, depend on the seasons. The higher the freshwater supply, the greater the stability which supports the stratification of the Backwater into two layers.

Thus, the Cochin Backwater is alternatively characterised by two estuarine types :

(1) During the pre-monsoon season and at the beginning of a monsoon with an abrupt onset, it is an estuary which vertically is almost homogeneous, although with varying salinities.

(2) At the end of the monsoon and during the post-monsoon season it is stratified, and it is continuously supplied with freshwater at the surface and with sea water at the bottom. According to Bowden (1967) it is a ' two layer flow estuary with vertical mixing '.

These observations were based on collections from only four stations positioned in one line. So eddies and advections were not measured, although they were seen.

The data on which this paper was based are kept in the archives of the National Institute of Oceanography, Biological Oceanography Division, Cochin-11, India, and of the ' Institut für Meeresforschung ', 285 Bremerhaven, Germany.

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