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Deducing temporal correlation between nearshore wave process and surficial heavy mineral placer deposits: A case study along the central Tamil Nadu coast, India

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In the present study monthly observation (January 2011 to January 2012) of wave measurements and sediment samples are considered for multivariate statistical analysis. The CCA plots revealed that heavy mineral concentration in the tidal region proportional to the breaker wave height, longshore current velocity and surf zone width, while concentration in berm region proportional to the wave period. The distant projection of backshore samples revealed that heavy mineral distribution controlled by the aeolian process. Moreover, results of 3D scatter plot between sediment characteristics and heavy mineral deposits confirm this correlation on a temporal scale. The overall result implies that the monsoonal wave process does not affect the heavy mineral distribution, but influencing the quantity of deposits.

[**Keywords***:* Beach; wave dynamics; heavy mineral; nearshore; Canonical Correlation Analysis; India]

Introduction

The accumulation of beach sediments concentrated with heavy and light minerals that can be used for understanding the nearshore wave dynamics, locating sediment provenance and depositional environment. Earlier workers have demarcated beach morphology based on the heavy mineral characteristics along the different types of coast[1-16].

Instead of traditional field interpretation, many statistical techniques were employed in order to estimate correlations between placer distribution and beach or wave condition. Several researchers have used factor analysis for examining the placer deposits in order to explore the process of selective grain transport and the distribution of placers[17-19]. For example, Q – mode factor analysis is employed to extract the erosion or accretion patterns of heavy minerals along Nile Delta, Egypt. The factors strongly reflect the natural processes of wave induced longshore current and sediment transport[20]. Similarly, empirical orthogonal function (EOF) is utilized to demarcate the temporal and spatial variations of beach sediment volume along the heavy mineral enriched beaches, southeast coast of India. The results show volumentric changes at foreshore region is mainly caused by the nearshore current and offshore wind[21]. The above statistical measures are significant only for single set of multi–temporal data, however, multi-dataset it is necessary to adopt higher order multivariate methods.

Canonical Correlation Analysis (CCA) is widely accepted statistical method, which provides linear correlation between two different data sets. Technique is initiated in coastal studies by Larson and team[22] in order to predict the beach profile response based on the wave dynamics. The findings proved that CCA prediction is consistent with the field observation. Recently, several researchers eventually employed CCA analysis to establish the correlation between beach morphology and nearshore wave condition[23-26]. However, temporal correlation between the wave process and concentration of surficial heavy mineral deposits is yet to be unrevealed. Present study is mainly employed to point out this issue using Canonical Correlation Analysis (CCA) and three dimensional scatter plots.

Materials and Methods

This study envelops a total coastal stretch of 51 Km, parts of Karaikkal and Nagapattinam district, central Tamil Nadu coast, India. The location map of the study region with bathymetry features is shown in Figure 1. On the whole, ten beaches were chosen with an approximate interval of 5 Km between Thirukadaiyur in the north and Velankanni in the south. Generally, the coast experienced three seasons over an annual cycle, namely southwest (SW) monsoon (July to October), northeast (NE) monsoon (November to February) and fair weather periods (March to June). Tides are semi diurnal with two highs and two lows during the day. During the normal sea condition, beaches have experienced average high and low tidal range of 0.68m and 0.28m respectively (Indian Tide Table (ITT) - 2010, Survey of India). The coastal landform covers a major portion of the Cauvery River consists of narrow wetlands divided by tributaries. This fluvial process imparts a prolonged sediment transport that enhances the amount of placer deposits. Most of the sediment in this region is bi-modal, moderately to well sorting and its mean size ranges from medium to find sand. The study region is found to be enriched with economic placer minerals and that too, in particular, minerals like garnet, rutile, zircon, ilmenite and magnetite[11]. This is one of the main reasons to choose a central Tamil Nadu coast for the present investigation.

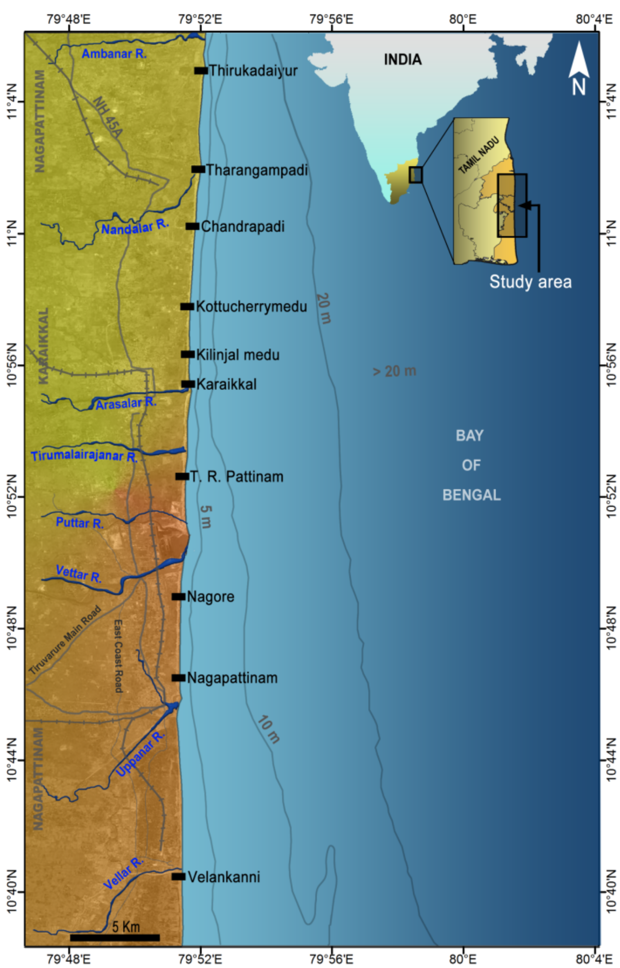

Fig. 1 — Location map of the study area with drainage and bathymetry features

The collection of sediment samples in the tide, berm and backshore region was carried out on a monthly basis during the period between January 2011 and January 2012. Breaking wave height (Hb) was measured by fixing the leveling staff at the low tide region. The height of the breaking waves is scaled by the line of sight to wave crest and horizon[27]. Significant wave height is obtained from the result of one third of the successive waves. Longshore current velocity (V) is measured by floating a buoyant plate at 2 minute interval at the breaker zone[28]. Total station is employed to record surf zone width (W) by measuring the distance between the boat at the breaker zone and the low tide region.

A heavy mineral analysis was conducted for the collected sediment samples in the laboratory environment. The clay fractions are separated from the sample, after soaking it in water overnight. Samples were processed by H_2O_2 and dil. HCL for removing organic, inorganic contents and fine broken shells. Treated samples were sieved in a Ro-Top machine with fixed mesh sizes from +40 to +230 ASTM units, in a quarter-phi interval. The mean and sorting of each sample were estimated through the weight percentage of sieve fractions, based on the method of moments[29-30]. As per the standard procedure, suggested by Milner[31], the heavy and light minerals are isolated by Bromoform heavy liquid (specific gravity is 2.89 and molecular weight 252.73 g/Mol). The isolated heavy minerals were weighted and tabulated further, for the CCA and scatter plot analysis.

The relationship between nearshore variables and surficial heavy mineral placer deposits were derived from canonical correlation analysis (CCA) using XLSTAT 4.0 software. The CCA analysis provides linear relation between two multi–temporal datasets. The CCA analysis is mathematically described by many researchers[23-24, 32-33]. In the present case, nearshore variables such as the wave period (T), breaker wave height (Hb), longshore current velocity (V) and surf zone width (W) are considered as multi–temporal dataset. The other dataset is the weight percentage of surficial heavy mineral placer deposits at tide, berm and backshore region. The results of eigenvalues reveal the variability exist in the first, second and third factors. Depending on the direction and strength of correlation factors, triplot have been

Table 1 — Monthly variation in wave period (T) (in sec)

Stations	Jan-11	Feb-11	Mar-11	Apr -11	May -11	Jun -11	Jul -11	Aug -11	Sep -11	Oct -11	Nov -11	Dec -11	Jan -12
Thirukadaiyur	8	9	9	9	11	10	11	11	11	10	9	8	8
Tharangampadi	7	8	9	9	10	9	12	11	12	11	9	8	7
Chandrapadi	8	9	8	10	11	10	11	12	12	10	8	8	7
Kottucherrymedu	8	9	9	9	10	11	12	11	13	11	9	9	8
Kilinjalmedu	7	8	9	9	10	11	11	12	10	9	8	7	8
Karaikkal	8	8	9	10	11	9	10	12	13	11	9	8	8
T.R. Pattinam	7	8	8	9	11	10	11	12	11	10	9	8	7
Nagore	8	8	9	9	9	9	10	11	11	10	8	9	7
Nagapattinam	8	9	9	10	10	9	11	10	12	11	9	8	8
Velankanni	8	9	8	9	10	11	11	12	11	10	9	9	8

drawn between input variables and canonical variables for temporal investigations. Similarly, a simple three dimensional scatter plot is constructed for examining the correlation between grain size characteristics and heavy mineral placer deposits.

Results and Discussion

The wave propagation is trivial during the northeast (NE) monsoon and larger in the remaining period (Table 1). Appearance of the beach and wave condition with respect to the monsoonal seasons is shown in Figure 2. Propagation of waves appeared to be surging breakers during the southwest (SW) monsoon as a result of the monsoonal wind condition. During this period, the wave energy is observed to be low at the foreshore and hence, the transported sediments are dropped over it. The repetition of this process along with landward sea winds (generated by offshore wave current) will form a steep slope at the foreshore region (Figure 2a). Alternatively, waves that obtain strong turbulence forces during the northeast (NE) monsoon induce erosion at the foreshore region. The collision between the backwash and the successive waves will drop the suspended sediments around nearshore region, due to which multiple sandbars are formed (Figure 2b). During the extended periods of non-monsoonal conditions, sandbars are slowly swept ashore by inept wave conditions that resulting an accretion or beach deposition occurs at the foreshore region. The present results are found to be similar to that of the results obtained at Waimea Bay, Hawaii[34].

The breaking wave height is found to be less (0.41 m– 0.7 m) during the SW monsoon due to the absence of sandbars present in the nearshore region (Table 2). During the NE monsoon, wave height is found to be maximized (above 1m) due to the presence of well developed sandbars in the surf zone and sometimes due to the influence of tropical cyclones. The direction of the longshore current found to be northward during the SW monsoon and fair weather period, while it is found to be southward during the NE monsoon (Table 3). Longshore current velocity is found to be high during the NE monsoon due to the tropical depression formed at the Inter – Tropical

Fig. 2 — a) Sediment deposition during the SW monsoon (August 2011), b) erosion during the NE monsoon (January 2012). Arrows indicate common landmark. (Station: Tharangampadi)

Convergence Zone (ITCZ) [35-38]. The surf zone is the most dynamic coastal region that reflects sediment transport, nearshore current, and associated hydrodynamic processes unveiled in the coast. During the NE monsoon, the surf zone width will be high due to the presence of multiple sandbars while during the SW monsoon, the surf zone width will be less due to the absence of sandbars (Table 4).

The result from Table 5 reveals an enhanced concentration of heavy minerals in the present study area. It is found that the sediments at backshore region contain 40 – 70% of heavy minerals, and about 20 – 60% at the berm and less than 10% of the foreshore region. The concentration of heavy minerals is found to be relatively similar at all the stations.

During the SW monsoon, the less energy of undertow currents imparts sediment sorting in the foreshore, hence the heavy minerals get settled at the bottom while light minerals gets settled over these heavies. Whereas, the concentration of heavy minerals is observed to be more in berm region due to the fact that aeolian process enables the migration of these minerals from the foreshore to the berm region.

Consequently, during the NE monsoon, the heavy mineral from the foreshore and berm region gets accumulated in the backshore region as a result of

Table 2 — Monthly variation in breakering wave height (Hb) (in m)

Stations	Jan-11	Feb-11	Mar-11	Apr -11	May -11	Jun -11	Jul -11	Aug -11	Sep -11	Oct -11	Nov -11	Dec -11	Jan -12
Thirukadaiyur	0.88	0.84	0.72	0.68	0.76	0.62	0.58	0.5	0.48	0.56	0.87	0.92	0.93
Tharangampadi	0.82	0.8	0.74	0.72	0.68	0.51	0.54	0.62	0.67	0.64	0.73	1.02	0.88
Chandrapadi	0.74	0.74	0.72	0.7	0.65	0.63	0.57	0.44	0.49	0.66	0.82	0.98	0.82
Kottucherrymedu	0.94	0.92	0.84	0.74	0.74	0.61	0.55	0.49	0.46	0.76	0.91	0.98	0.89
Kilinjalmedu	0.88	0.94	0.79	0.78	0.72	0.52	0.53	0.46	0.42	0.66	0.87	1.13	0.84
Karaikkal	0.83	0.78	0.72	0.68	0.66	0.65	0.66	0.64	0.68	0.65	0.73	1.06	0.93
T.R. Pattinam	0.92	0.83	0.78	0.75	0.71	0.48	0.46	0.43	0.38	0.61	0.77	1.06	0.96
Nagore	0.92	0.84	0.66	0.74	0.78	0.58	0.68	0.47	0.41	0.74	0.73	1.02	0.94
Nagapattinam	0.98	0.81	0.78	0.86	0.76	0.54	0.59	0.63	0.53	0.61	0.91	1.18	0.91
Velankanni	0.7	0.74	0.74	0.67	0.71	0.63	0.6	0.48	0.46	0.62	0.71	0.83	0.87

Table 3 — The biotope characteristics of the stations

Stations	Jan-11	Feb-11	Mar-11	Apr -11	May -11	Jun -11	Jul -11	Aug -11	Sep -11	Oct -11	Nov -11	Dec -11	Jan -12
Thirukadaiyur	0.11	0.1	0.14	0.17	0.2	0.19	0.15	0.14	0.13	0.18	0.16	0.16	0.13
Tharangampadi	0.22	0.14	0.14	0.16	0.16	0.17	0.13	0.14	0.13	0.23	0.15	0.17	0.21
Chandrapadi	0.16	0.13	0.16	0.17	0.13	0.16	0.12	0.11	0.11	0.19	0.13	0.18	0.22
Kottucherrymedu	0.17	0.15	0.15	0.15	0.18	0.19	0.14	0.12	0.17	0.12	0.14	0.16	0.14
Kilinjalmedu	0.18	0.14	0.17	0.18	0.14	0.18	0.12	0.12	0.13	0.21	0.14	0.15	0.19
Karaikkal	0.1	0.07	0.21	0.14	0.19	0.17	0.15	0.17	0.21	0.26	0.15	0.26	0.21
T.R. Pattinam	0.17	0.17	0.17	0.16	0.2	0.15	0.14	0.11	0.16	0.16	0.15	0.17	0.23
Nagore	0.21	0.12	0.13	0.18	0.22	0.16	0.13	0.12	0.13	0.18	0.18	0.19	0.24
Nagapattinam	0.3	0.08	0.13	0.24	0.24	0.17	0.11	0.11	0.13	0.19	0.15	0.23	0.28
Velankanni	0.24	0.1	0.18	0.13	0.2	0.18	0.11	0.12	0.13	0.14	0.16	0.18	0.21

Table 4 — The biotope characteristics of the stations

Stations	Jan-11	Feb-11	Mar-11	Apr -11	May -11	Jun -11	Jul -11	Aug -11	Sep -11	Oct -11	Nov -11	Dec -11	Jan -12
Thirukadaiyur	57	48	38	31	37	38	29	33	36	37	46	52	59
Tharangampadi	64	58	37	35	57	57	48	49	38	58	60	62	67
Chandrapadi	40	44	25	21	27	49	28	21	10	30	32	36	48
Kottucherrymedu	43	44	39	38	31	37	35	32	28	33	42	49	49
Kilinjalmedu	39	39	31	35	40	40	28	26	21	41	54	46	45
Karaikkal	60	63	31	33	47	42	31	25	20	32	48	65	69
T.R. Pattinam	50	48	43	40	44	41	32	34	26	39	46	51	58
Nagore	49	43	31	31	40	36	27	34	34	55	58	57	59
Nagapattinam	46	55	46	44	32	29	24	27	21	46	52	47	56
Velankanni	58	60	38	29	35	35	33	43	36	59	59	61	63

Table 5 — Temporal distribution of surficial heavy mineral placer deposits (weight %) at tide, berm and backshore region

Month	Morphological unit	Station									
		TKR	TGP	CNP	KCM	KJL	KRL	TRP	NGR	NGP	VKN
January 2011	Tide	17.23	4.89	8.56	2.24	8.79	12.7	4.12	2.38	5.41	8.02
	Berm	58.15	18.6	68.48	72.56	75.42	78.63	56.28	42.38	67.88	46.75
	Backshore	48.15	23.16	62.55	62.59	65.85	68.43	64.13	53.87	57.16	51.76
February 2011	Tide	12.81	6.42	4.75	2.77	5.25	4.23	5.65	1.23	6.94	5.55
	Berm	63.12	23.56	63.54	75.13	68.56	55.36	61.18	52.23	57.88	51.13
	Backshore	83.81	26.55	73.61	36.75	67.03	69.61	65.31	73.61	52.18	41.2
March 2011	Tide	8.89	4.5	2.83	0.85	3.33	2.31	3.73	0.69	6.02	3.63
	Berm	65.77	26.21	66.19	77.78	71.21	58.01	63.83	54.88	60.53	53.78
	Backshore	56.22	31.23	70.62	70.66	69.92	72.5	68.2	61.94	65.23	59.83
April 2011	Tide	6.33	1.94	2.27	1.12	0.77	4.25	1.17	1.25	3.46	1.07
	Berm	67.64	38.65	68.06	79.65	73.08	59.88	65.7	56.75	62.4	55.65
	Backshore	53.07	28.08	62.15	57.58	66.77	69.35	65.05	58.79	62.08	56.68
May 2011	Tide	5.81	2.24	4.75	0.77	5.25	4.23	3.65	0.92	6.94	5.55
	Berm	68.35	40.12	69.41	81.13	74.43	61.23	67.05	58.1	63.75	63.12
	Backshore	59.61	24.62	68.69	64.12	73.31	75.89	71.59	65.33	68.62	63.22
June 2011	Tide	8.24	1.29	3.8	1.6	12.65	3.28	2.7	0.23	5.99	4.6
	Berm	65.13	42.3	71.59	78.12	76.61	73.12	69.23	60.28	75.93	65.3
	Backshore	61.48	26.49	70.56	65.99	75.18	77.76	73.46	67.2	70.49	65.09
July 2011	Tide	9.85	2.24	5.22	0.98	16.32	13.7	6.54	0.62	9.41	5.04
	Berm	66.98	44.15	73.44	79.97	78.46	74.97	71.08	62.13	77.78	67.15
	Backshore	63.34	28.36	72.42	67.85	77.04	69.62	75.32	65.13	72.35	70.64
August 2011	Tide	5.83	1.88	3.86	1.62	10.96	6.34	7.18	1.26	10.05	5.68
	Berm	72.45	36.13	69.52	82.53	81.02	77.53	73.64	64.69	80.34	59.71
	Backshore	64.23	29.25	73.31	68.74	77.93	76.13	76.21	66.02	73.24	66.17
Sept. 2011	Tide	7.28	1.3	3.22	0.24	7.89	5.7	4.12	0.38	3.44	4.96
	Berm	76.01	39.69	73.08	76.09	84.58	81.09	77.2	68.25	83.9	63.27
	Backshore	61.58	20.85	70.66	66.09	75.28	73.48	59.54	63.37	70.59	63.52
October 2011	Tide	6.02	0.04	1.96	0.13	6.63	4.44	1.86	0.16	1.18	1.7
	Berm	71.45	29.56	68.52	71.53	80.02	76.53	72.64	63.69	79.34	58.71
	Backshore	59.72	19.54	58.86	64.23	73.42	75.62	57.68	61.51	68.73	65.58
November 2011	Tide	7.81	1.83	3.75	1.92	8.42	6.23	3.65	1.95	2.97	3.49
	Berm	68.15	26.85	73.48	69.54	78.42	81.63	61.28	59.56	73.45	56.72
	Backshore	63.05	22.87	62.19	67.56	76.75	78.95	61.01	64.84	76.63	68.91
December 2011	Tide	11.74	3.42	2.85	1.86	18.58	6.23	8.98	1.2	4.61	9.45
	Berm	59.37	23.34	68.91	66.54	75.19	84.65	56.32	52.12	70.84	51.18
	Backshore	60.92	20.74	60.06	65.43	74.62	76.82	58.88	62.71	74.5	66.78
January 2012	Tide	12.87	3.73	5.35	2.37	15.85	7.83	12.41	2.53	8.57	13.15
	Berm	58.25	31.69	62.26	60.48	65.765	72.71	63.285	51.35	50.74	41.61
	Backshore	62.23	15.71	72.59	70.95	79.03	82.73	53.49	45.49	71.99	47.27

Abbreviation; TKR: Thirukadaiyur, TGP: Tharangampadi, CNP: Chandrapadi, KCM: Kottucherrymedu, KJL: Kilinjal medu, KRL: Karaikkal, TRP: T. R. Pattinam, NGR: Nagore, NGP: Nagapattinam, VKN: Velankanni

tropical cyclone winds. Moreover, along the study area, heavy minerals in river sediments are accumulated adjacent to the river mouth due to its higher density characteristics.

The CCA analysis is employed to derive a temporal correlation between nearshore variables and surficial heavy mineral placer deposits. Table 6 shows the eigenvalues, variability and the cumulative percentage obtained from the CCA analysis. Table represents the strength of the gradient between nearshore variables and surficial heavy mineral distribution along the axis (axis named here as a factor). The factor 1 along with factor 2 envelops about 85% of the total variance. From Figure 3, the graphical representation reveals a

Table 6 — Eigenvalue, variability and cumulative distribution of CCA factors

Station	Eigenvalue			Variability (%)			Cumulative %		
	F1	F2	F3	F1	F2	F3	F1	F2	F3
Thirukadaiyur	0.685	0.565	0.144	49.118	40.536	10.346	49.118	89.654	100
Tharangampadi	0.920	0.426	0.080	64.500	29.887	5.613	64.500	94.387	100
Chandrapadi	0.963	0.752	0.215	49.905	38.943	11.152	49.905	88.848	100
Kottucherrymedu	0.950	0.474	0.132	61.087	30.441	8.471	61.087	91.529	100
Kilinjalmedu	0.778	0.577	0.092	53.757	39.875	6.368	53.757	93.632	100
Karaikkal	0.782	0.241	0.008	75.848	23.385	0.767	75.848	99.233	100
T.R. Pattinam	0.935	0.769	0.286	46.997	38.642	14.361	46.997	85.639	100
Nagore	0.878	0.270	0.026	74.809	22.994	2.197	74.809	97.803	100
Nagapattinam	0.795	0.484	0.204	53.606	32.666	13.728	53.606	86.272	100
Velankanni	0.892	0.436	0.024	65.989	32.236	1.775	65.989	98.225	100

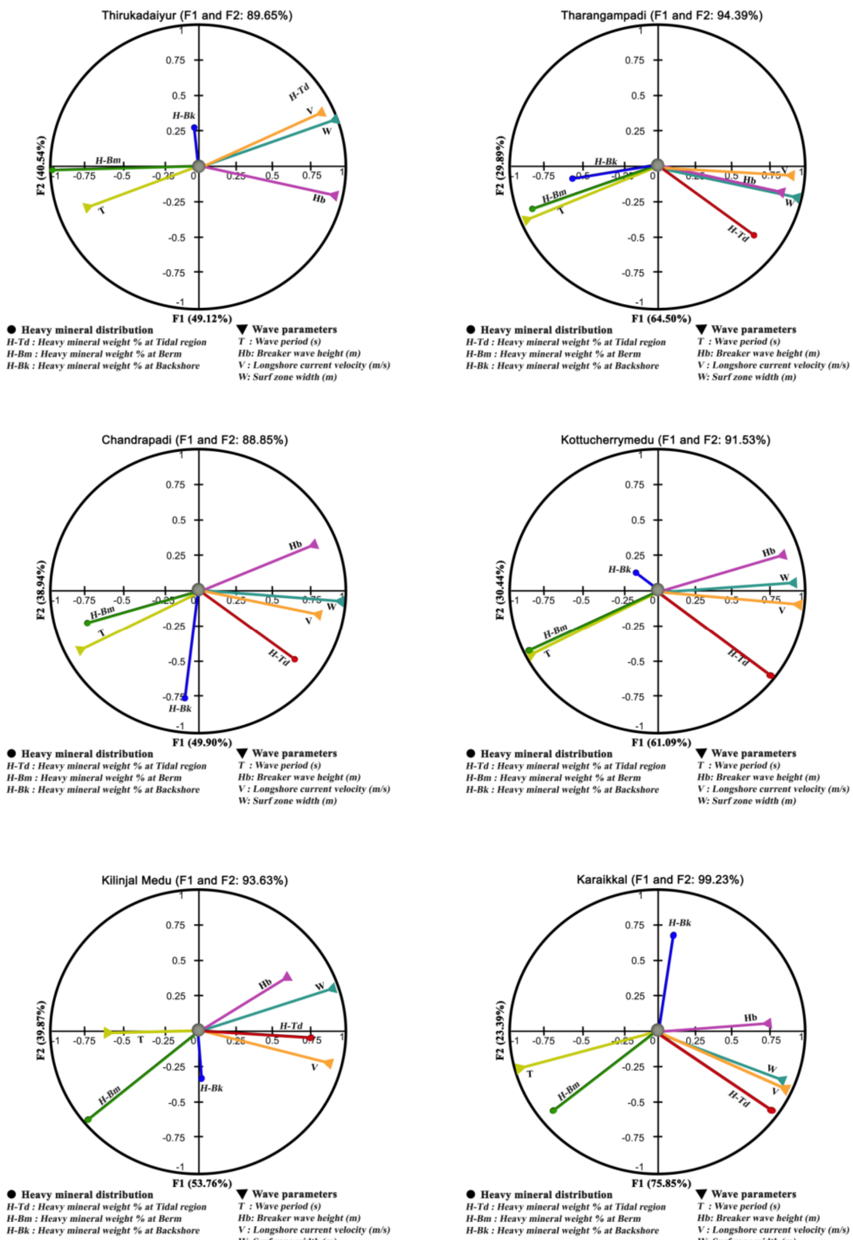

Fig. 3 — Continued

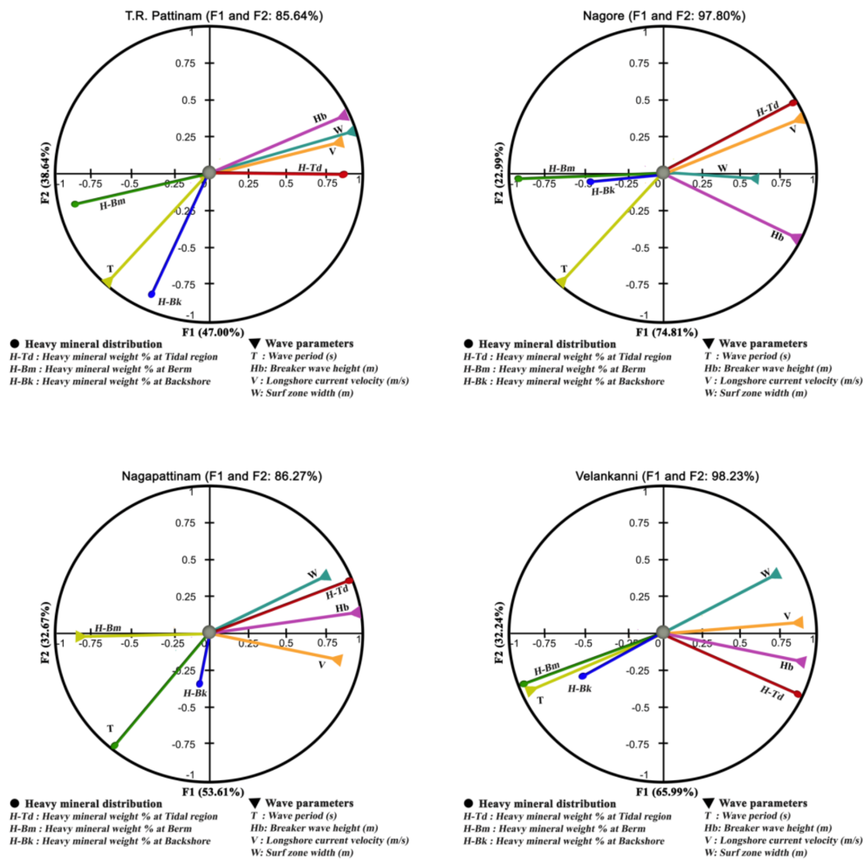

Fig. 3 — Results of the CCA analysis showing temporal correlation between nearshore variables and surficial heavy mineral placer deposits.

clear pattern of temporal correlation between the two datasets, in that the position of each arrow represents the degree of correlation with the factor.

The results from the CCA triplot reveal a positive correlation for breaking wave height, longshore current velocity, surf zone width and surficial heavy minerals in the tidal region. Except wave period, a clear association between the heavy mineral distribution in the tidal region and nearshore variables can be observed or in other words, heavy minerals in the tidal region is highly controlled by the nearshore variables. Compared to the above mentioned discussion, negative correlation is observed in wave period and heavy minerals at berm region. These variables have a positive relationship and correlated negatively with factor 1 and 2. It demarcates heavy mineral enrichment at berm region, which is strongly influenced by the caused by the landward wind force and not by the nearshore variables. However, backshore heavy mineral distribution is not significantly expressed by the CCA triplot. As seen in the figure, backshore heavy mineral distribution may have any type of correlations with other parameters, which reflects berm and tidal region are the active zones with respect to the nearshore dynamics.

A three dimensional scatter plot is constructed to establish temporal relationship between grain size characteristics and heavy mineral distribution (Figure 4). From the scatter plot, the mean value of tidal sediment tends to medium grained during the SW monsoon, while it appears to be fine grained during the NE monsoon. Similarly, from the plot, the sorting value appears to be very well sorted during the SW monsoon, while it appears to be moderately sorted during the NE monsoon. During the SW monsoon, waves posses less energy condition, therefore heavy minerals gets settled in the surf zone while lighter minerals are carried away to the foreshore. Hence, the presence of light minerals tends to be high at tidal region during this period. Alternatively, during the NE monsoon, waves posses high energy condition, hence both the heavy and light minerals are carried away to the foreshore. As a result, compared to that of the SW monsoon, the presence of heavy minerals will be more during the NE monsoon.

In the case of the berm and backshore region, the mean value of the sediment is fine grained and the sorting values of the sediments fall under the category of moderately well sorted to moderately sorted. The sorting value tends to be poor due to the ripple sand distribution caused by the wind force. The heavy mineral distribution is observed to be more at the berm and backshore region. This is due to the force of

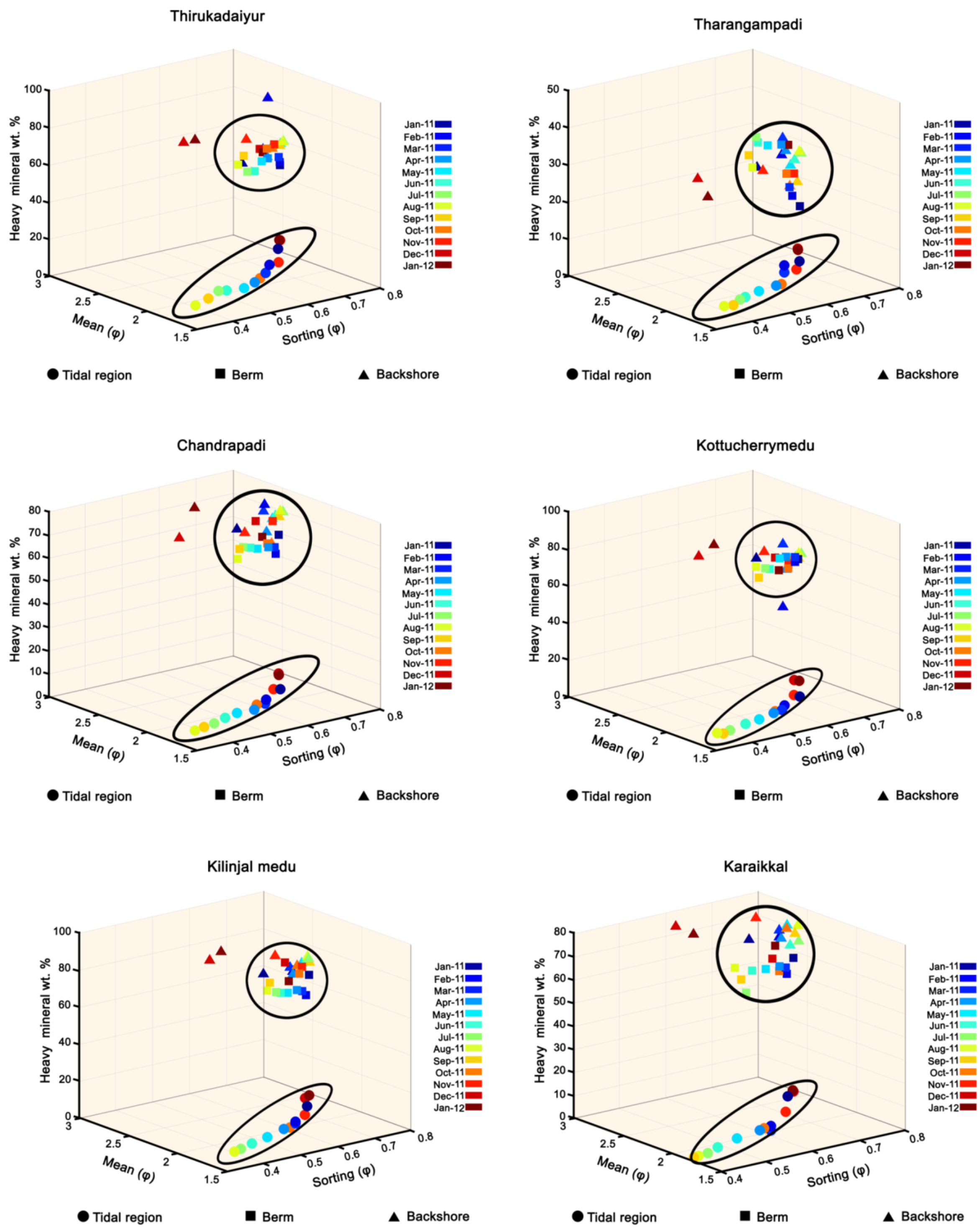

Fig. 4 — Continued

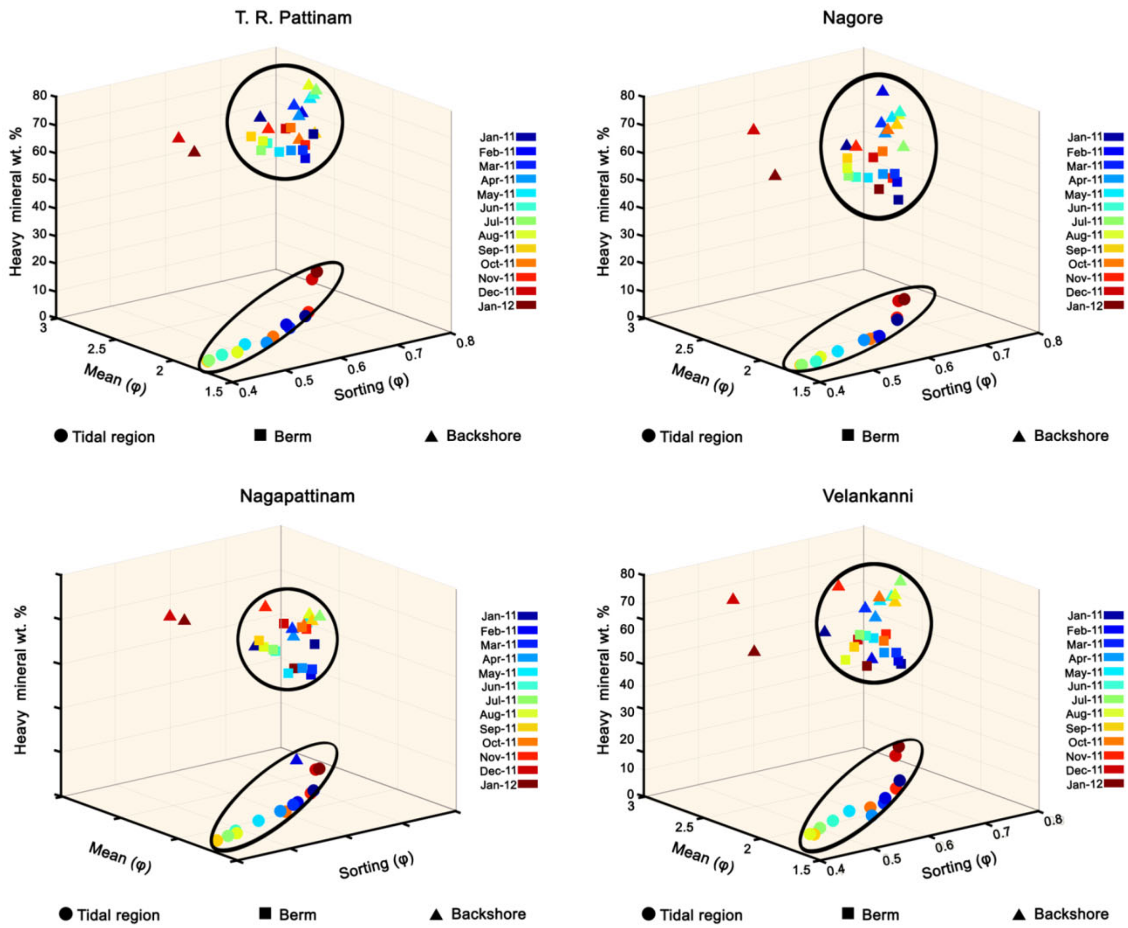

Fig. 4 — Grain size distribution associated with the heavy mineral deposits. The X axis indicates sorting value of the sediment samples. Y axis indicates mean value of the sediment samples and Z axis indicates heavy mineral weight percentage.

aeolian process and not the waves. The enrichment of heavy mineral distribution depends upon the fluctuating wind speed, induced by seasonal variations.

Based on the multivariate statistical analysis, it has been found that the foreshore heavy mineral distribution influenced by the modification of the nearshore zone caused by the different seasons. The temporal scores for the CCA factor indicate that a distinct shift between nearshore parameters. The wave period tends to negative while remaining are positive indicates fluctuation in wave propagation at breaker zone caused by the nearshore bars. Waves experienced a short wave period during the high-energy condition, while long wave period during the moderated to a lower regime. In the high energy condition, foreshore sediments are eroded by swash process, form sandbars at the surf zone. Conversely, in the moderate to low energy condition, less turbulence waves dropped suspended sediments at foreshore region resulting deposition. During the storm condition, nearshore bars tend to erode and the sediments redeposit on the foreshore and berm. Hence, beach width tends to maximize during the moderate to low energy condition (i.e. SW and non-monsoon seasons), whereas beach width tends to minimize during the high energy condition (i.e. NE monsoon). The impact of wave energy on beach morphology stabilizes the distribution of heavy mineral placer deposits. The process of heavy mineral enrichment at tidal region is positively correlated with the nearshore variables such as breaker wave height, longshore current velocity and surf zone width. During the NE monsoon, high energy waves flow up to the foreshore, at the limit velocity tends to zero and is followed by the return flow under the impetus of gravity, as a result denser placer minerals left on the foreshore slope. During the southwest and fair weather periods, downward trend in wave energy tend to distribute heavy and light minerals at the foreshore region[11]. As seen in the heavy mineral concentration at the berm and backshore, the nature of placer deposits by aeolian process than the impact of nearshore variables. Waves appeared high energy with flat foreshore during the NE monsoon while less energy, longer wave period with steep foreshore during the SW and fair-weather period. This is process clearly depict reworking of heavy mineral distribution during an annual cycle.

The above physical process clearly reflects on the relationship between heavy mineral placer deposits and grain size distribution. The sorting of present beach sediments varies from well sorted to moderately well sorted due to the addition of sediments of different grain size from the reworking of fluvial process and the prevalence of convergence or divergence of waves. Sorting of sediments has exposed the energy of wave condition and the presence of dense or lighter grained fractions[39]. During the NE monsoon, as a result of strong wave force, the foreshore of the study area shows a coarse nature, while berm and backshore samples have attained a fine sorting due to the rhythmic aeolian process[40-42]. The seasonal variation dominates the energy of turbulence at nearshore waves; thereby the distribution of heavy minerals varies over an annual cycle. During the NE monsoon, the moderate to well sorting nature reveals that light minerals are eroded by backwash process and heavies settled at settled at foreshore due to its density. During the SW and fair weather period, the well sorted sands reveal less turbulence force to impart light mineral enrichment at the foreshore region. This physical phenomenon reveals that longshore transportability of the heavy mineral increases with its relative grain size and decreases with its density.

Conclusions

In the present study area, NE and SW monsoons are the predominant cause of wave dynamics. The beaches have experienced eroded nature during NE monsoon and deposited nature during the rest of the period, which is conceivable that rebuilt of heavy mineral distribution occurred on the coast. The correlation between nearshore variables and the heavy mineral placer deposits were revealed by CCA analysis. A potentially novel element of this approach is the continuity of evaluation across the temporal scale. A clear assessment of temporal correlation is provided by the tri-plots based on the covariance statistics of the raw data. The differences in the direction of heavy minerals and nearshore parameters can be attributed to the fact that foreshore deposits are the result of wave processes while backshore deposits are the result of winnowing action by strong wave current / storm condition. Alongside, the scatter plot provides consistent justification for variation in the heavy and light mineral distribution at the tides, berm and backshore region. The results revealed that nearshore and aeolian process under the different monsoonal conditions, influences the quantity of heavy mineral distribution over a temporal scale.

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