Migration of Tidal Inlets of Chilika Lagoon, Odisha, India -A Critical Study

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Abstract: Chilika Lake, Asia's largest brackish water lagoon situated on the East coast of India is separated from Bay of Bengal by sand bars and connected with the sea by a series of tidal inlets. The inlets are maintained by discharges of inflowing streams during monsoon and by tides and ebb tides during non-monsoon. Imbalance in ingress and egress of sediment due to their continuous exchange between sea and the lagoon causes sedimentation of lagoon. Varying inflow, littoral drift and such other factors influence sedimentation. It results shifting mouths (inlets) continuously. Some mouths closed and some opened at various locations of the spits of the lagoon in course of time. This governs the inflow and the outflow characteristics and hence the salinity. A barrage at Naraj on Kathajodi, a major distributary of the river Mohanadi, and an artificial channel connecting the mouth of the Lagoon from Magarmunha to Bay of Bengal were provided to regulate the inflow. This phenomenon has been studied critically considering long history, geophysical parameters, terrestrial events and human interventions etc. Since the activities are location based, exact hydrodynamics has not yet been established for formation, closure and shifting of the tidal inlets. The present study deals with mouthing activities with time, the mechanism involved and effect of Naraj barrage on closure, migration and opening of new tidal inlets in Chilika Lagoon. The possible effects of celestial bodies and sun-earth geometry, which were unnoticed so far, are studied.

Key words- Chilika Lagoon, Tidal inlet, Shift, Barrier-spit, littoral drift

I. INTRODUCTION

Tidal inlets are small narrow passages in spits separating a lagoon and the sea. The dimensions and the flow through such inlets maintain the health and decides the characteristics of the lagoon (Kejerfve 1986)[1]. The Chilika Lagoon, the largest brackish water body of Asia, on the east coast of Odisha, India (lat $19^0 28' - 19^0 54'$ N and $85^0 15' – 85^0$-38' E) is 4000 years old (Venkatratnam 1970)[2].The lagoon is separated from Bay of Bengal by a barrier spit, 64.3km long and connected to it by four tidal inlets of varying depth and size.(Fig.1) All inlet activities occur on the onshore face of the lagoon. The brackish character of Chilika lagoon was deteriorated during past three decades of twentieth century. The hydrodynamic regime of the lagoon was affected during this period. Consequently the ecology, biodiversity and economy of the area were in Jeopardy. To regulate the inflow into the lagoon a diversion structure, the Naraj barrage is constructed at the mouth of river Kathajodi, adistributary of the river Mahanadi, which contributes about 61% of the inflow into the lagoon. An artificial mouth (inlet) is opened by excavating 17km long channel. Another 6.2m depth channel is dredged from confluence of Daya River, a branch of Kathajodi, to the tidal inlet to provide direct flow.These engineering interventions perhaps could change the geomorphic character of the lagoon to behave as a restricted lagoon. The present study deals with the mouthing activities with time, the mechanism involved and the effect of Naraj barrage on the closure, migration and opening of new tidal inlets in Chilika lagoon. Studies also have been done on the effect of meteorological events on mouthing activities of Chilika lagoon.

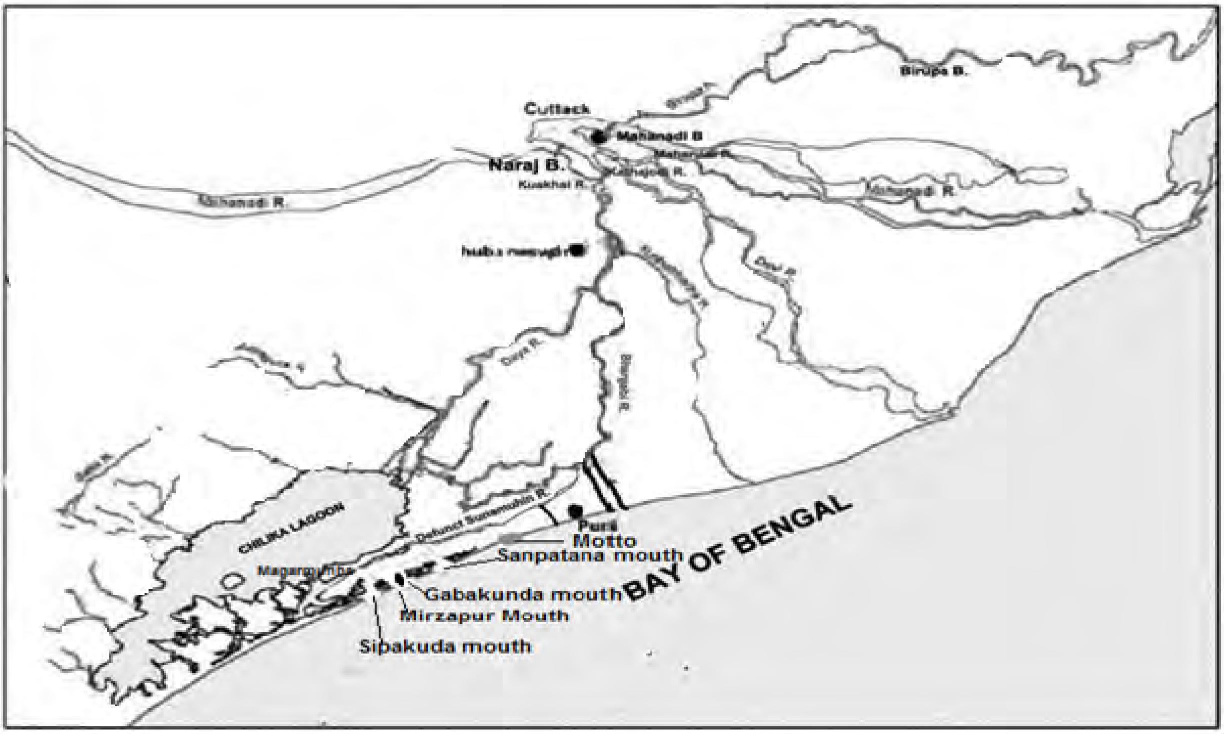

Fig 1 Index map of the study area: the Chilika lagoon, Southern Delta of Mahanadi River, the barrage and the mouths

II. PAST STUDIES

1. Mr. Andrew sterling, 1846,[3] was perhaps the first to record the presence of a mouth, 275m wide, 1.6km north of Manika Patna. He also noticed that the mouth was gradually silted up by sedimentation and littoral drift. It was excavated by the then Muslim landlords to facilitate movement of fishermen in 1820.
2. Hunter (1872)[4] reported the shifting to the north. However in case of severe storms and floods the shifting can back track.
3. Williams C. A. et al (1928)[5], on their tour notes reported that the shifting of mouth was caused by sedimentation in absence of proper flushing flood which should be maintained.
4. O' Brien et al (1972)[6], Escoffer et al (1978)[7], Kjerfve et al (1989)[8] and Ranasinghe et al (2003)[9] have studied the shifting of mouth and the quantum of sand transport through tidal inlets of different lagoons. They noted that the shifting, opening and closing of the tidal inlets are due to littoral drift and inland flood flow. They have indicated the mechanism of such phenomena.
5. Chandramohan P. et al (1993)[10] have calculated and measured the amount of sand transported from Bay of Bengal to the Chilika to be 1millon MT annually.
6. FitzGerald D. M. et al (2008)[11] mentioned that effect of Sea level rise (SLR) on coasts influence short term and long term mobility of barriers and coastal beaches. Sediment input by flow control onshore profile, a unique characteristic of each coast. The tidal inlet opening and enlargement in future will be due to this SLR.
7. Abinash K. et al (2013)[12] , on satellite imagery study recorded that strong current due to SW monsoon and long shore drifts are responsible for creation and growth of the spit.
8. Panda U. S. et al 2013[13] found that numerical modeling the geomorphic changes of the lagoon are due to combined actions of tides, waves and sediments. Tidal inlet activities and choking of outer channel are the causes of depletion of salinity, depth and weak flow exchanges.
9. Rao J. R. et al (2013)[14]: Taking the help of satellite imagery, the study of the barrier island in the out skirt of the outer channel of the lake and the stipulation of naturally opening mouths is done by Mr. Rao. The author is of opinion that a portion of the lagoon has been converted to sea.

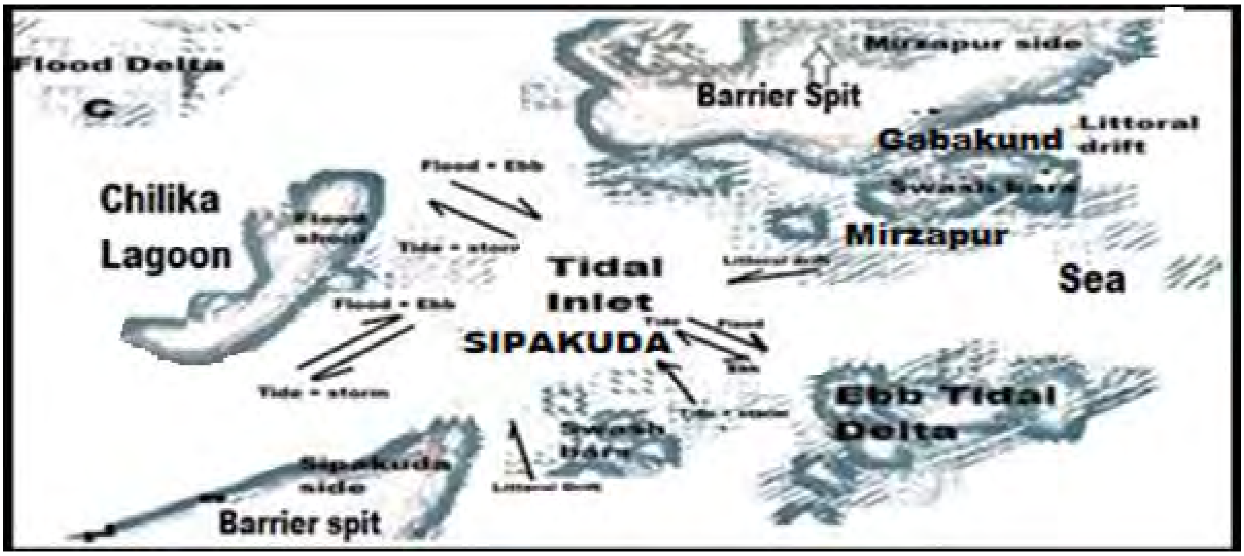

Fig 2: Sand corridor: Flood ebb delta and Ebb tidal delta on both sides of tidal inlet of lagoon.

III. INFLOW

Inflow into the lagoon plays vital role in shifting and widening of mouths. The lagoon behaves as a balancing reservoir to absorb flood flow and then discharge it to the sea. During expulsion of flood to the sea, the large volume of water opens the mouth wider and deeper. But on recession of the flood, the opened inlet section restores its depth. The width of opening from southern side gets filled up by accretion. But the northern flange remains as it is. Thus there is a shift.

This change in geomorphology of the inlets is mostly influenced by volume of flood flow. Since major contribution to the lake (about 61%) is from Mahanadi system, this flood plays a major role in the process (Mishra and Jena 2012).[15] Very high floods of the river Mahanadi more than 28700cumec, contribute much in changing the sand corridor and shoals within the outer channel of the lagoon and ultimately, the tidal inlets.[Fig. 2] The flushing flow required for the lagoon to maintain the health. Construction of the barrage at Naraj was made to moderate the flow and provide the flushing flood flow of 2830cumec to the Lagoon.(Dash & Jena 2008)[16]The effect of artificial tidal inlet of 2000 along with the Naraj Barrage on opening, closing and shifting of inlets across spit of Chilika is enlisted.[Fig.3] During expulsion of flood to the sea, the large volume of water opens the mouth wider and deeper. But on recession of the flood, the opened inlet section restores its depth. The width of opening from southern side gets filled up by accretion. But the northern flange remains as it is. Thus there is a shift.

Sediment ingress and egress across the mouth of Chilika Lake are governed by geometry, numbers of inlets, and topography of the back barrier channel near shore bed slope and quantum of available sediment around the mouth. Human interventions and hydrodynamic modifications are also responsible for the sedimentation.

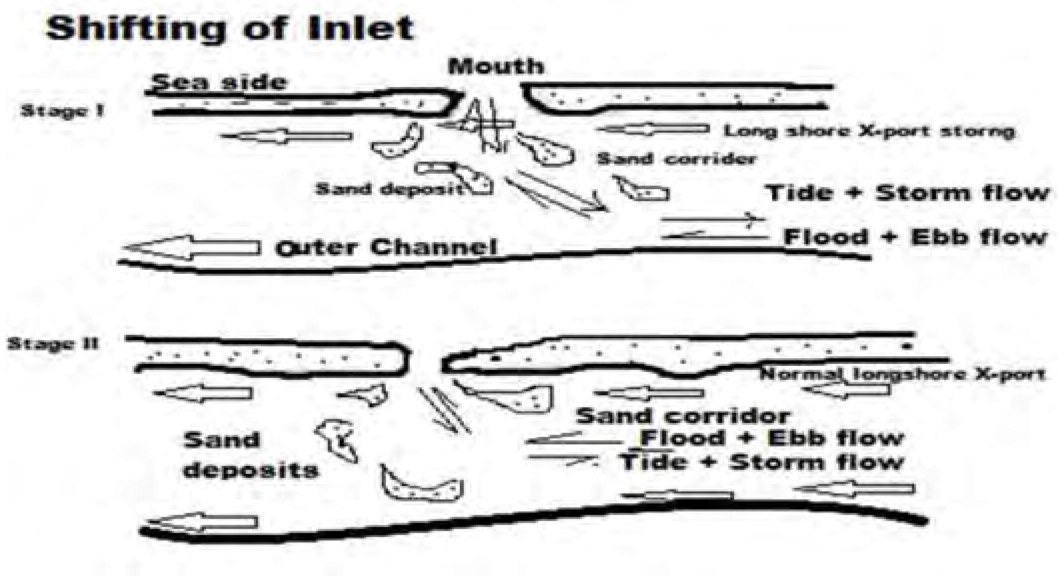

Fig 3: Process of shifting of tidal inlets

IV.TIDAL INLETS

At present the lagoon is connected to Bay of Bengal through four tidal inlets at Sipakuda, Mirzapur, Gabakunda and Sanpatna. Of these, only the Sipakuda mouth was artificially dredged 7.262km East of Magarmunha during Sept 2000. The old shallow inlet at Village Motto, 34km from the lake mouth Magarmunha was closed in natural processes by Nov 2003 and Sipakuda inlet shifted north by 400m [Fig.1]**.** Another mouth opened on 1st August, 2008, 2.3km north of Sipakuda, at Gabakunda. It was a full solar Eclipse day with influence of deep depression in the adjacent area. Sipakuda mouth was shifted by 550m north east during the same period. In Feb 2010 another tidal inlet at Mirzapur opened 1.0km SW of Gabakunda Mouth during solar eclipse day. By then the Sipakuda mouth had shifted by 830m and the Gabakunda mouth, by 200m to NE from the place of origin. By 2012 the Sipakuda mouth shifted by 1.5km, Gabakunda mouth by 500m and Mirzapur mouth by 300m from place of origin in north east direction. Meanwhile during December 2012 a mouth also opened at Sanapatna, 4.511km from the origin of the dredged mouth close to a full solar eclipse day. In 2013, Phailin, a very severe cyclonic storm (VSCS) visited the area. Though there was no eclipse during the period, the wave heights rose by 4m. Even then no new mouth opened. But under the influence of the VSCS, the artificial mouth at Sipakuda shifted by 1.857 km reducing the water channel. The Gabakunda mouth and Mirzapur mouth merged with each other and moved in NE direction. The inlet at Sanpatna was widened by 521m.The available information about the changes of inlet location in case of pre-dredging and pre-Naraj Barrage period is given in Table.I.

TABLE I
Shifting history of tidal inlets Pre-Naraj barrage

Sl No	Year /date	Location of mouth relative to village Arakhakuda	width	Status if any	Source
1	2nd,Jan-1632	Sanpatna (11.1km from Calepur (Hasimpur Kalapahara's port)		Strong tidal current the boat capsized	Thomas watts, Master of ship Hope Well- (Foster 1910) {Dujovny E 2009}
2	6th, sept-1680	1.6.5 km SW of Harachandi temple Manikpatna(Dahikhia) 2.River of Kempthron falling to sea near 3.25km NE S	small	Small entrance not used for ships, surf dominated	Port and land marks to lake Chilika (1680-87) source Britrish library(Pati D.C. 1940)
3	1708	10kms from Satapada in front of Manikpatna	-	A great inlet	Hamilton et al 2001 quoted by {Dujovny E 2009}
4	1780		1600m		S. Tripati and K. H Vora 2004
5	1820	1.6 km north of ManikaPatana	275m	choked and unfit for boat movement	Excavated by PWD (Sterling, A. 1846) and hunter 1847
6	1858	2.6kms NE is Arakhakuda	Large openin g	Less depth	W pearson's chart and Cap. J. P. Meadlr SE's Lr dt 16.10.1859
7	1907	In front Manikpatna	60m	choked	S. Tripati and K. H Vora 2004
8	1914	In front of Village Sanapatna, 6Km NE is Arakhakuda			S. Tripati and K. H Vora 2004
9	1927	In front of sanpatna	1500m	wide	Orissa flood committee 1928
10	28th Jan 1928	In front of Sanpatna	250m	Constricted	Orissa flood committee 1928
11	1942	Shifted towards (Arakhakuda) NE direction.		Stable and minimum changes	Orissa third interim flood committee report 1928
12	1965	8kms NE is Arakhakuda	1913m	Better hydraulic regime	S. Tripati and K. H Vora 2004
13	1968	About 7km NE is Arakhakuda	40-50m	choked	Locally collected
14	1975	About 4.5kms NE is Arakhakuda About 5.2kms NE is About 6.2kms NE is Arakhakuda near sanpatna		Behaved as a restricted lagoon	
15	1985	4.5km NE is Arakhakuda 0.6km SW is ArakhaKuda near village Motto		There are two inlets	
16	1986	4km Ne is Arakhakuda		Inlet near Sanpatna closed (choked)	
17	1991	5.5km NE is Arakhakuda			

A. Formation of tidal inlets

The dynamics of inlets in barrier spits of the coast is influenced by erosion and deposition of sediments. (Kirk Van De 2008)[17] The closure, shifting and opening of new inlets occur due to reduced hydraulic efficiency, circulation processes and off shore activities. The dynamics exhibits a semi cyclic pattern with time. Under usual milieu unstable barrier spits exhibit distortions along the mouth, migration of inlets, hydraulic deficiencies accompanied by formation of new inlets along the outer channel and have a quasi cyclic pattern (Giese G. S. 2008)[18] . The geometry of a tidal inlet consists of a main tidal channel (straight or bent), shoals near the barrier beaches having flood delta on the lagoon side and ebb delta on the fore bay side [Fig.2]. The position, dimension of the tidal inlets and the quantum of flow decide the flushing time, the residence time, number of tidal inlets, salinity stratification and shifting of mouths of the lagoon.

B. Shifting of tidal inlets

It has been noticed that sand is transported and deposited in the inlet zone of the long shore drift during shifting of inlets and breach of spits. This constricts the cross sectional area of the mouth gradually and reduces the flow area. Velocity increases due to constriction, scouring of the channel is accelerated and finally equilibrium is maintained for some period. But with time this equilibrium is disturbed due to extreme flood events and meteorological disturbances. Regular movement of the sediments due to long shore transport causes deposits on the southern flange and erosion on the northern. This process moves the centerline of the mouth to north**.** The rate of this migration depends upon the morphology of the spit, the tidal current, the wave energy and finally the quantum of sediment transported.

C. Opening of new tidal inlets

The opening to ocean from a lagoon may be artificial or natural. The mouths of Chilika lagoon were almost closed before 2000. To protect the lake from its ill health, Chilika Development Authority, excavated a new mouth 17km down the old one near Sipakida village on 23rd September 2000, to make the flow straighter. The cut was widened from 80m to 676m subsequently by itself. The extension is relatively more towards North East. But three mouths at Gabakunda (1st Aug 2008), Mirzapur (1st week Feb 2010) and Sanapatna (1st week of Dec 2012) opened naturally either due to sun-earth geometry or sediment transport mechanism along the mouth. [Fig. 4]

Four processes can be attributed to formation of inlets in Chilika.

1) The narrow spits are the most dynamic and transient landforms. Offshore Chilika lagoon encounters a number of meteorological events like eclipses, storms and earthquakes of mild intensity and low vulnerability index (Kumar T.S. et al 2010)[19]. These events create storm surges which overtop the spit at places. These surges scour the trough and cause breaching to form inlets.

2) Constriction of the old mouth induces seepage through the porous sand in the adjacent ridges due to difference in water level between the two interfaces. This sometimes creates an inlet.

3) In case of very high floods in river Mahanadi, the water level in the lagoon rises by 1.5m to 2.0m. When the flood situation persists and the reservoir capacity of the lagoon is exceeded, breeches occur in the low level areas of the spit and form a new inlet.

4) On landfall of storms along the area, large volume of water enters the lagoon. When the storm weakens, the wind blows in a reverse direction, which forces the water to create a vent in the low lying area. Hence a new inlet is formed.

Once the opening is made wind does its own work to widen the channel**.** [Fig.6]

D. Closure of tidal inlets

Closure of tidal inlet in a lagoon can be seasonal or permanent. In a shallow lagoon system, short term closure is attributable to meteorological phenomena, flood events, dispersion and advection of mixing processes, turbidity gradient and hydrodynamic regimes. Chilika Lake is a micro tidal and wave dominated shallow lagoon. Closure of mouths in Chilika takes a long period. This does not happen annually. The mouth reduces its cross section temporarily in reduced flow exchange process and enhances its flushing time. The mouth reforms by attrition during meteorological events, strong wind and high tide conditions. A permanent closure of a tidal inlet is due either to opening of another new mouth or continuous drought for a long period in the catchment. Absence of proper flushing, circulation, dispersion, stratification affects the salinity of the lagoon. The dominant-sediment loading either from the lagoon side or through littoral drift of the ocean also influences the salinity. Tidal inlet depth is depleted by sedimentation year after year and finally disallows flow through the channel. In case of Chilika Lake, the mouth opened at Sanapatna took six years to close (1980-1986). The age old inlet near Arkhakuda village took four years to close after the opening of a new artificial mouth at Sipakuda. The closure of mouth in the Chilika is associated with malignant growth of ebb shoals in front of the mouth.

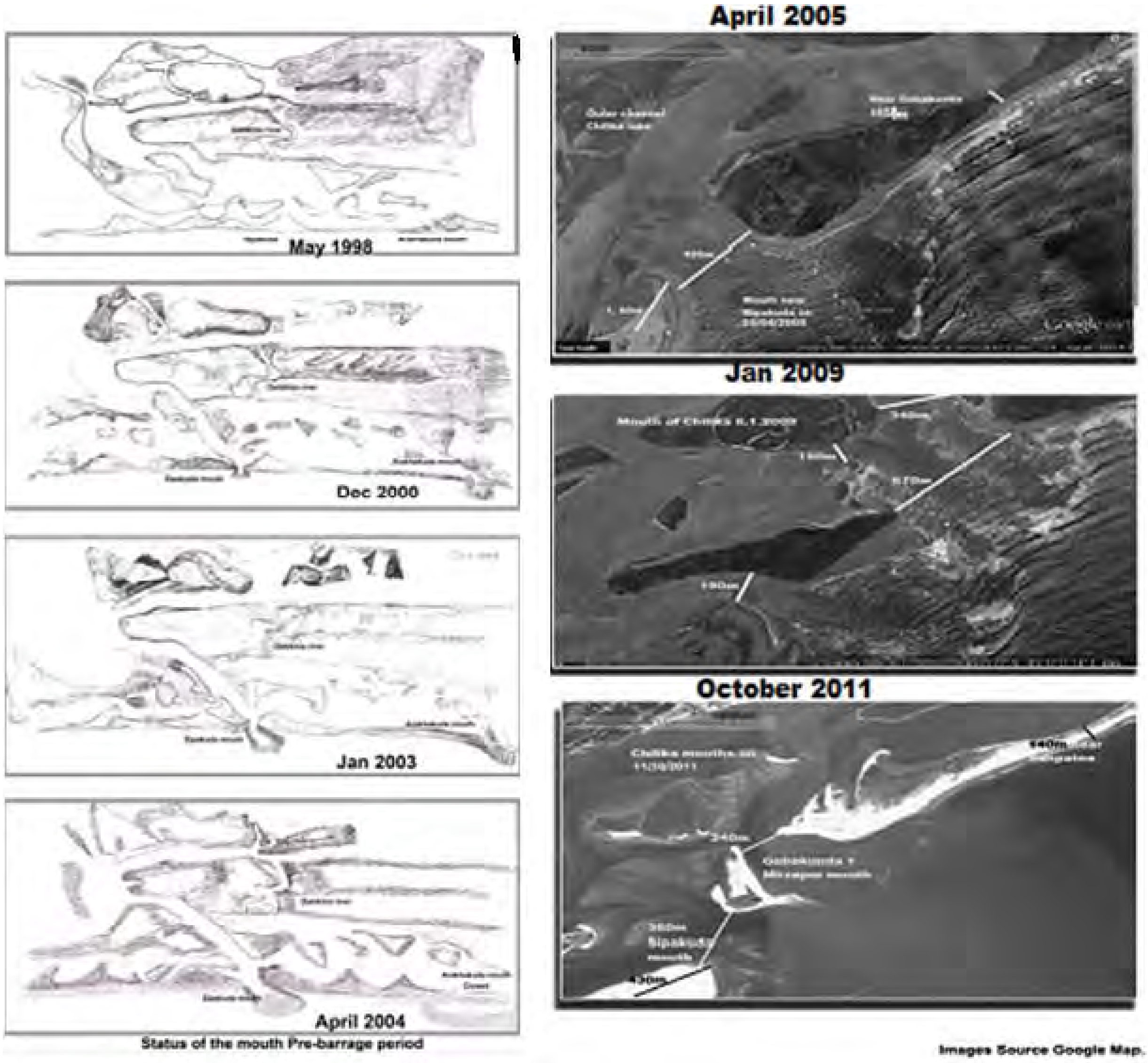

Fig. 4: Sketches and satellite imagery: tidal inlets of Chilika, pre and post Naraj barrage (Source Google Earth)

V. LITTORAL DRIFT

The sediment movement and shore line changes are influenced by number of lagoon entrances, section, location of inlets, inland flow, tide, waves, sediment size, Coriolis Effect and the aeolian physics. Any change in these factors can cause severe down-drift erosion or down-drift accretion of large swash bars.[Fig. 5]

The extreme climatic events fluctuate the shoreline of Chilika and the net shift was at the rate of 1.09 m per year towards Bay of Bengal from the year 1936 to 2005. The tidal inlets of Chilika Lagoon are influenced by micro tidal waves and the fine grained sandy coast with steeper slopes in north flank than the south. Sediment transport occurs in the surf zone, moves parallel to the coast. A part of the sediment gets deposited on the shore. Deposition is primarily due the oblique waves breaking near the shore. Storm surges overtop and overwash a large quantum of water laden with sediment from Bay to the back barrier lagoon. After the storm, the evacuation of that volume through the channel section slows down. Consequently the channel section either closes or shifts. The longshore transport is accountable for the closure of an inlet. The closure or opening of inlets transforms Chilika from choked to restricted.[Fig. 6]

Fig 5: Long shore drift in the northern end of the outer channel of Chilika Lagoon

It is also noteworthy that a coast parallel river Sunamunhi was running parralal to the coast for 25kms and debouching to the lagoon in past. It is defunct today due to Mangala cut and Gobakund cut, upstream. It is silted up today alongwith its drainage channels.The supply of monsoon flow through this river was helping in maintaining the inlet status. The absence of the river disturbed the smooth flow. As a result, Chilika went into ill health.

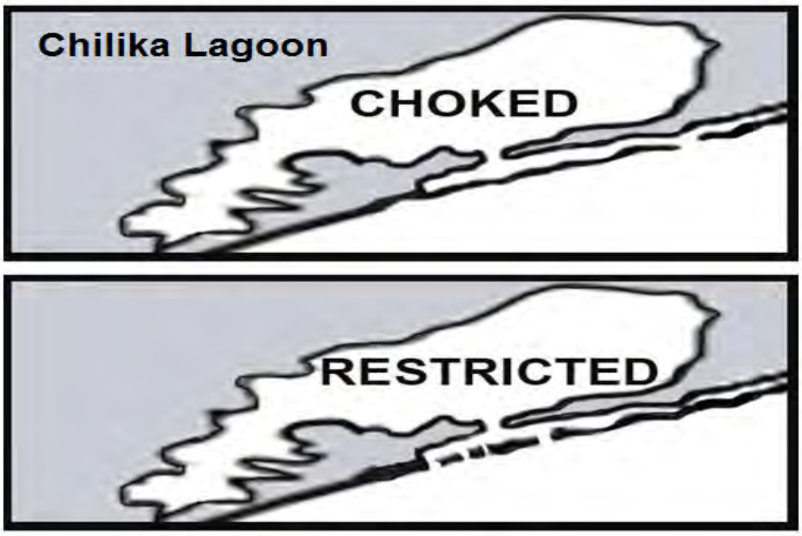

Fig 6. Chilika Lagoon from choked to restricted

VI. OBSERVATION AND DISCUSSION

The Chilika lagoon had all the characteristics of choked lagoon having a single window for flow exchange with a long flushing time, high wave energy, and significant littoral drift before 2000. After opening of the Sipakuda mouth, it has been converted to a restricted one (Kjerfve B. 1986). [20] Current and water levels are influenced by monsoons and wind force. Wind driven circulation pattern are poorly developed. As a choked lagoon Chilika had low frequency of flow exchanges occurring with slow rise and fall in the sea level. Now that it is a restricted lagoon the situation has altered.

The area up to Garh Krishna Prasad is an accretion zone of balance sediments. In this zone sand dunes are lying perpendicular to the spit. Mahisha Berhampur village is the erosion zone. Beyond Mahisha Berhampur lies the erosion zone and sand dunes of small width are parallel to the shore. This is the zone of all mouthing activities.

The storms crossing Chilika coast and the floods passing through the lake can be correlated with mouthing activities. The storm, the flood and the mouthing events from 1900 till date are presented in Table II.

TABLE II
Cyclonic storms Chilika coast and mouthing effect

Sl No	Year/ date	Disturbance type	VSCS/SC landfall coast	Surge data/ Flood condition	Wind speed km/h	Effect of the event
1	4th Oct. 1936	VSCS	Puri	Severe flood Puri dist.	137	No immediate effect known
2	10th Oct. 1938	VSCS	Ganjam	-	170	No immediate effect known
3	16th Oct. 1942	VSCS	Balasore	Severe	>168.5	No immediate effect known
4	16th Nov. 1942	VSCS	Ganjam	Less severe	168.5	No immediate effect known
5	9-11th Oct. 1967	VSCS	Puri	Water level rise 5m (app) and surge 25km inland river	157	No immediate effect known
6	Oct 21-28 & Nov 10-13 1968	SCS	Chilika	High flood in Chilika lake,25km U/S flooded during solar eclipse full	111	Three mouths opened at Kalabanta, Saibahata & Sanpatna
7	30th Oct 1971	VSCS	Paradip	Water level rise 6mtr, surge 10-25km inland	170	Two new mouths opened
8	22nd Sept 1972	VSCS	Gopalpur	Surge 2.4m	136	No immediate effect known
9	9th Nov. 1973	VSCS	Paradip	3-4.5m surge near paradip	139	No immediate effect known
10	24-28 Sept 1981	SCS	Puri	-	102	No immediate effect known
11	21-25 Jul 1989	SCS	South Orissa	--	102	No immediate effect known
12	9th Nov. 1995	VSCS	Gopalpur	1.5m surge Rushikulya River.	130	No immediate effect known
13	17th Oct 1999	VSCS	Gopalpur	2.0m surge in Rushikulya river	185	No immediate effect known
14	29th Oct 1999	SC	Paradip	Storm surge 8mtrs travelling 20km inland	259	No immediate effect known
15	9th – 12th Oct 2013	VSCS	Gopalpur	Storm surge of 3.5 to 40m	240	The artificial mouth opened on 2000 at Sipakuda got partly closed

It has been observed that the events of opening of new tidal inlets are also correlated to the terrestrial events mostly Solar Eclipse. The strong wind has caused opening of three mouths during eclipse period in the barrier spit. The Gabakunda inlet was opened on a solar eclipse day associated with a deep depression in the coast of the Chilika. The opening was fast and alarming. The Mirzapur inlet was opened gradually during solar eclipse period just after 15.1.2010. The mouth opened slowly and took 5 to 10 days after the eclipse. Similarly the latest Sanapatna inlet also opened during solar eclipse just after 13.11.2012. This indicates that the high waves due to solar eclipses are conducive to opening of new mouths in the Chilika barrier spits. Meteorological disturbances augment the process.

Naraj barrage was in operation since a decade. Its effect of allowing flushing flood of the lagoon is yet to be studied. The hydrological intervention incorporated by dredging the artificial tidal inlet at Sipakuda has played some role over the mouthing activities. It must have some effect on the opening or closing of mouths. Very high floods in association with storm surges created due to meteorological extreme events have become regular for last ten years. Opening of mouths at regular interval has changed the characteristics of the lagoon. The effect of the barrage and the artificial tidal inlet on the inlets of the lagoon during post Naraj barrage period is listed in Table III.

TABLE III
Status of Mouths of Chilika after Naraj barrage

Sl No	**Year /date**	**Location of mouth relative to village Arakhakuda**	**Width of mouths (South-North**	**Status if any/ Solar eclipse /flood status**	**Reference**
1	23 sept. 2000	7.262km NEE of Satapada at Sipakuda and 1.2km SW is ArakhaKuda near village Motto		New mouth Dredged and opened by CDA.	Mohanty, P. K. 2009
2	Nov 2003	Old Mouth at Motto vil. Closed completely.New mouth Sipakuda shifted .4km NE		Old mouth at Motto inlet 24kms from Satpada is closed. 23rd Nov. 2003 (total solar eclipse.)/flood of 38223 cumec prior in river Mahanadi 30th Aug	Mohanty, P. K. et al. (2009)
3	1st Aug 2008	Spikuda mouth shifted 0.55m NE and a natural mouth opened near Gabakunda 2.3km from Sipakuda mouth	Width 236m , depth 3m	A new shoal formed in front of Sipakuda mouth diverting major flow in the channel. 1st Aug. 2008 (total solar eclipse.) flood followed 44750 cumec 23rd Sept	Mohanty, P. K. et al. (2009) Google earth picture 6.1.2009
5	11th July 2011	Sipakuda mouth shifted .43km and Gabakund mouth 0.2Km to NE. 1.0 km NE of Sipakuda mouth. A small inlet opened near Mirzapur	360 m , 240m	Tendency of migration to NE in all mouths	Google earth picture of 11.10.2011
6	20th Nov. 2012	Sipakuda mouth shifted .85km and Gabakund mouth 0.35Km to NE. Mirzapur mouth .2km NE and a new mouth opened at Sanpatna 4.5km SW of Sipakuda Nov. 2012	340m 370m 250m	Tendency of migration to NE in all mouths, Reduction in width of Sipakuda and Gabakunda mouth and enlargement of Gabakunda and Sanapatna mouth. 13th Nov 2012 (total solar eclipse. not visible in India) flood of 17726 cumec on 6th Aug 2012	Google earth picture 28.4.2013
7	12th Oct. 2013	Sipakuda mouth shifted by 1827m from origin, Mirzapur and sipakuda mouth about to merge	392m 387m 521m	A VSCS (Phailin) crossed Chilika coast of wind speed of about 200km/h but no event of eclipse.	Field data

Fig 7: Status of tidal inlets of Chilika lagoon on 28.4.2013 (Source: Google earth)

A very severe cyclonic storm crossed Chilika coast on 12th Oct 2013 creating storm surges of four meters with a lot of devastaions to the ecology of the area. There was no eclipse during that period. The impact of the storm has partly closed the dredged mouth. This cyclone has almost closed the gap between the Gabakund and Mirzapur mouth. The Sanpatna mouth is widened but no new inlets formed. (Fig. 7)

VII. CONCLUSION

The status and the behavior of the Chilika lagoon for the last two centuries have been studied. The Lagoon is situated on a characteristic tropical humid area where there is a sinusoidal behavior of closing and opening of inlets. Within last ten years the lagoon has changed its character from a choked to restricted one.

The closing and opening of tidal inlets in Chilika lagoon are less influenced by meteorological disturbances by themselves. Very severe cyclones cause inlet formation. The solar eclipses not the lunar eclipses influence the mouthing activities. The contributing atmosphere to the breaching process is Meteorological disturbances combined with solar eclipses and very high flood in Mahanadi basin. No major storms crossed Chilika coast from 2000 to 2012. Yet three mouths opened and one mouth closed after operation of Naraj. This may be due to combined effect of Naraj barrage and the mouth artificially dredged in the year 2000.

Causes of opening, closing and shifting of inlets seem to be the following:

1) Meteorological events like eclipses, storms and earthquakes events create storm surges which overtop the spit at places. These surges scour the trough and cause breaching to form inlets.

2) Constriction of the old mouth induces seepage through the porous sand in the adjacent ridges due to difference in water level between the two interfaces. This sometimes creates an inlet.

3) In case of very high floods in river Mahanadi, the water level in the lagoon rises by 1.5m to 2.0m. When the flood situation persists and the reservoir capacity of the lagoon is exceeded, breeches occur in the low level areas of the spit and form a new inlet.

4) Floods of Mahanadi basin, aeolian activities along the shore front and wave dynamics cause shifting of tidal inlets.

5) On landfall of storms along the area, large volume of water enters the lagoon. When the storm weakens, the wind blows in a reverse direction, which forces the water to create a vent in the low lying area. Hence a new inlet is formed.

6) Littoral drift, continuous deficient runoff of the Mahanadi basin for two to three years forms large ebb deltas on both face of the inlet and induces closure of a tidal inlet.

ACKNOWLEDGEMENT

The authors pay their gratitude to use some remote sensing pictures from the source “Impact of new mouth opening on morphology and water quality of Chilika lagoon – a study based on resources Sat-1, LISS III, and AWiFS & IRS-1D LISS-III data” by Rajwat A. S., Gupta M.M. et al (2007). The authors are also thankful to the Department of Water Resources, Govt of Odisha and Dr. A. K. Pattnaik, CEO, CDA for providing information related to the works.

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