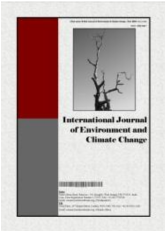

International Journal of Environment and Climate Change

12(10): 98-113, 2022; Article no.IJECC.86702
ISSN: 2581-8627
(Past name: British Journal of Environment & Climate Change, Past ISSN: 2231–4784)

Anthropocene Trails on Geomorphology of Meghalayan Chilika Basin Odisha

Siba Prasad Mishra [a*], Abhisek Mishra [a], Chandan Kumar [a] and Saswat Mishra [a]

[a] *Civil Engineering Department, Centurion University Techn, Management, CUTM, BBSR, Odisha, India.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJECC/2022/v12i1030774

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/86702

Original Research Article

Received 15 February 2022
Accepted 27 April 2022
Published 28 April 2022

ABSTRACT

The Chilika gulf in the pre-Meghalayan era has transformed into Greater Chilika, later a leaky lagoon and now downsizing. During early Anthropocene epoch (1950) became a restricted lagoon with the stable southern half of the barrier spit and fragile the northerly half. The sediment balance governed by the inland riverine flood flows from south Mahanadi delta (SMD), and through diurnal tides during other periods. The present anthropogenic development are the emerging Bhubaneswar capital (1948), rising population, and peripheral growth of urbans. Chilika, have deteriorated its eco-bio-hydro system and its associated delta. The anthropogenic interventions to flow by dams, barrages, new mouth dredging, Gobakund cut and natural sea-level changes, frequent storms, high waves, and longshore drift, have altered the geomorphology of the area. The present search envisages the physical changes that occurred in about 6000km^2 of study area. The Remote Sensing and GIS technology and the ERDAS software tool were in use to concoct for the years 1984, 1994 and 2022, and compared the basic geophysical features geospatially (1975 to 2022). The erratic changes have developed over the lacustrine area, tidal inlets variability, increase in stable barrier spit and ecosystem with the land slamming of storms. Excess tourism activities, exploitation of fishery, motorized communications, poaching and increase of stakeholders have lost its forests, hills, solitude, and tranquility within.

Keywords: Anthropocene; mahanadi delta; lagoon; land use/land cover; dunes; RS/GIS.

**Corresponding author: E-mail: 2sibamishra@gmail.com;*

1. INTRODUCTION

The isle/islands and barrier spits in an estuarine/lagoon setting have a geospatial life cycle of formation, development, mobilization, stabilization, and demolition in the coastal corridor with a varying life span of some days to hundreds of years depending upon the sediment influx, residue budget of the lagoon, littoral drift, and tidal activity. The varying east coast of southern Odisha has formed a barrier spit from southern fringe during post-Holocene period. The endless natural process of erosion/deposition during sediment transport occured with the fluvial status and sediment budget of the lagoon. They intermingle at the interface of fluvial vs. littoral developments. The inconsistent dynamics have substantial insinuations on the fragile marine-brackish –freshwater habitats, flora, fauna, aqua-fauna, and avifauna of the lagoon. The sustainable geodynamics of coastal landform maintained by the beach nourishment, restricted sand mining, maintenance of dunes, geohydrology, lacustrine bodies, estuaries, lateral channels, and the lagoons adjacent to the beach, Buffington [1]. Thompson et al. [2] van Rijn, et al. [3] Aagaard, et al. [4] Mishra et al. [5] Nardin, et al. [6].

The Chilika Lagoon, (19.8450° N, and 85.4788° E) housed parallel to east coast of south Odisha, India. The brackish water lagoon varies in spread of ≈1011 Km^2 in the rain to 775 Km^2 in dry summer [7]. The mean volume of the brackish water of 1530 cum [8,9]. The lagoon has three sectors, Northern, Central, and Southern opening to the outer channel (OC) at Magarmunha. The 34km long and average width 1200m OC and the 30km fragile barrier spit separate the lagoon from the Bay with all hydrodynamic activities that control the hydrology, ecology, economic, politics, and societal tenancy of its stakeholders. The shallow northern sector connected to the rivers Daya and the Bhargovi of the South Mahanadi delta (SMD) that contributes mainly (60-65%) to fluvial transactions of the lagoon. The central sector regulates the flow and the ecosystem. The southern sector is deep, saline, and stable. The OC has active TI's as seen at Gabakund (2008), Baidhar (2012), Nanganasi (Dhala Kuan) (2016) and Gaikona (2017). The OC has distinct small to large flood/ ebb deltas. Presently two TI's are hovering between Siandi and Manikapatna by March 2021 (Goole Earth) **(**Fig 1).

2. REVIEW OF LITERATURE

Hoyt et al. [10] Kumar et al. [11], Carr-Betts et al. [12] Duong et al. [13], reported that tidal inlets drift laterally in presence of longshore current by eroding the spit and substituting a highly energized cross bed which is bimodal-bipolar. The opening of a new TI may be due to breaching, narrowing of the mouth of flood delta, seepage, sand liquefaction dwarf spits, and piping Pierce, Kraus [14] Davies-Vollum, et al. [15], Bamunawala et al. [16]. Chilika lagoon has bi-layer circulation, sub-Arial estuarine outline consisting of surface flow of low salinity and tide induced subsurface saline water Mee [17], Mishra et al. [10], Pradhan [18]. The sediment of the migrated TI contains traces of barrier island deposits of the Holocene epoch, Baral et al. [19] Hardage et al. [20]. Hayes [21] reported that inlets formed due to breaches caused in the barrier islands during large storms when high storm surges and high waves occur. Barrier islands constitute 10 to 15% of the total shoreline of the globe. Immersed microphytes recover water quality in shallow eutrophic lagoons by different mechanisms Scheffer et al. [22]. Martínez et al. [23] Mahnty et al. [24]. The breach can occur in a barrier spit either from the sea or the Lagoon side Kairus et al. [25]. The tide-induced shoreline changes during high and low tides in Chilika Lagoon and area submerged the during high tides (Semidiurnal) are 60m and 44.36 km^2 respectively and the highest tide level is 0.83m Gupta M. [26]. Advancement of viable Hydro-Geo-ecotourism like eco-retreats within dunes, barrier spits, and islands in and around the water front's promotion and protection of the ecosystem without perturbing the biome Naik P. K. [27] Uddin et al. [28]. The stabilized dunes were mobile in past and most of the dry climates made them stable later Tsoar, [29], Murra,y, et al. [30], Bera et al. [31]. Inlets in Chilika Lake migrate in the direction of dominant littoral drift and longshore drift is inversely proportional to the tidal prism, which is conducive to TI closing Sahoo et al. [32], Pattanaik et al. [33]. The Barrier islands are unstable, migrating, and varying in nature and influenced by the action of extreme episodic storm events (EESE), MSLR, and anthropogenic activities. To sustain the coastal landscape, the dynamism needs study and pertinent action, Feagin et al. [34], Thronton [35].

Watabe et al. [36] interpreted through GIS metaphors that Tsunami-2004 affected less to the geomorphology of Chilika Lake, Fabiola et al.

[37]. The turbulent flow action on the on hold sediments in a plume and instituted that turbulent bursting arises with sediment influx correlation Salim et al. [38]. The Chilika lagoon has NO_3^{-1} concentration of low DO valued water has a range of .01 to 02 µ mole/lit giving rise to an increase in the concentration of chlorophyll to 4 mg/cum on studying by GIS and GPS by Rajkumari, et al. [39]. Chilika lake had eutrophic state with Carlson TSI value 49-63 from 2013 to 2015, Jally et al. [40]. The incursion of sediment, its texture, algal invasion, and anthropogenic interferences play a critical role for the varying low organic carbon content but rich in nitrogen concentration of phosphorous, and silica institute in the samples of sediment cores of the outer channel of Chilika that is a wave-dominated, micro-tidal coast, Nazneen [41] Duong TM, [13].

2.1 Reasons for Study

Field surveys conducted for the Chilika and its basin by the Survey of India (SOI) and British engineers during the late 18th century with considerable gaps. Experts from various disciplines rarely analyzed the maps generated and action plans are hardly in implementation for the sustainability of the basin. From 1970 onwards, the remote sensing tools with GIS methodology are in the application, which is a fast, efficient, accurate, and economic tool to give Land Use and Land Cover maps of the area depicting the status of the geo-bio-hydro environment. Analyzing tools (stochastics and soft computing) like ANN, Linear programming, and soft computing algorithms/models are available to give the status and predict the eco-health of the system in a fast forward mode. Under deteriorated eco-health of the Chilika basin, it is high time to have innovative studies, plans, and decision making in prioritizing to maintain the eco-health of the lagoon and its basin.

3. METHODS AND METHODOLOGY

GIS is the geographic information system. The GIS architecture and its synoptic view accomplished to capture, preserve, grip, analyze, and manage the existing limnology, geologic, and geographic data. The GIS is one of the methods to explore the crescendos of evolution and morphologic vicissitudes. The GIS Technique can employ the study of is-lets in the outer channel of Chilika. Deploying GIS technology, and using the MSS (Multi-Spectral Scanner), TMS the Thematic Mapper Sensors, and ETMS+ (Enhanced Thematic Mapper with Sensor Plus in the satellites LANDSAT- V or VII (or VIII) and their resources. That output is of better resolution of images. Google Earth practices high-resolution imageries like QUICK BIRD (the digital Globe). That is 65 cm panchromatic at NADIR, which operates at a few hundreds of km above the surface of the Earth to give those high-resolution images, https:// www.gearthblog.com /blog/archives/ 2014/04/ google-earth-imagery.html.

The phases in the methodology process are (1) Downloading satellite data from LANDSAT series from GLOVIS classic using Landsat Series Thematic mapper -5, (2). Digital Image Processing performed by using RS and GIS software for geo-referencing and layer stacking, (3). Interpretation of the RS data (various Landsat files) using ERDAS 9.2 software, (4). Focal analysis conducted for checking the disc tripping and the discarded cloud-covered images. (5). Atmospheric correction for meteorological interferences (noises or clouds) (6). Data preparation and subset image preparation (7). Thematic maps such as Land Use and Land cover map, (8). Checking accuracy (≥85%), (9). LU/LC map generation and compared with past results (GIS files) Fig 2.

Present investigation involves downloading of satellite imageries from Google Earth and preparation of the intermittent thematic maps of Chilika from 1984 to 2022. Transgression of the coastal zone and morphologic variations of the Chilika basin explored pre and post anthropogenic mediations. They were the opening of the artificial Sipakuda mouth (2000), the Naraj barrage operation (2003), the closing of the Motto tidal inlet (2004), High floods (2003, 2006, 2008, 2014, 2017), the opening of natural cyclone/high waves induced tidal inlets 2008, 2012, 2013, 2016, and 2019, Duong [13].

3.1 The Anthropocene Epoch

Based on the geological time scale of the earth, the homosapiens have allowed the Holocene era to conquer the earth about 12800YBP (Years before the present). With the surge in population, favorable climate, and technological developments the human gradually mastered the geo-bio-hydro sphere and shaped the earth as per his will. The explosion of the atom bombs in 1945 have a farewell to the Holocene epoch prevailing for a short duration and the emergence of the Anthropocene era from 1950 as pert the geochronologists of the earth. Though the epoch reigned in India from 1950, became prominent in 1973 with exponential population surge, scientific growth, and technological advancement. The climate and the rate of demographic changes surpassed the agricultural yield challenging food security and the geologists claimed the period from 1980 as the golden spike period on the earth.

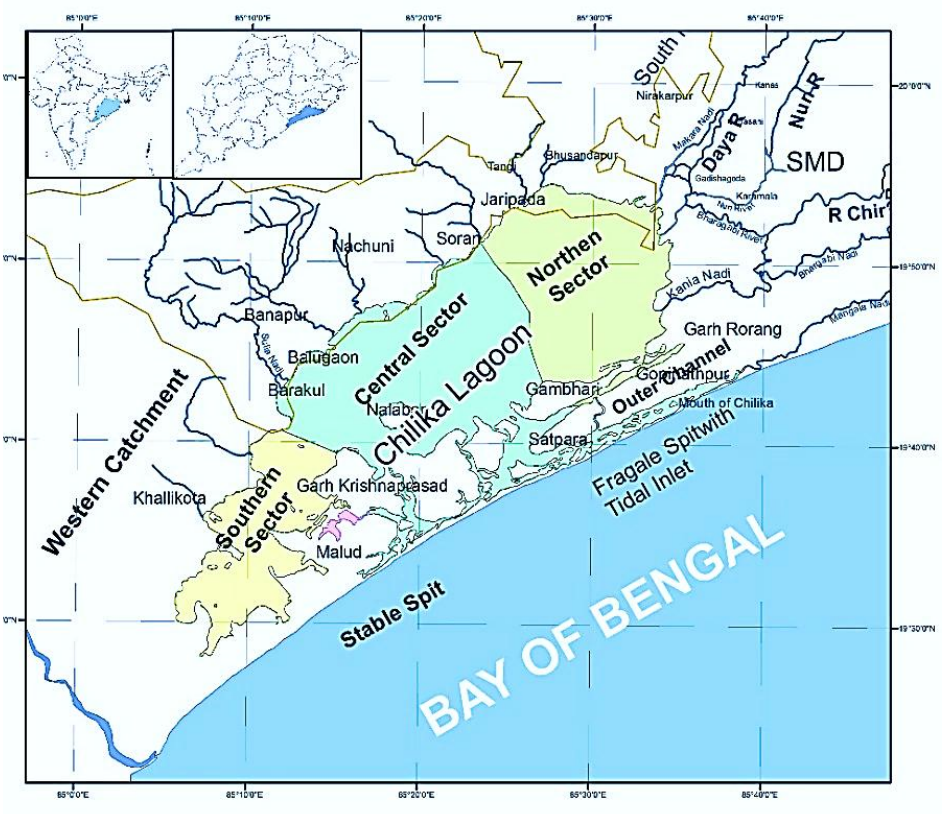

Fig. 1. Index map of the flow system to Chilika from the western catchment, and SMD

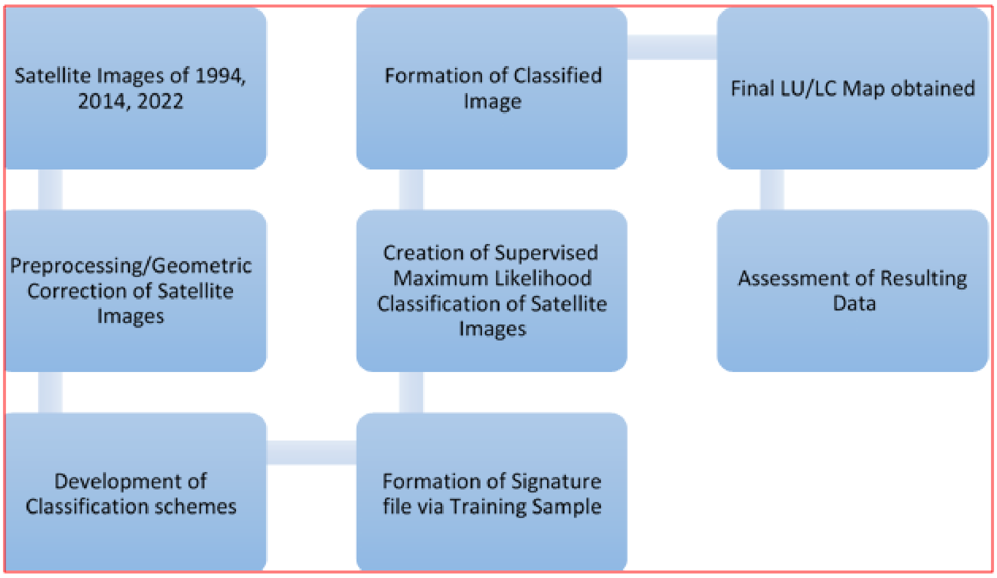

Fig. 2. The methodology for the preparation of LULC map from Satellite imageries

3.2 The Chilika in Past

During the Pleistocene epoch, the present Chilika was a low-lying area in the estuarine of the SMD Rivers, which later during the Pre-Holocene period converted to a gulf (later greater Chilika) due to the most active Indian summer monsoon (ISM) in India during 4200YBP. The greater Chilika with an extent of 1500 Km^2 area was formed by post-Holocene (Meghalayan era) sediments forming large dunes from the extreme south (Prayagi) to NE (Harachandi temple) [9]. By characteristics, the lagoon is restricted at present, which was choked (one inlet) from 1996 to 2000. There was a sporadic opening of TIs and continuous migration of inlets to the north with mutable diversities. There is an outer channel formed connecting the main lagoon of length 32km with fragile islets with temporary vegetation which is about 500years old, the length of barrier spit was from Prayagi to Harachandi temple (≈74km) has been reduced to 64.3km as of date up to Motto Village, [10].

3.3 The Chilika Basin

The basin of Chilika consists of three areas, South Mahanadi delta (SMD of ≈1977km^2 area), Western Catchment (≈2800Km^2), and its own spread (≈1500km^2). The SMD) originate from the start of the Kuakhai system in Barang (near Cuttack). The Kuakhai trifurcate as the rivers Kushabhadra, the Daya, and the Bhargovi. The rivers, the Daya and Bhargovi are joining at the NW corner of Chilika lagoon. They comprise about 62% of the lagoon's flood flows and debouch to Chilika and water flows out to the Bay of Bengal through the tidal inlets in the barrier spits of the Outer channel. Until 1950, the upper stretch of SMD housed in the Chandaka forest range and lower regions of the coastal tracks of Puri District. The shifting of the capital of the state Odisha from Cuttack to Bhubaneswar made the forests bald. After 1950. The western catchment was a small stretch of forests in the eastern interface of the Eastern Ghats belt (EGB) hills range. The exponential population growth and growth of 10-12 townships, Gobakund cut, abandoning and renovation of anastomosed drains, modernization, intensive agriculture have altered flow, polluted the distributaries and the sustained health of the basin has been deteriorated [7].

3.4 The eco-system Chilika Basin

The Chilika lagoon that epitomizes an enriched fragile biome is abating gradually. The ecosystem is waning due to changes in salinity, erratic floods in South Mahanadi Delta (SMD), imbalanced sedimentation, human interventions, weed proliferation, and downsizing. The average area of 100 Km^2 has transformed into landmass by sedimentation, reduction of salinity due to stalled tidal mix from 1990 to 2000. The only gateway was the depleted TI shifted to extreme north near village MOTTO restricting exchange process. From 1995 to 1999, there was a 500% reduction in the aqua catch, deserted Nalabana sanctuary (avifauna), and proliferation of phytoplankton. From the year 2000 onwards the basin has been deteriorating due to agglomeration of the Bhubaneswar city, increased urban areas along the west coast, conversion of NW swamps to agricultural land and prawn fields, and extension of SMD further south, and changes made in the anastomosed drains and riverine flow. There is drastic ecological, economic, and societal imbalance observed. The stakeholders compelled migration or marginalization. Possibility of conversion of the brackish water Chilika to a sweet water lake. The climate change and meteorological extremes caused the Lagoon's water surface temperature (SSWT) to rise trend 0.39^0 C/ decade. Consequently, there was a rise in evaporation, downsizing of the lake, the evolution of methane gas, and the fear of algal bloom growth of @20% was projected, Pandey K. [42], Mishra DR. et al. [43], Mishra S.P, [5].

3.5 21st Century Geomorphology Change

The dredging of a direct TI to Bay opposite to village Sipakuda (2000) and Naraj barrage across the Kathajodi (2004) at the apex of the delta, dredging the Gabakund and other channels were the major interventions made. The drought spell in the Mahanadi basin from 2000 to 2003 without the functioning of Naraj barrage at the apex of the parent river closed the remote mouth at Motto village. The results were affirmative and the ecosystem was restored and improved upgrading the lagoon from a choked to restrict one by 2008. Later at closed intervals, cyclonic, very severe, extreme severe cyclonic storms, Phailin (2013), Hudhud (2014), Titli (2018), Fani (2019), Amphan (2020), and YAAS (2021) drought period from 2014 to 2017 has devastated the geomorphology and biodiversity of the lagoon and its basin. The poor geo-bio-hydro ecosystem assigned are demographic growth, urbanization, migration/marginalization along with economic and political chaos within the basin.

3.6 The spit Geometry

The spit geometry, migration of tidal inlets, and fragile landform of the outer channel have changed the land use/land cover of the Chilika due to anthropogenic interventions in the fluvial system. The present study over 42 years investigates the fluctuations in LU /LC in the brackish water body area and outskirts extents in the South Mahanadi delta in the Puri district. The satellite imageries through LANDSATS, IRSP6 LISS III, and LANDSAT -8, for the years 1975 and 1995, 2012 were studied prior by various researchers, Ojha et al. [44]. GIS software is used to prepare the thematic maps. In the present study, a LU/LC map of the Chilika catchment for the years 1975, 1995, and 2012 were in consideration from the study of Ojha et al. [45], Chang et al. [46]. Image processing, visual interpretation techniques, and ground trotting were performed to check the accuracy of the classification. The GIS techniques were in use to examine the LU/LC of the Chilika area for the years 1987 and 2017. All the results were compared [47].

3.7 The Triple Points

It has been inference from various proxies, radioactive studies of sediment cores of the lagoon, and pollen studies made by Khandelwal et al. [48] Mishra S. P. [49] there is a discontinuity in lake life developments and transformations during early Meghalayan era till 2500YBP. The present barrier spit is hardly 500 to 1000 years old, the parallel barrier sprung through Magarmunha, Satapada, Manikapatna, and Harachandi temples. There are a series of triple points formed parallel to the coastline. The faded triple points are in the southern fringe, which is presently deployed, like agricultural fields whereas prominent are the recent formations. The triple points represent the sea-level fluctuations and sediment transportation from the inland basin and the SMD Rivers. The shape of the triple point at Trichina (Latest formed) when there is a northward shift of the tidal inlet and inadequate flushing through the outer channel is shown in Fig. 3.

3.8 Biodiversity Chilika Basin

In the Prayagi areas of Malud and Parikud areas about 1300 to 2200 years old and young alluvial plains containing paddy-cultivated areas are there. The major plantations are coconut mango, Jackfruit, Chakunda, etc., and thickly populated but mangroves are rarely seen. The NW corner of the lagoon has transformed into recent alluvial plains from waterlogged swamps. The rabi paddy fields are presently covered with sweet water aquatic plants like water hyacinth and ipomeas and other planktons. The periphery of the west coast is swampy and was covered with phytoplanktons, Nala grass (Local name), and seagrasses. They are augmenting the sedimentation process of the lagoon. The extended sandy beaches, sparse mangroves, disconnected islands, and barrier spits are covered with Jhaun (Tamarix dioica, Kia and Ketaki (Pandanus tectorius) and Cashew trees (Anacardium occidentale). The major source of livelihood of the lake users are fishery, tourism, paddy cultivation, etc. [50,51].

Fig. 3. The triple point at Trichina after the northward shift of the TI at Magarmunha

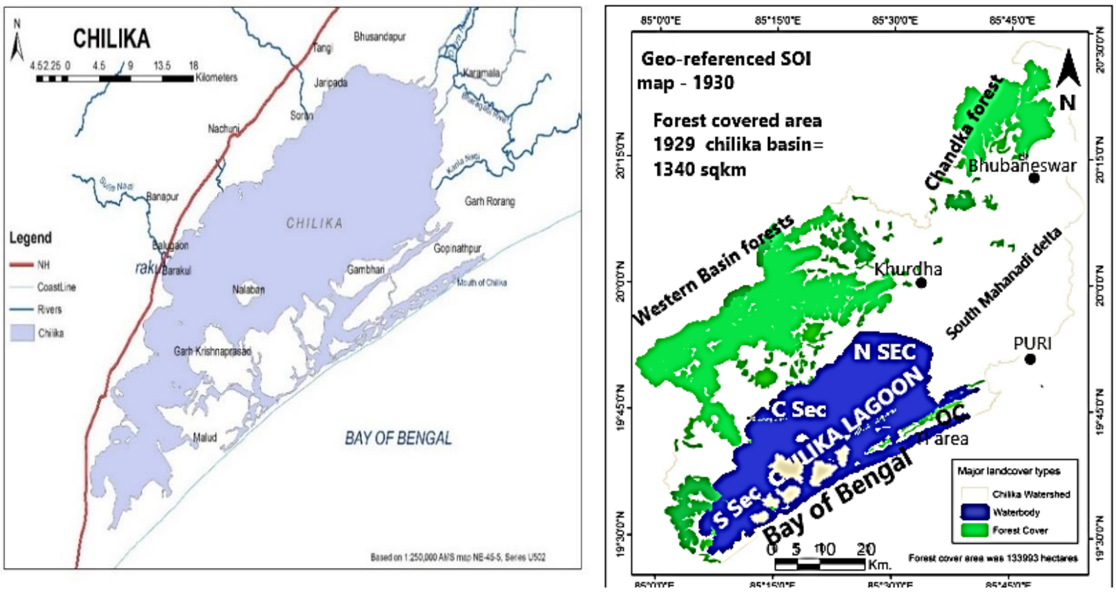

Fig. 4(a) and Fig 4(b). The georeferenced SOI map of the Chilika basin surveyed during 1929

Geomorphology of NW of SMD: The major geomorphology features in the SMD (Daya catchment) around NW of Chilika lake were delta plains of 238.24 Km^2, flood plain, levee and ridges of 16.22 Km^2, Paleo channels 57.92 Km^2 (some abandoned), pediment (some buried channels) of 142.94 Km^2, mudflat of 483.34 Km2, lateritic uplands of 71.05Km^2, and hills, valley are of 9.80 Km^2, Oinam B [52]. The SMD has been in the process of geomorphologic transformations like urbanization, deforestation, conversion of lake swamps to agriculture fields, a shift in livelihood, socio-political developments, and overall economic status of the basin dwellers [53,54]. The SOI maps of the Chilika basin are available for 1930. The forest area from the jointed and georeferenced Chilika basin map gave 1340km^2, of Chandaka, Banpur, Khalikote, and Rambha forests (Fig 4).

Land Use and Land Cover Chilika basin: The LULC, in and around the Chilika lagoon, rest on the characteristics of soil and the lagoon's salinity, residence time (RT), Peclet number, and surface water temperature (SWT) and their rising trend during summer [55]. The RT in N-sector is 132days (max) during summer, and 35days in the southern sector in the rainy season Mahanty et al. [56].

Geographical information systems and remote sensing data were downloaded from various satellites (LISS-3, LANDSAT 3, LANDSAT-4, LANDSAT-5, AND LANDSAT -& AND LANDSAT 8). They were in use by various authors to assess the Land use and Land cover (LU/ LC) of the local basins from south Mahanadi delta areas (1900km2), and the western catchment areas. At various intervals considered are from 1975 onwards to interpret the LU/LC of the local catchment of the Chilika Lagoon and NW-ly inflow from South Mahanadi delta (SMD). The downloaded Land sat data is of the same period, almost the same area, and considered for analysis, Fig 5(a), Fig 5(b), and Fig 5(c).

The LULC of major layers like water bodies including the lagoon, the built-up areas (all types of settlements and infrastructures), all types of forests (sparse, medium, and dense), hills, and open/ shrubs, and all agriculture The LU LC for the intermittent years Major climatic changes along with the LU/LC changes occurred during the twenty-first century, particularly from 2000. Details of anomalies are:

Period 1970-1994: The rise in human population from 1970 onwards has urged for an increase in human migration from rural settlements to urban cosmopolis. Bhubaneswar had the highest growth rate of 176.07% from 1961 to 71, instigating major migration from rural to the capital city. That had increased homestead land from about 30km^2 in 1950 to an expansion of 96.21km^2 by 1975.

Table 1. Geospatial geomorphologic changes in various components in Chilika B

LULC	Area	Area	Area	Area	Area	Area	Area	Area	Area	Area	Area	Area
Item	Km^2 1975	% 1975	Km^2 1994	% 1994	Km^2 1999	% 1999	Km^2 2012	% 2012	Km^2 2014	% 2014	Km^2 2022	% 2022
Water bodies+ Chilika)	1175.11	25.29	1145.8	23.59	1014.56	20.41	1098.83	22.76	1008.5	20.8	894.7	18.42
Built-up areas	655.69	13.56	865.56	17.82	1006.83	20.8	1100.55	22.8	1159.4	23.9	1388	28.57
Forests	1626.95	32.63	1216.3	25.04	716.41	14.79	1012.52	20.97	920.25	18.9	1032	21.24
Hills	475.29	9.84	336.12	6.92	367.07	7.59	322.66	6.68	371.34	7.65	280.3	5.77
Crop + Veget^n	903.64	18.68	1289.1	26.54	1734.39	35.84	1292.01	26.77	1397.7	28.8	1261	25.97
Source	OJha et al 2013[44]		Present study		OJha et al. 2013[45]		Wetland int. South Asia, CDA		Present study		Present study	

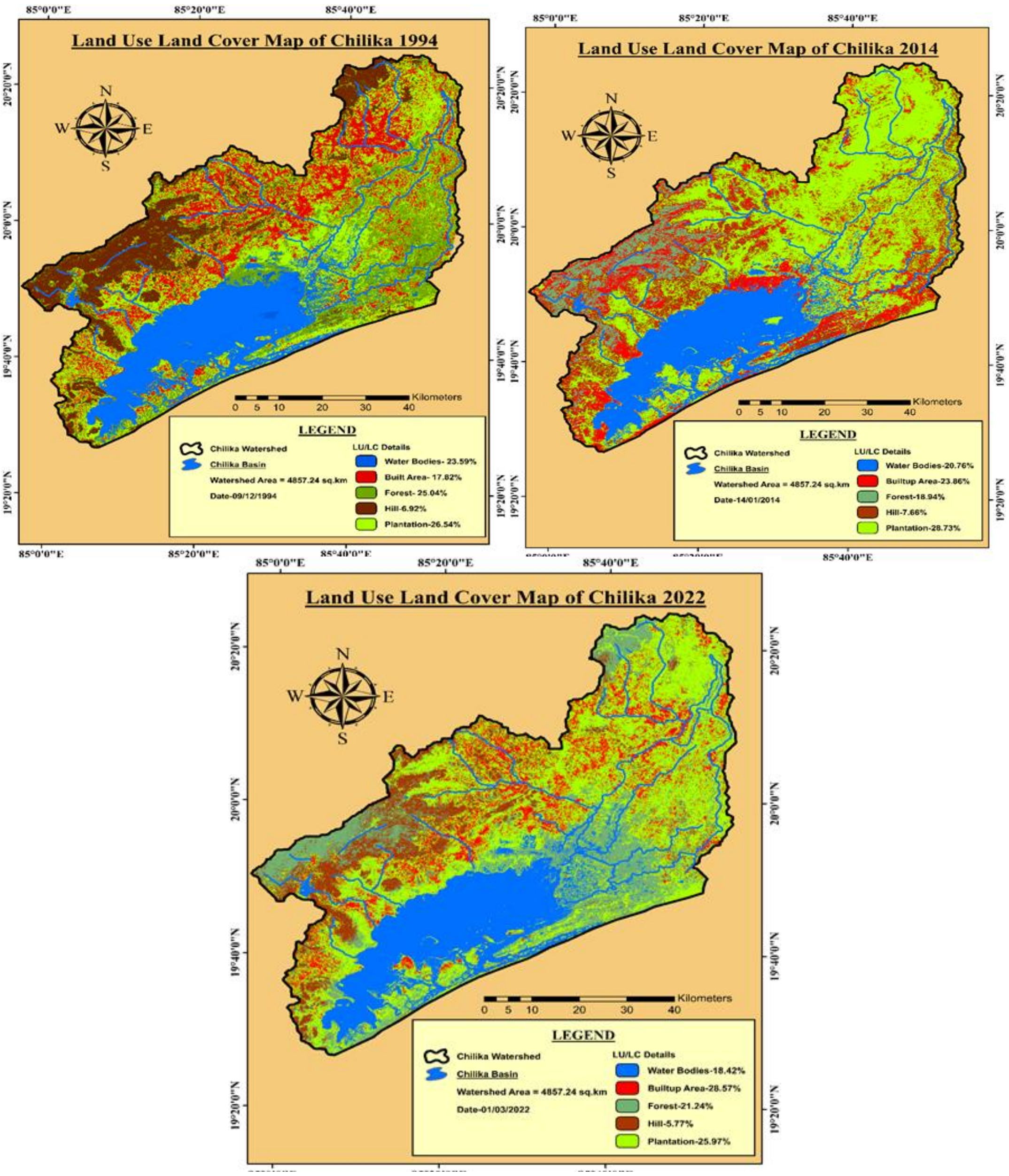

Fig. 5 (a), (b). The LU and LC changes of the south Mahanadi delta study years 1994, 2014 and 2022

Table 2. The floods and cyclonic system in the Chilika and the associated basin 1975 to 1994

#	Date/place of slamming Chilika Basin	Cyclonic Type	Wind km/h	Loss of life/ pretentious	Peak Flood Mahanadi R.
1	4th Nov 1976/Puri	SCS	<117	House/crop	26438 cumec
2	7th Aug 1981/Puri	SCS	83	15deaths	17535 cumec
3	24th Sept 1981/Puri	SCS	102	House/crop	17535 cumec
4	20th Sept 1985/ Puri	SCS	<117	Less damage	25216 cumec
5	21st July 1989/ Gopalpur	SCS	102	Less damage	6563 cumec

CS: Cyclonic storm; SCS: Severe Cyclonic storm; VSCS: Very severe cyclonic storm, ESCS: Extreme severe cyclonic storm; SC: upper cyclone, BoB: Bay of Bengal; AP: Andhra Pradesh

The population hike, built environment, deforestation for new settlements and have increased built-up areas 4.2%, forest spread by 7.59% and increase in copped area, shrubs and vegetation by 7.9% at the cost of hilly terrain and lacustrine areas including Chilika swamps and conversion of drainage channels to agriculture land (Table 1). The storms and climate change were less prominent. However, the years 1993 and 1994 have received four spells of flood flows from the Mahanadi River. The flood flow from the Mahanadi River, drought, and frequent slamming through the basin are given in Table 2.

Period 1994 – 1999: The LU/LC searches have indications of an increase of built-up areas (+3%), cropping and vegetation areas (+9.3%) at the cost of water spread areas, and the lagoon (-3.18%) with forest areas (14.05%), (Table 1). The climatic, meteorological, and anthropogenic strategies faced by the Chilika basin were important. This period is the driest period of the Chilika and the eco-health of the lagoon was at its last breath. The fish catch was reduced by 500%, the lagoon salinity reduced, resident time increased and the water exchange was very poor. It was due to shifting and depletion of spit to the extreme north of the OC near village Motto. The population rise, extreme heatwave conditions, one tropical storm in 5years, and deforestation in the basin have brought major changes in forest cover and vegetation areas. The supper cyclone (SC) hitting Paradip only destroyed the upper reaches of SMD but the western catchment was less affected. However, the previous storm had a severe impact on the basin (Table 3).

Period 2000 -2014: After the dredging of the artificial mouth at Sipakuda in Sep 2000, and other human interventions like Naraj barrage (2004), Gabakund Cut renovation (2007), the hydrodynamic status improved along with rising in salinity; augmentation of water spread area, aqua catch, the arrival of guest avifauna, and overall geo-bio-hydro atmosphere of the basin. There was an augmentation of the lacustrine area (+2.35%) and 3.1% in the built-up area, and 6.18% of various forest areas at the cost of agricultural land, vegetative cover (7.04%), (Tab 1). The year 2013 was the cyclone year (6 cyclones slammed the Coromandel Coast) that had a higher impact on Chilika and its basin. Though the Indian Ocean Tsunami Dec/2004 affected Andhra and Tamil Nadu coasts had less impact along the Chilika coast and basin after myth, huge waves have affected the coast at irregular intervals. The successive major cyclones that slammed/affected the Chilika basin are Phailin (2013), and Hudhud (2014). The human interventions are urbanization, huge vertical constructions, and conversion of 2 - to 6-lane NH roads along the west coast have caused huge deforestation and earthwork, augmenting sedimentation within the basin (Table 4).

Period 2015 to March 2022: In the comparison of LULC images of the Chilika basin; the observations are an increase in built-up areas (4.67%), all forests types (2.34%), and there is a decrease in water spread areas in the basin including Lagoon (2.38%) and agriculture and vegetation areas (2.83%), (Table 1). The Chilika basin passed through a dry spell from 2015 to 2017 and no cyclonic storms slammed the Chilika coast. COVID -19 has stopped human activities over the basin due to the stoppage of all types of work in the basin, doing less damage to the basin from 2019 to 2021 (Table 5).

Though the Supper cyclone Amphan flowed a track near the Chilika basin, there was less damage made to the basin.

Temperature plays a dynamic role in the change of climate and the meteorological, geo-bio-hydro environment of the basin. The temperature changes and its rate of departure from normal regulate the Land use, agriculture, and vegetation (Fig 6). The Chilika basin, its sustainability has been in jeopardy from the emergence of the Anthropocene epoch, and from 1980 onwards human activities have changed the built environment, vegetation, agriculture, and mainly the waterbody both naturally or man invoked.

Table 3.The floods and cyclonic system in the Chilika and the associated basin 1995 to 1999

#	Date/place of slamming Chilika Basin	Type of cyclonic	Wind km/h	Loss of life	Flood in the Mahanadi R.
1	7th Nov 1995/GPL	VSCS	111 (gust 195)	96 dead	26776 cumec
1	15th Oct 1999/Gopalpur	VSCS	185	295dead	17972 cumec
2	29th Oct 1999/SW Paradip	SC	260	≈260dead	17972 cumec

Table 4. The floods and cyclonic system in the Chilika and the associated basin 2000 to 2014

#	Date/place of slamming Chilika Basin	Cyclonic Type	Wind km/h	Loss of life & pretentious	Flood in the Mahanadi R.
1	20th Sept 2005/ Pyaar / KLN	CS	<65	65; (AP/Odisha)	25578 cumec
2	12th Oct 2013/ Phailin/ GPL	ESCS	259 max	45death/Odisha	20331 cumec
3	12th Oct 2014/ Hudhud/VSK	VSCS	213max	124; (AP/Odisha)	29800 cumec

KLN: Kalinga Putnam; GPL: Gopalpur; VSK: Vishakhapatnam BD: Bangladesh

Table 5. The floods and cyclonic system in the Chilika and the associated basin 2000 to 2014

#	Date/place of slamming Chilika Basin	Cyclonic Type	Wind km/h	Loss of life & pretentious	Flood in the Mahanadi R.
1	21st Sept 2018/ Daye/GPL	CS	70 (gust 80)	60dead	<20000 cumec
2	11th Oct 2018/ Titli/ GPL(s)	VSCS	126 gust 165km/h	15 dead (Odi)	< 2000 cumec
2	2nd May 2019/ Fani/Chilika	ESCS	185 (gust 215km/h)	89dead India/ B. D. (Wiki)	< 2000 cumec
3	4th Dec/2021/Jawad/GPL	CS	70km/h	No fatalities	<20000 cumec

NB: Mohanty et al. [57], Mishra et al. 58], Wikipedia year wise

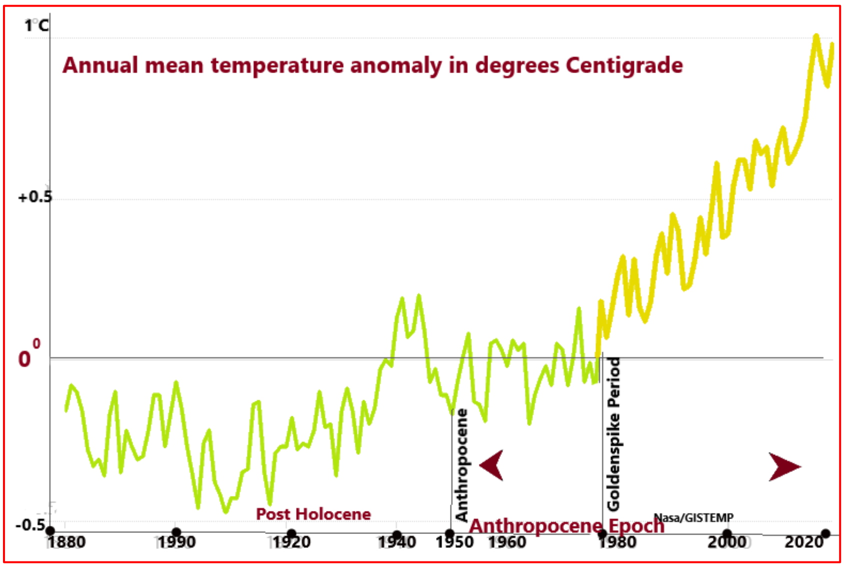

Fig. 6. Temperature anomaly from the emergence of Anthropocene to 2020 (Source mod: NASA)

4. RESULTS AND DISCUSSION

Formation of the capital town Bhubaneswar from 1948 onwards with an initial population of 16K and Lingaraj Temple centric area of 25Km2 have reached a population of 1200K accommodated within Bhubaneswar Municipal corporation within an area of about 147Sqkm in the year 2022.

The surface runoff from the Chandaka, Khalikote forest ranges, Ghantasala, Langaleswar, Bhaleri, and Solari hills ranges (within Eastern Ghats Hills range). The forests deteriorated is decanting the sediment from the bald hills range a specular amount of sediment to the lagoon. The city (Bhubaneswar) and townships developed such as Baranga, Jatani, Pipli, Sakhigopal, Banpur, Balugaon, Khalikote, Rambha, and Huma are discharging their liquid wastes through drains to the rivers Daya, the Bhargovi, the Ratnachira, the Nuna, the Malaguni, the Kusumi, the Salia or other 47 numbers of small rivulets, drains to the lagoon.

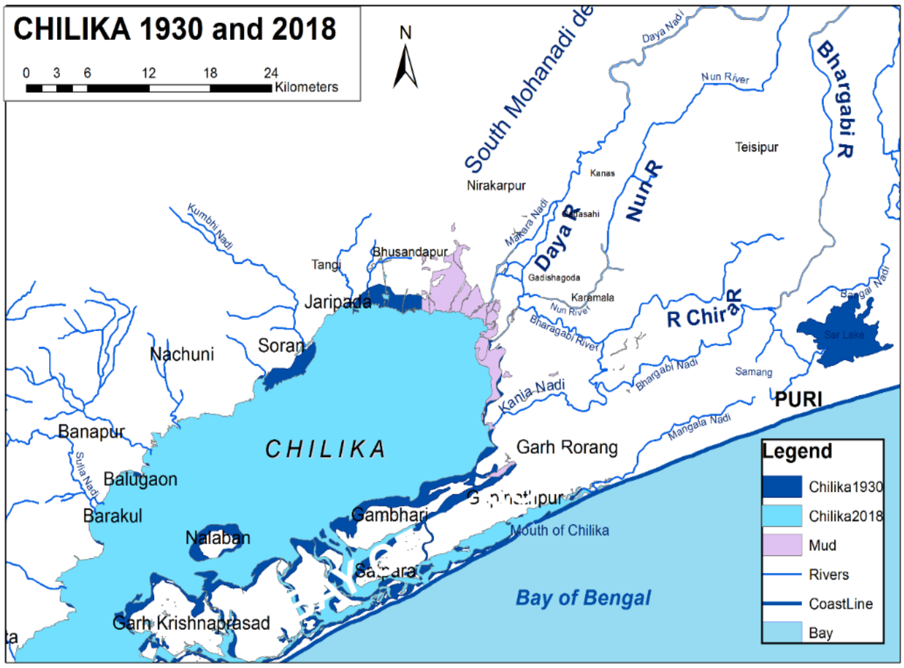

Fig. 7. The Chilika lagoon was a gulf in past and extended 20 to 30km inland

GIS results reveal that the total area of SMD and Chilika lagoon in 1999, the agricultural fields land (34.84%), water body (19.2%), settlement (10.6%), and Forest (9.3%), land without scrub (4.5%) (Ojha et al, 2013). The swamp area reduced drastically from 2.65% to 0.24 in the periphery of the lagoon in the NW fringe (Fig 7).

The TI shifts, and meteorological extremes impact in the south Mahanadi delta with the anthropogenic interventions have been under discussion. The devastation of mangrove forests, bundh constructed encircling the inner islands, dredging of depleted channels, the proliferation of weeds/ phytoplankton, has role in regulating the flood deltas in OC. Moreover, the local basin of Chilika comprising districts Ganjam, Puri, Khordha, and Cuttack lies in the high vulnerable zone of wind, wave, cyclone, coastal vulnerability, and inland flooding. The basin temperature such as Lagoon surface temperature and Surface air temperature plays a vital role in the change of LULC of the area.

5. CONCLUSION

After studying the GIS and RS interpretations of Land Sat series data of the barrier spit, outer channel, the spread of Chilika lagoon, the SMD, and the western catchment, the following inferences are drawn:

1. Chilika barrier spit is divided into stable towards the south and fragile to the north.
2. Stable barrier spit is continuous and islands once connected, are least affected by erosion and accretion. The dunes development in North is continuous process. The beach length is narrow in the south and wider in the north.
3. The tidal inlets are variable in number and barrier spits are fragile and continuously shifting north and have a tendency to convert the lagoon to a closed waterbody.
4. The basin has changed in the geo-bio-hydro environment from the start of the Anthropocene epoch (1950) but prominently from 1980 onwards. The population growth, modernization, and meteorological extremes are the main causes of the deterioration of the health of the Chilika lagoon environment.
5. The population growth in the urbans in south Mahanadi delta and the liquid wastes of Bhubaneswar city contribute more to the deterioration of the lagoon.
6. The increase in the area like built areas, agricultural areas, vegetation, and forest area and encroachment of the lacustrine areas, swamps, open shrubs, and hilly areas have added to the Chilika's health.
7. It is high time to monitor and record the LU LC changes annually or after the passage of one meteorological extreme exposure to

the lagoon and chalk out plans for the sustainability of the geo-bio- eco environment of the Chilika.

8. The western banks, SMD catchments of the Chilika lagoon need monitoring for records, and need planning by use of small-scale maps and implementation using UAV (Unmanned aerial vehicles), Drones, DGPS, and GPS to maintain the natural sustainability in the basin. A large-scale map (1:1000 or 1:2000 map) of the area with higher resolution is to be generated for better analysis.

DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1 Buffington JM. The legend of A. F. Shields, J. Hydraul. Eng. 1999;125, 376–387, 9429;125:4(376). Available:https://doi.org/10.1061/(ASCE)0733-.

2 Thompson CEL, Couceiro F, Fones GR, Helsby R, Amos CL, Black K, Parker ER, et al. In situ flume measurements of resuspension in the North Sea, Estuar. Coast. Shelf S., 94, 77–88, Available:https://doi.org/10.1016/j.ecss.2011.05.026, 2011.

3 Van Rijn LC. Simple general formulae for sand transport in rivers, estuaries, and coastal waters, Available:www. leovanrijnsediment.com, 2013.

4 Aagaard T, Jensen SG. Sediment concentration and vertical mixing under breaking waves, Mar. Geol. 2013;336: 146–159, DOI.org/10.1016/j.margeo.2012.11.015, 2013.

5 Mishra SP, Nanda RN, Mishra S, Sethi KC. Anthropocene Physiography and Morphology of Chilika; India. Annual Research & Review in Biology. 2021;36(2):71-95. DOI: 10.9734/ARRB/2021/v36i230344

6 Nardin W, Simeoni U, Bruno M, Corinne C. Geomorphological modeling of tidal inlets for sustainable deltaic lagoon management: A case study from the Po River delta, Italy. Ocean & Coastal Mngt. 2021;220(1). DOI: 10.1016/j.ocecoaman.2022.106081

7 Mishra SP. Geophysical changes of Chilika lagoon in post Naraj barrage period, Doctoral thesis, SOAA University, Bhubaneswar, India; 2016.

8 Panda US, Mahanty MM, Rangarao V, Patra S, Mishraa P. Hydrodynamics and water quality in Chilika Lagoon-A modeling approach, Elsevier, Procedia Eng. 2015;116:639-646.

9 Mishra SP. Catastrophism and Uniformitarianism in Decision Making of Meghalayan Age in East India. Int. Journal of Environment and Climate Change. 2022;12(4):19-37. DOI: 10.9734/ IJECC/2022/v12i43065

10 Hoyt JH, Henry VJ. Influence of island migration on barrier island sedimentation. Geol Soc Am Bull. 1967;78:77–88.

11 Kumar R, Sanders JE. Inlet sequences: a vertical succession of sedimentary structures and textures created by the lateral migration of tidal inlets. Sedimentology. 1974;21:291–323

12 Carr-betts E, Beck TM, Kraus NC. Tidal inlet morphology classification and empirical determination of seaward and down-drift extents of tidal inlets. Journal of Coastal Research. 2012;28(3):547–556.

13 Duong, TM. Climate Change Induced Coastline Change Adjacent to Small Tidal Inlets. Frontiers in Marine Science. 2021;8. Available:https://doi.org/10.3389/fmars.2021.754756

14 Kraus NC. Handbook of Coastal and Ocean Engineering (US Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory, 3909 Halls Ferry Road, Vicksburg, MS. 2009;39180, USA):867-900.

15 Davies-Vollum KS, Zhang Z, Agyekumhene A. Impacts of lagoon opening and implications for coastal

management: case study from Muni-Pomadze lagoon, Ghana. J Coast Conserv. 2019;23:293–301.
Available:https://doi.org/10.1007/s11852-018-0658-1
16 Bamunawala J, Ranasinghe R, Dastgheib A, Nichollset RJ, al. Twenty-first-century projections of shoreline change along inlet-interrupted coastlines. Sci Rep. 2021;11:14038; DOI:org/10.1038/s41598-021-93221-9
17 Mee LD. Coastal lagoons. In: Chemical Oceanography Ed. J. P. Riley and R. Chester, Academic press, London. 1978;7:441-490.
18 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
19 Baral R, Pradhan S, Samal RN, Mishra SK. Shoreline Change Analysis at Chilika Lagoon Coast, India Using Digital Shoreline Analysis System. J. of the Indian Society of Remote Sensing. 2018;46;10: 1637-1644.
20 Hardage K, Street J, Herrera-Silveira JA, et al. Late Holocene environmental change in Celestun Lagoon, Yucatan, Mexico. J Paleolimnol. 2022;67:131–162.
Available:https://doi.org/10.1007/s10933-021-00227-4
21 Hayes MO. Barrier island morphology as a function of wave and tide regime, in Leatherman, S. P. ed., Barrier islands from the Gulf of St. Lawrence to the Gulf of Mexico: Academic Press, New York, NY. 1979;1-29.
22 Scheffer M, Hosper SH, Meijer ML, Moss B, Jeppesen E. Alternative equilibria in shallow lakes. Trends Ecol. Evolution. 1993;8:275-279.
23 Martínez ML, Vázquez G. Coastal zones and estuaries – Coastal Sand Dunes and Barrier Islands, Published by Guset User, 2016-06-10 21:55:03, 1-10
24 Mahanty MM, Mohanty PK, Pradhan S, Samal RN, Ranga Rao V.) Spit and Inlet Morphodynamics of a Tropical Coastal Lagoon. Marine Geodesy. 2019;42:2:130-165.
25 Kraus NC, Wamsley Ty V. Coastal Barrier Breaching, Part 1:Overview of Breaching Processes, Army Corps of Engineers, Erdc/Chl Chetn. 2003;IV-56:1-15.
26 Gupta M. Tide-induced geometrical changes in Chilika lagoon using remote sensing, Current Science. 2014;107(1): 63-67.
27 Naik PK. Coastal Sand Dunes - Potential sites for the development of Hydro-geo-Eco tourism, International Research Journal of Earth Sciences. 2015;3(10):24-26.
28 Uddin MM, Schneider P, Asif MRI, Rahman MS, Arifuzzaman, Mozumder MMH. Fishery-Based Ecotourism in Developing Countries Can Enhance the Social-Ecological Resilience of Coastal Fishers—A Case Study of Bangladesh. Water. 2021;13(3):292.
Available:https://doi.org/10.3390/w13030292
29 Tsoar H. Sand dunes mobility and stability in relation to climate, Dept. of Geography and Environmental Development, Ben-Gurion, University of the Negev, Beer Sheva 84105, Israel; 2004.
30 Murray AS, Mohanti M. Luminescence dating of the barrier spit at Chilika lake, Orissa, India, Radiation Protection Dosimetry. 2006;119(1-4):442–445.
31 Bera A, Meraj G, Kanga S, Farooq M, Singh SK, Sahu N, Kumar P. Vulnerability and Risk Assessment to Climate Change in Sagar Island, India. Water. 2022;14:823.
Available:https://doi.org/10.3390/w14050823.
32 Sahoo RK, Mohanty PK, Pradhan S, Pradhan UK, Samal RN. Bed sediment characteristics and transport processes along the inlet channel of Chilika Lagoon (India).Indian Journal of Geo Marine Sciences. 2008;47 02):301-307.
33 Pattnaik AK, Chandramohan P, Jena BK. Sediment dynamics at Chilika outer channel. Pierce, J.W. 1970. Tidal inlets and washover fans, J. Geol. 2008;78:230-234. Publications, The Netherlands
Available: www.aqua publications.nl
34 Feagin RA, Smith WK, Psuty NP, Young DR, Martinez ML, Carter GA, et al. Barrier islands: coupling anthropogenic stability with ecological sustainability. Journal of Coastal Research, 00(0), 000–000. West Palm Beach (Florida); 2010.
35 Thornton TF. Coastal lakes and lagoons as dynamic sites of exchange among the Tlingit of Alaska. Maritime Studies. 2017;16:4.
Available:https://doi.org/10.1186/s40152-017-0059-3

36 Watabe Y, Sassa S. Sedimentation history of sandbars in flood-tidal delta evaluated by the seismic method in Lake Tofutsu, Japan. J. of Coastal Research. 2016;32(6):1389-1401.
Available:https://doi.org/10.2112/JCOASTRES-D-15-00113.1
37 Fabiola B, Torres-T, Pedro I. Matos-L. NDVI Comparison for Pre and Post-tsunami Images Using Quickbird High Resolution Images in Chilika Lake, India, University of Puerto Rico Mayagüez Campus, P.O. Box 9017, Mayagüez, P.R.. 2016;00681.
38 Salim S, Pattiaratchi C, Tinoco R, Coco G, et al. The influence of turbulent bursting on sediment resuspension under unidirectional currents, Earth Surf. Dynam. 2017;5:399–415.
Available:https://doi.org/10.5194/esurf-5-399-2017
39 Rajkumari S, Subramanium BR, Balsubramanium T. GIS based spatial distribution of environmental parameters at selected locations along the coast line of the country, Indian journal of Geo-marine Sciences. 2010;39(4):541-548.
40 Jally SK, Mishra AK, Balabantaray S. Estimation of Trophic State Index of Chilika Lake using Remote Sensing and GIS, ADR Journals, J. Adv. Res. Geo. Sci. Rem. Sens. 2016;3(1&2):09-24.
41 Nazneen S, Raju NJ. Distribution and sources of carbon, nitrogen, phosphorus and biogenic silica in the sediments of Chilika lagoon, J. Earth Syst. Sci. 2017;126:1- 13.
42 Pandey Kiran. Lakes warming faster than oceans and India's Chilika is no exception: A global study. Down to earth; 2015.
43 Mishra DR, Kumar A, Muduli PR, Equeenuddin SM, Rastogi G, Acharyya T, Swain D. Decline in Phytoplankton Biomass along Indian Coastal Waters due to COVID-19 Lockdown. Remote Sensing. 2020;12(16):2584.
Available:https://doi.org/10.3390/rs12162584
44 Ojha A, Rout J. Samal RN, Rajesh G, Pattnaik AK, Daspatnaik A. Evaluation of land use/ landcover dynamics of Chilika catchment. International Journal of Geomatics and Geosciences. 2010;4.
45 Ojha A, Rout J, Samal RN, Rajesh Pattnaik AK, Daspatanaik P. Evaluation of landuse / landcover dynamics of Chilika catchment, Int. j. of geomatics and geosciences. 2013;4(2):388-396.
46 Chang X, Zhang F, Cong K, Liu X., (2021). Scenario simulation of land use and land cover change in mining area. Sci Rep. 2021;11(1):12910.
DOI: 10.1038/s41598-021-92299-5.
47 Mishra SP, Sethi KC. The imprints of Holocene climate and environmental changes in the South Mahanadi Delta and the Chilika lagoon, Odisha, India—An overview, In book: Holocene Climate Change and Environment. 2021;457-482.
Available:https://doi.org/10.1016/B978-0-323-90085-0.00015-2
48 Khandelwal, Asha, Mohanty, M, (Vegetation history and sea level variation during the last 13,500 years inferred from a pollen record at chilika Lake, Orissa, India, Vegt hist Archaeobot. 2008;17:335-344.
DOI 10. 1007/s00334-007-0127-5.
49 Mishra SP, Dash Joykrishna. Hydro–morphology of cuts in coastal rivers debouching Chilika; South Mahanadi Delta, Odisha, India, International Journal of Advanced Research. 2016;4(5):391-404.
50 Panda SR, Mishra Siba Prasad, Tripathy, J. Ku. The Failed Resilience, Grim Water Future, and Salinity Intrusion through GIS of Kendrapara Coast, Odisha. International Journal of Lakes and Rivers. ISSN 0973-4570. 2021;14(2):161-181.
Research India Publications
51 Datta D, Bairagi M, Dey M, et al. Spatially explicit estimation of soil organic carbon stock of an estuarine mangrove wetland of eastern India using elemental analysis and very-fine resolution satellite data. Ecol Process. 2020;11:30.
Available:https://doi.org/10.1186/s13717-022-00370-4
52 Oinam B. Reconstruction of 2003 Daya River Flood, using Multi-resolution and Multi-temporal Satellite Imagery, Thesis submitted in Geo-information Science and Earth Observation, INDIAN Institute of Remote Sensing (National Remote Sensing Agency) Department of Space, Dehradun, India; 2006.
53 Kerbiriou C, Leviol I, Jiguet F, Julliard R.,. The impact of human frequentation on coastal vegetation in a biosphere reserve. J Environ Manage. 2008;88 (4):715-28.
DOI: 10.1016/j.jenvman.2007.03.034.

54 Lakshmi A. Coastal ecosystem services & human wellbeing, Indian Journal of Medical Research. 2021;153(3):382-387. DOI: 10.4103/ijmr.IJMR_695_21

55 Reilly CMO', Sharma S, Gray DK, E. Hampton S, Read JS, Rowley RJ. Rapid and highly variable warming of lake surface waters around the globe, Geophysical Research Letters, AGU Publications. 2010;01-08

56 Mahanty MM, Mohanty PK, Pattnaik A. K.; Panda US, Pradhan S, Samal R. N, Hydro-dynamics, temperature/salinity variability and residence time in the Chilika lagoon during the dry and wet period: Measurement and modeling, Elsevier, Continental Shelf Research. 2016;125:28-43.

57 Mohanty CR, Jain M, Radhakrishnan RV, Chandra Mohanty P, Panda R. Tropical cyclone Fani-perspective from the trauma and emergency department of an affected tertiary hospital. Chin J Traumatol. 2020; 23(4):243-248. DOI: 10.1016/j.cjtee.2020.04.002.

58 Mishra SP, Sethi KC, Ojha AC, Barik KK, Fani, an Outlier among Pre-monsoon Intra-Seasonal Cyclones over Bay of Bengal. Int. J. on Emerging Tech. 2020;11(2):271-282.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/86702