STUDIES ON THE HYDROLOGICAL FACTORS IN THE NORTH KANARA COASTAL WATERS.*

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INTRODUCTION

The role of the hydrological factors in the productivity of the seas is well known. The North Kanara coast supports a rich fishery constituted by the plankton-feeder—Indian mackerel and no information is available regarding the hydrological conditions existing in this area which is a prerequisite to understand the plankton production and fisheries of this region. A detailed investigation of the inshore waters of the North Kanara coast was therefore undertaken with special reference to the physical and chemical characteristics at the surface and to the meteorological factors. The work was carried out during 1954-1958 and covered a stretch of forty miles extending from Karwar in the north to Kumta in the south. The area chosen for the critical study possessed an additional point of interest in that a large river—the Kali river enters the sea at Karwar.

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DESCRIPTION OF THE ENVIRONMENT AND METEOROLOGICAL FEATURES

The North Kanara coast extends from Majali in the north to Bhatkal in the south to a length of 76 miles (Text Fig. 1). In this region the coastline runs more or less straight except for the shallow Karwar and Bellikeri Bays in the north where there are also some rocky islands. The coast is mainly rocky with capes projecting into the sea, and with short stretches of sandy beach. The northern half of this coastline has a shallow inshore area while the southern half from Gangavali to Bhatkal has deep inshore waters. There are four rivers entering the sea in this coast.

There is a well marked continental shelf along the west cost of India extending to an average depth of 100 fathoms. This shelf is widest at its north being over 120 miles and gradually narrows towards the south till off Cape Comorin it is only 30 miles in width. The continental shelf along the North Kanara coast extends to a width of about 60 miles. The sea bottom is sandy near the shore and muddy farther away.

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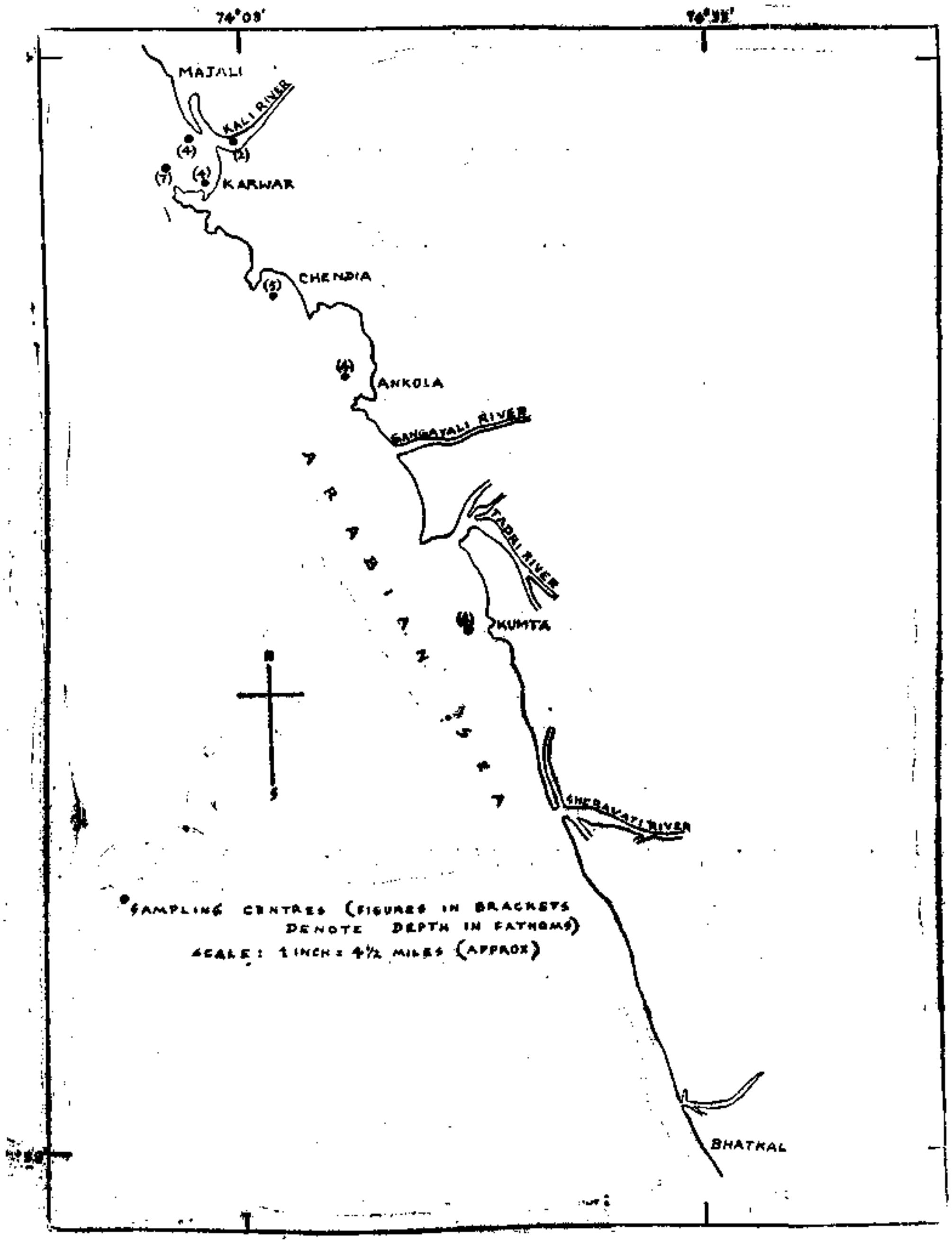


Fig. 1. Map showing the North Kanara coastline and the location of the sampling stations.

There are two periods of rainfall in this peninsular coast. They are the south-west monsoon lasting from June to September and the north-east monsoon lasting from November to February. The rainfall during the south-west monsoon season is considerably heavier (290 cm. on an average) than during the north-east monsoon (20 cm). The prevailing winds are south-westerly during the south-west monsoon season, the wind velocity ranging between 1·3 to 10·8 knots per hour. The prevailing winds during the north-east monsoon season are north-easterly, the wind velocity ranging from 0·7 to 3·5 knots per hour. The winds are variable during October and March-May. The monthly mean air temperature and rainfall during 1954 to 1957 are given in Text-Figs. 3 and 4.

Not much is known as regards the water movements in this coast. Our knowledge of the currents in the Arabian Sea is mainly derived from the accounts given by Sewell (1929 and 1955) and the British Admiralty (1950). The main currents seem to be in association with the prevailing monsoons, the speed and direction of the currents being regulated by the coastal conformations. In the more open parts of the sea, the currents are easterly during the south-west monsoon and westerly during the north-east monsoon period. In the coastal region however, during November to January, *i.e.* at the height of the north-east monsoon, the circulation is in an anticlockwise direction, the flow being north-north-westerly. From February to April, when the north-east monsoon weakens, the direction of the coastal current is reversed resulting in a clockwise circulation which is attributed to the formation of a gradient current, caused by temperature differences. At this time, in the more open parts of the sea, the flow is predominantly westerly or north-westerly. With the onset of the rains during the south-west monsoon the clockwise circulation is strengthened and the resultant current is in continuity with the Somali current of the East African coast. The south-west monsoon circulation is obtained from May to September.

MATERIAL AND METHODS

Seven sampling points were selected of which six were situated along the coast and one was in the Kali river about 1½ miles above its confluence with the sea (Text Fig. 1). These points were located at an approximate distance of 2 miles off the shore from the following places :

1. Karwar (three stations)
2. Chendia
3. Ankola and
4. Kumta

The depth of the sea at these sampling points varied from 8 to 14 metres and that at the Kali river was 4 metres. Samples of the water from the surface were collected at these points between 6·00 and 7·00 A.M. once a week at Karwar and once a fortnight at the other sampling stations.

The samples of the water were collected in 500 ml. polythene bottles for determining the salinity, dissolved inorganic phosphates, nitrites and silica contents. The sample for the determination of dissolved-oxygen was collected separately in a 250 ml. glass-stoppered bottle, observing the usual precautions for avoiding entrainment of air. The sample for the estimation of pH and total alkalinity was collected in another 250 ml. glass-stoppered bottle.

The temperature of the surface water was recorded by means of a centigrade thermometer at the site of collection. The pH was estimated with a Lovibond comparator using thymol blue. For pH values of 8·0 and below phenol red was used. The total alkalinity was determined according to the method described by Ellis *et al* (1946) and the values were expressed as parts per million. The samples were filtered through Whatman No. 4 filter paper before they were taken up for chemical analysis. The salinity was determined by Mohr's method of titration of the chlorides with silver nitrate using potassium dichromate as the indicator. The dissolved oxygen was determined by Winkler's method and the values expressed as ml/L. The percentage saturation of dissolved oxygen was calculated according to Fox's formula*. Methods described by Robinson and Thompson (1948a, b and c) for the estimation of phosphates, nitrites and silica were followed. The results are expressed as μg. at./L.

Data relating to the rainfall, air temperature and wind velocity were collected from the Indian Meteorological Department.

HYDROLOGICAL CONDITIONS

The hydrological data collected at the various sampling points on the North Kanara coast during the present investigations are presented as monthly averages in Text-Figures 3 to 10. The inshore water especially in and around Karwar is considerably influenced by the entry of fresh water from the Kali river during the south-west monsoon period. Hence a description of the conditions of this river are given first and the hydrological conditions of the inshore waters have been dealt with later.

(*A*) *Kali river* ; (Text-Fig. 2.)

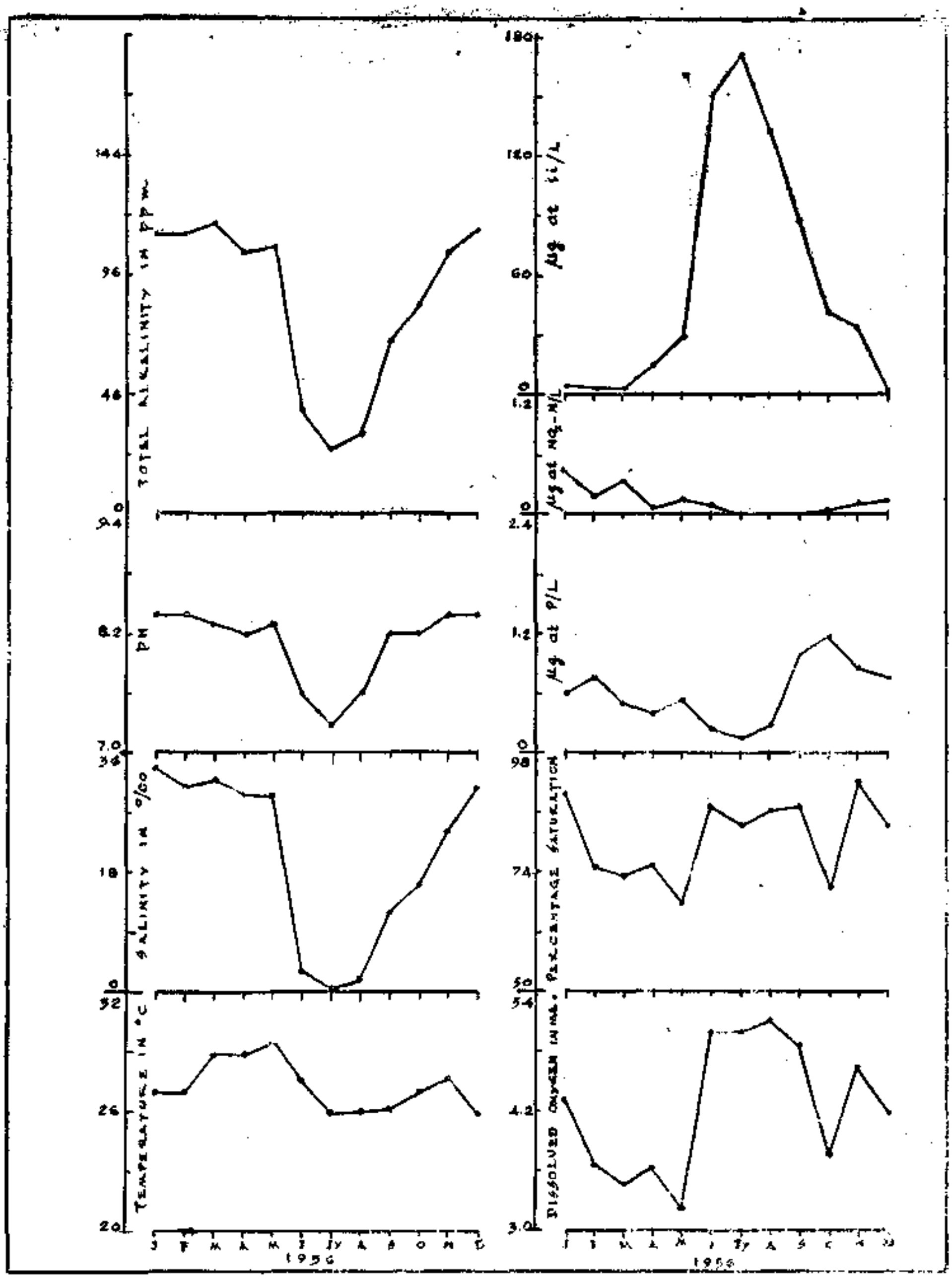
The temperature of the river water varied from 25·8°C. to 29·4°C. The maximum was noticed in May during the hot summer season and the minimum was recorded in July immediately after the period of the heaviest rainfall. A slight increase in the temperature of the river water (26·1°C.-27·6°C.) was observed between September and November after the cessation of the south-west monsoon.

The salinity of the river water showed wide fluctuations during the year at the sampling point. The lowest figure for salinity (0·27°/oo) was noticed in July at the time of the heaviest rainfall of the monsoon when a very large volume of fresh water was received in the river. The salinity remained low (1·78°/oo to 12·13°/oo) during the monsoon season. As the floods subsided, the salinity showed a steady increase due to admixture with the sea water when the tidal stream travelled upstream.

The pH value and the total alkalinity of the river water showed variations which followed the trends of the changes in the salinity. The pH at the sampling station varied between 7·3 and 8·4 while the total alkalinity varied from 24·5 ppm. to 116·0 ppm.

The dissolved oxygen content of the water was at the minimum in May (3·21 ml./L.). The fresh water which comes down the river with the floods of the monsoon carried a high concentration of dissolved oxygen and the maximum (5·10 ml./L.) was observed in August.

*The percentage values as per Fox's formula may be rather high (*vide* Apparatus and methods of oceanography by Barnes 1959). But in view of the dissolved oxygen values met with the Fox's formula has been retained.



TEXT-FIG. 2 Seasonal variations in the hydrological factors in the Kali river.

The dissolved oxygen content then decreased steadily during the period September-October consequent of the decrease in the flood flow, increase in the temperature of the water and rise in the salinity as a result of the tidal flow. A slight increase in the dissolved oxygen content was noticed in November which was followed by a decline in December.

The phosphate value of the river water varied from 0·15μg. at./L. to 1·19μg. at./L. The minimum was noticed in July at the time when fresh water with low salinity was received after the heavy monsoon rains and the maximum was found in October.

The river water was practically devoid of nitrites during the flood season. In the other seasons the nitrite content fluctuated between 0·05μg. at./L. to 0·42μg. at./L. the maximum being found in January.

The silica content of the water showed an inverse relationship to the salinity. Thus the silica content of the water rose from 30·0 μg. at./L. in May to a maximum of 171·5 μg. at./L. in July while the salinity decreased from 29·86°/oo to 0·27°/oo during the same period.

The major influence of the Kali river on the inshore water therefore would be exerted at the time of the floods during the south-west monsoon season and the river would supply a large amount of silica to the inshore water. Dilution of the sea water in the coastal margin would also occur to a certain extent.

(B) Coastal waters :—

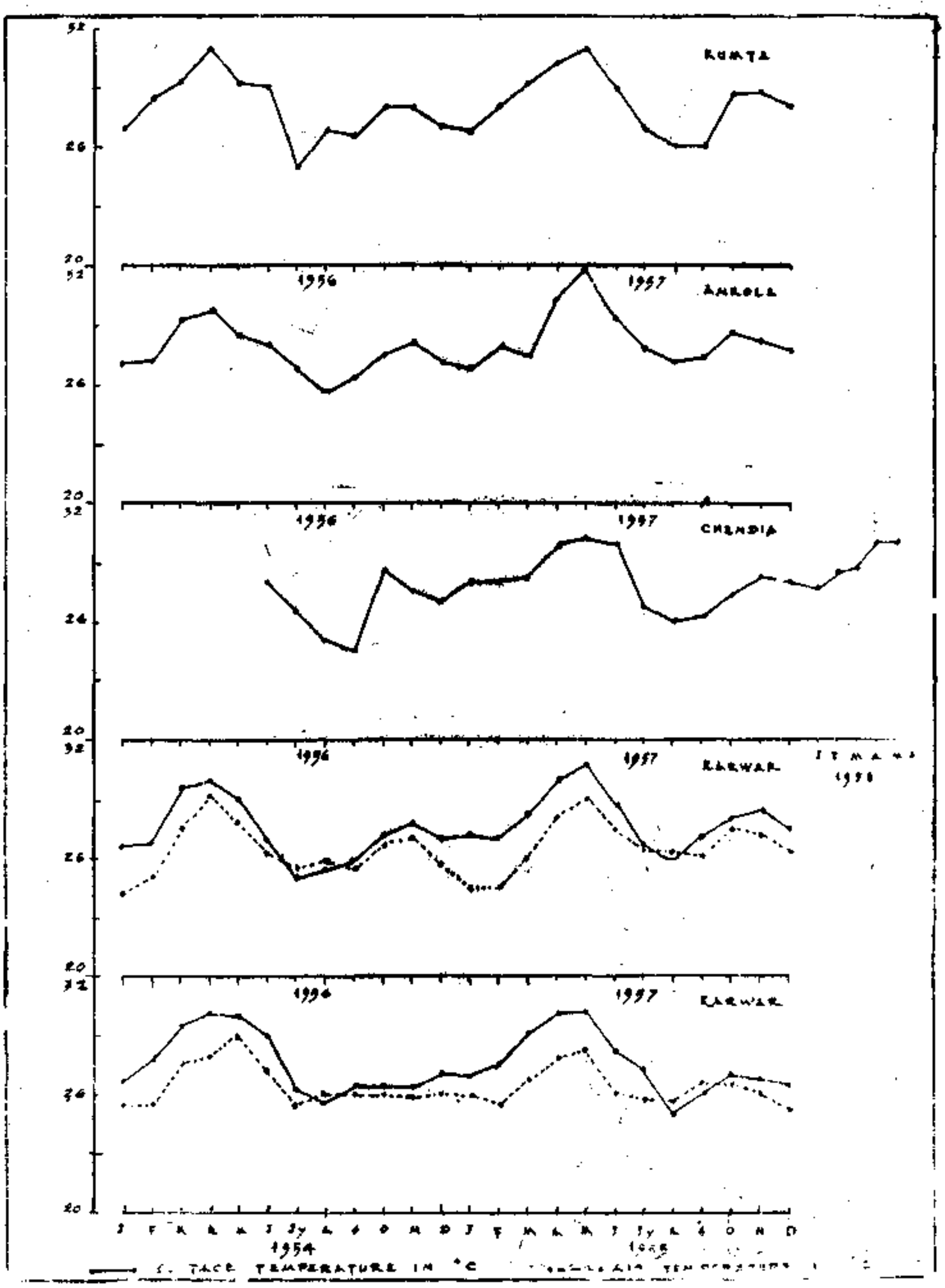
Temperature : (Text-Fig. 3) The temperature of the surface water showed a double seasonal oscillation in this coast. The primary maximum ranging from 29·8°C. to 31·7°C occurred during the summer season (April or May) at all the sampling stations. This was ollowed by a sudden decline in temperature reaching the lowest values (24·8°C. to 26·0°C.) during July to September in the south-west monsoon period. A secondary rise (26·5°C. to 28·8°C.) was noticed during October-November which was followed by a decrease (26·0°C. to 27·7°C.) during December-January.

The temperature of the sea water was higher than that of the atmosphere by 0·4°C. to 3·3°C. except during July to September in each year when the temperature of the surface water went lower than that of the atmosphere.

The double seasonal oscillation in the temperature of the water is seen to be related to the two monsoons on this coast. The peaks in the water temperature which occur before and after the south-west monsoon may be attributed to insolation. Such a double seasonal oscillation in temperature has been noticed also at Calicut (Chidambaram and Menon 1945).

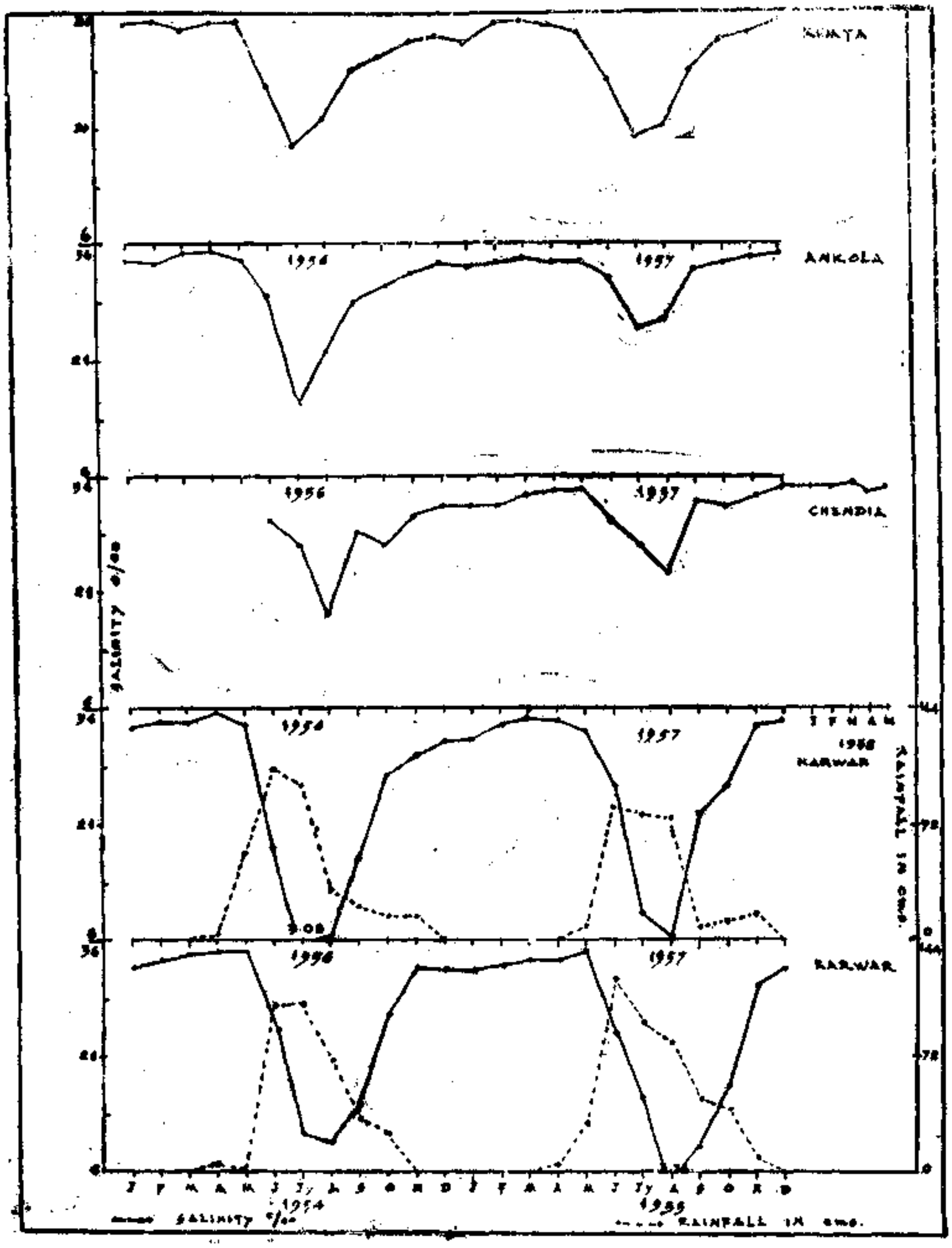
The surface temperature shows a minimum and a maximum yearly variation of 4·1° C. and 6·0° C. respectively, based on the mean monthly values. Sewell (1929) however has recorded an yearly variation of only 1·88° C. in the mean monthly temperature of the Laccadive sea off the West Coast of India.

Salinity : (Text-Fig. 4) The salinity of the sea water along the North Kanara coast ranged between 32·00°/oo and 35·76°/oo during November to May, which was also the season of maximum salinity of the water. With the onset of the heavy rains of the south-west monsoon season and the consequent land drainage a steady and marked fall in the salinity of the water occurred over the whole of the coastal area. The lowest value ranging from 3·08°/oo to 9·70°/oo was reached in July or August at Karwar. At the sampling stations Chendia, Ankola and Kumta the minimum values (15·24°/oo—24·66°/oo) were always higher than that at Karwar. The very low figure for salinity noticed in the inshore waters at Karwa



TEXT-FIG. 3 Seasonal variations in the surface temperature and air temperature in the N. Kanara coast.

s no doubt due to the dilution with the fresh water coming down the Kali river, the influence of which was noticed at this point to the maximum extent. At the other sampling stations viz., Chendia, Ankola and Kumta which are located at places far from the river mouths, the salinity did not decrease to the same extent as at Karwar during the period May to July. It



TEXT-FIG. 4 Seasonal variations in the salinity of the surface waters of the N. Kanara coast and rainfall.

is however interesting to note that even at stations well removed from the zone of immediate influence of the inflow of fresh water there is a decrease in salinity during the south-west monsoon season as a result of the general surface run-off and the mixing likely to take place from coastal circulation, which in this coast, is from north to south during this period.

pH : (Tex-Fig. 5) The pH of the sea water along this coast was between 8·4 and 8·5 during November—May. After the rains the pH value of the sea water decreased to 7·4 to 7·9 at Karwar (June—September) while at the other places viz., Chendia, Ankola and Kumta the pH showed only a slight fall to 8·1 to 8·3 during the same period. The somewhat greater decrease in pH at Karwar may have been due to the influence of the flood water of the Kali river.

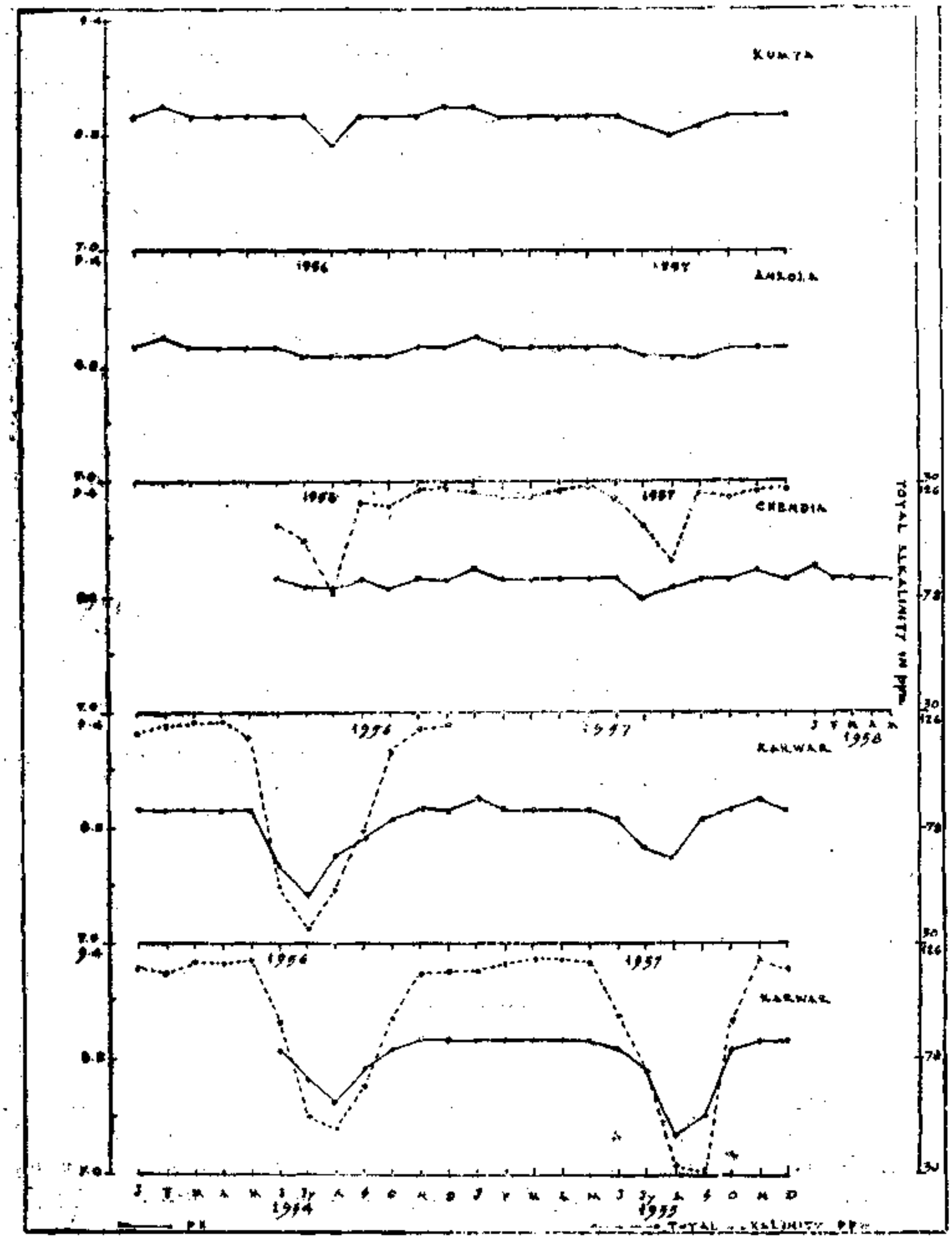
Total alkalinity : (Text-Fig. 5) The total alkalinity of the sea water along this coast was estimated periodically at Karwar during the year 1954 to 1956 and at Chendia during June 1956 to December 1957. It will be seen from the figure that the total alkalinity value ranged between 30·0 ppm. and 126·0 ppm. and followed the changes in the pH and salinity of the water. The total alkalinity tended to decrease during the periods when the dissolved oxygen content of the water increased. The maximum values (119·7—126·0 ppm.) occurred during April—May while the lowest figures (30·0—93·0 ppm.) were recorded during the south-west monsoon period.

Dissolved oxygen : (Text-Fig. 6) The dissolved oxygen content ranged from 2·75 ml./L. to 5·31 ml./L. during the period of study. It showed more or less similar seasonal variations at all the sampling points except at Chendia. There was a distinct rise in the dissolved oxygen content each year during July-August when the maximum was reached the value ranging from 4·58 ml./L. to 5·31 ml./L. This annual dissolved oxygen maximum occurred following the period of the heaviest rainfall of the south-west monsoon season. After reaching the maximum the dissolved oxygen content showed a rather steep fall and fluctuated within narrow limits. A secondary maximum was then noticed generally during the period November-December, sometimes a little later, when the dissolved oxygen content increased to 4·20 ml./L. to 5·03 ml./L. at the sampling stations examined. At Chendia the dissolved oxygen content showed only a single maximum (4·65 ml./L. to 4·78 ml./L.) which occurred during January-February.

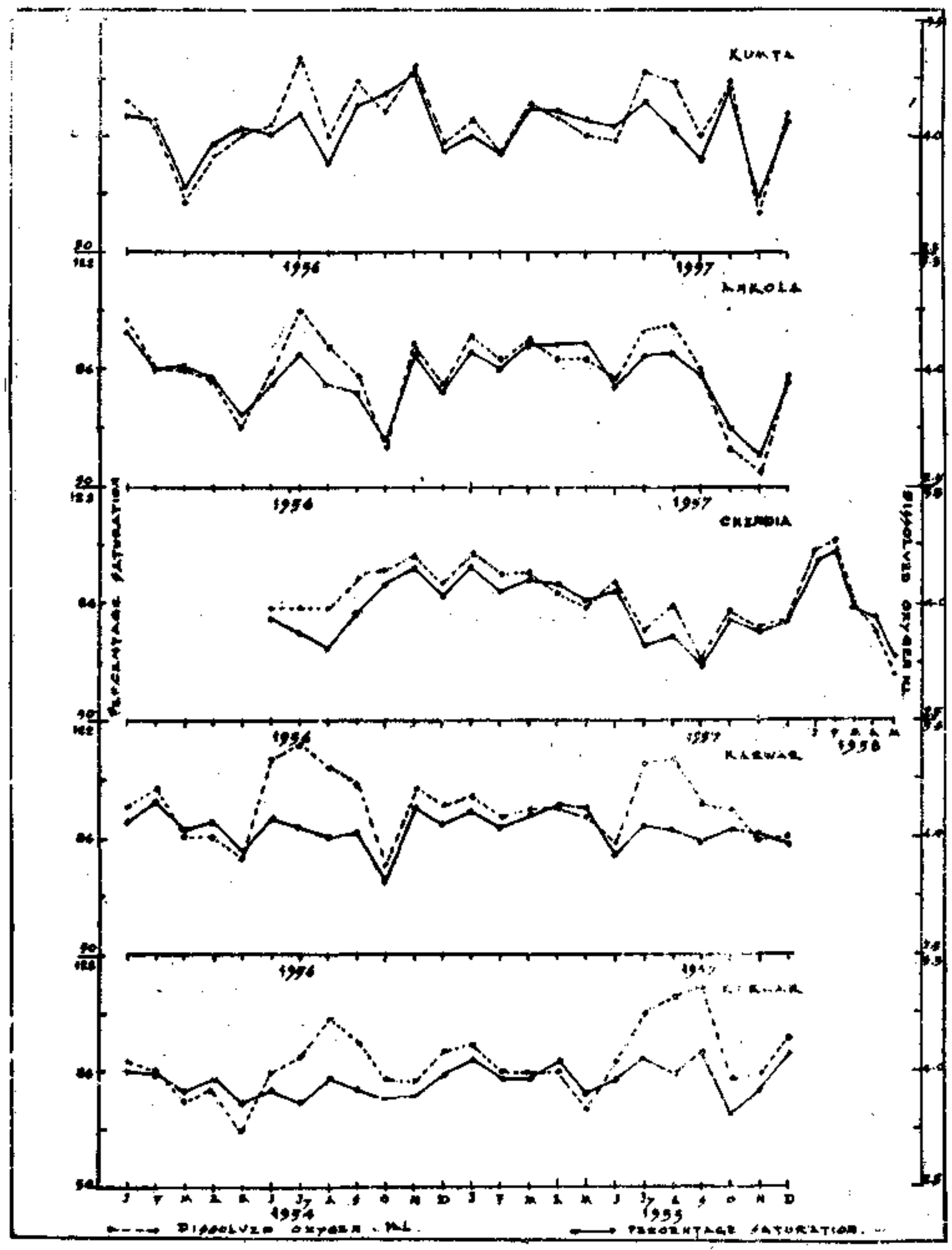
Considered from the point of view of percentage saturation it will be seen from Text-Fig. 6 that this follows closely the actual dissolved oxygen values. Saturation or super saturation levels were reached only on a few occasions.

Phosphates : (Text-Fig. 7) Phosphates never showed complete depletion at any time. The phosphate content showed a definite peak each year during August-September *i.e.* the atter half of the south-west monsoon season at all the sampling points except at Karwar. The values for the maximum ranged from 1·25 μg. at./L. to 1·78 μg. at./L. The minimum values ranged from 0·22 μg. at./L. to 0·38 μg. at./L. and were recorded during January-March.

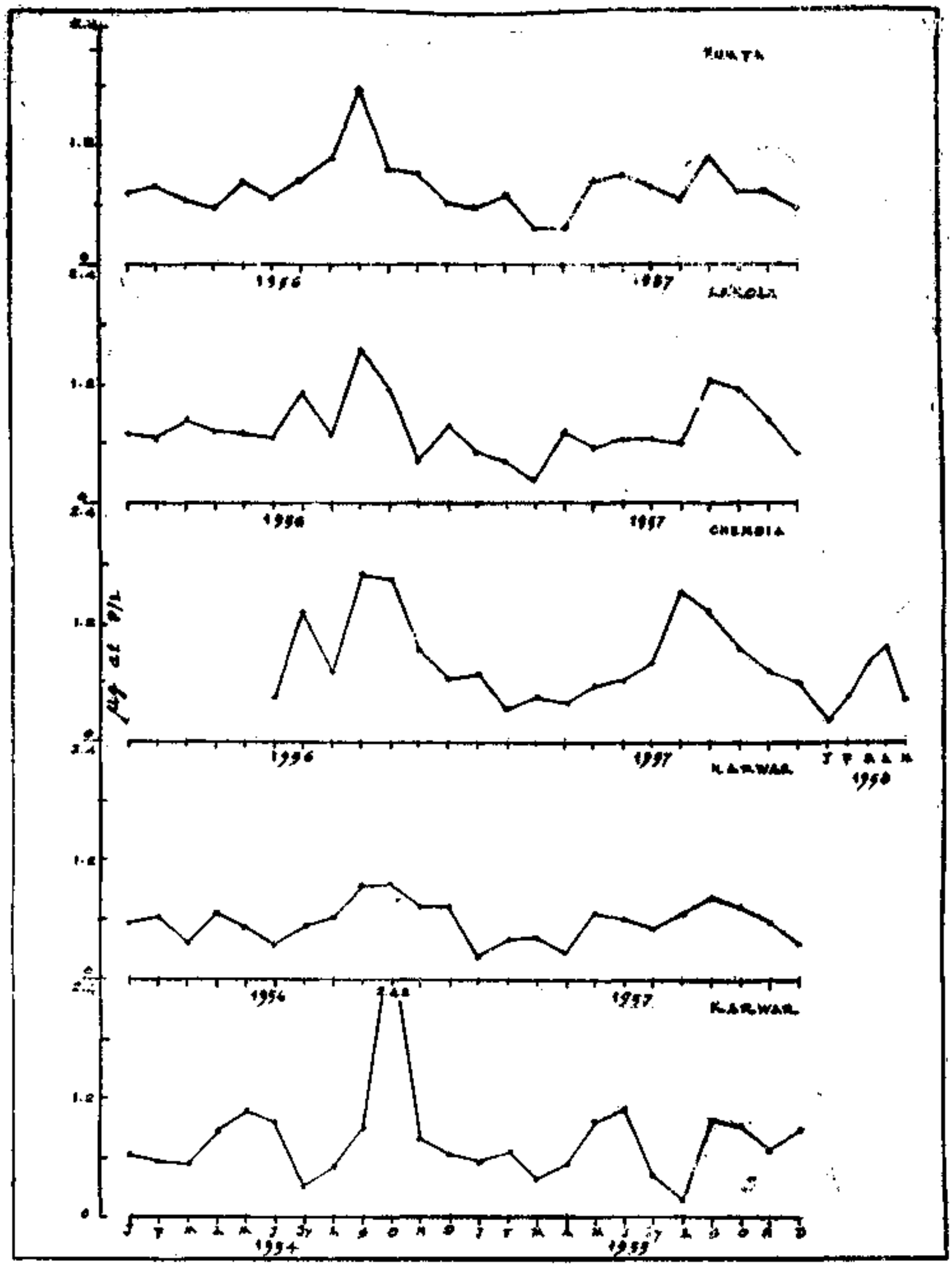
At Karwar such a distinct peak as at the other centres was not observed except in the year 1954, (October) when the value was 2·42 μg. at./L. During August-September the phosphate values ranged from 0·20 μg. at./L. to 0·99 μg. at./L. The comparatively low values noticed at Karwar during the south-west monsoon should be attributed to the greater freshening effect of the river water.



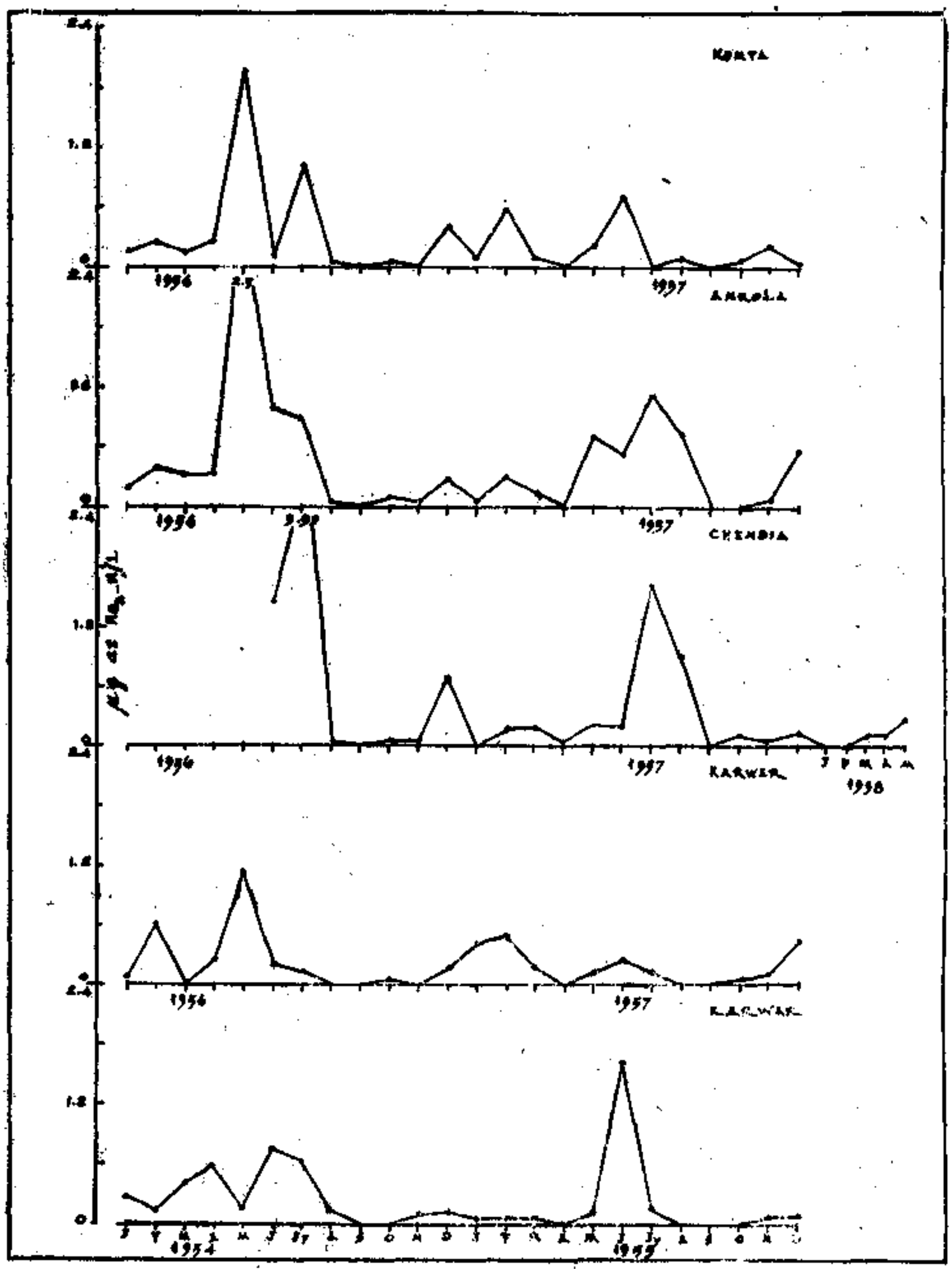
TEXT-FIG. 5 Seasonal variations in pH and total alkalinity of the surface waters of the N. Kanara coast.



TEXT-FIG. 6 Seasonal variations in the dissolved oxygen content and percentage saturation of the surface waters of the N. Kanara coast.

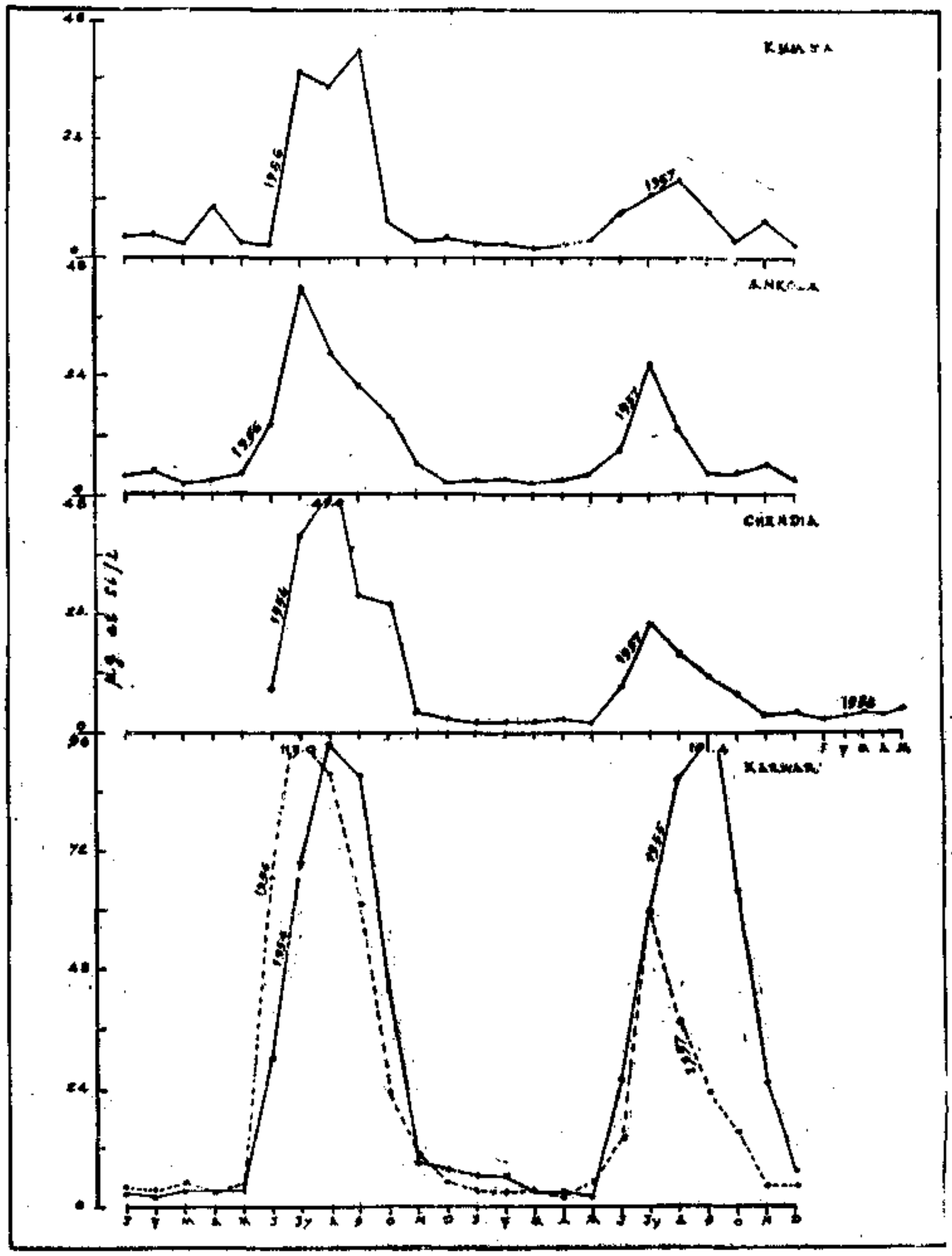


TEXT-FIG. 7. Seasonal variations in the phosphate content of the surface water of the N. Kanara coast.



TEXT-FIG. 8 Seasonal variations in the nitrite content of the surface waters of the N. Kanara coast.

Nitrites : (Text-Fig. 8) During August-October, towards the end of the south-west monsoon season, the sea water was either totally devoid of nitrites or the nitrite concentration was very low (0·1 µg. at./L.). The nitrite maximum was reached during the period May-July soon after the commencement of the south-west monsoon when the temperature was on the decline. The values for the nitrite maximum at Karwar ranged from 0·77g.·atµ/.L to 1·60 µg. at./L. while at the other sampling points they fluctuated between 1·16 µg. at./L. to 3·59 µg. at./L. Thus it will be seen that as in the case of the phosphates, the nitrites at Karwar remained comparatively low during May-July. A secondary maximum (0·1 µg. at./L. to 0·69 µg. at./L.) in the nitrite content was noticed during December-March. It is interesting to note that the primary nitrite maximum at the various sampling points preceded the phosphate maximum.



TEXT-FIG. 9 Seasonal variations in the silica content of the surface waters of the N. Kanara coast.

Silica : (Text-Fig. 9) The silica content reached the maximum at all the places during July-September. The values for this maximum ranged from 61·0 µg. at./L. to 113·0 µg. at./L. at Karwar and from 15·5 µg. at./L. to 49·0 µg. at./L. at the other places. The silica content showed a steep fall in the post-monsoon months and it remained low until the onset of the south-west monsoon (2·0 µg. at./L. to 10·0 µg. at./L.).

The silica content shows an inverse relationship to salinity. This has been noticed also in the Bay of Bengal by Jayaraman (1951 and 1954) and by Ganapati and Rao (1958). The land drainage would appear to contribute largely to the rise in the silica content during the the south-west monsoon season as the river water carries a high silica content at this time. This would also explain the particularly high content of silica noticed at the Karwar sampling station.

The concentration of the nutrients provides an index of the magnitude of organic production in the sea, which in turn supports the fishery (Cooper 1948 and Steemann Nielsen 1954). The available data regarding the content of the common nutrients in the surface water of the Indian coast are summarised in Table I.

TABLE I

Distribution of the dissolved inorganic nutrients in the Indian coastal waters expressed as mean monthly values in µg. at./L.

Place of Observation	Phosphates (P)		Nitrates (NO_3-N)		Nitrites (NO_2-N)		Silicates (Si)	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
East Coast :								
Gulf of Mannar & Palk Bay (Jayaraman, 1954)	0·09	0·30	1·1	5·0	..	..	3·7	18·3
Madras (Jayaraman, 1951) . .	0·24	1·06	1·3	9·7	0·00	0·32	3·8	19·7
Madras (Ramamurthy, 1953) .	0·34	1·2	..	..	0·02	0·30	3·8	11·2
Waltair (Ganapati & Sarma, 1958) .	0·27	1·66	0·61	3·36	..	..	6·78	23·7
West Coast :								
Calicut (Subrahmanyan, 1959) .	0·13	1·68	0·47	34·0	..	..	5·17	47·2
North Kanara coast (present study)	0·125	2·42	..	..	0·00	3·59	2·1	49·0
Bombay (Bal *et al.*, 1946) . .	0·212	0·347	..	..	0·11	2·54	8·5	20·8
Bombay (Jayaraman *et al.*, 1961) .	0·75	1·15	..	..	..	..	..	..

It is seen from this table that the coastal waters of North Kanara and Malabar on the west coast of the Indian peninsula show a higher phosphate maximum than the other areas. A seasonal cycle in the phosphate content was not found by Bal *et al* (1946) and Jayaraman *et al* (1961) in the Bombay harbour and inshore waters respectively and by the author (1953) at Madras nor in the Gulf of Mannar and in the Palk Bay by Jayaraman (1954). The results of the present study however show that there is a definite seasonal cycle in the phosphate concentration in the North Kanara coastal waters as in the case of the Malabar coast and that the annual maximum occurs at about the same time in both these areas. A marked seasonal cycle in phosphates was found by Ganapati and Sarma (1958) in the Visakhapatnam coast.

With regard to the nitrites and silica content also the waters of the west coast of India appear to be richer than those of the east coast. It is interesting to note that in both these coastal waters there is a period when nitrite nitrogen is totally absent.

It is thus seen that the waters of the west coast of India are richer in plant nutrients than those of the east coast. This would indicate that the organic productivity of the west coast is also greater.

DISCUSSION

Considering the seasonal variations in the hydrological characteristics of the North Kanara coastal waters it would be seen that they are more or less uniform over the entire coastal stretch.

The temperatutre of the surface water is higher than that of the air except during the period of the south-west monsoon season (July-September). During the south-west monsoon period it falls below that of the air and touches the annual minimum. The minimum air temperature is however met only in December. The fall in the surface temperature between July-September cannot however be attributed to the cooling effect of the heavy monsoon rains because the rainfall would normally bring down the air temperature much quicker and to a level below that of the sea water. This has been noticed by Sewell (1929) on the east coast of India. The dissolved oxygen content in the North Kanara coastal waters remained below the saturation level during the south-west monsoon period. The samples for oxygen estimations were taken in the mornings. While it is possible that the photosynthetic activity may not have reached the maximum at this time, it is significant that the dissolved oxygen supersaturation was noticed in the post-monsoon months and it was invariably below saturation in the monsoon period. The conditions for high dissolved oxygen saturation exist during the south-west monsoon period such as low temperature and low salinity. Besides the plankton samples collected during this period were found to be rich in diatoms. The phosphates show a well defined maximum in the North Kanara coastal waters during the south-west monsoon period. It is apparent that the high phosphate content of the sea water could not have been derived from the river flow since the river water is found to be poor in phosphates.

It will thus be seen that the changes in the hydrological characteristics of the inshore waters of North Kanara *viz.*, (a) fall in the surface temperature below that of the air, (b) absence of dissloved oxygen supersaturation in spite of the existence of favourable conditions and (c) marked increase in phosphate reaching the annual maximum are a special feature of the south-west monsoon season. Similar features have been noticed down south in the coastal waters of south-west India (Seshappa and Jayaraman 1956 and Subrahmanyan 1959). Sewell (1955) and Carruthers *et al* (1959) found that the upwelling waters of the Arabian sea are cold, poor in oxygen content and rich in nutrients. Upwelling has been reported off the south coast of Ceylon (Schott 1935) and off the south-west coast of India (Banse 1959 and Sastry 1959) in the south-west monsoon season. It is therefore possible that the hydrological features noticed during the south-west monsoon season in the North Kanara coastal waters are related to the influence of this phenomenon.

The temperature data presented in Table II for 1956 and 1957 indicates that there is a distinct progression in the fall in temperature from north to south (*i.e.*, from Chendia to Kumta). The continental shelf along the west coast of India shows a progressive widening from south to north. It is known that the cold Antarctic bottom drift enters the Arabian sea. It is probable that an arm of this drift strikes against the continental shelf in the north, gets upwelled and moving clockwise sweeps down the coast in a north to south direction *i.e.*, from Chendia to Kumta so far as the area of the present study is concerned and this would explain the progression in the fall in temperature noticed along this coast. As temperature of the water is independent of biological activity as well as of the fluctuations in the atmospheric temperature at this time, this factor should be taken as a reliable indicator of the progression of upwelling. Another point of interest noticed from the observations on the tempearture of the water (Table II) during the south-west monsoon season is that the temperature showed pulsations in 1956 whereas it was more steady in 1957. Significantly the winds which are known to have a direct bearing on the strength of upwelling were much stronger in 1957 than in 1956.

TABLE II

Progression of upwelling in the North Kanara coast during 1956 *and* 1957.

CHENDIA		ANKOLA		KUMTA		
Date	Temperature °C	Date	Temperature °C	Date	Temperature °C	Remarks
(1)	(2)	(3)	(4)	(5)	(6)	(7)
14-6-56	28·5	11-6-56	28·0	13-6-56	29·0	No upwelling.
						Sudden fall in temperature; Probable commencement of upwelling.
12-7-56	25·0	19-7-56	25·3	25-7-56	24·5	
27-7-56	27·8	31-7-56	28·0	8-8-56	25·4	
9-8-56	24·6	16-8-56	25·4	23-8-56	28·5	Wind velocity ranged from 1·4 to 4·8 onots/hr. during June-September.
28-8-56	25·4	30-8-56	25·4	31-8-56	26·5	
6-9-56	26·0	10-9-56	27·4	12-9-56	27·0	

TABLE II—*contd.*

CHENDIA		ANKOLA		KUMTA		
Date	Temperature °C	Date	Temperature °C	Date	Temperature °C	Remarks
(1)	(2)	(3)	(4)	(5)	(6)	(7)
20-9-56	23·0	24-9-56	25·0	26-9-56	26·2	
18-10-56	28·2	22-10-56	27·6	30-10-56	27·8	
27-3-57	28·2	3-4-57	30·2	23-3-57	29·0	
5-6-57	31·0	6-6-57	29·0	8-6-57	29·0	No upwelling.
..	..	3-7-57	28·6	..		Sudden fall in temperature; Probable commencement of upwelling.
13-7-57	27·0	19-7-57	27·0	26-7-57	27·0	
30-7-57	26·3	5-8-57	28·0	9-8-57	27·0	Wind velocity ranged from 5·4 to 10·8 knots/hr during June-September.
17-8-57	25·5	19-8-57	26·0	27-8-57	25·0	
31-8-57	26·4	..	..	..	..	
17-9-57	26·2	9-9-57	26·3	12-9-57	26·0	
30-9-57	26·0	27-9-57	28·0	27-9-57	26·0	
10-10-57	27·8	11-10-57	28·3	15-10-57	28·4	
7-2-58	28·8	..	No Data	..		

SUMMARY

The present study relates chiefly to the hydrological factors of the surface waters of the North Kanara coast and covers a stretch of forty miles on the west coast of India over a period of five years.

The physical and meteorological features of the area are given.

The seasonal variations in the temperature, salinity, pH, total alkalinity, dissolved oxygen and percentage saturation, dissolved inorganic phosphates, nitrites and silicates are described. The influence of land drainage on the hydrology of the coastal waters has also been recorded. The nutrients distribution in the Indian coastal waters has been reviewed.

The hydrological characteristics noticed during the south-west monsoon season suggest the influence of upwelling on the coastal waters. The progression of upwelling is from north to south as deduced from the temperature data and this appears to have been conditioned by the nature of the continental shelf along the west coast. The monsoon fluctuations in temperature were also found to be related to the strengh of the wind.

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