

CLIMATE INDUCED CHANGES IN BEACH MORPHOLOGY AND SEDIMENT DYNAMICS, MACHILIPATNAM

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ABSTRACT

The wave climate, littoral current patterns, monthly and seasonal longshore drift rates, beach profile changes, and sediment budget of the beach sediments were determined along Machilipatnam for the NE, SW monsoons, and for transition period. Low waves become moderate - high and moderate during the SW and the NE monsoons respectively. The occurrence of cyclone/storm during the NE monsoon is high, and there are sporadic enhancements in the winds and waves during such events. The littoral currents were moderate to strong during the SW monsoon, variable during the NE monsoon, and weak during non-monsoon period. The direction of these currents also varies during the SW and NE monsoons. Beach eroded during SW monsoon, but despite the prevalent moderate-high wave regime, and moderate-strong littoral currents, the beach profiles of the NE monsoon had accretion over the profiles of the SW monsoon. Based upon the variations in the longshore sediment transport, wave energy flux, magnitude and direction of littoral current, sedimentological parameters of the beach and location of the area in the vicinity of high fluvial discharge, the factors which contribute to the beach sediment dynamics under the SW & NE monsoons and transition period are delineated.

INTRODUCTION

Unlike the majority of the coasts of the world, the east coast of India experiences two phases of stormy conditions. They are the SW monsoon (June through early September) and NE monsoon (October - December). The studies from the east coast of India (Srivastava and Rao, 1976; Chandramohan et al. 1988; Sarma and Reddy, 1988; Chauhan, 1991, 1992(a,b); Chauhan et al., 1988) either have reported annual cyclic changes in the beach morphology or have presented net shore drifts determined based upon various energy flux models, and as such, influences of the monsoons on the beach processes are still not fully understood. The present work is aimed at elucidating the influences of climatic changes on the beach processes.

METHODOLOGY

The study area is about 30 km stretch of open beach at Machilipatnam (Fig. 1). Between latitude 15-17°N and longitude 81 - 83°E, the ship borne swell wave parameters correlated with a

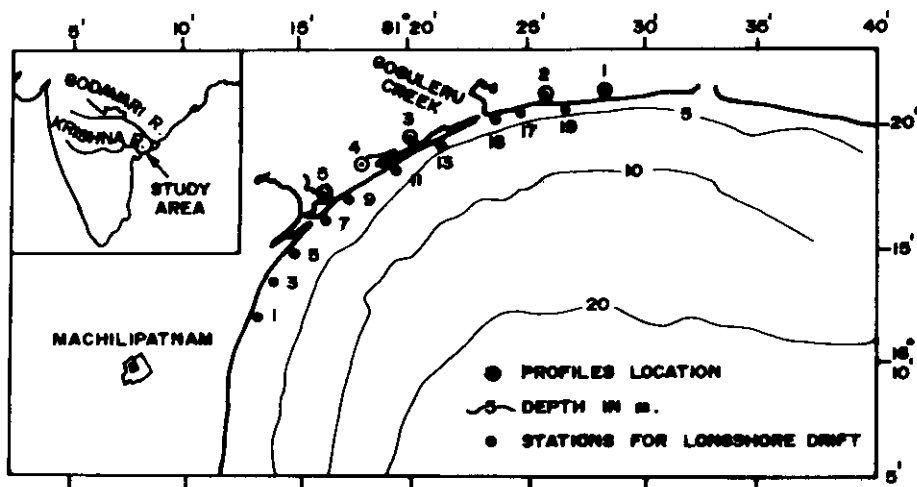


Fig. 1 Location of beach profiles and stations identification for study area.

wave rider buoy data, deployed in the study area, (Chandramohan et al., 1988), have been used as an input for the determination of longshore sediment transport rates, along 19 stations (Fig. 1), from the following empirical relations (Shore Protection Manual, 1977; Chauhan 1995):

$$Q = 1288 [\rho g^2 T(H_s H_r K_r)^2 \sin 2\alpha\beta] / 64 \tag{1}$$

Where, Q is the volume transport rates (m^3/y), H_s is the significant wave height, T is the wave period K_r is refraction coefficient $\alpha\beta$ is the breaker angle, ρ density of sea water (1025 kg/m^3), H_r is shoaling coefficient and C is (gd)^{0.5}

In the numerical wave refraction model, orthogonals were drawn at 50 m intervals, and bathymetry as given in the Naval Hydrographic Chart Number 355 was used. Values of H_r , K_r and $\alpha\beta$ were obtained at 2 m water depth. Longshore drifts were obtained for nonmonsoon (December-February), transition period (March-May), the SW monsoon (June- September) and the NE monsoon (October - November). In addition, monthly variations in longshore sediment transport have also been determined form:

$$Q_m = 1/12 \left[\sum_{H=0}^{H=\infty} \sum_{T=0}^{T=\infty} \sum_{\alpha\beta=30}^{\alpha\beta=280} Q f (H T \alpha\beta) \right] \tag{2}$$

Q_m is the monthly longshore drift (m^3/y), f is frequency occurrence of (H, T, $\alpha\beta$) in a month.

Qualitative picture of littoral currents was obtained from the wave refraction studies for the most prevalent wave directions during the SW, the NE and non-monsoon, and for the periods 6, 8, 10, and 12 sec. For validation of the refraction simulation studies, the patterns of littoral currents were also measured at 2 m water depth in February, April, September and November following the standard float and dye movement methods (Shore Protection Manual, 1977; Chauhan, 1986). The sediment budget has been estimated from the beach profile changes between February of 1981 and November of 1982 along five transects, spaced at about one km (Fig. 1), extending from berm to 2 m water depth (below low tide level). Seven observations were made on each transect, in November, February and September of 1981, 1982, and April of 1981 to separate out the influences of the NE and the SW monsoon and transitional conditions between the NE and the SW monsoons. Sediment budget for each cycle is estimated and presented.

RESULTS AND DISCUSSION

Synthesized variations in the wave parameters during the NE, SW and non-monsoon periods are presented in Tables 1. From these data, it is deduced that the waves during December through February are small and have low periodicity ($H_w < 1.5$ m, $T_w < 8$ sec; dir $30-90^\circ$). The wave environment begins to modify in April, and the waves are small to moderate with a large variations in their direction (H_w 1-1.5m, $T_w < 8$ sec, dir $90-180-300^\circ$) during April-May. From June to September, the area is under the influence of the SW monsoon and a high wave environment prevails in the region ($H_w > 2$ m, $T_w > 8$ sec, dir 270° , $210 - 240^\circ$ for $> 60\%$ time). Between October and November, the waves reduce in intensity, but there are frequent sporadic enhancements in wave height and period ($H_w > 2$ m for 40%, $T_w > 8$ sec for 30% time; Tables 1). The area also experiences cyclonic storms/ depressions during April and in May (probability of occurrence of cyclone/depression, (p) is 1.0 and 0.72 in November and May respectively). The beach responds to the changes in hydraulic conditions. The temporal and spatial variations in the beach slope and beach width under different environmental conditions suggest that low gradient long beach profiles (slope $2.3-3.6^\circ$) with swell berm (length about 15m) modify to the steeper (gradient $4.5-6.5^\circ$), shorter profiles with troughs and bars, and no berm, during the SW monsoon. With the cessation of the SW monsoon, characteristics of the beach modify. Despite the prevalent moderate - high wave climate, beach profile of November (NE monsoon) were gentler than the profiles of the SW monsoon ($3.5 - 4.8^\circ$), beach was wider. From the wave refraction simulation studies (Fig. 2), it is inferred that for the wave approaches $< 90^\circ$ the currents are from the NE, whereas, the wave approaches from $120-240^\circ$ will give rise to the flows from the SW. Utilizing this as input, and based upon the variations in the wave parameters in the SW, the NE and non-monsoon periods, it is deduced that the littoral currents during the SW monsoon are from the SW, variable during the NE monsoon and transitions period, and from the NE during December - February. The results of dye and float studies (Fig. 3) also exhibit that weak to moderate currents ($0-40$ cm sec^{-1}) from the NE prevail in February, whereas, moderate/strong ($20 - 70$ cm sec^{-1}) currents from the SW were observed in September (SW monsoon). In April and November, the magnitude of the currents was weak to moderate and they had variable directions (Fig. 3).

The sediment budget of the beaches is presented in Table 2. During the SW monsoon $42-56 \text{ m}^3 \text{ m}^{-1}$ sediments were eroded from the beach, whereas, during the NE monsoon (which has short term sporadic enhancement in wave parameters and cyclones/depressions) no erosion of the sediments was observed (Table 2). The beach on the contrary had an accretion of about $15-30 \text{ sediments m}^3$

m^{-1} over the profiles of the SW monsoon. The magnitude of deposition was significantly high between November–February (about $91 m^3 m^{-1}$; Table 2). Also, the spatial variations in the amount of sediments eroded between the NE and the SW monsoons and vice versa were

Table 1. Generalized wave parameters and the probability of cyclone and depression.

Period	Cyclones, storms/depression	Waves characteristics
December-February	Probability of cyclones and storms 0.04 and 0.09 respectively	From 30° for > 80% time, Wave height < 1.5m and wave period < 8 sec for 80% time
March - May	Cyclones in May only. Probability 0.72 and 0.11 for cyclones and storms respectively	Variables direction (< 90° - 180° - 300°), wave height 1-2.5m, wave period 5-10 sec (< 8sec for 60% time)
June - September	Cyclones and depression have probability of 0.2 and 0.19	From SW (180° - 240°) for >60% time. Wave height >2 m for > 80% time, wave period 8-10 sec. Wave height during depression 4m and period > 10 sec
October-November	Cyclones and depression occur with a probability of 1.0 and 0.45	Highly variable direction (0° - 150° for > 80% time). Wave height >2.0 m for 40% time. Wave period >8 sec for 30 % time. Wave height during depression >4m and period > 10 sec.

significant. The northern end (Profiles 1-2) had higher deposition compared to the southern portion of the study area (Profiles 3-5), during storm-swell transformation, between September and February (magnitude $113.50 - 98.58 m^3 m^{-1}$ in the north; $71-90 m^3 m^{-1}$ in the south. Overall higher accretion was, however, observed in the southern profiles, which diminished northwards (Table 2).

The longshore sediment transport during the NE and the SW monsoons and for transitional periods together with the annual gross and net drifts, at 19 stations (Fig. 1), are presented in Table 3. The drift during the SW monsoon (June-September) is high due to prevalent high wave environment (gross average drift $58.16 \times 10^4 m^3$; net $43.36 \times 10^4 m^3$, direction from the SW). The gross drift during the NE monsoon (October-November) is much reduced (gross drift $14.2 \times 10^4 m^3$, net drift

from the NE $7.1 \times 10^4 \text{ m}^3$). The transitional periods have a drift mostly from the NE (gross drift 16.97 and $9.62 \times 10^4 \text{ m}^3$, and net drift from the NE 16.59 and $7.4 \times 10^4 \text{ m}^3$ for December - February and March - May, respectively). The annual net drift for the area is from the SW ($14.24 \times 10^4 \text{ m}^3$; drift from the NE and SW are $42.36 \times 10^4 \text{ m}^3$, and $56.6 \times 10^4 \text{ m}^3$ respectively). The gross annual drift in the area is about $99 \times 10^4 \text{ m}^3$ (Table 3). The monthly variations in the magnitude of the average longshore drift during the SW and the NE monsoons, and in nonmonsoon period were also compared. The values of gross monthly drift during the SW and the NE monsoons and

Table 2. Budget of sediment exchanged at different beach profile stations.

Period	Beach Profile length (Av)	Profile Number					Average
		1	2	3	4	5	
Feb.81-Apr.81	150	+14.17	+11.72	+19.05	+17.21	+13.64	+15.1
Apr.81-Sep.81	110	-53.24	-56.78	-40.52	-42.97	-49.52	-48.60
Sep.81-Nov.81	115	+22.32	+23.15	+27.22	+25.45	+29.18	+25.46
Nov.81-Feb.82	150	+113.9	+98.58	+71.47	+83.65	+90.97	+91.74
Feb.82-Sep.82	110	-78.82	-70.21	-52.73	-41.45	-47.50	-58.16
Sep.82-Nov.82	120	+17.82	+15.42	+19.72	+18.35	+22.35	+18.73
Net deposition (Feb. 1981 to Nov. 1982).		+154.0	+137.15	+118.4	+127.45	+142.5	+135.93
Net erosion (Feb. 1981 to Nov. 1982)		-132.6	-126.99	-93.24	-84.42	-96.92	-106.76
Budget		+21.44	+10.16	+25.17	+43.03	+45.58	+29.17

values in $\text{m}^3 \text{m}^{-1}$, (+) denotes deposition, (-) denotes erosion, (*) values not taken for budget

non monsoon period works out to be 14.54 , 7.1 and $4.43 \times 10^4 \text{ m}^3$ respectively. For the SW and nonmonsoon periods, the average wave energy flux (Pls) is 1.35 and 0.4 K watts/m . During the NE monsoon, the wave energy flux is 0.66 K watts/m , and the gross longshore sediment drift is $14.2 \times 10^4 \text{ m}^3$. Generally, this wave power should have been utilized in regulating the sediment dynamics of the coastal region, leading to an erosion on the beach, and area as such should not have any accretionary trend, particularly during the NE monsoon.

However, despite the prevalent high- moderate waves environment, sediments get deposited in this area particularly during the NE monsoon (Table 2), the probable reason for which appears to lie in the location of the area between two great rivers of the south India with high annual discharge of $122 \times 10^9 \text{ m}^3$ loaded with suspended matter (Total suspended matter (TSM) 1845 & 1158 for Godavari and Krishna respectively; Subramanian, 1987). In Thematic Mapper imagerys

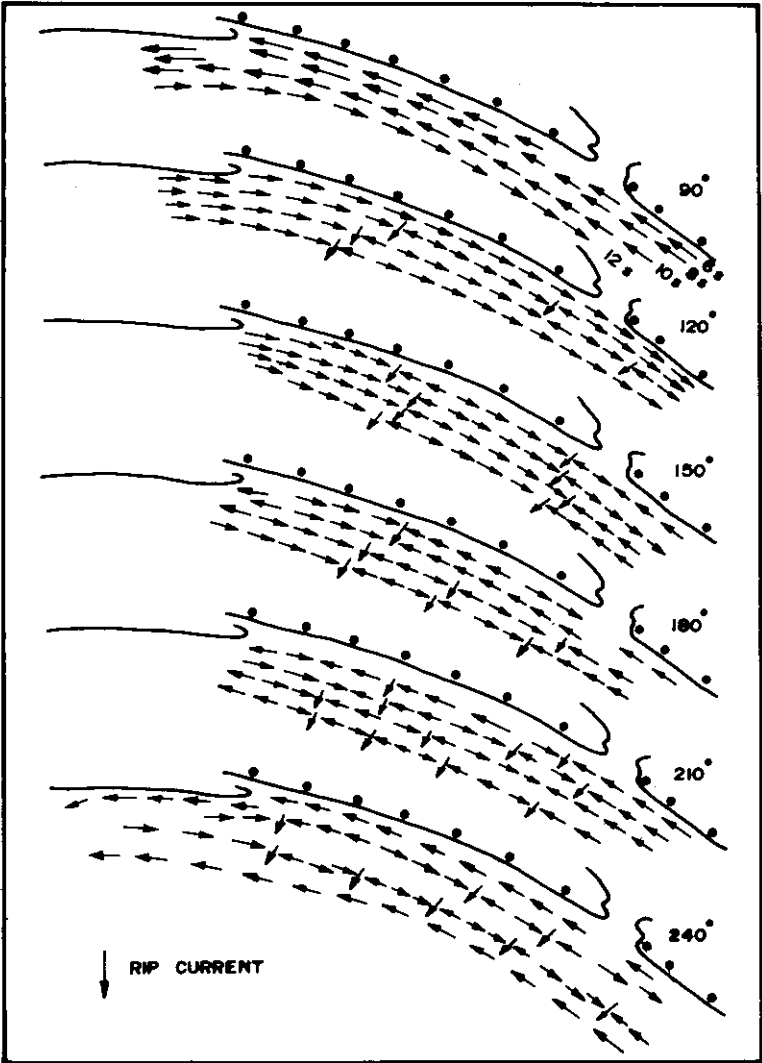


Fig. 2. Patterns of the littoral currents for wave approaches 90 - 210° and wave periods 6-12 sec (refer methodology for details).

of this area, the coastal waters along the entire coast, were observed to be highly turbid (< 20 m water depth) due to contribution of sediments by fluvial plumes, and at Vijayawada sediment input is $1.56 \times 10^6 \text{ m}^3 \text{ y}^{-1}$ (Kunte and Wagle, 1993). Chauhan (1995) has demonstrated that during the SW monsoon, due to prevalent high wave environment, beach sediments are subjected to rolling, whereas during the NE monsoon suspension is the mechanism of deposition. Also the currents during the SW monsoon are from the SW (Figs. 2-3), and these high magnitude currents contribute the sediments of the rivers to the turbid waters as seen in the Thematic Mapper Imageries. Though the drift from the south is larger than that from the north (Table 3), yet the reversal in the current directions does not affect sediment input, as change in the current direction from the SW to the NE will instead transport the sediments discharged by the River Godavari into the area (located north of the study area, Fig. 1), and as such the supply of the sediments to the

Table 3. Variations in the longshore sediment transport rates (10^4 m^3) during the SW and the NE monsoons, and transitional period along the study area.

St. No.	Dec-Feb		March - May		June-September		October-November		Annual		Budget	
	NE	SW	NE	SW	NE	SW	NE	SW	NE	SW	Net	Gross
1.	1.06	16.26	0.21	3.13	58.1	2.06	4.3	12.3	65.6	33.8	33.8	99.41
2	0.23	17.36	0.53	6.61	38.1	1.35	2.9	11.2	41.8	36.6	5.25	38.45
3.	0.12	18.96	2.0	6.56	42.1	0.89	4.3	18.9	48.6	37.3	11.3	85.93
4.	0.11	17.39	0.73	7.59	44.3	13.3	4.3	9.29	49.5	47.6	1.91	97.15
5.	0.14	14.39	0.60	6.68	68.2	0.96	6.3	10.5	75.3	32.6	42.7	107.9
6.	0.12	16.39	0.73	7.32	41.1	12.6	3.6	14.3	45.6	50.7	-5.1	96.39
7.	0.06	12.36	0.82	5.92	58.9	8.06	2.6	9.36	62.4	35.7	26.7	8.14
8.	0.16	14.36	0.93	7.82	41.9	12.3	2.7	11.3	45.7	45.9	0.2	91.60
9.	0.21	18.36	2.16	9.37	66.9	11.9	4.3	9.56	3.63	49.2	24.4	112.8
10.	0.16	16.59	2.36	7.36	69.7	1.19	5.6	9.36	77.8	34.5	43.3	112.3
11.	0.07	22.26	0.63	9.62	36.2	1.39	2.6	5.96	39.6	39.2	-2.6	75.83
12.	0.12	24.12	0.26	10.6	54.1	1.96	4.3	8.69	58.8	45.3	13.4	104.1
13.	0.16	28.32	2.07	11.2	76.1	1.36	5.7	11.7	84.0	52.0	31.3	136.7
14.	0.19	11.20	1.96	8.90	51.3	2.36	4.3	10.6	57.9	33.1	24.8	91.02
15.	0.11	12.20	0.76	9.90	68.1	1.39	2.3	12.1	71.3	35.6	35.7	106.9
16.	0.06	16.76	0.16	10.9	41.2	1.96	1.8	12.7	43.3	52.3	-8.9	95.65
17.	0.16	11.26	0.78	9.16	36.3	12.4	1.6	13.7	38.9	46.5	-7.6	85.33
18.	0.19	16.96	0.36	12.9	48.6	11.3	1.8	7.86	50.9	49.1	1.76	100.4
19.	0.17	13.36	2.16	10.1	41.3	12.6	1.7	10.7	45.5	46.8	-1.3	92.38
Av.	0.19	16.78	1.11	8.51	51.7	6.40	3.5	10.6	56.6	42.3	-14.2	98.96
NET	-16.5		-7.4		43.36		-7.1				14.20	
Gross	16.97		9.62		58.16		14.20				98.96	
Gr(mm)			4.43		14.54		7.10				8.24	

SW = Drift to SW, NE = Drift to NE, (-) net drift from NE, Gr(mm) monthly drift

remains unaffected. Further during the NE monsoon, the deposition of the sediments on the beach,

despite high wave energy conditions takes place due to dampening of wave energy by turbid water (part of the wave energy is utilized to maintain a high suspended load), and also due to the fact that the magnitude and the direction of longshore currents changes in this season, leading to the deposition of the sediments from the turbid waters. These processes induce accretions in the area,

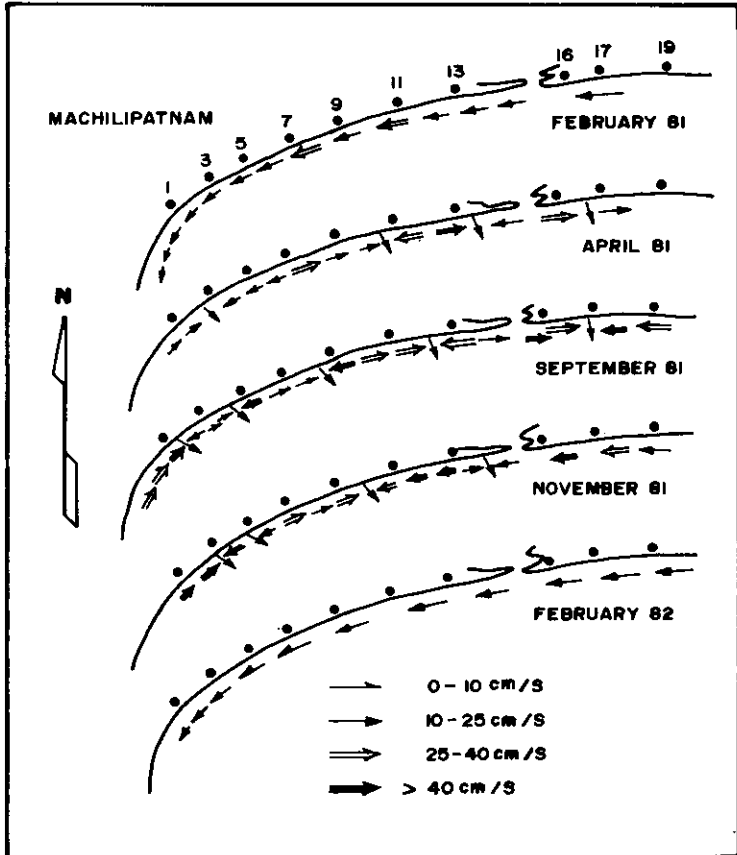


Fig. 3. Observed current patterns during February of 1981,82, and April, September, and November of 1981.

and the mouth of the creeks with emanating cyclic tidal flows interacting with the littoral drift appears to be the most favorable locations. The turbid coastal water charged with high suspended matter is also likely to be carried into the inner regions of creeks and channels by the tidal flows, which may also lead to frequent silting of the navigational channels in the area. Since the sediment

budget along the beach suggests a higher accretion rates in the southern area (Profiles 4-5), which diminishes northwards on Profiles 1- 2, it may be deduced that the drift from the SW appears to be the main source of the accretion. Therefore, in the events of the construction of any offshore structure obstructing this drift, will, in all probability, lead to the deposition of the sediments on the southern side of such structure. However, due to location of the River Krishna in the south, and the River Godavari in the north, contributing ceaselessly to the highly turbid coastal waters, the area irrespective of drift direction will have depositional tendency.

CONCLUSIONS

The results of the present work lead to the following conclusions:

1. During the NE and the SW monsoon, the Andhra coast experiences high wave environment, moderate-high littoral currents, with a high probability of occurrence of storms/depressions in November ($p = 1.0$).
2. Despite a prevalent high wave and current regime during the NE monsoon, area has accretionary tendency due to high input of the fluvial sediments to the coastal turbid waters, and their deposition due to fluctuations in the wave energy flux.
3. Due to high fluvial flux, the channels of the harbours located in the area are susceptible to siltation. Since the area has higher drift from SW and the sediment accretionary rate reduces northwards, it may be also inferred that the jetties and other structure constructed at Machillipatanam will lead to an accumulation of the sediments in the south of such structures.

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