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Application of Principal Component Analysis to Ascertain the Beach Morphological Conditions Adjacent To a Major Port

M. Phani kumar[1] Prof. Y. Abbulu[2] Prof. P. Malleswararao[3]
1. Scientist, Central Water and Power Research Station, Pune, Maharashtra, India
2. Professor, Department of Civil Engg, AU College of Engineering, Visakhapatnam, AP, India
3. Rtd. Professor, AUCoE, AU, Visakhapatnam, Andhra Pradesh, India
Corresponding Author: M. Phani Kumar, Scientist, CWPRS

ABSTRACT: *Littoral drift phenomenon is dynamic and affects beach morphology which cannot be ignored particularly when any port development is made on the open-coast having moderate to high drift rate. This paper brings out the utility of 'Principal Component Analysis' (PCA) by adopting the same to long-term data of beach indices at Visakhapatnam Port situated on east coast of India in the state of Andhra Pradesh. The major port of Visakhapatnam was designed with integrated vision fulfilling various criteria viz. wave tranquillity, siltation and morphological aspects with the help of physical and numerical model studies. By providing offshore south breakwater with a gap in the surf zone to allow entry of littoral drift sediments towards a protected 'sand trap' within the harbour and with regular sand bypassing on to the down-drift side, dynamic equilibrium of 3 km long beach is maintained. The inferences drawn from 'Principal Component Analysis' carried out on beach indices extracted from regularly monitored beach profile data covering a period of more than three decades till 2012, clearly indicate the efficacy of various strategies adopted for beach nourishment. In order to tackle the littoral drift phenomenon, beach sediments have been disposed mainly in two ways viz. 'on-shore disposal' using along-shore fixed pipe line and 'shore-face disposal' using rainbow technique to counter-act the down-drift side beach erosion. The analysis carried out and presented in this paper reflects the character of down- drift beach of Visakhapatnam in response to the artificial sand nourishment, long-shore and cross-shore wave dynamics. This approach is useful to understand the effect of driving factors and true behaviour of down-drift coast line adjacent to major ports and these insights are useful in designing suitable measures as and when required for similar projects.*

KEY WORDS: *Port development, Breakwaters, Littoral drift, Sand trap, Dredging, Beach Nourishment, Onshore disposal, shore-face disposal/ Rainbow technique, Principal components, wave dynamics*

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I. INTRODUCTION

Visakhapatnam Port, which consists of inner and outer harbours, has been developed on the East Coast of India almost mid way between Paradip and Chennai. This coast being subjected to two monsoons viz. South West (SW) and North East (NE) is prone to high rates of along-shore drift. Coastline configuration and debouch of major rivers namely Godavari, Krishna etc. into the Bay of Bengal are causes of concern giving rise to siltation and morphological problems linked with the development of port facility on this coast. The development of port on open coast requires the construction of breakwaters which cause hindrance to the natural long shore sediment transport affecting the morphology of the adjacent coast lines causing accretion on updrift side and erosion on down drift side. This problem needs to be addressed with appropriate design of port layout along with suitable provision of sand trap and sand bypassing. Particularly the down-drift coastlines are to be monitored regularly and the conditions are to be ascertained with systematic analysis which in turn helps to optimize the sand bypassing/ beach nourishment efforts.

1.1 Sand Bypassing At Visakhapatnam

Though SW and NE monsoons invoke littoral drift in two different directions northwards and southwards respectively, the impact of SW monsoon is high in view of its higher intensity and duration making the net littoral drift direction towards the north. Prior to the Outer harbour construction, cutter suction dredger was used to bypass the sediments onto the eroding northern beach adjacent to Visakhapatnam city by means of floating pipeline. Taking the site specific conditions into consideration, an apt layout was designed for Visakhapatnam Outer harbour with the help of modeling techniques by Central Water & Power Research Station. The outer harbour, protected by breakwaters, was commissioned in 1976. The present layout of outer harbour (Figure 1) mainly consists of three breakwaters viz. south breakwater of 1543m, east breakwater of

1069m and north breakwater of 412m length. The sand trap of 0.64 M cum capacity provided within the basin, by leaving a gap of 250m between the western tip of south breakwater and Dolphin's nose head-land for passage of sediments, would entrap the SW monsoon drift with sufficient efficacy. The dredging activity in sand trap is planned to cause minimum hindrance to the port operations. The Trailing Suction Hopper Dredger (TSHD) can work in sand trap region almost during any time of the year taking benefit of the tranquil conditions offered by south and east breakwaters. Regular annual maintenance dredging of the sand trap and surrounding area is being done to avoid the further passage of littoral drift material towards the other working areas viz., turning circle, offshore tanker terminal etc. from filled sand trap region. The maintenance dredging of the gap between the shore and the shoreward tip of the south breakwater is also carried out regularly to avoid choking of this gap by sediment accumulation. Generally, the grab dredger employed by the port takes care of the maintenance dredging of the inner harbour where as TSHD of an outer agency like Dredging Corporation of India (DCI) is deployed for maintenance dredging in outer area particularly the sand trap and its approaches. Beach nourishment can be effectively done by pumping slurry using dredge pumps of TSHD. The use of grab dredgers with hoppers or hopper barges would not be effective due to shallow depths and existence of rock outcrops near northern shore

The recommendations made to counteract the erosion of down-drift northern beach were adopted by the project authorities besides executing the designed layout as per the recommendations of the research station. Even though TSHD has been invariably used for maintenance dredging and beach nourishments the discharges were through shore based fixed pipeline, rainbow technique and by use of floating pipeline.

1.1.1. On-Shore Disposal

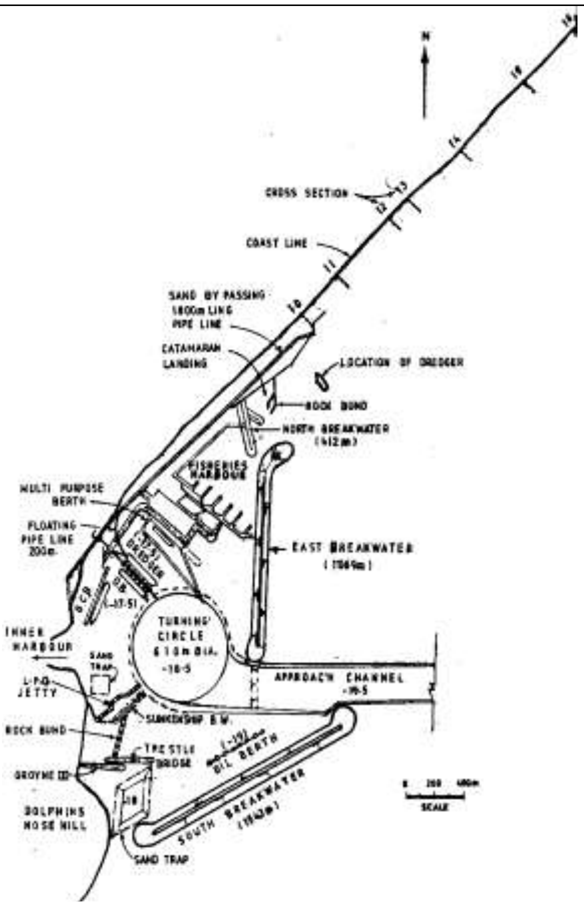
Based on extensive desk studies and mobile bed model studies at CWPRS, an annual sand bypass quantity of 0.42 M cum was evolved for north shore nourishment to counteract the erosion. It was also recommended to monitor the behaviour of the beach to optimize the beach nourishment programme. Till the year 2002, the down drift northern beach was nourished through an along- shore fixed pipeline with the coarser sediments dredged from sand trap by TSHD. The pipe line of 0.74 m diameter from Ore berth to north of north breakwater was of 1800 m length (Figure 2). After filling its hopper with dredging in the sand trap region, the dredger used to be stationed at ore berth by connecting its outlet to the fixed along shore pipeline through 200m long floating pipeline.

Data pertaining to twelve year period (1982-1993) indicated that most of the quantity is being dredged from sand trap area which comprises about 57% of the total dredging quantity of about 1.4 M cum per annum. 23% of maintenance dredging requirement is in the turning basin. These figures obviously indicate the large effect of littoral drift and need for its tackling with a suitable strategy. The data base indicated that an average quantity of 0.32 M cum sand was being bypassed per annum to the northern down drift beach during 1980-2002 which works out to be 24% of maintenance dredging quantity with rest being dumped to deep sea spoil ground located seaward of -30m contour. Out of total sediments trapped in the sand trap region, only about 42% was used for beach nourishment. Though the nourishment rates are less compared to the recommended quantity of 0.42 M cum, the efforts for continuous sand bypassing are appreciable. Besides the regular sand trap dredging, periodical maintenance dredging is also suggested by CWPRS in the approaches of sand trap to facilitate uninterrupted movement of material through the gap between the Dolphin's nose headland and south breakwater thus ensuring the efficacy of sand trap.

Besides maintaining the dynamic equilibrium of the northern beach through a very effective sand bypassing system, it was also essential to ensure that no shoal formations are taking place near the approaches of fisheries and catamaran harbour facilities. The strategy adopted for more than two decades using the fixed pipeline with single point onshore disposal till year 2002 was successful in counter-acting the erosion of northern stretch without any shoal formations in the approaches of fisheries harbour situated on the northern portion of Outer harbour.

1.1.2. Shore-Face Disposal

In the year 2003, the pipeline disposal was discarded and the rainbow technique was resorted to (Figure 3) for economic dredging and disposal activity and to feed the lower reaches of beach with shore-face disposal. Later on, to improve the effectiveness of the beach nourishment programme and to avail of the benefit of alongshore currents for spreading, a floating pipeline was connected to the dredger to discharge near the shoreline (Figure 4).



Visakhapatnam Outer Harbour and Down-drift Northern coastline

On-shore Beach nourishment by TSHD

Shore-face nourishment by Rainbow Technique

Shore-face nourishment by floating pipeline

Figure 1: Harbour Layout alongwith Beach Cross-sections. CS-10 to CS-16 (Photos: Sand Bypassing Systems for beach nourishment)

II. PROTOTYPE MONITORING

Since the coastal processes are complex and dynamic in nature, regular monitoring of the prototype through systematic data collection is vital. In order to assess the behaviour of the beach, monthly cross sections / beach profiles are regularly surveyed upto Low Water Line (LWL). Seven beach cross sections viz. CS-10 to CS-16 (Figure 1) are monitored on monthly basis covering about 3 km length of down-drift coastline. Analysis of monthly data of beach profiles during various periods helps to identify the efficacy of beach nourishment strategies adopted during that period. Collection of profile data in the surf zone as such is difficult and in the present case it is practically impossible due to the presence of rock outcrops. The analysis of the data pertaining to dry beach, inter-tidal beach and deep contour bathymetry would identify the surf zone bathymetric conditions. In the absence of long-term measured wave data impinging on the coastline, in order to understand the effect of various factors, PCA was resorted to considering the raw data of beach indices extracted from the beach profile data. Analysis carried out and results obtained there from are given in the following sections.

III. PROTOTYPE DATA ANALYSIS

Principal Component Analysis (PCA) is one of the useful tools in Multi-variate data analysis and helps in dimension reduction. By writing suitable software coding in the MATLAB package, extensive analysis / data mining can be done to derive useful inferences. In view of the increased utility of computer-based instrumentation and electronic data storage, availability of large and high-dimensional data sets is common now. Sometimes, measured features in a data set may be irrelevant or redundant. High-dimensional data pose many challenges for visualization, analysis, and modeling. PCA is useful here for recognition of spatial and temporal patterns and thereby to understand the effect of underlying driving principles which govern the behavior of the physical system. In PCA, data are approximated by points in a lower-dimensional space and is a quantitatively rigorous method for achieving the simplification. This is useful when measurements are expensive and visualization is important. Simplification of the problem can be achieved by replacing a group of variables with a single new variable.

PCA generates a new set of variables, called principal components. Each principal component is a linear combination of the original variables. Since the principal components are orthogonal to each other there will be no redundancy. When you project each observation on to the first principal component, the variance of resulting variable is maximum among all possible choices. Projecting the observations on to the second axis generates another new variable and the variance of this variable is the maximum among all possible choices of second axis. Number of principal components can be as large as the original set of variables. But the sum of the variances of the first few principal components would exceed 80% of the total variance of the original data. The plots of these few components would give deeper understanding of the driving forces that generate the original data.

'Matlab' software and the function 'princomp' has been used to find the principal components using raw data of beach indices extracted from surveyed beach profiles. Season-wise and index wise data matrices are prepared in excel sheets and PCA was carried out. Salient beach indices viz. Position of High Water Line (HW) from the reference line, Position of Low Water Line (LW), and Inter-tidal slope between high water and low water (Slope) are extracted for all seven profiles measured every month during 1980 to 2012. Status of these indices clearly indicates the health of the visible beach. PCA was applied to the beach indices bifurcating the data into two different periods viz. On-shore disposal (1980-2002) and Shore-face disposal (2003-2012). PCA was carried out initially for the total data set considering all indices (of all profiles and mean of the stretch). To derive additional information, individual data sets were prepared index-wise viz. for HW, for LW and for slope as well as season-wise viz. SW-monsoon, NE-monsoon, Non-monsoon. Combined and individual data sets comprising monthly extracted values of various indices for all the seven cross sections including the mean of the stretch were prepared in separate excel sheets for better workability and readability from the Matlab.

Three outputs viz. coefficients, scores and variances are obtained from PCA conducted on different data matrices of beach indices (X) with 'princomp command' in Matlab as given below;

[coefs,scores,variances] = princomp(X);

The percent of the variability explained by each principal component will be;

Percentage explained = 100*variance/ sum of variances

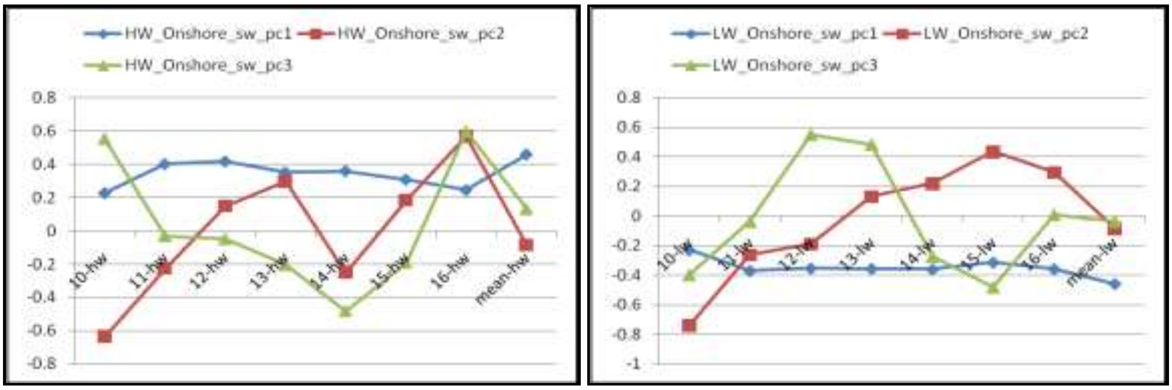
Number of principal components to be considered in the analysis is generally decided by total percentage explained. Physical interpretation of the principal components is very useful, though difficult in certain cases, as it will provide deeper understanding about the physical processes that are affecting the measured variables.

IV. RESULTS AND DISCUSSIONS

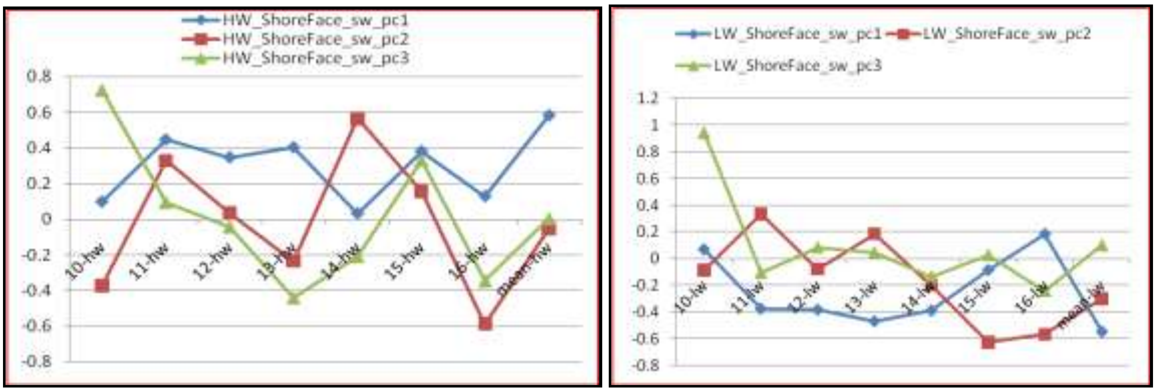
Additional information obtained from PCA about each of the above index clearly depicts the status of the visible sub-areal beach and inter-tidal stretch. Since the data was acquired over a long period, covering both "on-shore disposal" and "shore-face disposal" periods of beach nourishment, PCA is carried out on different data sets to understand the prototype behaviour and capture vital information about the season-wise and profile-wise response about the beach morphology. Individual data matrices are prepared with variables in columns and temporal observations in rows as per the practice in vogue. Period-wise, season-wise and index-wise data matrices are prepared to conduct PCA. Principal Component Analysis is conducted for different periods and the coefficients of the first three principal components are given vide tables 1, 2 for on-shore disposal period and shore-face disposal period respectively.

Generally first three components reasonably explain the variability in the data set and sufficient enough to reconstruct the values with less residual. Total Percentages explained by first three principal components for PCA conducted on different data sets of onshore disposal and shore-face disposal periods are given in Table.3. Percentage of variance explained by principal components is better for on-shore disposal period (1980-2002) than shore-face period (2003-12). This is true with PCA of the data sets pertaining to three indices viz. HW, LW and slope. Having further observed the percentages explained by first three components, it can be seen that PCA for index-wise data is better explaining the data. During shore-face disposal period many factors may be affecting the beach status necessitating the need to consider more components. Nourishment effect is insignificant here unlike onshore disposal period.

Plots drawn for three principal component coefficients, obtained from PCA of SW monsoon data of HW and LW indices for are given vide figures 2 & 3 for On-shore nourishment period and vide figures 4 & 5 for Shore-face nourishment period. Observation of plots or corresponding coefficients/ loadings (of PC1, PC2 and PC3) help to identify the spatial pattern.

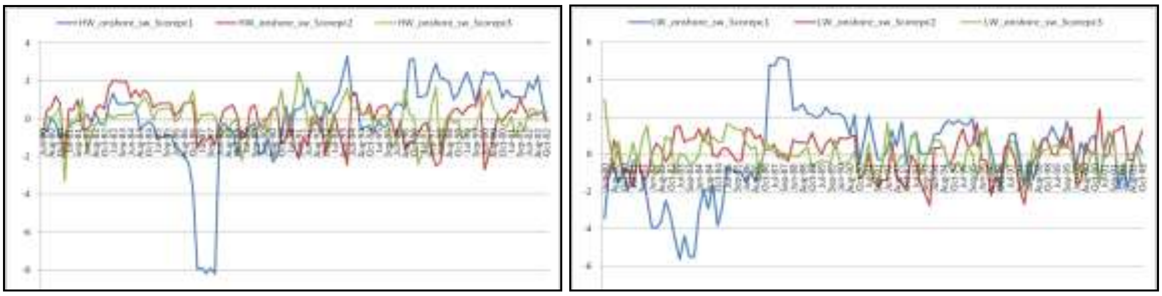


Figures 2 & 3: Principal components for HW data (Left) & LW data (Right)
(Data covers SW monsoon months of On-shore Disposal period)

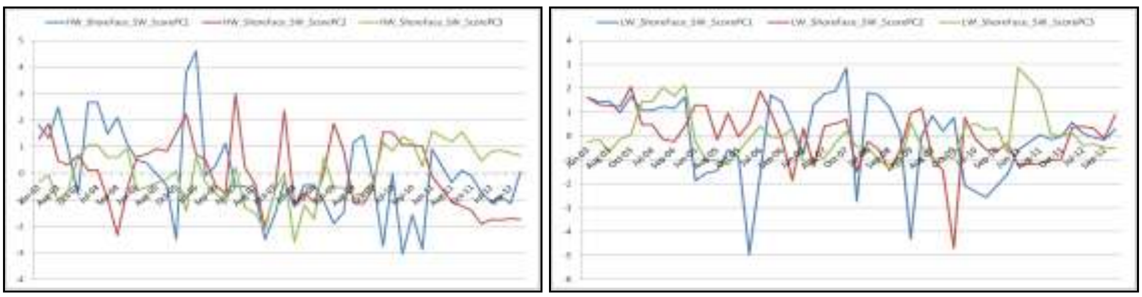


Figures 4 & 5: Principal components for HW data (Left) & LW data (Right)
(Data covers SW monsoon months of Shore-face Disposal period)

Similarly plots drawn for 'Scores' derived from the PCA of SW monsoon data (HW & LW indices) for Onshore (figures 6 & 7) and Shore-face (figures 8 & 9) disposal periods, provides information about the temporal trends. The highs and lows of PC1 scores can be correlated with annual beach nourishment quantities (figure.10). Scores of PC2 and PC3 components, particularly for onshore disposal, can be related to the waves observed at Outer channel (figure.11).



Figures 6 & 7: PCA Scores for HW data (Left) & LW data (Right)
(Data covers SW monsoon months of On-shore Disposal period)



Figures 8 & 9: PCA Scores for HW data (Left) & LW data (Right)

(Data covers SW monsoon months of Shore-face Disposal period)

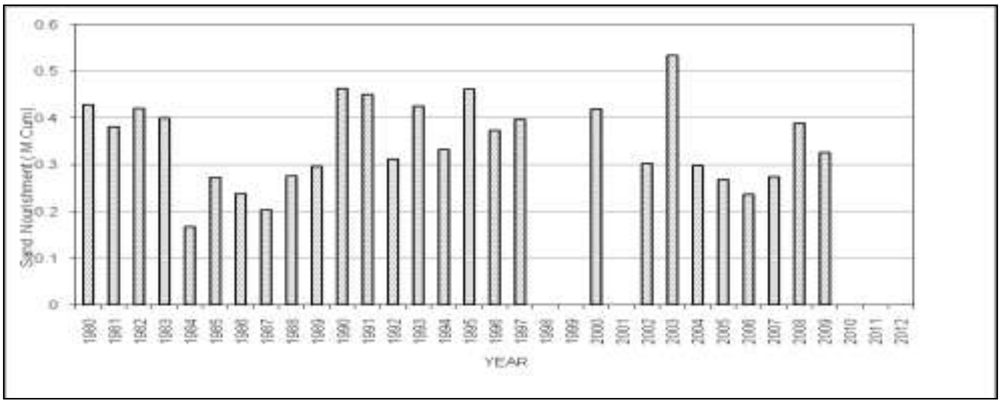


Figure 10: Beach Nourishment at Visakhapatnam

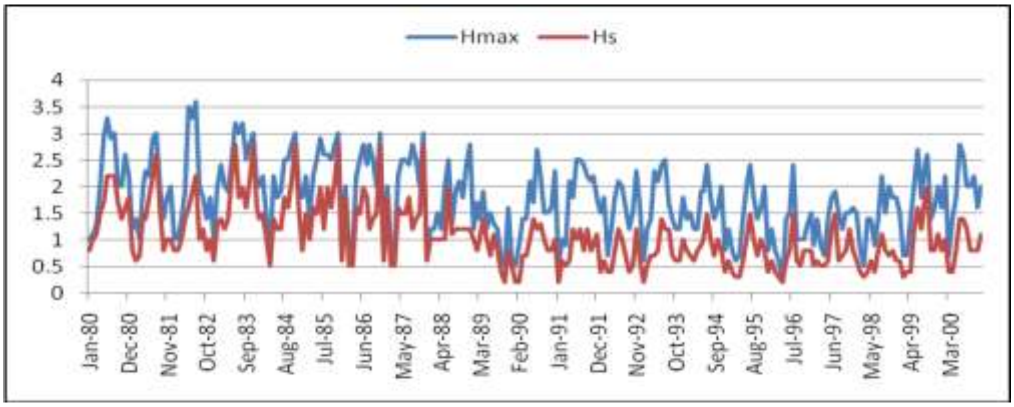


Figure 11: Hmax & Hs Observed at Outer channel location

Table 1: Principal component coefficients – PCA for On-shore Disposal period (1980-2002)

HW_Total Year			HW_SW monsoon			HW_NE monsoon			HW_Non monsoon		
0.292003	-0.44332	-0.23319	0.22714	-0.63751	0.556169	0.321108	-0.40995	0.113299	0.31422	-0.4562	-0.27431
0.418322	-0.21238	0.022994	0.400288	-0.22717	-0.02924	0.417752	-0.09956	-0.13817	0.408894	-0.10845	-0.2473
0.407979	0.257172	-0.20341	0.416155	0.149951	-0.04803	0.410393	0.119729	0.236641	0.408631	-0.07621	0.353803
0.311069	0.373581	-0.49696	0.350526	0.299246	-0.20365	0.323038	0.097061	0.670113	0.29511	0.076119	0.772664
0.354072	-0.349	0.140425	0.35824	-0.24903	-0.48168	0.327517	-0.36364	-0.43205	0.379688	-0.14324	-0.17149
0.322725	0.097219	0.776685	0.307364	0.185675	-0.19001	0.314869	0.37111	-0.52328	0.31252	0.432241	-0.32134
0.12014	0.648726	0.176073	0.244858	0.571042	0.60026	0.122209	0.72674	-0.03315	0.161128	0.749031	-0.09291
0.482263	0.023684	-0.05284	0.457558	-0.08576	0.132714	0.477757	0.012919	0.037826	0.460661	-0.01089	-0.01036
LW_ Total Year			**LW_SW monsoon**			**LW_NE monsoon**			**LW_Non monsoon**		
-0.25186	-0.75566	0.150017	-0.22883	-0.73854	-0.39651	-0.2653	-0.67268	0.227016	-0.25028	-0.31723	0.752835
-0.38638	-0.21261	-0.11836	-0.36867	-0.26079	-0.03685	-0.40457	-0.21805	0.002616	-0.37903	-0.23272	-0.02132
-0.37492	-0.05875	-0.45102	-0.35161	-0.18677	0.549926	-0.39677	-0.15155	-0.31571	-0.37265	-0.38099	-0.18973
-0.35644	0.216875	-0.43895	-0.35492	0.132343	0.482038	-0.36059	0.088972	-0.51037	-0.37483	-0.26841	-0.30302
-0.34293	-0.00275	0.440093	-0.35923	0.220842	-0.27293	-0.30631	0.059046	0.637385	-0.33939	0.391772	0.238028
-0.30614	0.277479	0.610895	-0.31201	0.436177	-0.48038	-0.28224	0.489431	0.392524	-0.29332	0.625988	0.190096
-0.31958	0.502624	-0.02199	-0.35671	0.297232	0.011252	-0.31269	0.474932	-0.16673	-0.33556	0.287443	-0.4582
-0.4541	-0.06043	0.005703	-0.45661	-0.08236	-0.0355	-0.45523	-0.02198	-0.0129	-0.44778	-0.00635	0.047235
Slope_ Total Year			**Slope_SW monsoon**			**Slope_NE monsoon**			**Slope_Non monsoon**		
-0.32599	0.249826	-0.32394	-0.31084	-0.34447	0.674171	-0.33388	-0.17774	-0.57476	-0.33486	-0.04217	0.563377
-0.36644	0.179989	-0.25951	-0.36151	-0.11313	-0.16357	-0.39458	-0.24477	-0.04513	-0.38831	-0.16119	0.109245
-0.36987	0.385316	0.039824	-0.33433	-0.49076	0.003926	-0.38925	-0.22619	-0.21824	-0.37375	-0.33821	-0.03375
-0.36256	0.137989	-0.00937	-0.33585	-0.2546	-0.65041	-0.37017	0.0577	0.163039	-0.37863	-0.2929	-0.04914
-0.32008	-0.46153	-0.37312	-0.35678	0.316075	-0.04043	-0.30752	0.4835	-0.13313	-0.28619	0.491246	0.367887
-0.27599	-0.72389	0.109755	-0.31752	0.61089	-0.04583	-0.24069	0.710231	0.198776	-0.22036	0.727033	-0.24224
-0.33073	0.025398	0.821305	-0.33832	0.298793	0.302862	-0.29658	-0.3402	0.731876	-0.34605	-0.01788	-0.68712
-0.45077	-0.00184	0.015245	-0.45337	-0.02267	-0.01498	-0.45146	0.008575	0.022924	-0.45147	0.042989	-0.03094

Table 2: Principal component coefficients -- PCA for Shore-face Disposal period (2003-2012)

HW_Total Year			HW_SW monsoon			HW_NE monsoon			HW_Non monsoon		
-0.17345	-0.09137	-0.64202	0.098485	-0.37291	0.723733	-0.1917	-0.38963	0.491547	0.175122	-0.39404	-0.30436
-0.16393	-0.54394	0.01059	0.447001	0.330411	0.095916	0.118592	-0.52537	0.088528	0.379742	0.390332	0.25299
-0.46617	-0.00161	-0.144	0.348128	0.035802	-0.04179	-0.35652	-0.26235	-0.12486	0.477487	-0.11255	-0.21644
-0.49015	0.162567	-0.10921	0.404393	-0.23483	-0.43969	-0.50802	0.05242	0.254421	0.439233	-0.18291	-0.22216
0.098956	-0.56319	-0.04088	0.032233	0.566983	-0.20794	0.44133	-0.40085	-0.11219	0.370603	0.411462	0.117652
-0.13871	-0.32032	0.653382	0.382457	0.156131	0.331884	-0.00192	-0.19585	-0.72179	0.035442	-0.04797	0.73796
-0.31439	0.451933	0.353225	0.129182	-0.58889	-0.34428	-0.46891	0.210598	-0.33736	-0.10676	-0.61038	0.354942
-0.598	-0.21287	0.041065	0.584606	-0.05197	0.004194	-0.38644	-0.50717	-0.15114	0.504191	-0.31951	0.250493
LW_ Total Year			**LW_SW monsoon**			**LW_NE monsoon**			**LW_Non monsoon**		
-0.26835	-0.29766	-0.02931	0.069309	-0.08612	0.94477	-0.38592	-0.27135	0.277024	0.300703	0.077845	-0.74775
-0.3871	-0.20907	-0.25628	-0.3749	0.336352	-0.10456	-0.38164	-0.34814	-0.15877	0.401303	0.274444	0.391707
-0.25331	0.353595	-0.52653	-0.38184	-0.07716	0.085409	-0.22455	-0.32073	0.590534	0.060774	-0.46188	-0.00286
-0.20727	0.62458	-0.17715	-0.46821	0.186188	0.047815	-0.0962	0.530497	0.524812	0.167199	-0.53108	-0.05987
-0.40832	-0.19097	0.116309	-0.38873	-0.19551	-0.13428	-0.36393	0.02919	-0.35227	0.354789	0.345908	-0.27651
-0.37504	-0.18085	0.449831	-0.08591	-0.62644	0.027463	-0.35745	0.130083	-0.3797	0.455879	0.038416	0.451574
0.015563	0.508223	0.628645	0.182909	-0.56452	-0.24028	-0.19494	0.620014	-0.03034	0.051662	-0.50716	0.029391
-0.60282	0.158408	0.117367	-0.5456	-0.29915	0.101856	-0.58952	0.136689	0.068581	0.616858	-0.2119	-0.05096
Slope_ Total Year			**Slope_SW monsoon**			**Slope_NE monsoon**			**Slope_Non monsoon**		
-0.25583	0.144616	0.511979	0.171156	-0.1796	-0.83571	0.33553	-0.44697	-0.01252	0.351875	0.218629	-0.3956
-0.37673	-0.18469	-0.11482	-0.35254	-0.33754	-0.32243	0.394688	-0.15434	0.023218	0.402112	0.03486	0.160388
-0.2883	-0.37557	0.505673	-0.40385	-0.12323	0.22902	0.180478	-0.60851	-0.17856	0.11223	-0.71008	-0.07613
-0.36977	-0.42711	-0.13428	-0.46565	-0.18917	0.042659	0.23394	0.158275	-0.74233	0.36437	-0.2426	-0.08834
-0.31226	-0.05844	-0.66906	-0.39087	0.159433	0.046452	0.262985	0.501228	-0.30369	0.360424	0.329025	-0.39783
-0.32787	0.499821	0.030283	-0.14327	0.619534	-0.30882	0.384392	0.122416	0.488163	0.30874	-0.01427	0.74974
-0.17341	0.60097	-0.0332	-0.01435	0.615344	-0.02057	0.330362	0.338666	0.292904	-0.13812	-0.49521	-0.28865
-0.58113	0.084231	0.035957	-0.54128	0.122292	-0.21308	0.564166	-0.01253	-0.00641	0.569934	0.18501	-0.02196

Table.3: Sum of the percentages explained considering first three components of PCA conducted for different data sets of On-shore Disposal Period & Shore-face Disposal Period

Data	On-shore Disposal Period				Shore-face Disposal Period			
	Total Year	SW Monsoon	NE Monsoon	Non Monsoon	Total Year	SW Monsoon	NE Monsoon	Non Monsoon
All Indices	69.44	69.87	71.01	73.11	50.81	54.80	56.90	57.97
HW	83.47	82.79	83.00	85.76	70.70	67.82	73.08	77.24
LW	83.25	81.30	83.22	86.03	64.75	65.28	70.51	69.29
Slope	80.12	80.50	81.90	83.61	66.48	69.05	73.69	67.68

Having observed the principal components for both on-shore and shore-face periods, one can interpret the first component (PC1) as the beach response to sand nourishment effect, second component (PC 2) as beach response to cross-currents (rip currents) and third component (PC3) as beach response to long-shore wave induced currents (littoral currents). i.e. PC1 represents nourishment effect, PC2 represents on/off shore transport and PC3 represents along-shore transport. This kind of physical interpretation of principal components is very useful to ascertain the prototype behaviour with better insights and also help to improve the performance of the system with appropriate measures.

4. 1 Observations from PCA pertaining to On-shore disposal period

For on-shore disposal period, stretch near HW at CS-11 & CS-12 is getting more benefited by nourished sediments, with positive coefficients of the order of 0.41 for PC-1, being near the disposal point or beach nourishment location. All cross sections are having positive coefficients for PC1 (HW data) indicating the distribution of nourished sediments from disposed location and coefficient value is getting reduced, when moving towards down-drift side i.e. towards cs-16, indicating the diminishing effect of nourished sand. During NE-monsoon, reversal of nourished sediments appears to have improved the conditions at CS-10. PC-1 coefficient for CS-10 is 0.32 in NE whereas the same is 0.22 in SW. It can be noticed from all coefficients that on-shore pipe-line nourishment affect is almost same in all seasons. Negative coefficients of PC2 indicate the negative contribution due to off-shore / rip currents. Coefficients of cs-10 and cs-11 are negative indicating the location of rip currents near catamaran rock bund. Rip currents are stronger in SW-monsoon compared to NE and Non-monsoon seasons. Negative value at cs-14 for PC-2 indicates another location of off-shore current. Since cs-14 is in the middle of crescent shaped bay, this would be the obvious location for off-shore current with approaching wave flux diverging on either side. Rip currents adjacent to breakwater/ rock-bund are stronger compared to off-shore currents near cs-14 during SW monsoon. However, both are almost same during NE monsoon. Effect of cross-shore dynamics is more positive in NE and Non monsoon seasons compared to SW-monsoon. In general, on-shore transport prevails during low to moderate wave flux. Critical observation of PC-3 coefficients indicates that this component can be interpreted as the effect of alongshore dynamics on the beach profiles. Positive coefficients of PC-3 for cs-10 and cs-16 during SW, indicate sheltering effect of breakwater system and effect of protruding head-land near Waltair point. Over-all effect of alongshore dynamics appears positive on the stretch because of the sheltering effect of outer-harbour breakwaters during SW. During NE-monsoon, though the wave intensity is less, stretch is relatively exposed and overall effect is slightly negative with negative coefficients at cs-11, cs-14, cs-15 and cs-16.

All PC1 coefficients for LW data, i.e., for all seasons, are negative indicating the insufficient quantum of nourishment. Negative effect is small at cs.10 i.e. near nourishment point with lesser magnitude of coefficient compared to other profiles. Alternate changes of signs (positive for two cross sections and negative for another two) indicate along shore current effect on beach index of LW. PC1 represents nourishment effect and its effect is less negative on the slope at CS15 compared to other sections in all seasons. Due to cross currents, slope at CS 15 is getting affected positively with higher positive coefficients of 0.6 to 0.7 in different seasons. Mean slope coefficients of PC1 reflect that nourishment is not sufficient to maintain healthy slopes. PC3 coefficient of slope for CS 10 is positive for SW and Non-monsoon seasons indicating the sheltering effect of breakwater system.

4.2. Observations from PCA pertaining to shore-face disposal period

Negative PC1 coefficients for HW during NE monsoon indicate that material is not reaching visible beach. Sand nourishment generally takes place in the months of March, April and gets distributed during SW Monsoon. If the quantum is not sufficient, return monsoon cannot rebuild the sections. Material disposed in the deeper contours may not reach the surf zone for proper distribution thus not serving the purpose of maintaining the stability of visible beach. Comparing the effects on all the indices (namely HW, LW and slope), shore-face disposal strategy is not appearing good for HW index i.e. for visible beach. Negative coefficients for PC1 are noticed for LW data during SW & NE monsoons except non-monsoon season during which nourishment takes place. In general, nourishment effect is positive immediately after disposal i.e. during non monsoon, and with its effect getting reduced during SW and with further reduction during NE on position of LW. Single cyclonic event like Hudhud can take away the shore-face material from lower stretches of cross-shore profile. PC1 coefficients indicate that slopes are good for NE and Non-monsoon seasons except during SW monsoon. For Inter-tidal slopes, things appear good for shore-face disposal strategy during NE and Non Monsoon seasons, with no significant overall effect during SW monsoon. Compared to on-shore strategy, negative effects appear mitigated for LW index and Slope in Shore-face disposal strategy.

Observations about the time history can be made from temporal trend of PCA scores. From PCA it has been found that beach status due to nourishment effect during on-shore disposal period is good compared to wave effects whether it is due to cross shore dynamics (On-off shore transport) or long shore dynamics (Littoral drift). Beach status due to all the above mentioned effects is not encouraging during shore-face disposal period. Nourishment effect is marginally positive for LW index because of the placement of nourished sand near LW line during shore face disposal. As the time passes on, the overall trend is negative due to shore-face disposal effect.

After detailed analysis of beach profiles, it has been recommended to use floating pipeline and with the installation of on-shore fixed pipelines for effective on-shore disposal in the long run. It is also recommended to increase the annual beach nourishment to provide buffers to take care of minor delays due to non availability of suitable dredger having shore pumping capability. Sand buffers can provide protection to the reach against wave action and also feed further northern reaches. The benefit of beach nourishment programme has been immense as no damage occurred to beach road almost for three decades providing beach for recreation to city dwellers and tourists. The successful functioning of existing layout would need to be ensured with efficient maintenance of sand trap and suitable adaptation of disposal strategy for beach nourishment

4.3 Reconstruction of indices

After arriving at principal components or empirical orthogonal functions, i.e. component coefficients and scores are saved, reconstruction of indices and computation of the residuals can be made. On the basis of first three salient components, ‘CS10 HW’ index is reconstructed and compared with original data alongwith residuals (figure.12) which indicates that PCA of ‘SW-monsoon data’ during ‘On-shore disposal period’ is providing good model with less residuals. Index of ‘CS16 LW’ is plotted in figure.13 which is reconstructed from PCA of ‘NE monsoon data’ during ‘shore-face disposal period’ as it provides reasonably good model since the beach is being nourished near LW.

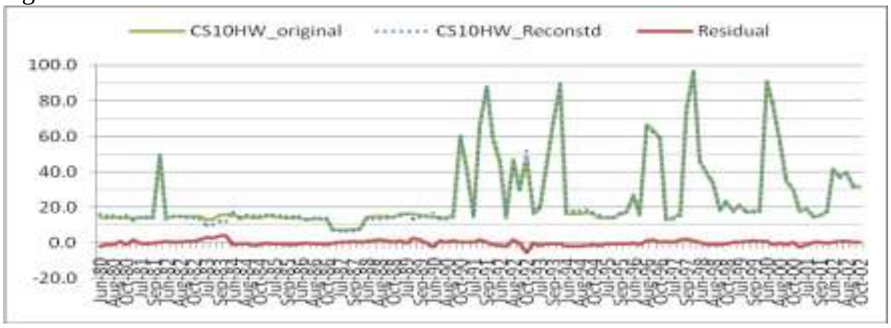


Figure 12: Comparison of Reconstructed and Original index- CS10 HW (obtained from PCA of SW-monsoon data during On-shore disposal)

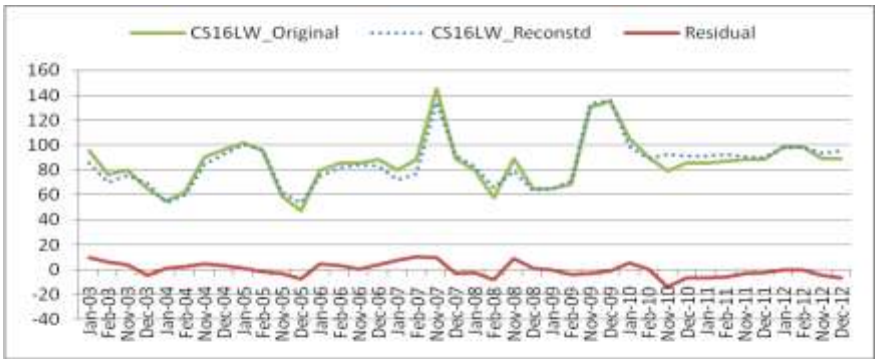


Figure 13: Comparison of Reconstructed and Original index- CS16 LW (obtained from PCA of NE-monsoon data during Shore-face disposal)

V. CONCLUSIONS

Application of ‘Principal Component Analysis’ for beach indices is found useful to capture the structural pattern from the huge data collected monthly for several years at seven profiles of the immediate northern coast.

Interpretation of salient components from PCA indicated that PC1 represents nourishment effect, PC2 represents on/off shore dynamics and PC3 represents along-shore dynamics. Physical interpretation of principal components is useful to ascertain the prototype behaviour and help to improve the implementing system.

From percentages of variance explained by first three components, it is found that PCA for index-wise data is better explaining which indicates that bifurcation of data for PCA provides better models.

Observations obtained from temporal trend of PCA scores indicated that beach status due to nourishment effect during on-shore disposal is good compared to wave effects due to cross shore / long shore dynamics.

PCA clearly indicated that on-shore disposal strategy is effective compared to shore-face disposal for beach nourishment.

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