

Anthropocene Trails on Geomorphology of Meghalayan Chilika Basin Odisha

Abstract

The Chilika gulf in the pre-Meghalayan era has transformed into Greater Chilika leaky lagoon and later by the Anthropocene epoch (1950) became a restricted lagoon. The southern half of the barrier spit is stable and the northerly half is fragile with all fluvial exchange activities. The sediments carried by floods the Southerly Mahanadi Rivers, the Daya, and the Bhargovi and reversely through diurnal tides. The anthropogenic development during the present Anthropocene like the emerging Bhubaneswar capital (1948), exponentially rising population, and peripheral growth of urban Chilika, have deteriorated both the eco-bio-hydro system of the lagoon and associated delta. The anthropogenic interventions like dams, barrages, new mouth dredging, Gobakund cut in south Mahanadi delta (SMD), natural players sea-level changes, frequent storms, high waves, and longshore drift, have altered the geomorphology of the lagoon and the SMD. The present study envisages the search for the physical changes that occurred in about 6000km² area comprising of lagoon and SMD. The RS and GIS technology and the software tool ERDAS were in use to concoct the basic features of the LU/LC map of the scheduled inuring 1984, 2014, and 2022. The results were compared with research results of other studies for the years from 1975 to 2022 (47years) from various Landsat imageries. The inferences are erratic changes developed in the lacustrine area, variability in the number of tidal inlets, increase in stable barrier spit and ecosystem with the passage and land slamming of storms. Excess tourism activities, exploitation of fishery, motorized communications, poaching, and increase of stakeholders have deteriorated geo-bio-hydro sustainability. The SMD, which was a place of forests and hills with solitude, and tranquility before 70years, has its geo-bio-hydro and ecosystem, and sustainability is in jeopardy at present.

Key Words: Anthropocene, Mahanadi delta, Lagoon, Land use/land cover, dunes, RS/GIS,

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. The life span is from some days to hundreds of years depending upon the sediment influx, residue budget of the lagoon, littoral drift, and tidal activity in the continental self. The east coast of southern Odisha was a prograding coast during the post-Holocene period. Barrier spit is formed by the extension of dunes growing from beach curvature or headland beheading a lagoon to the sea. The endless natural process of erosion/deposition and suspension/re-suspension during sediment transport occurs 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 geodynamic coastal landform is essential. It is

the nourishment of the beach, restricted sand mining, maintenance of dunes, geohydrology, lacustrine bodies, estuaries, lateral channels, and the lagoons adjacent to the beach, Buffington (1999)^[1]; Thompson et al.,(2011)^[2]; van Rijn, et al., (2013)^[3]; Aagaard, et al. (2013)^[4]; Mishra et al., (2021)^[5]; Nardin, et al, (2022)^[6].

The Chilika Lagoon, (19.8450° N, and 85.4788° E) is housed parallel the to east coast of south Odisha, India. The brackish water lagoon varies in the average spread of 1011 Km² in the rainy season to 775 Km² in dry summer (Mishra S.P. 2016^[7]) and the mean volume of the brackish water of 1530 cum (Panda et al 2015^[8]; Mishra et al., 2022^[9]). The lagoon has three sectors, Northern, Central, and Southern opening to the outer channel (OC) at Magarmunha. The 34km long OC and the 30km fragile barrier spit separating the lagoon from the Bay and have all hydrodynamic activities that control the hydrology, ecology, economic, political, and societal tenancy of its stakeholders. The shallow northern sector connected to the rivers Daya and the Bhargovi of the South Mahanadi delta (SMD) 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 at Gabakund (2008), Baidhar (2012), near Nanganasi (Dhala Kuan) (2016) and Gaikona (2017). The OC is of 32km stretch average width 1200m and forms distinct small to large flood/ ebb deltas. Two TI's are hovering between Siandi and Manikapatna by March 2021 (Goole Earth) (Fig 1).

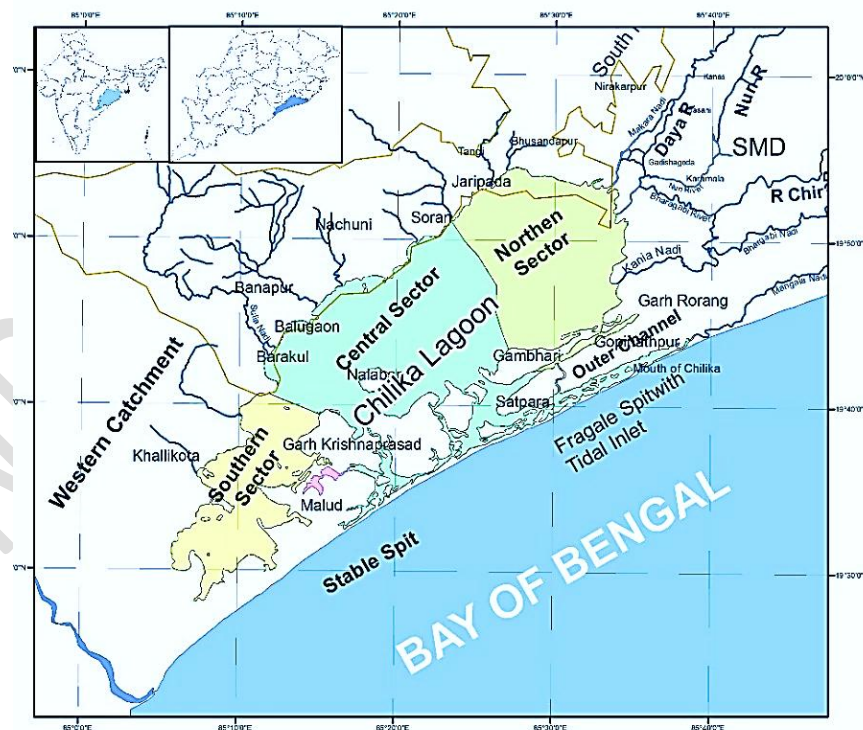


Fig 1: Index map of the flow system to Chilika from the western catchment, and SMD

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 Km² area was formed by post-Holocene (Meghalayan era) sediments forming large dunes from the extreme south (Prayagi) to NE (Harachandi temple) (Mishra S.P. 2022^[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 ($\approx 74\text{km}$) has been reduced to 64.3km as of date up to Motto Village, (Mishra et al, 2014^[10]).

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.

The Chilika basin:

The basin of Chilika consists of three areas, South Mahanadi delta (SMD of $\approx 1977\text{km}^2$ area), Western Catchment ($\approx 2800\text{km}^2$), and its own spread ($\approx 1500\text{km}^2$). 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 (Mishra S. P. 2016^[7]).

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 Km² 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 0.39⁰ 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., (2015)^[11], Mishra DR. et al., (2020)^[12], Mishra S.P, (2021)^[5].

Review of Literature

Hoyt et al (1967)^[13], Kumar et al. (1974)^[14], Carr-Betts et al.,(2012)^[15], Duong et al.,(2021)^[16], 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 (2009)^[17], Davies-Vollum, et al., (2019)^[18], Bamunawala et al.,(2021)^[19]. Chilika lagoon has bi-layer circulation, sub-Arial estuarine outline consisting of surface flow of low salinity and tide induced subsurface saline water Mee 1978^[20], Mishra et al 2014^[10], Pradhan 2017^[21]. The sediment of the migrated TI contains traces of barrier island deposits of the Holocene epoch, Baral et al., (2018)^[22], Hardage et al, (2022)^[23]. Hayes 1979^[24] 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., (1993)^[25]. Martínez et. al., (2009)^[26], Mahnty et al 2019^[27]. The breach can occur in a barrier spit either from the sea or the Lagoon side Kairus et al, (2003)^[28]. 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 km² respectively and the highest tide level is 0.83m Gupta M. (2014)^[29]. 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. (2015)^[30], Uddin et al., (2021)^[31]. The stabilized dunes were mobile in past and most of the dry climates

made them stable later Tsoar, (2004)^[32], Murra,y, et al., 2006^[33], Bera et al., 2022^[34]. 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 Pattanaik et al., (2008)^[35], Scapin et al., 2022^[36]. The Barrier islands are unstable, migrating, and varying in nature and influenced by the action of extreme episodic storm events (ESEE), MSLR, and anthropogenic activities. To sustain the coastal landscape, the dynamism needs study and pertinent action, Feagin et al, 2010^[27], Thronton, 2017^[37].

Watabe et al., (2016)^[38] interpreted through GIS metaphors that Tsunami-2004 affected less to the geomorphology of Chilika Lake, Fabiola et al 2016^[39]. 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 2017^[40]. 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., 2010^[41]. Chilika lake had eutrophic state with Carlson TSI value 49-63 from 2013 to 2015, Jally et al 2016^[42]. 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 2017^[43], Duong TM, (2021)^[16].

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.

Methods and Methodology

GIS is the geographic information system. The GIS architecture and its synoptic view are 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](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 is done 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 was 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 ($\geq 85\%$), (9). LU/LC map generation and compared with past results (GIS files) **Fig 2**.

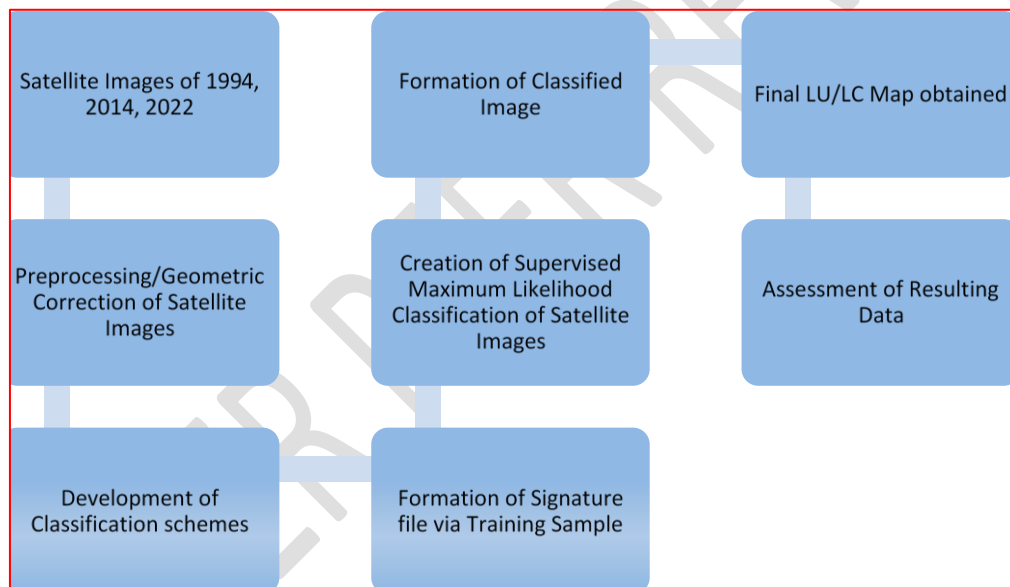


Fig 2: The methodology for the preparation of LULC map from Satellite imageries

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 \(2021\)](#)^[16]

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.

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, IRS P6 LISS III, and LANDSAT -8, for the years 1975 and 1995, 2012 were studied prior by various researchers, [Ojha et al \(2013\)^{\[44\]}](#). 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 \(2013\)^{\[44\]}](#), [Chang et al., \(2021\)^{\[45\]}](#). 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 ([Mishra et al, 2021^{\[46\]}](#)).

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., 2007^{\[47\]}](#), [Mishra S. P. 2017^{\[48\]}](#) 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.



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

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., ([Mishra S.P., 2016^{\[50\]}](#), [Mishra et al, 2021^{\[51\]}](#), [Datta et al, 2022^{\[52\]}](#))

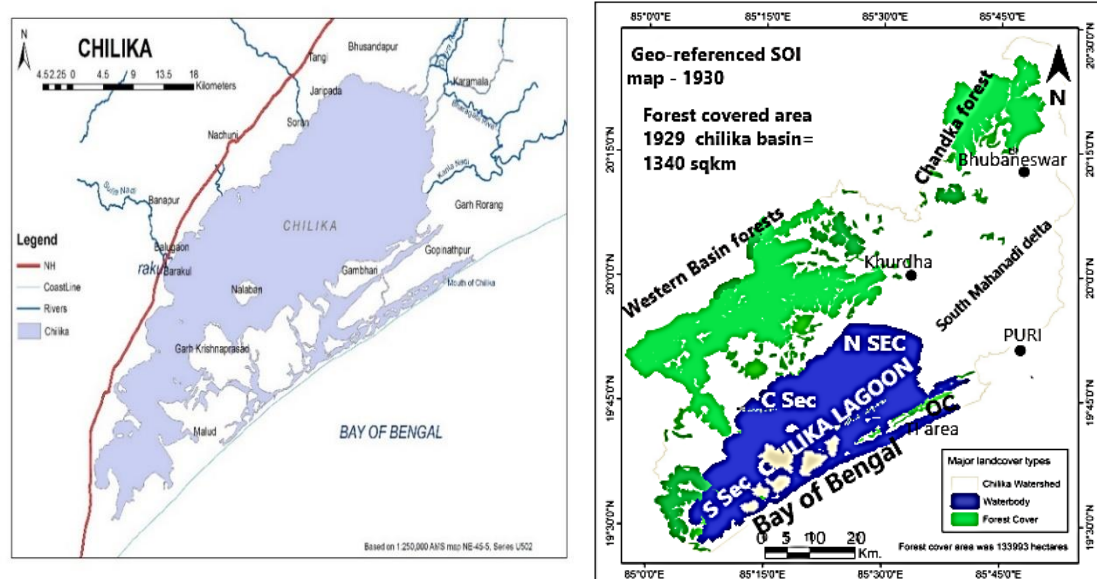


Fig 4(a) and Fig 4(b): The georeferenced SOI map of the Chilika basin surveyed during 1929

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 Km², flood plain, levee and ridges of 16.22 Km², Paleo channels 57.92 Km² (some abandoned), pediment (some buried channels) of 142.94 Km², mudflat of 483.34 Km², lateritic uplands of 71.05Km², and hills, valley are of 9.80 Km², [Oinam B \(2006\)^{\[53\]}](#). 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 ([Kerbiriou et al., 2008^{\[54\]}](#), [Laxmi et al., 2021^{\[55\]}](#)). The SOI maps of the Chilika basin are available for 1930. The forest area from the jointed and georeferenced Chilika basin map gave 1340km², 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 ([Reilly CMO. 2010^{\[56\]}](#)). The RT in N-sector is 132days (max) during summer, and 35days in the southern sector in the rainy season [Mahanty et al \(2016\)^{\[57\]}](#).

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).**

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	%	Km ²	%	Km ²	%	Km ²	%	Km ²	%	Km ²	%
	1975	1975	1994	1994	1999	1999	2012	2012	2014	2014	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 ^[58]		Present study		OJha et al. 2013 ^[58]		Wetland int. South Asia, CDA		Present study		Present study	

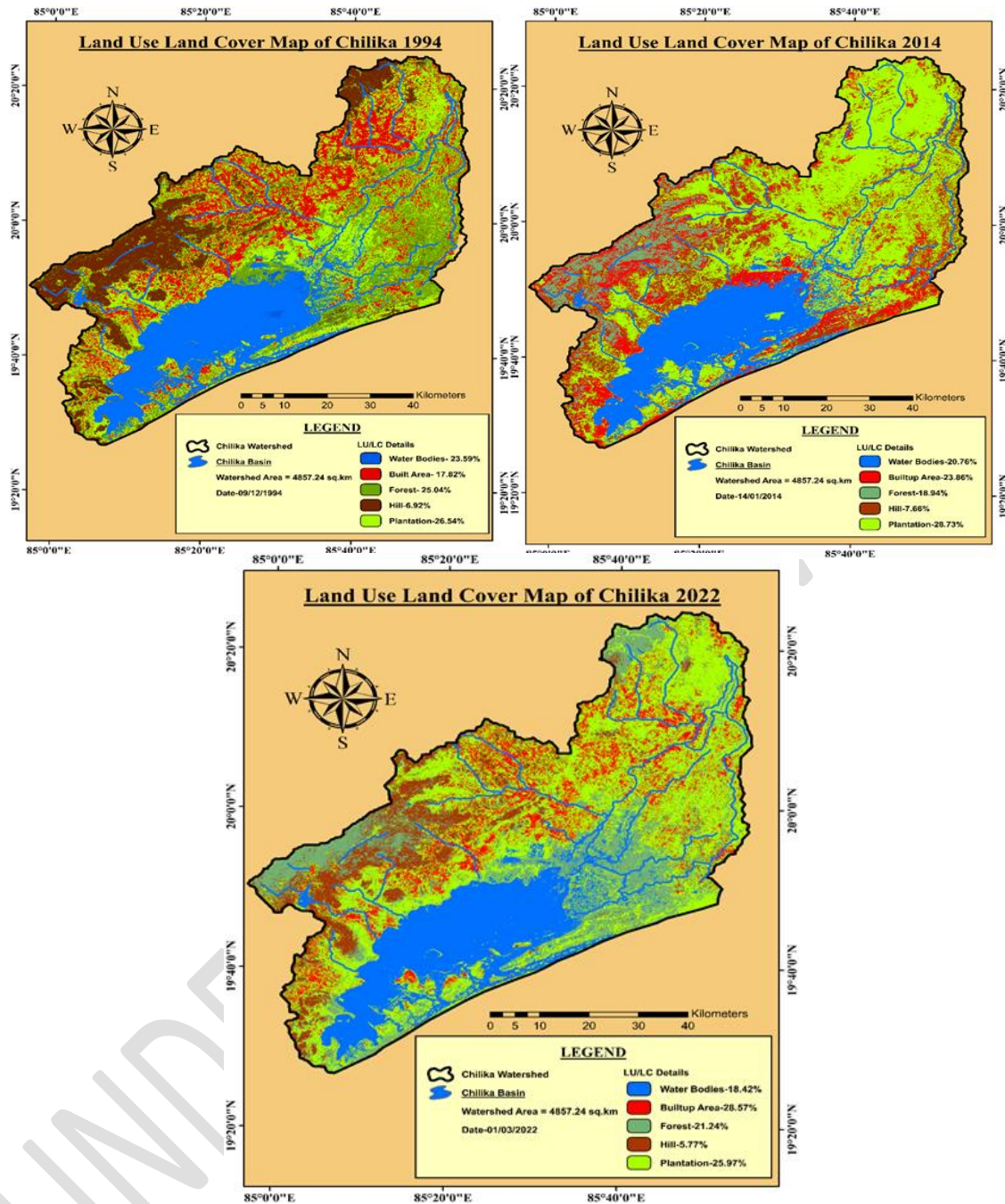


Fig 5 (a), (b): The LU and LC changes of the south Mahanadi delta study years 1994, 2014 and 2022

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 30km² in 1950 to an expansion of 96.21km² by 1975.

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	4 th Nov 1976/Puri	SCS	<117	House/crop	26438 cumec
2	7 th Aug 1981/Puri	SCS	83	15deaths	17535 cumec
3	24 th Sept 1981/Puri	SCS	102	House/crop	17535 cumec
4	20 th Sept 1985/ Puri	SCS	<117	Less damage	25216 cumec
5	21 st 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**)

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	7 th Nov 1995/GPL	VSCS	111 (gust 195)	96 dead	26776 cumec
1	15 th Oct 1999/Gopalpur	VSCS	185	295dead	17972 cumec
2	29 th Oct 1999/SW Paradip	SC	260	≈260dead	17972 cumec

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).

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	20 th Sept 2005/ Pyaar / KLN	CS	<65	65; (AP/Odisha)	25578 cumec
2	12 th Oct 2013/ Phailin/ GPL	ESCS	259 max	45death/Odisha	20331 cumec
3	12 th Oct 2014/ Hudhud/VSK	VSCS	213max	124; (AP/Odisha)	29800 cumec
KLN: Kalinga Putnam; GPL: Gopalpur; VSK: Vishakhapatnam BD: Bangladesh					

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).

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	21 st Sept 2018/ Daye/GPL	CS	70 (gust 80)	60dead	<20000 cumec
2	11 th Oct 2018/ Titli/ GPL(s)	VSCS	126 gust 165km/h	15 dead (Odi)	< 2000 cumec
2	2 nd May 2019/ Fani/Chilika	ESCS	185 (gust 215km/h)	89dead India/ B. D. (Wiki)	< 2000 cumec
3	4 th Dec/2021/Jawad/GPL	CS	70km/h	No fatalities	<20000 cumec
NB: Mohanty et al., 2020^[58] , Mishra et. al., 2020^[59] , Wikipedia year wise					

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

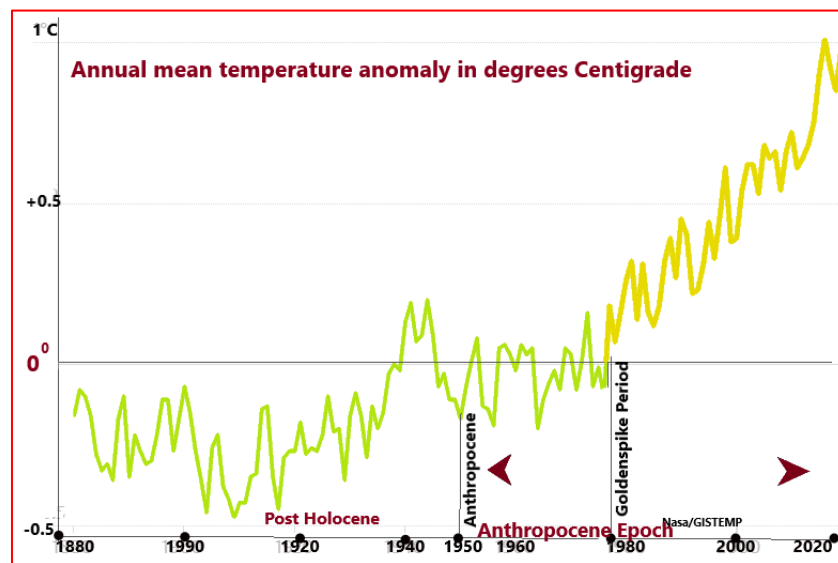


Fig 6: Temperature anomaly from the emergence of Anthropocene to 2020 (Source mod: NASA)

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.

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.

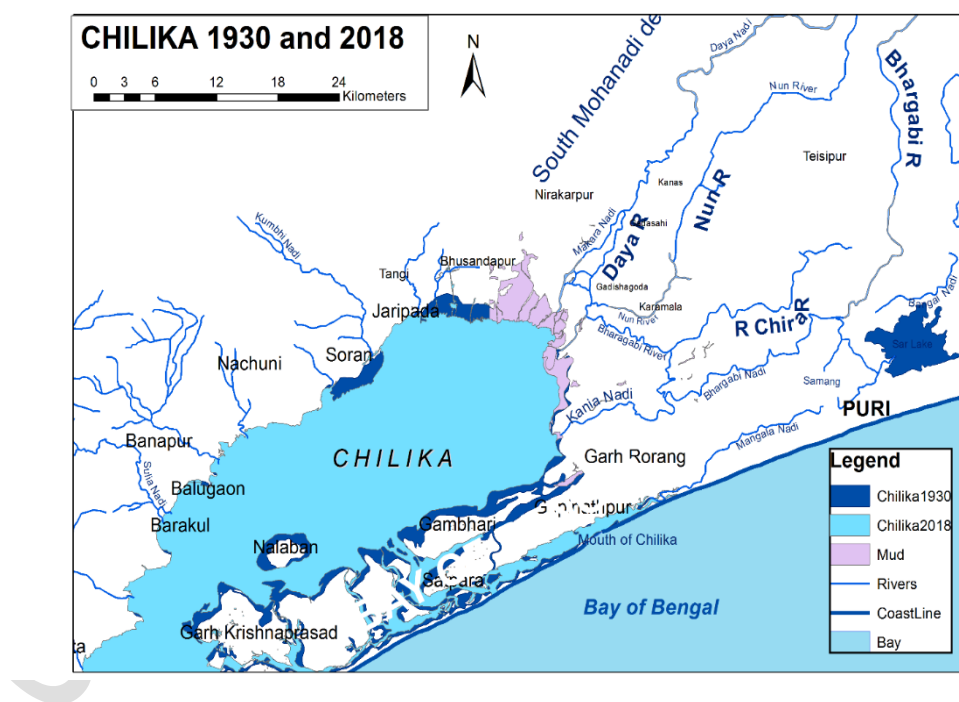


Fig 7: The Chilika lagoon was a gulf in past and extended 20 to 30km inland.

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).

Conclusion

The change in the dimension of the TI, and the impact of meteorological extremes in the south Mahanadi delta. The anthropogenic interventions like the devastation of mangrove forests, Gerry bundh is encircling the inner islands, dredging of depleted channels, the proliferation of algae/phytoplankton, ipomeas, and water hyacinths regulated the flood deltas. Moreover, the Chilika basin comprising districts Ganjam, Puri, Khordha, and Cuttack lies in the high zone of wind, wave, cyclone, coastal vulnerability, and inland flooding as per IMD. The basin temperature such as Lagoon surface temperature and Surface air temperature plays a vital role in the change of LULC of the area.

After studying the GIS and Land Sat series from Glovis classic (Landsat Series Thematic mapper -5) of Google 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. Later the dunes develop as wider barrier spits. The beach length is narrow in the south and wider in the north.
3. The unstable barrier spits are in the north fringe with openings. The spit geometry is fragile and the TI's within are nomadic. Continuous oscillatory propagation is towards the north.
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 Chilika lagoon and its peripheral basins of the Chilika lagoon.
5. The population growth and the development of Bhubaneswar contribute more to the deterioration of the lagoon.
6. There is an increase in the area of human efforts like built areas, agricultural areas, vegetation, and forest area. They are an encroachment on the lacustrine areas, swamps, open shrubs, and hilly areas.
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.
8. The western, SMD catchments and Chilika lagoon 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.
9. A large-scale map (1:1000 or 1:2000 map) of the area with higher resolution is to be generated for better analysis.

COMPETING INTERESTS DISCLAIMER:

Authors have declared that no competing interests exist. 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.

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