551.464 (267.4)

# Sea Water Density at four stations on the East Coast of India

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(*Received 3 April 1956*)

## 1. Introduction

A knowledge of the density of sea water is important for determining the buoyancy of cargo ships, ocean current (Helland-Hensen 1916, La Fond 1956), and the distribution of marine plants and animals (Ganapati and Satyanarayana Rao 1956).

The density of the water is controlled by its temperature and salinity, which are in themselves related to oceanographical and meteorological conditions. Along the east coast the density of the surface water undergoes an unusually large change from season to season. These changes have been studied and are discussed in relation to the ocean currents.

## 2. Density Data

Data necessary for the determination of water density are available from four near-shore stations, nearly equally spaced along the east coast. They are Saugor Island, Waltair, Madras (Harbour) and Mandapam (see Fig. 1).

*Saugor Island*— The most northerly seasonal data are from Saugor Island. Observations of the sea surface temperature and specific gravity (hydrometer readings) have been made for many years at this point near the mouth of the Hooghly River. The daily readings reported by P. K. Das have been averaged by months.

A plot of the average monthly sea water density on a temperature-density-salinity chart is shown for Saugor Island in Fig. 2A. Each monthly average is represented by a large dot, labelled with the first letter of the name of the month. Monthly values are connected by a dashed line. The solid diagonal lines represent $\sigma_t$ values, a customary way of expressing surface density (La Fond 1951).

$$\sigma_t = 10^3 (\rho_{s,t,o} - 1)$$

where, $\rho_{s,t,o}$ is the density of the water at a given salinity $s$, temperature $t$ and surface pressure $o$.

*Waltair*—Moving down the coast, the next set of temperature and salinity data comes from Waltair. Here the excellent open sea data were obtained by V. S. R. Murty and V. L. Kanta Rao of the Zoology Department of Andhra University. The samples and measurements were taken from a catamaran located about half a mile out at sea and away from any major river or obstruction. Samples were collected 3 or 4 times per week and the salinity was determined by chemical methods. These data were processed and are presented in the same way as those from Saugor Island. Data covering a period of only a year and a half were available for averaging and plotting in Fig. 2B. Observations over a long period would modify the monthly average values a little, but the major features of the annual cycle would probably remain the same.

*Madras Harbour*—The next sea surface data to the south comes from Madras Harbour.

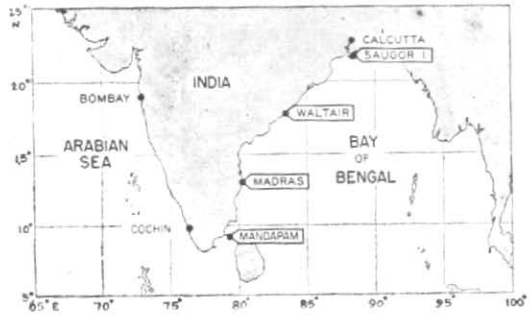


**Fig. 1. Location of stations on the east coast where water density data are available (Saugor Island, Waltair, Madras (harbour) and Mandapam)**

The open dots of Fig. 2C represent data taken inside the harbour, and were furnished by Dr. U. K. Bose. They, like the Saugor Island data, were in the form of daily water temperatures and specific gravities, which have been averaged and converted to $\sigma_t$. Because the observations were taken in the harbour, local runoff may influence the salinity and, to some extent, the temperature. Salinities are also available for a station 3 miles off the coast and are reported by Jayaraman (1951). Using the harbour temperatures and the offshore salinities, a second set of monthly $\sigma_t$ values are presented as solid dots in Fig. 2C.

*Mandapam*—The most southerly seasonal density data on the eastern coast come from Mandapam. There, extensive studies of the oceanographic environment were made by the Central Marine Fisheries Laboratory. The surface temperature and salinity for 1950 to 1953 is from the Director, Dr. N. K. Panikkar. The salinity and other chemical properties are presented by Jayaraman (1954). Observations were made in the shallow western approach to Adams Bridge, which is situated between India and Ceylon. The seasonal density relation for Mandapam is shown in Fig. 2D.

### 3. Discussion

It can be seen from Fig. 2A that near Saugor Island the lightest surface water occurs, as might be expected, in early fall. The lowest $\sigma_t$ values fall in September and October, with average monthly values of less than 10.00. The highest values of about 25.00 are reported for April, May and June.

In the three northern stations the seasonal cycle of sea surface density partially follows the normal seasonal heating and cooling caused by atmospheric conduction and radiation (La Fond 1954a). The retarded heating in April, May and June is attributed to the effect of upwelling, which occurs principally in the central part of the coast (La Fond 1954b). However, salinity is the principal factor controlling density along the east coast.

The salinity in September and October is easily accounted for by the large rainfall and runoff at that time of the year. Although figures for the monthly runoff of the Hooghly are not available, data for the Mahanadi River for 1932 show a maximum runoff at Sambalpur in August (Anonymous 1950). By the time this reaches the sea and causes maximum dilution it will account for the September and October minimum salinity. Further, at this time of year the runoffs of rivers in East Pakistan and Burma would flow to the west under the influence of winds associated with the northeast monsoon, and introduce still more low density water around Saugor Island.

The higher salinity values are more difficult to explain. The April, May, and June salinities, calculated to be over $37^{o}/_{oo}$ are higher than would be encountered in the Hooghly River proper, or anywhere in the open Bay of Bengal. They must be the result of evaporation in shallow water.

The surface water density, $\sigma_t$, for Waltair has its lowest period during October and November and highest period during March, April and May. This low period is attributed to the effects of the northeast monsoon. The runoff of northern rivers is greater at this

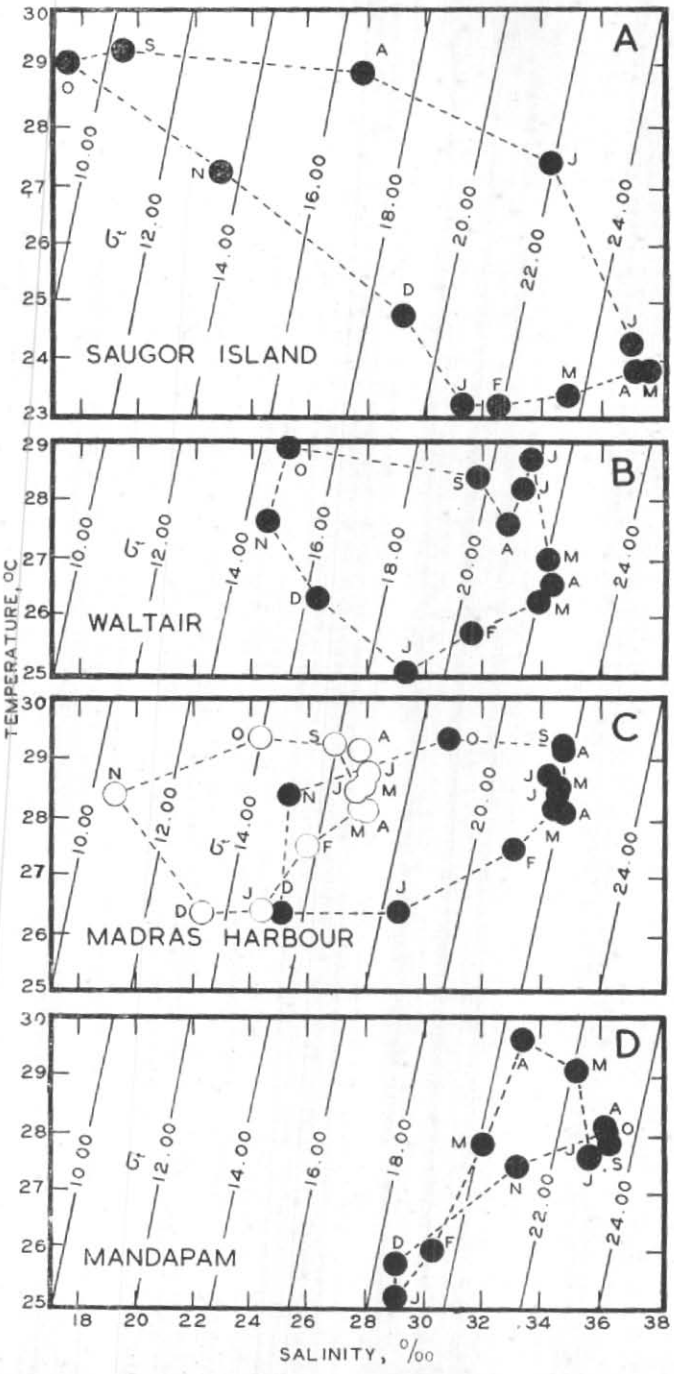


**Fig. 2. Annual cycle of monthly sea surface density ($\sigma_t$) plotted as a function of temperature and salinity, for the four stations shown in Fig. 1.**

(Solid dots represent monthly averages in the open sea and open dots in 2C are from the harbour)

time, and the coastal current flows down the coast. The high values of density during March, April and May are the result of higher salinity water being brought into the area by the northerly flowing current, coupled with the actual upwelled subsurface water in a zone a few miles wide next to the coast.

The Madras Harbour data, though not equivalent to off-shore conditions, do illustrate the seasonal trend, and are represented by open circles in Fig. 2C. The density in the harbour shows a definite low in November. From March to August the average monthly density is exceptionally constant.

The solid data represent the monthly density derived from off-shore salinity and harbour temperatures. This representation of Madras sea water density values, also illustrated in Fig. 2C, falls between that of Waltair and Mandapam. The low $\sigma_t$ values of less than 16·00 occur in November and December which correspond to the rainy season. The spring and summer density for seven months is nearly constant, around 22·00. It does not appear that this denser water is the result of upwelling, but rather results from the influx of higher salinity from Southern Bay of Bengal waters.

At Mandapam, Fig. 2D, the density cycle also coincides with the NE and SW currents observed along the Coromandal coast. That is, the salinity is high during the months when the current is to the NE and low during those months when the current is SW. With the SW currents there is a flow of low salinity water from the northern coast, which reduces the density ( $\sigma_t$ ) to about 18·50. This lowering is also influenced by about 30 inches of local rainfall—most of which falls between November and January.

The SW monsoon brings in higher density water from the Central Indian Ocean as well as some from the southern part of the Arabian Sea. In addition, the unusually high evaporation during the summer increases the salinity, and thus the density, over the shallow near-shore areas to values greater than 23·00.

#### 4. Comparison of Density Cycles

*Annual Range of Density*—The annual density range is greatest at the northernmost station and decreases progressively from north to south. The Saugor Island monthly average of $\sigma_t$ varies about 14·20 throughout the year, Waltair about 7·70, Madras about 7·00, and the Mandapam density ranges only 4·80.

This decrease is largely attributed to the seasonal cycle of runoff from the major rivers which empty into the head of the Bay of Bengal. The effect of the dilution then becomes progressively less with distance from the source.

*Time of Minimum and Maximum Values*—The effect of dilution is felt at Waltair in October and November, nearly one month later than it occurs at Saugor Island. Still further down the coast, the lowest density months at Madras are November and December, six weeks later than at Saugor Island. Finally, the lightest water is observed at Mandapam in December and January, three months after the maximum dilution in the northern end of the Bay. It must be remembered that the local rainfall and runoff at the southern stations, also associated with the northeast monsoon, influence the season of minimum density.

The months of maximum density at the various stations are, in general, the results of a reverse current up the coast, caused by winds associated with the southwest monsoon. However, some of the high Mandapam, and probably Saugor Island, salinity-density effect is the result of summer evaporation in a localized area, rather than the advection of high salinity water in September.

**5. Summary**

The sea surface density occurring along the east coast is dependent upon the seasonal cycles of temperatures and salinity which in turn, are largely controlled by the NE and SW current systems. While the annual heating at the surface plays but a small part in the water density, the monthly salinity changes are from 4 to 7 times as important. Therefore, most of the density changes can be explained by the influx of relatively fresh water brought to the east coast during the SW current season, and the relatively high salinity water introduced during the NE current seasons. The time of year of minimum density at different stations occurs progressively later down the coast; the times of maximum density occur later to the north of Waltair. Some modification of the temperature and salinity (and thus density) cycle is caused by upwelling, which takes place along the east central coast during the spring. Comparable data would be more valuable if all collections were made in the open sea, such as is being done off Waltair, and if more collection stations were to be established all along the coast.

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