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# PHYSICAL FEATURES OF AN EXPOSED SANDY BEACH AT GOPALPUR (ORISSA COAST)

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## ABSTRACT

Some physical parameters which determine the properties of the interstitial environment of the sandy beach at Gopalpur have been discussed. The beach sediment is composed mostly of medium sand of mean particle size 250-350 μ m, and is well sorted. Large scale sand movements caused by seasonally reversing longshore currents and tide-dependent cyclic erosion and deposition affect beach stability. Sand temperatures show wide fluctuations diurnally and seasonally: the extremes recorded are 14.5° C and 39.5° C. The salinity of interstitial water varies between 16.53 and 34.16‰ and is not significantly different from that of shore water. The oxygen concentration of interstitial water was slightly lower than that of shore water. Reduced layers were not encountered even at a depth of 100 cm in sand.

On a 20-point rating system the beach is classified as 'exposed'. Moderate to heavy wave action, a surf zone that is 50-150 m wide and absence of Stable burrows of macrofauna are the other features that characterize the Gopalpur beach.

*Key-words* : Physical features, sandy beach, Gopalpur, Orissa Coast.

## INTRODUCTION

During the course of an investigation on the ecology of the interstitial fauna on an exposed sandy beach at Gopalpur (Orissa) data were collected on processes and parameters which determine the properties of the interstitial system (Pattnaik, 1984). These include the physical characteristics of the beach which are largely controlled by waves, tides and currents as well as sediment parameters, air, sea and sand temperatures and salinity and oxygen content of shore and interstitial waters. As there were no earlier reports on the physical features of the coast and hydrography of the sea at Gopalpur it is felt desirable to give descriptions of the study area and the physical conditions investigated, before presenting the results of ecological studies.

## METHODS

All observations were made at the time of low tide along the transect marked 'A' in Figure 1. These are supplemented by tidal cycle observations and data on temperature, salinity and dissolved oxygen of surface waters recorded at a fixed time (8-9 a.m.) on every tenth day of the month.

Sea water samples for salinity and oxygen determination were collected from the shore. Interstitial water was collected by digging into the sand till the water table is reached. Because of the well drained nature of the beach it was not possible to collect interstitial samples from surface layers or from upper levels of the beach; all samples were taken a little below the midtide level and at a depth of 40-50 cm in the sand. Standard method of titration for sailnity and Winkler's method for oxygen were followed.

Atmospheric temperature was read on the beach and sea temperature was recorded from knee-deep water with a mercury themometre of 0.1°C accuracy. Sand temperature was measured by inserting the thermometer into the sand to the desired depth. At depths exceeding 10 cm it was necessary to remove the sand and then quickly read the temperature; care was taken to see that the mercury bulb is fully covered by a mound of sand from the same depth.

The graphic mean ($M_Z$), the inclusive standard deviation ($\sigma I$) and the inclusive garphic skewness ($SK_I$) were determined by the method of Folk recommended by Hullings and Gray (1971). The verbal classification of he sediment given in Table I is after the Wentworth scale and the notations suggested by Folk (1974) in Holme and McIntyre, (1984). Beach profiles were taken by adopting the technique of Emery (1961). Unless otherwise indicated, the results presented are for the period May, 1983 to May, 1984.

## DESCRIPTION OF STUDY AREA

### *Topography*

Gopalpur (19°16'N and 84° 54' E) is a small fishing village on the south Orissa coast, about 50 km south of the mouth of Chilka lake. The area receives an average annual rainfall of 1210 mm and nearly 80% of it is contributed by the south-west monsoon (India Meteorological Department, climatological data for the years 1931-1960). The coastline at Gopalpur is fairly straight having an orientation of 48° E of the north and is a completely sandy stretch for several tens of kilometers north and south. Well developed and stable sand dunes are the characteristic of the backshore. Immediately north of the village is a narrow lagoon and a small stream, the Nandia Nalla which discharges into the lagoon and joins the sea in a north-easterly direction (Fig. 1). The mouth of this backwater is disconnected with the sea except during the monsoon period when the fishermen cut open the beach. During the period of this study the bar was opened on 6-8-83 and by the end of December it was reformed, separating the lagoon and the sea. Phleger (1981) calls such bodies of water as 'pocket, lagoons which have a significant amount of water exchange with the open sea by seepage through the porous sandy-barrier. That a similar situation prevails at Gopalpur is evident from tidally-induced rise and fall of water level in the lagoon even when it is disconnected with the sea.

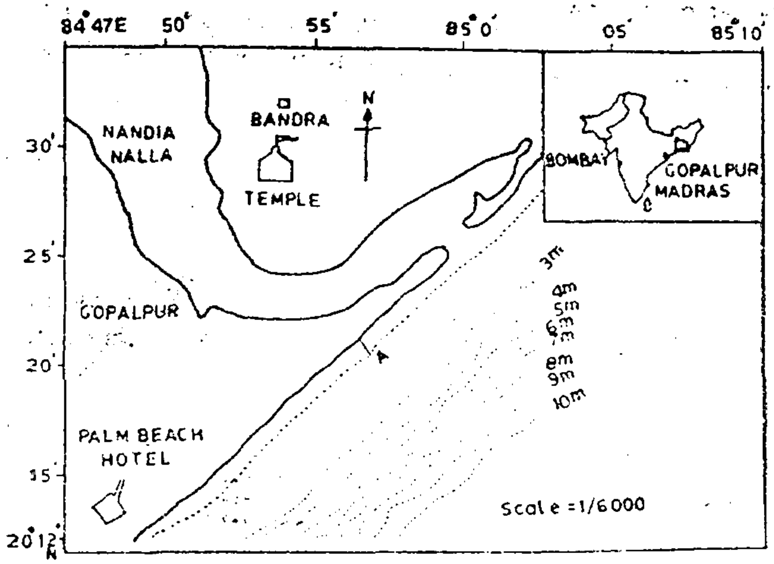


Fig 1. Map of study area showing position of transect 'A'.

*Waves, tides and currents*

Waves, tides and longshore currents control beach stability, but there are no published reports on these physical processes at Gopalpur. However, some preliminary data were collected by a team of investigators from the Central Water and Power Research Station, Pune and some points relevant to the present study are taken from this report (CWPRS, 1972)

At Gopalpur the south-west monsoon prevails from May to September though it does not get established till the middle of June. The north-east monsoon extends from October to December. Wind force is high during the south-west monsoon and in June-July may reach Beaufort 6-7; wind force is less during the north-east monsoon and seldom exceeds Beaufort 4. Wave heights are usually in the range of 0.2 to 0.7m, waves exceeding the height of 1 m occur less frequently and exceptionally high waves, rarely. Our observations throughout the year show that the width of the surf zone varies between 50-150 m. Surf zone phytoplankton blooms were noticed on a number of occasions.

Tides are semi-diurnal. The highest high water level is 2.35 m above the chart datum.

Longshore currents provide the mechanism for sand movement along the coast. During the south-west monsoon high energy waves coming from the south and south-east cause enormous sand movements northward (0.9 x $10^6$ $m^3$/yr). Similarly during the north-east monsoon the predominant north-easterly waves cause a return drift in the opposite direction (0.16 x $10^6$ $m^3$/yr). Since the wave energy is much higher during the south-west monsoon the net drift is of the order of 0.74 x $10^6$ $m^3$/yr from south to north. It has been estimated that 85% of this drift travels from the shore up to the 4 meters isobath (Central Water and Power Research Station 1972).

## RESULTS

### *Beach Profiles*

Beach profiles measured during different seasons of the year are shown in Figure 2. These and visual records on dates of sampling indicate that the beach

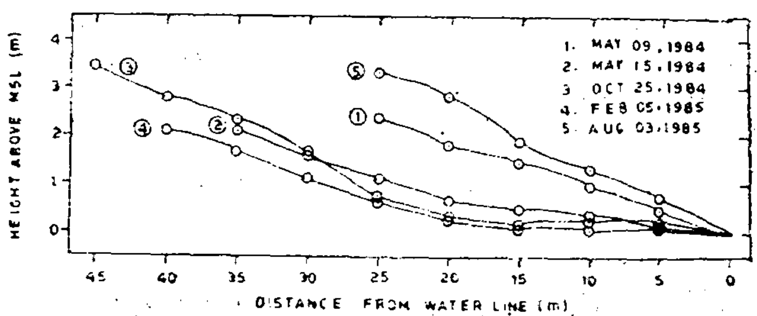


**Fig. 2. Beach profiles measured near the sampling site.**

configuration changes perceptibly through the year and more so during the south-west monsoon period. These changes are reminiscent of cyclic beach erosion and deposition associated with spring and neap tides (La Fond and Prasada Rao, 1954) and seasonal changes in beach configuration (Sastry, Swamy, Rao and Vasudev, 1979) observed on the exposed sand beaches between Waltair and Bhimunipatnam. Profiles 1 and 2 (Fig. 2) give some idea of tidal-induced beach fill and cut at Gopalpur. During the south-west monsoon the combined effects of waves and tides may be so drastic as to leave a terrace of more than 1.5 m high at the high tide level (Fig. 3 A and B).

The width of the intertidal zone varies from 25 to 50 m depending on tides and seasons. During periods of calm weather deposition of sand near low tide level results in a bar formation and 60-70 m of the beach may be exposed as noticed between December and March.

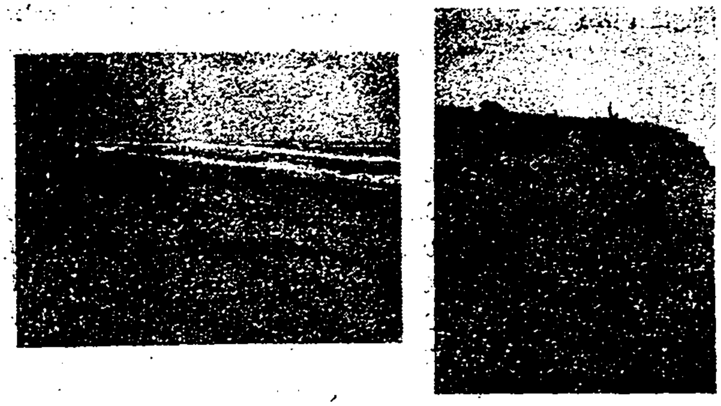

Fig. 3. The beach at Gopalpur; A. with a gentle slope (4-6-84); B. the same beach cut earlier by high energy waves (3-5-84). The girl to the left is 1.6 m tall.

Beach slopes range between 1/8 to 1/22. In general the beach had gentler slopes between October and April and slopes were steeper during the south-west monsoon. However, beach slopes do not show any cognizable correlation with seasons, tides or particle size.

*Particle size*

The mean particle size, uniformity of sorting and skewness of selected samples are given in Table I. The sand at Gopalpur may be classified as medium sand with occasional presence of coarse sand. The mean particle diameter shows an annual variation of 240-480 $\mu$m. But for a greater part of the year the particle size remains within the range of 250-350 $\mu$m ($\Theta$ 2.0-1.0). Coarser grades occurred during September and probably reflect increased turbulence during the peak of monsoon season. Fine sand was encountered only occasionally and the silt-clay fraction is negligible. Sand becomes progressively coaser from low to high tide levels as well as with increase in depth of the sediment. However, there are exceptions to these trends. The sands were well sorted to moderately sorted. It may be seen from Table I that all the four samples from the low tide level are coarse skewed. This is to be expected because of greater turbulence at this area. The mid and high tide samples are either symmetrical or fine skewed.

*Temperature*

Monthly averages of air and sea temperature recorded at Gopalpur between 8-9 a.m. are shown in Figure 6A. Atmospheric temperature reaches a summer maximum of 31.0°C in June and a minimum of 22.5°C in

Table I. Phi mean grain size ($M_z$) sorting ($\sigma$ I) and skewness ($SK_I$) of selected samples

| Date | Stn. | Depth (cm) | $M_z$ | $\sigma$ I | $SK_I$ | Physical description of sand |
|---|---|---|---|---|---|---|
| 18, Jul. 1983 | L | 0-5 | 1.69 | 0.474 | −0.200 | Medium; well sorted; coarse skewed |
| | M | 0-5 | 1.63 | 0.452 | +0.150 | Medium; well sorted; strongly fine skewed |
| | H | 0-5 | 1.52 | 0.422 | +0.660 | Medium; well sorted; strongly fine skewed |
| 28, Sept. 1983 | L | 0-5 | 1.48 | 0.365 | −0.710 | Coarse; well sorted; strongly coarse skewed |
| | M | 0-5 | 1.05 | 0.481 | +0.325 | Coarse; well sorted; strongly fine skewed |
| | M | 5-10 | 1.25 | 0.402 | +0.024 | Coarse; well sorted; symmetrical |
| | M | 10-15 | 1.22 | 0.445 | +0.125 | Coarse; well sorted; fine skewed |
| | H | 0-5 | 1.38 | 0.375 | +0.107 | Coarse; well sorted; fine skewed |
| 19, Dec. 1983 | L | 0-5 | 2.46 | 0.510 | −0.230 | Fine to medium; moderately well sorted; coarse skewed |
| | M | 0-5 | 2.05 | 0.507 | +0.002 | Medium; moderately well sorted; symmetrical |
| | M | 5-10 | 1.66 | 0.720 | −0.050 | Medium; moderately well sorted symmetrical |
| | M | 10-15 | 1.58 | 0.458 | −0.060 | Medium; well sorted; symmetrical |
| | H | 0-5 | 2.18 | 0.390 | −0.038 | Medium to fine; well sorted; symmetrical |
| 27, Feb. 1984 | L | 0-5 | 1.36 | 0.500 | −0.273 | Coarse to medium; well sorted; coarse skewed |
| | M | 0-5 | 1.92 | 0.695 | +0.007 | Medium; moderately well sorted; symmetrical |
| | M | 5-10 | 1.85 | 0.477 | +0.254 | Medium; well sorted; fine skewed |
| | M | 10-15 | 1.43 | 0.787 | −0.014 | Medium to coarse; moderately sorted; symmetrical |
| | H | 0-5 | 2.23 | 0.498 | −0.056 | Medium; to fine; well sorted; symmetrical |
| 30, Apr. 1984 | M | 0-5 | 1.80 | 0.452 | 0.000 | Medium; well sorted; symmetrical |
| | M | 5-10 | 1.73 | 0.515 | +0.571 | Medium; moderately well sorted; strongly fine skewed. |
| | M | 10-15 | 1.60 | 0.522 | +.062 | Medium, moderately well sorted; symmetrical |

(L-low tide, M Mid tide & H-High tide)

January. The lowest and highest air temperatures recorded during this study were respectively 15.0°C (at 11.45 p.m. on 19-12-84) and 33.2°C (at 11 a.m. on 16-9-83). Seawater temperature closely follows the trend exhibited by air temperature. The maximum and minimum values are respectively 29.7°C in June and 24.6°C in January. The lowest sea water temperature recorded was 22.2°C (at 4 a.m. on 20-1284) and the highest was 32.2°C (at 1.30 p.m. on 9-5-84). Sea water temperature was lower than air temperature except during the colder season, November to February, when the reverse was the case.

Sand temperature was measured on all observation days, at low, middle and high tide levels, from the surface to depths raging between 15 to 50 cm in sand and during tidal cycles. The following points summarize the more important features of the horizontal and vertical gradients (Fig. 4). Temperature of surface sand increased from low to high tide level with intermediate values registered at the mid tide station; depending on season and time of the day, the difference between tidal levels varied from 0.3°C (at 8 a.m. on 27-11-83) to 6.8°C) (at 12.30 p.m. on 16-1-84). Surface-depth gradients were much less pronounced at low tide station than at the two upper level stations. Surface-depth differences were greator during the colder part of the year. Temperature fluctuation was more pronounced in the top 15 cm while sand below this depth was relatively homothermal. The vertical distribution of temperature at high tide level followed different patterns. The maximum temperature differences observed were 7.2°C on 16-9-83 (Fig. 4A) and 9.5°C on 16-1-84

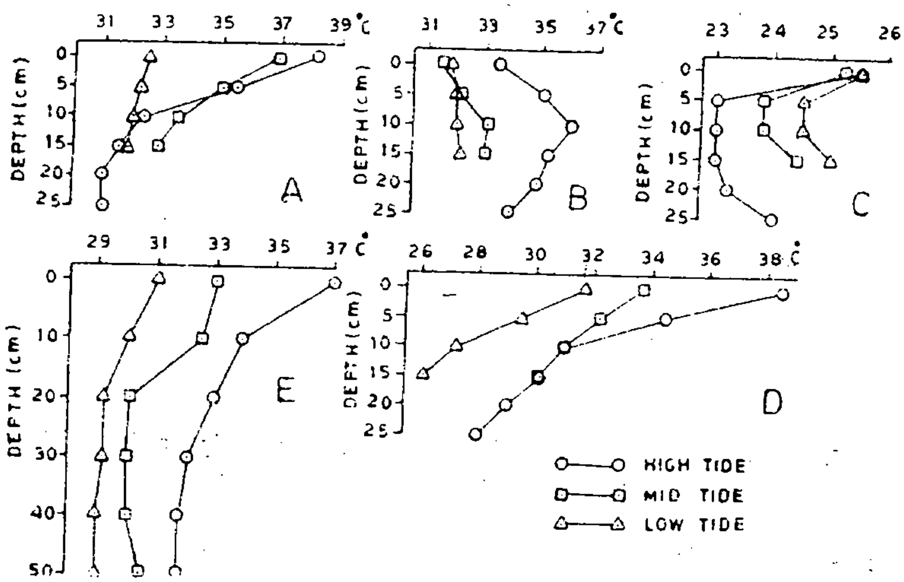


Fig 4. Sand temperature profiles : A. 16-9-83 (11 a.m.); B. 28-983 (4 p.m.); C. 27-11-83 (8 a.m.); D. 16-1-84 (12.30 p.m.); E. 29-5-84 (1.30 p.m.).

(Fig. 4D). The maximum temperature attained by sand surface showed no correlation with seasons. Thus high temperatures were recorded in July (38.0° C), September (38.2°C), January (38.5°C), March (36.0°C) and May (37.0°C). The highest sand temperature recorded during the present study was 39.5°C at 2 p.m. on 17-5-84, the lowest was 14.5° C at 2 a.m. on 20-12-84. On several occasions between July and October surface sand was cooler than sand at 5 and 10 cm depths during day time (Fig. 4B); strong breeze was responsible for this cooling effect at the surface. Reverse temperature gradients were observed between midnight and the early hours of the morning during winter as well as early summer (Fig. 5A and B). Reverse gradients were also recorded during day time in colder months (Fig. 4C).

Diurnal variations in temperature at different depths in sand at the upper levels of the beach were noticed during observations on tidal cycles. Two of these, one in the cold season (December) and another in early summer (April) are shown in Figure 5A and B for comparable time periods. It may be noticed

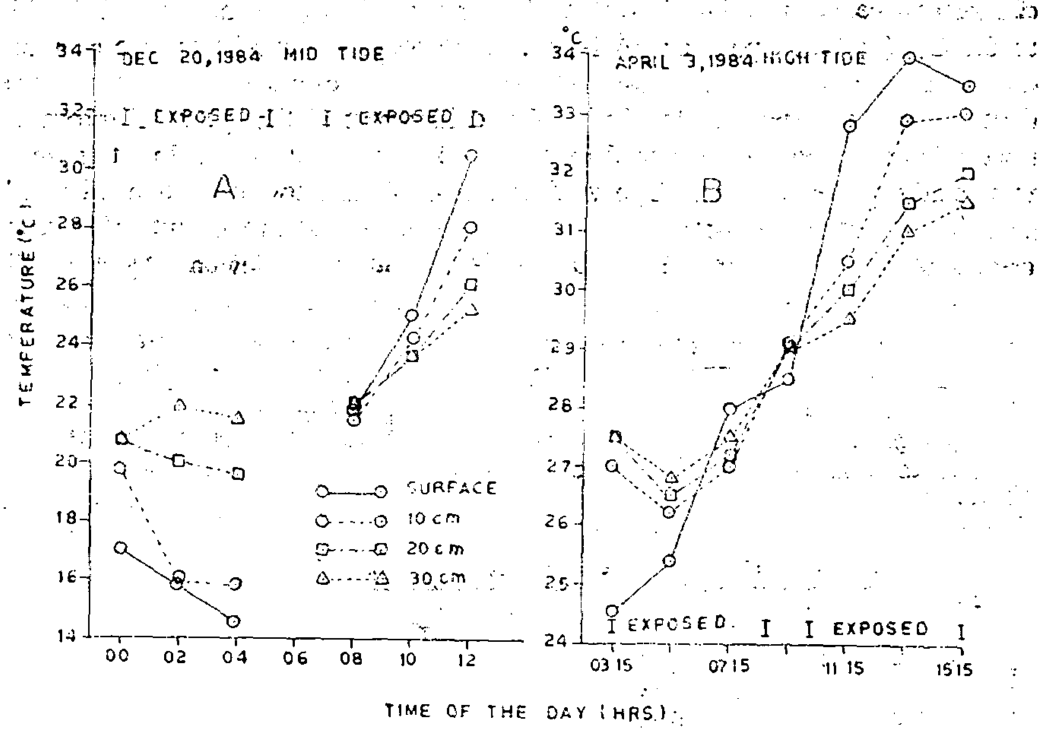


Fig. 5. Diurnal temperature variations in different depths in sand: A. Winter season; B. Summer season.

that the sand which is heated during day gets cooled during the night and through the early morning hours (till 4 a.m.). The cooling effect is greater at the surface and decreases progressively with increase in depth. Surface-depth differences become minimal when the observation spot is covered by the flood tide. Following the ebb and with increasing insolation during the day the sand at all depths gets heated rather quickly. The highest ranges of diurnal variation at 0, 10, 20 and 30 cm depths were respectively 15.5°, 13.8°, 9.1° and 6.2°C during the winter period. More or less similar ranges are also characteristic of the sumer months except that the actual temperatures recorded were higher (Fig. 5B).

*Salinity*

The seasonal variation in salinity of surface water is shown in Figure 6 C. High salinity values (33.04-33.08‰) were recorded during May-July. These may be attributed to the influence of the northerly current which brings in warm, high saline waters from the Equatorial Indian Ocean into the Bay of Bengal (Sewell, 1929), diminished run off from rivers discharging into and the prevailing high atmospheric and sea temperatures. It may be noted from Figure 6 D that the maximum rainfall of nearly 220 mm was recorded at Gopalpur Observatory in July. Despite this the shore waters remain highly saline. Most of the rain water drains into the lagoon and even though seepage occurs through the porous sand bed it was not sufficient to cause dilution of shore or interstitial water. The bar was cut open on 6-8-83 and the salinity of shore water on 10-8-83 fell to 18.96 %o. The decrease in the average value of salinity (22.33%o) in August was due to drainage of very dilute water from the lagoon, continued rainfall and incursion of low salinity waters brought in by the southerly current from the head of the bay (Sewell 1929). Low salinities (Ca. 22.00%o) prevailed during the rainy season which extended till the end of October and early November. The salinity showed a steady increase from January through April.

Salinity of shore and interstitial water are compared in Table II. It may be seen that the differences are not appreciable and ranged between 0-2.32‰ While this may be due to the fact that interstitial water was collected somewhat

Table II. Salinity and oxygen of shore and interstitial water on dates of collection (Difference expressed as + or — with reference to shore water)

| Date | Time (hrs.) | Salinity (‰) Shore water | Interstitial water | Difference | Oxygen (ml/l) Shore water | Interstitial water | Difference |
|---|---|---|---|---|---|---|---|
| 27.07.83 | 16 04 | 34.16 | 34.16 | 0.00 | 5.16 | 3.52 | — 1.64 |
| 10.08.83 | 15 50 | 18.96 | 20.07 | + 1.11 | 5.56 | 3.57 | — 1.99 |
| 16.09.83 | 10 59 | 21.16 | 20.34 | — 0.82 | 5.44 | 3.86 | — 1.58 |
| 06.10.83 | 14 19 | 16.35 | 16.53 | + 0.18 | 3.17 | 2.45 | — 0.72 |
| 05.11.83 | 14 10 | 15.08 | 17.52 | + 1.44 | 5.93 | 5.77 | — 0.16 |
| 27.11.83 | 08 00 | 20.59 | 20.41 | — 0.18 | 5.16 | 4.70 | — 0.46 |
| 03.12.83 | 13 30 | 20.81 | 23.13 | + 2.32 | 5.99 | 4.86 | — 1.13 |
| 19.12.85 | 14 00 | 23.86 | 25.62 | + 1.76 | 3.24 | 3.73 | + 0.49 |
| 16.01.84 | 12 31 | 27.59 | 27.77 | + 0.18 | 7.94 | 4.21 | — 3.73 |
| 31.01.84 | 14 00 | 28.30 | 28.13 | — 0.17 | 9.56 | 3.08 | — 6.48 |
| 22.02.84 | 08 00 | 28.66 | 28.84 | + 0.18 | 7.29 | 4.54 | — 2.75 |
| 27.02.84 | 12 04 | 28.30 | 28 12 | — 0.18 | 10.41 | 11.24 | + 0.83 |
| 08.03.84 | 16 09 | 30.79 | 30.07 | — 0.72 | 5 51 | 3.56 | — 1.95 |
| 27.03.84 | 11 42 | 32.54 | 32.56 | + 0.02 | — | — | — |
| 13.04.84 | 13 17 | 32.01 | 33.08 | + 0.07 | 7.78 | 4.60 | — 3.18 |
| 30.04.84 | 14 26 | 31.67 | 32.54 | + 0.87 | 6.08 | 3.61 | — 2.47 |
| 15.05.84 | 14 42 | 32.90 | 32.38 | — 0 52 | 5.72 | 8.37 | + 2.65 |

lower down the beach, samples taken on a few occasions very high on the beach and at a depth of 80-100 cm did not give salinity values that are significantly different from those of shore waters. Apparently ground water has very little effect on the interstitial system at this locality.

*Dissolved Oxygen*

The seasonal distribution of dissolved oxygen of the surface water is shown in Figure 6 B. The waters were well saturated throughout the year and the concentrations ranged from 4.53 to 5.90 ml|1. The oxygen content was lower during the period May to September and increased from October to January. The oxy-

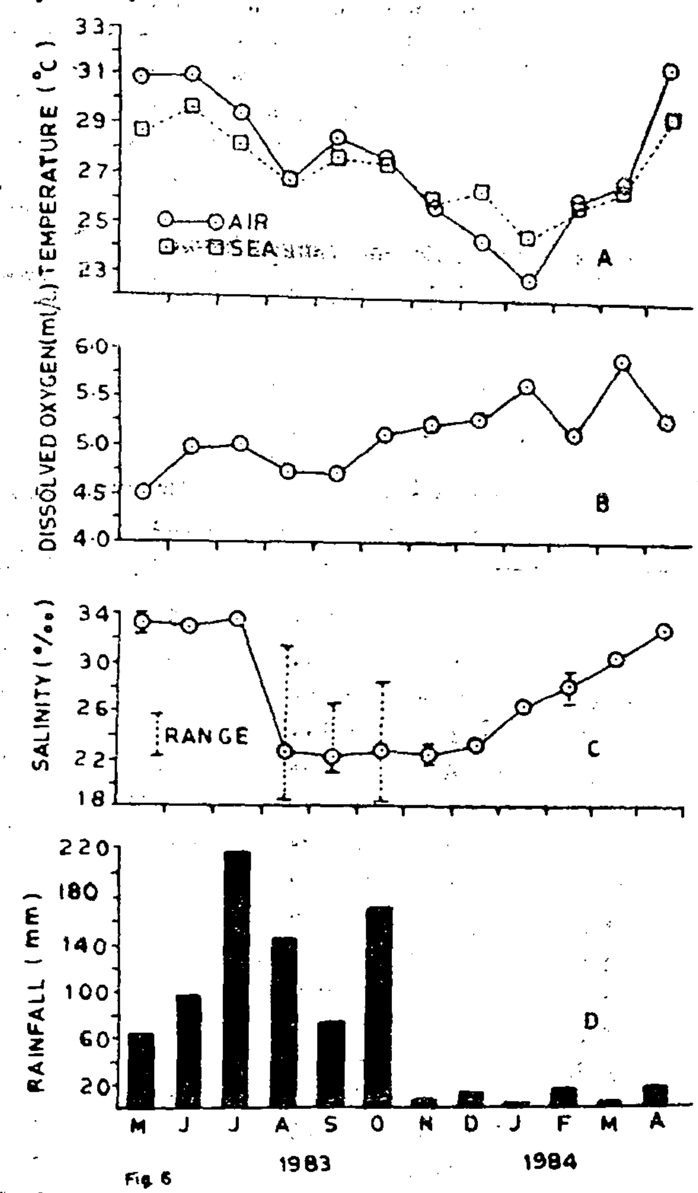


Fig. 6. Air and sea temperature (A), dissolved oxygen (B), salinity (C) and rainfall (D) recorded at Gopalpur.

gen concentration did not show any consistent relation to either temperature or salinity.

Table II shows the difference in oxygen concentration between shore and interstitial waters on the dates of collection. These differences normally ranged between 0.09 to 3.73 ml/l, except on one occasion (on 30-1-84) when the oxygen content of shore water was 6.45 ml/1 more than that of interstitial water. On all except three dates the interestitial water was less well oxygenated than shore water. On these three occasions and particularly on 15-5-84, the sand surface was covered with patches of the benthic diatoms *Hantzschia* and *Pleurosigma*. Oxygen liberated during active photosynthesis of these diatoms during day time must have rendered the interstitial water highly oxygenated. The high oxygen values in January and February coincide with surf zone phytoplankton blooms.

There was no indication of the presence of reduced layers even at a depth 100 cm in the sand; if present they must be deeper than this.

Terms like exposed, moderately exposed, semi-exposed and sheltered or high energy and low energy have been used to describe beach types. McLachlan (1980) pointed out the difficulty of ascertaining what different authors meant by these terms and stressed the need for uniformity in terminology or rating system whereby workers from different areas may objectively rate the exposure of the beach they are studying. He had outlined a 20-point exposure scale which takes into consideration not only the degree of wave action but also other parameters which reflect the dynamics of the beach environment. The Gopalpur beach fits into this system quite well. Given below are the parameters used, their rating and the scores assigned to these for the Gopalpur beach on the basis of McLachlan's scheme:

| *Parameter* | *Rating* | *Score* |
|---|---|---|
| Wave action | Continuous, moderate to heavy, wave height seldom exceeds 1 m | 2.0 |
| Surf zone width | Moderate, waves usually break 50-150 m from shore | 1.0 |
| % of very fine sand (62-125 μ m) | Mostly < 1%, but occasionally 1-5% | 2.0-1.5 |
| Median particle diameter (μ m) and slope of intertidal zone | 250-480, mostly 250-350 (2.0-1.5 ɸ); beach slope 1/8 to 1/22 | 3.0-5.0 |
| Reduced layers | Not encountered, if present more than 100 cm deep | 4.0 |
| Stable burrows | Absent | 1.0 |
| | Total Score | 13.0-14.5 |

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