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RESEARCH ARTICLE

DELINEATION OF FLUVIAL-AEOLIAN DUNES ALONG THE SMD AND CHILIKA COASTS OF ODISHA, INDIA.

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Abstract

Coastal sand dunes (CSD's) offer a valued ecosystem for the shoreline habitats, flora, fauna, avifauna and a natural shield between the waves and wind. CSD'S and its vegetation offer a tool for protecting coast line against Storms, coastal flooding, erosion and the carbon sink for future. Burgeoning population is encroaching and nature is destructing the sand dunes and its vegetation for their settlement, tourism and sand mining. After the great Sumatra tsunami – 2004 it is found that 138.74Km of coasts of the South Mahanadi Delta and the Chilika coasts has increased its coastal activities like erosion, accretion resulting continuous formation and collapse of sand dunes sporadically. The dune activities along coast of Chilika lagoon are natural and rest up to Konark is the combined effect of environment and anthropogenic activities. The coastal dunes were probably active in the past warm periods of high wind under high deltaic sedimentary budget during post Holocene epoch. The present study is the zonation and delineation of sand dunes along the prograding South Odisha coast. The study area has all the forms of coastal dune structures and are continuously forming along the coastal beach where as the back dunes encroached by the beach stake holders. However in the present warm period of Anthropocene epoch the dune activities have an increasing trend and there is a constant decrease of sand dune @ 2.24 Km²/year ..

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Introduction:-

Coastal sand Dunes (CSD's) are initiated under dynamic environment in shorefronts of the sea, lagoons, and lakes above the high water mark. Dunes are depositional landforms visible from the Antarctic to the equator in both arid and semi-arid regions. The sand dunes are formed in the shelter bed behind the coast line accumulating sand received from riverine source (terrestrial), marine waves or coral reefs. The CSD's reduces the impact of strong wave energy by absorbing storm surges and flood, the vegetation creates a carbon sink, protecting the flora, fauna, the avifauna and the coastal habitats. The sand dunes also maintain the beach for human for sports and recreation, wading and fishing. The influencing factors for formation are the shape of the coastline, form of the beach, currents and swell of the ocean, prevailing wind, quantity sedimentary budget, grain size and frequency of storm events.

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India has 7500km of coast line. Out of which 480km (**Fig 1**) lie along the coast of Odisha which is regularly slammed by storms and affected by storm surges. The south Mahanadi delta (SMD) and the Chilika have shore line of 138.74Km from end of the south Chilika coast to Kushabhadra river mouth. The coast line was protected by bio-shields in past but at present the shelter belts and the dunes are deforested or encroached for human use. The area of sand dunes and sandy beach coverage between Puri and Konark is around 296.33Km² whereas the sand dune area along the Chilika coast is varying constantly **Fig 2**.

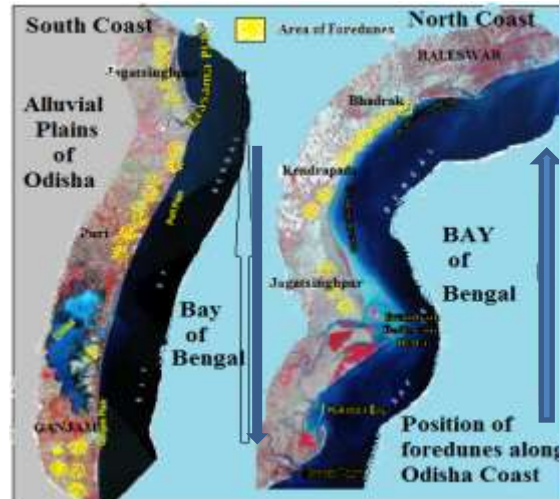


Fig 1:- The coastal Buffer zone of Odisha

Millenium CSD's impacts on Odisha coast

The submergence of 320sqkm of 42 coastal villages (Satabhaiya) in the Bay of Bengal from 1930 at the confluence point of the rivulet Panki branch of the river Mahanadi is as per Revenue records. Around 4300 Ac. of area have been plunged in sea in last 40years and set back coast by 2.5 Km and 2500 acres are vulnerable to greenery due to sand accretion and dune formation along Odisha coast (Sahoo S. K., 2012)^[1]. The lateral channel formation at the mouths of the river Kushabhadra and the cuts Gabakund and Mangala are eroding the coast to north at the cost of dune area. The Mangala and the Gabakund cut have destroyed the golden beach of Puri. The Kushabhadra river mouth is destroying the panoramic view of the Konark beach and had ruined the dense dune vegetation for about 8.5 Km (Mishra et al., 2016)^[2].

The vulnerability of the tidal inlets in the spits and transgression of sand dunes to west in the outer channel along the northern coast have made vulnerable to about 22 villages in the west bank of Chilika after Sumatra Tsunami-2004. The rise in MSL due to global warming has also added to coastal susceptibility of the beach loss and dune destruction along Odisha coast.

2.0 Review of Literature:-

Sand supply, Aeolian strength and the vegetation intensity of the onshore are the crucial aspects for dune formation (Hack 1941)^[3]. The present delta of the river Mahanadi have been claimed to be formed after mid Holocene period (10,800±155 years B.P) after refurbishment of mean sea level which was 7 to 8 m than the present coast line (Naidu., 1968)^[4]. (Lancaster N., 1988)^[5] Remobilization of existing sand occur in linear dunes (Tosar H., 1978)^[6] reported that the permeability of sand of dune is 2500 times that of clay. (Sahu et al., 2012)^[7] reported that the high waves along the coast are shattering the coast line and changes the shore front by large insurgence and fluctuate the shore mark. Studies reveal that the Chilika was a gulf to Bay of Bengal and the coast line during Pleistocene and Holocene era was at head of the delta i.e at Naraj, shodhganga.inflibnet. ac.in/ jspui/ bitstream /10603 /165773 /8/08_chapter % 202. pdf. There is a NE-SW trend along the Konark Coast to Devi river mouth which controls the coast line and the beach of the Puri district (Vinod K. Ku. 2003)^[8]. The present delta of the river Mahanadi have been claimed to be formed after mid Holocene period (10,800±155 years B.P) after refurbishment of mean sea level which was 7 to 8 m than the present coast line (Naidu 1968)^[4] and the rate of progradation is 9.1Km/000'years (Somanna et al 2016)^[9]. The beach dunes of about 15 to 20m high and 2 to 5m wide are developed along the Chilika – Konark coast. They are mostly Aeolian origin covering tidal flats or swamps. Latter Parabolic dunes form over those incipient dunes (Mahalick et al 1996)^[10]. (Murty et al., 2007)^[11] rported south Odisha coast represents dune

type environment for inner self <15m and beyond 15m its beach type distribution which is due to Holocene transgression of sea during emergence of inner self. Studies based on the analysis of long-term tide-gauge data from various stations along the Indian coastal regions, corrections for vertical land movements included, indicated that sea levels are rising at a rate of about 1.0–1.75 mm per year due to global warming (Theiler et al., 1999)^[12], (Unikrishnan et al 2006)^[13], (Unikrishnan et al ,2007)^[14]. Dune vegetation plays a substantial role in maintaining the coastal sustainability. Their conservation can save the dunes from destruction (Ramesh et al 2007)^[15]. (Sharma V. S. et al., 2008)^[16] have mentioned that the sand dune area in Puri beach was 10.53sqkm in 1999 and it has increased to 13.83 in 2005. Chilika coast faces high velocity in summer (S to SW) and low in winter (N to NE). Average wind speed range during 2007-08 it was 2.3-86.1 km/hr at Satpada and 0.6 to 49.04 km/hr at south west coast (Ritesh Ku. et al 2012)^[17] whereas previous assessment in 1983-89 was 0.18-57.43 km/hr (Nayak et al., 2008)^[18]. The NIO, Goa had reported that the sea at Puri has receded for a length of 45 to 65 m along the coast of Puri city from year 1889 to 1974 and have made the beach wider http://shodh.ganga.inflibnet.ac.in/bitstream/10603/119542/10/10_chapter

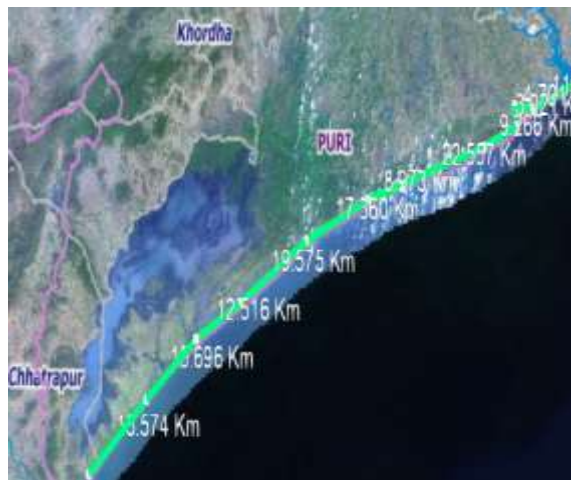


Fig 2:- The geomorphology of study area

2.1 Reasons for study:-

The morphologic, physiologic, sand dunes act as buffer to eustatic environment and protect the coastline. These sand dunes and spits are affected by the substrate mobility, geologic, meteorological extremes, salinity, sand mining, urbanization, anthropogenic activities, sea level rise and climate change. Sand dunes with or without vegetation, the Aeolian landforms, the Barrier islands, the linear sandy ridges, the fluvial sandy mini-islands are the protector of the marine coastal system. Since the east coast is prograding in nature, attempt has been made in this paper to have a geomorphologic study of the construction, sustenance and destruction of sand dunes along 138km coastal tract of south Mahanadi delta. The present study describes the causes and different stages of formation and erosion of sand dunes and their zoning along SMD and Chilika coast (**Fig 2**).

3.0 Coastal dunes in history:-

During transit from Pleistocene to Holocene era short-lived Aeolian existed for a short period along SE Norway coast after deglaciation. Chilika coast and spit activities is hardly 4000 years old in mid-Holocene era. Spit /sand dune events have ceased the heritage naval activities of Odisha. Old dunes on the outskirts of Puri was have been lost in last 50years by the side of Puri to Satapada road no longer exists today being adorned by activities of. Anthropocene epoch.

The old monuments constructed last 1500 to 1000 YBP on the dunes as in Odisha History are Konark Temple (1236 to 1264 AD), Ramachandi Temple, Beleswar Siva Temple , Jagannath Temple (1135-1198 AD), Lokanath Temple, Harachandi Temple were constructed on high coastal dunes adjacent to the Puri beach. Jagannath temple was initially constructed during Mahabharat era (4000 to 4500 YBP) as Adi Sankaracharya included Puri as one of the Chatrudham in 9th century AD. The dune activities destroyed the old temples twice once new temples were constructed in 1000 AD (by Jajati Keshari) and then the present temple in 12th century AD (year 1135 to 1198) (PKDA report 2013)^[19]. These existing temples indicate the loss of sand dune activities at present and the beach is

retreating. Present coast line have been shifted in the area 3-5km from those coasts claiming the Odisha coast is prograding in nature.

3.1 Geomorphology of Odisha coast:

The coast line of Odisha is 480 Km and width 150m to 15km covering an area of 5033 Km². The coastal dune covers 64.7 km² out of the total coastal land. The dunes formed in and around the Chilika coast have heights 5m-25m whereas the dunes formed in Puri coast is 5 to 15m (Sharma et. al., 2008)^[16]. The 5033.6 Km² beach area has coastal features like Mud flats. Tidal flats (286 Km²), Sandy beach 120.3 Km², Paleo mud flats 2405.2 Km², Island/bars and ridges (332.6 km²), mangroves/ vegetation 336.2 Km², The Chilika lagoon area has water spread area of 790 km² (1145 Km² in 1846), paleo beach ridges of 332.6 km² and other features are of 118.8 km². The coastal features plays important role in formation of dunes. The estuaries, mud flats and the erosion zone have the process of destruction of the CSD's whereas the accretion zone is favorable for formation of fore dunes along the coast (Table 1).

Table 1:- Landform assembly of dunes along SMD and the Chilika area (Ramesh et al 2011)^[20]

Name of the coast	Estuaries of Major rivers	Southern Coast	Northern coast	Sanddune area		Source
				1990/99	2005	
				Km ²	Km ²	
South Odisha	Bahuda	Stable	Accretion (L)	11.41	8.27	(NCSCM) Society of Integrated Coastl Mngt. SICOM (MoEF),GOI. http://ncscm.res.in/cms/geo/pdf/research/orissa_final.pdf
Ganjam (1990)	Rushikulya	Accret ⁿ (M)	Erosion (L)	5.32	3.9	
SMD coast Puri (1999)	Daya/Bhargovi (Chilika TI)	Accret ⁿ (L)	Erosion (L)	1.81	2.68	
Puri (1999)	Bhargovi(G. cut)	Accret ⁿ (M)	Accretion (M)	0.84	0.99	
Puri(1999)	Kushabhadra	Erosion (L)	Erosion (L)			

3.2 Climate of SMD and Chilika coast

The study area lies in the tropical humid region of Indian peninsula lying towards south of tropic of cancer with maximum temperature of 35 -45⁰C and average annual rainfall of 1300 to 1400mm. 75 to 80% rainfall occurs during south west monsoon (JASO months). Construction and destruction of sand dunes occur mostly during gusty strong winds and particularly during Bay of Bengal (BoB) storms. The study of BoB storms from 1901 to 2000, the recurrence interval of the cyclonic storms (CS of wind speed 62-88Kmph), Severe Cyclonic storms (SCS of wind speed 89-117Kmph) and Very Severe Cyclonic Storms (VSCS of wind speed 118-220Kmph) and Supper Cyclones (SC of wind speed >220Kmph) slamming Odisha coast and other coasts of east coast (E.C.) of India is given below (Mishra et al 2014)^[21]. (Sahoo et al 2017)^[11], have reported that the ferocity of BoB storms land falling Odisha coast exhibits increase trend (Table -2).

Table 2:- Recurrence interval (RI) for slamming of BoB storms in various regions of E.C., India

East coast (India)	BoB Storms (RI)		Coasts of Odisha (old)	BoB Storms (RI)		Study area (New)	BoB Storms (No)	
	(1901-2000)			(1901-2000)			(1901-2016)	
	CS/SCS	VSCS/SC		CS/SCS	VSCS/SC		CS/SCS	VSCS/SC
W.B. Coast	4.8	4.8	Baleshwar	4	13	Ganjam	5	5
Odisha Coast	1.8	4.3	Cuttack	6	25	Chilika	6	1
Andhra coast	3.1	4.0	Puri	8	20	Puri	4	3
T. N. Coast	5.9	4.0	Ganjam	13	9			

3.3 Meteorological parameters:-

The surface temperature is vital for dune formation to dry the sand. The rainfall erodes or washes out the dunes. The maximum temperature and rainfall data of Puri and Gopalpur (IMD observatories) are available. Gopalpur and Puri recorded maximum temp. 44⁰C and 44.2⁰ C on 12th June 1966 and 12th may 1965 respectively. Present average of maximum temp. has come down to 37⁰ C for the last 25years. The maximum daily rain fall recorded at Gopalpur and Puri were 311.8Cm (1989) and 362.Cm (2001). Heavy rainfall and settlement expansion have caused the back dune environment to collapse. Hard hot summer, storms,, tsunamis, continuous strong unidirectional winds have

accelerated formation of CSD's. Persistent climate change Odisha coast and affecting coastal morphology (**Fig 3**) [https://www. Geospatial world.net/blogs/weather- Forecasting -windy-interactive-map](https://www.Geospatialworld.net/blogs/weather-Forecasting-windy-interactive-map)

3.4 Factors influencing dune formation:

The protection, conservation and management of these sandy structures are essential to protect both the sea and lagoon coast. The barriers spits are lined up parallel to the outer channel are of 150m to 1500m width and 08 to 10m above the MSL in altitude. Sand dunes are covered with mangroves and marine flora. The increased rates of permeability wash away all nutrients and leaching action does not allow any other plant to grow except few orchids and plants.

3.5 Various works on dune activities:

From the studies made by various researches (Table 3), it can be inferred that the sand characteristics, grain size, sediment transport budget, meteorological extremes, wind direction and velocity, vegetative cover and coastal physiognomies are responsible for dune and beach migration. The additional parameters can be the human activities along the coast such as coastal protection works, coast used for settlement, urbanization, recreation and coastal afforestation. The change in geomorphology along the Chilika coast in last 1000 years BP has remarkable impact along the coast. Very less research has been taken up on the morphology of the Puri Konark coast except few on mineralogy and phytology of the area. The effect of anthropogenic activities needs to be added to research. Dunes occur in deserts and also along the coast lines. Their formation and growth methodology are different. The various equations pertaining to dune parameters are given in **Table 3**:

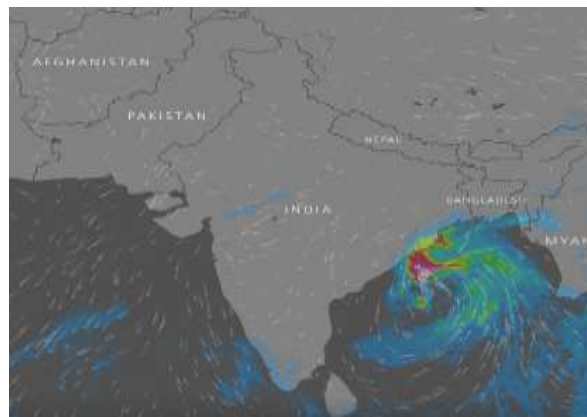


Fig 3: Abnormal climate 8.12,2017, GFS cyclonic weather the study area

Table 3:- Various equations related to dune activities in different coasts formulated by various Researchers

#	Condition along coast	Equation	Denotations	Reference/Remarks
1	Dune density (η)	<i>As per area</i> $\eta = A' / A$ <i>As per number</i> $\eta = N / A$	H =dune density, A' area of dune A =Total area N = No of funes	(Liu Baoli 2014) ^[22]
2	Dune migration rate (r_d)	$r_d = R_d / \gamma_h$ Where $= \text{for sand in average dunes } 1600 - 1750 \text{ Kg/m}^3$ Puri coast	R_d = sand transport rate ($\text{kg/m}^2\text{S}$) γ =bulk density of sand (kg/m^3) and h height of dune (m)	(Bagnold, R. A. , 1941) ^[23]
3	M Index= dune Sand mobility eqn. (Austalia)	$M = 0.21 (0.13 W + \log^{PET}/P)$	P= Av. Rainfall/yr, W= Av. Wind vel./year PET = annual pot. evaporation	(Wasson R. J., 1984) ^[24]
4	M Index= dune Sand mobility eqn.(simplified)	$M_i = W / [P/PET]$ $M_i=200$ (Fully active dunes) $M_i=50$ (Vegetative cover)	P= Av. Rainfall/yr, W= Av. Wind vel./year PET = annual pot. Evaporation, (Wind vector not taken)	(Lancaster N. 1993) ^[25]

5	Drift potential (DP) of the wind	$DP = [U^2(U - U_t)t]/100$ U is taken at 10m,	U= Wind vel at 10m ht. U _t = Threshold wind vel. 12 Knots	(Tsoar H 2004) ^[26]
6	M Index= dune Sand mobility eqn	$M_i = \frac{DP}{1000 - 750 \frac{RDP}{DP}}$ M> 1(dunes mobile/vegetative cover and stabilized)	Resultant drift potential (RDP). RDP/DP ≈ 1 Narrow unidirectional drift potential	

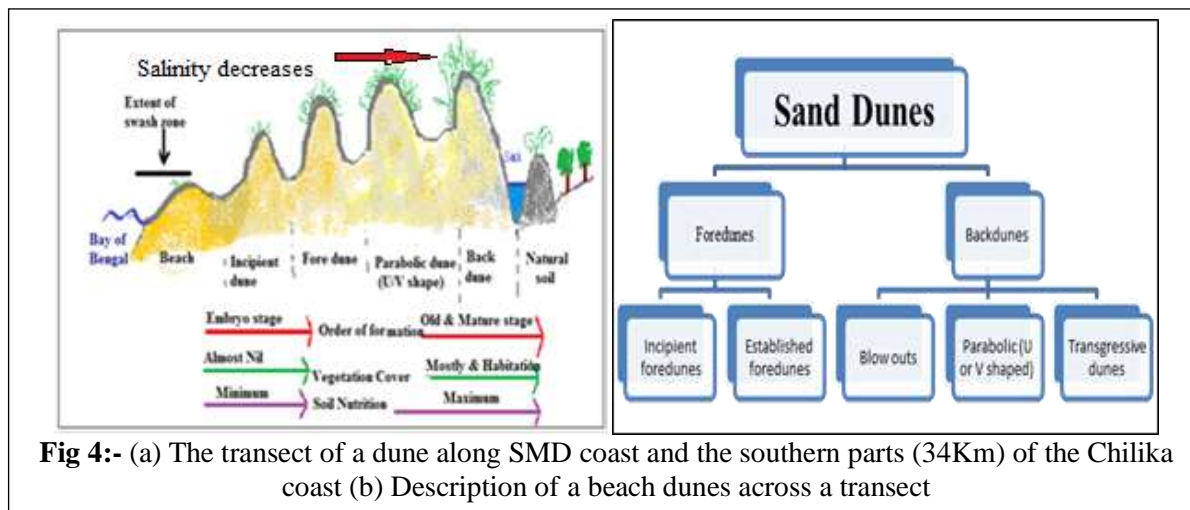
4.0 Formation of Sand Dunes:-

The Psammosere (salt tolerant species) of marine environment can develop the CSD's along a coast line and help in formation of sand dunes. They are in an ecological succession along the sand dunes (**Fig 4 a**). The pH value of the sand and soil decreases towards inland which is conducive for the seral community growth. CSD's transform along a coast line on availability of ample sand, continuous strong wind, solid embryo as nucleus, a large free area and a large difference between high and low tides for more sand exposure. The wind forces for erosion and accretion of sand, waves and tidal forces over the swash zone and state of surf zone of the beach (eroding, accretion and stable) and the extent of human interference and use also influence the dune formation. These plantations on sand dunes can sustain spray of saltwater droplets, high wind, hot radiation during day time and spreading root structure. The steps of mechanism of formation (Saltation or Cut and fall cycle) of sand dunes and the various stages (**Fig 4.b**) of formation are as follows:

- Remobilization of standing sand as linear dunes and inter-dune areas depending on with an embryo, sand size and wind velocity
- Extension of linear dunes to lunette dunes then fore dunes develop grass
- Growth of the fore dunes capturing Aeolian sand develop bushes and creepers
- Migrate away from the beach and develop dune vegetation
- The shape changes depending upon sand input.
- The transformation to parabolic, parallel, transgress dunes and vegetative cover.

4.1 The embryo (Incipient) dunes:

The embryo (or incipient) dunes are the initial stage of a sand dune succession. The embryos of the dunes may be any solid mass which act as a barrier to capture sands blown by wind and accumulate in and around it. They form in the shadow of obstacles at the strandline.



The embryo dunes are the harsh plants that have special adaptations to marine colonization or any obstacles in the beach. The pH of the sand is high (~8–8.5) as a huge amount of marine shells are deposited in the beach as embryo dunes at the nucleus. These cells (CaCO_3) is alkaline raises the pH of sand. These salt tolerant species (halophytic) have long roots which help the embryo dune to stabilize for a period.

4.2 Fore dunes:-

The incipient dune can trap sand in their stems and stabilize it. The embryo dune grows till a new embryo dune starts to form in the vicinity converting the old incipient dune as a fore dune. These dunes are mobile dunes as composed of mainly sand (called yellow dunes also). The species that existed in the incipient dunes have adapted to the soil and sand. The vegetation has depleted the pH of soil to (pH ~7.5–8). New genera of fore dune species like prickly salt worth, marram grass grows. These long root halophytic plants can reach the ground water table (GWT) and grows larger than the embryo dune plants.

4.3 Grey Dunes or Parabolic dunes

The dry leaves form an organic layer on soil (slightly acidic) and reduce the pH to (~6–7) of the soil at the back of fore dunes. New species of coastal shrubs/plants can grow along the grey dunes. The organic content impart grey colour so called as **grey dunes**. The fore dune migrated away from shore line is converted to **fixed grey dunes or back dunes**. *Casuarina equisetifolia* (Casurina), *Pandanus fascicularis* (Kia) a *Tamarix ericoides* (Jhaun) are the common plantation along the dunes can protect them (Selvam et al, 2005)^[27].

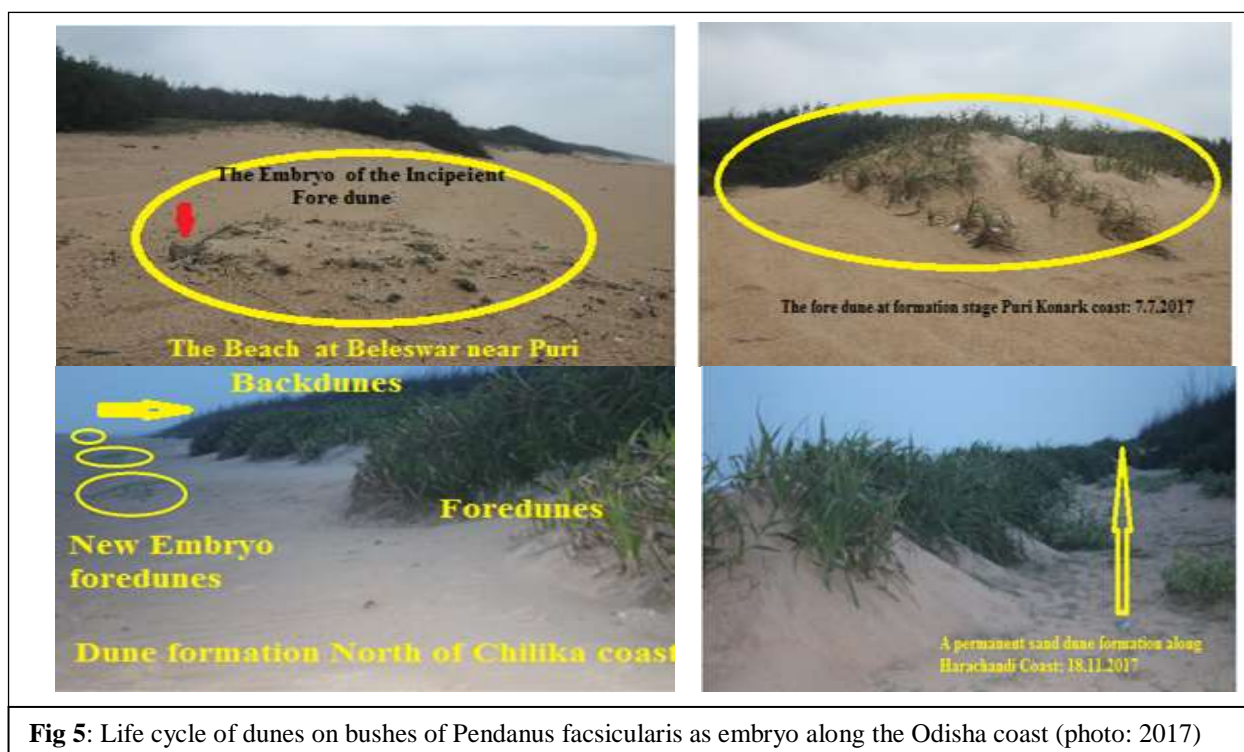


Fig 5: Life cycle of dunes on bushes of *Pandanus fascicularis* as embryo along the Odisha coast (photo: 2017)

The lower part on lee side of the ridge is called dune slack which may be deep or shallow. The deep dune slacks may be below the GWT and have water channels. The fore dunes gradually make the process to grow large to form a dune ridge and goes back when new fore dunes are formed. These huge fore dunes obstruct any further deposition by blocking the wind (**Fig -5**).

Dune slacks:

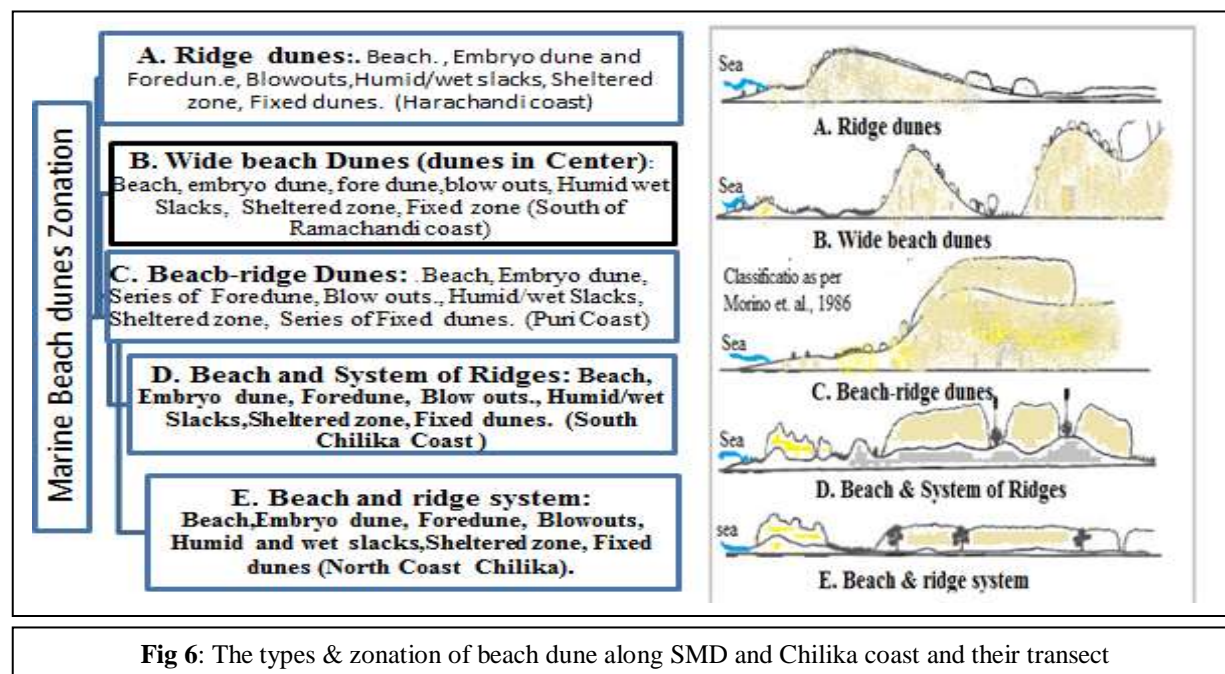
Since there's little erosion taking place behind the dune ridge, the water table generally isn't exposed in the dune slack. These dune roots are not melded to have stability. Beyond the dune slack, the fresh water brings new types of vegetation and they can grow where the pH is low enough like alluvial soil.

4.4 Dune zonation:

Liu 2014 classified dunes as barchans, Transverse and perpendicular. depending upon the sand drive, salinity and positioning GWT across transect of the coast dunes succession it can be divided into six types (Judd et al., 1977)^[28]; (Doing H. 1981)^[29], (Mareno et al., 1986)^[30]. Field visits are made to assess the coast line and dune status of the study area and Zoning of dunes along the study area are classified as in Fig 6:

4.5 Sand slope/grain size in dunes:

Different types of sand have diameters such as Very fine sand (0.0625 to 0.125 mm), fine sand (0.125 to 0.25 mm), medium sand (0.25 to 0.5) mm, coarse sand (0.5 to 1.0 mm) and very coarse sand (2mm to 64mm) respectively. <https://sciencing.com/different-types-sand-4586437.html> Beach dunes are an accumulation of coastal sand particles (2-3mm), deposited in a river or marine system (Manguet M. 1984)[31] . Dunes can be simple and or complex. Depending upon the types of dune in succession, the dune's transect differs less. However CSD's can be of five types. But shape of each dune differs from other. However the wind ward slope of the dunes are gentle and of about 150 to 200 and never exceeds the angle of repose of sand <http://blog.nialbarker.com/898/relationships-and-the-natural-angle-of-repose-of-beach-sand>. The leeside of the back dune, the slope is steep. In moist environment or high vegetative zone the dune can take the parabolic shape U or V shaped (**Fig -6**).



4.5 Dune Migration

CSD's are the mounds that self-adjust depending upon the angle of repose and the sand that slides down along the steep slope. The drive of the sands in the dune occurs either by saltation (by bouncing 95%), creeping (collision and impact 4%) or suspension (very fine particles 1%) <http://science.howstuffworks.com/environmental/earth/geology/sand-dune>.

The mound extends to a direction northerly or north easterly (migrates) depending upon the velocity of wind (v), rotation of the earth and the Coriolis force (F) given by ($F = \tau v \sin \phi$) where τ is the coriolis force and ϕ is angle with which the sands strike the sand dunes (Mishra S. P. 2016) . The sand maintains the slope till the angle of repose is attained then avalanche or sand falls and carried by the wind again.

4.6 Dune destruction

Sand and soil in sand dunes of Chilika and Puri coast have pH values (8 and 7 to 7.5), carbon content (loss on ignition 0.175 to 0.180) and moisture content (0.003 to 0.385) respectively (Page 206, Ch -10 of thesis shodhganga.inflibnet.ac.in/bitstream/10603/18140/10/10). Further the Aeolian process helps to develop dunes along the coast. Further the grade of sand along the Odisha coast is 0.9 to 2.84 ϕ and at the back shore it is coarse but gradually it become finer towards offshore (Ramesh et al., 2011). In summer the size reduces (FMJ) months but in rainy season (JAS) it is large comparatively.

The coastal waves of high amplitude are formed along Puri and Chilika coast from Sumatra Tsunami-2004. (Sahu S.K., 2012)^[7] observed that anticlockwise circular pattern geostrophic current are observed along near shore of Chilika and Puri coast during Sept to Nov of the year. This circular patten creates very strong eddies in the waves

and causing increased from 2004 the numbers of drowning deaths along Puri and Konark coast. These eddies are scour huge sand drive in toe the sea eroding the beach and the adjacent sand dunes. After subsidence of the turbulent action the sand is again carried back to the coast in a resultant direction of wind. Coriolis force and waves, deposit them in the southward and extend the beach (**Fig -7**).

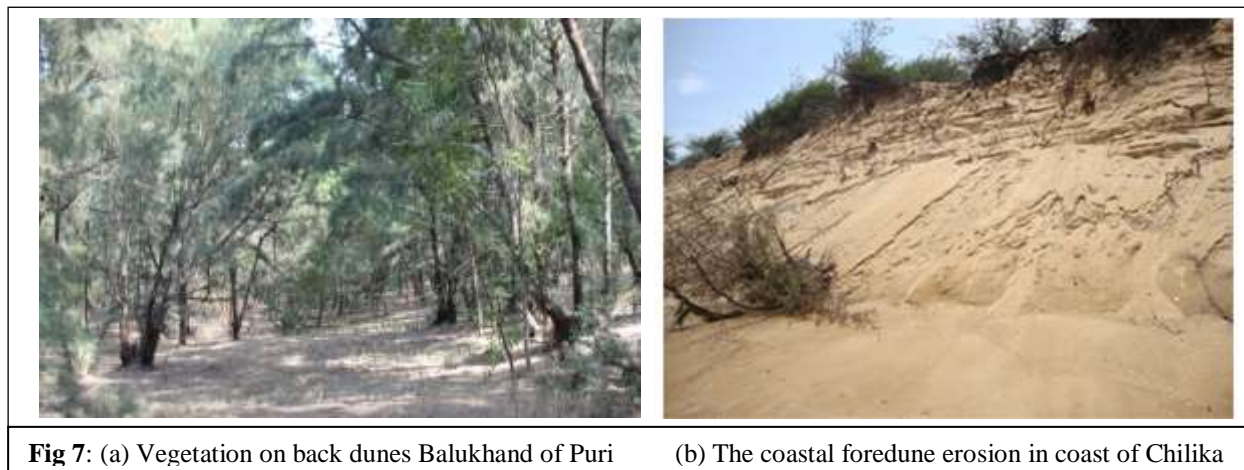


Fig 7: (a) Vegetation on back dunes Balukhand of Puri (b) The coastal foredune erosion in coast of Chilika

5.0 Geological formation of the coast

CSD activities have commenced with delta formation. In warm periods the activity have accelerated due to warm climate, high wind (more storms), under high deltaic sedimentation. The formation of coastal sand dunes is the sign of a prograded coast line. Last 500-1000 years back the northern hemisphere had experienced the Mediaval warm period, the coast have accelerated its dune activities and made the coast prograding. The present study area lies under such progradation @9.1Km/1000years and an amphitheater for dune activities.

Chilika area is contemporary to Eastern Ghats Hills. The off shore region joins the 85° L ridge The Delta development Plan of W. R. Deptt. Odisha, 1986, informs the EGB hills were formed during Gneisses Amphibolites Archean era, 2000 - 3200 m. years. The south Mahanadi delta is of Early Miocene to Quaternary period i.e 23.7 to 1.6 million YBP. The deltaic construction of SMD seems to have started in the Late Holocene (6000 yrs. to 800 yrs. B.P. (Mohanti, 1993) and the present shore line is prograding seawards @9.1Km/1000 years. The dune activities along Puri Coast had accelerated during Holocen climate optimum **Fig 8**

Fig 8: Holocene temperatures distribution in the northern hemisphere favorable for dune formation Source modified: David Archibald <http://climate.geologist-1011.net/>.

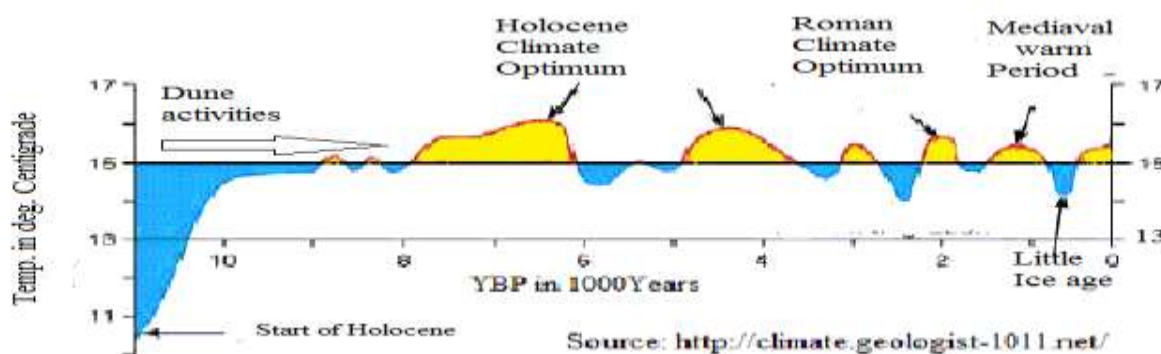


Fig 8: Holocene temp. distribution in the northern hemisphere Source: D. Archibald <http://climate.geologist-1011.net/>

Shoreline has further shifted seaward during the last 800 years. The geological age, the Land form, sand beaches, the associated natural processes of the coastal area is given in **Table 3**

Table 3:- The sand dune activities, features and formation age along Puri and Chilika coast

#	Places	Minor features	Age(YBP)	Sand dune activities	Reference
1	SMD				
I	Motto to Hara chandi temple	Beach ridges, Meandering dune, Paleo channels	538± 05	Beach ridge dunes, , dune vegetation, dunes reducing, human action	(Sharma and Ramesh 2012) ^[16]
II	Harachandi temple to Puri	Beach ridges Beach ridge dunes and Paleochannel	8200± 150	Medium to fine sand, 0.25% gradient to north, 445m below garnetiferous Schist	http://environmentclearance.nic.in/writereaddata/FormB/EC/Additional_Report/29122016
II I	Puri beach (63.57 Km ²)	Long coast urban area	10,000	Sandy beach, sand stone at 600m, destructive as dune	http://shodhganga.inflibnet.ac.in/bitstream/10603/18140/
I V	Puri to Balighai	Balukhand (8Km)	10,000 years	Casurina, bushes, beach evolution	(Delta dev. Plan, Irrgn. dept. Odisha, 1986) ^[33]
V	Balighai-Konark	Ramachandi coast	2300± 750	Beach armoring sand mining , beach retreat Kushabhadra R.	http://shodhganga.inflibnet.ac.in/bitstream/10603/119542
2	Chilika				
i	Chilika lake	Lagoon, coast length 64.3Km	3750± 200	South 34Km Sand dune formation and north 30Km dune obliteration	(Arya R. et al., 2006) ^[34]
ii	Outer Channel (barrier spit)	TI activities/ Isle formation (fluvial Dunes system) (30Km)	300 – 40 Coast	Spit back dunes, TI move North, dunes eroded with coast. Dunes outer channel	Murray and Mohanty taken from (CDA report 2009) ^[35]
iii	North Sector Chilika coast	Mostly dune activities	1850-1300	Formation of sand dunes , Increased settlement decreasing dune density	(Naik P.K et al 2008) ^[18]
iv	Central sector Chilika coast	Dune migrating pH is high ranging 8.0 to even 9.5	1850- 300 16.2 Km	Transverse stable dunes with clear triple pts., early formation	(Naik P. K. et al 2014) ^[36]
v	SS & Chilika coast	Stable old dunes (34Km)	1850-2200 (17.8Km)	Back dunes, back ridge dunes & beach ridge system dunes	(Ritesh Ku. et al 2012) ^[17]

5.2 Sand source for dunes:

The Chilika and the South Mahanadi delta has long beaches of length 120Km out of which around 35Km of coast is spread with huge sand dunes. The major portion of the beach area is under erosion. Huge quantity of sand is carried into the BoB annually along with 75 to 150 Th tons/year reaches river mouth with flood (**Ramesh et al 2011**)^[20]. (V **Sanil Kumar et al 2006**)^[37] have reported that the Puri coast have a northerly long shore drift of net 735436 MT/year The huge long shore sediment reach the coast and get deposited in the Puri and Chilika coast. Huge quantity of sand blown away onshore by the strong wind during storm and helps the dune development (**Fig 9**).

Sand supply from vicinity observed low in a narrow erosional coast of low wind velocity with landward dipping and degenerating vegetation. The sand supply is medium, in a mixed stable coast with balanced sedimentary budget, variable wind with constant marine dune vegetation and the front of the dune is sea ward dipping. A fore dune is having constant unidirectional strong wind, with huge sand supply in a wide accretion coast possess successional transgressed vegetation and there formation of back dunes.

5.3 Soil characteristics of dunes area:

The Coastal reach is the recent alluvium formation with sands extending average 5Km inland. Back dunes even extend 10 to 15 Km inland and join the recent alluvium. The longitudinal (Transverse) sand dunes are special character of the sand dunes as high wind blows mostly from southerly direction. The soil of the Aeolian sand are in the form of longitudinal sand dunes developed under SW winds. The sand dunes are associated with beach ridges and runnels under *Casuarina* (Cashew nuts), *Pandanus fascicularis* (Kia) and *Tamarix Ericoides* (Jhaun) and many others up to the deltaic alluvium. The width of the beach was from 150m to 15Km. The transect across a beach dune in succession have decreasing pH, salinity, vegetative cover and soil nutrition. The pH across a sand dune decrease from coast to inland. Along SMD the pH of soil is near shore (8.0 to 8.5), fore dunes and blowouts (7.0 to 8.0) and in back dunes and sheltered zone (6.5 to 7.0). The land profile of the dunes across the coast line is in Fig- 4.

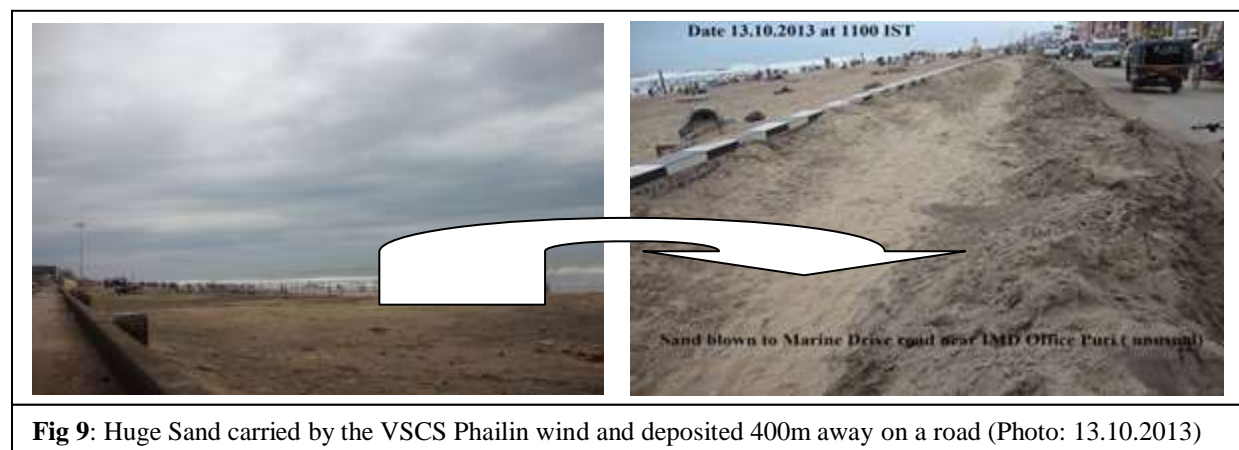


Fig 9: Huge Sand carried by the VSCS Phailin wind and deposited 400m away on a road (Photo: 13.10.2013)

5.4 Dune Landform assemblage of SMD and Chilika coast

The coastal front of Chilika and the south Mahanadi delta is 138.739Km long out of which Chilika coast is 61.361Km and SMD coast is 77.378Km (**Fig: 3**). The land form assemblage in the coastal area of Chilika and South Mahanadi delta is given in **Table 4**

Table 4:- The land use and land cover over beach and back dunes SMD and Chilika Coast

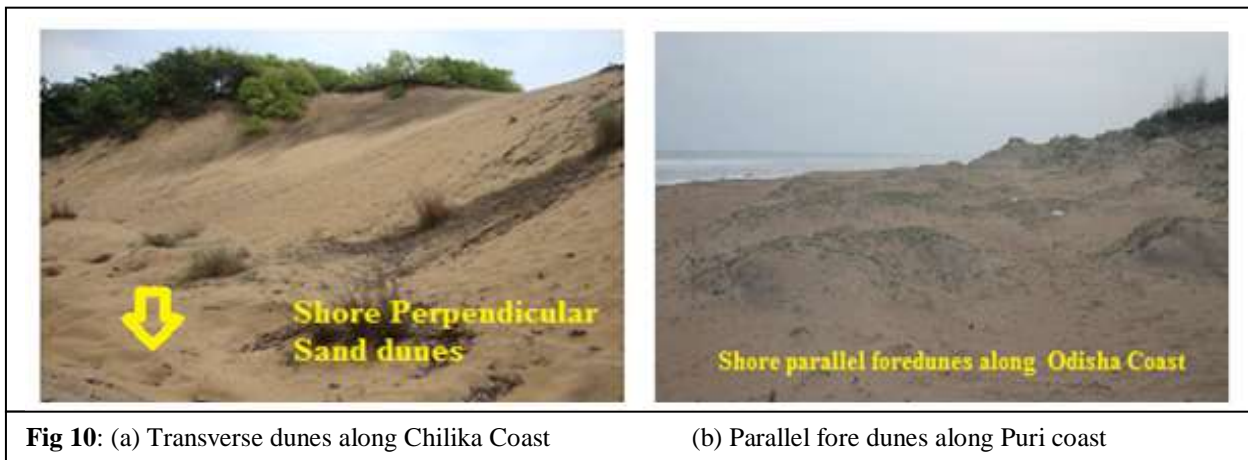
#	land use category	1972	1975	1990	1999	2005	2012	Source
I	Chilika lagoon area	Km ²	Km ²	Km ²	Km ²	Km ²	Km ²	
	Sand/Sand dunes	40.83	15.79	27.36	7.19	12.45	4.729	Ramesh et al 2011 ^[20] Samal et al., 2012 ^[38] Puri draft plan 2013 ^[19]
	No. Tidal Inlets	3	3	2	1	1	3	
	Coastal forest				28.374	168.58	30.74	
	Chilika lagoon area	912.96	1034.11	918.62	910.05	900.95	887.35	
II	SMD Coastal Area	1984	1999	2017				http://shodhganga.inflibnet.ac.in/bitstream/10603/119542/10/10 Sharma et al 2008 ^[16]
	Sand/Sand dunes	575	564	526	10.53	13.83		
	Coastal forest		74.4	106.65	127.67	127.11		

Dune Community in study area:

Coastal sand dunes are of two types, near shore and farther shore. The cores of the dunes existing near shore are yellow and consist of very fine particles of sand and minerals. The farther shore sand dunes are greyish in colour and its embryo is combined sand silt and organic materials. Once a sand dune is formed either develops or demolishes and become stable over time. The stabilization process continues till the wind driven inflow of sand balances the stability so that equal sand is out flown (Fig 10 a and Fig 10 (b)).

In addition to the classification above, the sand dunes in Odisha can be classified as shore parallel and shore perpendicular (Transverse dunes) and fluvial dunes. The fluvial dunes are formed within the outer channel due to the fluvial and Aeolian action within the outer channel of the Chilika lagoon. These Isle/sand dunes are migrating coast wards regularly

The sectors Brahmagiri to Astarang, Ersama to Ramnagar and Ghanteswar to Baleshwar (kanthi) along Odisha coast are dominant with the sand dunes as these portions of the Mahanadi tri-delta lies on a raised platform influenced regularly by the anastomosed drainage system.



Sand /sand dune status:-

To earmark individual dunes and to find the area of the dunes is a herculean task. Attempt has been made to demarcate the sand area dune area, the line of vegetation and the intermediate water bodies have been found from the Google satellite map for the year 1984, 1999, 2015 and 2017. Field visits and ground trothing has been made to establish the fact. The areas of coastal region with sand, beach, dune vegetation and water bodies were taken together and found to be 575 Km² in 1984, 564 Km² in 1999, and 542 Km² in 2015 and 526 Km² from the image on 22.3.2017 respectively. It is to mention that 2015, 2016 and 2017 were the dry years and the Mahanadi delta has not received single medium floods (<7000 Cumec) from its basin. From the ground trothing it is observed the back dunes in Puri Konark reach is destroying which is due to anthropogenic activities along with high wave activities along Puri coast. There is also continuous migration of coast and the estuaries to north and destructing the sand dunes along the Northern part of Chilika coast. The rate of destruction of sand dunes along Puri coast is 0.73 Km²/year in later part of 20th century. But it is highly alarming that in 21st century in last 17years the loss of sandy area was 2.24 Km²/year. To save our coast line it is high time to save our sandy beach without sand mining, protecting and increasing our dune vegetation.



Fig 11: Changes in Sandy area/Sand dune loss along Puri & Chilika 1984 to 2017

Flora fauna and avifauna:-

The migrating sands in a salt laden Aeolian environment, the beach provide a model area for the growth of the psammophytic vegetation in a sandy dune area. Plantation of casuarina of the area was done early 19th century and the forest is under the subhead Dry Deciduous Scrub Forests. It was declared reserve forest and a sanctuary for Deer and Olive Ridley tortoise in 1984 (area of 87Km²) and in 1984 revised to an area 71.71 Km². The original dune

flora fauna has been vanished except Casuarina, Tamarind, Anacardium, Karanja, Polanga, Neem etc existing. The wild animals found in the sanctuary are, Blackbuck, Spotted Deer, Jungle Cat, Stripped Hyena, etc.

Conclusions:-

From the study of the coastal regime of Odisha the probable conclusions are:

1. The fore dunes are formed in the coastal plains and in the stable spits. The fore dunes are being destroyed affecting the back dune and its bio shield and shelter belt vegetation.
2. Marine activities are responsible for formation in an accretion environment or destruction in an erosional situation.
3. Bio-shield has proven to be the best protection to adverse marine extremes. The mangroves plantation and with extensive planting of marram grass decelerate the sand erosion from the fore dunes.
4. There is an inverse relationship between grain size, dune height and migration speed.
5. Local dune vegetation controls the sand dune and healthy sand budget. Particularly the fore dune plants are vital for dune protection.
6. Both longitudinal and transverse dunes are formed along the Puri and Chilika coast.
7. In the present warm period, the dune activities should have an increasing trend but there is a constant decrease of sand dune @ 2.24 Km²/year which was 0.73 Km²/ year in fag end of 20th century due to anthropogenic activities and climatic vagaries.

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References:-

1. Sahoo B. P., Bhaskaran P. K., 2017, Coastal Vulnerability Index and Its Projection for Odisha Coast, East Coast of India, World Academy of Science, Engineering and Technology, International Journal of Env. and Ecological Engineering, Vol-11 (6), 2017
2. Mishra Siba Prasad, 2016, Estuaries and lateral channel development along east coast of India, International Journal of Advance Research, Vol. 4(12), pp- 2360-2371
3. Hack John T., 1941, Dunes of the western Navajo Country, The Geographical Review 31,240–263.
4. Naidu, A.S., 1968: Some aspects of texture, mineralogy and geochemistry of modern deltaic sediments of Godavari River. Unpubl. PhD thesis submitted to Andhra University, Waltair, India. Pp.250 (Source: Somanna K. et al 2016).
5. Lancaster N., J., 1988, Development of linear dunes in the southwestern Kalahari, southern Africa, Int. Jour. Arid Environment. 14 (3), pp- 233-244
6. Tsoar, H., 1978. The Dynamics of Longitudinal Dunes. Final Technical Report to the US Army European Research Office. US Army European Research Office, London.
7. Sahu S. Ku., 2012, Formation of high amplitude coastal waves in the Bay of Bengal (east coast of India) due to climate change, The 33rd Asian conference of remote sensing , Nov 26-30, 2012, Ambassador City, Jomtien Hotel, Pattava, Thailand , PP- 1-6
8. Vinod K. Ku., Bhattacharya A., 2003, Geological evolution of Mahanadi delta, Orissa using high resolution satellite data, Current Science, Vol. 85 (10), 1410-1412.
9. Somanna K., Reddy S. T., Rao M. S., 2016, Geomorphology and Evolution of the Modern Mahanadi Delta Using Remote Sensing Data, International Journal of Science and Research (IJSR), Vol 5(2),pp-1329-1335.
10. Mahalick N.K. et al (1996): "Geomorphology and evolution of the Mahanadi delta, India", Journal of Geoscience, Osaka City University, Vol-39(6) pp- 111-122
11. Murty, T.V.R.; Rao, K.M.; Rao, M.M.M.; Lakshminarayana, S.; Murthy, K.S.R., 2007, Sediment - size distribution of innershelf off Gopalpur, Orissa coast using EOF analysis, Journal of Geological Society, India: 69(1); pp- 133-138. <http://drs.nio.org/drs/handle/2264/5547>
12. Thieler E.R., Hammar-Klose E.S., 2009, National assessment of coastal vulnerability to sea level rise: preliminary results for the U.S. Atlanta coast USGS, Open File Report 99–593". Available via <http://pubs.usgs.gov/of/1999/of99-593/index>.
13. Unnikrishnan A.S., Rup Kumar K., Fernandes S.E., 2006, "Sea level changes along the Indian coast: observations and projections". Curr Sci ,90, pp.362–368.
14. Unnikrishnan A.S., Shankar, 2007, Are sea-level-rise trends along the coasts of the north Indian Ocean consistent D. with global estimates? Global Planet Change 57:301–307 doi:10.1016/j. gloplacha. 2006.

15. Ramesh.R. and Dr.Purvaja Ramachandran. 2007,'ENVIS – MoEF on Coastal Zone Management and Coastal Shelter belt Vol (6)',pp 25.
16. Sharma V. S., Ramesh R., Ramachandran S., 2008, Coastal land use and land cover mapping of Puri to Konark coastal stretches of Orissa, The Indian Geological Journal, Vol 80 (1), pp-37-42
17. Ritesh Kumar, Pattnaik, A.K., 2012, Chilika - An Integrated Management Planning Framework for Conservation and Wise Use. Wetlands International - South Asia, New Delhi, India and Chilika Development Authority, Bhubaneswar, India.
18. Naik P. K., Pati G. C., Choudhury A., Naik K. C., 2008, Conservation of Chilika lake, Orissa, India, Proceedings of the Taal 2007, the 12th world conference , 1988-1992, <http://www.moef.nic.in/sites/default/files/nlcp/Indian>
19. PKDA report, Government of Odisha (GOO), 2013, Draft comprehensive development Plan -2031, Puri Konark development Authority (PKDA) area, Submitted by Centre for environmental Planning technology, Ahamadabad and ORSAC Odisha.
20. Ramesh R., Purvaja R., and A Senthil Vel, 2011, National assessment of shore line change: Odisha coast, NCSCM/MOEF, GOI, Report 2011-1, <http://www.ncscm.org/reports.php>, pp-1 – 164
21. Mishra S. P. and Panigrahi R. K., (2014), Storm impact on south Odisha coast, India, International Journal of advanced research in Science and Engineering , IJARSE, Vol. 3,(11), pp 209-225 http://www.ijarse.com/images/fullpdf/1416649374_28_Research_Paper.pdf
22. Baoli Liu, 2014, Exploring the interaction between rivers and sand dunes –implications for fluvial-aeolian geomorphology, Thesis, the Degree of Doctor of Philosophy in the University of Hull, China, P 1-195
23. Bagnold, R.A., 1941. The physics of blown sand and desert dunes. Methuen, London. Progress in physical geography revisited, Vol 18 (1), 1994 pp- 91-96, <http://journals.sagepub.com/doi/pdf/10.1177/>
24. Wasson R. J., 1984, In Late Cainozoic Palaeo climates of the Southern Hemisphere, edited by J. C. Vogel, A.A. Balkema, Rotterdam,.
25. Lancaster N., 1988, Development of linear dunes in the southwestern Kalahari, southern Africa, Journal of Arid environments, Vol 14, pp- 233-244
26. Tsoar Haim, Blumberg D. G., Stoler Y., 2004, Elongation and migration of sand dunes, Elsevier, Geomorphology, Vol- 57(3), pp- 293-302
27. Selvam.T. R., Karunagaran. V.M., Subramanian. R. R., Eganathan P., and Parida A. K.. 2005 , 'Toolkit for establishing Coastal Bioshield', pp 117. <http://59.160.153.185/library/sites/default/files/17-Toolkit%20.pdf>
28. Judd, F. W., Leonard, R. I. & Sides, S. L., 1977. The vegetation of South Padre Island, Thxas, in relation to topograpy Southwest Nat- 22(1): 31- 48.
29. Doing, H., 1981. A comparative scheme of dry coastal dune habitats, with examples from the eastern United States and some other temperate regions. Veroff. Geobot. Inst. Rubel 77:41 -72.
30. Moreno-Casasolal P.& Espejel I., 1986, Classification and ordination of coastal sand dune vegetation along the GnU and Caribbean Sea of Mexico, Vegeta 147 tio 66: 147-182, 1986, © Dr W. Junk Publishers, Dordrecht - Printed in the Netherlands
31. Mainguet M. (1984) A classification of dunes based on aeolian dynamics and the sand budget. In: El-Baz F. (eds) Deserts and arid lands. Remote Sensing of Earth Resources and Envir., vol 1. Springer, Dordrecht, https://doi.org/10.1007/978-94-009-6080-0_2
32. Mohanti M., 1993, Coastal processes and management of the Mahanadi River deltaic complex, East Coast of India. Proceedings Coastal Zone 93, American Society of Civil Engineers, New York, U.S.A., 75 - 90.
33. Government of Odisha, 1986, Delta development plan, Water resources Department, Bhubaneswar , Odisha (Unpublished)
34. Arya, R. and Lakhota, S. C., "Imprints of Chilika lake in the offshore region – a geomorphic evidence" Current science, Vol. 90, No.9, 10May 2006.
35. Chilika Development Authority, 2009, Report of Chilika Development Authority, Government Odisha, Bhubaneswar,
36. Naik P. Ku. and Hota R. N., 2014, Geomorphological study of Sand Dunes with special reference to their Hydrogeology in Southern Coast of Odisha, India, International Research Journal of Earth Sciences,Vol. 2(9),pp- 15-21, October (2014)
37. V. Sanil Kumar, Pathak K. C., Pednekar P., Raju N. S. N. and Gowthaman R., 2006, Coastal processes along the Indian coastline, Current Science, Vol. 91 (4), 25 August <http://www.iisc.ernet.in/currsci/aug252006/530.pdf>
38. Samal R.N., Rout J., Ojha A., Pradhan S., Kumar Ajit., "Geomorphological change analysis of Chilika Lagoon Inlets- A case study", Chilika Development Authority, C-11 BJB Nagar, Bhubaneswar, 2013.