

## **Morphological changes at Godavari Delta Region due to Waves, Currents and the Associated Physical Processes**

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### **Abstract**

All the major deltas of India are on the East Coast, starting from the Ganges in the north to Cauvery in the south. In this article, Godavari delta is discussed in relation to the factors which cause morphological changes around the delta region.

Wave conditions, the most important in coastal modification, prevailing in this region for different seasons are illustrated. The analysis of Geosat altimeter data for the period November 1986 to October 1987 shows that only during the southwest monsoon season waves reach heights of the order of 2 m. Otherwise they are of the order of 1 m. The fair weather promotes delta build-up. Tides and tidal currents are other important factors which affect the overall gradient of the deltas, especially their seaward section. Dye experiments conducted in Kakinada Bay show that tidal currents are generally of the order of 10-20 cm/sec. However, during the period of maximum discharge from the Godavari river (June-November), the ebb current exceeds the speed of 200 cm/sec. The morphological changes due to the effect of river discharge during various seasons are also briefly discussed.

One of the factors controlling the circulation in the Kakinada Bay is the general coastal current, which runs along the East Coast of India. A few current measurements carried out in the Godavari Basin are described. Wave induced littoral currents are stronger during the southwest monsoon season and the net drift is northerly all along the Andhra coast. However it is surmised that most of the drift is towards offshore contributing to the formation of offshore bars and spits which during fair weather migrate towards shore restoring the beach to its normal state. The development of Godavari sand spit off Kakinada and its influence to delta modification are also detailed. It is concluded that a systematic approach using the past records, fresh field data and satellite imagery would alone bring out clearly the picture of deltaic processes along the East Coast of India.

### **INTRODUCTION**

Oceanographically, delta is one of the three broad classes of coastal inlets, the others being lagoon and estuary. Inman and Nordstrom (1971) have suggested that coastal features having a scale of about  $100 \times 10 \times 1$  km, and associated with large scale processes of deposition and erosion are deltaic. The largest of deltas at the mouths of great rivers are of the order of hundreds of kilometres across. Waves dislodge sediments and keep them in suspension. Currents carry the materials. River flows are unidirectional, tidal currents oscillatory, and general coastal currents largely seasonal. When the sediments reach a site conducive to deposition, sedimentation takes place. The factors leading to redeposition of sediments are low wave energy and low current strength. When river water joins the sea water flocculation, which is an electrochemical process, takes place resulting in sedimentation. Thus super abundance of fluvial deposits combined with low wave

energy and low current strength enable the formation of deltas. Even in low wave energy environment, the delicate forms of sedimentary jetties tend to be modified as soon as reduced distributary outflow and diminished sediment yield bring the process of prolongation to an end. A delta grows if the sediment is introduced at a point on the periphery of a water body faster than that can be removed from that vicinity by coastal processes. Absence of delta may be due to (i) river mouths exposed to strong wave and current action and consequently all the sediments received by the sea from the river being removed simultaneously and (ii) rivers themselves carrying very little load to the sea (Vaidyanadhan, 1990).

The morphology of the delta region is affected by (i) the natural agencies such as waves, currents, tides, river discharges, etc. (ii) man-made structures, development of offshore sandspits and bars, etc. and (iii) other phenomena such as storm surges and tidal waves which persist through a relatively short period. In addition to these, regional factors such as exposure to prevailing winds, local climate and vegetation, vary and influence morphology of deltas on a smaller scale. When these processes give rise to net deposition or erosion, the deltaic region is subject to morphological changes. Modern deltaic plains are prone to periodic flooding caused by hurricanes and river flood waters.

All the major deltas of India are on the East Coast, starting from the Ganges in the north to Cauvery in the south. Mahanadi, Godavari and Krishna are the other major deltas. Godavari delta is the third largest among Indian deltas after those of the Ganges and Mahanadi. In this article, Godavari delta is discussed in relation to the factors which lead to morphological changes around the delta region. In fact, most of the features are common to any of the above deltas.

### GODAVARI DELTA REGION

Andhra coastline is characterised by open sandy beaches, sand bars, sand spits and river mouths. The coastline has 15 km long sand bar, north of the Godavari river mouth. Krishna and Godavari rivers transport considerable loads of sediments to the sea which nourish the sandy beaches and also build up the delta. Godavari is an arcuate type of delta whereas, Krishna belongs to lobate type. Numerous ancient channels and beach ridges with different orientations have been traced in Godavari delta. Progradation of the delta can be easily inferred from the positions of earlier estuaries and the variation in the orientations of the ancient beach ridges (Sambasiva Rao and Vaidyanadhan, 1979). Godavari deltaic area consists of four parallel beach ridges located far behind the present coastline. Much of the coastal plain is composed of Holocene–Pleistocene sediments. Godavari delta has a projection of about 35 km into the sea from the adjoining coast (Ahmad, 1972). Godavari opens through several mouths, namely, (i) Vasishta Godavari entering into the sea on the western side of the Narasapur Point (ii) Vainateyam Godavari, about 25 km east-northeast of the Narasapur Point and (iii) Vruddha Gautami River, entering into the sea at about 35 km eastnortheast from the mouth of Vainateyam Godavari River. Hence, Godavari delta consists of a wide belt of riverborne alluvium. At the mouths of almost all river distributaries, spits are

formed. A few islands have also been formed adjacent to the mouth of Godavari River.

On low wave energy coasts, sectors of the delta shore are fringed with swamp vegetation, typically saltmarsh with mangroves. Saltmarsh are probably more effective in promoting sedimentation than mangroves which tend to spread onto tidal mudflats on low wave energy sectors of tropical deltas. Mangroves are found to colonize in soft muddy shores of the delta. Mangroves of Godavari delta are subject to a particular hydric regime, dominated by the river floods. The plants with their roots help consolidate the loose muddy soil and build up a barrier between tidal action from the sea and floods from the river.

### WAVE CONDITIONS

Waves are the most important agents of coastal modification; any attempt to examine delta form must deal with wave climate. In general, growth of deltas is possible only in low wave energy environment. The low wave energy permits extensive deposition of fines supplied by rivers. In a moderate wave energy environment, sand supplied by the rivers or eroded from the delta shore, is built into beaches, spits or barriers enclosing lagoons on the delta margin. In a high wave energy environment, the development of a protruding delta may be completely inhibited. When wave action is important, the coarser sand is spread around the delta margin to produce a more rounded outline.

Most of the wave measurements in Indian coasts or deep waters report only the wave height and wave period and not wave direction. However, ship reported waves give wave direction as well, but based on visual observations and should be taken with care. Only very recently instruments have been used for measuring wave direction. It is reported that wider deltas tend to be associated with strong oblique swell. Like wave height and wave period, wave direction is an important parameter, decisive of the form of the delta.

NIO has published a wave atlas (1982) for the Arabian Sea and Bay of Bengal compiling the Indian Daily Weather Report for the period 1968-73. The rose diagrams presented in this atlas show the frequency distribution of wave height and wave period independently in different directions. Recently, Chandramohan *et al.* (1989) updated the wave tables for the Indian coasts, based on ship observations for the period 1968-86. The climatic conditions along the Godavari delta region are influenced by all the three seasons, namely, southwest monsoon (June-September), northeast monsoon (October-January) and nonmonsoon season (February-May). Percentage distribution of wave height versus wave period for Andhra coast is presented seasonwise in Table I. The Table clearly shows that southwest monsoon wave heights are greater than the northeast monsoon waves, and predominant wave heights are around 2 m. Vethamony *et al.* (1984) carried out spectral studies for the wave data collected off Godavari Basin during September-October 1980. Their study shows that waves are predominantly swells, with significant wave heights centred around 1 m. Typical wave spectra are shown in Fig. 1. Significant wave height values obtained from Geosat altimeter data for the period November 1986 to October 1987 show that only during southwest monsoon season waves reach

TABLE I  
Wave conditions off Andhra Coast.

FEB-MAY (FAIR WEATHER)											1968-86	
H(m)/- T(s)	5	6	7	8	9	10	11	12	13	14	SUM T	
											CALM (%)	7.5
0.5	9.2	2.9	1.1	.	.	2.3	1.1	1.7	2.9	2.3	23.6	23.6
1.0	15.5	6.9	1.1	.	1.1	1.1	1.1	1.1	2.3	5.2	35.6	35.6
1.5	5.2	1.7	2.3	1.1	.	0.6	0.6	.	1.1	1.1	13.8	13.8
2.0	2.3	1.7	0.6	2.3	.	1.7	0.6	.	.	1.7	10.9	10.9
2.5	1.1	2.9	0.6	1.7	.	0.6	.	.	.	.	6.9	6.9
3.0	.	.	.	1.1	.	.	.	.	.	.	1.1	1.1
3.5	.	.	.	.	.	.	.	.	.	.	.	.
4.0	.	.	.	.	.	.	.	.	.	.	.	.
4.5	.	.	.	.	0.6	.	.	.	.	.	0.6	0.6
SUM H	33.3	16.1	5.7	6.3	1.7	6.3	3.4	2.9	6.3	10.3	100.0	100.0

JUN-SEP (SOUTHWEST MONSOON)											1968-86	
H(m)/- T(s)	5	6	7	8	9	10	11	12	13	14	SUM T	
											CALM (%)	5.0
0.5	2.0	.	0.5	2.5	0.5	1.0	1.5	2.0	.	.	9.9	9.9
1.0	4.5	1.5	1.0	2.0	1.5	1.0	0.5	1.5	1.0	0.5	14.9	14.9
1.5	2.0	2.5	2.5	3.0	1.0	1.0	0.5	0.5	1.0	.	13.9	13.9
2.0	5.4	5.0	2.0	3.5	1.0	0.5	1.0	1.0	.	1.0	20.3	20.3
2.5	4.0	3.5	2.5	4.0	0.5	2.0	.	.	0.5	0.5	17.3	17.3
3.0	1.0	0.5	1.5	2.5	1.5	0.5	0.5	.	.	0.5	8.4	8.4
3.5	0.5	.	.	3.0	.	0.5	.	.	.	.	4.0	4.0
4.0	1.5	.	0.5	0.5	.	1.5	0.5	.	.	.	4.5	4.5
4.5	.	.	0.5	1.0	.	0.5	.	.	.	.	2.0	2.0
SUM H	20.8	12.9	10.9	21.8	5.9	8.4	4.5	5.0	2.5	2.5	100.0	100.0

OCT-JAN (NORTHEAST MONSOON)											1968-86	
H(m)/- T(s)	5	6	7	8	9	10	11	12	13	14	SUM T	
											CALM (%)	8.2
0.5	4.1	2.4	2.4	0.6	.	1.8	.	1.2	2.4	1.2	15.9	15.9
1.0	12.4	6.5	4.7	1.2	.	2.4	.	3.5	1.8	2.4	34.7	34.7
1.5	7.1	2.9	0.6	1.8	.	0.6	1.2	.	1.8	1.2	17.1	17.1
2.0	1.8	2.4	2.9	.	.	.	0.6	0.6	.	2.9	11.2	11.2
2.5	1.2	0.6	1.2	0.6	0.6	.	.	0.6	.	0.6	5.3	5.3
3.0	0.6	.	1.8	1.8	.	.	.	.	.	.	4.1	4.1
3.5	0.6	.	.	0.6	.	.	.	.	.	.	1.2	1.2
4.0	.	0.6	0.6	.	.	.	.	.	.	.	1.2	1.2
4.5	1.2	.	.	.	.	.	.	.	.	.	1.2	1.2
SUM H	28.8	15.3	14.1	6.5	0.6	4.7	1.8	5.9	5.9	8.2	100.0	100.0

heights of the order of 2 m; otherwise they are of the order of 1 m. A typical Geosat map showing significant wave heights for November 1986 is presented in Fig. 2, and it will give wave heights that prevailed in the Indian Ocean region. With the availability of voluminous satellite data, it is now possible to study systematically the morphological changes of the Indian deltas due to waves.

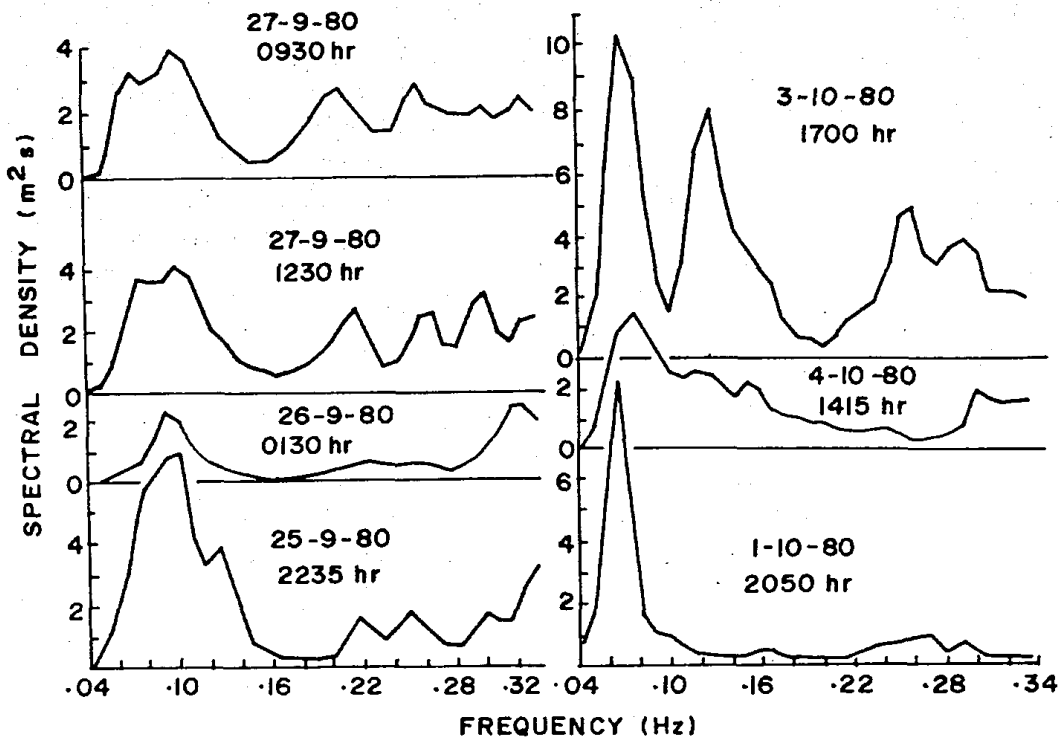


Figure 1. Typical wave spectra off Godavari.

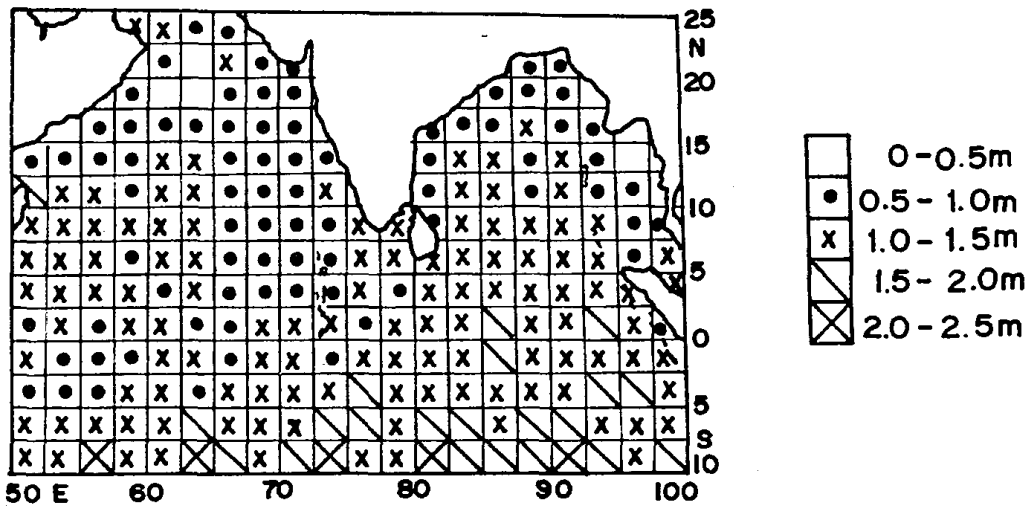


Figure 2. Significant wave height derived from GEOSAT Altimeter for November 1986.

### TIDES AND TIDAL CURRENTS

Tides and tidal currents are periodic natural processes which influence the modification of the delta fronts and the development of barriers around delta. For example, in Godavari, where tidal range is less and sand supply by littoral drift

from the south is strong, relatively large barrier systems have developed. Same is the case with the Mahanadi delta. On the other hand, in delta like the Ganges with a large tidal range, barriers are either very poorly developed or nonexistent. Also, tidal range is an important factor which affects overall gradient and has an effect on the height and form of the seaward section of relatively flat deltas. For example, in Ganges tidal action (range over 5 m) is more successful than the river in building levees. The result is that the coastal strip tends to be higher than the inland parts and as the delta progrades, chains of depressions are produced parallel to the coast. Where tides are important, the river mouth channels show a distinctive flared pattern formed by reversing tidal currents. Tidal currents are strong where tidal ranges are high, and in a way the combination of water level, current speed and wetted area define the active zone. For large river mouths, tidal distortions are prominent, augmenting a phase of the tide over the other.

Unnikrishnan and Asthana (1989) have conducted dye experiments during flood tides at four points in the Kakinada Bay. Current speed, direction and tidal elevations at the release points are shown in Fig. 3. Tidal range is of the order of 0.5 m and magnitude of currents of the order of 10–20 cm/sec. The curves of current

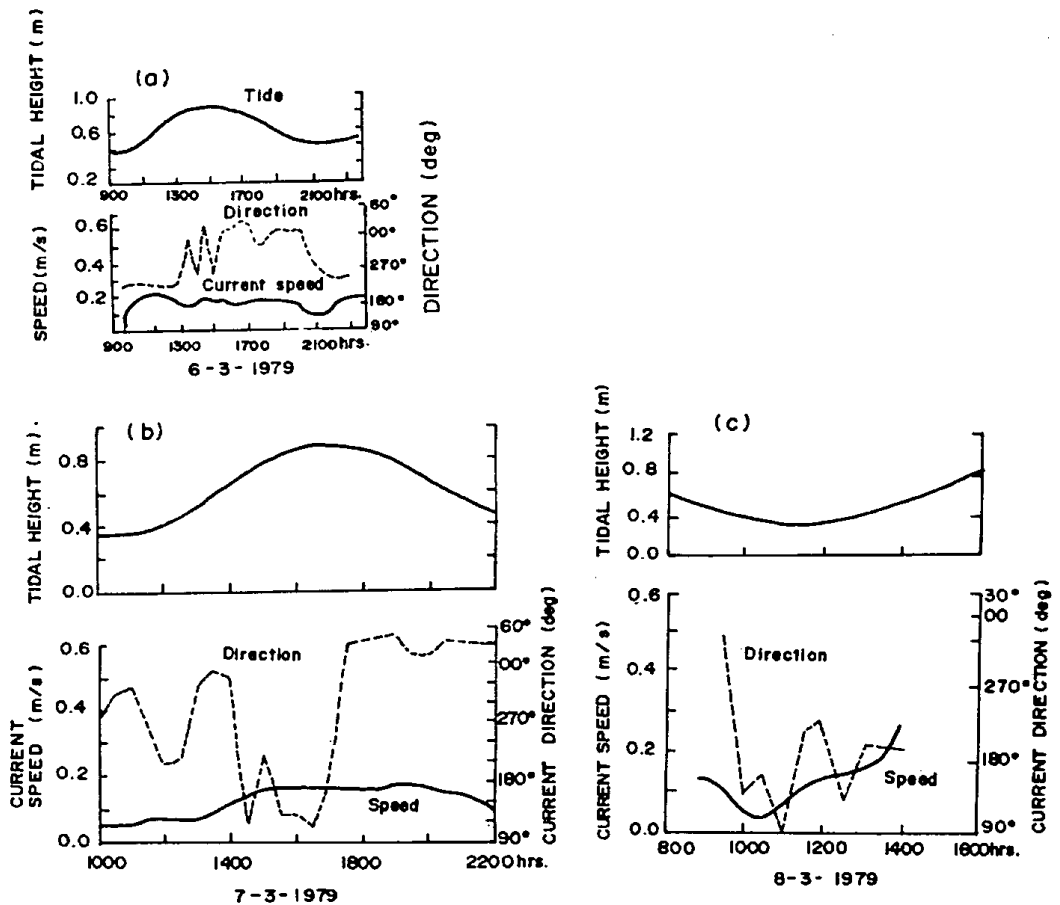


Figure 3. Current speed, current direction and tidal height of Kakinada Bay.

speed versus time show some periodicities similar to that of the tidal curves, indicating the influence of tides on the circulation in this region. The flood currents flow in a general southerly direction towards the head of the Bay. This current reaches its maximum velocity (about 125 cm/sec) near the Kakinada entrance channel. The ebb current has its maximum velocity (about 200 cm/sec) at the Godavari Point, flows in a general northerly direction along the sand spit. During the period of maximum discharge from the Godavari River (June–November) the ebb current reaches still higher velocities. Besides developing barriers around the deltas, tides and tidal currents, which are oscillatory in nature, are of considerable importance in sediment transport, especially in the regions of river mouths.

### CURRENTS OFF GODAVARI

One of the factors controlling the circulation in the Kakinada Bay is the general coastal current, which exists along the East Coast of India. The coastal current changes its direction seasonally, being northerly from January to July and southerly from August–December. Between Sacramento shoals and Gopalpur, northgoing currents of strength 100–150 cm/sec, with a maximum of 200 cm/sec are observed during January–April. The measurements of currents off Godavari during September 1980 show that current speed is between 20 and 30 cm/sec at 15 m depth and between 10 and 30 cm/sec at 115 m depth (Sarma and Rao, 1986). The direction of current during this period is between southeast and southwest. These currents do not seem to be influenced much by the tides. Rao *et al.* (1987) have studied the currents off Godavari just before the southwest monsoon of 1982 (Fig. 4). The *u*(east–west) component which attains a maximum of about 20 cm/sec remains almost constant throughout, whereas, the *v*(north–south)/ component with a maximum value of 50 cm/sec reduces to almost half of it during the rising phase of the tide. Other than this decrease in the *v*-component, the tidal influence is not clearly identifiable at this location. The flow remains unchanged with depth and exhibits very weak vertical shear. As these are open sea currents, their influence is not much felt in the delta region, unlike tidal currents or the wave induced littoral currents.

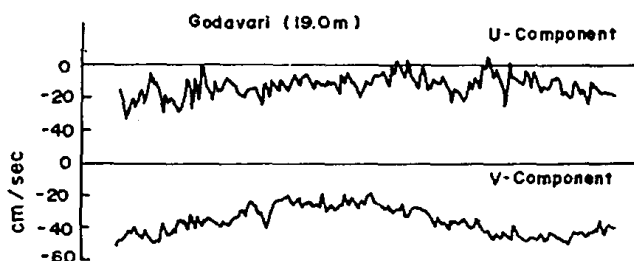


Figure 4. U and V components of flow off Godavari.

## GODAVARI RIVER DISCHARGE

River discharge brings sufficient quantity of sediment which is needed for the delta build-up. Godavari River is 1450 km long and the mean discharge is 3600 m<sup>3</sup>/sec. Off Godavari, the continental shelf is only 15 km wide. Discharges from Godavari commence from June and reach the maximum in August (Suryanarayana, 1988). August and September are the months of peak discharge for this river (Fig. 5). The freshwater influx is a potential driving mechanism for the coastal circulation, though the discharge is irregular and non-uniform along the coast. The freshwater input into the Kakinada Bay is from two small distributaries, viz. the Coringa and the Gaderu. On the eastern side there is a long narrow sand bar, separating the Kakinada Bay from the Bay of Bengal. During the period of maximum discharge, the Godavari River forms a channel along the western edge of the sandspit. The river current is stronger along the sandspit than at any other region in the Bay. When river influence increases, particle size decreases. So lagoons are sandy, estuarine muddier and deltas muddiest. Silvester and Cruz (1970) found that the apex to sea dimension varies directly with river discharge and inversely with river gradient inland, continental slope, sediment particle size and tidal range.

The origin and growth of the Godavari sandspit itself has been attributed to a large quantum of sediment supply from the river discharges, because of extensive deforestation in the Godavari drainage basin during the 1850s, resulting in an extensive sediment load being deposited at the southern corner of the Bay (Mahadevan and Prasad Rao, 1958). It is observed that part of the sediment moves northward along the East Coast during the southwest monsoon and gets deposited at the southeastern corner of the Bay, where calm conditions prevail. But continuous accumulation of sand in this region is prevented by the winnowing action of the Godavari discharges into the Bay. Consequently, the greater amount of deposition at the southeastern corner of the Bay has resulted in the formation of an island which has further grown to be the present sandspit. This shows that though the net transport is towards north (discussed elsewhere), sufficient quantity of sediment moves offshore and results in the formation of offshore bars, islands or sandspits.

## SEDIMENT TRANSPORT

Deltas are characterised by a high rate of sedimentation. Sediments are transported mainly by the wave induced currents, generated when waves set up along the shore. These currents, resulting from oblique wave approach, run parallel to the shore in the surf zone. The net result of sedimentation in deltas is a seaward sediment embankment. In the Ganges delta area, 30 km long Sagar Island has emerged as a result of sediment deposition from the mouth of Hoogly. Sand generally remains fairly close to the shoreline except during periods of very strong river flows or during heavy storm activity when large waves will suspend it and allow some of it to escape seawards. If the sediments brought in by the river is no longer active, then the delta becomes inactive and will be quickly attacked by the sea. This condition creates imbalance between sea and river forces and favours



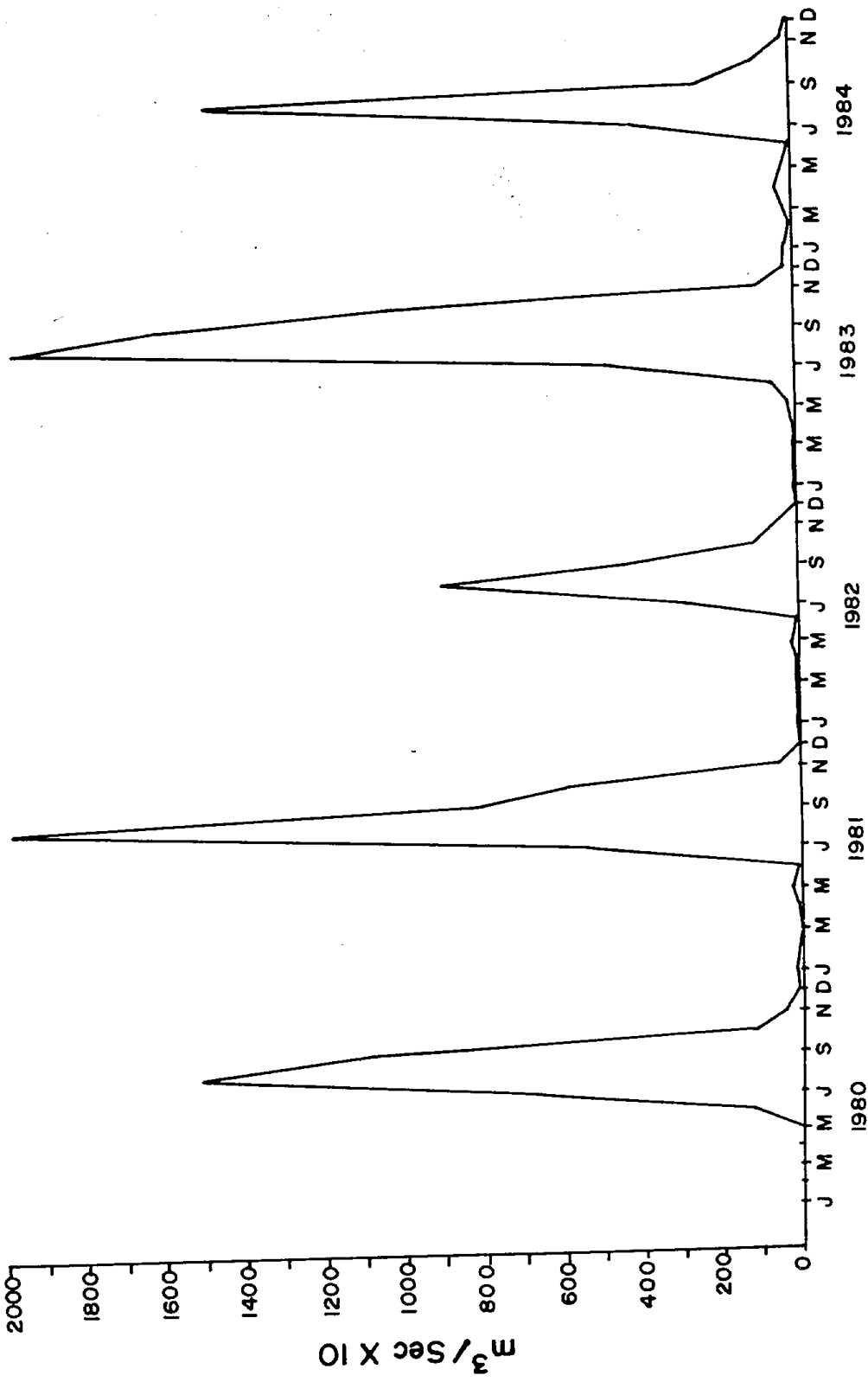


Figure 5. Monthly mean discharge of Godavari River.

erosion. The large quantities of coarse materials carried by rivers are piled into barrier features by waves. Where there is strong longshore drifting, spits develop on a delta shore and may grow to deflect river mouths or seal off distributary outlets.

Along Andhra coast, from March to September, the waves approach from a general southeasterly to southerly direction and during the remaining period, waves approach from a general northeasterly to east-southeasterly direction. Wave refraction studies by Sastry (1958) indicate that when wave direction is southeast, the associated littoral current is directed upcoast while it is directed downcoast for the waves approaching in the general northeasterly direction. As wave heights during southwest monsoon season are higher than those of the northeast monsoon season, littoral current is stronger during southwest monsoon than the northeast monsoon, resulting in a net northerly drift all along the coast. Littoral transport for the entire Andhra coast has been assessed theoretically by Chandramohan *et al.* (1988) as shown in Fig. 6. The computations suggest that the general predominant direction of transport along the Andhra coast is towards northeast from March to October and towards southwest during the rest of the period. The rate of sediment transport is very large during the southwest monsoon period (June–September) owing to the prevalence of the high wave climate in the Bay of Bengal. The coastal segments near Ramaypatnam, Machilipatnam and Yanam have much lower annual net transport with approximately equal volume of transport on either direction. Consequently, the coastal segments near Nizampatnam, Gollapalem and Narasapur are subject to large longshore transport with a net rate of  $1 \times 10^3 \text{ m}^3$  during the annual cycle. In the northwestern region of the Godavari Point an extensive mudflat (fine grained silt and clay) is located. The growth in a general northerly direction is the result of sand migration in the northerly direction on both sides of the spit.

### GODAVARI SANDSPIT

Morphological changes of Godavari delta, to a great extent, can be linked with the development of the sandspit. Kakinada Bay is getting silted up heavily with deposits brought down by Godavari River. The development of the Godavari sandspit off Kakinada (the tip of which is called Godavari Point) has resulted in changing the coastline from Kakinada to Uppada more conspicuously than the rest of the region. The bottom topography of the Bay has also been modified indirectly by the growth of the sandspit. The bathymetric chart of 1846 shows that the discharges of the Godavari River were mostly into the Bay. The Sacramento shoals and the sandspit were not indicated on this survey chart. The later surveys (1920 and 1950) indicate the emergence and growth of sandspit and shift of the main discharge of Godavari River to about 15 miles south of Kakinada Bay with the development of the Sacramento shoals off the confluence (Sastry, 1958).

The erosion of Uppada beach has been attributed to the northward growth of Godavari sandspit as a result of which the sediment transport across the Bay and further northwards along the main coast is cut-off, the major portion of the sediment supply being utilised for the growth of the sandspit (LaFond and Prasada Rao, 1958). Sambasiva Rao and Vaidyanadhan (1979) are of the opinion that the northward drifting of sand has extended the Godavari sandspit of the Godavari delta by several kilometers during the past century.

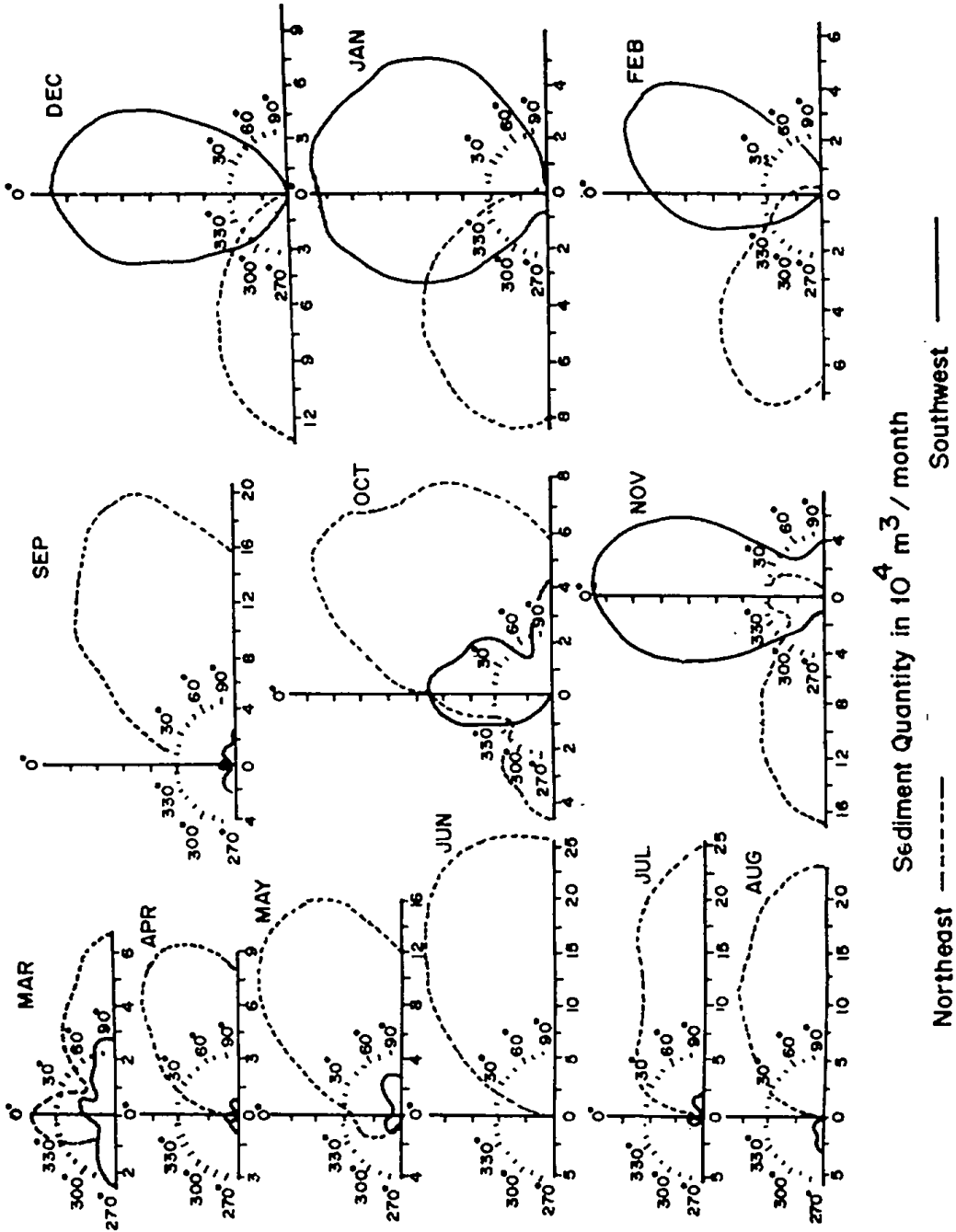


Figure 6. Monthly longshore transport roses for the Andhra coast.

Similarly, spit growth on a smaller scale has accompanied the evolution of the Krishna delta between 1928 and 1978. General progradation has been interrupted by erosion of the coastline during the 1977 cyclone (Nageswara Rao and Vaidyanadhan, 1979). In the Mahanadi delta, there has been a slight overall progradation by fluvial deposition, although the shoreline has shown alternating advance and retreat, while to the north, the coastline bordering the Brahmani River mouth has started eroding (Meijerink, 1982).

## CONCLUSIONS

Part of this article is based on the available literature and there exists, in our present knowledge of our deltas, a large number of gaps to be filled up. The possible factors which are likely to influence the morphological changes of the east coast deltas in relation to Godavari have been outlined here based on this scanty knowledge. It is very essential to assess qualitatively and quantitatively the changes in delta fronts with the available past data through systematic field studies, and using the satellite imagery. Remote sensing techniques provide useful information about the large scale changes in the morphology of coastlines. For example Landsat MSS and TM imagery provide information on major coastal geomorphic features like coastline, sediment transport, river discharge, spit, etc. Satellite techniques will also enable us to link the changes in the form and features of deltas with wave parameters.

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