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Turbidity of waters off the East Coast of India

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1. Introduction

Coastal waters are commonly characterized by their vertical and horizontal thermal and chemical properties. In the complex near shore environment however, the distribution of these variables is not always sufficient to establish the processes taking place. More recently the turbidity or opacity of the water has been adopted as an additional aid in describing coastal water masses. It is proposed that turbidity may be used as a conservative property of the water mass as its rate of change is usually slower than that of the other processes, such as layering, wave action, mixing and other circulations, therefore, it can be used as a tracer or indicator of the process. Consequently, from the observed patterns of turbidity in the sea, an attempt is here made to explain the water structure and circulation off the east coast of India.

2. Nature of Turbidity

The degree of light absorbed or scattered in the water is dependent upon the nature of the material suspended or dissolved in the sea. These suspensoids may be *organic* or *inorganic* (Atkins, Jenkins and Warner 1956). The major part of suspended organic matter is composed of phytoplankton (Clark and Oster 1934). Its profuse growth is attributed to a favourable water temperature, nutrient composition and light intensity. These circumstances commonly arise in the spring months and sometimes the rapid growth markedly colours the water. However, some phytoplankton are always present in coastal waters in varying amounts and depths. The larger zooplankton also contribute to turbidity but to a lesser extent, except when specific production conditions are favourable, such as frequently follows a phytoplankton flowering.

The *inorganic* suspended matter affecting turbidity is largely the result of land drainage. It comprises muds and clays brought down to the sea by rivers during flood season. Sometimes chemical reactions occur under these conditions, creating flocculents of aluminium and silicates which contribute to the turbidity.

Other inorganic (and some organic material) is brought into suspension by turbulent water motion in shallow water. This is especially noticeable in the surf zone and along the bottom when the waves are above average height. The suspended inorganic particles comprise minute shell fragments and minerals common to the area.

Turbidity is also dependent upon a third category of matter commonly called "yellow substances" or "leptopel" (Kalle 1938). It is the residue obtained from evaporating filtered sea water and is believed to be dissolved organic matter. The difference in the optical characteristics of coastal waters, then, depends upon the amount and properties of yellow substance as well as upon those of the suspended organic and inorganic material.

3. Measuring Turbidity

Various methods of measuring turbidity are used. One method is by filtering the water through various types of nets or through clay and collodium membranes. The latter retains particles as small as one micron which can then be analysed by microscopic and chemical means.

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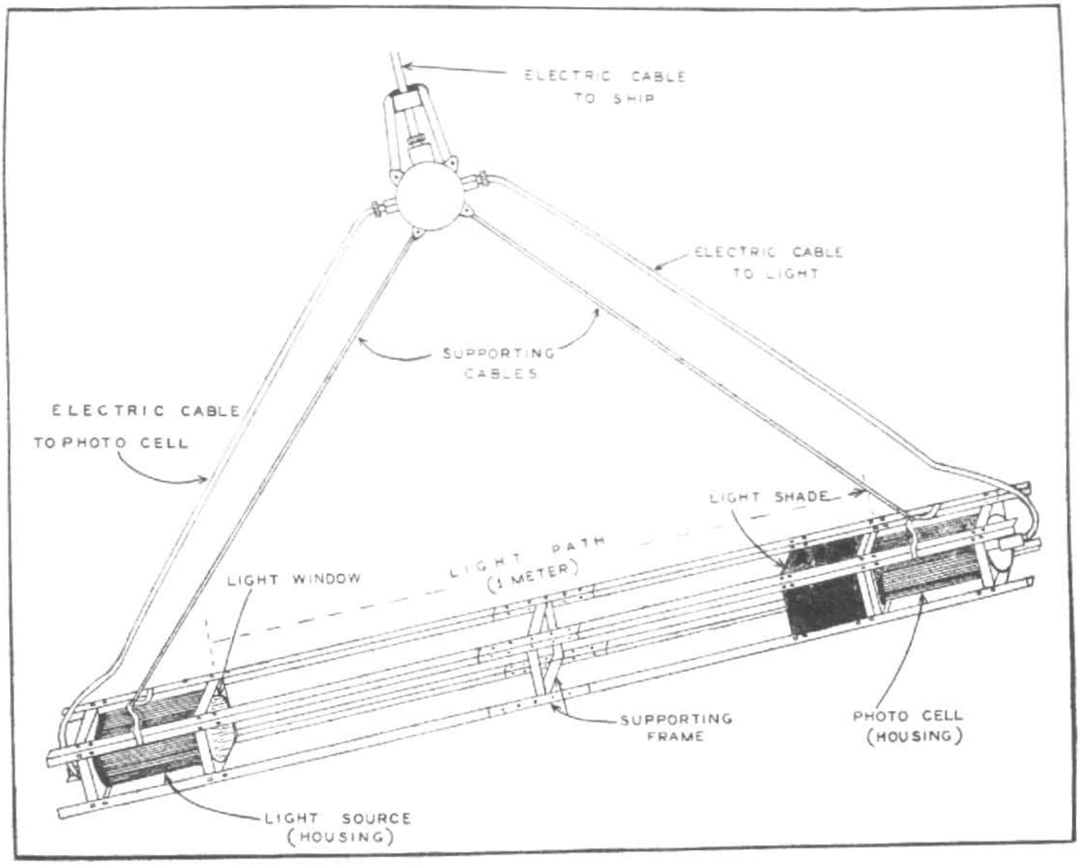

Fig. 1. Schematic illustration of hydrophotometer used to measure transparency of water off east coast

TABLE 1

Transparency data

Cruise	Date	Stations	Section length (miles)
33	27-10-55 to 28-10-55	479A—Y	0 (anchored)
34	11-11-55	489—99	25
38	19-1-56	B555—P569	10 (square)
39	24-1-56	570—73	15
42	21-2-56	593—604	25
43	7-3-56	612—17	15
44	13-3-56	621—29	22
45	20-3-56	639—42	7
46	13-4-56	663—73	27
48	4-5-56	710—15	13

The visual methods are most common. The depth at which a white Secchi disc just disappears when lowered into the sea is a popular measure of turbidity and has been used extensively by Dr. T. S. Satyanarayana Rao on the Andhra University's Oceanographic cruises.

He found that in general the near shore waters were more turbid than were those farther from the coast. More recently a hydrophotometer, which gives greater detail, has been used.

The equipment now used consists of a focussed 12-volt light source and photoelectric cell, each incased in separate watertight housings, and mounted 1 metre apart. A sketch of the arrangement is shown in Fig. 1.

The light intensity registered 120 foot candles on the GE 8PV IFAA photo-cell. The cell was sensitive to wavelengths between 3000 Å to 7000 Å, with greatest sensitivity at 5600 Å. The tungsten light in air showed a scale deflection of about 300 milliamps on an ampmeter. The current into the light was held constant at 2·5 amps during all readings on the ampmeter which were made as the instrument was lowered into the water.

Ambient light readings were taken when the 12-volt light was switched off. These were subtracted from the corresponding over-all reading at each depth.

Reference readings were made in air with no external light. This reading, about 300 milliamps, was taken as a reference, and the water readings were computed as per cent of this air reading.

Operation—The instrument (Fig. 2a) was attached to a 5/32 inch wire rope and lowered off the stern of the *I.N.S. Rohilkhand* by means of an electric winch (Fig. 2b). The depth was read from the meter wheel (Fig. 2c). As the hydrophotometer was lowered and raised both the ampmeter and milliammeter on deck were read after lowering every two metres (Fig. 2d). To correct the wire depth, the wire angle was measured with an inclinometer each time the hydrophotometer was slowly lowered and raised. In this way transparency data were collected from the surface down to depths of nearly 20 metres.

4. Data

Hydrophotometer readings were taken on nine cruises. These extended from Madras on the south to Gopalpur on the north. However, most of the data are from the waters over the continental shelf off Visakhapatnam (Fig. 3). They were taken between October 1955 and May 1956 as shown in Table 1.

In addition, a set of repeat observation in one location was made while the ship was anchored for 24 hours. A total of 82 vertical series of transparency—depth measurements have been studied.

The interpretation is facilitated by simultaneous observations of vertical temperature, salinity, phosphate, silicate, oxygen, plankton net hauls, meteorological data, current information, and Secchi disc readings.

The transparency, or per cent of light transmitted (with respect to air), varied from 0 to over 100 per cent. The values over 100 per cent occurred only in exceptionally clear water and are believed to be due to refraction and the scattering of light from particles at the edge of the light beam, which phenomenon does not occur in air. In any case, the greater the per cent of light transmitted, the greater the transparency of the water. This is borne out by the unusually great Secchi disc readings when the hydrophotometer read over 100 per cent.

5. Diurnal Cycle

At an anchor station one mile off Waltair on 27 and 28 October 1955 lowerings were made at about hourly intervals, except for 5 hours during the night. The plotted data are shown in Fig. 4. It can be seen that during this rainy season, with maximum land drainage, the water is turbid, especially near the bottom. In the lower 4 metres the water transmits less than 20 per cent of the light. The near surface transparency is generally greater than 80 per cent. The striking feature of this series of observations is the

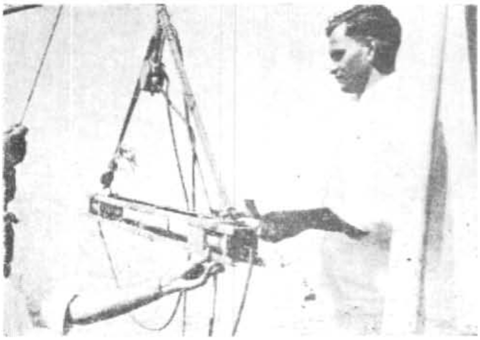

Fig. 2 (a). Operation of hydrophotometer at sea

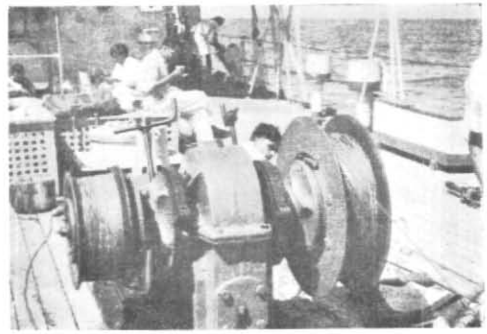

Fig. 2(b). Electric winch with wire rope for lowering hydrophotometer

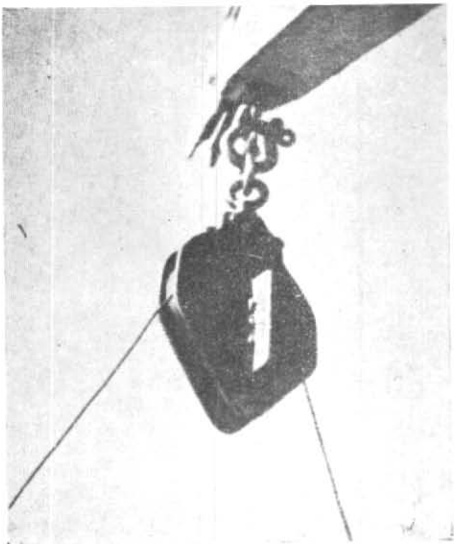

Fig. 2(c). Lowering hydrophotometer

Fig. 2(d) Reading ampmeter on deck of *INS Rohilkhand*

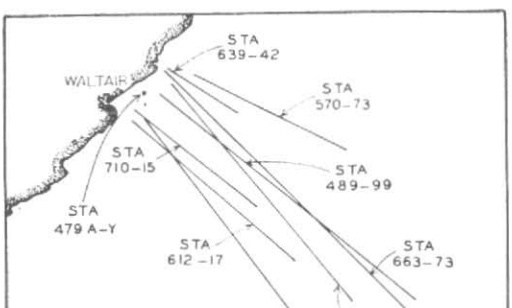

Fig. 3. Location of section of stations off Waltair where transparency measurements were made
(The data are plotted in Figs. 4—13)

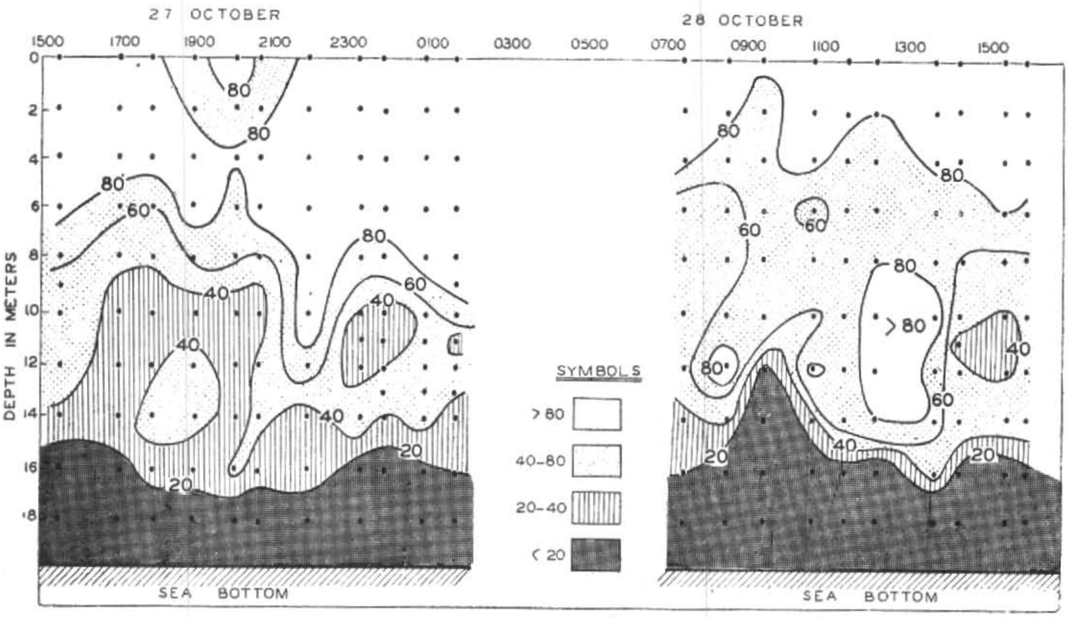

Fig. 4. Repeated transparency measurements at anchor on station 479A-Y on cruise 33 observed on 27 and 28 October 1955. Shows the variability of transparency from hour to hour off Waltair

variability. It would suggest that the turbid water is in the form of clouds of varying density. However, the concentration of turbid material in the water generally increases with depth.

On examining samples of the water it was found that the turbidity at this time was caused by very finely suspended inorganic material. The salinity was low, 15–18 parts per thousand, indicative of the great runoff at this season. The sediment in the water undoubtedly was the result of muddy rivers emptying into the Bay.

The source of turbid water was further investigated by using the hydrophotometer in the Vizag channels. Here the turbidity was very much greater, as shown in Fig. 5. Only three to six per cent of the light was transmitted in the upper part of the water and less than one per cent in the lower part. It had rained the night before and water was running out to sea. Harbour and river drainage is obviously one of the main sources of turbid water observed along the east coast in the fall.

6. Seasonal Cycles

Eight vertical sections of transparency were made across the continental shelf as shown in Fig. 3. These repeated sections, in nearly the same location, were made in order to determine the seasonal trend of transparency in the near shore shelf waters. The first of these sections was taken on 11 November and is shown in Fig. 6.

In a 25 mile section the transparency varied from about 30 to 90 per cent. There appears to be a relatively turbid layer at around five to ten metres, becoming slightly deeper out to 12 miles. Beyond that distance it again becomes more shallow.

This turbid water may originate near shore and sink as it moves seaward, since this is the season for near shore sinking (La Fond 1954). Winds in November are from a general northeast direction and, therefore, tend to transport surface water towards the shore where it accumulates and sinks, thus lowering the thermocline. Probably the turbid material is an indication of an offshore subsurface flow which partially compensates for the onshore surface displacement.

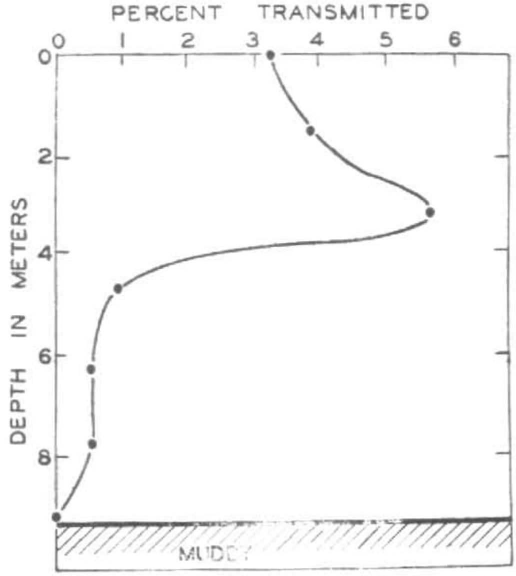

Fig. 5. Transparency in Visakhapatnam harbour channel on 23 October 1955 during runoff following a rain

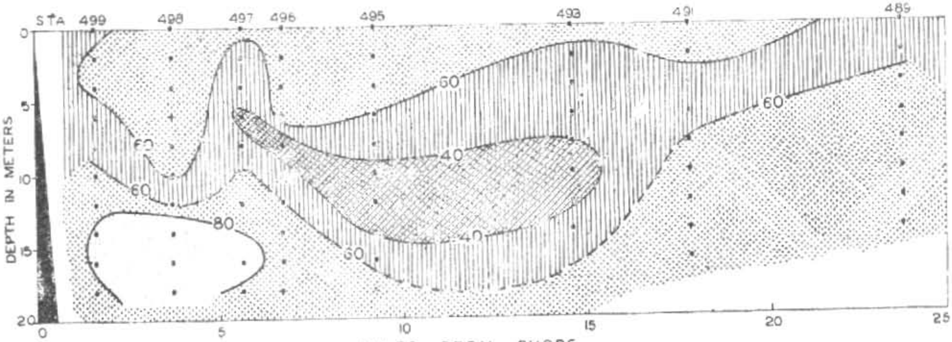

Fig. 6. Vertical transparency section—11 November 1955
(see Fig. 3 for location of section)

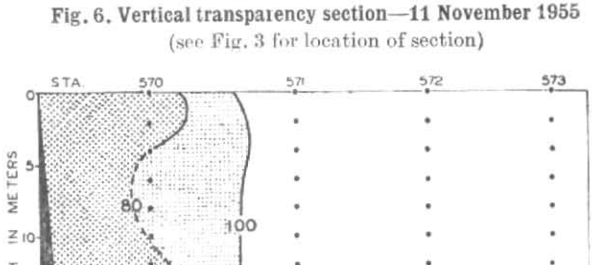

Fig. 7. Vertical transparency section—24 January 1956
(see Fig. 3 for location of section)

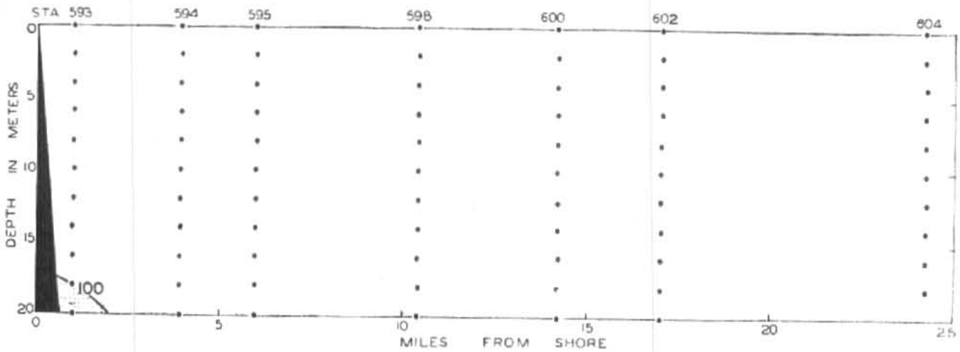

Fig. 8. Vertical transparency section—21 February 1956

(see Fig. 3 for location of section)

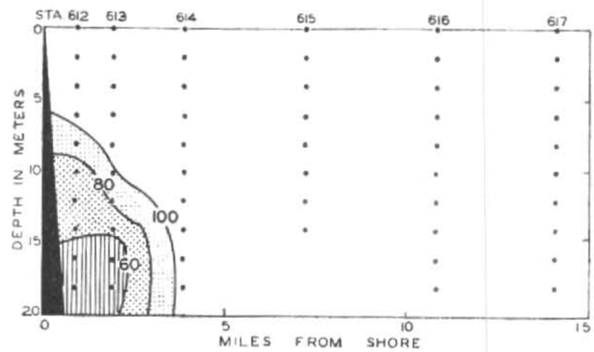

Fig. 9. Vertical transparency section—7 March 1956

(see Fig. 3 for location of section)

The next section shown in Fig. 7 was taken on 24 January. Considerable clearing of the water has taken place and there is only a slight turbid zone near shore. The water beyond five miles is very clear—over 100 per cent on the arbitrary scale. This is the calm season, with low winds and current, but some northern dilute water still exists in the upper 20 metres, especially near shore.

By 21 February the water off Waltair is the clearest of the entire year, as shown in Fig. 8. Only a slight indication of turbidity was found near the bottom near shore. At this season the currents are nearly slack, the waves are low and the northern dilute water is mixed with the clear southern Bay of Bengal water.

In Fig. 9, there is a definite indication of subsurface turbidity, observed to extend out to about 3 miles. It becomes more intense with increasing depth and less intense with distance from shore. This is an organic turbidity. It can be explained by the beginning of upwelling, that is, the surface water is being displaced seaward and nutrient rich subsurface waters are rising near the shore. The chemical analyses of the water made by P.V. Bhavanarayana of the Zoology Department show that the rich nutrients have not reached the surface, but have risen to a level where there is sufficient sunlight to create a rich production of phytoplankton at 5 to 15 metres. This occurs only near shore where the first indication of upwelling is felt.

As the season progresses, the water becomes more turbid, especially near shore, as shown in Fig. 10. These data were taken on 13 March and upwelling is now well developed. The nutrient rich water has reached the

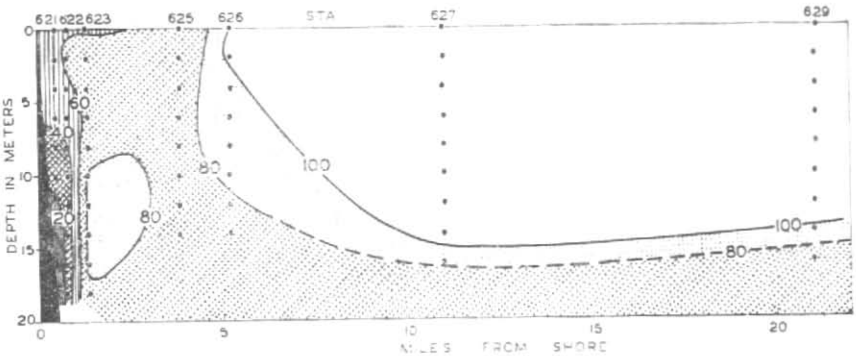

Fig. 10. Vertical transparency section—13 March 1956
(see Fig. 3 for location of section)

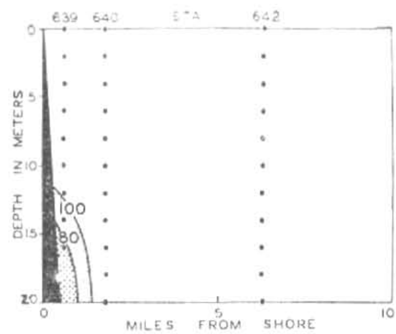

Fig. 11. Vertical transparency section—20 March 1956
(see Fig. 3 for location of section)

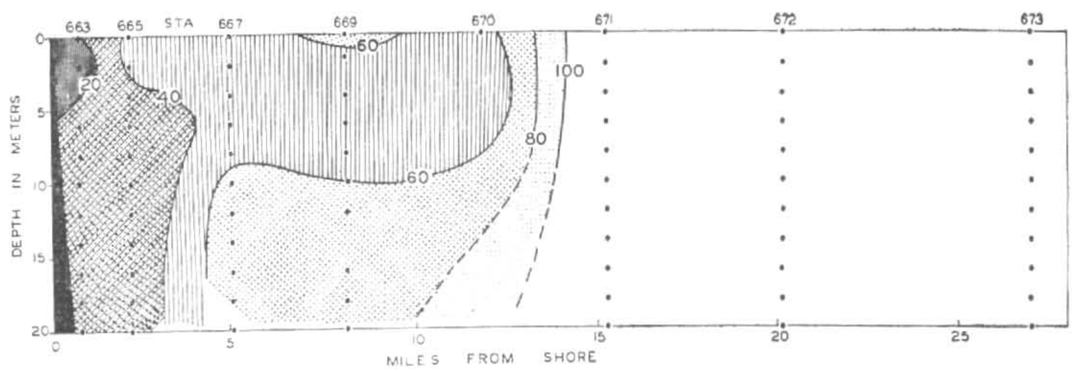

Fig. 12. Vertical transparency section—13 April 1956
(see Fig. 3 for location of section)

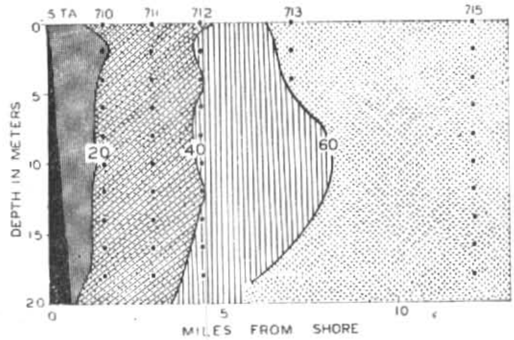

Fig. 13. Vertical transparency section—4 May 1956
(see Fig. 3 for location of section)

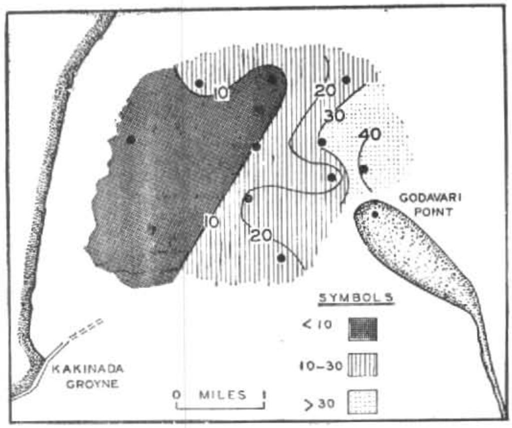

Fig. 14. Horizontal transparency at 2 metres in the northern end of Kakinada Bay observed on 19 January 1956

surface and the phytoplankton growth is well advanced, giving the water a green algae appearance. The maximum turbidity, less than 20 per cent transparency, is still found near the bottom near shore. From 10 to 20 miles off shore the rich nutrient salts apparently have risen to the euphotic zone and the production of organic material occurs from 15 to 20 metres.

Three stations taken after a storm on 20 March showed surprisingly clear water, as indicated in Fig. 11. This demonstrates what can happen when a strong wind displaces the turbid water with clear offshore water. It further emphasises the variability which can exist in the coastal waters.

By 13 April conditions were back to normal and the upwelling effect is especially prominent, as shown in Fig. 12. The high turbidity indicative of upwelling of sub-surface water has extended to 14 miles from the coast. The circulation of upwelling, *i.e.*, the upward and offshore movement, appears to be expressed by the turbidity. The more turbid water is near shore with a tongue extending seaward near the surface. Beyond 14 miles the water is quite clear, probably due to the lack of upwelled water beyond this point at this date.

The last section was made on 4 May. The turbidity as shown in Fig. 13 indicates very turbid water near shore, with a light transmission of less than 20 per cent. The water became progressively clearer with distance from shore up to 13 miles, which is the distance to the last station. It is likely that the turbid water extends out beyond 14 miles, as found on the previous cruise in April. The organic content is very high but the increased wind and size of the breaking waves at this season may account for some of the near shore turbidity.

7. Horizontal distribution

On one cruise the horizontal distribution of turbidity in the north end of Kakinada Bay was studied. The transparency of the water at 2 metres below the surface is plotted in Fig. 14. It can be seen that in this delta region the water is more turbid near the mainland than it is seaward or near Godavari Point. The turbid coastal water flows down the coast at this season and spreads out to the east, where it mixes with the clearer offshore waters. By determining the distribution of sediment laden water, the circulation of bays and river runoff may be established.

8. Summary

By means of hydrophotometer readings it has been found that the turbidity of the water off the east coast varies greatly from season to season. In the fall, suspended sediments empty into the Bay of Bengal from the numerous rivers. As fall is the near shore sinking season, this turbid water tends to remain near shore, and flows down the coast towards the southwest. The maximum turbidity is near the bottom, due to the greater density of turbid water and the gradual sinking of suspended particles. It also appears that at a subsurface level some of the turbid material is carried seaward and upward.

As the rainy season subsides the water becomes clearer the near shore areas, however, tend to be less clear than those over the shelf. Even in the rainy season the water 30–50 miles off the coast is clear and blue, characteristic of open sea tropical waters.

Near shore in October and November the transparency, or per cent of light transmitted with respect to air, is about 60 to 90 per cent in the surface layers and is less than 20 per cent near the bottom. In January and February the transparency is 80 to 100 per cent at the surface. By March the surface remains clear, but the upwelled subsurface layers near shore become turbid. This is attributed to sunlight reaching the highly nutrient upwelled layer creating a flowering of plankton which results in a turbid subsurface layer near shore. In April the upwelling reaches the surface and the plankton bloom is heaviest, extending out to five miles from shore. This clearly shows the effect of upwelling on the transparency of the water.

From a knowledge of the causes of turbidity it appears to be possible to identify water masses and determine both horizontal and vertical circulation as well as determine the distribution of plankton. In other words, transparency may be used as a conservative property of the sea and used as an aid in solving the many problems of oceanography along the Indian coasts.

9. Acknowledgement

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REFERENCES

Atkins, W. R. G., Jenkins, P. G. and Warner, F. J. — 1956 *J. Mar. Biol. Assoc.*, **33**, pp. 497-509.

Clark, G. L. and Oster, R. H. — 1934 *Biol. Bull.*, **67**, 1, pp. 59-75.

Kalle, K. — 1938 *Ann. d. Hydrogra. und Mar. Meteor.*, Bd. 66, s. 1-13.

La Fond, E. C. — 1954 *Andhra Univ. Mem. Oceanogr.*, **1**, p. 117-121.