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Sediment Movement on Aligadde Beach, Uttara Kannada District, West Coast of India

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ABSTRACT

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To understand the erosional and accretional behaviour of Aligadde Beach, monthly measurement of beach profiles over a period of three years (November, 1988 to December, 1991) disclose spatial as well as temporal changes in beach configuration in response to different environmental process variables. In the present study, Empirical Orthogonal Function (EOF) analysis and volume changes have been compared to better understand the on-offshore sediment movement.

Monthly observations during November, 1988 to February, 1990 revealed a net gain of 34.6 $m^3 m^{-1}$ sediment, and the overall for November, 1988 to December, 1991 showed a net gain of 58.0 $m^3 m^{-1}$. During the southwest monsoon season (June–August), however, major loss of sediment was observed. Accumulation or removal of sediment on or offshore is ascribed to waves and tides, and longshore to convergence or reversal of longshore currents. The observed longshore currents revealed reversal trends; *i.e.*, west to east during the southwest monsoon and northeast monsoon seasons and east to west during the rest of the year.

The study revealed that the beach morphology undergoes cyclic seasonal changes in response to the changing wind and wave climate in three distinct phases: (1) major erosional phase (seaward sediment movement) during May–August, (2) accretional period (landward sediment movement) during fairweather season, and (3) a minor erosional phase during December–February.

ADDITIONAL INDEX WORDS: *Beach erosion, India, monsoon, pocket beaches, EOF analysis.*

INTRODUCTION

Studies on sediment transport and accumulation are of vital importance to many projects involving the water to land interface (CRICKMORE *et al.*, 1990). Beach profiles help us to understand and quantify the variations in sediment levels which are undergoing continuous changes in response to the environment process variables (wind, waves, tides, groundwater, *etc.*). Major changes in sand volume on the beach tend to be systematic and can be related to the character of wave motion, tidal cycles and currents (SASTRY *et al.*, 1979). The profiles also help us to understand the energy conditions and the longshore and onshore-offshore sediment transport. Most of the morphological studies on this stretch of coast have been limited to monthly measurements, over 13/18 months (CHAVADI and NAYAK, 1989; CHAVADI and HEGDE, 1989) and on a lunar tidal scale (HANAMGOND and CHAVADI, 1992). Other studies in this area deal with wave refraction (REDDY and VARADACHARI, 1972; VEERAYYA and PANKAJAKSHAN, 1988; JAIN, 1990), with nearshore and shelf sediments (KIDWAI *et al.,* 1981; NAIR, 1989) and with heavy mineral studies (NAYAK and CHAVADI, 1989). The onshore-offshore and longshore sediment transfers on sandy beaches have previously been determined by EOF analysis by WINANT *et al.* (1975); ARANUVACHAPUN and JOHNSON (1979); BOWMAN (1981); CLARKE *et al.* (1984); SHENOI *et al.* (1987); LOSADA *et al.* (1991). The general objective of the present study is to enhance our knowledge of modern coastal environments/processes over different temporal scales in a sheltered type of beach with special reference to onshore-offshore sediment movement using volume changes and Empirical Orthogonal Function (EOF) analysis.

MATERIALS AND METHODS

To study in detail the beach changes, three stations were selected on Aligadde Beach (Figure 1) situated south of Karwar on the central west coast of India. Aligadde is a sheltered type of pocket beach, oriented east-west, about one kilometre in length and varying in width some 25–75 m. It is partly sheltered by Arge Cape and Arge Island on the western side. Manzel Creek separates the

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western end of the beach from Arge Cape and is also its principal source of sediments. The beach at all times exhibits a small berm (10–15 m), a steep foreshore and a wide low tide terrace. The tides are semidiurnal with the tidal difference during the study period ranging between 0.36 m (during monsoon) and 1.62 m (fairweather season).

Three stations (reference sites) were established well behind the backshore so as to represent the entire beach; *i.e.*, both ends and centre. Profiles were monitored using graduated poles and measuring tape as described by LaFond and Prasad Rao (1954) and Emery (1961). Profiling was carried out every month on the 4th day before the full moon day at the time of low tide to beyond the low water level as far as wading depth. Profiles were monitored monthly for 16 months (November, 1988 to February, 1990) and seasonally to December, 1991 (November, April and August), so as to compare the seasons of three years with annual observations. From the profile data, volume of sediment eroded or accreted at the three stations was computed (using an unpublished programme developed by Mr. Bannur at the Department of Geology, K.U. Dharwad) separately for backshore and foreshore (Tables 1 and 2). The programme compared each survey by location and gave the algebraic sum of erosion/accretion as the net volume (m^3 m^{-1}). The monthly changes in volume were calculated with respect to the superimposed profile.

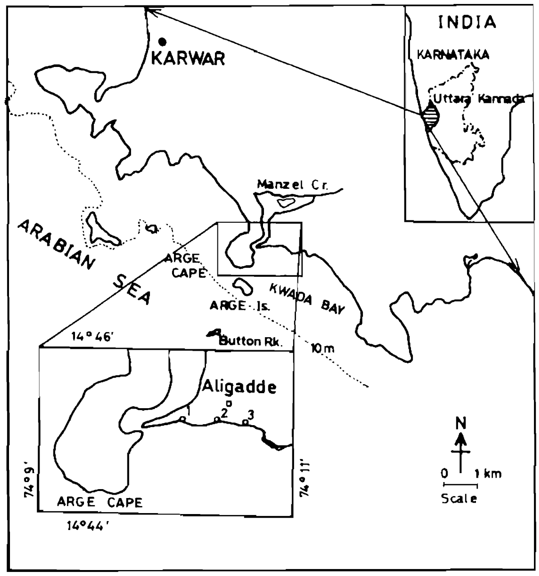


Figure 1. Location map of the study area.

Observations on waves (height and period) and longshore currents (speed and directions) were also made visually using a graduated pole, measuring tape and Rhodomine-B dye.

Table 1. *Monthly changes in the volume of sediment of Aligadde Beach.*

		Station 1			Station 2			Station 3		
Sl. No.	Months	Back-shore	Fore-shore	Net	Back-shore	Fore-shore	Net	Back-shore	Fore-shore	Net
1	Nov. 88/Dec. 88	+00.975	+07.225	+08.200	+00.225	−01.775	−01.550	−00.050	−00.050	−00.100
2	Dec. 88/Jan. 89	+00.200	+03.250	+03.450	+00.800	−05.299	−04.499	+01.300	+02.675	+03.975
3	Jan. 89/Feb. 89	−01.050	−03.875	−04.925	−01.600	+08.775	+07.175	−01.175	−01.875	−03.050
4	Feb. 89/Mar. 89	+01.950	+05.350	+07.300	+01.575	+00.875	+02.450	−00.575	−05.525	−06.100
5	Mar. 89/Apr. 89	00.000	+00.150	+00.150	+00.925	+02.375	+03.300	+01.150	+02.675	+03.825
6	Apr. 89/May 89	+01.000	+03.425	+04.425	+00.250	+01.550	+01.800	−00.650	−01.650	−02.300
7	May 89/Jun. 89	00.000	+00.199	+00.199	+00.275	−01.050	−00.775	00.000	−03.100	−03.100
8	Jun. 89/Jul. 89	−00.050	−02.425	−02.475	−01.350	−02.275	−03.625	+01.000	+02.050	+03.050
9	Jul. 89/Aug. 89	+00.325	−02.250	−01.925	+00.850	+03.150	+04.000	−00.075	+02.950	+02.875
10	Aug. 89/Sep. 89	−00.825	−02.150	−02.975	−02.675	+01.825	−00.850	+00.899	+02.625	+03.524
11	Sep. 89/Oct. 89	+00.275	+08.225	+08.500	+00.300	+03.250	+03.550	+02.450	−00.125	+02.325
12	Oct. 89/Nov. 89	+00.175	+03.150	+03.325	−00.225	−01.225	−01.450	−00.550	−02.499	−03.049
13	Nov. 89/Dec. 89	+00.100	+00.225	+00.325	00.000	+03.925	+03.925	−00.250	−01.675	−01.925
14	Dec. 89/Jan. 90	−00.600	−00.825	−01.425	−00.675	−01.025	−01.700	−02.450	−04.750	−07.200
15	Jan. 90/Feb. 90	−00.825	−03.525	−04.350	+00.875	+01.825	+02.700	+03.400	+06.225	+09.625
Net change (m^3 m^{-1})				+17.799			+14.451			+02.375

"+" = accretion, "−" = erosion

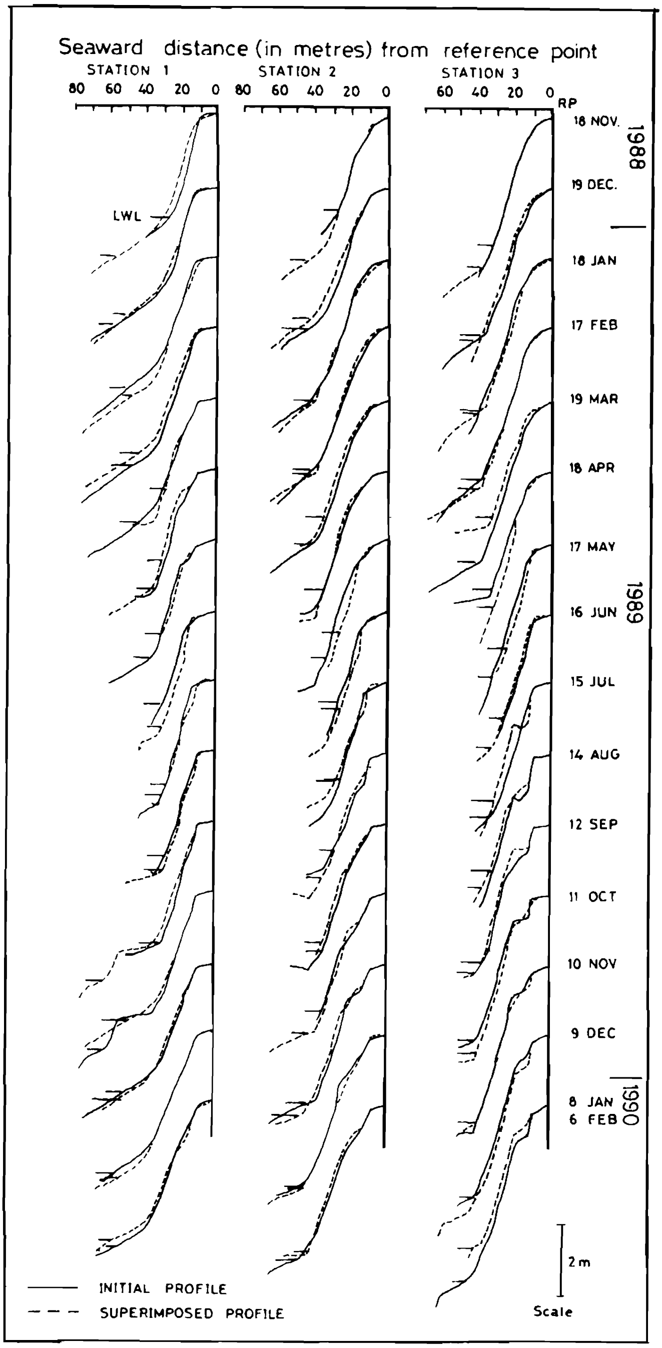


Figure 2. Monthly beach profile changes at station 1, station 2 and station 3 (LWL and the marks on profiles indicate low water levels).

Table 2. *Seasonal and annual changes in the volume of sediment of Aligadde Beach.*

Sl. No.	Months	Station 1 Back-shore	Station 1 Fore-shore	Station 1 Total	Station 2 Back-shore	Station 2 Fore-shore	Station 2 Total	Station 3 Back-shore	Station 3 Fore-shore	Station 3 Total
					Seasonal changes ($m^3 m^{-1}$)					
1	Nov. 88/Apr. 89	−00.275	+05.450	+05.175	+01.975	+05.025	+07.000	+00.650	+01.900	+02.550
2	Apr. 89/Aug. 89	+00.175	−03.375	−03.200	+00.225	+00.825	+01.050	+00.725	−02.725	−02.000
3	Aug. 89/Nov. 89	−00.375	+15.000	+14.625	−02.650	+05.225	+02.575	+00.175	+04.425	+04.425
4	Nov. 89/Apr. 90	+00.175	+09.300	+09.475	+00.175	+04.625	+04.800	00.000	−04.775	−04.775
5	Apr. 90/Aug. 90	−00.025	−02.950	−02.975	+00.475	+00.050	+00.525	+01.225	+09.275	+10.500
6	Aug. 90/Nov. 90	−00.125	+00.475	+00.350	−01.725	+04.675	+02.950	+03.750	+03.725	+07.475
7	Nov. 88/Aug. 89	−00.100	+02.075	+01.975	+00.575	+02.450	+03.025	+00.575	−00.025	+00.550
8	Nov. 89/Aug. 90	−00.050	+03.325	+03.275	+00.450	+02.850	+03.300	+00.975	+03.999	+04.974
9	Nov. 90/Aug. 91	+00.050	−04.375	−04.325	+00.250	−17.975	−17.725	−08.225	−05.800	−14.025
10	Aug. 91/Dec. 91	00.000	+27.000	+27.000	+00.025	+31.725	+31.750	+03.350	+21.575	+24.925
					Annual changes ($m^3 m^{-1}$)					
11	Nov. 88/Nov. 89	−00.475	+06.799	+06.324	−00.150	+03.675	+03.525	+00.150	+06.950	+07.100
12	Nov. 89/Nov. 90	+01.150	+02.700	+03.850	+01.400	+06.100	+07.500	+04.475	+05.150	+09.625
13	Nov. 90/Dec. 91	+00.325	+02.899	+03.224	+00.275	+04.600	+04.875	−00.825	+10.975	+10.150
14	Aug. 89/Aug. 90	−00.099	+04.450	+04.351	00.000	+05.500	+05.500	+00.225	+09.175	+09.400
15	Aug. 90/Aug. 91	+00.025	−04.625	−04.600	−01.225	−13.550	−14.775	−01.850	−04.775	−06.625
16	Nov. 88/Dec. 91	−00.075	+12.125	+12.050	+00.600	+13.650	+14.250	+05.325	+26.350	+31.675

"+" = accretion, "−" = erosion

For the presentation of beach profiles, an Empirical Orthogonal Function (EOF) analysis has been adopted which is amenable to simple interpretation and is useful for comparison of the different profiles across the beach as well as along the beach and for data sets spanning different durations. The EOF analysis program was developed by FERNANDES and MAHADEVAN (1982).

RESULTS AND DISCUSSION

The beach profiles have been presented for all three locations on monthly, seasonal and annual timescales (Figures 2, 3 and 4). A glance at the profiles reveals that the erosional activity is rather minor, but does respond to southwest and northeast monsoons, specifically in the months of May–August. During the rest of the year, it exhibited accretion with a secondary cycle of erosion during December–February at some locations. The erosion/accretion patterns are mostly on the foreshore and lower portions. The replacement of beach material lost during the monsoon began after the southwest monsoon; *i.e.*, from August onwards. Accretion on the upper foreshore caused the subaerial beach to widen and the berm crest to move seaward.

The amount of erosion or deposition varies between successive months/seasons and from station to station. These net changes are quite variable, but follow a pattern governed mainly by waves, longshore currents and physical setting of the beach.

Volume Changes

The volume computations (Tables 1 and 2) show that the beach at all three locations experienced accretion through episodic as well as continuous cycles of erosion/accretion giving rise to a net gain of 34.6 $m^3 m^{-1}$ sediment during November, 1988 to February, 1990. Of this gain, station 1 contributes 17.8 $m^3 m^{-1}$ (51.4%), station 2 about 14.4 $m^3 m^{-1}$ (41.7%) and station 3 contributes 2.4 $m^3 m^{-1}$ (6.9%) volume of sediments. A comparison of the November, 1988 and February, 1990, profiles indicates negligible erosion at station 1 and progressive accretion at stations 2 and 3 (towards the east).

The seasonal changes were examined by superimposing representative seasonal profiles from November, 1988 to December, 1991 (Table 2 and Figure 3). These indicate (1) net accretion at all the stations, but more at the centre during November, 1988 to April, 1989, whereas the November, 1989 to April, 1990 profiles show erosion at the eastern end with progressive accretion at the western end; (2) comparison of the April, 1989 to August, 1989 profiles shows erosion at both ends

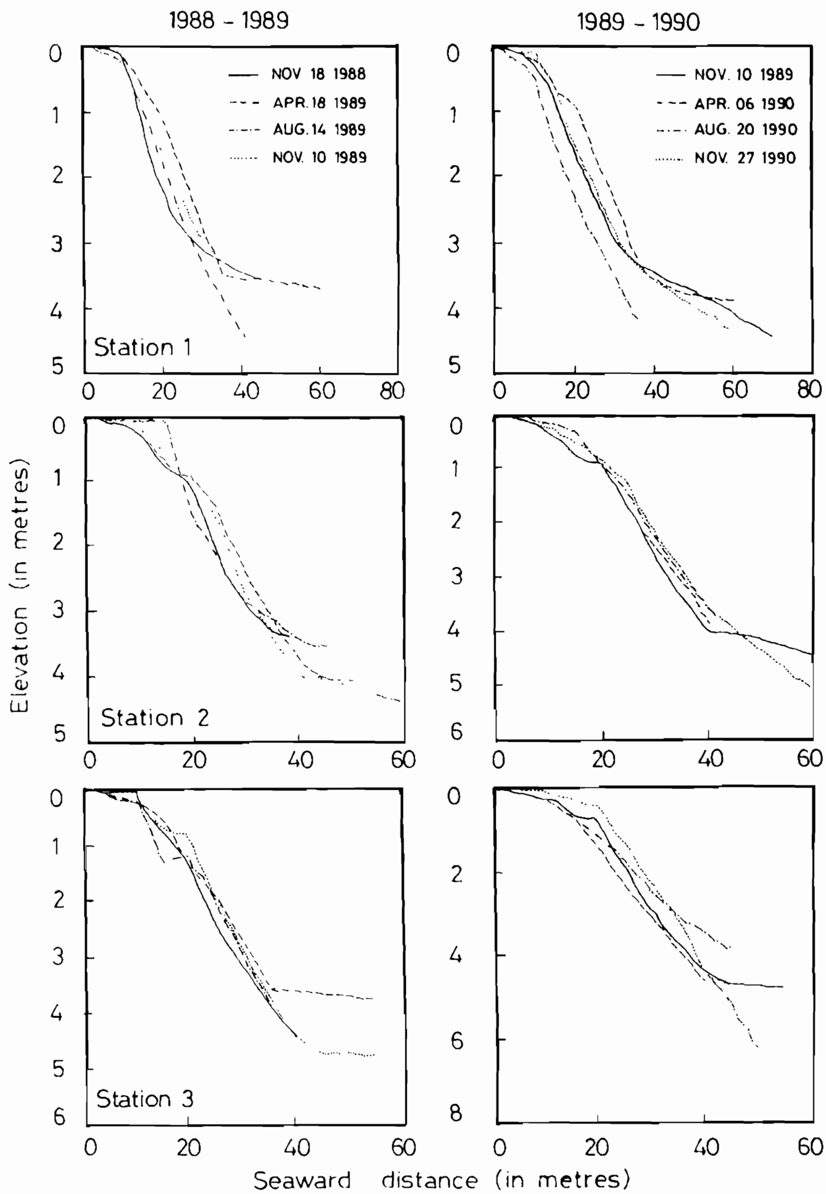


Figure 3. Seasonal beach profile changes at station 1, station 2 and station 3.

and deposition at the centre whereas during April 1990 to August 1990 erosion occurs at the western end and progressive accretion towards east; and (3) comparison of the August, 1989 to November, 1989 profiles show accretion at all the locations, but more at the western end while the August, 1990 to November, 1990 profiles show progressive deposition towards the east and comparison of August, 1991 to December, 1991 shows accretion at all stations with more at the centre.

Comparison of the November, 1988 to August, 1989 profiles show accretion at all the locations and more in the central portion than at the two ends. The November, 1989 to August, 1990 pro-

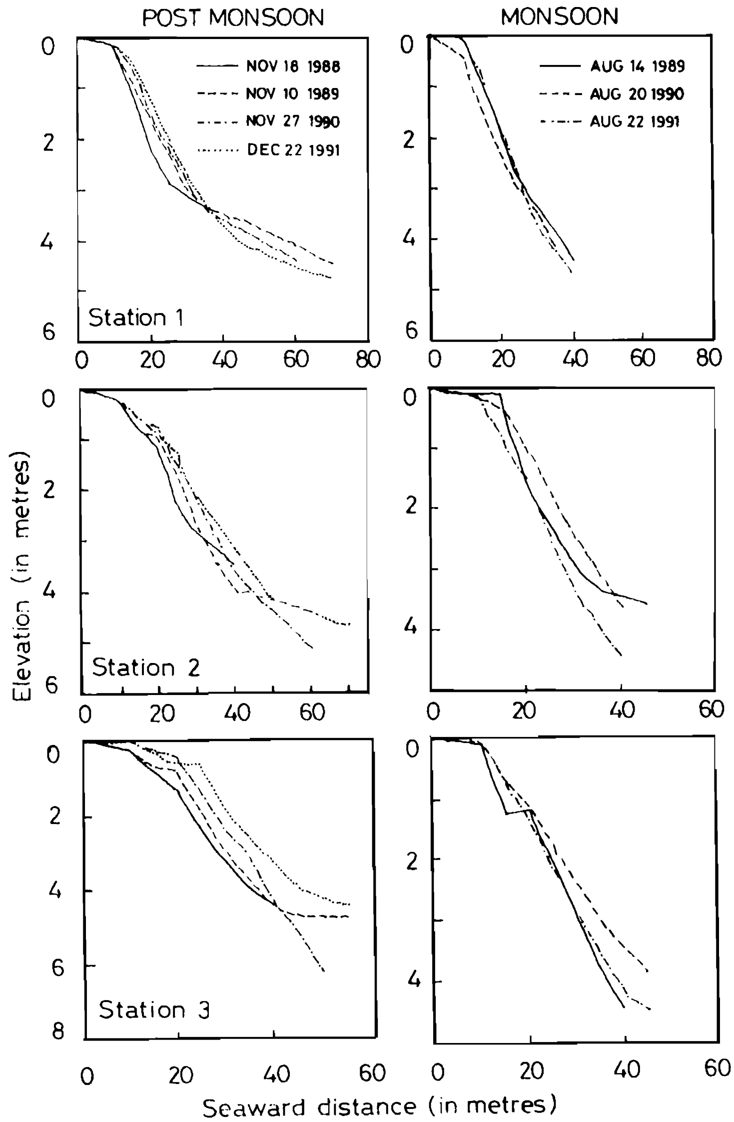


Figure 4. Annual beach profile changes at station 1, station 2 and station 3.

files show progressive accretion towards the east, but erosion at all the locations during November, 1990 to August, 1991, with more in the centre.

The annual variations (Table 2 and Figure 4) were examined by comparing the November, 1988, November, 1989, November, 1990 and December, 1991, and the August, 1989, August, 1990, August, 1991 profiles. These reveal that (1) profiles of November, 1988 to November, 1989 show accretion at all the stations, but less in the central portion; (2) profiles of November, 1989 to November, 1990 shows progressive accretion towards the east; (3) profiles of November, 1990 to December 1991 also indicate progressive accretion eastward; (4) the annual monsoon profiles of August, 1989 to August, 1990 shows progressive accretion eastward; and (5) the profiles of August, 1990 to August, 1991 show overall erosion with more in the central portion.

The overall variation during November, 1988 to December, 1991 has been examined by overlapping the profiles of December, 1991 onto November, 1988. This comparison shows accretion at all three stations and the accretion is progressive towards station 3, *i.e.*, eastward. The volume shows a net gain of 58 $m^3\ m^{-1}$. Of this gain, stations 1, 2 and 3 contributed 20.8%, 24.6% and 54.6%, respectively.

Onshore-Offshore and Longshore Transport

In the present paper, only monthly (November, 1988–February, 1990) profiles have been used to describe the shore normal sediment movement. The removal of sediment from a beach suggests either a movement of sand seaward or longshore. Correspondingly, accumulation of sediment suggests either landward or longshore movement of sand. It is difficult to distinguish, however, between on-offshore and longshore transport because the shore normal movement of sediments can be superimposed by substantial longshore transfers when waves approach the beach obliquely (CRICKMORE *et al.*, 1990). But one can arrive at an approximation, if the erosion/accretion patterns of the adjacent profiles are considered. Eight possible accretion/erosion patterns were observed as follows:

Erosional/ Accretional Patterns at Stations (W)	1,	2,	3	Inferences (+ = accretion; − = erosion)
(i)	−	−	−	Mainly seaward transport.
(ii)	+	+	+	Mainly landward transport.
(iii)	−	−	+	Mainly seaward transport in the west with a superimposed onshore and easterly longshore movement at the centre-eastern part.
(iv)	+	−	−	Same as iii, but vice versa.
(v)	−	+	+	Suggests two possibilities: (a) landward movement at the eastern end and a superimposed onshore and easterly longshore movement from the western end; or (b) if Station 2 has accreted more than Station 3, the currents have converged (Pattern viii). However, if the third Station has accreted more than Station 2, it can be a unidirectional eastward longshore drift.
(vi)	+	+	−	Same as v, but vice versa. However, if Station 2 has experienced more accumulation, it will be similar to Pattern viii.
(vii)	+	−	+	Suggests that the sediment is driven longshore from the centre due to energy concentration owing to wave refraction leading to a divergence of currents. However, if Station 2 is negligibly eroded, then it can be an onshore transport.
(viii)	−	+	−	The pattern suggests that the sediment is brought to the centre by longshore flows from the ends (VEERAYYA and PANKAJAKSHAN, 1988; HANAMGOND and CHAVADI, 1992).

During November, 1988 to February, 1990, the frequency of occurrences of the Patterns iv–vi were compared to the others and ii type of patterns were mainly observed during the postmonsoon season.

Figure 5 (A, B and C) and Figure 6 are presented to show the monthly changes in volume (spatial changes and net changes) calculated with respect to the November, 1988 profile. They clearly indicate onshore-offshore sediment movement. Figure 5 (A, B and C) shows beach profiles affected either by erosional/accretional activity and movement of the sediment up and down the shore. Overall, Figure 5 shows that the beach has been influenced by accretional activity around 15–35 m and erosional activity after 35 to 40 m from the reference point. This fact indicates transfer of sediment from lower parts of the profile on to the upper foreshore. Figures 5 and 6 show, in general, alternate on-offshore sediment movement. However, the erosion/accretion pattern clearly indicates seaward sediment movement during the southwest and northeast monsoons and landward movement during the rest of the year. Figure 6 also indicates that station 1 is close to stability (returning to the position of the first survey) during February, 1990.

EOF Analysis

The variability in the beach configuration at the selected locations has been quantified by a

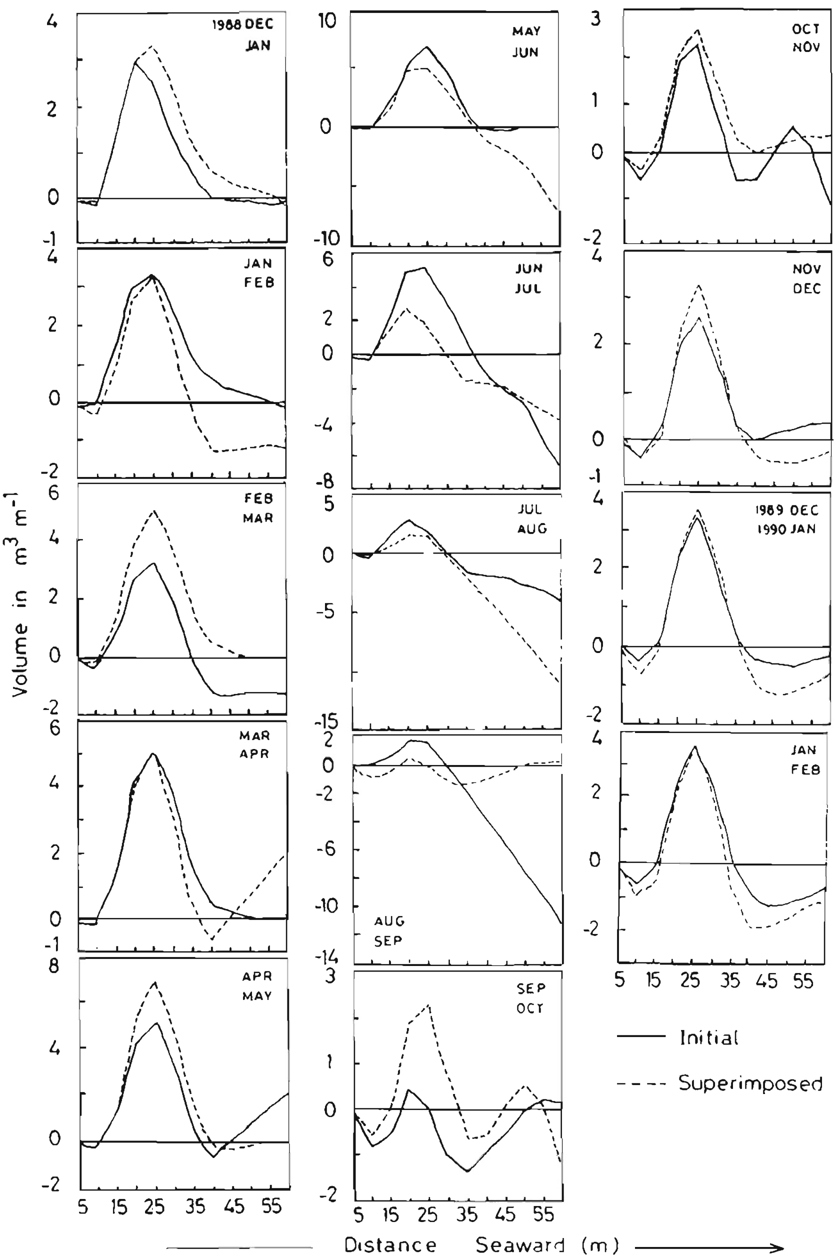
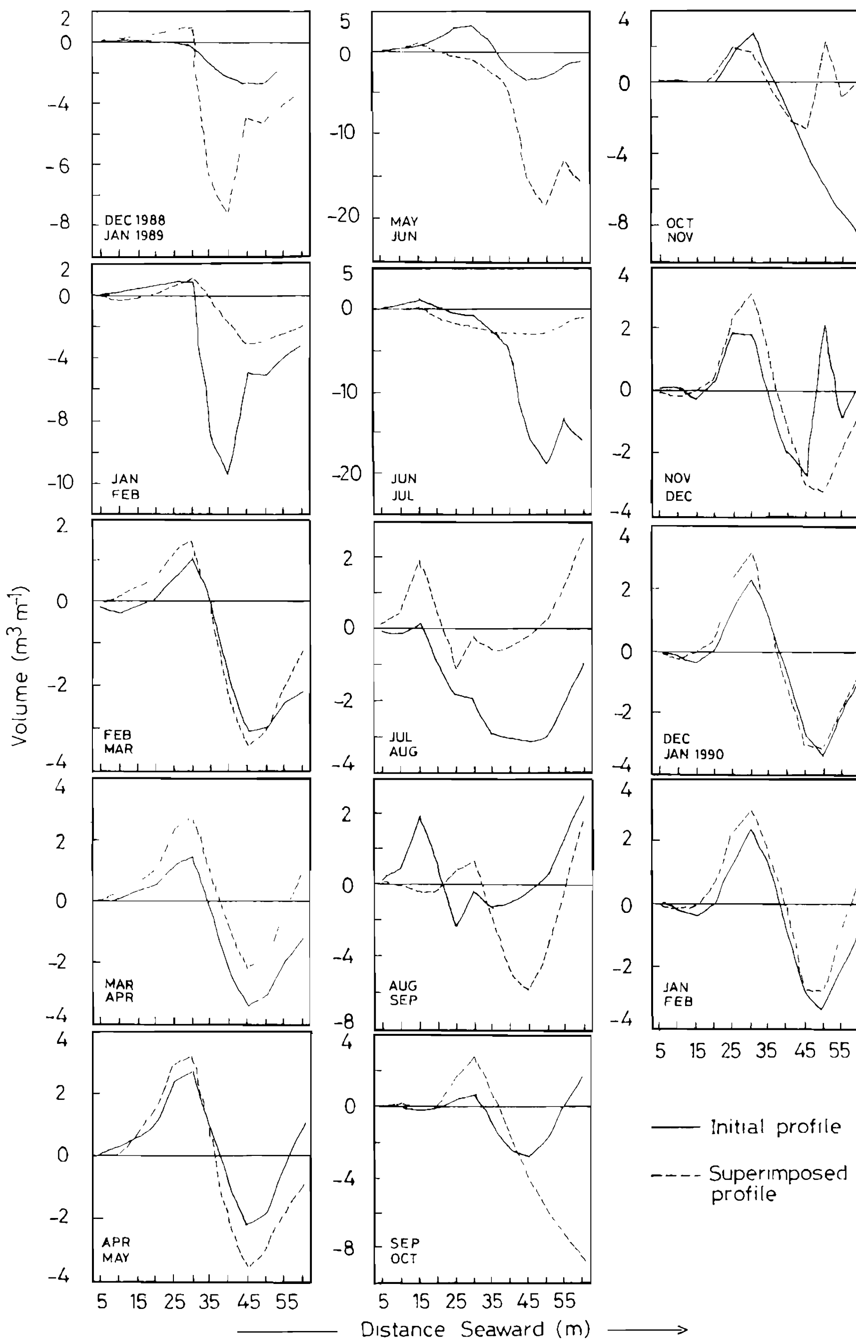


Figure 5A. Monthly cross-shore variations in sediment levels (m' m ') of the beach at station 1, with respect to November, 1988. 5B. Monthly cross-shore variations in sediment levels (m' m ') of the beach at station 2, with respect to November, 1988. 5C. Monthly cross-shore variations in sediment levels (m' m ') of the beach at station 3, with respect to November, 1988.


DEC 1988
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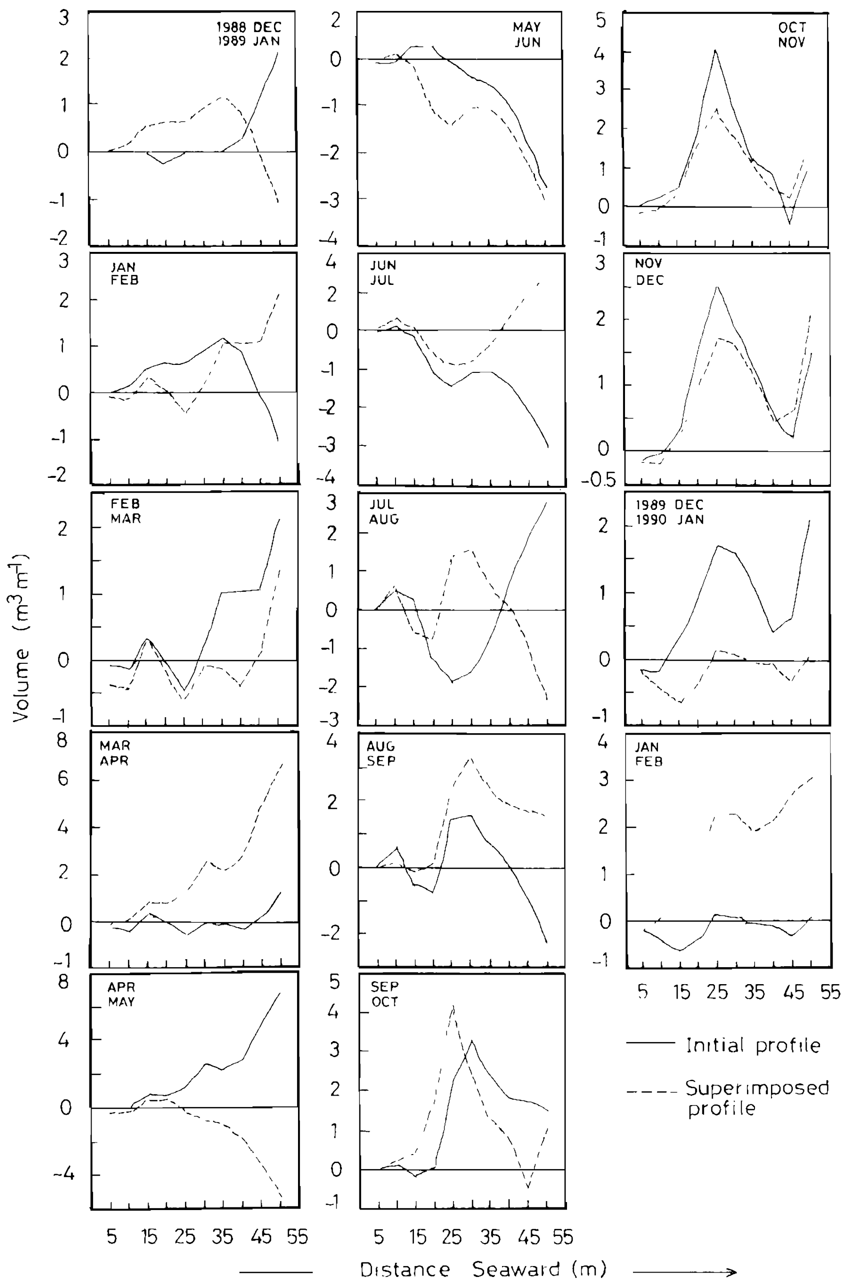
Volume (m3 m-1)
5 15 25 35 45 55
Distance Seaward (m)
Initial profile
Superimposed profile

Figure 5B.



1988 DEC
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Volume (m3 m-1)
5 15 25 35 45 55
Distance Seaward (m)
Initial profile
Superimposed profile

Figure 5C.

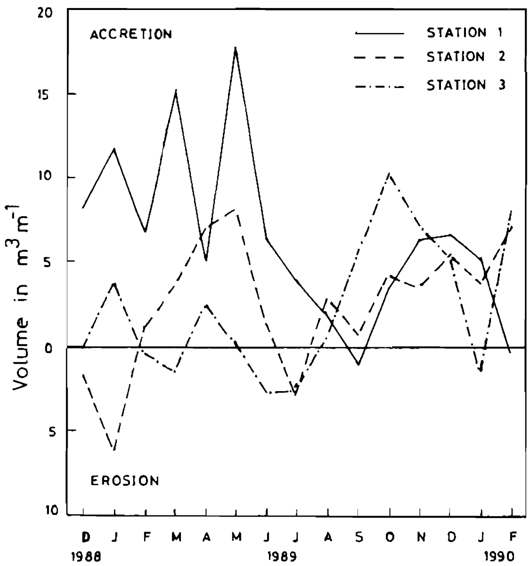

Figure 6. Monthly net changes in the sediment levels with respect to November, 1988 at station 1, station 2 and station 3.

set of eigenvalues and their eigen functions. Eigen functions are the curves that best fit the beach profiles in the least square sense, and each eigenvalue defines the importance of the eigen functions (SHENOI *et al.*, 1987).

The first three eigen functions account for more than 99% of the data variability and are used in the present paper. The first three spatial and temporal dependent eigen functions are presented in Figure 7 (A, B and C). The first eigen function corresponding to the largest eigenvalue accounts for between 98.7–99.6% of the total mean square value represents a mean beach function. The spatial function corresponds to mean beach profile and the temporal function corresponds to the erosion/accretion pattern of the beach for the period of the study. The spatial function revealed the almost similar nature of the curve for all three stations. The temporal function for all three revealed clearly that the beach has experienced maximum erosion during the southeast monsoon (May–August) and the northwest monsoon (January–February) with maximum accretion during premonsoon (April). In general, it reveal cyclicity during the study period.

The second largest eigen function accounts for between 0.17–0.53% of the variance. The second temporal eigen function identifies seasonal variations through the surveyed data and the second spatial eigen function identifies the location and the magnitude of these seasonal changes (LOSADA *et al.*, 1991).

The third largest eigen function accounts for 0.03–0.13% of the variance. Different authors have given different interpretations to its meaning. But, in the present paper, an attempt has been made to compare the empirical orthogonal functions (especially the second and third functions) with spatial and net volume changes computed with respect to the November, 1988 profile (Figure 5, A, B and C and Figure 6). This comparison has revealed some interesting points:

(1) The second and third spatial dependent eigen function can be compared closely with the monthly spatial changes in volume computed with respect to the November, 1988 profile; *e.g.*, in Figure 5A for station 1, it is observed that the 'V' trend in the EOF plots coincide well with the inverted 'V' trend of the volume changes; *i.e.*, in Figure 5A (December and July), the broad maximum peak for accretion is at 20 m from reference point, which can also be seen in EOF plots. (2) The second function represents the volume changes for monsoonal period (December–March and June–August), whereas the 3rd function corresponds to the volume changes during April and September–November. (3) The 3rd function represents the volume changes (erosion/accretion) at more than three different levels, *e.g.*, during September and October, accretion was observed at 20 m and 50 m with erosion at 10 & 35 m from reference points which can also be seen in the plot of 3rd eigen function; and (4), an important observation worthy of mention is that the third function is characterised by the addition of one peak more than the peaks present in the 2nd function (peaks in 2nd function + 1 = peaks in 3rd function).

In this way, the 2nd and 3rd temporal dependent eigen functions can be compared with the net volume changes/temporal changes (algebraic sum of erosion/accretion across the beach) computed with respect to the November, 1988 profile (Figure 6). For example, in Figure 6, it is seen that at station 1, the maximum deposition (through alternate accretion/erosion) was during May and maximum erosion was during September. This fact is clearly observed in the 2nd temporal function. However, a lag for a month or two was ob-

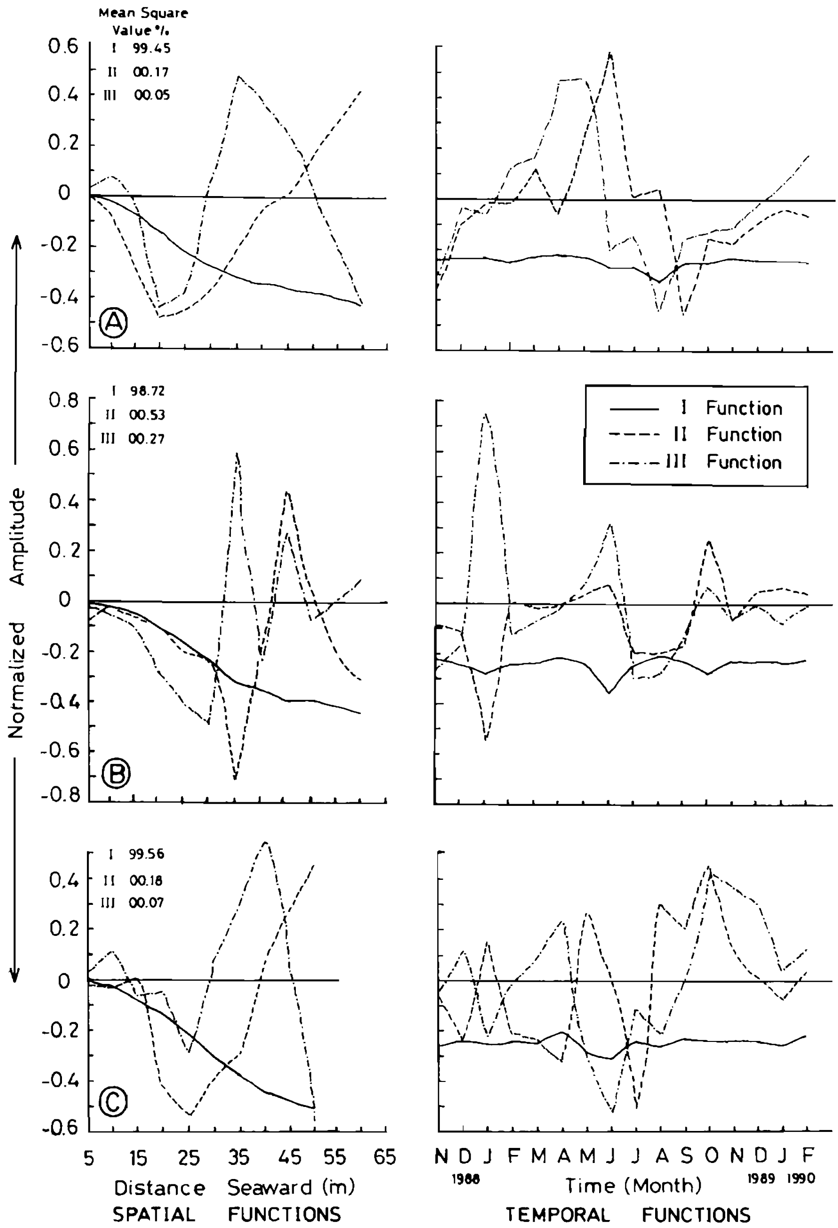

Figure 7. Spatial and temporal dependence of the eigen functions for Aligadde beach at station 1, station 2 and station 3.

served at all the three locations for the maximum accretion/erosion (Figure 7). The comparison of the 2nd temporal dependent function (Figure 7) with the net monthly volume changes (Figure 6) also reveals that the trends are almost similar; for example, the peaks for monsoon erosion and the peaks for postmonsoon accretion (October) for all three locations nearly coincide. However, the peaks for premonsoonal accretion show a month's lag, which may be due to the alternate erosion/accretion during this period as noted from the morphological changes.

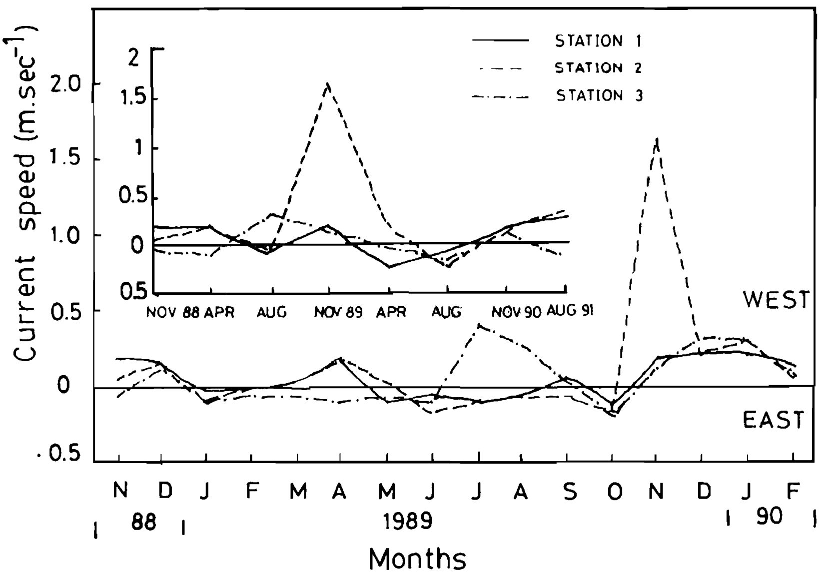

Figure 8. Monthly and seasonal distribution of longshore currents at Aligadde beach.

Morphological studies indicate, in general, more growth in the central portion of the beach compared to distal portions during November, 1988 to November, 1989, whereas progressive growth of the beach was observed eastward towards Station 3 during November, 1989 to November, 1990.

During all seasons, the central growth of the beach can be explained by converging currents (opposed longshore flows) which bring sediments from both the ends and deposit them at the centre (VEERAYYA and PANKAJAKSHAN, 1988; HANAMGOND and CHAVADI, 1992). Further, there was progressive accretion westward and eastward, which is attributed mainly to the unidirectional longshore currents/flows prevailing at those seasons. The dominating eastward flow corroborates with the earlier wave refraction study on this beach (VEERAYYA and PANKAJAKSHAN, 1988).

An examination of the wave data for this stretch of coast shows wave approach to the coast in deep water at directions of 238–258° from June to August, 213–219° from September to December, March and April, and 258–332° during June and February. The data measured at 16 m water depth near Button Rock indicate predominant wave heights of 1.7–3.1 m during the southwest monsoon (June–August), less than 0.45 m during the northeast monsoon (November–January) and around 0.65 m during the (January–April) fairweather period (JAIN, 1990). The observed wave heights during the study period were 0.5–2.5 m with the periods ranging from 8 to 12 sec, and these contribute significantly in the littoral sediment movement along this coast.

The observed longshore currents are presented in Figure 8, which shows alternating easterly or westerly current directions. Easterly currents dominate during the southwest and northeast monsoons and westerly during the rest of the period. A speed of 0.03–1.6 m sec^{-1} was measured for westerly currents and 0.05–0.30 m sec^{-1} for easterly currents, which were always weaker than the westerly currents.

In addition, the migration of the water line (HWL and LWL) (Figure 9), has also been monitored during the study period. It indicates that the major landward movement of the water line coincides with the monsoon and the seaward movement with the fairweather season. Further, this figure also shows that the width of the foreshore is greater during the fairweather season than in the monsoon seasons. As a result of this wide foreshore, the incoming wave energy dissipation is more and hence the development of the beach.

As the width of the foreshore decreases during monsoon season, the impacting wave energy increases and favors more erosion.

CONCLUSIONS

From the foregoing account, following conclusions were drawn: (1) During the study period, Aligadde Beach has experienced accretion, monthly as well as on an annual scale at all three surveyed locations. However, the beach also exhibits a cyclic response to changing wind and wave conditions. (2) The beach at the western end shows more accumulation of sediment (algebraic sum of monthly changes in volume) compared to other portions and it is attributed to the shelter provided by the Arge Cape and Island. (3) The progressive accretion towards the east is due to dominantly unidirectional longshore currents. (4) The sediment moving from one end to the other occurs mostly due to wave refraction and longshore current patterns. (5) The study of volume changes revealed the presence of both longshore and on-offshore sediment movement and that the major seaward transport is during the southwest and northeast monsoons and during the rest of the period, a landward transport superimposed by westerly/easterly alongshore currents prevails. (6) The 2nd and 3rd eigen functions can be compared with the volume changes computed with respect to the first survey. (7) The plots of spatial and temporal volume changes computed with respect to the first survey indicate both on and offshore sediment movement. (8) The broad negative maximum or 'V' trend in the second and third eigen functions represents accretional areas and the broad positive maximum or inverted 'V' trend reveals erosional areas. And (9), the truncation (35/40 m) at the right arm of the inverted 'V' trend in the 3rd spatial dependent function represents a break in slope seaward of the foreshore; *i.e.*, the low tide terrace, and hence corroborates WINANT *et al.* (1975).

The present study demonstrates the usefulness of spatial (cross-shore) and temporal (monthly net changes) volumes computed with respect to first surveyed data. It helps us to understand the movement of sediment up and down the beach profile as well as the portions of the beach affected either by erosion or accretion. These volume changes when compared using EOF analysis (spatial and temporal functions) confirm the processes actually observed during the study period. The

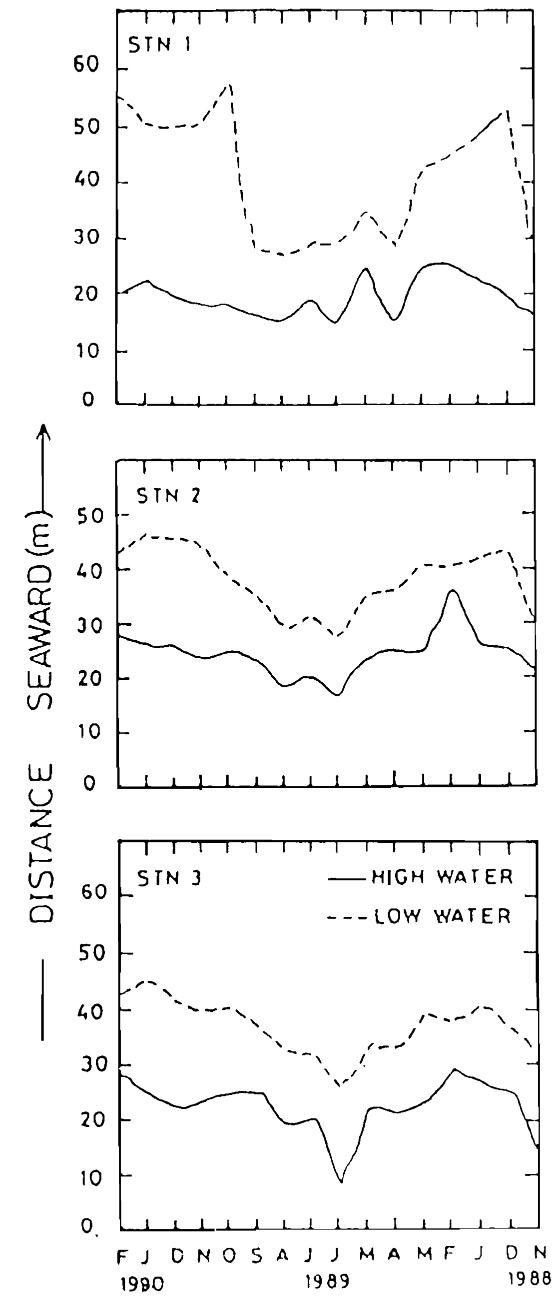

Figure 9. Migration of water line at station 1, station 2 and station 3 during November, 1988–February, 1990.

present study also confirms that the curves of the 2nd and 3rd spatial eigen functions are dependent on cross-shore sediment level changes.

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