Assessing Significant Changes in the Geomorphology and Biological Productivity of Chilika Lagoon under the Influence of Natural Events and Anthropogenic Interventions

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Abstract:
Chilika Lake is Asia's biggest brackish water lagoon. It is a significant biodiversity hotspot along India's east coast. The geomorphology, water quality, and biological productivity of the lake have all changed significantly throughout time as a result of natural occurrences and manmade interventions. Weeds were expected to cover 300 square kilometres of the lagoon in 2011, posing a severe danger to the lagoon's health and a local population of 300,000 who rely on the lagoon for a living. An assessment of the lagoon's health based on benthic diversity can help in the development of effective management practices because benthic indicators such as foraminifera not only quantify prevailing environmental conditions such as salinity, dissolved oxygen concentration, and pH changes but also the impact of natural and anthropogenic stressors. Decades of research have demonstrated that the water exchange between the lake and the sea which affects salinity, siltation, macrophyte infestation, and marine form recruitment, affected the biological changes of the lake system and its fisheries the most. The northward displacements of the lake's entrance and silting up of the outer channel have been connected to fisheries depletion and biodiversity loss in the 1980s and 1990s. In September 2000, a new mouth was dug open to improve the lagoon's health and restore its biodiversity. The purpose of this research is to highlight the major changes in the geomorphology, water quality, and biological productivity of Chilika Lake as a result of natural and human interventions. It may be traced by looking at historical facts as well as the literature and conclusions of many researchers and experts. The results of this study will be a valuable addition to our continuing seasonal ecological research. The results of the research additionally provide baseline data that can help in the long-term monitoring of the Chilika lagoon and its stability.

Keywords: Brackish, Evolution, Livelihood, Sedimentation, Anthropogenic

Introduction

The Chilika Lagoon (19° 28′ - 19° 54′ N and 85° 05′ - 85° 38′ E), located in the east coast of the State of Odisha, India. It is the largest sub elliptical brackish-water lagoon in Asia. It was part of the Bay of Bengal, in the later stages of the Pleistocene period (Pascoe, 1964). In course of time several changes in the morphology of the coast occur. It occurs mainly along north of the lake with strong winds and shifting sand to the shore. Long shore drift (littoral drift) with the absence or presence or of strong river and tidal currents in the different areas are the main reasons which attributed to the gradual growth of the spit. A 60 km (37 miles) long barrier beach which iscalled Rajhansa formed due to northerly currents in the Bayof Bengal.

This was the result in the formation of this shallow lake and thus forms its eastern side of the lake. The shallow brackish-water inshore lake which is connected to the Bay of Bengal through a very narrow mouth. The Chilika Lagoon is surrounded between the sea and mountains. The Formation of a barrier spit close to Palur due to the littoral drift. Thus, creation of a sand bar along the eastern shore almost have transformed the lake gradually to a shallow and pier shape lagoon. Recent study shows the sea is connected with the lake near Satapada through a number of sand spits, shoals, sand bars, and openings of shallow depth, with a narrow channel. As a result, presence of these features mainly reduces tidal flow inside and outside of the lake. In the very part, discharge of sediment by the tributaries of the Mahanadi River made the lake shallower. Gradually the lake was separated from the sea after the formation of the spit (Krishnan, 1968). It is observed that the lake is continuously becoming shallow with sand banks and a number of Islands are available just above the surface due to the discharge of silt and sediment due to the rivers Bhargavi, Daya, Nuna and Makara. Nearly about 1.5 million metric tons per year of sediment is deposited in the Chilika Lagoon by many rivers and several streams. Mainly, rivers are tributaries of the Mahanadi River. Several others streams are joining the lake directly. Fluctuation of Water level in the lake occurs seasonally during low tides and high tides and maximum area of the lake experiences submergence and emergence in every year. The geomorphology, water quality and biological productivity the lake had undergone significant changes over the years under the influence of natural events and anthropogenic interventions. Decades of research have shown that the changes of the lake system and its fisheries were influenced mainly by the water exchange between the lake and the sea that controls the salinity, siltation, macrophyte infestation and recruitment of marine forms. Depletion of fisheries and loss of biodiversity in 1980s and 1990s have been linked to the northward shifting of lake's inlet and silting of the outer channel. Opening of the new mouth has resulted in some improvements with substantial increase in capture fishery, reduction in weed infestation, growth of sea grasses, appearance of dolphins and increase in the population of migratory birds. But many stake holders claim that the problems associated with the lake ecology and its contribution to the socio-economic development of the stake holders still persist which could escalate in future. The main objectives of the work to assess significant changes in the Geomorphology and Biological productivity of Chilika Lagoon under the influence of Natural events and anthropogenic interventions.

The Scope of the Study:

The Chilika is one of the largest brackish water lagoons in Asia and is well known for its biologic diversity. It is designated as one of the Ramsar sites in 1981; Chilika was under serious threat in the late 1990s due to severe physical and ecological degradation. Some of the severe problems included large-scale siltation and reduction in the water level as well as salinity, threatening some of the rare species of fauna in this region. The Chilika lagoon is of estuarine ephemeral in character of catchment area of 4577 sq.km. The basin canopy comprises of the western catchment 2800 sq.km and SMD of 1777 sq.km. 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. The lagoon has capacity of 4 Km^3 with average inland inflow of 14331 MCUM per year. The local catchment of Chilika consists of denudation hills (southern fringe),

sand dunes and barrier spit along coast in the east, swamps of about 4300 km^2 in NW and alluvial deltaic plains of the SMD. The studies were made on zone of littoral transition, the Chilika Lake coastline geology. A considerable number of researchers have studied on the coastal activities, socio political issues, physiochemical character in the lagoon to meet the human requirement. Least work is done on geomorphology, Physiographic and biological productive of the Chilika Lake which is the present scope of the study.

Objectives:

- To assess the Changes in the Geomorphology of Chilika Lagoon.
- To study habitats, ecologic responses and evolution of the lagoon.
- To understand the causal factors of the degradation of Chilika Lake

Materials and Methods

With the continuous erosion and/or sedimentation of Chilika Lake Inlet Dynamics could be studied by using the Satellite images. Satellite imagery has an important role for studying the dynamics of the inlet. The present study has been carried out to investigate spatio-temporal inlet dynamics due to erosion and/or sedimentation by using Remote Sensing and GIS Technique. All historical information, records of archeological remains from the available existing literature were collected. Topo Sheets on 1:50, 000 Scale (Sheet No. 74E/3, 4, 7, 10, 11) obtained from Survey of India office located at Bhubaneswar were scanned and converted into digital format. These maps were georeferenced with longitude and latitude using Arc GIS (10.1) to demarcate the Chilika Lagoon boundary. Geological maps of the study area from GSI office located at Bhubaneswar were collected. Textural analysis of sediment was collected from Chilika Development Authority (CDA). All the above data are collected from different available sources and considered for the purpose of current study.

Study Area

The Chilika Lagoon (19°28′–19°54′ N and 85°05′–85°38′ E), located in the east coast of the State of Odisha, India, is the largest lagoon in Asia. It is separated from the Bay of Bengal by a sandbar whose width varies between 10.0 and 1.5 km, a long outer 32 km channel connects the main lagoon with the Bay of Bengal near the village of Arakhukuda.

The pear-shaped lagoon has a maximum linear axis of 64.3 km, with an average mean width of 20.1 km. The lagoon is spread over three coastal districts of the state Puri, Khurda and Ganjam. In the early twentieth century, the lagoon area is reported to have varied between 1165 km^2 in the monsoon season and 906 km^2 in summer (Annandale 1915–1924). Hydrologically, Chilika is influenced by three subsystems, including the Mahanadi River system, rivers flowing in the lagoon from the western catchment and the Bay of Bengal. The lagoon receives freshwater from a series of 52 channels. The Chilika drainage basin, including the lagoon itself, covers an area of over 4300 km^2 (Das & Samal 1988). The lagoon was declared a wetland of international importance in 1981, thereby becoming a Ramsar site. The Nalabana Island was declared a bird sanctuary in 1973.

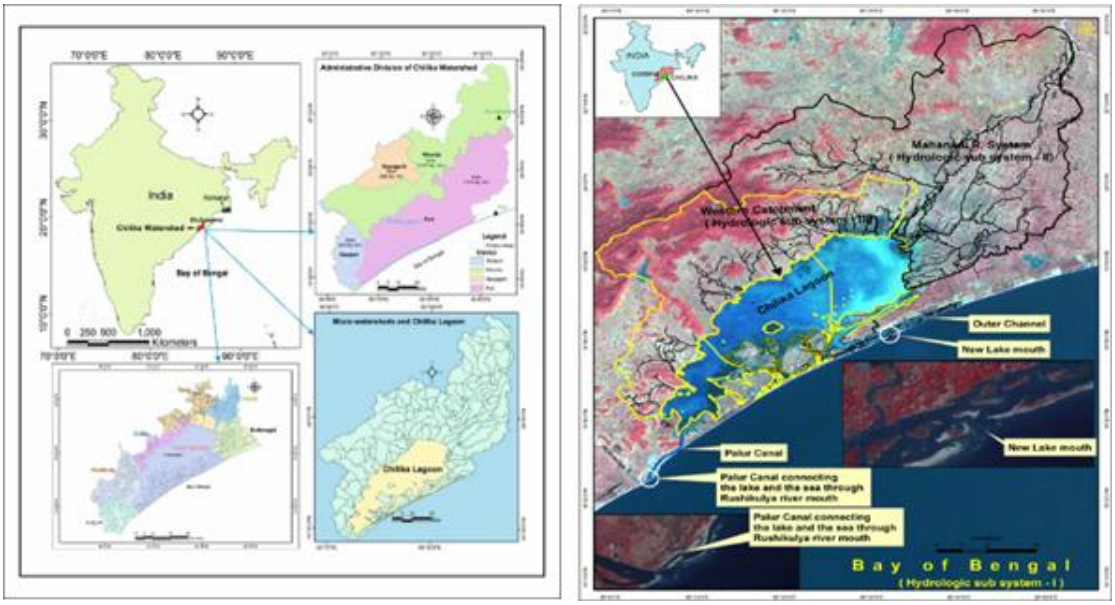

Fig.1 (Left) Study area Map showing, watershed area. (Right) Chilika Lake and its Connection C.D. Block, and administrative division with River systems. (Source: Chilika Development Authority - CDA, Odisha).

Methodology:

Topographic maps and satellite imageries were used. The toposheet Nos. 74E/3, 4, 7, 10, 11 on scale 1:50000 were collected from Survey of India office located at Bhubaneswar. Maps were scanned and converted into digital format. Using ArcGIS (10.1) these maps were georeferenced with longitude and latitude to demarcate the Chilika Lagoon boundary.

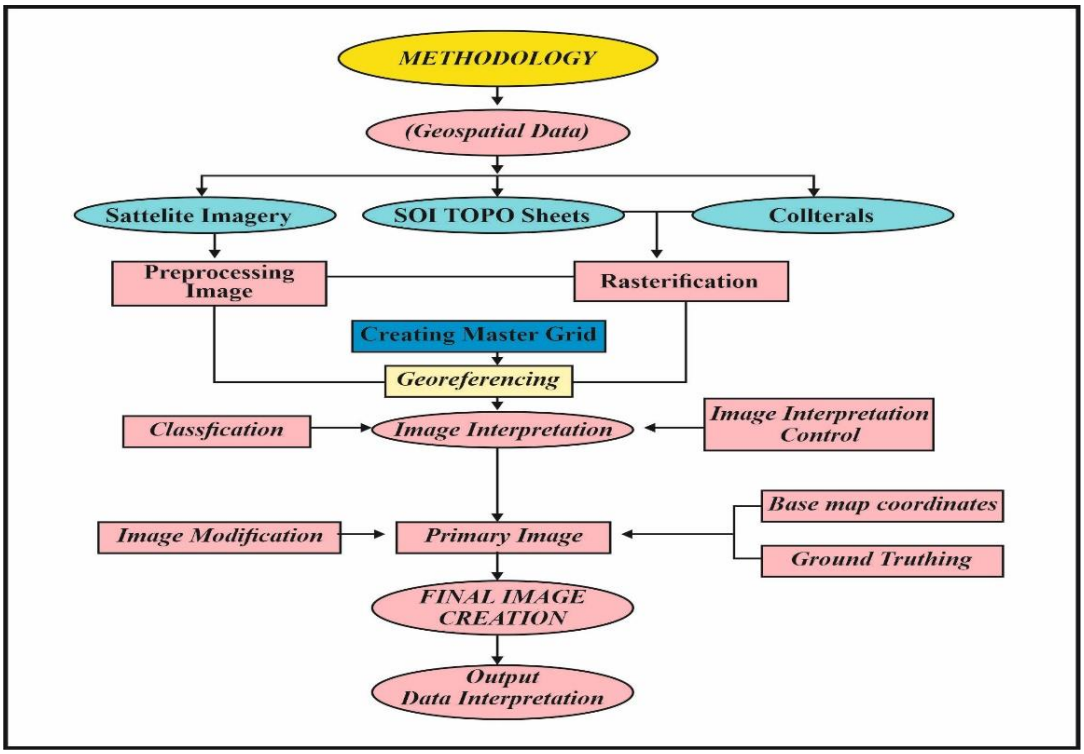

Fig. 2 The methodology of analysis of image by GIS.

Georeferenced Landsat satellite imageries were downloaded from USGS website (http://earthexplorer.usgs.gov). These were taken for the years 1980, 1988 with spatial resolution 79 m. And also, for the years 2000, 2005, 2010, 2020 with spatial resolution 30 m. ERDAS Imagine (version: 2014) software was used to create False Colour Composites (FCCs). The software ArcGIS (10.1) were also used for extracting the study area Chilika Lagoon.

For the accuracy assessment ground verification were carried out using topographic sheets and prepared Google Earth maps for the years of 2015, 2010, 2005, 2000. The various geomorphic landforms within the Chilika lagoon were visually interpreted. Then using ArcGIS (10.1) digitization was carried out manually.

Results

Anthropogenic Interventions:

The South Mahanadi Delta (SMD) has been urbanized with many townships from the year 1950. It is onwards after Bhubaneswar became the capital of Odisha. So many settlements were gradually grown to accommodate the steep rise in population from 1960 along with marginalization of fisher folk. It is also including Migration from other areas even rural areas too. It is due to growth of different institutions like educational, healthcare, livelihood, tourism and transports, other resources. The anthropogenic activities on land, water and ecosystem have transformed many swamps. Other activities like fallow lands to agricultural land and 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. Mostly the liquid wastes and effluents from populous areas from urban areas and industries have contaminated the coastal aquifers, drains and the river runoff. The water of the Kuakhai River is turned off as unsuitable for human use during especially in summer months. Around 50% of the total areas were under cultivation. These are with subsidiary livelihood like fishery, coconut farming in the Chilika and its local Mahanadi basin areas as per report by SREP (ATMA) of Puri District (2007-2008). Maximum sectors such as Industries, township, tourism are with improved connectivity. Irrigation has 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.

Geomorphology of the Chilika Basin:

There is very less information are available on the geomorphic evolution of the Chilika lagoon, particularly about its origin. Pascoe (1964) suggested about its structure during the later stages of the Pleistocene period that it was a shallow brackish water inshore lake connected to the Bay of Bengal. The northern and western parts of the Lagoon are surrounded with pediplain, structural hills, and residual hills. On the other hand, deltaic, coastal plains, and alluvial are present in the north-eastern and eastern parts of the lagoon. A recent study was made by Khandelwal et al. (2008) recovered 8 m long sediment core from Chilika for pollen and sediment logical studies. As per his views the Chilika Lake was a part of a river and the sea

level was very lower. According to him this might be a river delta with fresh water vegetation. Hence the mangrove vegetation dominated the area. The longshore drift, tidal currents, probably strong winds shifted to the shore. Therefore, there is the growth of the barrier spits and sand ridges. The barrier beach that protects the Chilika from all direct type of influence in the Bay of Bengal. Then this gradually converted the lake into a shallow lagoon. Moreover, the presence of sand bars, a number of shoals and openings of shallow depth that helps in maintaining lake's estuarine of character with the help of considerably reducing, tidal flow in and out of the Chilika.

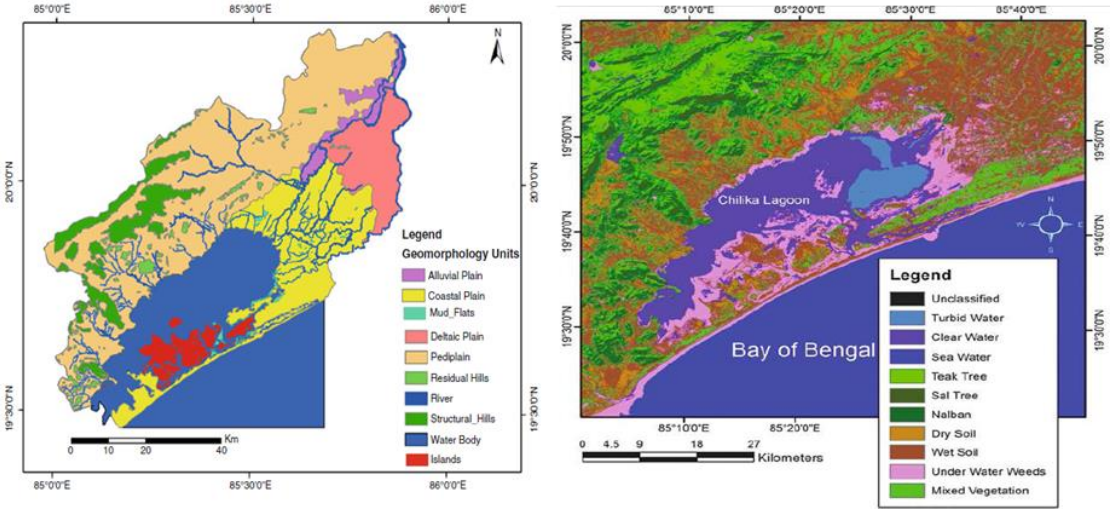

Fig. 3 (Left) Geomorphology of Chilika Watershed (Prepared for this Study). (Right) Land covers map in and adjacent areas of the Chilika (Prepared for this Study).

Table 1. Landform changes within the Chilika Lake between 1980 and 2020.

Landform Types	1980 Area Km^2	2000 Area Km^2	2015 Area Km^2	2020 Area Km^2	Effects/Changes observed
Island	175.49	167.44	158.90	159.50	Decreased then Increase
Deep water	284.80	234.44	80.84	80.75	Continuously decreased
Shallow water	273.66	92.48	306.26	306.50	Decreased and then abruptly increased. Depth of the lake decreased,
Sand bars	6.14	4.78	11.33	11.50	Reduced and then small increase, old mouth passage closed
Lagoon	865.42	871.80	876.10	878.20	Sedimentation rate increased, depth decreased, Submergence of island and increase in inundation
Inland	102.49	147.05	111.37	110.55	Decreased
Fresh vegetation	65.39	79.71	23.12	22.52	Decreased, salinity influxincreased
Floating vegetation	144.69	245.37	112.94	112.55	Increase and then small decrease;

It is Observed that barrier spit is backed by an outer channel (32km long 1-3 km wide). This outer channel of marine environment connected at Magarmunha. The Hydrodynamics, the salinity, the semi-marine ecosystem of the lagoon is governed by

the continuous process. This is of breaking, making of flood-deltas, ebb-deltas and also swash zone controls the flow exchange, opening/closing of tidal inlets (TI) northerly shift. 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.

Biological diversity: The Chilika Lagoon act as a spawning/nursery ground. A good numerous marine aqua fauna mostly varying along the channel mainly in the central sector. The Coastal regulatory zoning is made based on ecological sensitivity. It starts from CRZ I (the spit; highly eco- sensitive). This includes mangroves, (CRZ IA), the Inter tidal zone (CRZ I B). The CRZ III includes (NDZ area or sand dunes, township, municipalities (corporations as per Annexure-III of CRZ Notification 2011. About 1100 Km^2 area of the Chilika lagoon retain many endangered species like limbless 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.

Migratory birds in Chilika Lake: Migratory birds visiting Chilika Lake has been continuously improved because of the availability of open spaces for their habitat improvisation. After the eviction of prawn gherries by Govt. of Odisha (GoO), and in addition to removal of floating phyto-planktons by providing adequate flushing flow by efficient operation of the Naraj barrage by Water Resources Dept. Government of India. 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 1.142 million of 190 species during 5th Jan 2021. It was 0.893 million (147species) during 2018, 1.048 million in 2019, and 1.105 million in the year 2020. The numbers are increasing after the interventions made in the lagoon from 2004.

Discussion

Present study envisages the elementary morphology, flushing flow, BoB storms, tidal inlets, sediment transport, and dynamic behavior 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 capacity building against poaching, organic farming in the out skirt and within the lake islandsis 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 intensiveresearch and development for a sustained biodiversity.

Interpretation: The hydrology of the Chilika Lagoon is mainly affected by the river

systems in the northern, western catchment and also by the Bay of Bengal. The Mahanadi distributaries are responsible for significant freshwater. The silt loads into the lagoon whereas the long shore sediment transport of the Bay of Bengal is mostly restricted to the coast and outer channel. This wetland environment is under serious threat due to the changes in salinity values. This is controlled by freshwater inflow from the rivers. Secondly also the tidal exchange between the lagoon and sea. Natural factors like storm surges, cyclones, monsoonal floods, sediment deposition by longshore drift.

The Findings: The land is a natural resource for supporting the life system. This work has highlighted that the water bodies, agricultural plantation, and settlement are the predominant LULC in the study area. Agriculture plantation and barren lands are more vulnerable due to urbanization such as engineering construction, settlements, and transport. Changes in the island landforms within the lake are mainly due to theriver as well as sea input into the lake. Sandbar area fluctuations reflect that dependsupon the sedimentation input as well as the opening of the mouth. After the openingof the new mouth, there is an increase in the number of small sand bodies in the form of islands in the northern part of the lake. Sedimentation in the Chilika remains a serious concern, and there is no reasonable estimate of annual sediment flux into thebasin. The tidal inlet was drifting in the NE direction due to the influence of long- shore currents at a higher rate in the pre-hydrological invention, and the rate of driftthas been quite significant in the artificial mouth as well after the hydrological invention.

Implications of the study: The Chilika lagoon should be safety of waterfowl, the indigenous flora and other faunal species by restricting weed infestation, catchment treatment, pollution control, community participationpublic awareness and with among the stake holders, capacity building, controlled fishing and encouraging clean energy technology for better transportation along with intensive research work and overall development for a sustained biodiversity in future days to come.

Future research directions: Chilika Lagoon should be monitored at regular intervals of time. Researchers should correctly assess the rate of reduction. It would help in taking decision and appropriate measures to control the same. The celestial events such as lunar and solar eclipse, which have to be validated through further study. More details on Hydrodynamics of the coast are to be studied. Continuous recording of fluvial, hydrological and also sedimentation data would help to ascertain geophysical and hydrologic changes. Mainly Ground water hydrologic studies of the study area have not been taken up in the present study. This can be taken up at later stage. Lastly it is concluded that a constant watch over the climate changes and with proper documentation are needed for future study.

Conclusions

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.

Future Perspectives: The study on Chilika should be monitored at regular intervals basis to correctly assess the rate of reduction. As a result, this would help in taking appropriate and necessary measures to control the same. Hydrodynamics of the coast is to be considering for studied in more details. Most important is continuous recording of hydrological, fluvial, and sedimentation data would help to ascertain hydrologic and geophysical changes. However, a constant and regular watch over the climate changes with proper documentation are essential for future study.

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