Migration of Chilika Lake Mouth

R. Sundaravadivelu, P. Shanmugam, A. K. Patnaik and P. K. Suresh

Abstract Chilika lake is the largest lagoon along the east coast of Indian state Odisha, situated between latitude 19° 28′ and 19° 54′ N and longitude 85° 05′ and 85° 38′ E. The place is known for rich biodiversity and is the largest wintering ground of migratory bird and largest population of Irrawaddy dolphin, habited by migratory birds and by a special type of dolphins. The highly productive ecosystem of the lake supports the livelihood for fishermen and also acts as drainage for Mahanadi River Basin. The estuary is very sensitive to the sediment dynamics. The closure of estuary mouth or shifting of Chilika Lake mouths tremendously changes salinity and ecology of the lake system. The east coast of India along this coast is having a net alongshore drift of about 0.7×10^6 m^3 annually toward north direction. The inlets of Chilika Lake are under the influence of alongshore sediment transport from the coast. Apart from this, the rivers bring sediments during peak southwest monsoon season. Because of this the inlets are migrating, depending on the season. The details of migration of estuary opening were analyzed using satellite imageries. The analyses of watershed, coastal process, and configuration of estuary are detailed in this paper.

Keywords Chilika lake · Ecosystem · Salinity · Coastal process

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1 Introduction

Chilika Lagoon, the largest brackish water body of Asia, on the east coast of Odisha, India is 4000 years old [4]. The lagoon is separated from Bay of Bengal by a barrier spit shown in Fig. 1, 64.3 km long and connected to it by four tidal inlets of varying depth and size. All inlet activities occur on the onshore face of the lagoon. The brackish character of Chilika Lagoon was deteriorated during past three decades of the twentieth century. The hydrodynamic regime of the lagoon was affected during this period. Consequently, the ecology, biodiversity and economy of the area were also affected. The present study deals with the variation of geometry of mouth of estuary with time. The extreme meteorological events, hydrological aspects, tidal outlet (Fig. 2), and coastal process involved on the closure, migration, and opening of new tidal inlets in Chilika Lagoon at Arkhakuda, Gabakund, and Sipakuda are discussed.

- Project location details
  Satapada and Magarmukh area of Chilika Lake are under Krushnaprasad and Brahmagiri block under Krushnaprasad Tahasil in Puri district.
- Demographic details of the population
  Total fisherman population of peripheral villages of Chilika is more than 2 lakhs. Those are directly dependent on the lake fishery for their daily livelihood.

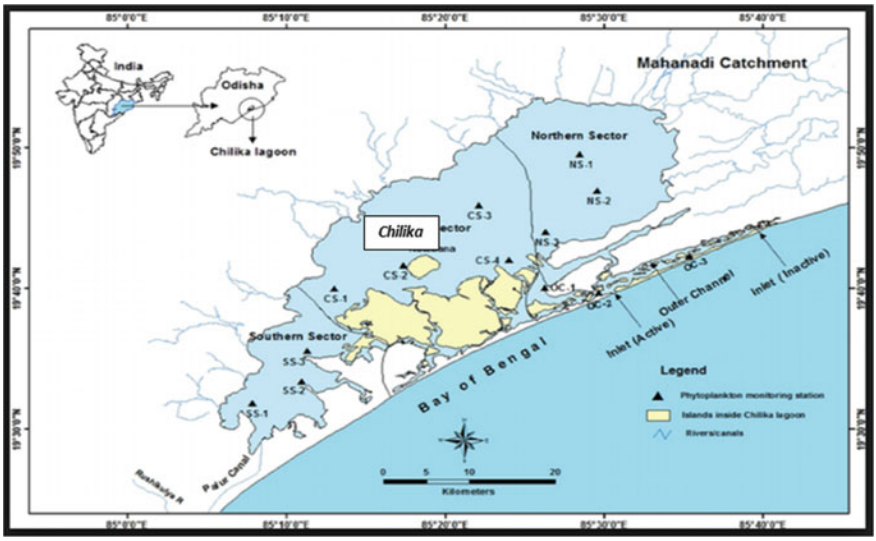

Fig. 1 Location of Chilika lake

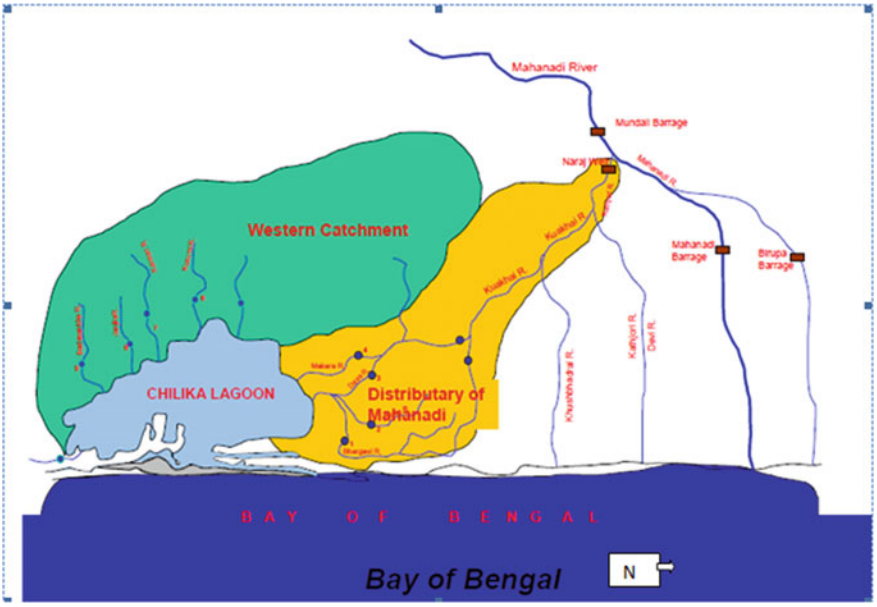

Fig. 2 Tidal outlets to Bay of Bengal

2 Geological Process

Geological processes change the geomorphological landform features continuously. The study on the old topographical maps of 100 years indicates complete change of Chilika lagoon especially along the shore. The prevailing wind erodes transports and deposits sand from one place to another. These geodynamical actions may be due to several causes. However, identifying these causes, it is possible to make some sustainable development such as mouth stabilization.

3 Geological History

Geological studies reveal that coastline along Chilika has shifted toward sea. The evidence is Konark temple is present now at 3 km from the shore since it was built on the shore. The causes of coastline shifting and growth of the spit are strong wind, absence of strong river and tidal current. Most of the lagoons were formed due to sea level rise over the last 6000–8000 years.

The mouth of the Chilika Lake keeps on changing its position especially toward northeast. The width of the mouth was 1.5 km in 1780 and then reduced to half in 1820. The mouth is closed up frequently, so that it is necessary to dredge the silted sand for seawater entrance. Chilika Lake is being silted up and the depth is shallow.

The coastline of the Odisha is being subjected to various environmental impacts which results in both accretion and erosion. The opening of the outer channel near Arkhakuda was reported during 1914 and was found ineffective in 2000. A new mouth was opened near Sipakuda in 2000. At present, Arkhakuda mouth is completely closed off and the artificially opened mouth near Sipakuda is enlarged.

Satellite images indicate that 46 km^2 areas have been silted up due to a constant inflow of 13 million tons of sediments per year due to erosion and transportation from the catchment area. Restoration plan for an integrated watershed management of the lagoon with active participation of local community and nongovernmental organizations on a micro-watershed basis, enhancement of welfare of local people, and communication and developments of various centers are required.

4 Hydrological Network

Chilika is influenced mainly by the tributaries of Mahanadi River, namely, the Mahanadi River Delta and its branches which is shown in Fig. 2. The rainfall varies from 1000 mm to extreme values of 2500 mm. The southern distributaries, Daya and Bhargovi in Mahanadi delta join the sea via Chilika Lagoon. The abnormal rainfall has caused high floods during 2001, 2003, 2006, 2008, 2011, and 2014. Year 2000 was the minimum discharge year of the millennium. Chilika Lagoon, largest in Asia receives 61% of inland flow from Mahanadi system. As per studies of Mishra and Jena [3] major inflow to Chilika (60%) is from Mahanadi system. The number of rivers/rivulets draining into the lake is 52 and the catchment area is 3729 km^2.

5 Studies Using Satellite Imageries

Preliminary studies were conducted on the migration of inlet of estuary adopting satellite imageries from Google Earth which is shown in Figs. 3, 4 and 5. The Chilika Lake mouth located originally near Sipakuda in 1800 has gradually shifted in the last 200 years toward the northern side to Arkhakuda. The sedimentation in the south and erosion in the north due to littoral drift is the major cause of continuous shift of the mouth toward north. The outer inlet channel of 18 km length was formed between Sipakuda and Arkhakuda and the tidal exchange through this channel was not sufficient to maintain the quality of brackish water and overall brackish ecosystem in the Chilika Lake. Because of low tidal prism, an intervention was made by cut opening a mouth of width 200 m near Sipakuda in September 2000 by the Chilika Development Authority (CDA) based on the numerical model study by CWPRS, Pune and implementation methodology by IIT, Madras. The opening of the new mouth at Sipakuda in the year 2000 improved the tidal and salinity flux to desired level in 2001. The satellite images of the mouths along the coasts in the years 1990 and 2000 are shown below.

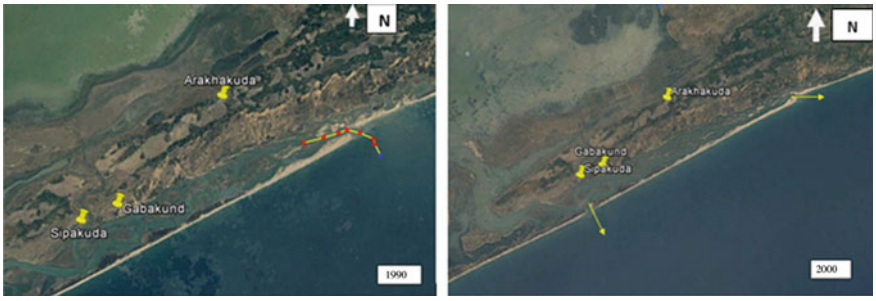

Fig. 3 Satellite view of mouths in year of 1990 and 2000

Fig. 4 Satellite view of mouths (extension) in year of 2008 and 2012

Fig. 5 Recent satellite view of mouths in year of 2016

The Sipakuda mouth has gradually widened from 200 to 850 m toward NE and is now migrated from the original cut by about 2000 m. The widening of mouth is

generally due to erosion of the northern spit and the sliding of sandbar embankment. The rates of tidal water flow and fresh water flow also play a critical role in widening of the mouth. Due to erosion of the spit on the north of Sipakuda mouth due to less supply of sediment and cyclone, another mouth was opened in August 2008, opposite to Gabakund at a distance of 1900 m from Sipakuda on the day of lunar eclipse.

The Sipakuda mouth was consistently migrating toward north. The shifting of mouth is marginal and is only 300 m from 2000 to 2004. But from 2004 to 2016, the mouth has migrated by 3800 m with an average movement of about 300 m per year. In the process of migration, the Sipakuda mouth merged with Gabakund mouth in 2012 and the width was about 2700 m at the time of merging. However, the mouth opened at Sipakuda location has gradually closed and the Gabakund mouth stabilized with reduced width.

Again in September 2012, a new mouth got opened by nature due to erosion of the northern spit, opposite to "Dhalabali". Now the Chilika Lake has two mouths, viz., (i) Gabakund mouth on the southern side and (ii) Dhalabali mouth on the northern side of Gabakund mouth. The approximate distance between the centers of two mouths is around 2250 m. The length of the sand spit in between these two mouths is around 1850 m. The Gabakund mouth has the width of 800 m, whereas the Dhalabali mouth has the width of 300 m. Both Gabakund mouth and Dhalabali mouth are branching out into two major channels. The Gabakund mouth main channel leads toward main lake, i.e., toward south heading Satpada, whereas the Dhalabali mouth main channel leads toward north heading to Arkhakuda. The depth remains very shallow showing less than 1.6 m w.r.t. MSL in Dhalabali mouth. Gabakund mouth remains deeper than Dhalabali mouth with a maximum depth of 3.7 m w.r.t. MSL. Similarly, the quantity of flow through Gabakund mouth is very much higher compared to Dhalabali mouth and the required tidal prism is maintained.

6 Coastal Process

The bathymetric details obtained from studies of [1] are provided which is shown in Fig. 6. The tide levels at Satapada before opening of the mouth (March 2000) was 10 cm, while this improved to 60 cm in March 2001 and the figures in March 2012 stood at 45 cm. The tidal chart is shown in Fig. 7. The tidal variations were observed and it was about 2 m.

7 Alongshore Sediment Transport

The gross longshore sediment transport rate is about 1×10^6 m^3/year. The net sediment is toward north from May to October and is about 0.7×10^6 m^3/year as per studies and measurements by Chandramohan et al. [1]. The sediment transport is predominantly directed toward north direction. In a year, the alongshore sediment transport is directed toward north from May to October and toward south from

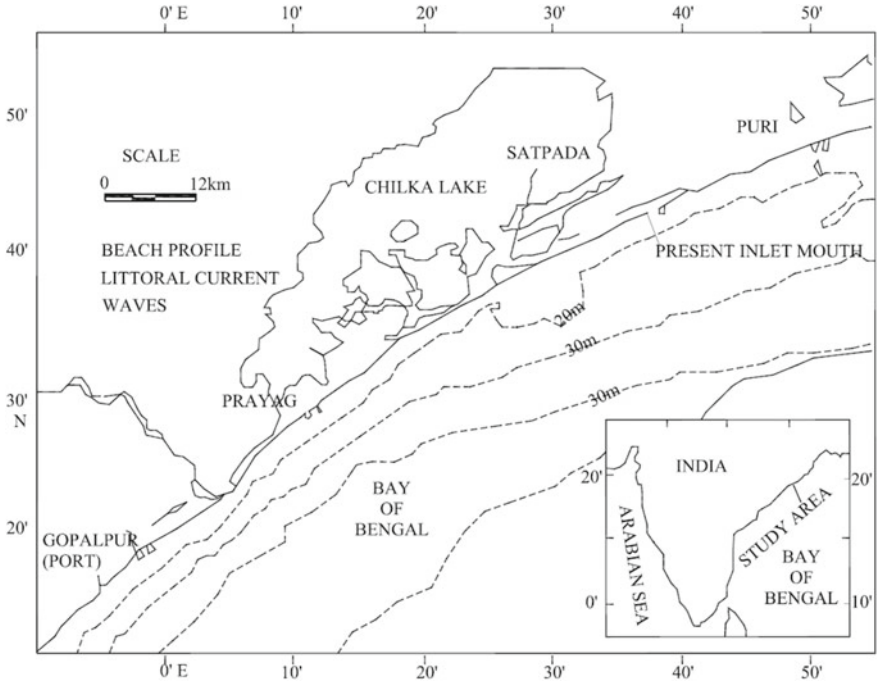

Fig. 6 Bathymetric details of Bay of Bengal

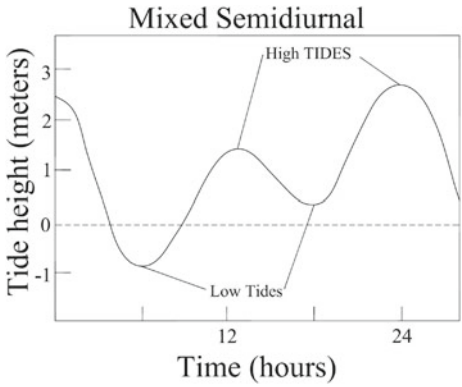

Fig. 7 Tidal chart for the site location

November to February. The southwest monsoon is active and during this period rivers carry large discharge and also bring enormous sediments. Hence, during monsoon, the estuary is flushed by flood waters. Considerable siltation is observed during fair weather period. Observation on sediments along Mahanadi was studied in detail by Central Water Commission [2] from 2002 to 2012. The average annual sediment is 4.44 million metric tons.

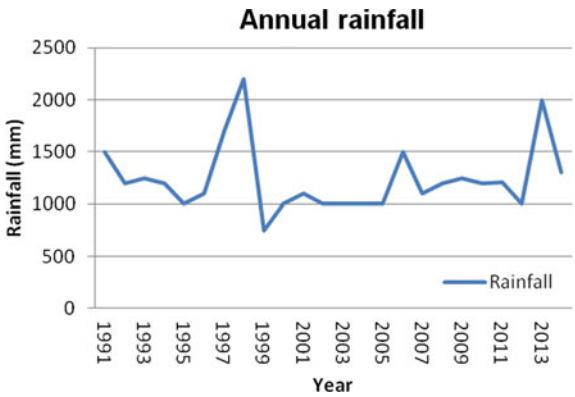

Fig. 8 Rainfall pattern in the watershed of Daya river

8 Rainfall Details

The details of rainfall are analyzed as per Mishra and Jena [3]. Chilika Lagoon receives flow from distributaries of Daya and Bhargovi in Mahanadi delta that joins the sea via Chilika Lagoon which is shown in Fig. 8. The variations of Chilika are in terms of geomorphology, ecology, and biodiversity for changes in precipitation and threshold flushing flow. Abnormal floods are observed because of rainfall during 2001, 2003, 2006, 2008, 2011, and 2014. Year 2000 was the minimum discharge year of the millennium. The tourist, flora, and aqua catch decreased remarkably during 1995–2000 for lagoon's reduced salinity, siltation, and biodiversity. The anomaly in monsoon precipitation has trimmed down the threshold flushing flow to maintain salinity.

The coast is vulnerable to cyclone during northeast monsoon. In the year 1999, it was subjected to a super cyclonic storm. Another very severe cyclonic storm Phailin crossed the coast in 2013.

9 Water Resources and Climate Changes

Climate change is expected to have implications for several wetland features. The main diverse in Chilika is decrease in monsoon rainfall, increased temperature, sea level rise, and tropical cyclone events. It also has impacts on winter rainfall in India where drought and flood situation is quite normal. The storms, surcharges, and cyclones occurred frequently in coastal area of Odisha which has got bad impacts on the coastal lake ecosystem. During the heavy flood, the sediment along with the nutrient loads and debris enter to Chilika Lake and will cause siltation and eutrophication.

Due to impact of climate change, the lake mouth was shifting at a faster rate and also Chilika catchment has been receiving erratic rainfall. When more precipitation

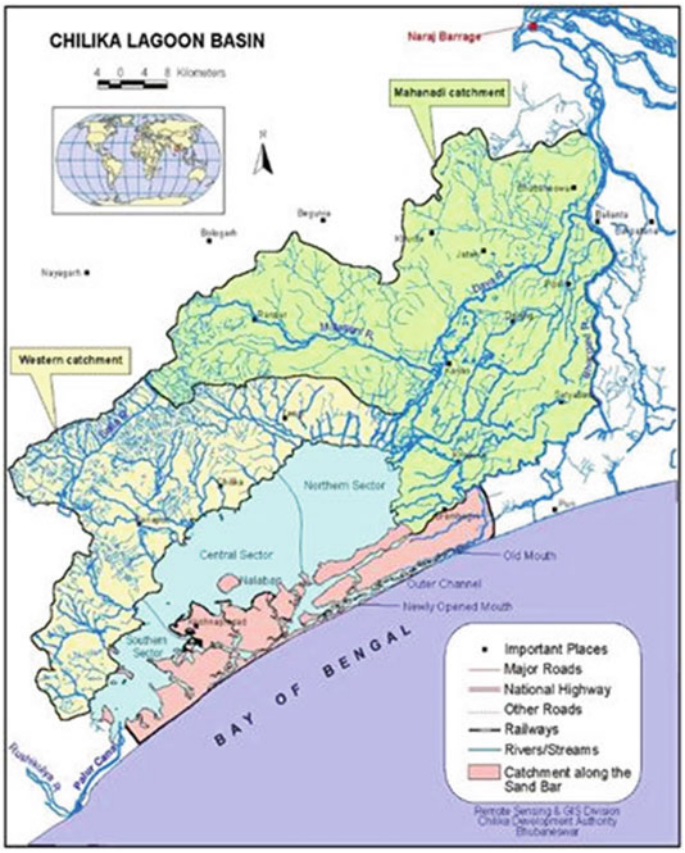

Fig. 9 The area of waterlogging by flooding

will occur in the catchment area, the waterlogging will take place and the paddy field of the Kanas, Delanga and Brahmagiri blocks of the lake will get submerged. Figure 9 is showing the area of waterlogging by flood.

The lake has faced two consecutive cyclones in the year 2013, the cyclone "Phail-in" had the landfall in the close proximity in Chilika Lake on 12.10.2013 and another high impact cyclone also hit in the southern part of Chilika Lake called "Hud Hud" on the same day, next year, i.e., 12.10.2014 followed by a severe flood in the river system draining to Chilika lake. This has become a regular practice in these areas; a cyclone, drought, or flood is experienced every year. The occurred adverse climate phenomena are listed in Table 1.

Table 1 List of occurrence of adverse climate phenomena

S. no	Category	Year of occurrence
1	Flood	1956, 1959, 1969, 1970, 1986, 1987, 1988, 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998, 1999, 2001, 2003, 2005, 2006, 2008, 2011, 2014
2	Cyclone	1967, 1968, 1970, 1971, 1972, 1973, 1999, 2013, 2014
3	Drought	1956, 1970, 1987, 2000, 2002, 2010, 2015
4	Earthquake	2013, 2015

10 Desiltation of the Channel

From the above observation, it has been felt that some further interventions inside the lake are essential like the desiltation in the main connecting channel from the mouth to lake, Balugaon channel and a ferry route is shown in Fig. 10. The ferry route will be maintained for years together as the propeller of the boats moving inside will make the channel free from siltation. The depth of ferry route with respect to mean sea level is shown in Fig. 11.

The Balugaon channel is the interface between the main lake and also the outer channel of Chilika. The recruitment of fish and fish juveniles are taking place through Balugaon channel only and so the extension of the Balugaon channel is inevitable for maintaining the fish production of the lake.

Fig. 10 Ferry routes in Chilika lake

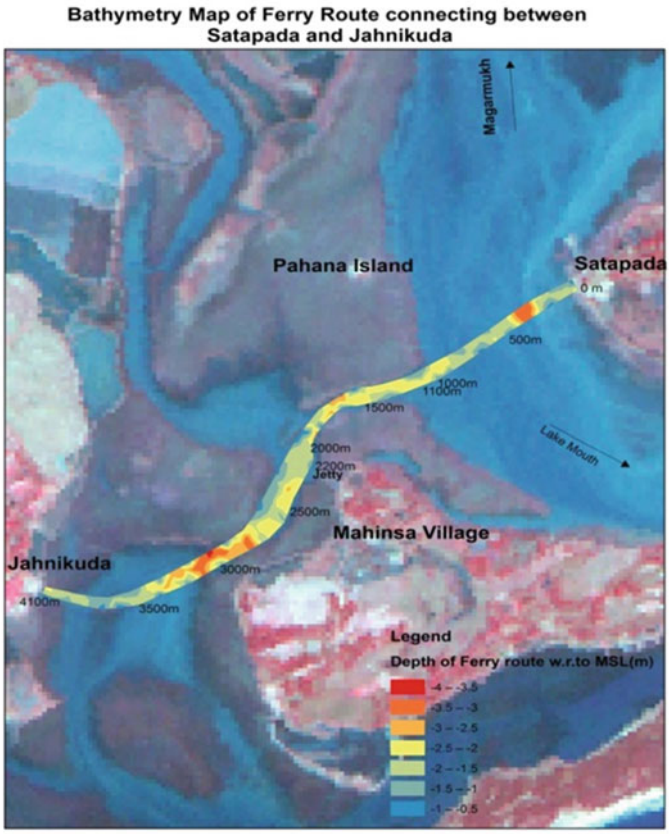

Fig. 11 Depth of ferry route w.r.to MSL

By desiltation of the channels, the navigation in the lake will improve. The desiltation processes will also pave the way for the recruitment of juvenile from sea as 85% of the fish in Chilika Lake are migratory in nature. The lead dredged channel also facilitate in discharge of flood water from Delanga, Kansa, and Brahmagiri block, in the Mahanadi catchment (Chilika) in Puri district of Odisha which is more than 70,000 hectare of cultivable agriculture land.

11 Summary

The opening of the mouth at Sipakuda in 2000 resulted in annual fish production from 2000 tons to 14,000 tons in 2003. The annual fish yield of Chilika has decreased from 14,000 tons (2003–04) to around 12,000 tons. The tide levels at Satapada before

opening of the mouth (March 2000) was 10 cm, while this improved to 60 cm in March 2001 and the figures in March 2012 stood at 45 cm. Chilika as a brackish water lake is known for its substantial coverage of seagrass beds which acts as carbon sinks (blue carbon).

Based on the outcome of this successful hydrological intervention, the Ramsar Wetland Conservation Award and Evian special prize 2002, which is the award of highest order by the Ramsar Bureau for outstanding achievement in the field of restoration of the wetlands is conferred on CDA. Chilika was also removed from threatened list of Wetlands, i.e., Montreux record in 2002. CDA is the first recipient of this prestigious award from Asiatic region.

Chilika Estuary is mainly influenced by sediment transport by rivers into the lake and alongshore sediment transport along the coast toward north by wave action. The mouth is also migrating toward north due to deposition of sand in the south and erosion in the north of the mouth. The coast is also vulnerable to cyclone and this can also alter the mouth configuration. Substantial rainfall creates runoff into inlet and creates flushing of mouth. During below average rainfall, the mouth gets closed and there is no proper tidal prism action.

If proper desiltation of channels inside the lake and lake to outer channel is carried out, the high siltation can be flushed out during substantial rainfall and the rate of migration of mouth can be reduced. Dredging of channels in the lake will also help movement and distribution of fishes, seaward breeding migration, etc.

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