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RESEARCH ARTICLE

ESTUARIES AND LATERAL CHANNEL DEVELOPMENT ALONG EAST COAST OF INDIA

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Abstract

Coastal corridor of India is the life line to many civilizations. The 2853km long east coast has huge continental self of 22411sqkm. Major east flowing rivers the Mahanadi, the Godavari, the Krishna and the Cauvery have huge sedimentary deposits in the offshore which are either subaqueous or sub aerialand developing estuaries or sand bars along the coastal interface. Geospatially cyclones, Tsunami, meteorological and geological extremes are conducive forchange of the coast line. Continuous formations of bars and spits along the shore front have changed the configuration of river outlets.Sediment deficit from inland rivers, formation of lateral parallel channels along offshore have been observed in the river mouth for last 10 to 12 years. In the present study, the satellite imageries are used to establish the reformation in the river outlets. The changes initiated by bar formation bendingof river mouths to north are prominent from the Subarnarekha to Godavari mouth. Coriolis force, human interventions, wind, tides and bay disturbances were studied for last two decades to establish such diversion. The present study enumerates the causes and effects of northerly movement of river outlets, formation of sand bars and development of estuariesalong east coast and sedimentary input to Bay of Bengal.

Introduction:-

Coastal regulatory zone (CRZ), the area between high tide lines (HTL) and low tide line (LTL), is highly dynamic and fragile but interestingly resilient in east coast of Indiawhich is under constant pressure due to meteorological and geological extremes.Sedimentary imbalance and hydrologic interventions in the riverine system haveadded to the issue. East coast of India is 2853km long extending from Kanyakumari in south to Haladia port in northandcontinental shelf of area 22411km^2 up to 50m., Kulkarni et. al. (1985)[1] (Table 1).

Erosion, accretion and northerly shifting of outlets of northern rivers and inlets of lagoons, formation of parallel channels and back waters propagation are observed to be increasing along East Coast (Fig 1 and Fig 2). Either formation of shore parallel lateral channels or development of sand bars in the estuaries has become more prominent along the East Coast. The present study enumerates the causes and effects of northerly movement and formation of sand bars of river outlets in east coast and their sedimentary propositions along coast line of east coast of India. If effective coastal protection measures are not taken in time the portion from the parallel channel shall slide in to Bay of Bengal (BoB) along Odisha coast.

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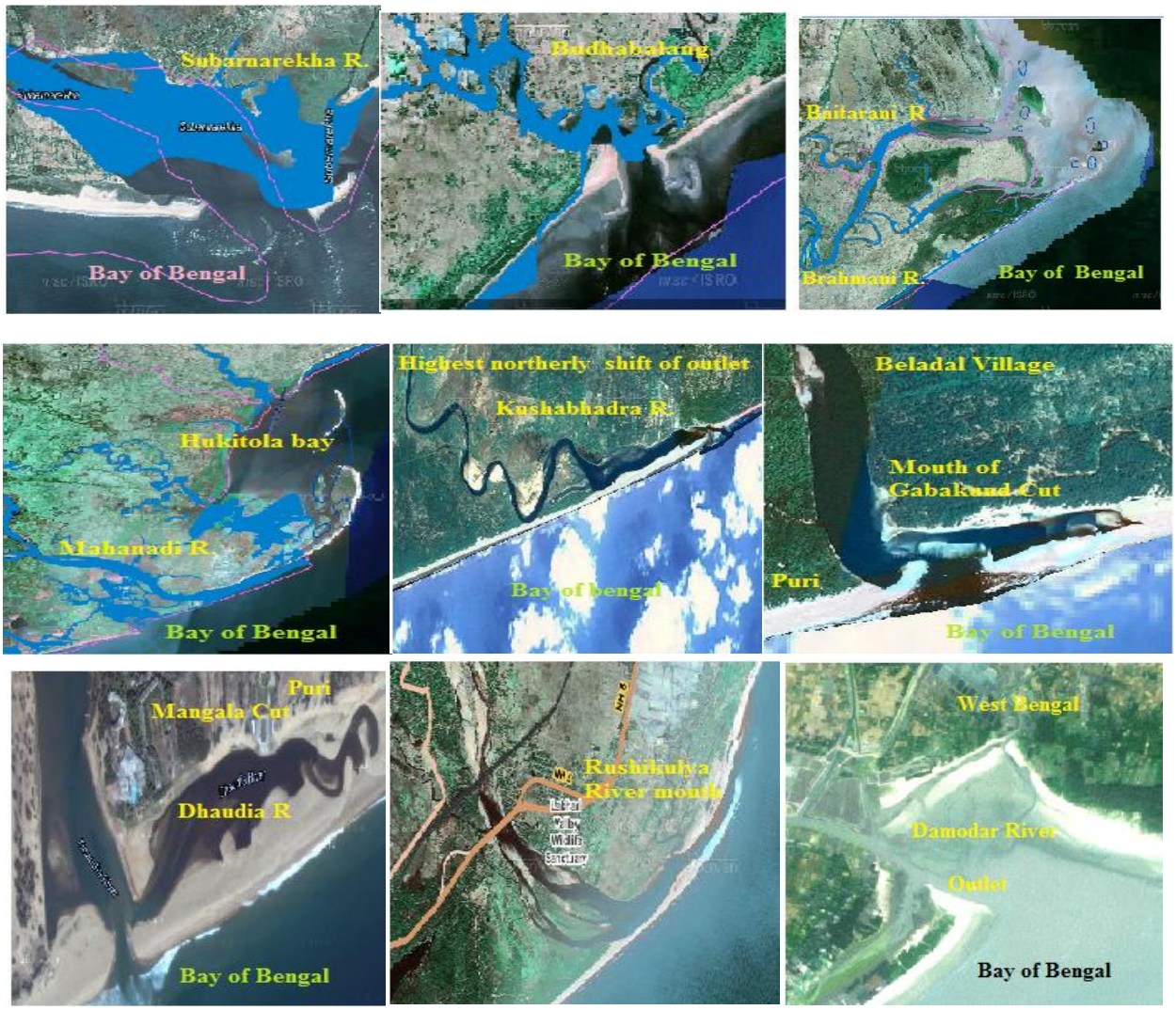

Fig 1:- Outlets of rivers in Odisha joining Bay of Bengal (a) Subarnarekha, Budhabalang, Baitarani, Bramhani, Mahanadi (Distributaries), Rushikulya and Damodar of West Bengal (Source Google and USGS EE).

Review of literature:-

Mahadevan et. al., (1958)[2], stated that in 18th century, the growth of coast was 16 km at Mouth of river Godavari after increased deforestation, construction of dams and barrages after independence. Ramanadham et. al., (1970) [3], stated that tide, wind and wave were the three parameters responsible for changes of Kakinada coast during 1958. Shetye et. al., (1990) [4] reported about higher vulnerability of Odisha coasts to coastal erosion than other states in EC. The average submergence was 0.76mm during 20th century.Chandramohan et al., (1988) [5], (1991) [6]& (2001) [7],reported that the direction of longshore lateral drift was NE-ly in the months from Mar to Oct and SW-ly during rest period along offshore which form the coast front. Kakani et al. (1993)[8], (2003)[9]& (2007)[10] stated that rivers in the East Coast are monsoon fed and floods of these rivers form new spits and deltas regularly. The archeological findings in the intertidal zone of Mahabalipuram, Vanagiri, Tranquebar and Pompuhar coasts in T.N. indicate shifting of coast in ancient days asreported by Kailashsundaram et al (1991)[11] and Murli M., (2014)[12].Similarly the legendary monuments (Konark Temple), structures, temples of Odisha reveal prograding of shore lineby about 2 to 4 km along Odisha coast during last millennium.

Tsunami-04 (26th Dec.2004) distorted the outlets of some rivers in Tamilnadu and devastated the southern part of East Coast. Ministry of Home affairs, GOI, reported 11000 fatalities, 5000 missing and 3.8lakh people displaced

with a pecuniary loss of 12crore dollars (World Bank). As post tsunami effect 2004, the shore line was withdrawn by 20m forming a back shore of 500m in 2006 along Odisha coast Jayakumar et. al., (2008) [16]. and Umadevi et. al.,(2012)[13]. The coastal areas, Uppada, Bhumipatnam and Visakhapatnam in AP and Puri, Satabhaya, Astaranga and Gopalpur in Odisha were heavily eroded in the 21st century. Shore line have moved back and eroded 87km^2 coastal front of length 418km in the EC of India during the period 1990 to 2006 Ajay N.,ISRO,–(2012). [14]

Mishra et. al.,(2014)[15] , observed regular closing/opening and shifting of tidal inlets of Chilika Lagoon after Tsunami-04 at the time of solar eclipse with disturbances in BOB. Tsunami effect was not observed immediately from north Andhra coast to West Bengal Coast. Kunte et al., (1993)[16],(2001)[17], collected data for wave convergence, divergence and rip currents to quantify correct longshore drift. P. Pandian K et al., (2002)[18],(2004)[19], (2007)[20], stated that tidal inlets of Pulicat lagoon and littoral drift along Nellore coast were towards north. Mohanti et al. (2005)[21] had quoted Bhareli about migration of shore line towards sea during process of delta building in Holocene period. Philips et al. (2004) [22], (2006) [23] stated that the base level change, sea level rise are the causes of changes of river mouths in the coast. Tsunami-04. Rao Subba et. al., 2009[52], stated that the energy due to convergence of refraction waves and direct hitting of waves were the reasons for change in river course near shore in west coast of India.

Fig 2:- The river outlets/ estuaries along Andhra Pradesh coast India. (Source: Bhuvan NRSC & Google)

Pravakaran et al.(2010)[24] described the evolution of Vaigai delta which is constantly changing since 7000years BP. Ramesh et al, (2011)[25], (2011)[26], (2012) [27]on studying the shore front changes along EC (1972-2010) have stated that north and southern coast are depositional and the central coast is extremely erosive. Murali et al (2014)[12], reported from GIS studies (1999 to 2009) that the spit of Maipura river near Gahiramatha estuary in the Mahanadi delta has shifted 2700m in NE direction by formation of sand bars Hedge et al (2015)[28] identified propagation of Yedmavina river to south and adjacent Baindur river to north along West coast of India.

Unnikrishnan et. al. (2010)[29], predicted rising trend in local sea level rise (SLR) @ 1.3mm/year as a result of increasing intensity of tropical storms, low tides and high storm surges at Nagapatnam, Paradip and Calcutta ports. Kunte et al (2001)[17], reported that positive sediment surplus constructed huge barrier spits, sand bars and deltas along the EC. Kumar et. al. (2010)[27],reported 194km erosion, 231km accretion, sea level change @ 1mm/year. Out of 7517km coast line of India, the erosion length is 45.5%, accretion of 35.7% and rest is stable as told by Rajwat et al., (2015)[30]. The rate of erosion and accretion reported by Natesan U., 2015[31]was 34.3m/year accretion at south Pulikat mouth and erosion @ 26.4m at Ennore, near Chennai. Panda et al 2011[32]and Gupta et al 2012[33]reported annual downward trend in sediment influx to Bay from the EC rivers.

Methods and Methodology:-

Prominent changes like erosion, accretion and northerly shifting outlets of rivers and inlets of lagoons, back waters and formation of sand bars were observed along East Coast form in 21st century (Fig 2 and Fig 3). Erratic monsoon, high floods, tsunami, long standing waves, storm surges and deltaic sediment deficiency are the probable causes of lateral channel formation along coast accompanying erosion and accretion. Hydrologic interventions like dams, sea walls, breakwaters, groins and dredging activities might have added to the activity.

The lengths of erosion, accretion and configuration of river outlets, lagoon inlets and formation of sand bars along with other coastal parameters, like wind, amplitude and frequency of waves and current along the EC were collected

from satellite imageries and literatures.Time series of the annual flow and sediment of east flowing rivers along EC of Indiaare compiled from CWC, MOWR data [34] from 1984 to 2012

Coriolis forces at the river outlets are calculated by the equation $ma_i = ma - 2m\omega * v + mr2$ where m, a, ω, v are the mass, acceleration, angular velocity of earth's rotation and flow velocity. The simple form is $F = \frac{2\,\omega v Sin\varphi}{g}$.where$\omega and g\ are$ taken as constant. Hence $F = 2\,\tau v sin\emptyset$ where τ is Coriolis force parameterused in the present study as per Dongsheng Yu, (2006)[35],.

The geomorphology changes observed in 21st century in the topography and positioning of river outlets and Lagoon inlets are studied from satellite imageries downloaded from USGS EE, Bhuvan, NRSC Hyderabad India and Google earth and others (fig 2, Fig 3 and fig 4).

Geomorphologic feature along the east coast:-

The rivers from Hooghly to Bhaigai along east coast were formed by initial rifting of Gondwana and Ender bay land of Antarctica. Subsequent motion of Indian plate. The ECMI, (Eastern Continental Margin of India) was formed by tectonic activities in two stages (i) Rift stage (ii) Post rift stage. The coast parallel dyke intrusions and later the formation horst and graben configuration have formed the rivers and east coast (Murthy 2015). The geomorphic features like length of beach, coast line deformation and coastal features along EC (Lagoons) of India are in Table 1

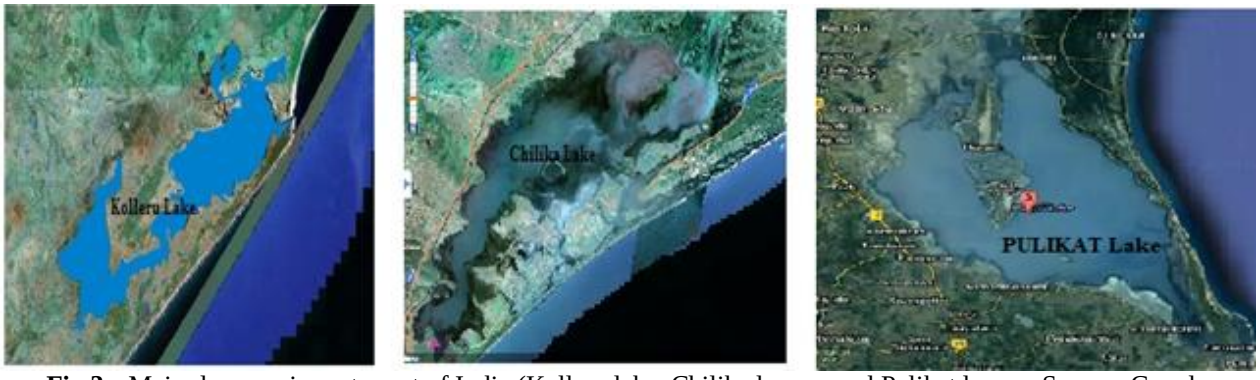

Fig 3:- Major lagoons in east coast of India (Kolleru lake, Chilika lagoon and Pulikat lagoon Source: Google

Table 1:- The State wise geomorphologic features of EC of India (Rajwat A. S. et al 2015)[43]

#	Coast	State	beach (km)	Rock beach (km)	Mud flats (km)	Marsh (km)	Stable (Km)	Erosion (Km)	deposit (Km)	Total length Km	D/C (rivers No)
1	East coast	W.B.	0	0	80	77	48	115	19.5	282	05
2		Odisha	274		158	48	80.32	204	196	480	25
3	Sirkara (N)	Andhra Pradesh	370	29	506	68	343	444	187	974	12
4	Coromondal/	Pondicherry	4.49	Nil	0.33	05	9.3	01	07	41	5
5	Sirkara (S)	T.N	613	54	409	156	29	282	514	1076	41

Geological featuresalong the coast:-

The East Coastof India have coastal features like Cliff (Nagavali & Vansadhara in AP Coast), Clayey coast (Godavari), muddycoast (Hooghly to Subarnarekha coast), sandy coasts (Subarnarekha to Nagavali river, and Tamilnadu coast). Sandy beaches inEast Coast are at Digha, Puri, Chennai and others (Table 1).The geologic features like grabens, folds, faults, lineaments existing along east coast of India are shown in fig 4(a, b& c), Vinod Ku. et al (2003)[36]. The concavities in the topography are at north Odisha, Machilipatnam, Chirila, Ongle and Rameswaram coasts. The estuaries of river outlets are found at the mouth of the rivers Subarnarekha, Budhabalang, Bramhani, Godavari and Krishna and others. Facts about ecologically sensitive areas are in Table 2 and Fig 1(a), Fig 1(b) and Fig 1(c).

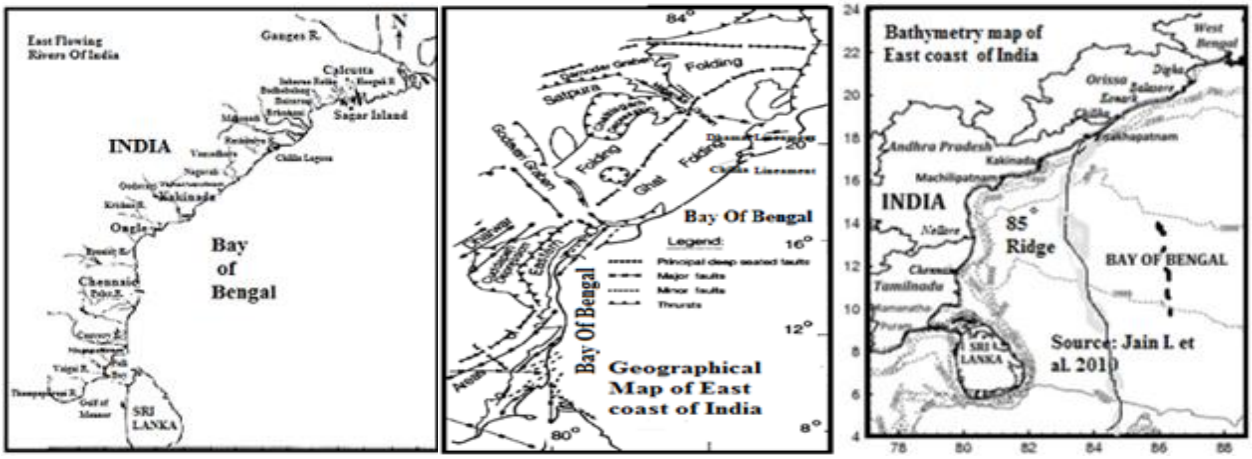

Fig 4:- (a) East flowing main rivers (b) Geologic features C) Shore floor in the EC of India (Source Google)

Table 2:- The status of important ecologically sensitive areas, the lagoons along East Coast India

Pelagic item	Sundarban (Earth's largest mangrove)	Chilika Asia's largest lagoon	Koleru (Asia's largest fresh water body)	Pulikat Lake Asia's 2nd largest lagoon	Golf of Mannar, Coral Hub
State	W. Bengal(40%) Bangladesh (60%)	Odisha	Andhra Pradesh	Andhra Pradesh (84%)/ Tamil Nadu (16%)	Tamilnadu
Position	21˚40'04"N- 22˚ 09' N lat& 88˚02E -89˚06'01"E long.	19°43'N, 85° 19'E to 19. 17°N 85.32°E	16°32' - 16°47' N and 81° 05'E-81° 21'E	13˚24' N- 13˚ 24' 27"N - 80˚46'E - 80˚ 19' 01"E long	08°45' - 9°25'N and 78° 05'E-79° 05'E
Area	4260sqkm	906- 1155 km^2	308 -954 km^2)	350-450 km^2 and	10500 Km^2
Coast length	85km inland	64km	inland lake	60km	63.22km
Status of Inlet/ channels	Cluster of 102 Islands, eroding/ depositing coast	North shifting / opening and closing inlets	60km long river Upputeru joining sea and lake	Three inlets, Tupili Palem,Pulicat vil. , Rayadoruvu.	21 islands, coral reefs, estuaries, saltpans/ mangrove
Importance	210km^2 lost from 2000. (erosion). Largest mangrove.	Aqua catch, Dolphins, Birds	Aquaculture, agriculture, Birds	Mangroves, Aqua culture and ISHRO 120 Km^2 Islands	Coral reefs, Biome 21 Islands

Wave characteristics:-

The waves are high at Kanya Kumari and low at Rameswaram coast. From the mouths of the riversHooghly to Subarnarekha,the coast is mesho tidal, ICZAM W. B. (2010)[37]. The intermediary coast from the river mouths Subarnarekha to Thamarparani is either micro or macro tidal. The central and southern East coast is vulnerable to both SW and NE monsoons. Theaverage wave heights in Tamilnadu coast changes during SW monsoon between 0.4m to 0.6m whereas in NE season it increases from l.0 m to 1.2m and more. The most frequent wave period along the coast are ranging from 8 to 10 sec. Wave power is highest during SW monsoon. V. Sanil Ku. et al, (2013)[38].Swells are noticed with locally generated waves. But during SW (JJASO months) and NE monsoon (ND months) the coast is wind dominated having both primary and secondary waves. The tides and the meteorological extremes provide direct long waves of high amplitude. The waves follow wind pattern, upper air cyclic circulation and direction of movement of the disturbances. Waves cause erosion and deposition and alsocarry sediment from the offshore and deposit onshore. The amount of sediment carried by inland rivers along EC is given in Table 3.

Coriolis Force:-

Coriolis force, an artifact of revolution of earth, moves northerly (Clockwise) in the subtropics and directs objects towardsright in northern hemisphere and vice versa. It plays vital role in the opening, movement, closure or shifting of the outlets and tidal inlets and deformation of estuaries. This may be the reason for all outlets to sea, a cluster of

islets are formed near the northern fringe where shores either remain deposited or unaffected or eroded. U.S. Corps of Eng., 1984[39] hasreported that 72% of sediment deposit occur in the ebb shoals due to the effect of Coriolis force.

Table 3:- Coastal Erosion, accretion, and longshoretransport (LSTR) in $10^5 m^3$/sec at river outlets inEC

River Outlets	District	Erosion (km)	Accretion km)	Stable (km)	Total (km)	Type of Shelf/slope	Net LSTR	Source from
West Bengal								
Hooghly	Hooghly	115	19	148	282	wide/gentle	12.55	
Odisha								Chandra Mohan, 19881991, 2001[,5,6,7],V Sanil Ku. et al 2006[38], 2013 [39], Kunte et al [16,17],Laxmanan[41] Ramesh et al [25,26,27] Jain et al [41] Sravanan [42] Jena et al [43] Murthy 2015[44]
Mahanadi	J.singhpur	40.2	9.8	8.95	58.95	wide/gentle	13.41	
Devi	Puri	40.2	9.8	8.95	58.95	wide/gentle	13.41	
Rushikulya	Ganjam	32.4	1.86	26.6	60.85	wide/steep	1.1	
Andhra (AP)								
V.dhara/Nagavali	Srikakulam	35.1	130.7	26.06	191.9	Wide/steep	6.87	
Gostani	Vizianagaram	10.8	16.56	4.02	31.38	Wide/steep	6.98	
Sharada	Visakhapatnam	64.1	64.34	28.1	156.5	Wide/steep	2.28	
Godavari	Godavari (E)	77.6	62.84	7.84	148.3	Wide/steep	6.98	
Macchalipatnam	Krishna	41.1	44	6.56	91.76	Wide/steep	0.62	
KrishnaPatnam	Guntur	3.5	30.4	6.86	40.77	narrow/gentle	1.97	
Pondicherry								
Ginjee, Poniyar	Pondicherry	7.16	7.19	9.27	23.62	narrow/ very steep	1.71	
Arslar	Karaikal	2	9.27	6.09	17.36	narrow/ very steep	1.68	
Tamilnadu								
Palar	Thiruvallur	0.71		27.19	27.9	narrow/steep	1.68	
Korttalaiyar	Chennai	2.09	8.53	8.38	19	narrow/steep	2.44	
Ponnaiyar	Cuddalore		1.54	55.96	57.5	narrow/steep	1.97	South west and North East monsoon area
Veller	Thiruvarur			47.2	47.2	narrow/steep	0.37	
Cauvery	Nagapattinum	6.94	0.97	180	187.9	narrow/aver. Gentle	3.33	
Uppanar	Nagapattinum	6.94	0.97	180	187.9	Narrow/aver. Gentle	0.06	
Vellar	Pudukottai		3.6	39.2	42.8	Wide/gentle	3.37	
Nariya Payur	R.nathpuram	7.57	6.2	223	236.8	Wide/gentle	0.87	
Vaigai	R.nathpuram	7.57	6.2	223	236.8	Wide/Very gentle	0.29	
Vaipar	Tithookudi		1.33	162.2	163.5	Wide/gentle	0.24	
Thamarparani	Kanyakumari	13.85	6.65	51	71.5	Wide/gentle	-0.22	

ForCoriolis force, V = wind speed in m/sec, f= Coriolis parameter =2Ω Sinϕ. ω, the angular velocity (ω) of the earth= 7.2 $X10^{-5}$ in SI units, ϕ is the latitude of the study point. The Coriolis force acting on unit length of wave along EC is given in Table 4.

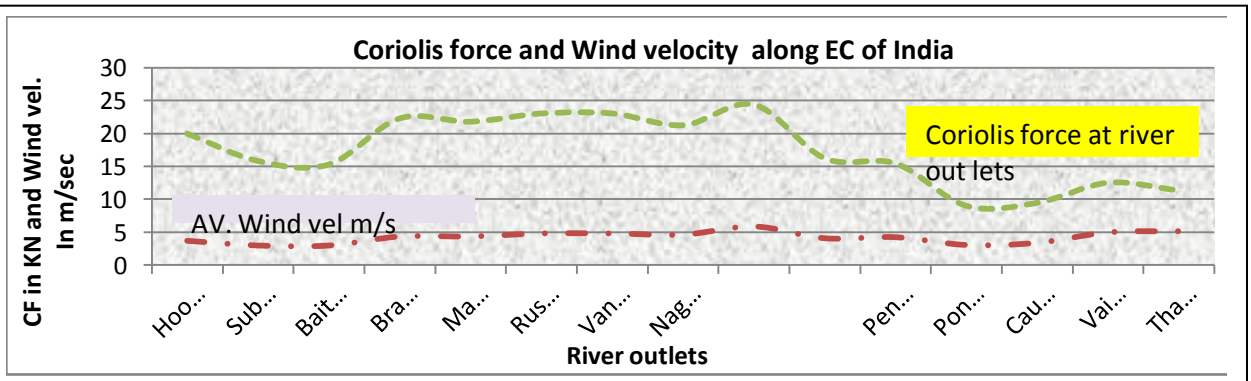

Fig 5:-Coriolis force and Wind velocity pattern from north to south, along East Coast of India

and carried by theTsunami waves. Those waves stroke the southern EC of India and disturbed the sea floor configuration and stability. The Tsunami had less impact on Odisha coast but post tsunami effects were remarkable.

The river mouths in Odisha coast had moved north and formed coast parallel drainage channels during 2005 to 2008.

Long Shore Transport rate:-

The low height ebb tides change the morphology of the coast. Sand bars and dunes are formed during constructive and destructive action of low tidal waves triggered by the Aeolian effect. Long shore sediment transport always occurs inside the surf zone but parallel to a shore, generated by waves which slam the shore obliquely. The plunging waves with high energy in breaker zone carry more sediment but they vary in quantity. Long shore drift is almost constant in the surf zone but highest in the Swash zone. They are the reasons for formation of sand bars and changes in coastal configuration.The submerged bars formed at the sea river interface catalyze spit growth in pre-monsoon period. Behind the bars; the depressions are filled with over flow water by high waves and form parallel channel along the coast line either by plunging or spilling or surging. The sedimentsdeposited obstruct river outlets during non-monsoon season and tend to be diverted.

The sediment transport rate (Q_u) was estimated by Kamphius (2002) (CERC formulae), Graff V. D. et al (1979) [12]

$$Q_u = 2.27\, H_{sb}^2 T_p^{1.5} m_b^{0.75} d_{50}^{-0.25} Sin^{0.6}(2\theta_b), \qquad \text{eqn. 1}$$

Where Q_u = LSTR in Kg/s, H_{sb} is the significant wave height, T_p =Wave period (peak), m_b = beach slope that causes breaking (modified), d_{50} = median size of the beach particles and θ_b =braking wave angle. The LSTR rate has been estimated by various authors given in Table 3.

The gross rate of sediment flow along the surf zone of India is lower in the coasts of south Tamilnadu (0.5 Mcum to 1.0 Mcum/ year) but higher along south Odisha coast and north Tamilnadu coast (1.5Mcum to 2 Mcum per year) Kunte et al., (2001)[17]. The long shore drift is SW-ly along the coast from Nov-Feb and NE-ly rest of the years. However the net drift is always N-ly.The long shore drift starts from the breaker zone, proceed to the surf zone, and ends near the swash zone. The long shore current in the surf zone moves parallel to coast line. It is observedthatwhen waves reach the shore at very small acute angle on a steep slope the current is more as the waves are plunging and vice versa when they are spilling or surging.

Sediment transport from Inland Rivers:-

Flow and sediment data of CWC, MOWR[37]from 1993 to 2011 are collected annually and analysed.The sediment flow rate of inland river the Cauvery is the lowest @0.02gm/lit and of the Mahanadi is 2nd lowest @0.23gm/lit followed by theGodavari 0.57gm/lit. Sediment transport rate by the rivers along EC is given in Fig 6.

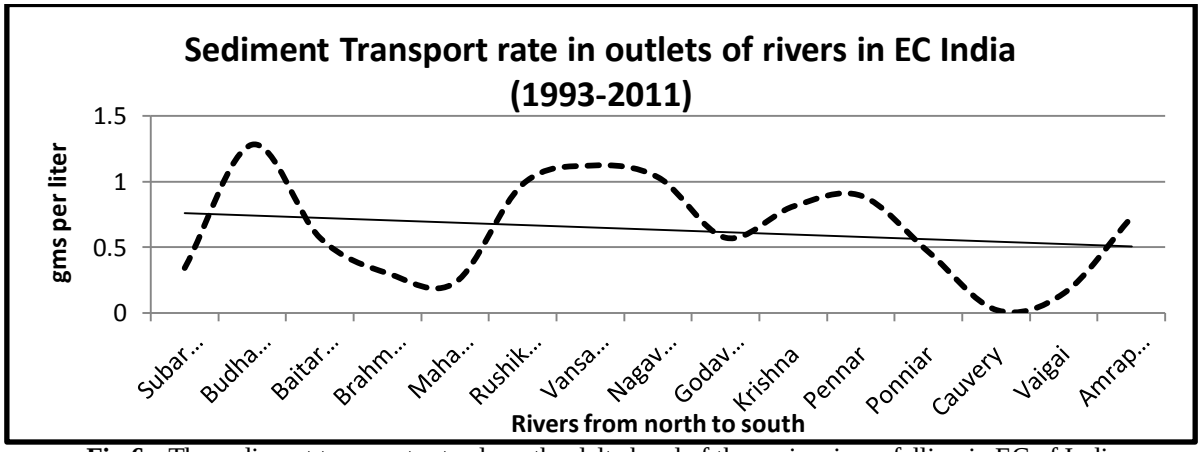

Fig 6:- The sediment transport rate along the delta head of the major rivers falling in EC of India

The high sediment transport rate of the rivers Budhabalang (1.28gms/lit), Vansadhara (1.12gms/lit) and Pennar (0.89gm/lit) may be due to less hydrologic structures in the rivers. Sediment inflow rate curve along EC is sinusoidal from north to south. The % of increase or decrease were studied 1993 to 2005 and 2005 to 2012 and It was found that rivers in north Andhra coast adjoining south Odisha coast showed decreasing trend in sediment inflow.

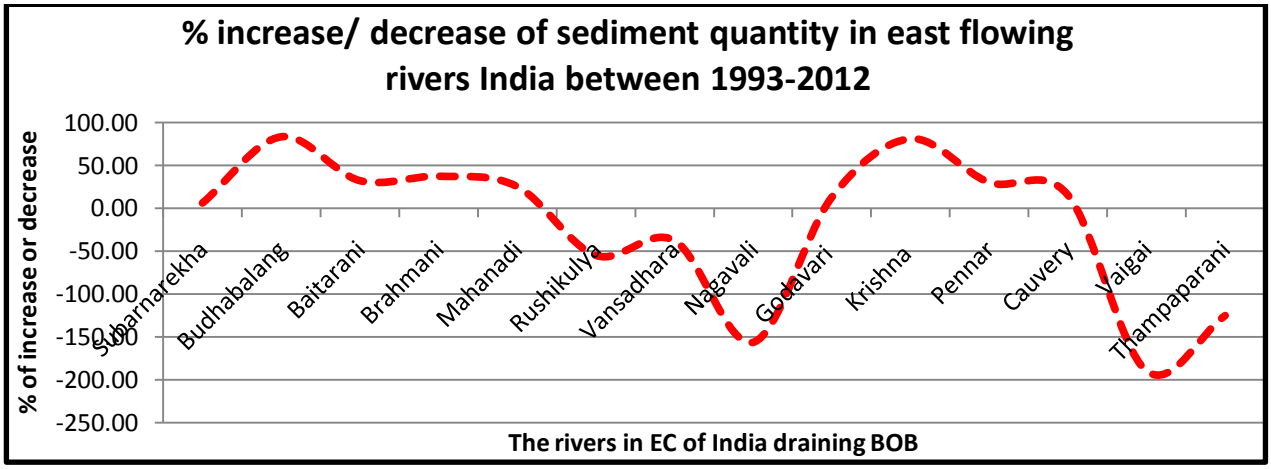

Fig 7:- The sediment transport rate along the delta head of the major rivers falling in EC of India

Inflow was least in the Bramhani, Godavari and Cauvery. Chandra Mohan in (2001)[7] and Gupta in (2012)[33] estimated the amount of sediment influx to BOB through the east flowing rivers up to 1984 and up to 2005 respectively (Table 4 and fig 8).

Table 4: % change in average sediment (MMT) in east flowing rivers during 1993 to2012.

Name of river	Cor. parameter (f) (10^{-5} N)	Av Wind vel. m/sec	Coriolis force N/kg (V*f)	Length in Km	Sed up to 1984[4]	Sed up to 1984-05	Sed up to-05-12	Sed 1993 – 2004 (CWC)	Sed 2005-12 (CWC	% excess (-)or less(+)
West Bengal										
Hooghly	5.4	3.7	19.98						100	(Mm^3)
Odisha										
Subarnarekha	5.285	2.99	15.80	395	5.911		2.64	2.769	2.59	6.5
Baitarani	5.112	2.99	15.28	355	5.954		2.24	2.571	1.733	32.6
Bramhani	5.112	4.36	22.29	799	13.28	7.12	5.23	6.155	3.835	37.7
Mahanadi	4.997	4.36	21.79	851	13.20	17.6	11.02	12.28	9.125	25.7
Rushikulya	4.781	4.82	23.04	162			1.998	1.522	2.355	-54.7
A.P.										
Vansadhara	4.781	4.82	23.04	254	1.836		1.087	2.246	3.087	-37.4
Nagavali	4.579	4.64	21.25	256	38.89		2.587	1.267	3.247	-156.3
Godavari	4.147	5.88	24.38	1465		45.4	45.57	48.12	41.743	13.3
Krishna	3.96	4.09	16.20	1401	0.199	1.09	16.08	30.451	5.676	81.4
Pennar	3.629	4.25	15.42	597	0.257	1.6	1.157	1.424	0.989	30.5
T.N./Pacher										
Ponniyar	2.923	3.07	8.97	247				0.55	1.044	90
Cauvery	2.779	3.4	9.45	800	0.471	0.37	0.326	0.348	0.293	15.8
Vaigai	2.506	4.99	12.50	258	0.002		0.073	0.029	0.084	-189.7
Thampaparani	2.187	5.17	11.31	130		0.446		0.008	0.018	-125.0

*Note: The sediment (Krishna river) for 1996 and 2001 is not considered as abnormally high

Wave refraction and wave divergence:-

Waves in northern part of EC strike the shore line either SE or SSE whereas outlet discharges to BOBare from west to east. During pre and post monsoon, low energy condition persists. During monsoon strong freshwater waves interact with strong energized monsoon waves. That creates a surf muddy zone near off shore.The sediment creates ebb deltas by depositing the sediment around the outlets causing progression of shore seaward. Long swell waves during post monsoon create low energy at the off shore zone. The breaking waves sweep over these ebb deltas and carry back the sediment shoreward and form beach. In the process of movement of sediment, sand bars and spits are formed in post and pre-monsoon.The diverged waves add to sand bars and increase depressioncaused by sediment carried by floods. The channel moves north due to action of Aeolian forces, Hypopycnycal Flow and littoral drift. The erosion and accretion along different states in EC are shown in fig-9.

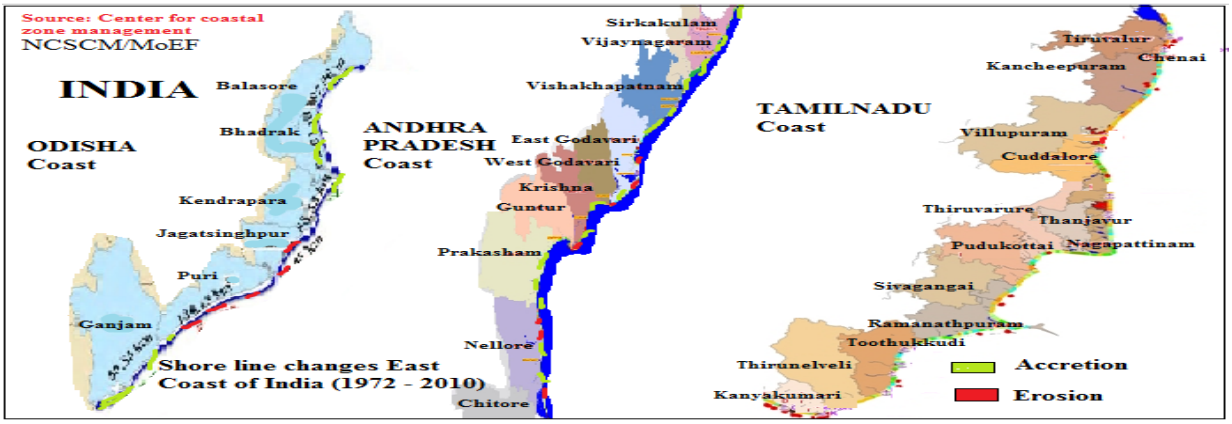

Fig 8:- Erosion/accretion along Odisha (Northern), Andhra (Central) and T.N. (southern) coast of India.

Bay of Bengal is an ideal cytogenesis area. EC, India receives 60% of cyclones formed in BOB. The highest devastating cyclone ever recorded was at river Hooghly during Oct 1737 having surge of 13m and caused 300000 fatalities. The frequencies of bay disturbances have decreased along the EC of India but the intensities have increased in 21st century Mishra et al (2014)[46].

Very high zone –I, High zone –II and Moderate zone – III are the three cyclone zones. The number of bay disturbances from 1877 to 2014 along EC is given in Table 5. Tamilnadu coast is least affected by cyclones but storm on 22nd Dec 1964, Mandapam road and railway bridge got washed away andDhanuskoti Island was submerged forever.

85^0 East Ridge:-

The submerged 85°E Ridge line wedge outs on both sides is covered with clastic sediments and extending from Ceylon to ChilikaMishra et al., (2013)[47] .The stable sediment columns in the wedges were disturbed by Tsunami 2004. The turbulent sediment both from 85°E and 90^0 ridges penetrated the southern EC by surges of height 5-6m up to 1-2km inland. Additional sediment loading occurred when the surgesretreated. The excess sediment load continued inpost-tsunami yearsi.e. 2005-06 to 2007-08. Being propelled bylong shore current, the sediment moved north gradually. They get deposited in the face of the river outlets forming huge sand bars. The coastal processes forced them to propagate north ward.

AnthropogenicInterventions:-

The River Damodar has 5dams and one barrage. Odisha has 180dams, and 39 (Barrage, Weir and Anicuts) BWA. Andhra Pradesh has 121dams and 22 BWA, Tamilnadu 111 dams and 40 BWA. The sediments carried from the basin get piled up behind the dams. The low sediment transport by the inland rivers along east coast made deltas to sink and shrink.The sea walls, groins, jetties, ports and break waters add to the coastal instability and cause erosion or accretion. The paucity of sediment input to deltas, land use and land cover of basin cause changes along coast.

Conclusion:-

The northern shift in outlets was observed in rivers Subarnarekha to Vansadhara.Bramhani river outlets have moved maximum (9.25km).The rivers in Tamilnadu coasts exhibit tad bit southerly tilt.The amplitude of tidal wave is highest in Hugli estuary (2.1m to 4.9m)and gradually decreases towards south.The zone, north Andhra coast to South Odisha is almost stable.

The amount ofCoriolis force differs all alongthe east coast and is high along the north Sirkara coast whereaverage wind velocities are higher.The disturbances observed along east coast are due to combined effect of wind, tide wave, near shore current, beach gradient, sea level rise, offshore current, meteorological extremes, anthropogenic interventions and tremors.

The rivers with more hydrologic interventionsare having lower rate of sediment transport (0.02gms/l in River Cauvery).Decrease in sediment rate makes the delta to sink,shrink andsubside. The south Odisha and North Andhra coast are carrying more sediment thanthey did ten years back.

Net long shore sediment transport rate have local minima near the spits of the coastal lagoons. due to daily tidal exchanges. The regional LSTR along WB, Odisha, Andhra Pradesh, Pondicherry and Tamilnadu are 1.226, 0.75, 0.41, 0.17 and 0.12MMT respectively.

The shifts of the outlets and formation of lateral channels are higher in case of small rivers than in large rivers. Large rivers form estuaries whereas small rivers tilt their outlets to north in the north Odisha coast and to south along Tamil Nadu coast. It also depends on the angle and intensity of approach and the configuration of coast line.

Construction of spits at river outlets are due to Coriolis force, Hypopycyncal flow, Littoral drift and paucity of sediments from inland rivers.The sediment formsbarrier spits away from the existing beach either in the ebb delta or in the flood delta extending north. Construction of the barrier spit closes the mouth of the river during lean flow of rivers and helps in tilting of river mouths. Channels are created behind the spits. During the floods of the next season when flow cannot penetrate the newly constructed barrier spit, itfind the northern path and joins the sea.

The abnormal behavior of the outlets of rivers in the marine marginal zone between Mahanadi and Godavari has possibility of pushing around 400 km in to the Bay of Bengal if not attended in time.

Reference:-

1. Kulkarni J. R., Srivastav U. K., 1985, A systems of network of marine foods industry in India, M. Visveswaraya Industrial Research and Development Centre, Bombay, IIM, Ahmadabad, published by concept publishing company, New Delhi. 1991, pp. 73–82.
2. Mahadevan C, Rao R. P., 1958. Causes of the growth of sand spit north of Godavari confluence. Andhra Univ. Memoirs of Oceanography 2: 69–74.
3. Ramanadham R., Reddy B. S., Murthy K. R. G. K., 1970, Coastal Circulation in Kakinada Bay during monsoon period, Springer, Pure and applied Physics,Vol 89, PP 183-191.
4. Shetye S. R., Gouveia A. D. and Pathak M.C. 1990, Vulnerability of Indian Coastal region to damage from sea level rise., Current Science, Vol 59, No 3, PP- 152-156.
5. Chandramohan P., Nayak B. U., and Raju, V. S., 1988, Application of longshore transport equations to the Andhra coast, east coast of India, Coastal Engineering,Vol 12(3), 285-297.
6. Chandramohan P., and Nayak B., 1991. Longshore sediment transport along Indian coast, Indian Jour. Marine Science, Vol-20, pp- 110-114
7. Chandramohan P., Jena B. K., and V. Sunil Kumar, 2001, Littoral drift sources and sinks along the Indian coast, Current Science, vol. 81, no. 3, and pp- 292-297.
8. Kakani N. R., Takayasu K., SadakataN.and H. M. Bandaru, (1993), Studies on the Holocene evolution of the east coast deltas of India:present status and future prospects" ASCE, Deltas of the world, PP-1-15
9. Kakani N. Rao, K., Sadakata, N., Hema Malini, B., Sarma, V.V.L.N., Takayasu, K., Kawase, M., 2003. Reconstruction of the late Holocene progradation of the Godavari delta, India: a preliminary study. Transactions of Japanese Geomorphological Union 24, 295–309.

10. Kakani. Nageswara Rao, , Vardhan, D.A., Subraelu, P., 2007. Coastal topography and tsunami impact: GIS/GPS based mobile mapping of the coastal sectors affected by 2004-tsunami in Krishna-Godavari delta region. Eastern Geographer 13, 67–74
11. Kaliasundaram G., Govindasamy S. and Ganesan R. (1991), 'Coastal Erosions and Accretions', In: Coastal Zone Management in Tamilnadu State, India, Natarajan R., Dwivedi S.N. and Ramachandran S. (eds.), Ocean Data Centre, Anna University, Madras, pp. 73-82.
12. Murli R Mani Sunderesh, Bethamoni P., 2014,Morpho-dynamic evolution of Ekakula spit of Odisha coast, India using satellite data, Indian Journal of Marine Scince, Vol 43(7), pp-1-5.
13. Uma Devi E, Shenoi S S C, (2012), Tsunami and the Effects on Coastal Morphology and Ecosystems: A Report, Proc Indian and Sci. Academy, 78 No. 3 September 2012 pp. 513-521.
14. Ajay Nayak Sailesh, Team leaders, 2012, Coastal zones of India, Sponsored by Ministry of Environment and forests, Govt. of India, Space application center, ISRO Ahmadabad.
15. Mishra S.P. and Jena J. G. (2014),Migration of Tidal Inlets of Chilika Lagoon, Odisha, India -A Critical Study, Int. Journal of Engineering and Technology, Vol 6 No, 2014, Pp- 2453-2464.
16. Kunte P. D., Wagle B. G.,. 1993, Remote sensing approach to determine net shore drift direction - A case study of central east coast of India. Jour. of Coastal Research,Vol 9(3), 623-672.
17. Kunte P. D., Wagle B. G, Sugumori Y., 2001, Littoral transport studies along west coast of India, Ind. Journal of marine science, Vol–30, pp-57-64.
18. Pandian P. .K, Ramanamurthy M.V., Ramesh S., Ramachandran S., 2002, Hydrodynamics of Coloroon Inlet and its Influence on Pichavaram Mangrove Ecosystem, East Coast of India, Procs. 11th Biennial Conf. on Physics of Estuaries and Coastal Seas, (2002), Hamburg, Germany, Sept-17 – 20, 2002, pp- 162 - 166.
19. Pandian P.K.and Dharanirajan K., 2007, Beach morphology and coastal protection along Ennore coast in the north of Chennai city, southeast India, Indian Journal of Science and Technology, Vol 1 (1), pp-1-7.
20. Pandian.P.K., Ramesh S., Ramanamurthy M. V., Rama Ch.S.,&Thayumanavan S., 2004, Shoreline changes and near shore processes along Ennore Coast, EC of South Ind. Jr. Coastal Res. 20, 828-845.
21. Mohanti M. M., Swain M. R., 2005, Mahanadi river delta, east coast of India : an overview, Professor, Dept. of Geography, Utkal University, Odisha, Bhubaneswar 751 004, India, PP-1-9.
22. Phillips J. D., M. C. Slattery, 2006, Sediment storage, sea level, and sediment delivery to the ocean by coastal plain rivers, Progress in Physical Geography 30, 4 (2006) pp. 513–530.
23. Phillips J. D., Slattery M. C., Musselmana A. Z., 2004, Dam-to-delta sediment inputs and storage in the lower trinity river, Texas, Geomorphology 62, pp - 17–34.
24. Prabhakaran K. , Anbarasu. K., 2010, Evolution of Vaigai Delta, Tamilnadu, India (East Coast) During Quaternary, International Journal of Geomatics and Geosciences, Volume 1, No 2, 2010.
25. Ramesh R, Purvaja R., Senthil Vel A., 2011, National assessment of Shoreline changes: Pondicherry coast, NCSCM/MoEF report 2011-01.
26. Ramesh R, Purvaja R., Senthil Vel A., 2011, National assessment of Shoreline changes: Odisha coast, NCSCM/MoEF report 2011-01
27. Ramesh R., Purvaja R., Senthil V. A., 2012, National Assessment of shore line changes of Indian coast,NCSCM,/MOEF Report 2011-01, 57p, available at http:;//www.ncscm. org/reports .php
28. Hedgde V. S., Nayak S. R., Krishnaprasad P. A., Rajawat A. S., Shalini R., et al. (2015) Evolution of Diverging Spits Across the Tropical River Mouths, Central West Coast of India. J Coast Zone Manag , Vol 18: p-402. doi: 10.4172/jczm.1000402
29. Unnikrishnan A.S., Manimurali M., Ramesh KumarM.R.,(2008), Sea-level changes along the Indian coast, National Institute of Oceanography, Goa, www.moef.nic.in/sites/default/.../Un
30. Rajawat A. S.,Chauhan H. B., Ratheesh R.,Rode S., Bhandari R. J., Mahapatra M. et. al., 2015, Assessment of coastal erosion along the Indian coast on 1 : 25,000 scale using satellite data of 1989–1991 and 2004–2006 time frames, Current Sc., Vol. 109, no. 2, 25 ,pp- 347-353.
31. Natesan U., Parthasarathi A., Vishnunath R., Edwin G, Jeba Kumar, Vanecent A. et al, 2015, Monitoring long term shoreline changes along Tamilnadu, India, using geospatial technique,Elsivier, Aquatic Proceda, Volume 4, pp- 325-332
32. Panda D. K., Kumar A., Mohanty S., (2011), Recent trends in sediment load of the tropical (Peninsular) river basins of India, Elsevier, Global and Planetary Change 75 (2011) 108–118
33. Gupta Harish, Shuh-Ji Kao, Minhan Dao.,2012, The role of mega dams in reducing sediment fluxes: A case study of large Asian rivers, Journal of hydrology, Elsevier, Vol 464-465, P 447-448, 2012.

34. MOWR, GOI ,2006, 2012, and 2015, Integrated Hydrological data Book, non-classified rivers, Hydrological data directorate information system organization water planning and project wing, Central Water Commission, New Delhi.
35. Dongsheng Yu, 2006, Analysis on Impact of the Coriolis Forces on Flow in the Yangtze River Estuary, Third Chinese-German Joint Symposium on Coastal and Ocean Engineering National Cheng Kung University, Tainan November 8-16, 2006
36. K Vinod Ku**.** and Bhattacharya Asish, 2003, Geological evolution of Mahanadi delta, Orissa using high resolution satellite data, Current Science, VOL. 85,(10), pp- 1410-1412.
37. ICZAM Project Directorate, Chennai, 2009, Report on use of Satellite data for detection of violation of land use along the Coastal Regulation Zone and Impact of Port structures on Shoreline changes, Ministry of Earth Sciences Indian National Centre for Ocean Information Services (INCOIS), Hyderabad.
38. 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, no. 4, 25 August 2006
39. V. Sunil Ku., Dubhashi K. K., Balakrishnan Nair T. M. and Singh J., 2013, Wave power potential at a few Department of the Army, U S Army crop of Engineers, 1984, Shore Protection Manual, Waterways experiment station, Corps of Engineers, Coastal Engineering Research Center, Washington, D. C., 20402, Part I and Part II.
40. Laxmanan N., Gomathinayagam S., Harikrishna P., Abraham A.and S. Chitra Ganapathi,2009, Basic wind speed map of India with long-term hourly wind data, Current Science, Vol. 96, (7), pp-911-922
41. Jain I., Rai A. D., Jitendra V., Dube S. K., 2010, Computation of Expected Total Water Levels along the East Coast of India, Journal of Coastal Research, Vol26 (4), pp 681-687.
42. Saravanan S. and Chandrasekar N., 2010, Potential littoral sediment transport along the coast of South Eastern Coast of India, Earth Sci. Res. J. vol.14 no.2 Bogotá July/Dec. 2010.
43. Jena B.K., Chandramohan P.andV.Sanil Kumar, 2001, Longshore transport based on directional waves along north Tamilnadu coast, India, Journal of coastal research, Vol 17 (2) pp- 322-327.
44. MurthyK. S. R**.,** 2015, Exploring the Passive Margins–a case study from the Eastern Continental Margin of India, J. Ind. Geophysics. Union, Vol**.**19 (1), pp-11-26
45. Julian P. McCreary Jr. and ShulmanZhang,Shetye R., 1997, Coastal circulations driven by river outflowing a variable-density l 1/e-layer model, Journal of Geophysical Research, Vol.102,(C7),PP- 535-554
46. Mishra S. P., Panigrahi R., 2014, Storm impact on south Odisha coast, India, IJARSE, Vol. No.3, Issue No.11, pp-209-225
47. Misra K. S. and Joshi Vartika, 2013, Tectonic Disposition and Hydrocarbon Potential of 85° East Ridge in Bay of Bengal, presented at AAPG Int. Conven. and Exhibition, Singapore, 16-19.