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Anthropocene Physiography and Morphology of Chilika; India

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Authors' contributions

This work was carried out in collaboration among all authors. Author SPM designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors RNN and KCS managed the GIS and RS works of the study. Author SM managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Introduction: Based on stratigraphy, events, ecology and climatology, the present time is assigned Anthropocene epoch due to dominance Homosapiens over geo- bio-hydro-aero spheres of the mother earth during its accepted Anthropocene epoch succeeding the official 11700 years old Holocene epoch from 1950. Asia's largest shallow brackish water lagoon, the Chilika housed over about 1000km^2, behind 64.3km barrier spit with multiple tidal inlets to Bay of Bengal. It is sinking and shrinking due to rapid dimensional diminution, environmental degradation, sedimentation, salinity depletion, phytoplankton invasion. Present study envisages the elementary morphology, formation mechanism, sediment transport, and dynamic performance of tidal inlets and the lagoon by applying GIS methodology between the year 1930 and 2017 including its local catchment land use changes within the lagoon and associated south Mahanadi delta. Under vulnerability, the

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brackish water lagoon is constantly deteriorating its ecosystem, it is required for wise use of the wetland that can alleviate the poverty, uplift lagoon users economy, and disallowing the stakeholders living standard during present Anthropocene epoch

Keywords: Anthropocene; Chilika lagoon; Mahanadi delta; morphology.

ABBREVIATIONS

SMD	*: South Mahanadi delta;*
RSLR	*: Regional sea level rise;*
KYBP	*:Thousand years before present;*
IUGS	*:International Union of Geological Sciences;*
ICS	*:The International Commission on Stratigraphy;*
TI	*: tidal inlets*

1. INTRODUCTION

Coastal lagoons are fugacious hydrologic land-forms in geological time scale and ephemeral water body sustains for three to four thousand years [1]. The Chilika is formed during three to four thousand years before present (KYBP) estuarine brackish water lagoon which was well-thought-out as a gulf in coastal environment in past. The estuarine amphitheater is attached to the south Mahanadi delta (SMD) of south Odisha that spreads over east coast of India. The Lagoon enjoyed tropical climate, burgeoning demography and was running with wide-ranged fiscal growth in past with port, and harbor activities. Presently the lagoon users are running under marring economy, impairing food and water security. It is also facing numerous meteorological extremes and has problems of sedimentation, diminutions and weed infestation. Severe stress on its biome has led to bio-degradation, ecosystem services depletion from 1980 to till date.

The Chilika area was an estuary of the river Daya, low lying coastal areas prior to Holocene epoch [2]. Later regional sea level rise (RSLR) has inundated the area during pre-Holocene. It was transformed to a shallow lagoon after construction of a barrier pit from south. The continuous declining of its expanse had reduced the Greater Chilika (area 1500 Km^2) had shrank and shallowed it to ≈1000 Km^2 as on date. Now it is struggling for its survival as a river/tide induced flushing lacustrine area with asymmetric inland vs. tidal flow. The large water body was having marine connectivity of east and west till 15th century. It is under threats of conversion to a freshwater lake or swamp due to loss of depth, and loss of oceanic-inland exchanges. Records reveal that it started declining under burgeoning demographic growth and anthropogenic pressure has increased from 1970 onwards.

1.1 Geological Time Scale Stratification

The geological time scale the earth is running as on date in the Phanerozoic eon, Cenozoic era, Quaternary period and widely accepted Anthropocene epoch though not declared by the International Union of Geological Sciences (IUGS) and the International Commission on Stratigraphy (ICS). The Anthropocene epoch has succeeded the 11.7K years old Holocene epoch after the nuclear explosion on 16th July 1945 (proposed 1950). The dominance of homosapiens over geo-bio-hydro and atmosphere is the Anthropocene epoch [3,4]. The homosapiens evolution was from ≈2.0 MYBP and is mainly accountable for the frame work for the eco-system anomalies, climate changes [5].

2. REVIEW OF LITERATURE

The post Holocene research works were scanty and were mainly based on history Sterling et al. [6], Cotton FC. [7], etymology, geography, geology, hydrology, and hydraulics Harrish JC. [8],Blanford [9], Mahalanobish [10], report (unpublished) and geomorphology of the Chilika lagoon and the south Mahanadi delta were studied by various in the past before 16th to 19th century by, Hunter [11], Sewell RBS [12], William et al. [13]. The extensive study of flora, Biswas [14], fauna Stephenson [15], Annadale N [16], Annandale, Kemp [17], Chaudhury BL [18], avifauna and the aqua faunal diversity and availability were studied by many authors during last part of Holocene epoch [19,20].

Anthropocene studies of geomorphology of coastal systems was originated by Pritchard D. W. [21], by defining inland ocean connected systems like lagoons, estuaries, Fjords etc. The studies such as estuaries, O'brien [22], Lagoon, Phleger [23], Fjord, Bay, strait and tidal rivers are explained by Kjerfve et al. [24,25]. The origin and sorting of the lagoons are initiated by Lankford R. [26], Fair Bridge [27], worked on classification of lagoons, coastal processes, Kjerfve et al. [24,25]. The tidal inlets formation occur under high energy and constrict the coastline due to asymmetrical sediment transport at the estuaries head or drowned river valleys with growth of spits and barrier islands, Fitz Gerald et al. [28], Mishra SP. [29]. The closing and opening of tidal inlets in the barrier spit of the lagoon take place by wave action, sedimentation and littoral drift Mishra SP. [30]. Anthropogenic and natural factors change geomorphology of a lagoon Mee [31], Mangor K. [32], Nayak PK. [33], Pradhan S et al. [34],

The Chilika lagoon was declared as a Ramsar site number 229, on 1st Oct., 1981, based on Zoological survey report of India 1985-87, placed in IUCN red list in 1993 for its biodegradation and vulnerability of conversion to a sweet water lake, during the golden spike period of the Anthropocene. Its ecology [35], archeology, meteorology [36], hydrology [37], geomorphology [38], fluvial influx [39], sedimentology [40,41] and lithology and geography [42,43], Sarkar et al. [44] were researched and unanimous opinion was about deteriorating health of the lagoon.

The pre-Anthropocene period from 1950 to 1980; many researchers have worked on the lagoon on various aspects; like its geography, formation of Chilika Venkat ratnam K [45], Change in coast line, flora, fauna Mahapatra LK. [46], avifauna Kachar KS. [47], methods of catching Jhingran VG. [48], geography, hydrology, sedimentology etc., Venkatratnam K [49], Roy Chaudhuri B. [50], Banerjee AC [51]. They have worked in different fields like geology, Bhattacharaya S. [52], Sahu et al. [53], Nandi AK. [54], hydrology Das et al. [55], Das et al. [56], Mukherjee S. [57], meteorology Mishra SP et al. [58], water resources Mishra SP [59], Hazara et al. [60], petrology Mohanty et al. [61], geomorphology Pattanaik S [62], Environmental impact assessment Bhatta et al. [63], sedimentology, radiology, Fossils and pollen grain studies and other fields Mishra SP. [64].

The lagoon started deteriorating gradually from 1980 onwards on the wake of golden spike period of the Anthropocene Epoch. Under the emerging anthropogenic pressure, climate change and meteorological extremes, the lagoon users are put to threat of their livelihood, and the ecosystem since last 3-4 decades. Least researches particularly made over Physiography and morphology of SMD and the associated Basin of the lagoon.

2.1 The Scope of the Study

The lagoon Chilika is of estuarine ephemeral in character of catchment area of 4577km2. The basin canopy comprises of the western catchment 2800sqkm and SMD of 1777sqkm draining locally to Chilika at a ratio constituted 61.15% and 38.85% along with supplemented by about 6% high flood flow of the Mahanadi river through the rivers Daya and the Bhargovi [65]. The lagoon has capacity of 4Km3 with average inland inflow of 14331 MCUM per year [66]. The local catchment of Chilika consists of denudation hills (southern fringe), sand dunes and barrier spit along coast in the east, swamps of about 4300km 2 in NW and alluvial deltaic plains of the SMD [67]. The studies were made on zone of littoral transition, the Chilika coastline geology [68], Rao N Kakani et al. [69]. A considerable number of researchers have studied on the geomorphology, coastal activities, socio political issues, physiochemical character in the lagoon to meet the human requirement. Least work is done on Physiography and morphology changes of SMD and the western catchment which is the present scope of the study.

3. OBJECTIVE

The study is made to probe the climatic, anthropogenic interventions on the lake dimensions, salinity, ecosystem disparity, and migration due to economic disproportion during both the pre-Anthropocene (1945-1980) and great acceleration period (1981-till date). The changes include the lake characteristics, land use and land cover of the catchment, the pollution rate, salinity changes, inland flow, biodiversity, coastal spit and contentious issues, relate to the flash points for degradation of the panoramic lagoon. During early 21st century, ameliorative measures are taken considering threats to the Chilika. They are dredging a direct mouth at Sipakuda (2000), operation of Naraj barrage at delta head (2004), renovating Gabakund cut and the channel from Badagotha to the tidal inlets (TI's) in OC. Past researches reveal that all aspects pertinent to the lagoon like soil, water, flora and fauna *etc,* has been investigated, models are verified on socio economic, political interventions with futuristic predictions were made. Least studies are made about the change in geo-morphology of the area as impact of the hydrologic, Anthropogenic and physiographic interventions.

3.1 Methodology

The IRS P6 LISS III (1999) and the IRS (Resource-sat 2) and Quick-bird satellite imagery (2013) are downloaded, georeferenced, digitized and layers are provided with the help of ArcMap 10.1 software. The layers are considered for analysis and the thematic picture was obtained for water spread area, vegetative cover, denotation of various types of forest for the years 1987, 2011 and 2016. The steps involved in methodology are in Fig 2.

The survey of India has prepared educational topographical maps in 1:50000 as sheet No 64P/13 and OSM sheet No F44X13 for Odisha. The Topo sheet numbers 74E (1,2, 3, 5, 6, 9,10 and 13) were collected and utilized to determine the local catchment area of the Daya and Bhargovi and other rivers basins and drainage channels debouching to the lagoon. The base TEXAS SURVEY map of 1930 of the same scale is collected, georeferenced and compared with the water spread, forest area between the pre and post Anthropocene.

3.2 South Mahanadi Delta

The south Mahanadi delta (SMD) extends from emerging place of Kuakhai River at the apex. The Daya and the Bhargovi rivers (distributaries of the Kuakhai), pass through the Bhubaneswar area, and covering 8blocks of Puri district fall in northwest corner of the lagoon (Fig 2).

The major drainage channels are the Ratnachira, the Nuna, the Malaguni, (were in past), the Rajua and the Makara (recent origin). The average flow (≈6%) to Chilika from the Mahanadi system during flood is about 4% through the river Daya (≈ 4% of total), and the Bhargovi (≈2%) from 2014. The SMD Rivers contribute in average 61% of the total inland inflow whereas 70-80% of the total sediment flows to the lagoon Mishra SP. [78].

3.3 The Chilika Lagoon

The Chilika, 2nd largest brackish water lagoon in the globe, (lat. 19.845 0N. and long. 85.479 0E) is a shallow lagoon (Fig 1) separated from Bay of Bengal (BoB) by barrier spit starting from Palur Hills (Rambha) to Village Motto (64.3km). The average water spread area of the lagoon has contracted from 1045sqkm in early 20th century to 770km2. The coastal stretch was reduced from 71km to 64.3km during early 21st century, Ghosh A. [79] and Mishra SP. [80]. The pear shaped wetland has declined its maximum and minimum depth from 4.88m-0.6m [81] to 1.42m to 0.42m in monsoon and summer (1995-1996). The barrier spit is stable for 33.3km from south having width 3-15km with densely habituated. The balance 31 km towards north has variable width 0.15 to 1.5km is narrow, dynamic and fragile with all inlet dynamics, path for salinity and sediment transport with mangroves, sand dunes, and, few fishermen hamlets.

3.4 Present Anthropogenic Concerns

The SMD was urbanized with many townships from 1950 onwards after Bhubaneswar became the capital of Odisha. Many settlements were grown to accommodate the steep rise in population from 1960 along with marginalization of fisher folk and migration from other areas. It is due to growth of different institutions like livelihood, educational, healthcare, tourism and transport *etc.* The anthropogenic activities on land, water and ecosystem has transformed many swamps and fallow lands to agricultural land or settlements. Making of Mahanadi Delta stage II and barrages in Mahanadi delta system have converted the flood prone area to agricultural bumper zone. To augment the productivity, the ground water was over exploited which resulted in salinity intrusion of inland aquifers. The liquid wastes and effluents from populous areas from urbans and industries have contaminated the coastal aquifers, drains and the river runoff. The water of the Kuakhai River is turned off as unfit for human use during summer months.

About 50% of the total areas were under cultivation with subsidiary livelihood as fishery, coconut farming in the Chilika and its local Mahanadi basin reported by SREP (ATMA) of Puri District, 2007-08. The sectors like tourism, Industries, township with improved connectivity and irrigation have curbed the life of the rain fed and water logged agricultural workers. They have also engaged themselves their livelihood activities in developing profitable agriproducts, and small scale industrial activities instead of orthodox farming or fishing.

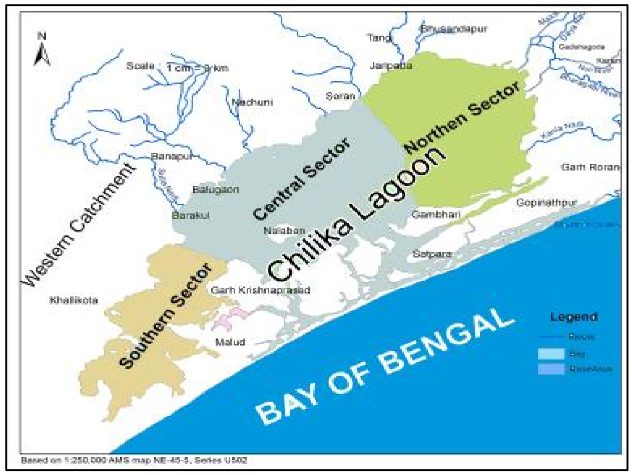


Fig. 1. Index map of Chilika during anthropocene

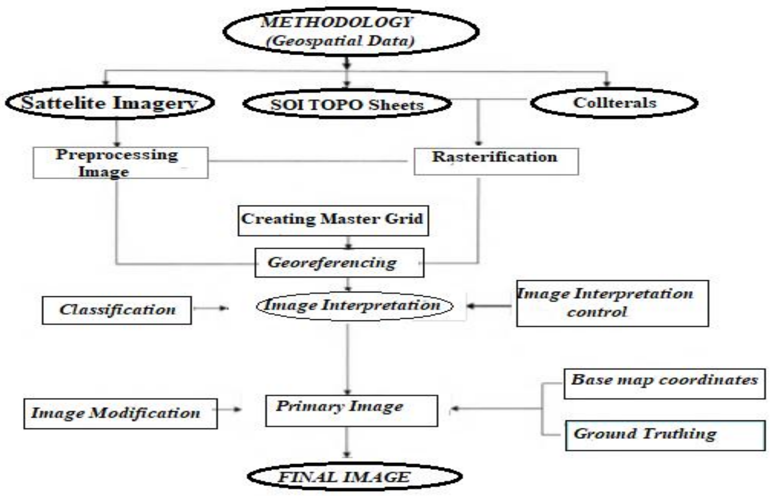


Fig. 2. The methodology of analysis of image by GIS

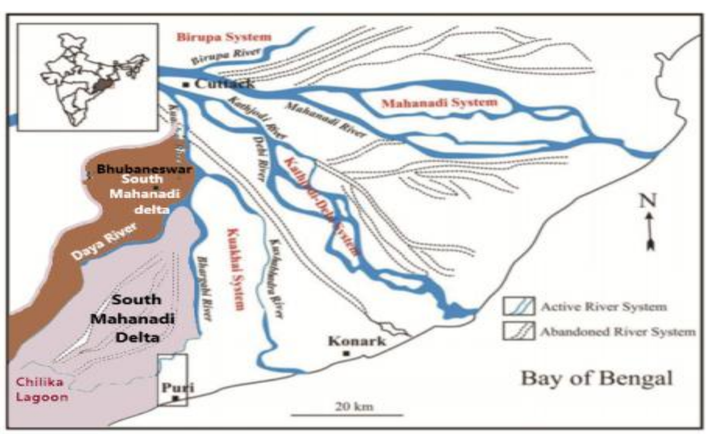


Fig. 3. The SMD in the Mahanadi delta and the Chilika lagoon

3.4.1 Deterioration of Chilika (pre and post intervention)

The lagoon had a deteriorating health from 1990 onwards where a comparative study is given in Table 1.

The lacustrine area of the Chilika was during 1985 and 1995 were 620km2 and 650km2 during summer and 700km2 and 750km2 in post monsoon respectively [74]. But researchers have less attention about the local catchment and meteorological impacts along with anthropogenic pressure over the lagoon. It is felt imperative to study the climatic changes, human interventions and geomorphology changes over the lagoon. The combined anthropogenic interventions have augmented the catch statistics from 1274MT (19995-96) to 16358MT during the year 2017-18, wetland avifauna were about 1142000 (surveyed on 5th Jan 2021, PTI | January 16, 2021) and the number flag ship species like Irrawaddy Dolphins in the year 2020 were 156.

3.5 Shoreline and RSLR Changes Along Chilika Coast

Morph-dynamic studies of the micro-tidal Chilika reveals that there was progradation of 0.58m between the years 1930 to 1975 whereas retro-gradation during 1933 to 2002 was 143.68m The shore line was retreated by 97.18m during 2006 (may be due effect of Tsunami 2004) and had increased to 320.754m, by 2010 where the base year is 1933 [82]. The regional sea level rise along and off Chilika coast is raising @ a rate of ≈1.0–1.75 mm/annum due as a result of global warming during 21st century, [83]. The present coast line has been separated to southern stable and northern unstable coast.

3.6 Climate of Study Area

The climate particularly rainfall of the study area is influenced by both SW and NE monsoon due to variable placing of the ITCZ. The land falling of the BoB cyclones have increased for the last 20years. From 1951 to 2020 the South Odisha coast slammed 17numbers of cyclonic storms between Gopalpur and Konark. Severe cyclonic storms like Fani, Titili, Hudhud, and Phailin were the worst in intensity including 4consecutive storms during 1968. The five severe cyclonic storms had slammed Chilika and SMD coast after 1999 were very severe. The anthropogenic interventions with these natural hazards have made the health of the lagoon wretched. The rainfall in the catchment area has also reduced by 6-7% (Table 2).

3.7 Drainage flow to SMD

The river Mahanadi is bifurcated at delta head near village Naraj. At the junction, there is major shift of the flow either to left or right depending on configurational changes after each high flood above 40000cumec in the main river. Very high floods after the 1950 were during 1982 and 2008. The peak flow bifurcation in branches the Mahanadi and the Kathajodi observed changes (Table 2). The flow through the sub branch Kuakhai, a 2^{nd} order distributary of Kathajodi has reduced peak flow from 2009 onwards reducing Chilika's flushing flow (Table 3).

4. CHILIKA AND SMD FROM PRE ANTHROPOCENE

The dimensions of the lagoon recorded to be 1165Km2 during high floods and 906Km2 during summer with 71km coastal length with maximum width of 30Km [6]. The present SMD claimed to be made during mid Holocene period (4200YB.P) after renovation of Regional MSL rise by 7 to 8 m higher than present coast [84] and prograde @≈9.1km/ 000' years [85].

4.1 The Forest Cover

The Canopy of the basin was encompassed by 1340Km2 of forest area. In 1930, the total area was of ≈5240 km2. During 1972 it was reduced drastically to ≈856 km2 and further reduced to 610.39 km2 during 1989. An active step for restoration of the deteriorated forest, the rate of jungle loss was reduced ≈572.81Km2 in 2004. By massive afforestation and public participation in forest management, the rate of loss had further reduced to 568.14Km2 [75]. The dense forest has increased by 2.2% between 1989 and 2004 and was converted to open forest and later by 2011, whereas the dense forest was reduced by 9.48%, Fig 4(A) and Fig 4(B).

The loss of forests was in Chandaka, Patia, Badamal,Tamna, Katuala, Bankar, Dhanai Baharmal, Rajin hills. They were bald in the SMD. Reserve forests which were dense before 1950 were converted to open or shrub forests. The west coast forests affected were in Bhaleri, Jhinkaridi, Solari, Karakhol, Talakhol, Rambha and Ghantashila etc. The mangroves and forests deforested. within the lagoon were in Barakuda and Samala Islands and the spit area.

Table 1. The deterioration of the Chilika pre intervention period during 1990's of Anthropocene

The feature object	Early Anthropocene		Fag end of 1990's		During 2020's		Sources
Pre intervention period			**Deterioration period**		**Post intervention**		
	Year	**Quantity**	**Year**	**Quantity**	**Year**	**Quantity**	
Water Spread Area (Minimum)	1972	824Km^2	2000	790Km^2	2008	704Km^2	ORSAC Data; Gupta et al. [70]
Maximum depth	1985-87	2900 mmm	1996-97	1420mm	2018	4.1m	Ghosh [71]; (ORSAC-1997)
Minimum depth	1985-87	400mm	1996-97	420mm	2018	1.1m	Mukherjee M. [72]
Maximum salinity	1957-58	22.3ppt	1990	15.83ppt	Jun-17	≈38.7ppt	Raman et al. [73],
Weed spread Area	1973	20 Km^2	2000	523Km^2	2011	300km^2	CDA.Rep. [74]
Av mid Ch. Salinity	1957-58	22.3ppt	1995	1.4-6.3ppt	20015	9.77ppt	CDA Report [74]
Aqua Catch	1985-86	8.667TMT	1995-96	1.274TMT	2017	12.2MMT	Odisha Fish. Dept.
Catch. Forest cover	1972	856Sqkm	1989	610.69	2011	568.4km^2	I. Sk Majharul [75]

Source: Raman et al. *[73], Biswas [76]; Ghosh* et al. *[71]; CDA Report 2010–11 & 2012[74], Bulletin 80-CIFRI-1998[77])*

4.2 Anthropogenic Interventions (Hydraulic)

The water spread area of the lagoon during Dec 1930 was found to be 877.37Km2 during summer. Hirakud dam (1956) was the first intervention designed to save Chilika. The continued deterioration of the lagoon afterwards forced for an official opening of TI at Sipakuda village (2000) and construction of Naraj barrage at head of Mahanadi delta (2004). Two small barrages over river Bhargovi at Gobardhanpur (1998) and submerged weir at Gabakund (2014) were constructed to save the local people from annual flood devastations. The Palur canal leading to the Rushikulya River was renovated. After the hard interventions, the ecosystem has improved from average 8.0MMT to average 12MMT of aqua catches, upsurge in salinity and reduction in proliferation of weeds as rejuvenation of the ecosystem.

4.3 The Watersheds around the Chilika

Inland fresh water contribution to the lagoon is through 52numbers of rivers, rivulets and major drainage channels (d/c's). The seven drainage channels of SMD debouch in the northern sector. The serpentine 45number d/c 's emerging from eastern Ghats are debouching the lagoon through western banks Fig 5(a) and Fig 5(b).

4.4 The Local Catchment of Chilika

The SMD catchment includes 7rivers/rivulets and the western catchment have 45 drainage channels (D/C's) feeding their flow to the Lagoon. A doab is the upland between two rivers as hydraulic boundary. The local catchment of the Chilika wet land enclosed within of four doabs i.e Doab VII (the Daya-Bhargovi), Doab VIII (West of Daya - the Malaguni), Doab XV (west of Daya - the Salia), and Doab XVI (the Salia - the Rushikulya) (Fig. 2B) that have canal systems and agricultural lands (Fig 3(a)) and Fig. 3(b). With sea level fluctuations two parallel outer channels exists in the northern fringe of the lake representing strand lines within a distance of 2-3km. (Table 4).

Thus Chilika has three subsystems: *Subsystem I* is Own catchment of 1560Km^2, Subsystem II is flow from SMD Catchment of 1777Km^2), and *Subsystem III* the rivers emerging from EGB Hills debouching Chilika as western catchment of area 2800Km^2)

4.5 Morphological Changes

The barrier spit is backed by an outer channel of 32km long 1-3km wide outer channel (OC) of marine environment connected at Magarmunha the doorway of the lagoon. The Hydrodynamics and the salinity and the semi-marine ecosystem of the lagoon is governed by the continuous process of breaking and making of flood-deltas and ebb-deltas in OC. The swash zone controls the flow exchange, northerly shift, and opening/closing of tidal inlets (TI).

The unstable spit configurations oscillate between Hathikhal George to village MOTTO of length 34Km during the start of Epoch. Tidal action and flow energy of waves are conducive for TI migrations. Dimensions of inlet, islet erosion and accretion, barrier island breaching, sediment imbalance, meteorological extremes, and littoral drift are the causes of mechanics of sediment transport. Sediment bypassing occurs due to wave dynamics near the flood/ebb delta complex, tidal influence and migration of islet complex within the channel [86].

4.6 The Geomorphology of the Chilika during Anthropocene

The Chilika maintained its sustainability with difficulties during pre-Anthropocene period (1950 – 1970). Later with sudden population growth and the expansion of Bhubaneswar city, changes in agrarian practices, water use, waste management system, urban growth, changes in LU/LC, mining, and ground water over-exploitation and other anthropogenic stresses has altered the geo-bio-hydro climate of the study area. The soil erosion and the balanced sediment deposited in Chilika (after influx and outflow) is about 365.0Th MT/year Finlayson et al. [87].The Chilika was an estuary of the river Daya in the pre Holocene acting as port till 14 to 15th century connecting the East and the west. The lagoon was inundating up to Kanas area 20Km U/S of the present lake periphery. Later it dried up and suffering for her existence as a brackish water lagoon (Fig. 6).

4.7 The LU and LC Changes

Nature has also waned the ecosystem both intrinsic and extrinsically through historic floods during 1982 and 2008 in the Mahanadi system, number of devastating cyclonic storms and erratic monsoon rains and devastator floods in the catchment area of the lagoon. A comparative study of the demographic, habitat and LU/LC changes in the lagoon area and the local catchment is compared between Year 1987 and 2016 Fig 7.

The drainage basin of Chilika includes 2325 km^2 of agricultural land (mostly dry land), 526 km2 of forests, 192 km2 of permanent vegetation predominantly used for plantations, 71 km2 of swamps and wetlands, and 91 km2 of grassy mud flats in the northeast of the drainage basin. Only 52 km^2 of the basin are occupied by human settlements, roads, railways, and others Ramesh et al. [88], Ghosh et al. [89], Weed spread area [76]; CDA Report 2010–11[74]).

5. MORPHOLOGICAL FEATURES DURING ANTHROPOCENE

Off-shore Landforms

The Chilika coast is the conjoint place of 85^0 Ridge and the northern end of the EGB Hills. So the offshore precinct is of shallow zone. The coastal topography along the coastline is influenced by wind, wave, tide, littoral drift, from sea ward. The land ward forces are water and inland silt transport which deforms the coast and coastal landform and vegetation regularly. The main geological landforms that transforms are:

5.1 Barrier Islands and the spit

The transversely formed barrier islands or bars in the swash zone are adjacent to coast has developed the beach and always fragile based on the actions of wind, waves, tides, and sediment supply. After formation, growth, and attaining stability (whether submerged or emerged), these bars resist the wave action from both the lagoon and sea side of the Chilika. They are constructed due to deposition of sediments from inland or through longshore drifts under low gradient in front of the TIs [91]. Such bars are found along the mouths of past tidal inlets to the Bay of Bengal coast line from Parikud (southern end of the Chilika) to the southern end of SMD. The spits are curved towards the land at their extreme end like hooks.

The northerly longshore drift of sediment across the Chilika coast, there is accretions and depositions across the shoreline when reaches a bay or form a bend along the seaward shore front. In case of Chilika the main spit is attached to lands of Palur hills near Rambha. The spit had extended up to the Harachandi Temple (71km) up to mouth the defunct Sunamunhi R. with shrinkage of the lagoon it is presently 64km and of width 0.15 to 2km [92].

Table 2. Major Av. rainfall in mm of seven block headquarters in SMD and Chilika (2000-2016)

Year	DOBA VII (Water Shed -2)							
	Barang	BBSR	Jatani	Delang	B-giri	Kanas	K Prasad	
2000	1572	1136	1064	977	483	1003	750	1590
2001	1861	1929	1439	1812	1737	1761	1883	2521
2002	1884	2005	1462	1977	1766	1835	1939	2629
2003	2785	1718	1367	1189	1657	1302	1443	1997
2004	1169	1330	872	1062	1117	664	1130	1318
2005	1264	1302	730	1712	1078	506	1220	1438
2006	1777	1843	1449	1964	1770	1830	1932	2636
2007	1662	1551	646	1412	1229	1336	1388	1437
2008	1498	1929	398	1504	1497	1157	1534	1884
2009	1183	1084	546	1596	1329	1962	1445	1437
2010	1434	1469	544	1668	1322	1971	1378	1458
2011	1437	1469	890	1616	1287	1881	1432	1408
2012	1377	1694	1800	759	1163	1243	1346	1239
2013	1598	1846	1942	945	1726	1769	1695	1756
2014	1638	1424	1839	1238	1458	1737	1542	1705
2015	969	1151	1287	852	812	1009	1382	1279
2016	1569	1555	1142	1393	1339	1435	1465	1733
av.		1539				1418		

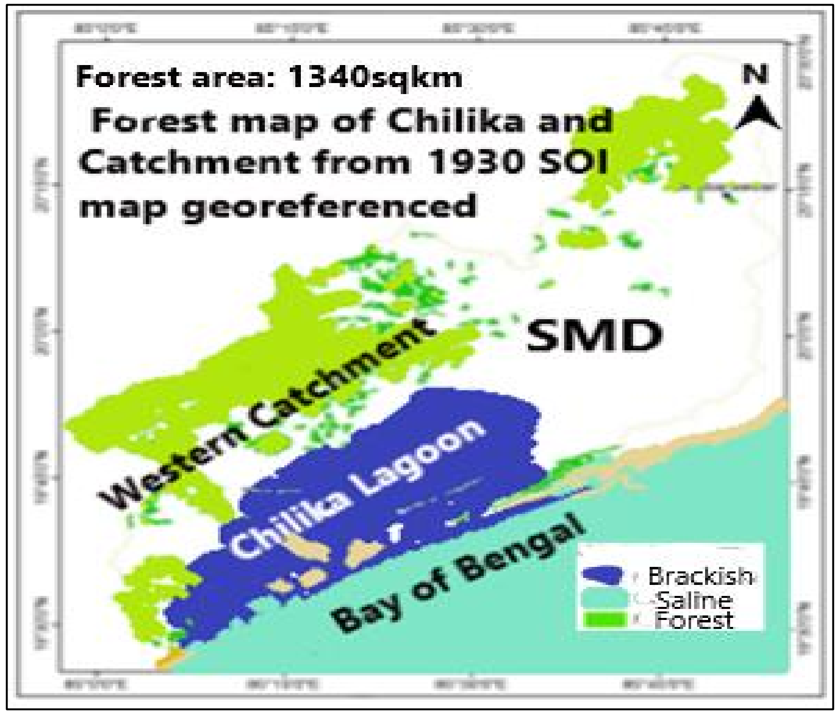
Ref: https://rainfall.nic.in/PubRainChart.asp

Table 3. The annual peak flow bifurcation at Naraj between main distributaries the Mahanadi and the Kathajodi Br

Year	**Peak M-nadi flow**	**Flow**	**Max Kathjodi**	**flow**	**Max M-nadi Br.**	**flow**	**Year**	**Peak M-nadi flow**	**% of Flow**	**Max Kathjodi**	**Flow**	**Max Maha Br.**	**flow**
	Cumec	**%**	**Cumec**	**%**	**Cumec**	**%**		**Cumec**	**%**	**Cumec**	**%**	**Cumec**	**%**
1964	19962	100	8883	44	11079	56	1998	22907	100	17362	76	5545	24
1965	8869	100	5609	63	3260	37	1999	17972	100	9176	51	8796	49
1966	16572	100	7943	48	8629	52	2000	5050	100	3190	63	1860	37
1967	22155	100	8693	39	13462	61	2001	39887	100	20918	52	18969	48
1968	21355	100	9565	45	11790	55	2002	16332	100	11852	73	4480	27
1969	27680	100	12771	46	14909	54	2003	38223	100	11778	31	26445	69
1970	23361	100	11223	48	12138	52	2004	21695	100	11179	52	10517	48
1971	21239	100	9984	47	11255	53	2005	25578	100	13726	54	11853	46
1972	20222	100	9004	45	11218	55	2006	36318	100	17178	47	19140	53
1973	26261	100	11334	43	14927	57	2007	20530	100	10570	51	9960	49
1974	21590	100	9692	45	11898	55	2008	44777	100	24488	55	20289	45
1975	23159	100	11092	48	12067	52	*Av. Distn. in M-nadi distribut. 1983-2008*			*12036*	*52*	*11825*	*48*
1976	26438	100	9518	36	16920	64	2009	24508	100	11829	48	12678	52
1977	26475	100	13995	53	12480	47	2010	19539	100	10103	52	9436	48
1978	27881	100	11700	42	16181	58	2011	38700	100	20857	54	17843	46
1979	17727	100	9856	56	7871	44	2012	19142	100	8334	44	10808	56
1980	34747	100	16481	47	18266	53	2013	20331	100	7250	36	13081	64
1981	17535	100	8085	46	9450	54	2014	32517	100	14744	45	17773	55
1982	44750	100	18716	42	26034	58	*Av. Distn. in M-nadi distribut. 2009-2014*			*12186*	*46*	*13603*	*54*
Av. Distn. in M-nadi distribut. 1964-1982			*10744*	*46*	*12833*	*54*	M-nadi: the Mahanadi R. Av.: Average,			Distrib: Distributaries			

Table 4. The local catchment area Doab wise decanting the runoff to the Chilika lagoon [58]

sl no	Name of river/major drainages	Length (km)	Catchment area (km^2)	sl no	Name of river/ drains	Length (km)	Catchment(km^2)
	South Mahanadi delta system				**West of Daya-salia doab (continued**		
1	Daya and Rajua	60	540	10	Patnakula		4.03
2	Nuna drainage sys.	26	445	12	Kantabania		6.28
3	Bhargovi drainage sys.	85.5	646	13	Chhamankantalbari		144.19
4	Ratnachira drainage sys.	22	145.4	14	Badanai		86.91
	Total drainage to Chilika from SMD		*1777*	15	Batanadi		26.19
West of Daya doab (extension of SMD) Doab XV				16	Kansarinallah	23	160.99
1	Gangua sys. (join Daya)	37	740.75		sub-total		481.57
2	Malaguni sys (join Daya)	22.5	289.01	Salia-Rushikulya doab (Doab XVI)			
	total		1029.76	17	Salia (River)	36	454.82
West of Daya-Salia doab (Doab XV)				18	Janjira d/c		8.4
3	Kusumi	8.2	141.19	19	Badasankha, Kalajhar d/c	15	128.45
4	Saharajodi	10.5	13.5	20	Badaghati d/c	11	179.53
5	Weikhia	16	14.05	21	Sabulia drain (Manipalli)	10	88.66
6	Tarimi	7.8	86.56		sub total		859.86
7	Makara (Rivulet)	13	159.49		*Total western catchment*		*2799.78*
8	Mangalajodi	6.9	62.18		*Chilika own catchment*		*1560*
9	Tengulipada	6	4.6				



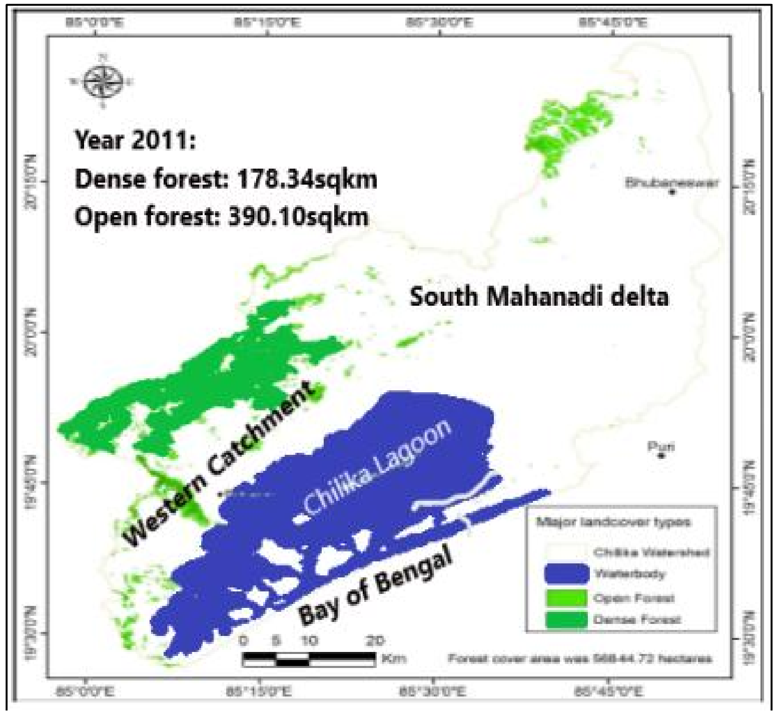


Fig. 4(A). Forests in Chilika catchment (1930), Fig. 4(B). Forests in Chilika catchment area (2011) after geo-referencing (Source: Texas Library) and source modified; http://hdl.handle.net/10603/292449

Fig. 5 (a). The 3-D view of the Chilika local catchment (Source modified: http://hdl.handle.net/10603/165773)

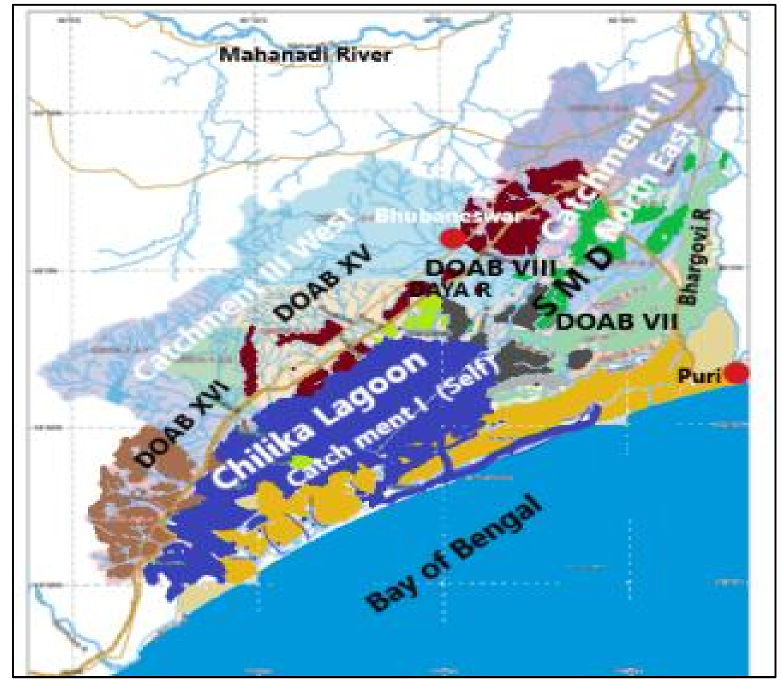


Fig. 5(b). Isolating doab wise of the Chilika local catchmen

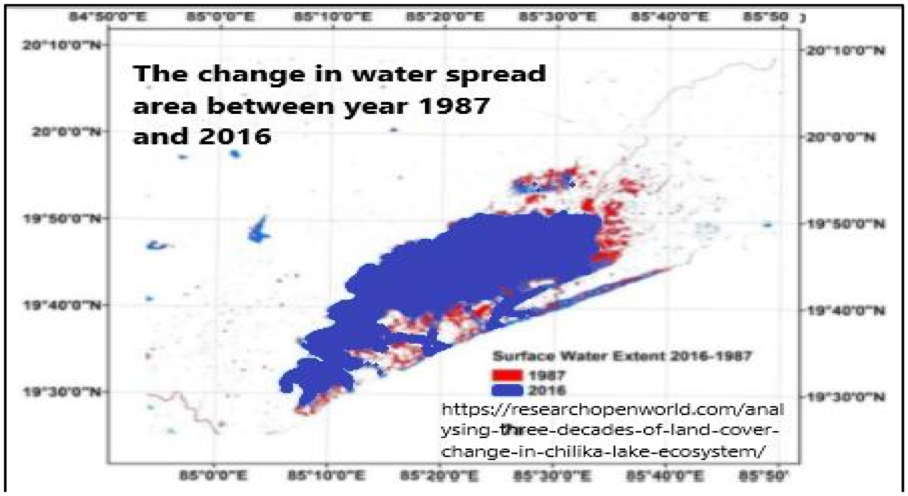


Fig. 6. The Change in water spread area of Chilika between 1987 and 2016 (Red)

5.2 Barrier Islands and Isles

The formation of islands and isles are due to inlet shifting, sediment availability, flood bypassing and tidal fluctuations under the hydraulically inefficient outlet channel. There is leftward migration of swash bars or mouth bars and towards the bank, due to unsymmetrical flow, and low wave energy condition in the OC of Chilika. . They try to join the shoreline due to down-drift or up-drift. Shoals moving towards the barrier face, encounter more tides, with a little time gap between inland waves and tidal current under less sediment movement to form small shoals. The continuous process of transformations of flood deltas and ebb deltas in outer channel and swash zone control flow exchange, northerly movement, closure and opening of tidal inlets. The Chilika lagoon has varying number of Islands due to the making and breaking of Isles within the outer channel. Presently there are 204 numbers of islands comprising of area 223Km^2 [54]. The permanent islands with permanent settlements are Parikud, Malud, Nuapada, Garh Krushna Prasad, Kalijai, etc.. The Nalabana (Reed Forest) of about 1553ha is a swamp and a bird sanctuary within the central sector. Few islands are rocky beds in the southern fringe whereas the northern sector has least islands except many isles in the outer channel.

5.3 Tidal Inlets

The barrier islands of the Chilika coast are about 34km (half) stable and rest narrow unstable spit with an outer channel (14Km) accommodating the narrow, fragile, dynamic tidal inlets. The TIs are path for transporation of inland and oceanic flow. The dimensions and positioning of the tidal inlets determine the geomorphologic character of the Chilika. Opening of natural tidal inlets by the raising waves of bay disturbances are mostly triggered during full solar eclipse and closing under inland drought and flow paucity Chandramohan et al. [93], Mishra SP. [43]. Unwarranted manual opening of inlet (done 1828 and 2000) had threatened the stake holders in the vicinity of the lagoon under altered geomorphology and hydrodynamics.

The shifts of the tidal inlets are continuous and northerly. The southern fringes of the TI go through accretion and the northern face undergoes erosion. The bi-way motion occur due to shoreline progression/recession east–west. The natural shift is @ of 4.60km has occurred between Sept 2000 to 2019 with average rate of northerly shift of TI is 242m/year.

Historical records reveal the first anthropogenic intervention to the natural TI of 1.6 km wide was hydraulically found inefficient in 1780 and was depleting. Gradually the TI was obstructed thoroughfare of the country boats. During 1825 the shallow TI was dredged by the Zamindary which was later choked by 1837. The natural tidal inlets hover in and around Arakhakuda at the debouching point of the Dahikhia river, the second channel after Magarmunha connecting the lagoon and the bay of Bengal.

Lagoons are considered temporal coastal landforms. Historical data points to rapid shrinking and sinking of the lagoon in area and shallowness, dimension and positioning of the tidal inlets. The inlet in 1970 was narrow and was migrated extreme north to village Motto having width (15 m) and depth (1-2 m) with similar mouth positioning even during 1989. Three or more TI's were reported during 1933, 1975, 2012 and 2019 either due to number of BoB storms land falling south Odisha coast or/with eclipses with rising tides along the coast [43].

5.4 Foreshore Landforms

The foreshore zone (between high tide level and low tide level) is influenced by tidal inlets, waves, barrier islands, tides, mangroves and wind of various t landforms. The physiography's are the beaches, tidal landforms (flats or mudflats or back swamps), coastal sand-dunes, beach ridges, emerging Islands, Isles, mangroves.

5.4.1 The well-developed beach

Stable sandy beach has been developed from south of the Chilika (Prayagi) to Sipakuda. with well-built sand dunes and barrier spits running parallel to the coast . The northerly 32km of the lagoon has coast has perpendicular sand dunes mainly constructed of river, littoral sediments of recent origin (4 to 5 hundred years BP). Beaches are constructed during calm sea with riverine inputs like fine/coarse sands, shingles/ pebbles. Behind the present beach (3km inland) anther beach profile exists from Satapada to Kushbhadra river mouth.

5.4.2 Beach vegetation

The shoreline vegetation has diversified from fresh water plants (Northern Sector), to marine flora along the beach line and behaves as an ecotone which depends up the substratum, chemistry of GW, submergence and emergence period, and the topographic and other edaphic factors. The other coastal areas of the lagoon are amalgamation of fresh, brackish and saline water vegetation. The beach is largely influenced by sand dune vegetation, and the lagoon's breast water has luxuriant growth of brackish water flora.

5.4.3 Back-shore landforms in SMD

The impact of oceanic environment continues is prominent along the coastal areas and gradually influenced by one to 20kilimeter inland. They contain swamps, lagoons, lakes, sand dunes, beach ridges, swale deposits, estuaries and other land forms. Apart from the Chilika, there are lakes along the coast like Sar along the Kushabhadra river, Samanga along the coasts of Bhargovi river which has been defunct and converted to swamps, agricultural land or settlements. Bordering the N- sector, mudflats indicate about the extensions as greater Chilika of past.

5.4.5 The stable coast

Aeolian beach sand dunes of length 200m to 5km and of height 2 to 5m (even higher) are commonly found along the SMD and Chilika coast from Prayagi to Ramachandi temple.

The geo hydrological multiple triple points from southern edge propagating from Parikud to Jahnikuda can predict the age of conversion from gulf to a lagoon is also narrated.   Along certain stretches of the coasts have large and permanent offshore bars. Towards southern fringe of the coast line (Fig 8).

5.4.6 Longshore sediment transport

Odisha has 480Km coast line out of which 57% sandy, 33% muddy, 10% marshy and have least rock coast line of water depth 10m-15m in the offshore region and longshore sediment transport @ 997594m3/year V Sanil ku. et al. [94]. The east coast of India is vulnerable to rise in MSL @ 0.76mm/year (Visakhapatnam) and shall submerge the coast line due to large storms striking the coast and flat continental slope Shetye et al. [95].

There is drift of sediment along the offshore is along northerly direction most of the time in the year. The littoral drift is maximum @19x104m^3/month with velocity 0.8 m/s during months of May and June. It is minimum @0.6x104 m^3/Dec-Jan months. The minimum current 0.4 m/s in March, April, July, Sept and 0.3 m/s during other months. The sediments received through the inland river move northerly due to wave refraction, the angle of strike, spinning of earth and Coriolis force. The maximum sediment through littoral drift entering via tidal inlets to the lagoon was about 1MMT annually [96].

The littoral drift along off the Chilika coast cause changes in shore line regularly. The shore line change of the lagoon is analyzed for 64.3km from 1975 to 2015. The results obtained were accretion due to littoral drift was 62%, and 25% stable coast. The only length eroded was 13% of the coast. The rate of accretion and erosion was 9.12 m and 10.7m per annum./ Erosion was in the left fringe and accretion with stability of the spit. was in the right fringe [97].

5.5 Coastal Plain

The plain areas back to the shore (SMD) are coastal plain comprising of the tidal or mud flats etc running with agriculture and plantations. The coastal plain along SMD extends up to Jatani areas with scattered agriculture, water logged areas, upland settlements. Beach ridges and tidal land forms have been identified near Jatni and Kanas areas indicate the land was a part to the lagoon in past during its formation stage. These sub-parallel beach ridges and berms comprise of of sand, pebble, shells of varying dimension. No tidal flat / mud flats have been identified in the study area which indicates the sandy beach has been developed under full score.

5.5.1 The limnology and lithology

The rivers Daya, and the Bhargovi the third order distributaries of the Mahanadi system debouch the lagoon to N-Sector. Many small serpentine streams emerging from EGB Hills are joining the lagoon from west coast. The hills surrounding the lagoon are composed of hard stratum of metamorphosed Precambrian origin rocks of different genesis like, quartzite, and Chamockites etc that projects as promontories in to Chilika that act as spurs to arrest inflow sediments. The spit is plunged into the Palur Hills along the coastline near. The barrier spit is the a chain of sand dunes connected, [45].

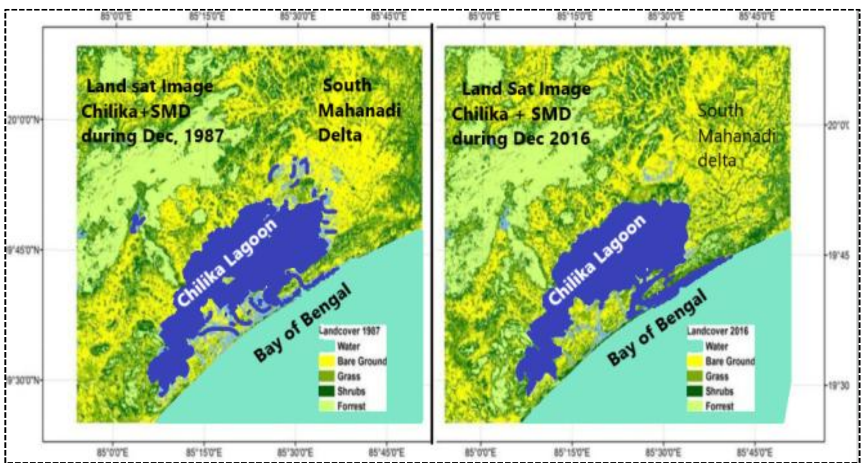


Fig. 7. The contrast of LU/LC in the Chilika and the south Mahanadi delta 1987 and 2016

Fig. 8. The regular shift of triple points along coast showing the temporal character of the lagoon

Table 5. The demography and rough geomorphology status of the Chilika and its catchment

#	Changes	1930	1972	1987	1990	1999	2012	2016
			Ojha et al. 2013	**Present study**	**Wet land Int. 2012**		**Wet land Int.2012**	**Present study**
1	Population density(Puri)		286.88 (1971)		428 (1991)	431 (2001)	488 (2011)	488 (2011)
2	Settlement area (rural + urban)		210.09 Km2		204.78 Km2		292.63 Km2	
3	Forest all types (Km^2)	1339.9 (1930)	1340.4 (1975)	1070 Km^2	1099.5 (1990)	1172.8 Km^2	1346.8 Km^2	1287 Km^2
4	Agriculture(Km^2)		1918.14		2006.9	1686.1	1257.3	
4	Bald terrain/ hills ($Km^{2)}$			1893				1743
5	Shrub (km^2)		574.58	866	422.59	409.2	455.77	1046
6	Plantation (Km^2)		75.57		99.92	45.31	34.71	
7	Chilika lacustrine area(Km^2)	877.37	829.84		778.17		699.08	
8	Marshes ($km^{2)}$		14.72		23.59		15.45	
8	Aquaculture (Km^2)	00	00		11.68	17.61	51.59	
9	Total Water body (km^2)		912.96	999	918.62	910.5	887.35	860
10	Swamps ($Km^{2)}$		128.37		121.86	116.2	97.88	
11	Water logged area (Km^2)		58.10		82.60	74.85	60.31	

Source links: Ahmed M. [90], Wetland International south Asia and CDA – 2012: https://www.idrc.ca/sites /default/ files /sp /Documents%20EN/Chilika-Framework.pdf, Population density: Source - District Statistical Handbook, Orissa & Census of Orissa, http://cesorissa.org/soe/Demography .pdf https://researchopenworld. com/analysing-three-decades-of-land-cover-change-in-chilika-lake-ecosystem/, Ghosh et al. [89]

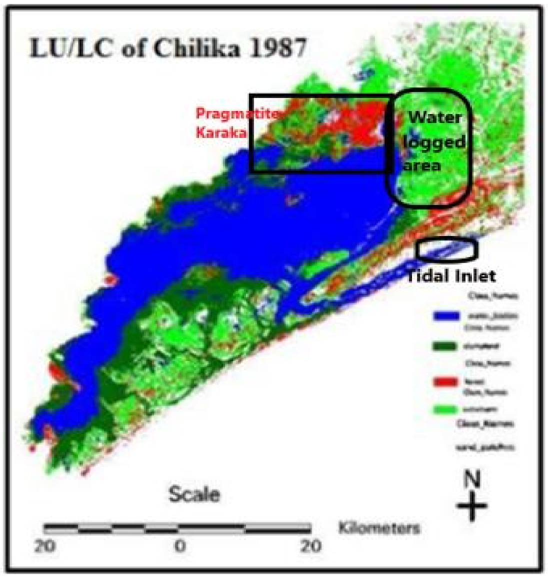


Fig. 9. The LU/LC map of Chilika & SMD 1987

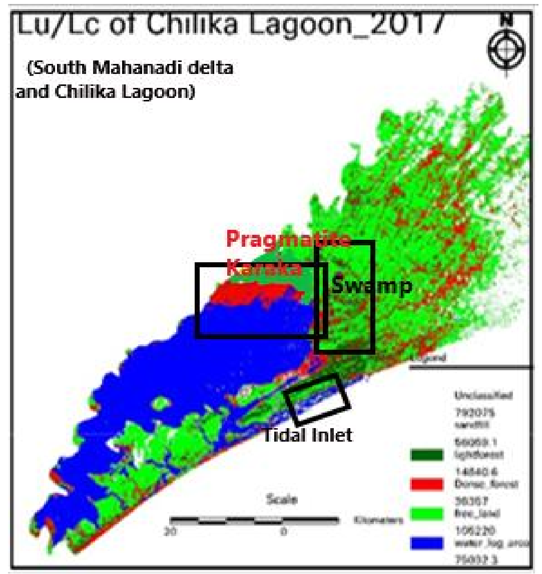


Fig. 10. The LULC map of Chilika and SMD

5.5.2 The biodiversity

The Chilika Lagoon act as a spawning/nursery ground numerous marine aqua fauna mostly varying along the channels and central sector. Coastal regulatory zoning is made based on ecological sensitivity as per E 43 A 10 / NE . It starts from CRZ I (the spit; highly eco- sensitive) that includes mangroves, (CRZ IA), the Inter tidal zone (CRZ I B). The CRZ III includes (NDZ area or sand dunes, township, municipalities and corporations as per Annexure-III of CRZ Notification 2011. In around 1100Km^2 area of the Chilika lagoon retain many endangered species like linbless lizards (Barakudia insularis), Irrawaddy dolphin, fishing cat (Felis viverrina), white bellied sea eagle (Haliaeetus leucogaster), Platalea leucorodia white spoon bill (Pandion haliaetus osprery) and many other species [98].

5.5.3 Tourism and biodiversity hub

Not only Chilika attracted the guest avifauna of cold NW countries even beyond subtropics during winter stay and hatching but also fascinated huge tourist both from foreign and inland to have glimpse of the panoramic view of the lagoon. The record tells a Chilika welcomed tourists were 515381 tourists in 2010, 525637 tourists during 2011, 536383 in 2012, 545420 in 2013, 555964 in 2014 and 601,666 tourists in 2015 which is continuously rising, Khuntia et al. [99]. The spectacular tidal inlets, the flying birds, dancing dolphins and the bluish fabric of brackish water attract tourists from inland and foreign to enjoy the panorama of the lagoon.

5.5. 4 Migratory birds

Migratory birds visiting Chilika Lake has been improved due to the availability of open spaces for their habitat improvisation after the eviction of illegal prawn gherries by Govt. of Odisha (GoO), and removal of floating phyto-planktons by providing adequate flushing flow by efficient operation of the Naraj barrage by Water Resources Dept. GoO. The arrival of guest birds through central Asian fly from subtropics during winter and the indigenous local birds have increased during the 21st century of 1.142million of 190species during 5th Jan 2021.It was 0.893millios (147species) during 2018, 1.048millions in 2019, and 1.105million in the year 2020. The numbers are increasing after the interventions made in the lagoon from 2004.

6. DISCUSSION

Present study envisages the elementary morphology, flushing flow, BoB storms, tidal inlets, sediment transport, and dynamic behaviour of the fragile ecosystem of the Lagoon Chilika. Formation of stable, unstable sand spits, islands, terraces, shoals, mudflats, swamps and flood deltas inside the lagoon is discussed. Dimensions of inlet, islet erosion and accretion, barrier island breaching, sediment imbalance, meteorological extremes, and littoral drift are controlled by mechanics of sediment transport. Sediment bypassing occur due to wave dynamics near the flood/ebb delta complex, tidal influence and migration of islet complex within the channel [86]. The flood volume is suffering under sediment starvation (reduced by 66.7% between 1980-2009) as a result there is recession and down drift of the barrier. The geo hydrological multiple triple points from southern edge propagating from Malud to Jahnikuda can predict the age of conversion from gulf to a lagoon is also narrated.

In 3 decades from 1987 to 2017 it is observed that there is prominent decrease in clean water spread, agricultural land, aquatic vegetation, clean water and beach area. It may be due to anthropogenic activities like settlements, building urban infrastructure, prawn gherries and tourism activities etc. However the best management of the lagoon and its basin has developed dense forest and decrease in phytoplankton's, seagrasses and floating weeds etc.The results from the land use and land cover of the Chilika and SMD between the years 1987 and 2017 are in Table 6.

6.1 Rapid Urbanization in Catchment Area

During post Holocene (1901-1941) there were only on urban settlement in the catchment of the lagoon i.e the Puri Town. During pre-Anthropocene (1951-1971), with shifting of the capital of Odisha from Cuttack to Bhubaneswar, the number of urban areas have increased to five with growth rate of 378.98% (Resurgence Period) whereas during the golden spike perod it has increased to 27 in numbers. The increase in ULB's have surged the quantity of wastes, plastics, construction debris, and industrial rejections. The newly formed Bhubaneswar city, Khurdha as district headquarters, Jatni township, loss of forest, loss of latosol cover and green agricultural land in the catchment area of the lagoon in the south Mahanadi delta. Similarly in the western catchment the major ULB's developed are Tangi, Balugaon, Khalikote, and Rambha The people in the 103numbers of Islands (Prominently Parikud, Malud, Krushna Prasad and Nuapada) are polluting the lagoon with their .

6.1.1 Ecology of Chilika and its catchment; Anthropocene

The ecological wealth and health of stake holders of the lagoon based on their economic status, fishing arena, fishing gears, temporal/seasonal fishing, and traditional tourism practices. The rights were vested upon different line departments with an aim to achieve the optimum by over exploiting the available means but not in a coordinated manner. Without delimiting the catch, tourists, harvests the lake users had deteriorated the eco-health of the lagoon by prawn farming, using motorized boats, gill and khonda nets, draining urban waste to the drainage channels debouching the lagoon. The Irrawaddy dolphins, Nalaban (15.53Km^2), the hatching and nursing ground for aqua fauna and avifauna, Mangalajodi (the land of high rising grasses) needs to be protected from poachers and intruders with provision of sustained ecosystem services. The ecologically drowning Chilika needs adequate.

6.2 Present Requirement for the Lagoon

Under all hydraulic ameliorating measures, the continuous attempt is to provide the lagoon intermittent flushing flow to maintain hydrologic regime and the user's clean water for aquatic habitats. The stake holders of the lake must be provided with drinking water, desalinizing aquifer and recharging groundwater in the basin, better fishing gears (zero mesh) and reducing destructive fishing practices to enhance means for rising aqua catch for poverty alleviation without affecting the ecosystem. It is also essential to increase grazing ground for live stocks, planting fast growing mangroves, the watershed and river corridor must be under afforestation, protecting natural habitats from poaching, controlling bird flu for preserving biodiversity. It is essential to abandon the prawn gherries (presently ≈13-14% of total area), fishing right for the natives along with fishing regulation during breeding periods, charging zero waste to lagoon, fixing navigation route, abandoning fishing during hatching time, restricting fishing in the OC, legalising fishing zone and finally utilizing the phytoplankton and sea grasses for human use. Actions must be taken to protect the lake users for a peaceful settlement the restoration of cultural activities, recreational and aesthetic values, http://www.chilika.com/ documents/ publication_ 1564535640.pdf.

The fast urbanization and modern agricultural drives have left imprints on the geo-bio-hydro environment of the area since Anthropocene. Land use and land cover analysis divulges that the canopy of the area and basin's forest

Table 6. The comparative study of the geomorphology of the lagoon Chilika from 1987 to 2017

Name	Area (ha) 1987	Area (%) of 1987	Area (ha) 2017	Area (%) (2017)	Increase in %
Muddy Water	6882.5	1.92	2079.99	0.58	Reduced
Beach	729.27	0.22	625.59	0.17	Decreased
Clean Water	97179.5	27.23	94118.1	26.36	Decreased
Dense Forest	22680.1	6.35	29307.9	8.21	Increased
Mixed Vegetation	57562.6	16.12	84615.8	23.70	Increased
Aquatic Vegetation	36246.8	10.16	32846.8	9.20	Decreased
Agricultural Land	97595.4	27.35	70627.7	19.78	Decreased
others	38024.5	10.65	42721.7	11.96	Increased

expanse have been shrank by 53Km^2 from 1987 to 2017 in spite of arduous actions for the forest survival. The delta has lost 4600 hectares of agriculture land and 360 hectares of pristine mangrove forest to urban/rural settlements and aquaculture2001 and 2011 alone.

The delta is shrinking and sinking which has created challenging threat. The vulnerable communities are the fisher folk and the stake holders are the worst sufferers. In addition natural calamities like storms 1971, 1981, 1998, 2013, 2014, and 2019 have changed the configuration of the lagoon's morphology and landform [100]. There is asymmetric flow distribution in the main Mahanadi and the Kathajodi branch. The asymmetric percentage of flood flow also changes is caused after each very high flood (>40000cusec) causing potential devastations to the delta and the lagoon users.

7. CONCLUSION

To save the lagoon from ecological and hydrological degradation; it is essential for the south Mahanadi delta to have both soft and hard measures with effective operation of the Naraj barrage. The catchment treatment plan is to be encouraged against entry of inland sediment to the lagoon, control of weeds, sea grass, ipomeas, and water hyacinth, maintaining the tidal inlets to for salinity, augmenting conducive atmosphere for growth of aqua fauna and tempt more migratory birds to cluster within the lagoon. The prohibition of waste influx through the inflowing drainage channels and invoking the flushing flow by regulating barrage through planned operation procedures, catchment treatment plan, luring ecotourism, socio economic development of stake holders and lake users, destroying prawn culture farms etc.. Introduction of solar panels for boat operation, use of bio degradable plastics, plantation of mangroves, training the fishermen for their capacity building against poaching, organic farming in the out skirt and within the lake islands is essential.

The present protocol for the lagoon should be safety of waterfowl, other faunal species and the indigenous flora by catchment treatment, restricting weed infestation, pollution control, public awareness and community participation among the stake holders, capacity building, controlled fishing and encouraging clean energy technology for transportation along with intensive research and development for a sustained biodiversity.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Kjerfve B. Coastal lagoons, Coastal lagoon processes. Editor Bjorn Kjerfve, Elsevier oceanography series. Elsevier science publishers B.V. 1994; 60:1-576
2. Khandelwal A, Mohanty M, Rodriguez F. G, Scharf WS. Vegetation history and sea level variation during the last 13,500 years inferred from a pollen record at Chilika Lake, Orissa, India. Vegthist Archaeobot, Springer verlag-07. 2008;17:335-344
3. Crutzen P, Stoermer E, The Anthropocene. IGBP Newsletter, 2000;41:17–18.
4. Zalasiewicz Jan, Williams M, Haywood A, Ellis M. The Anthropocene: A New Epoch of Geological Time? Philosophical Transactions of the Royal Society 2011; 835-841.
5. Mishra SP, Human Evolution and Extermination up to Present Anthropocene: India. Journal of Shanghai Jiaotong University; JSJ. 2020;16 (7):115-133. ISSN: 1007-1172.

6. Sterling, Andrew, Orissa, its geography, statistics, history, religion and antiquities. John Snow, 35 Paternoster Row, sold by Brooks, Leicester, Noble, Boston 1846. Source: British library; 1846.
7. Cotton AT. General, report on the Mahanadi River, source. Water Resources Dept. Library Odisha. 1858;8.
8. Harrish JC, Young CB. Reports and correspondence relative to the control of the mahanadi river at Cuttack, correspondences between the Chief engineer and superintending Engineer and Executive engineer, lower provinces 1858 to 1860, source Water Resources Dept. Library Odisha; 1860.
9. Blandford WT. Note on the laterite of Orissa. T. Oldham, (editor) Memoirs of the Geological Survey of India. 1859;1:253-276.
10. Mahalanobis PC. Mahalanobis Reports, Source: Irrigation and power dept., Orissa; 1940.
11. Hunter WW. Orissa or the vicissitudes of an Indian Province under Native and British Rule. Vol- II, London, 1872;182,
12. Sewell RBS. Hydrography of the Rambha Bay. Mem. Indian Mus. 1922;3(10):679-690.
13. Williams, et al, Svarup, Bishnu. Orissa Flood committee report-1928", Irrig^{n}. Dept., Govt. of Bihar and Orissa; 1928.
14. Biswas K. algal flora of the Chilika Lake. Memoirs of the Asiatic Society of Bengal. Royal Asiatic Society of Bengal. Calcutta. 1932;11(5):165-198.
15. Stephenson J. Littoral oligochaeta from the Chilka Lake on the east coast of India, Rec. Indian Mus. 1914;10: 225-262.
16. Annandale N. Fauna of the Chilka Lake: Mammals, Reptiles and Batrachiana. Mem. Indian Mus., 19155(2): 163-174.
17. Annandale, N. and S. Kemp (1915). Fauna of the Chilka Lake. Sponges. Mem. Indian Mus, 5(1): 21-54.
18. Chaudhuri, B. L. (1916). Fauna of the Chilika Lake: Fish, Part I. to part IV); Mem.Indian Mus., 5(4, 5, 6, 11): 403-439. 441-458., 491-508, 711-736.
19. Chilton C. Fauna of Chilika, 1916, Zoological Survey of India. 1916;5(5). 459-482.
20. Mitra GN. The development of the Chilika lake. Orissa Government Press, Cuttack. 1946;1-26.
21. Pritchard DW. Salinity distribution and circulation in the Chesapeake Bay estuarine system. J Mar Res. 1952;11: 106–123.
22. O'Brien MP Estuary and tidal prisms related to entrance area. Civil Engineering. 1931;1(8):738–739.
23. Phleger FB. Some general features of coastal lagoons. In: Ayala-Castaneres A (ed) Lagunas Costeras. Universidad Nacional Autonoma de Mexico, Mexico, DF. 1969;5–26
24. Kjerfve B, Magill K. Geographic and hydrographic characteristics of shallow coastal lagoons. Mar Geol. 1989;88:187–199.
25. Kjerfve B. Coastal lagoons. In: Kjerfve B (ed) Coastal lagoon processes. Elsevier, Amsterdam. 1994;1–8.
26. Lankford RR. Coastal lagoons of Mexico: their origin and classification. In: M. Wiley, Ed. Estuarine Proceses. Academic Press, New York, NY, USA. 1976;2:192–216
27. Fairbridge RW. The estuary: Its definition and geodynamic cycle. In: E. Olavsson and I. Cato, Eds. Chemistry and Geochemistry of Estuaries. John Wiley & Sons, New York, NY, USA. 1980;1–35
28. Fitz Gerald DM, Georgiou I, Miner M, Masselink G, Gehrels R. Estuaries and tidal inlets. In: Coastal environments and Global change, Wiley. 2013;268-298.
29. Mishra SP, Jena JG. Migration of tidal inlets of Chilika Lagoon, Odisha, India -A Critical Study. Int Journal of Engineering and Technology. 2014;6:2453-2464.
30. Mishra SP. Rejuvenation of lagoons along the east coast of India, management: Anthropocene approach. Int Jr of Adv. Research. 2019;7(1):688-714.
DOI:URL:http://dx.doi.org/10.21474/IJAR01/8378
31. Mee LD. Coastal lagoons. In: Riley JP, Chester R (eds. Chemical oceanography 7. Academic Press, New York. 1978;441–490.
32. Mangor K, Brøker I, Rand P, Hasløv D, Waterfront developments in harmony with nature. In book: Coastal and Ocean Engineering Practices. 2012;1-30.
33. Nayak PK. The chilika lagoon social-ecological system: An historical analysis. Ecology and Society. 2014;19(1):1.
DOI: http://dx.doi.org/10.5751/ES-05978-190101

34. Pradhan S, Mishra SK, Baral R, Samal RN, Mohanty PK. alongshore sediment transport near tidal inlets of Chilika Lagoon; East Coast of India, Marine Geodesy. 2017;40:2-3,187-203,
DOI: 10.1080/ 01490419.2017.1299059
35. Biswas KP. Ecological and fisheries development in wetlands –A case study of Chilika lagoon. Daya Publishing House, Delhi. 1995;110035:189.
36. Dasgupta S, Fukuoka M, Roy S. Hematite-pyrophanite intergrowth in gondites, Chilka area, Sausar Group, India. Mineralogical Magazine. 1984;48:558-560.
37. Tripathy SK. Hydrological studies in Chilika Lake, a tropical lagoon. M. Phil. Dissertation, Berhampur University, Orissa; 1985.
38. Samal RC. Remote sensing on geomorphic and sedimentologic evolution of the coastal tract between Dhamara and Paluri, Orissa, India. Ph. D. Thesis; Utkal Univ.,Bhubaneswar. 1993;198.
39. Government of Orissa, Delta Development plan, Stage II. Water resources Dept. (unpublished); 1985.
40. Anand NM, Chandramohan P. Studies on waves and longshore sediment transport along the coastline of Chilika Lake, NIO, Goa. 1992;1-4.
41. Mishra SP. Management of the sediment transported by the south Mahanadi deltaic rivers to the Chilika lagoon. Int Jour Adv Research. 2017;5(6):1005-1020.
42. Bhattacharya S, Sen SK, Acharyya A. Structural evidence supporting a remnant origin of patchy charnockites in the Chilka Lake area, India. Geol Mag. 1993;130: 363–368.
43. Bhattacharya S, Sen SK, Acharyya A. The structural setting of the Chilika Lake granulite- migmatite-anorthosite suite with emphasis on the time relation of charnockites. Precamb. Res. 1994;66(1-4): 393-409.
44. Sarkar SK, Bhattacharya A., Bhattacharya AK, Satpathy KK, Mohanty AK, Panigrahi S. Chilika Lake. In: Bengtsson L., Herschy R.W., Fairbridge R.W. (eds). Encyclopedia of lakes and reservoirs. Encyclopedia of Earth Sciences Series. Springer, Dordrecht; 2012.
DOI: https://doi.org/10.1007/978-1-4020-4410-6_57
45. Venkataratnam K. Formation of the barrier spit and other sand ridges near Chilika Lake on the east coast of India. Marine Geology. 1970;9(2):101-116.
46. Mohapatra LK. Fishing & Fishermen on the Chilika Lake in Orissa. India. Museum Bulletin. 1973;8(1).
47. Kachar KS. Chilika Lake. A pilot survey of birding possibilities, J Bomb Nat Hist Soc. 1966;63(2):290-297.
48. Jhingran VG. Report on the fisheries of the Chilka lake 1957-1960, Bulletin, CIFRI. 1963;1:113.
49. Venkataratnam K. Studies on some aspects of the sediments of Chilika Lake. Ph.D. thesis, Department of Geology, Andhra University, India. 1965;268.
50. Roychaudhuri B. The fishing communities of Chilika: A study in their ecosystem. Journal of the Indian Anthropological Society. 1977;12(2):101-112.
51. Banerjee AC. Hydrology of Chilika Lake. In: Summer Institute on brackish water capture and culture Fisheries. Central Inland Fisheries Research Institute (ICAR), Barrackpore, West Bengal. 1980;1-8.
52. Bhattacharya S. Review: The charnockite problem, a twenty first century perspective. Natural Science. 2010;2(1):402-408.
53. Sahu BK, Pati P, Panigrahy RC. Environmental conditions of Chilika lake during pre and post hydrological intervention: an overview, Springer. Journal Coast Conservation. 2014;18:285-297.
54. Nandy Ku A. Geology of Chilika Lake; 2016.
Available:https:// aknandy. wordpress.com /2016/ 12/14 /geology-of-chilika-lake/
55. Das Bishnu P, Jena J. Impact of mahanadi basin development on eco-hydrology of Chilika. In: Sengupta, M. and Dalwani, R. (eds.) Proceedings of Taal 2007: The 12th World Lake Conf. 2008;697-702.
56. Das Lalu, Jitendra Kumar Meher, Monami Dutta. Construction of rainfall change scenarios over the Chilka Lagoon in India.Atmospheric Research. 2016;182: 36-45.
57. Mukherjee Subham. Influence of discharge of river Daya in Chilika Lagoon: A brief study using mohid simulation model. Suresh Gyan Vihar University. Journal of Engineering & Technology (An International Bi-Annual Journal). 2016;2 (2):10-21.
58. Mishra SP, Jena JG. Geophysical changes of Chilika lagoon in post Naraj barrage

period; PhD thesis, 2016,Sikhya o' Anusandhan Univ. Inflibnet; 2016.
Available:http://hdl.handle.net/10603/136580

59. Mishra SP, Jena JG. Intervention of Naraj Barrage: Its effects on sediment inflows into Chilika Lake, India. Lakes and Reservoirs: Research and Management, Wiley Blackwell, John Wiley and sons, Australia. 2015;20:77-88
60. Hazra S, Das S, Ghosh A, Raju PV, Patel A. The mahanadi delta: A rapidly developing delta in India. In: Nicholls R., Adger W., Hutton C., Hanson S. (eds) Deltas in the Anthropocene. Palgrave Macmillan, Cham; 2020.
Available:https://doi.org/10.1007/978-3-030-23517-8_3
61. Mahanty MM, Mohanty P, Patnaik Ku A, Samal RN, et al. Hydrodynamics, temperature/ salinity variability and residence time in the Chilika lagoon during dry and wet period: Measurement and modeling Cont Shelf Research. 2016;125:28-43.
DOI: 10.1016/j.csr.2016.06.017
62. Pattanaik S. Conservation of environment and protection of marginalized fishing communities of Lake Chilika in Orissa, India. J Hum Ecol. JHE 1507, © Kamla-Raj; 2001.
63. Bhatta KS, Pattnaik AK. Environmental monitoring of Chilika lake Proc. Inter. Workshop on sustainable Development of Chilika lake. Orissa, Bhubaneswar. 2002; 95-113.
64. Mishra SP, Jena JG. Morphological reconstruction of Southern Mahanadi Delta and Chilika Lagoon, India – a critical study. Int. Journal of Advanced Research. 2015;3(5):691-702.
65. Mishra SP, Sethi Ku B, Barik Ku K. Delta partitioning, geospatial changes, anastomosis of Mahanadi Tri-delta, India. International Journal of Earth Sc and Eng Caffetinnova org. 2019;12(1):21-40.
DOI: 10.21276/ijee.2019.12.0103
66. Panigrahi S, Acharya BC, Panigrahy RC, Nayak BK, Banarjee K, Sarkar SK. Anthropogenic impact on water quality of Chilika lagoon RAMSAR site: A statistical approach. Wetlands Ecology and Management. 2007;15(2):113-126.
67. Parida Saibala, Bhatta KS. Watershed and livelihood through picsi-culture. Souv. 5th Chilika Mahotsav, Chilika Development Authority, Bhubaneswar. 2017;111-113.
68. Barnes RSK. Costal lagoons. Cambridge studies in Modern Biology. 1980;105.
69. Rao NK, Takayasu K, Sada Kata N, Hema Malini B. Holocene evolution of deltas on the east coast deltas of India, present status and future prospects. Kay R, editor, Deltas of the World, N.Y. Am Society of Civil Eng. 1993;010–015.
70. Gupta GVM, Sarma VVSS, Robin RS. Raman AV, Jai Kumar M, Rakesh, Subramanian BR. Influence of net ecosystem metabolism in transferring riverine organic carbon to atmospheric CO2 , in a tropical coastal lagoon (Chilika Lake, India). Biochemistry. 2008;87:265-285.
71. Ghosh AK, Pattnaik AK. Chilika lagoon experience and lessons learned brief. UNEP Int. Waters learning exchange and resource network. 2008;115.
Retrieved: 2008-12-23, 2008.
72. Mukherjee M, Suresh VR, Manna RK. Microplankton dynamics of a coastal lagoon, Chilika: interactive effect of environmental parameters on microplankton groups. Environ Monit Assess. 2018;190:689.
DOI: https://doi.org/10.1007/s10661-018-7049-9
73. Raman AV, Satyanarayan C, Adiseshasai K, Prakash KP. Phytoplankton characteristics of Chilika Lake, a brackish water lagoon, east coast of India. Indian J Mar Sci. 1990;19:274–277
74. Chilika Dev. Authority DPR. Integrated Coastal Zone Management: Strengthening of wetland research &training centre and bio-diversity conservation on Chilika Lagoon. czmpodisha. org/.../Chilika; 2012.
75. Majharul Islam Sk, Paul AK. Geospatial technologies for assessment of the role of chilika lagoon and its present environmental status on the economy occupation and hazard of the coastal society of Khurda Puri and Ganjam districts of Orissa. PhD Thesis, Vidyasagar University; 2016.
Available:http://hdl.handle.net/10603/292449
76. Biswas KP. Ecology and fisheries development in wetlands: A study of Chilika lagoon. E-book, Google. 1995;192.
77. Central Inland Capture Fisheries Research Institute (CIFRI), Chilka Lake - Present

and Past. Bulletin-80, Indian Council of Agricultural Research), Barrackpore-743 101West Bengal. 1998;1-46.

78. Mishra SP. Management of the sediment transported by the south Mahanadi deltaic rivers to the Chilika lagoon. Int Jour Adv Research. 2017;5(6):1005-1020.
79. Ghosh Asish. Experience brief for Chilika lake, Orissa, India. Center for Environment and Development. 2003;22:2003.
80. Mishra SP. Estuaries and lateral channel development along east coast of India, International Journal of Advance Research. 2016;4(12):2360-2371.
81. Pearson W. Chilika Chart, the bathymetry map of Chilika lake, First Officer of H. M. Surveying Brig. Krishna, source Water Resources Dept. Library Odisha (Unpublished); 1858.
82. Kanungo A, Panda GK. Morphology of the coastal landforms Along the Orissa coast A study based on remote sensing. Thesis, Dept. of Geography, 2010;17:140.
Available:http://hdl.handle.net/10603/281374
83. Unnikrishnan AS, Rup Kumar K, Fernandes SE. Sea level changes along the Indian coast: observations and projections. Curr Sci. 2006;90;362–368.
84. Naidu AS. Some aspects of texture, mineralogy and geochemistry of modern deltaic sediments of Godavari River. Unpubl. PhD thesis submitted to Andhra University, Waltair, India. 1968; 250.
85. Somanna K, Reddy ST, Rao MS, Geomorphology and evolution of the modern mahanadi Delta using remote sensing data. International Journal of Science and Research (IJSR). 2016; 5(2):1329-1335.
86. Bruun P, Gerritsen F. Natural bypassing of sand at coastal inlets. Jr. of the Waterways and Harbors Division, ASCE. 1959;85:401-412
87. Finlayson CM, Rastogi G, Mishra DR, Pattanak AK. Ecology, conservation, and restoration of Chilika Lagoon, India; Springer, Book. 2020;15.
88. Ramesh R, Purvaja R, Lakshmi A, Newton, A, Kremer HH, Weichselgartner J. South Asia Basins: LOICZ global change assessment and synthesis of river catchment - Coastal sea interaction and human dimensions. LOICZ Research & Studies No. 32. GKSS Research Center, Geesthacht. 2009;121.
89. Ghosh AK, Pattnaik AK, Ballatore TJ. Chilika lagoon: Restoring ecological balance and livelihoods through re-salinization. Lakes and Reservoirs: Research and Management. 2006;11:239–255
90. Ahmed M. Census of India, Orissa, Part I-Report, 1951;11.
Available:http://lsi.gov.in:8081/jspui/bitstream/123456789/6821/1/7732_1951.pdf
91. Fairbridge RW. Swash, swash mark. In: Geomorphology. Encyclopedia of Earth Science. Springer, Berlin, Heidelberg; 1968.
DOI: https://doi.org/10.1007/3-540-31060-6_364
92. Mishra SP. Delineation of fluvial-Aeolian dunes along the SMD and Chilika coasts of Odisha, India. Int. Journal of Advance Research. 2017;5(12):412-425.
DOI: 10.21474/IJAR01/5975
93. Chandramohan P, Nayak BU. A study for the improvement of the Chilka Lake Tidal Inlet, East Coast of India. Journal of Coastal Research. 1994;10 (4):909–918.
94. Sanil Kumar V, Pathak KC, Pednekar P, Raju NSN, Gowthaman R. Coastal processes along the Indian coastline, Current Science. 2006;91(4):530-536.
95. Shetye SR, Gouveia AD, Pathak MC. Vulnerability of the Indian coastal region to damage from Sea levek rise, Current Science. 1990;59 (3):152-156.
96. Chandramohan P, Sanil Ku V, Nayak BU. Coastal processes along the shore front of Chilika Lake, East coast of India. Ind J of Marine Science. 1993;22:268-272.
97. Baral R, Pradhan S, Samal RN, et al. Shoreline change analysis at chilika lagoon coast, India using digital shoreline analysis system. J Indian Soc Remote Sens 2018; 46:1637–1644.
DOI: https://doi.org/10.1007/s12524-018-0818-7
98. Peetabas N, Panda RP. Conservation and management of bioresources of Chilika Lake, Odisha, India, Int. Jr. of Scientific and Research Pub. 2015;5(7):1-4.
99. Khunti N, Mishra JM. Sustainable tourism development in wetlands a study with reference to Chilika lake Odisha; thesis, Department of Tourism Studies; Pondicherry University. 2017;2.
Available:http://hdl.handle.net/10603/259906

100. Mishra SP, Ojha AC. Fani an Outlier among Pre-monsoon Intra-Seasonal Cyclones over Bay of Bengal. International Journal on Emerging Technologies. 2020; 11(2): 271-282. ISSN : 2249-3255

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